Geologic Map of the Hereford 7½' Quadrangle and the northern part of the Stark 7½' Quadrangle, Cochise County, Arizona

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Introduction

This map depicts the geology of the Hereford and the northern part of the Stark 7 ½' quadrangles, which are located in the upper San Pedro Valley north of the U.S. – Mexico border. The quadrangles cover much of the piedmont east of the San Pedro River and southwest of the Mule Mountains, including a portion of the San Pedro Riparian National Conservation Area along the river. The map also covers a small portion of the piedmont west of the San Pedro River. The geology of the quadrangle is diverse and includes Paleozoic sedimentary and igneous rocks, exposures of the upper part of the late Cenozoic basin-filling deposits, and Quaternary surficial alluvium deposited by tributary streams and the San Pedro River. Bedrock geologic mapping was compiled from Ferguson and Johnson (2006). This map is one of several 1:24,000-scale geologic maps that have been completed recently in the upper San Pedro Valley. Other maps cover the Lewis Springs (Pearthree et al., 2006), Fairbank (Ferguson et al, 2006), Land (Shipman and Ferguson, 2005), St. David (Youberg, 2005), Huachuca City (Pearthree, 2003), McGrew Spring (Shipman and Ferguson, 2003), and Benson (Youberg et al, 2004) quadrangles. This mapping was completed under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992.

Mapping Methods

Surficial deposits that cover most of the quadrangle were mapped using stereo pairs of 1:24,000-scale color aerial photos taken in 1979 and 1988, georeferenced digital color orthophotos taken in 1997, and topographic information from the U.S. Geological Survey 7 1/2' quadrangle map. Mapping was verified by field observations during the summer of 2006, and unit boundaries were spot-checked in the field. Map data was compiled digitally using the ArcMap program and the final linework for the map was generated from the digital data. The bedrock mountains in the northeastern quarter of the quadrangle were mapped and structural measurements obtained in the spring and summer of 2006.

Characteristics evident on aerial photographs and on the ground were used to differentiate and map various alluvial surfaces. The color of alluvial surfaces depicted on aerial photographs is primarily controlled by soil or deposit color, vegetation type and density, and locally by rock varnish on surface gravel clasts. Significant soil development begins on an alluvial surface after it becomes isolated from active flooding and depositional processes (Gile et al., 1981, Birkeland, 1999). Two typical soil horizons in Pleistocene alluvial sediments of southeastern Arizona are reddish brown argillic horizons and white calcic horizons. On well-preserved surfaces, increases in soil clay content and reddening are excellent indicators of increasing soil age (Pearthree and Calvo, 1987). Soil carbonate content also increases with soil age, especially in lower altitude portions of the map area or where soil parent material is rich in carbonate. As a result, on color aerial photographs older alluvial surfaces characteristically appear redder or whiter (on more eroded surfaces) than younger surfaces. Differences in the drainage patterns between surfaces provide clues to surface age and potential flood hazards. Young alluvial surfaces that are subject to flooding commonly display distributary (branching downstream) or braided channel patterns; young surfaces may have very little developed drainage if unconfined shallow flooding predominates. Dendritic tributary drainage patterns and increasingly deep dissection are characteristic of older surfaces, although dissection varies substantially across the piedmont based on proximity to the incised San Pedro River. Topographic relief between adjacent alluvial surfaces and the depth of entrenchment of channels can be determined using stereo-paired aerial photographs and topographic maps. Young flood-prone surfaces appear nearly flat on aerial photographs and are less than 1 m above channel bottoms. Active channels are typically entrenched 2 to 15 m below older surfaces.

Surficial Geology

Variations in the distribution of surfaces of different ages and sources and concomitant variations in dissection across the quadrangle provide evidence regarding the recent geologic evolution of this area. Generally, the landscape along the San Pedro River is deeply dissected, with extensive exposures of basin-fill deposits (the Saint David Formation, QTsd). Magnetic polarity stratigraphy and dated tephra deposits in the San Pedro Valley north of this quadrangle indicate that the St. David Formation was deposited during the late Tertiary and early Quaternary (Johnson et al, 1975; Lindsay et al, 1990). St. David beds exposed in the Hereford and Stark quadrangle are middle and upper members of the formation (Lindsay et al, 1990), and thus likely date to less than about 2.5 Ma. Modern channels are incised into relatively flat valley bottoms that are covered with Holocene deposits, and limited preserved Pleistocene surfaces are perched well above the valley bottoms. The valley bottom of the San Pedro River is covered by Holocene river deposits and tributary fan deposits. Historical incision of the San Pedro River (Hereford, 1993; Huckleberry, 1996) has resulted in the isolation of the former floodplain (unit Qy_2r) from significant flooding and the development of low inset terraces (unit Qy_3r) along the active channel (unit Qy_cr). The highest remnant tributary deposits on the distal piedmont (unit Qo) and high terrace remnants of the San Pedro River (units Qi_2r and Qyir) record approximate levels of the valley bottom in the Pleistocene. Since the early to middle Pleistocene, the San Pedro River has downcut about 30 m. Because of the recent incision of the San Pedro River and adjacent tributary washes, flood inundation is relatively restricted, but the potential for lateral bank erosion into young valley-bottom deposits is high.

The eastern 2/3 of the quadrangle is covered by deposits of various ages that were emplaced by piedmont washes draining from the Mule Mountains to the east. Much of this piedmont is mantled by old Pleistocene tributary deposits (units Qo, and Qi_1) that have been eroded into broadly rounded ridges or left as planar remnants several meters or more above the valley bottoms. Incision along these tributary drainages is quite variable, but generally decreases toward the eastern margin of the quadrangle. There is enough topographic confinement throughout most of the quadrangle that late Pleistocene deposits typically are found on the fringes of the eroded middle Pleistocene ridges, and Holocene deposits are found on valley bottoms. Some active channels are incised into valley bottoms as a result of historical entrenchment. Several extensive late Pleistocene fans exist near the eastern margin of the quadrangle where overall incision is less, however. Flood hazards are greatest along active channels (unit Qy_c where channels are mappable; also including smaller channels within unit Qy_2). Locally, areas mapped as Qy_2, Qy_1, and Qi_3 that are not high above active washes may be subject to shallow inundation.

Bedrock Geology

Bedrock in the Hereford 7.5' Quadrangle was mapped by Charles Ferguson and Brad Johnson (2006, Arizona Geological Survey Digital Geologic Map 58) and compiled on this map by Jon Spencer. Bedrock consists of a generally west-dipping sequence of Paleozoic rocks intruded by two sets of porphyries. The Paleozoic strata are gently folded into a set of weakly west-vergent, disharmonic folds. The folds are interpreted to be post-Early Cretaceous and pre-Cenozoic in age for two reasons. First, the fold train's orientation and geometry is similar to a fold train less than 12 km to the northwest that involves Lower Cretaceous Bisbee Group strata (Pearthree et al. 2005; Ferguson et al, 2005). Secondly, although no Mesozoic sedimentary rocks are present in the western Mule Mountains, two suites of porphyry dikes, sills and stocks are present whose relationship to the rocks they intrude suggest that the older, Jurassic porphyries (~170-180 Ma) are folded, but that the younger, possible Laramide are not (one reported date, ~63 Ma, analytical technique not indicated).

Quaternary map units

Piedmont Alluvium

Quaternary piedmont deposits derived from the Mule Mountains in the northeastern portion of the map area grade toward the San Pedro River near the western edge of the Hereford quadrangle. Piedmont alluvium was deposited primarily 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. Piedmont deposits range in age from recent Holocene to early Pleistocene with some exposure of Tertiary basin fill deposits near the San Pedro River where incision is greatest.

Qy_c - Modern stream channel deposits- Unconsolidated deposits in active piedmont channels consisting of very poorly sorted sand, pebbles, cobbles, and occasional boulders. Channels may exhibit bar and swale microtopography with bars generally containing coarser sediments and greater vegetation coverage. Channels are generally incised 1 to 2 m below adjacent Holocene piedmont terraces and may be incised into Pleistocene alluvium by 10 m or more. Qy_c deposits typically exhibit little to no soil development. These deposits commonly become submerged during moderate to extreme precipitation events and can be subject to deep, high velocity flow and lateral bank erosion.

Qy – Holocene alluvium, undifferentiated

Qy_2 - Late Holocene alluvium- Young deposits primarily located near active channels on floodplains, low-lying terraces, and small tributary channels which are part of the modern piedmont drainage system. Floodplain deposits generally consist of medium to coarse sand mantled by very fine sand and silt exhibiting desiccation cracks in low-lying areas. Localized bar and swale microtopography is common with coarser sediments (pebbles to cobbles) making up bars. Ephemeral tributary drainage deposits may be inset into older alluvium by up to 2 m and typically exhibit poorly sorted, loosely consolidated sand, pebbles, and small cobbles. Terrace surfaces are very planar between numerous small rills, with up to 1 – 2 m incision near tributary drainages. Soil development is typically absent or very weak in Qy_2 deposits, which are generally pale brown (10 YR). Qy_2 surfaces are susceptible to flooding under moderate to extreme precipitation conditions when flow exceeds channel capacity. Vegetation on Qy_2 surfaces consists of abundant grasses and small shrubs.

Qy_1 – Early to Middle Holocene alluvium- Piedmont terrace deposits located primarily along the flanks of incised drainages. Qy_1 terraces are lower than, and inset into, older Pleistocene deposits but sit higher than adjacent Qy_2 surfaces. Qy_1 terraces are likely only subject to flooding during extreme precipitation events and exhibit weak soil development characterized by incipient stage I calcium carbonate accumulation and medium brown (10 to 7.5 YR) coloration. Terraces are planar to gently rolling with remnant bar and swale microtopography. Vegetation density is slightly higher on bars and consists mainly of grasses, shrubs, and small (<1 m tall) creosote.

Qi_3 – Late Pleistocene alluvium- Deposits associated with slightly dissected alluvial terraces that occupy intermediate topographic positions between adjacent Holocene and older Pleistocene terraces. Incision by active drainages ranges from 1 to 3 m below Qi_3 surfaces. Surficial clast cover consists of large pebbles to small cobbles, some of which exhibit Stage II to III calcium carbonate rinds and are likely reworked from older units higher in the piedmont. Qi_3 terraces are gently crowned but still exhibit an abrupt change in slope near drainages and younger inset terraces. Qi_3 surfaces exhibit moderately developed soils with medium to dark brown (7.5 YR) near-surface horizons and stage I to II calcium carbonate accumulation. Vegetation consists of small shrubs, and abundant medium (~1 m tall) creosote interspersed with isolated acacia.

Qi_2 – Middle to Late Pleistocene alluvium- Deposits associated with extensive relict alluvial fans and terraces throughout the mapped area. Surfaces are broad and moderately to well-crowned, exhibiting moderate dissection near active channels. Terraces stand significantly higher than younger surfaces and subtly grade to higher standing, older surfaces. Modern drainage networks may be incised from 3 to 10 m below Qi_2 surfaces. Terraces are mantled by large pebbles, cobbles, and partially submerged boulders. Soils on Qi_2 surfaces are well developed and exhibit dark brown to reddish brown (7.5 to 5 YR) near surface horizons overlying significant (stage II to III) calcium carbonate accumulation. Globular calcium carbonate nodules and thin (<15 cm) petrocalcic horizons are exposed in arroyo cuts. Calcium carbonate accumulation is also evident in medium to coarse prismatic ped structures in near surface horizons. Vegetation consists of small shrubs, abundant mature creosote, many acacia, and the occasional small mesquite tree.

Qi_1 – Early to Middle Pleistocene alluvium- Deposits associated with very well rounded, moderately to highly dissected, high-standing relict alluvial fans. Soils are red in color and have well-developed argillic and calcic horizons where well-preserved. Qi_1 surfaces typically are covered by large cobbles to boulders exhibiting moderately dark rock varnish development. Elevation differences between active channel bottoms and Qi_1 surfaces can be greater than 10 m. Qi_1 deposits are drained by broad swales and well-developed, deeply incised tributary channel networks. Qi_1 terraces gently grade into younger deposits with no abrupt change in slope. Soil argillic horizons are reddish (5 YR) and stage IV calcium carbonate accumulation are found at depth. Vegetation consists mainly of abundant large (> 1.5 m tall) creosote, small shrubs, acacia, mesquite, agave, and ocotillo.

Qo – Early Pleistocene alluvium- Deposits associated with moderately to deeply dissected, very well rounded remnant alluvial fan deposits exhibiting strong petrocalcic horizon development. Qo surfaces have been eroded, with degradation ranging from significant soil loss due to piping to complete stripping of soils down to a thick (10 to 60 cm), completely indurated matrix-supported (stage IV to V) calcium carbonate cemented horizon. A significant portion of Qo surfaces are capped by younger (Qi_2) fine grained deposition directly on top of the exposed petrocalcic horizon. Vegetation on Qo surfaces is composed of small shrubs, mature creosote, acacia, mesquite and agave.

QTsd – Tertiary to Quaternary basin fill - Upper member St. David formation basin fill deposits exposed in arroyo cuts and deeply dissected distal piedmont deposits east of the San Pedro River. Calcium Carbonate accumulation is exposed as massive petrocalcic horizons (~10 to 20 cm thick), abundant 1 to 3 cm diameter nodules, prismatic peds, and filaments interspersed with poorly sorted coarse sand and pebbles. QTsd deposits are commonly mantled by thin Qi_2 deposits and gently slope towards San Pedro River terraces and floodplains to the west. Vegetation on QTsd surfaces generally consists of large creosote, acacia, and the occasional mesquite.

San Pedro River Alluvium

Qycr – Holocene channel deposits – These deposits are composed of unconsolidated sand, pebbles, and cobbles. Located within the active drainage of the San Pedro River these deposits are often inundated when flooding occurs. Qy_cr deposits locally exhibit bar and swale topography with bars being typically more vegetated. These surfaces are typically dominated by grasses and small shrubs or young mesquite trees. On this surface the main channel commonly diverges into braided channels. These surfaces typically have little to no soil development.

Qy_4r – Holocene alluvium, younger member – Unit Qy_4r consists of bars within the San Pedro River, which are not over topped during low flow stages. These were mapped from present day photos. Qy_4r is composed of unconsolidated sand, pebble, and cobbles. This unit is not covered with vegetation and there is no soil development.

Qy_3r – Late Holocene floodplain and terrace deposits – The Qy_3r unit consists of abandoned historical floodplains flanking the main channel along the San Pedro River. Terraces are flat with punctuated incision near tributary drainages. Qy_3r deposits consist of thinly bedded, weakly to unconsolidated sand, silt, and clay. Qy_3r surfaces were identified comparing 1955 and 1996 air photos to evaluate terrace development through time. Soils are minimal to weakly developed, with some carbonate filaments and fine masses and weak soil structure in buried horizons and the near-surface layer. Hereford (1996) suggests that this terrace is younger than 1947 based on a tire found within the deposit. This terrace is 20-50 cm below Qy_2r. Qy_3r surfaces developed after the 1937 photosurvey and are presently the active floodplain of the San Pedro River.

Qy_2r – Holocene floodplain and terrace deposits – The Qy_2r unit consists of low terraces flanking the main floodplain along San Pedro River. Terraces are flat with incision near tributary drainages. This unit was identified by using 1937 air photos from the San Pedro River valley and comparing them to present day air photos. Qy_2r terraces were most recently flooded in 1977. Qy_2r deposits consist of well-bedded, weakly consolidated sand, silt, and clay. Soils are weakly developed, with some carbonate filaments and fine masses and weak soil structure in near surface horizons. These units were the existing floodplain in 1937 photos.

Qyir – Early Holocene to Late Pleistocene alluvium – Unit Qyir consists of planar surfaces deposited along the river valley. Qyir is composed of mudstone with thin silty sandstone interbeds, with abundant gastropod shell fragments within the mudstone. Mudstone contains a high percentage of shrink swell clay (smectite). This surface is incised about 3-5 meters and in some places is the bank wall of the San Pedro River. Although this surface is close to the river, it should only be inundated during extreme flooding events within the river valley. Piping occurs where this surface is close to incised channels. Qyir soils are poor to moderately developed, with prismatic blocky peds, silty clay, pinkish grey 7.5 YR 6/2, reaction with HCl, and root traces. This surface is dominated by medium to large mesquites trees as a bosque. Qyir deposits were associated with the floodplain deposits from the San Pedro River and related spring environments that created overbank swamps.

Qi_2r – Late Pleistocene alluvium – Unit Qi2r consist of isolated paleoterraces found outside of the incised river. Qi2r is composed of cobble to pebble clast-supported conglomerate with subrounded to round clasts composed of granite, limestone, marl, and quartzite. This surface is approximately 2 meters thick and is degraded with beveled edges. Due to the degradation and parent material soil was not preserved on this surface.

Other units

d – Disturbed - Disturbed ground due to agriculture, extensive excavation, or blockage of drainages for cattle tanks.

Qc – Colluvium deposits - Unconsolidated to moderately-consolidated colluvium deposits mantling the lower slopes of bedrock outcrops.

Bedrock Units (from Ferguson and Johnson, 2006)

TKp – Coarse-grained rhyolite porphyry (Late Cretaceous-Early Tertiary) - Felsic porphyry containing 10-30% phenocrysts of subhedral quartz (2-6 mm), euhedral to subhedral potassium feldspar (1-5 mm), euhedral to subhedral plagioclase (1-3 mm), and biotite (1-3 mm). Age is based on a 63 Ma date of unreported provenance (probably a personal communication) shown on the map of Drewes (1980) for a related, petrographically identical stock just to the north of the map area.

TJp – Phenocryst-poor rhyolite porphyry and aplite (Late Cretaceous-Early Tertiary or Jurassic) – Phenocryst-poor rhyolite porphyry containing <5-7% <2-3 mm feldspar phenocrysts that grades into aplite towards the margins of dikes. Contact zones of some dikes have very fine-grained vitric matrix in some areas. The dikes show little or no evidence of internal brittle deformation suggesting that they are related to the Late Cretaceous-Early Tertiary coarse-grained rhyolite porphyry. The north-northwest striking dikes of this unit are steeply dipping and cross-cut Paleozoic strata at various angles suggesting that they were emplaced after folding.

Jp – Coarse-grained rhyolite porphyry (Jurassic) - Felsic porphyry containing 10-30% phenocrysts of subhedral quartz (2-6 mm), euhedral to subhedral potassium feldspar (1-5 mm), euhedral to subhedral plagioclase (1-3 mm), and biotite (1-3 mm). The Jurassic age of this unit is based on its connectivity to the main mass of the Juniper Flat Granite which has been dated at 171 $\pm$ 7 Ma (K/Ar biotite age, Marvin and others, 1973), and 175.2 $\pm$ 0.7 Ma (U-Pb zircon, Lang et al., 2001).

Pc – Colina Limestone (Permian) – Medium- to thick-bedded, amalgamated skeletal limestone, typically with matrix-supported texture. Skeletal micrite and skeletal wackestone dominate, with lesser amounts of skeletal packstone, and very little or no grainstone. Skeletal debris consists largely of crinoidal columnals, brachiopods, bryozoans, solitary rugose corals, colonial tabulate corals, echinoid spines, and abundant very large gastropods (up to 30cm). Greater than 150 m (500') thick.

Pℙe – Earp Formation (Permian- Pennsylvanian) – Interbedded thin- to medium-bedded red shale, mudstone, silty mudstone, and fine-grained ripple cross-laminated sandstone with subordinate thin- to medium-bedded carbonate beds, dominated by massive micrite and skeletal wackestone. Skeletal debris is similar to the assemblages of the Colina Limestone. Echinoid spines are particularly abundant in some beds. 75-105 m (250-350') thick.

ℙh – Horquilla Limestone (Pennsylvanian) – Medium- to thick-bedded cherty limestone with subordinate interbedded siliciclastic units; dark shale throughout the main part of the unit and red shale, silty shale and rare fine-grained ripple cross-laminated and cross-stratified sandstone in the upper part. Limestone beds are dominantly skeletal packstone and wackestone with lesser amounts of grainstone and micrite. In general, clast-supported limestone (grainstone and packstone) dominate in the lower part of the unit, whereas up-section matrix-supported wackestone and micrite are more abundant. 300-365 m (1,000-1,200') thick.

Me – Escabrosa Limestone (Mississippian) – Medium- to thick-bedded limestone, dominated by thick-bedded, amalgamated, crinoid columnal grainstone, especially towards the base of the unit, which is typically a cliff-former. The main part of the unit consists of medium- to thick-bedded, locally very thick-bedded skeletal grainstone and packstone with subordinate thin- to medium-bedded, cherty micrite, and skeletal wackestone with minor dark shale interbeds. 150-275 m (500-900') thick.

Dmu – upper Martin Limestone (Devonian) – A two-part sequence that grades upward from lithologies typical of the lower Martin; recessive, medium-bedded micritic carbonate and sparsely skeletal wackestone (typically dolostone) with shale or mudstone interbeds, into lithologies typical of the Escabrosa; medium- to thick-bedded crinoid columnal skeletal packstone and grainstone. The upper Martin is distinguished from the Escabrosa based on fossils (the upper Martin contains sparse 2-20 cm rounded fragments of the colonial rugose coral *Hexagonaria*) and because it includes several erosional unconformities similar to the one that defines the base of the Escabrosa, each defined by a massive thick-bedded grainstone or packstone carbonate overlying a recessive, strongly recrystallized carbonate (typically dolostone) with abundant sparry calcite-filled cavities. The uppermost unconformity is identified as the top of this unit. 60-125 m (200-400') thick.

Dm – lower Martin Limestone (Devonian) – Dolostone, limestone, and shale. A complex sequence of thin- to medium-bedded skeletal wackestone, sparsely skeletal micrite, rare skeletal packstone, shale, calcareous mudstone, and minor quartz sandstone. Carbonates occur in amalgamated sequences 0.5-5 m thick that are typically strongly recrystallized and commonly dolomitized. 75-90 m (250-300’) thick.

Ꞓa – Abrigo Formation (Cambrian) – Thin- to medium-bedded carbonate, siltstone, silty mudstone, and fine-grained argillaceous sandstone. Carbonate beds are typically micritic and dolomitized and fossils are rarely preserved. Silty mudstone and fine-grained sandstone typically occurs in amalgamated ripple-laminated sets. Bioturbation is intense and ubiquitous in nearly all lithologies. 185-215 m (600-700’) thick.

Ꞓb ir Bolsa Quartzite (Cambrian) – Medium- to thick-bedded, cross-stratified quartz sandstone, and pebbly feldspathic quartz sandstone. The sequence fines upward, and is also more quartzose upwards. The basal portion is commonly thick-bedded in wedge-planar to trough cross-stratified sets and contains abundant, rounded quartz pebbles up to 8cm. The uppermost part consists, in some areas, of relatively massive, thick-bedded, very fine-grained quartz sandstone. Up-section the abundance of interbedded siltstone and silty mudstone or shale increases. The contact with the overlying Abrigo Formation is defined as the top of the highest quartz sandstone bed in a sequence in which quartz sandstone is more abundant than siltstone or shale. 125-365 m (400-1200’) thick.

Xp – Pinal Schist (Paleoproterozoic) – Medium- to fine-grained sericitic schist ranging from light green to dark gray. Dark gray, fine-grained to very fine-grained schist commonly contains recrystallized tabular porphyroblasts up to 2 cm. Coarser grained schist tends to be lighter colored and includes psammitic intervals in which are preserved faint laminations and cross-laminations.

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