



Geologic Map of the Hereford 7 1/2' Quadrangle and the northern part of the Stark 7 1/2' Quadrangle, Cochise County, Arizona

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THE UNIVERSITY OF ARIZONA
College of Science

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

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_{cF}). The highest remnant tributary deposits on the distal piedmont (unit Qo) and high terrace remnants of the San Pedro River (units Qi_{2r} and Qy_{ir}) 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 Qi₁) 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

Other units

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

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

Qtc – Quaternary hillslope talus and colluvium - Unconsolidated to moderately-consolidated talus and colluvium deposits mantling the lower slopes of bedrock outcrops.

San Pedro River Alluvium

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 found adjacent to active channels in the form of lightly vegetated in-channel bars, small planar fluvial terraces within 30 cm of river elevation, and recent erosional meanders outside the presently active channel. Terrace deposits are inset into older river alluvium and are generally narrow, rarely more than 100 meters across. Qy4r deposits are composed of poorly sorted unconsolidated sediments ranging from fine silts to gravel bars depending on location in the channel at the time of deposition. Pebbles and cobbles are well-rounded to sub-rounded. These surfaces are commonly inundated under moderate to extreme flow events and can be subject to deep, high velocity flow and lateral bank erosion. These deposits do not exhibit soil development but may exhibit a light vegetation cover of small trees, bushes, and grasses.

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 terrace deposits – Deposits beneath 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 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. Analysis of local exposures and archaeological sites associated with these deposits indicates that some of the surface, and most of the sediment package, is prehistoric. Radiocarbon dates and diagnostic pottery sherds indicate an age of 0.5-3 ka (Onken et al., 2014). Where Qy2r deposits are moderately to deeply incised they are 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 Qy3) onlap onto Qy2r deposits, although interfingering relationships exist 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 occupy elevations 5 to 20 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 the mountains from which modern piedmont material is derived from. Qi3r terrace surfaces are planar, often surrounded by distal piedmont alluvium, and are generally lightly vegetated except for 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.

Qi3ra - Late Pleistocene river terrace deposits (older member)

Qi2r – Middle to late Pleistocene river terrace deposits – Terrace deposits are similar to Qi3r deposits but occupy higher positions in the landscape 15 to 35 m above the active San Pedro River channel. Terrace surfaces are slightly to moderately rounded. Clast composition is diverse. Well-rounded pebbles to cobbles with stage I-II calcium carbonate accumulation armor Qi2r surfaces. Vegetation is sparse, consisting of small shrubs and grasses. Soil development is generally weak on Qi2r surfaces but is more evident in finer grained sections. Qi2r 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.

Piedmont alluvium and surficial deposits

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.

Qyc - 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. Qyc 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.

Qy₃ - Latest Holocene alluvium - Recently active piedmont alluvium located primarily along active drainages including floodplain, low-lying terrace, and overflow channels. Qy₃ deposits are composed of unconsolidated to very weakly consolidated silty to cobbly deposits and exhibit greater vegetation than Qyc deposits. These deposits generally exhibit bar and swale microtopography and are susceptible to inundation during moderate to extreme flow conditions when channel flow exceeds capacity. Soil development is generally absent or incipient on Qy₃ 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 - 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 Qy₂ deposits, which are generally pale brown (10 YR). Qy₂ surfaces are susceptible to flooding under moderate to extreme precipitation conditions when flow exceeds channel capacity. Vegetation on Qy₂ surfaces consists of abundant grasses and small shrubs.

Qy₁ – Older Holocene alluvium - Piedmont terrace deposits located primarily along the flanks of incised drainages. Qy₁ terraces are lower than, and inset into, older Pleistocene deposits but sit higher than adjacent Qy₂ surfaces. Qy₁ 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.

Qys – Fine-grained Holocene alluvium derived from the St. David Formation - Qys deposits are unconsolidated, very fine to fine grained alluvium located in close proximity to basin fill deposits. These sediments are lighter in color and finer than alluvium derived from further upfan, generally consisting of clay, silt and sand, with occasional deposits of open, unvarnished, fine gravel. Where evident, soil development is typically a brown (7.5 YR) sandy loam with substantial disseminated carbonate but no visible carbonate accumulation. Vegetation on Qys deposits consists of small shrubs, grasses, creosote, and acacia.

Qy – Holocene alluvial deposits, undifferentiated

Qi₃ – Late Pleistocene alluvial fan and terrace deposits - 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 Qi₃ 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. Qi₃ terraces are gently crowned but still exhibit an abrupt change in slope near drainages and younger inset terraces. Qi₃ 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.

Qi₂ – Middle to Late Pleistocene alluvial fan and terrace deposit - 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 Q_{i2} surfaces. Terraces are mantled by large pebbles, cobbles, and partially submerged boulders. Soils on Q_{i2} 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.

Q_{i1} – Early to Middle Pleistocene alluvial fan and terrace deposits - 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. Q_{i1} surfaces typically are covered by large cobbles to boulders exhibiting moderately dark rock varnish development. Elevation differences between active channel bottoms and Q_{i1} surfaces can be greater than 10 m. Q_{i1} deposits are drained by broad swales and well-developed, deeply incised tributary channel networks. Q_{i1} 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.

Q_o – Early Pleistocene alluvial fan deposits - Deposits associated with moderately to deeply dissected, very well rounded remnant alluvial fan deposits exhibiting strong petrocalcic horizon development. Q_o 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 Q_o surfaces are capped by younger (Q_{i2}) fine grained deposition directly on top of the exposed petrocalcic horizon. Vegetation on Q_o surfaces is composed of small shrubs, mature creosote, acacia, mesquite and agave.

Quaternary to Tertiary Basin Fill deposits

QTsd – Pliocene to early Pleistocene Saint David Formation - 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 Q_{i2} 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.

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 ± 7 Ma (K/Ar biotite age, Marvin and others, 1973), and 175.2 ± 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.

•[♠] – 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.

■ – 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.

☐ – 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.

☐ – 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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