Geologic Map of the Wildhorse Mountain 7½′ Quadrangle, Cochise County, Arizona

by

Jon E. Spencer, Joseph P. Cook, Steven H. Lingrey,
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INTRODUCTION

The Wildhorse Mountain 7 ½′ Quadrangle includes part of the central San Pedro River and flanking valley fill, as well as areas of bedrock on both sides of the valley and at the south edge of the Quadrangle where the San Pedro River crosses bedrock at the San Pedro Narrows (Figure 1). Production of this new geologic map continues the Arizona Geological Survey mapping program of the San Pedro River valley. This mapping was done under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992, and was jointly funded by the Arizona Geological Survey and the U.S. Geological Survey under STATEMAP Program Contract award number 06HQAG0051. Mapping was compiled digitally using ESRI ArcGIS software.

The Wildhorse Mountain 7 ½′ Quadrangle was mapped previously by Drewes (1974, scale 1:48,000), with additional mapping and reinterpretation by Lingrey (1982) and Dickinson (1986, 1998). Adjacent areas to the north were mapped by Mark and Goodlin (1985), to the east by Cooper and Silver (1964), and to the south by Youberg et al. (2006). Some low-angle faults in and near the map area, interpreted by Drewes (1974) as thrust faults, were reinterpreted as low-angle normal faults by Lingrey (1982) and Dickinson (1984, 1991).
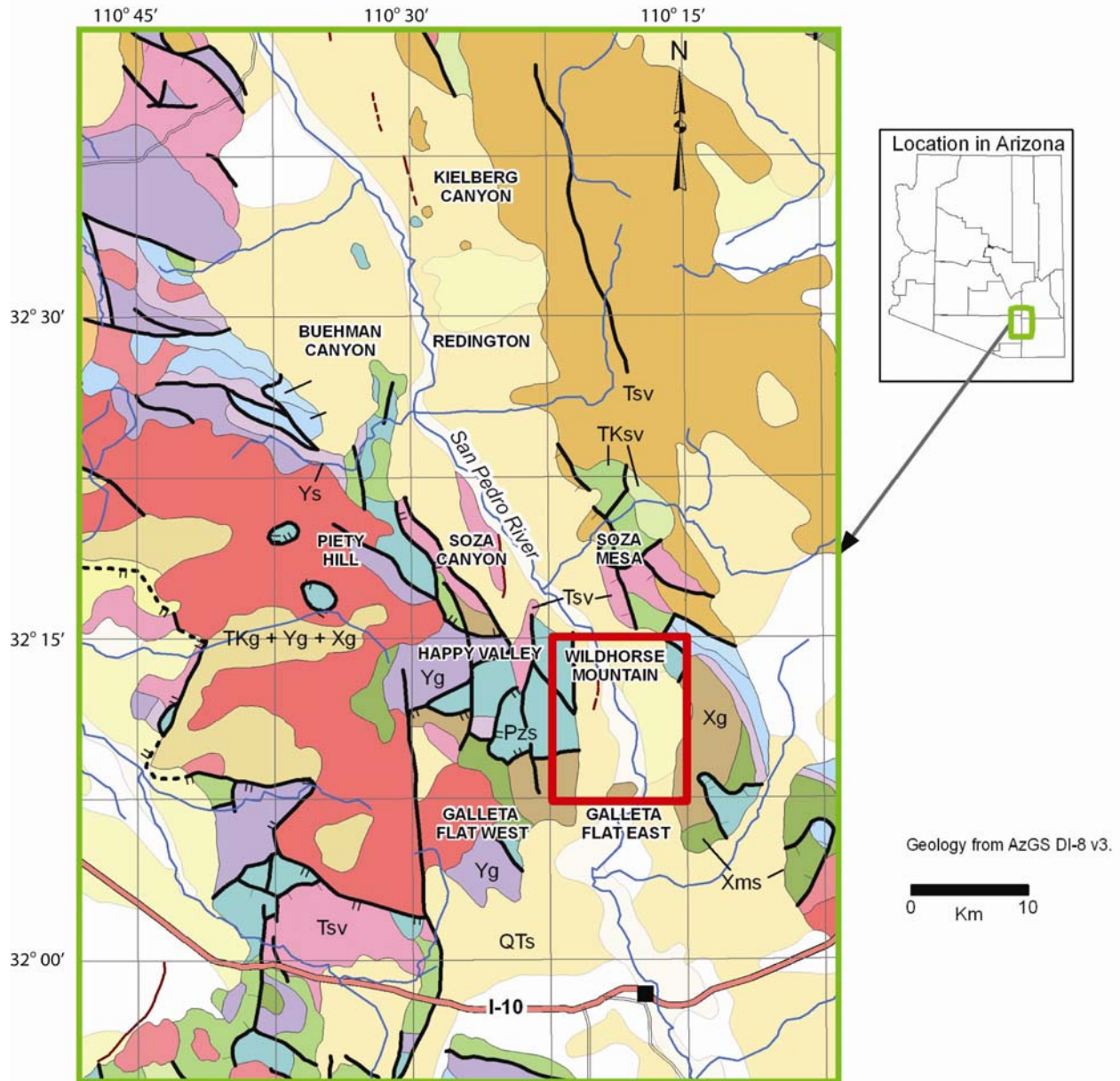
QTs - Quaternary and upper Tertiary sedimentary units
Tsv - Oligo-Miocene sedimentary and volcanic rocks
TKg - Early Tertiary and late Cretaceous (Laramide) granitic rocks
TKsv - Early Tertiary and Cretaceous sedimentary and volcanic rocks
Pzsu - Upper Paleozoic sedimentary rocks
Pzsl - Lower Paleozoic sedimentary rocks
Pzs - Paleozoic sedimentary rocks, undivided
Ys - Mesoproterozoic sedimentary rocks of the Apache Group and diabase
Yg - Mesoproterozoic granitic rocks
Xg - Paleoproterozoic granitic rocks
Xms - Paleoproterozoic metasedimentary rocks

Figure 1. Geologic map of the lower San Pedro River valley area, southeastern Arizona, showing 7.5' quadrangles and DGM map area.

STRUCTURAL GEOLOGY

Bedrock in the eastern Rincon Mountains, an area also known as the Little Rincon Mountains, forms part of the eastern flank of the Catalina-Rincon metamorphic core complex (Davis, 1980; Keith et al., 1980; Lingrey, 1982; Spencer and Reynolds, 1989; Dickinson, 1991). This complex is bounded above by the Catalina – San Pedro detachment fault, which is arched over the Rincon Mountains. At least 28 km of top-southwest displacement on this fault is responsible for tectonic exhumation of much of the range (Dickinson, 1991). From structurally lowest to highest in the western part of the Wildhorse Mountain 7 ½' Quadrangle (west of the San Pedro River), the sequence of structural units consists of the following: (1) A penetratively deformed sequence of Proterozoic crystalline rocks (1.4-1.7 Ga), overlying Mesoproterozoic Apache Group and intruding 1.1 Ga diabase, and Paleozoic metasedimentary rocks consisting primarily of carbonates with less abundant siliciclastic strata. Several faults that attenuate stratigraphy are present within this sequence (Lingrey, 1982). (2) Paleoproterozoic Johnny Lyon Granodiorite (Cooper and Silver, 1964), which is thrust over structural unit (1) along the Wildhorse Mountain thrust. Sparse lineations in mylonitic fabrics associated with the thrust zone trend east-northeast or west-southwest and are associated with well developed top-northeast shear-sense indicators at one location and suggestive top-northeast shear-sense indicators at another (Figure 2). (3) Weakly metamorphosed Paleozoic strata and Proterozoic granite overlie structural units (1) and (2) along the San Pedro detachment fault (see cross sections on Plate 1). (4) Tertiary conglomerate is faulted against penetratively deformed Paleozoic metasedimentary rocks of structural unit (1) at the east foot of the eastern Rincon Mountains, but at several locations rests on the metasedimentary rocks along a moderately east-dipping depositional contact. Deposition of the conglomerate must have post-dated displacement on the San Pedro detachment fault because restoration of detachment slip would restore the metasedimentary rocks to a position beneath hanging-wall bedrock and well below the Earth's surface. We infer that a buried, west-dipping normal fault beneath the conglomerate and underlying bedrock is responsible for eastward tilting of the eastern Rincon Mountains and overlying Miocene conglomerate.

In the northeastern corner of the map area, at the northwestern foot of the Johnny Lyon Hills, Paleoproterozoic Pinal Schist and Johnny Lyon Granodiorite are thrust over strata of the Mesoproterozoic Apache Group, the 1.1 Ga Sierra Ancha diabase, and Paleozoic and Mesozoic strata as young as the Cretaceous Bisbee Group. These rocks form the footwall of a southwest-dipping range-front normal-fault system (Dickinson, 1984; Dickinson et al., 1987). Deformation conditions during thrusting were not sufficiently hot to cause crystal-plastic deformation or metamorphic recrystallization. Upper Jurassic Glance Conglomerate overlies sandstone of probably Jurassic age in the footwall of the thrust, and is not overturned as indicated by Dickinson (1998). Several parallel faults form the thrust zone, with likely complex geometries that were not determined because of isolated exposure and extensive Quaternary cover.

Figure 2 (next page). Top-ENE shear-sense indicators (top to the left) above Wildhorse Mountain thrust (station JES-05-653). Width of upper photo area is approximately 80 cm. Width of lower photo area is approximately 40 cm.

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MAP UNITS

SURFICIAL MAP UNITS

Other units

Plowed areas - Historically or actively plowed fields, irrigated pastures, and other lightly disturbed ground.

d   **Disturbed ground** – Heavily disturbed ground due to agriculture, extensive excavation, or construction of earth dams.

Qtc   **Quaternary hillslope talus and colluvium** – Unconsolidated to weakly consolidated, very poorly sorted angular rock debris deposited at the base of bedrock slopes.

San Pedro River alluvium

Quaternary San Pedro River sediments derived from both adjacent and upstream piedmont and basin fill alluvium are transported north through the mapped area towards the San Pedro's confluence with the Gila River. Pleistocene age river deposits are located outside the modern floodplain and stand much higher than the present-day channel. Prior to about 1900, the San Pedro was a low energy, unentrenched, narrow channel and cienega drainage system (Hereford, 1993). Late Holocene river valley and floodplain deposits were much more widespread than the modern incised meandering system. Modern and historical San Pedro deposits are confined to the entrenched meandering swath occupying the lowest elevations in the mapped area.

Qycr   **Active river channel deposits -** Deposits are dominantly unconsolidated, very poorly sorted sandy to cobbly beds exhibiting bar and swale microtopography but can range from fine silty beds to coarse gravelly bars in meandering reaches based on position within the channel. Clasts are typically well-rounded but may be angular to sub angular. Qycr deposits are typically unvegetated to lightly vegetated and exhibit no soil development. Qycr deposits are entrenched from 30 cm to 5 meters or more below adjacent early historical floodplain deposits depending on location, geomorphic relationship, and local channel conditions. Although much of the San Pedro River was a perennial stream historically, some modern sections are dry or marshy at the surface throughout much of the year. These deposits are the first to become submerged during flow events and can be subject to deep, high velocity flow and lateral bank erosion.

Qy₄r   **Flood channel and low terrace deposits-** Deposits are dominantly unconsolidated, very poorly sorted sandy to cobbly beds exhibiting bar and swale microtopography but can range from fine silty beds to coarse gravelly bars in meandering reaches based on position within the channel. Clasts are typically well-rounded but may be angular to sub angular. Qycr deposits are typically unvegetated to lightly vegetated and exhibit no soil development. Qycr deposits are entrenched from 30 cm to 5 meters or more below adjacent early historical floodplain deposits depending on location, geomorphic relationship, and local channel conditions. Although much of the San Pedro River was a perennial stream historically, some modern sections are dry or marshy at the surface throughout much of the year. These deposits are the first to become submerged during moderate to extreme flow events and can be subject to deep, high velocity flow and lateral bank erosion.

Qy₃r   **Historical river terrace deposits -** Terrace deposits that occupy elevations from 1 to 2 meters above Qycr or Qy₄r deposits and are inset below the pre-incision historical floodplain. These surfaces are generally planar but exhibit bar and swale microtopography. Although no soil development is present, dense grasses and small mesquite trees abound. Sediments composing these deposits are poorly sorted silt, sand, pebbles and cobbles. Pebbles and cobbles are well-rounded to sub-angular. Trough crossbedding, ripple marks, and stacked channel deposits viewable in cross-section indicate deposition in a low to moderate energy braided stream environment. These deposits are prone to flooding during extreme flow events, and undercutting and rapid erosion of Qy₃r surfaces is possible during lower flow events.

Qy₂r   **Latest Holocene to historical river deposits-** Deposits associated with the floodplain that existed prior to the early historical entrenchment of the San Pedro River (Hereford, 1993; Huckleberry, 1996; Wood, 1997). Qy₂r deposits are associated with broadly planar surfaces that locally retain the shape of historical river meanders. Qy₂r surfaces are up to 7 meters above modern Qycr deposits and are the most extensive river terraces in the valley. Qy₂r sediments were deposited when the San Pedro River was a widespread, shallowly-flowing river system and are dominated by fine grained floodplain deposits. Dense mesquite bosque and tall grass is typically present on these surfaces except where historic plowing or grazing has taken place. These surfaces appear predominantly fine grained at the surface due in part to the input of organic matter and windblown dust deposition but are composed of interfingering coarse sandy to pebbly braided channel and fine sand to silty river floodplain deposits. Where Qy₂r deposits are moderately to deeply incised they not subject to inundation by river floods, but they may be flood-prone in areas with less channel incision. Qy₂r deposits are subject to catastrophic bank failure due to undercutting and lateral erosion during flow events. Distal piedmont fan deposits (Qy₂ ,Qyaf, and Qys) onlap onto Qy₂r deposits although an interfingering relationship likely exits in the subsurface.

Qy₁r   **Late to early Holocene river terrace deposits -** Deposits associated with slightly higher terraces that represent either higher elements of the early historical floodplain or remnants of older Holocene aggradation periods. These fine-grained terrace deposits commonly have been disturbed by plowing or cattle grazing. When undisturbed, Qy₁r deposits are densely vegetated by mature mesquite trees (mesquite bosque) and tall grasses. Soil development is moderate and surface color ranges from 10 to 7.5 YR 4/4. Due to the dense vegetation input of organic matter at the surface is high and often results in a thin (< 10 cm) organic soil horizon. A light dusting (incipient stage I) calcium carbonate accumulation is evident on the undersides of some buried clasts. Qy₁r surfaces stand up to 7 meters above the active channel in highly incised locales and typically are located less than 1.5 m higher than adjacent Qy₂r surfaces. These terraces are typically covered with fine-grained floodplain deposits, but relict gravel bars and lenses are common.

Qi₃r   **Late Pleistocene river terrace deposits -** Terrace deposits are up to 10 to 25 m higher than and up to 500 m outside the margins of the modern San Pedro channel. These deposits consist of well rounded pebbles to cobbles exhibiting stage I+ calcium carbonate accumulation with cross-bedded coarse sandy interbeds. Clast composition is varied and includes rock types not found in nearby mountains from which modern piedmont material is derived. Qi₃r terrace surfaces are planar, often surrounded by distal piedmont alluvium, and are generally lightly vegetated by small weeds and grasses. Commonly, Qi₃r deposits are inset into adjacent piedmont alluvial deposits but can also be inset into older river gravel terraces. Soil development is weak, possibly due to the porous nature of these deposits.

Qi$_2$r   **Middle to late Pleistocene river terrace deposits -** Terrace deposits are similar to Qi$_3$r deposits but occupying higher positions in the landscape. Terrace surfaces are slightly to moderately rounded. Clast composition is diverse. Well-rounded pebbles to cobbles with stage I-II calcium carbonate accumulation armor Qi$_2$r surfaces. Vegetation is sparse, consisting of small shrubs and grasses. Soil development is generally weak on Qi$_2$r surfaces, but soil development is more evident in finer grained sections. Qi$_2$r surfaces are typically found as high-standing isolated mounds surrounded by distal fan alluvium or as small terraces inset into older fan or basin fill alluvium.

Qi$_1$r   **Early to middle Pleistocene river terrace deposits** – Deposits are associated with high-standing, well-rounded river gravel terraces. Where Qi$_1$r deposits are extensive, remnant planar caps are preserved near the center of the surface. Qi$_1$r deposits are composed of very well rounded to well rounded pebbles and cobbles from diverse lithologies. Cross-bedded sands with pebbly stringers are interbedded throughout. Near-surface cobbly beds exhibit stage II+ calcium carbonate accumulation. Moderately to strongly calcium carbonate coated clasts or cemented aggregates of clasts mantle the flanks of Qi$_1$r deposits, but clay accumulation is variable, probably due to poor surface preservation. Sparse small shrubs, weeds, and cacti are present on these surfaces.

Qi$_1$r?   **Possible early to middle Pleistocene river terrace deposits -** Qi$_1$r? terraces strongly resemble Qi$_1$r river gravel terraces but due to position within the landscape and access restrictions a level of uncertainty remains.

Piedmont alluvium and surficial deposits

Holocene to late Pliocene piedmont deposits derived from the Rincon Mountains to the east, the Johnny Lyon Hills off the southeastern corner, and the Galiuro Mountains to the east of the mapped area grade toward the San Pedro River running along the center of the Wildhorse Mountain quadrangle. Piedmont alluvium was deposited by repeated episodes of alluvial channel migration, incision, and aggradation. These processes have resulted in a series of nested terraces, some of which are partially sourced from older alluvium. Due to multiple source lithologies, similar age surfaces on one side of the river may exhibit different pedogenic and geomorphic characteristics. In many places throughout the mapped area these deposits are incised into and deposited directly upon latest Tertiary Quiburis basin fill sediments. Due to historical downcutting of the San Pedro River, relief between active piedmont channels and perched terraces can exceed 20 meters.

Qyc   **Modern stream channel deposits -** Qyc deposits are composed of unconsolidated, very poorly sorted sandy to cobbly ephemeral piedmont channel sediments. Channels may exhibit bar and swale microtopography with bars composed of coarser sediments. Qyc deposits are typically unvegetated and exhibit no soil development although small shrubs and grasses can be found on slightly elevated bars. Qyc deposits commonly become submerged during moderate to extreme flow conditions and can be subject to deep, high velocity flow and lateral bank erosion. Channels are generally incised 1 to 2 m below adjacent Holocene alluvium and may be incised into adjacent Pleistocene alluvium by 10 m or more.

Qy$_3$ **Latest Holocene alluvium** – Recently active piedmont alluvium located primarily along active drainages including floodplain, low-lying terrace, and ephemeral tributary channels. Qy$_3$ deposits are composed of unconsolidated to very weakly consolidated sandy to pebbly deposits and exhibit greater vegetation than Qyc deposits. These deposits generally exhibit bar and swale microtopography and are susceptible to inundation during moderate to

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extreme flow conditions when channel flow exceeds capacity. Soil development is generally absent or incipient on Qy_3 deposits which exhibit pale buff to light brown (10 YR) surface coloration.

Qyaf **Late Holocene alluvium, active fan deposits** – Qyaf deposits consist of active alluvial fan deposits in the San Pedro valley. These deposits have distributary drainage patterns and are extremely prone to flooding and channel migration. Sediments are unconsolidated and consist of very poorly sorted sand to cobbles. Vegetation includes small mesquite trees, shrubby acacia, prickly pear, and medium creosote.

Qy₂ **Late Holocene alluvium** – Qy_2 deposits consist of piedmont terrace deposits located primarily along the flanks of incised drainages, broad low-relief distal fan deposits onlapping onto Holocene river alluvium, and infrequently active tributary drainage deposits. These deposits consist of predominantly fine grained unconsolidated to weakly consolidated sediments although isolated sub-rounded to sub-angular cobbles and boulders may be present at the surface in small quantities. Where inset into older alluvium, Qy_2 deposits are planar with remnant bar and swale microtopography. Distal fan Qy_2 deposits are broad and sandy with numerous small braided channel systems. Rarely active Qy_2 tributary drainages are generally of limited extent, relatively steep, and more densely vegetated than Qy_3 tributary drainages. Soil development on Qy_2 deposits is minor, characterized by incipient stage I calcium carbonate accumulation in the form of small filaments and medium brown (10 YR) surface coloration. Vegetation on Qy_2 surfaces ranges from numerous small mesquite trees and grasses in distal fan environments to medium creosote, acacia, and cholla in tributaries and inset terraces. These surfaces are subject to inundation during moderate to extreme flow conditions when channel flow exceeds capacity or due to channel migration on low-relief portions of broad distal fan deposits. Planar Qy_2 terraces are typically elevated from 30 cm to 1.5 m above active channels.

Qy₁ **Older Holocene alluvium -** Qy_1 deposits consist of broad, low-relief, undulating fan deposits, exhibit shallow widespread braided drainage patterns, and sit higher in the landscape than younger Holocene alluvium. Portions of these deposits are mantled by coarse to very coarse angular quartz sand and exhibit diverse vegetation patterns dominated by cholla, prickly pear, small (1-1.5 m tall) mesquite, and numerous small shrubs and grasses. Overall relief between broad fan crests and incised drainages on gently rolling Qy_1 deposits typically does not exceed 1.5 meters. Numerous shallow braided channels drain widespread portions of Qy_1 surfaces. Qy_1 deposits exhibit incipient calcium carbonate accumulation (stage I) and soil development characterized by medium brown (10-7.5 YR) coloration where unincised. Deposition of Qy_1 sediments in a braided channel aggrading alluvial fan environment has, in places, resulted in shallow burial of adjacent piedmont deposits. This relationship is visible along incised channels where thin Qy_1 deposits overly redder, grusy, clay-rich Qi_2 or Qi_3 deposits.

Qi₃ **Late Pleistocene alluvial fan and terrace deposits -** Qi_3 deposits are characterized as widespread planar reddish fan terraces mantled by angular to sub-angular pebbles to cobbles. These deposits exhibit moderate calcium carbonate accumulation (stage I-II) and soil development with shallow subsurface coloration ranging from 7.5 to 5 YR 4/4. 7.5 YR soil coloration is typically found in Qi_3 deposits sourced from lithologically varied parent material found west of the San Pedro in the mapped area whereas 5 YR coloration is associated with sediment sourced from predominantly granitic parent material east of the river. Qi_3 deposits exhibit medium (1-2 m tall) mesquite, cholla, prickly pear, creosote, acacia, and numerous small grasses and shrubs. Qi_3 deposits stand up to 3 meters higher in

the landscape than adjacent Qy_1 and Qyc deposits depending on local incision and position within the piedmont.

Qi_2 **Middle to late Pleistocene alluvial fan and terrace deposits** – Qi_2 surfaces consist of broad planar fan terraces found capping Quiburis basin fill deposits, inset into older, more well-rounded alluvial deposits, or lining significant piedmont drainages. These deposits generally exhibit reddish (7.5-5 YR 5/4) soils and moderate calcium carbonate accumulation (stage I-II+). Qi_2 deposits are overall planar but can exhibit mild to moderate rounding near incised channels or inset terraces. Vegetation on Qi_2 surfaces consists of medium mesquite, prickly pear, cholla, barrel cactus, and numerous small shrubs and short grasses. Where incised, these deposits often exhibit a cap up to 1 meter thick of moderately calcium carbonate cemented clasts. This cap preserves underlying, less-indurated portions of the Qi_2 surface as well as any deposits it may overly. Qi_2 terraces deposited onto basin fill deposits may stand as much as 30 meters above active piedmont channels.

Qi_1 **Early to middle Pleistocene alluvial fan and terrace deposits** – Qi_1 deposits are characterized by high-standing, moderately to well-rounded alluvial deposits exhibiting strong (stage II-III) calcium carbonate accumulation and, where preserved, dark reddish (5–2.5 YR 4/6) soils. Like Qi_2 deposits, Qi_1 deposits may cap underlying Quiburis basin fill deposits. Where widespread (greater than 30 meters across), Qi_1 deposits retain a remnant, indurated planar cap with moderately to well rounded edges. Narrow (less than 30 meters across) Qi_1 terraces and caps are generally well-rounded and do not exhibit a planar remnant. Qi_1 terraces are commonly mantled by coarse pebbles to boulders and exhibit vegetation consisting of medium to large mesquite, acacia, saguaro, prickly pear, cholla, barrel cactus, and grasses.

Qo **Early Pleistocene alluvium** – Deposits associated with very high relict alluvial surfaces. A remnant planar cap may be present on extensive surfaces. Where preserved, soils on Qo surfaces exhibit clay rich argillic and well developed calcic horizons. Dark red soils (2.5 YR 4/6) are sparsely covered by mild to moderately varnished pebbles to small cobbles. Near surface soil is loamy and overlies much coarser clasts visible on the eroded flanks of Qo surfaces. Vegetation consists of tall yucca, prickly pear, mesquite, and isolated creosote. The creosote population becomes significantly denser on the eroded flanks of Qo surfaces, possibly due to greater proximity to buried clays and carbonate. Remnant argillic horizons exhibit clay faces, blocky ped structures, and are deep red in color. Exposures of the calcium carbonate horizon exhibit stage III-IV accumulation. Aggregate chunks of eroded portions of the carbonate horizon commonly litter the flanks of Qo and underlying deposits. Qo surfaces generally occupy the highest position in the landscape, capping Quiburis basin fill deposits. Thin relict ridge-capping reaches of Qo deposits are commonly encountered where the underlying basin fill deposits are highly eroded and incised. Underlying basin fill deposits stand much higher in the landscape relative to comparable, uncapped deposits.

QTa   **Late Pliocene to early Pleistocene fan gravel** - Coarse gravelly deposits that erosionally overlie Quiburis basin-fill sediments and form the upper parts of high, very rounded ridges. QTa deposits are composed of very poorly sorted angular to sub angular sand, pebbles, cobbles, and boulders arranged in alternating fine to coarse beds common in alluvial fan deposits. High standing rounded ridges are composed of carbonate-cemented fanglomerate cap which armors the underlying, less indurated basin-fill sediment. The flanks of QTa ridges are also armored against erosion due to the mantle of coarse clast cover derived from weathered sections of the cap. Exposures of QTa deposits are generally poor, but they may locally be at least 30-40 meters thick and are commonly the highest standing deposits in the

proximal piedmont. Locally these deposits are capped by very old, very high relict Qo alluvial fan deposits, but are generally not capped and are deeply incised.

Tertiary Basin Fill alluvium (Quiburis Formation)

Ts **Red sandstone, silty sandstone, and siltstone** - Massive to bedded, reddish brown (5YR to 10YR) sandstone, siltstone, and mudstone that forms low-relief outcrops. Outcrops are commonly mantled in dried mud with polygonal fractures that possibly formed by expansion of clay minerals. This unit correlates to the lower Saint David Formation of Gray (1965), and Smith (1994).

Tqc **Late Miocene to Pliocene Quiburis deposits, alluvial fan facies** – Gravelly alluvial-fan and braidplain facies. Gray to buff-colored deposits vary from massive, sand-rich beds that predominate in the lower piedmonts to imbricated pebble-cobble-small boulder beds higher on the valley margins. In some areas, Tqc deposits grade into alternating thin unconsolidated beds of gypsum, silt, and very fine sand with occasional pebble stringers (Tqa deposits) along the valley axis. Tqc sediments are encountered throughout the mapped area and are generally well-exposed in deeply incised piedmont channel walls. In these exposures, Tqc deposits are often observed as capped by relict QTa, Qo, or younger (Qi_1 to Qi_3) deposits.

Tqa **Pliocene Quiburis basin fill deposits, distal fan to axial valley deposits** – Tqa deposits are located along the axis of the San Pedro Valley and represent a period of sedimentation in a closed basin prior to the initiation of the San Pedro River (Dickinson, 1998, 2003). Tqa deposits are composed of alternating thin unconsolidated beds of silt to very fine sand with sparse pebble stringers. In some areas small gypsum flakes are found on the eroded flanks of Tqa deposits. Fine-grained Tqa deposits grade up-fan into or are covered by coarser clastic deposits. Tqa deposits are light to medium brown and are easily erodible unless protected by an indurated capping unit. Uncapped Tqa deposits are commonly observed to form intricately-dissected mounds similar in appearance to those found in badlands landscapes. The flanks of each mound often exhibit "elephant skin" textures. Tqa deposits are similar to QTsd deposits mapped south of the Narrows in the Galleta Flat East quadrangle (Youberg et al., 2006) and in quads further south.

Tqf **Pliocene Quiburis basin fill deposits, fanglomerate** – Tqf deposits are characterized by completely indurated (stage III-IV) sections of Quiburis basin fill sediments. Portions of these deposits are clast supported while others are completely calcium carbonate matrix supported. These deposits are generally exposed in highly incised drainages (> 25 meters) in the proximal to middle piedmont and are commonly overlain by slightly less indurated, very well-rounded Tqc deposits. Tqf deposits are generally limited in exposure to small areas such as these incised drainages but are likely far more widespread in the subsurface. Where incision is enhanced by faulting, waterfalls and narrow winding fanglomerate slot canyons are cut through Tqf deposits. These canyons can be very deep (> 30-40 meters) and are extremely prone to high velocity, powerful flooding during moderate to extreme precipitation events. Channels incised into Tqf deposits are usually devoid of any loose sediment and behave more similarly to bedrock lined channels than typical sediment-laden alluvial channels. A complete lack of soil development and vegetation is common for Tqf deposits due to the level of cementation.

Bedrock units

Tmi **Mafic intrusion (Miocene)** – Hypabyssal basaltic intrusion.

Tcg   **Conglomerate (Miocene)** – Generally poorly to moderately bedded and poorly sorted conglomerate with bed dips of 10° to 50°. This unit was included within the Paige Gravels by Lingrey (1982), which is considered equivalent to the more extensive San Manuel Formation (Dickinson, 1987, 1991). Near the northeastern corner of the quadrangle, this unit consist of massive to poorly bedded and poorly sorted conglomerate with subrounded, 2-100 cm clasts. Up to ~90% of clasts consist of Johnny Lyon granodiorite, with sparse to locally dominant Paleozoic quartzite and carbonate. At one locality, boulders of Johnny Lyon granodiorite are up to 5 m diameter (station JES-07-513).

Tgl   **Heterogeneous pegmatitic leucogranite (Eocene)** – Leucogranite that varies from highly heterogeneous and pegmatitic to medium to fine grained muscovite granite, to very fine grained leucofelsite that is locally so siliceous that it grades into pure silica.

Mesozoic - Johnny Lyon Hills

Kbs   **Sandstone, Bisbee Group (upper Jurassic to middle Cretaceous)** –Sandstone with sparse, thin, dark magnetite-rich laminations that define bedding.

Jg   **Glance conglomerate member of the Bisbee Group (Jurassic)** – Massive to crudely bedded, locally moderately well bedded, clast-supported conglomerate. Clasts are generally <30 cm, subrounded to subangular, and consist mostly of pale to medium gray limestone or, less commonly, of fine-grained quartzose sandstone. Some conglomerate looks like debris flows with incomplete mixing of different clast types.

Jvs   **Volcanic-lithic conglomerate and sandstone (Jurassic)** – Volcanic-lithic conglomerate and sandstone near the northeast corner of the Wildhorse Mountain Quadrangle. Small cobbles and pebbles consist of generally medium to dark gray volcanic or hypabyssal rock debris. Many clasts contain phenocrysts of feldspar, hornblende, and biotite, and a small fraction contain quartz.

      This unit is part of the Walnut Gap Volcanics as defined by Cooper and Silver (1964) and mapped Drewes (1974). In the original usage of Cooper and Silver (1964), the Walnut Gap Volcanics are depositionally overlain by Glance Conglomerate. However, as mapped here and by Dickinson (1987), this unit forms only a small, fault-bounded sliver of volcanic-lithic conglomerate adjacent to a larger fault block of Glance Conglomerate. We tentatively consider this to be a facies of the Glance Conglomerate.

Jss   **Sandstone (Jurassic)** – This unit consists predominantly of medium- to fine-grained, pale tan sandstone and medium reddish brown, quartzose siltstone. Local medium to coarse sandstone beds contain planar cross beds. Truncation of these beds, and one channel with a pebbly base, reveal stratigraphic tops in several locations that indicate these beds are upright (not overturned as indicated by Dickinson, 1987) and are stratigraphically beneath the Glance Conglomerate.

Paleozoic and Mesoproterozoic Tectonites, Little Rincon Mountains

PlPet   **Tectonite derived from Earp Formation (Pennsylvanian to Permian protolith)** – Generally consists of medium to light gray limestone, silty limestone, sandy limestone, and beds of quartzite.

PlPhet   **Tectonite derived from Horquilla Limestone and Earp Formation, undivided (Pennsylvanian to Permian protolith)** – Interbedded marble and calc-silicate (Lingrey, 1982).

lPhMet   **Marble tectonite derived from Horquilla Limestone and Escabrosa Limestone, undivided (Mississippian to Pennsylvanian protolith)** – Calcite marble, slightly siliceous calcite marble, and zones up to tens of cm thick of calcite marble containing silt or very fine sand. This unit also includes medium to pale gray, light tan, to dusty white marble tectonite with rare siliceous stringers and nodules. Colors are variable, and include whitish tan, pale red, pale gray, and grayish white. One approximately 5 m thick layer of pure silt, now very fine grained micaceous schist, was identified in this map unit.

DmЄat   **Tectonite derived from Martin Formation and Abrigo Formation, undivided (Devonian and Cambrian protoliths)** – Gray and dusty white calcite marble and tan, dolomitic marble, commonly with siliceous marble containing silt or fine sand, with interlayered silty to sandy layers and marble layers on scale of 2-20 mm. Interlayered silty marble is commonly greenish, probably because of secondary chlorite. Sand is locally medium grained. North of Red Rock Canyon near the western edge of the Wildhorse Mountain Quadrangle, where the only throughgoing road crosses the western edge of the Quadrangle, tremolite(?) is abundant, and forms almost pure tremolite(?) beds within and north of the pass that is occupied by the road.

ЄYqt   **Dripping Spring Quartzite and Bolsa Quartzite, undivided, tectonite (Middle Proterozoic and Cambrian protoliths)** – White, light to medium gray, or pale reddish gray quartzite, with laminations and thin beds containing <1%, <<1 mm magnetite which clearly reveal transposed bedding. Metamorphic white mica locally imparts parting along compositional layering, with parallel mica flakes up to 2 mm diameter. Several conglomerate beds, 0.5 to 3 m thick, contain quartzite clasts that are flattened parallel to compositional layering and that rarely exceed 10 cm in longest direction. Truncated crossbeds suggest that stratigraphic tops is to the east.
     In the Johnny Lyon Hills and Little Dragoon Mountains east of the Wildhorse Mountain Quadrangle, largely unmetamorphosed and undeformed Bolsa Quartzite rests directly on unmetamorphosed Dripping Spring Quartzite on a low-angle unconformity (Cooper and Silver, 1964). The undivided quartzite unit described here is thought to be the metamorphosed equivalent of these two quartzite units in the Johnny Lyon Hills. However, the unconformity between them could not be confidently located in the tectonites. It is also uncertain if the presence of multiple conglomerate beds is due to original stratigraphy or to repetition associated with transposition or other deformation.

Ypt   **Tectonite derived from Pioneer Shale (Mesoproterozoic protolith)**

Paleozoic

Pzc   **Carbonate, undivided (Paleozoic)** – Includes the following lithologies: (1) Pale gray limestone with irregular siliceous stringers and knots, with less common tan siltstone and silty carbonate. (2) Tan dolostone and tan silty dolostone, with protruding layers of silty carbonate. (3) Pale gray to pale tannish gray and medium gray, massive to thick bedded

limestone and possibly dolostone, all with sparse stringers and irregular, web-like disseminations of silica.

PIPe   **Earp Formation of the Naco Group (Pennsylvania to Permian)** – Interbedded, fine-grained, quartzose sandstone and variably silty to pure limestone. In the Johnny Lyon Hills this unit consists of very fine grained quartzite (~50 micrometer grains) with 1%, ~20 micrometer grains of black magnetite(?). Adjacent blocks in wash (not mapped), which look like Jelly Bean Conglomerate Member of the Earp Formation, support interpretation of this quartzite as Earp Formation, but possibly this outcrop is part of the Bisbee Group.

IPh   **Horquilla Limestone (Pennsylvanian)** – Medium- to light-gray, massive, medium- to thick-bedded limestone with very sparse, possibly secondary, silica stringers and blobs. Also includes sparse 5-15 m thick cherty limestone beds.

Me   **Escabrosa Limestone (Mississippian)** – Typically massive medium to pale gray limestone.

Dm   **Martin Formation (Devonian)** – Typically tan to gray dolostone, silty dolostone, sandy dolostone, and limestone. Bedding is apparent on scale of 1-100 cm.

Ca   **Abrigo Formation (Cambrian)** – In the far northeastern corner of the Wildhorse Mountain Quadrangle (northwestern Johnny Lyon Hills), this map unit consists of very fine grained, somewhat calcareous, quartzose sandstone that is pale to medium orangish tan to yellowish orange, and is laminated to thin bedded. Locally sandy beds are brecciated and floating within more calcareous matrix due to what appears to have been soft-sediment deformation. The base of the Abrigo Formation is placed at the top of the stratigraphically highest quartzite bed greater than 20 cm thick. Near the western edge of the Quadrangle this unit is highly faulted but its composition appears to be the same.

Cas   **Abrigo Formation, upper sandstone member (Cambrian)** – In the far northeastern corner of the Wildhorse Mountain Quadrangle (northwestern Johnny Lyon Hills), this map unit consists of fine grained, very quartz rich, well sorted sandstone, medium to pale brown sandstone, with numerous iron oxide pits after altered grains that were possibly originally calcareous. Some sand beds are quite calcareous and weather like carbonate. Local cross beds are 10-20 cm thick. One 40-cm-thick bed consists of rip-up fragments of sandstone a in calcareous sand matrix. Unit is about 10 m thick and is overlain by slightly sandy carbonate that is typical of the Martin Formation. This unit was described by Cooper and Silver (1964) as the stratigraphically highest unit in the Abrigo Formation.

Cb   **Bolsa Quartzite (Cambrian)** – In Johnny Lyon Hills, this unit is generally fine to medium grained, quartz-rich sandstone that is moderately to strongly indurated. Near base, the unit is commonly brown or contains magnetite laminations that clearly reveal 5-20 cm thick trough cross beds, locally with coarse sand or pebbly sand at base of troughs. Near the western edge of the Quadrangle this unit is highly faulted but its composition appears to be the same.

Proterozoic

q   **Vein quartz**

Yd　　　　**Sierra Ancha diabase (Mesoproterozoic)** – Dark greenish black metadiabase with shape fabric and cleavage.

Apache Group

Yds　　　**Dripping Spring Quartzite (Mesoproterozoic)** – Pale orangish brown, fine-grained to very fine-grained sandstone and siltstone that form an indurated quartzite. Generally, this rock unit is not as fine-grained as the Pioneer Shale, and not as coarse as typical lower Bolsa. Also, it does not have iron-oxide-stained laminations and/or thin beds that are common in lower Bolsa. A pebbly zone, ~50 cm thick, consists mostly of <1 cm white vein-quartz clasts, locally up to 3 cm. Sample of quartzite adjacent to pebble zone has no visible feldspar fragments or black opaque minerals, which is unlike lower Bolsa and perhaps unlike all of Bolsa. Correlation of this unit with the Dripping Spring Quartzite is tentative.

Yp　　　　**Pioneer Formation (Mesoproterozoic)** – Reddish brown, very fine quartzose sandstone and dark brown phyllite. A 10-40 cm thick, coarse, poorly sorted sandstone containing angular pebbles (< 1cm) forms the base of the Pioneer Formation. Generally this rock is too fine and too dark to be Bolsa Quartzite or Dripping Spring Quartzite.

YXg　　　**Biotite granite, undivided (Paleoproterozoic or Mesoproterozoic)** – Extensive exposures of "porphyritic biotite quartz monzonite to granodiorite" mapped by Lingrey (1982) in the footwall of the San Pedro detachment fault. This unit was correlated with the Continental Granodiorite by Drewes (1974; see also Silver, 1978). Lingrey (1982, p. 22) further described the granite as "predominantly quartz monzonitic (adamellitic) to rarely granodioritic" with "feldspar crystals (usually K-feldspar, but sometimes oligoclase)...set in a coarse-grained hypidiomorphic-granular fabric. Clump like aggregates of biotite create a characteristic mottled appearance." Lingrey (p. 22) also noted that "Locally, and particularly near the contact with the overlying metasedimentary tectonites, a strong gneissic to mylonitic foliation indicates the presence of some synmetamorphic deformation."

YXgr　　**Granite of upper Red Rock Canyon (Paleoproterozoic or Mesoproterozoic)** – Medium to coarse grained, megacrystic biotite granite with pale pink K-feldspar up to 3 cm diameter, and 4-7% biotite in < 5 mm clots.

Xgj　　　**Johnny Lyon granodiorite (Paleoproterozoic)** – Medium-grained biotite granodiorite with blocky, 1-4 cm long, K-feldspar megacrysts that make up 10-25% of the rock unit, and ~5-10% mafic minerals, most of which are probably biotite but are generally too altered for definitive identification. On the north side of Wildhorse Mountain, within a few hundred meters of the trace of the Wildhorse Mountain thrust fault, K-feldspar phenocrysts are generally 5-12 mm diameter, and gray quartz phenocrysts (up to at least 6 mm) are conspicuous. Possibly this is due to alteration near the thrust, or to proximity to the San Pedro detachment, or it could be due to primary textural variations within the granodiorite. Two modal mineral analyses by Cooper and Silver (1964), from samples east of the map area in the Johnny Lyon Hills, determined that the unit is a granodiorite. A sample of this rock unit from the Johnny Lyon Hills, east of the map area, yielded a U-Pb zircon date of 1643 ± 4 Ma (Eisele and Isachsen, 2001), and a sample of this unit from just south of the map area, in the adjacent Galleta Flat East 7 ½′ Quadrangle, yielded a U-Pb date of 1667 ± 21 Ma (G. Gehrels, written communication, 2007).

　　　　　　　Rocks of this unit area locally and variably crushed in the San Pedro Narrows area, but crushing was not so pervasive that the unit appeared obviously permeable to groundwater (e.g., Haney and Lombard, 2005).

Xdj   **Dioritic rocks associated with Johnny Lyon granodiorite (Paleoproterozoic) –**

Xgjm   **Mylonitic Johnny Lyon granodiorite (Paleoproterozoic)** – Mylonitic granodiorite above
the Wildhorse Mountain thrust.

Xgjmb   **Brecciated mylonitic Johnny Lyon granodiorite (Paleoproterozoic)** – Brecciated
mylonitic granodiorite above the Wildhorse Mountain thrust.

Xp   **Pinal Schist (Paleoproterozoic)** – Very fine grained quartz-mica schist.

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