Geologic Map of the Lewis Springs 7.5' Quadrangle, Cochise County, Arizona

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Arizona Geological Survey Digital Geologic Map 51 (DGM-51), version 2.0

May 2009

Scale 1:24,000 (1 sheet)

Arizona Geological Survey
416 W. Congress St., #100, Tucson, Arizona 85701

Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number #04HQAG0072. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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Introduction

This map depicts the geology of the Lewis Springs 7 ½' Quadrangle, which is located in the upper San Pedro Valley a few miles north of the U.S. – Mexico border. The quadrangle covers much of the piedmont west of the San Pedro River and south of the Babocomari River, including the eastern fringe of Sierra Vista and a portion of the Fort Huachuca Military Reservation. The quadrangle also covers about 10 miles of the San Pedro Riparian National Conservation Area along the river, and bedrock hills and a small portion of the piedmont east of the San Pedro River. The geology of the quadrangle is diverse and includes Cretaceous sedimentary and igneous rocks, extensive 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. This map is one of 7 1:24,000-scale geologic maps that have been completed recently in the upper San Pedro Valley. Other maps cover the 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. Revisions to this map were made in 2008 and 2009 as part of an effort to systematically map Holocene alluvium associated with the San Pedro River; funding for this effort was provided by the Arizona Department of Water Resources.

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 1987, georeferenced digital color orthophotos taken in 1997, and topographic information from the 7 1/2' quadrangle map. Part of the quadrangle had been mapped previously (Demsey and Pearthree, 1994); this mapping was reevaluated, modified and incorporated into this map. Mapping was verified by field observations during the spring and summer of 2005, 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 hills in the northeastern quarter of the quadrangle were mapped and structural measurements obtained in the spring of 2005.

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 30 m below older surfaces.

Surficial Geology and Geologic Hazards

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 late Tertiary and early Quaternary (Johnson et al, 1975; Lindsay et al, 1990). St. David beds exposed in the Lewis Springs 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_3r, Qi_2r, and Qi_1r) 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 western 2/3 of the quadrangle is covered by deposits of various ages that were emplaced by piedmont washes draining from the Huachuca Mountains to the west. 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 western 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. Active channels typically are incised into valley bottoms as a result of historical entrenchment. Several extensive late Pleistocene fans exist near the western margin of the quadrangle where overall incision is less, however. There are no sizable distributary channel networks with extensive young deposits on this quadrangle, so we do not identify any potential active alluvial fan flooding. 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.

The map area includes the northern termination of the Huachuca fault zone. Alluvial scarps associated with this fault zone extend northward for about 15 miles from about the U.S. – Mexico border. The northernmost obvious fault scarps are at the southern margin of the Sierra Vista sanitary waste facility, and prior to the construction of the facility may have continued slightly farther to the north. The complex branching pattern of the fault scarps just to the south is consistent with the termination of faulting in this area, however, and there is no clear expression of faulting north of the sanitary waste facility. The Huachuca fault zone displaces early and middle Pleistocene alluvial fan deposits (units Qo and Qi_1); late Pleistocene fan deposits (unit Qi_3) are definitely not faulted, and middle to late Pleistocene deposits (unit Qi_2) are not clearly displaced. Thus, the fault zone has been active most recently in the middle Pleistocene. Previous analysis of alluvial fault scarps along the zone suggested an age of at least 100 ka for the most recent faulting (Demsey and Pearthree, 1994). They estimated a paleoearthquake magnitude of 6.5 to 7.

Agricultural activity, aggregate extraction pits, a waste water treatment plant, and recent residential development have modified the landscape to greater or lesser degrees. Areas are mapped as “disturbed” where the surficial deposits are profoundly altered (gravel pits, treatment plant); surficial deposits other areas with less profound disturbance are depicted with concealed (dotted) contacts.

Bedrock Geology

Introduction

The Lewis Springs is dominated by an Upper Cretaceous plutonic-volcanic complex that is closely associated with silver-rich, porphyry ore deposits of the Tombstone district located directly northeast of the map area (Goodale, 1927; Butler et al., 1938; Newell, 1974; Devere, 1978; Williams, 1980). The volcanic rocks overlie Lower Cretaceous siliciclastic strata of the Bisbee Group with angular unconformity. The older rocks were folded into northwest-striking folds that show evidence for two phases of deformation. The Upper Cretaceous volcanics are moderately to gently tilted to the northwest forming two low-lying, southwest-striking horst blocks that transect the San Pedro River valley directly north of the map area.

The principal volcanic unit in the area is a monotonous pile of andesitic lava intruded by the approximately 76 Ma quartz monzonite of Brunckow Hill (on the 1952 topographic map this feature is called “Bronco Hill” but on the 1983 version the same feature is named “Brunckow Hill”), and a swarm of northeast-striking andesite porphyry dikes that are present throughout the Tombstone Hills. The dikes appear to come from an undated stock, the quartz monzonite of Government Draw, which lies to the south of the stock at Brunckow Hill. Both stocks have previously been correlated with the approximately 76 Ma Scheffelin Granodiorite, an important stock associated with mineralization in the Tombstone district. Since the andesite porphyry dikes intrude the stock at Brunckow Hill, and the Scheffelin Granodiorite, the quartz monzonite of Government Well is tentatively interpreted to be a younger unit.

Stratigraphy

Lower Cretaceous Bisbee Group. In its type locality in the Mule Mountains of southern Cochise County, the Bisbee Group consists of at least 5,000 feet of sandstone, shale, siltstone, conglomerate, and limestone (Ransome, 1904). The basal unit, the Glance Conglomerate is overlain by two siliciclastic units, the Morita (older) and Cintura Formations (younger) with an intervening limestone unit, the Mural Limestone. The unit was deposited in a complex series of generally northwest-striking rift basins, where depositional environments ranged from proximal alluvial fan to alluvial and marginal marine and/or lacustrine to deep-water marine and lacustrine (Bilodeau, 1982; Dickinson and Klute, 1987). The two main siliciclastic formations of the Bisbee Group are virtually indistinguishable. If the intervening Mural Limestone is not present, previous workers (Gilluly, 1956 and Hayes, 1970) recommend that no attempt be made to differentiate the two. This is the case along the San Pedro Valley in the Tombstone area. Gilluly (1956) believed that the Mural Limestone was not present north of the Mule Mountains, and referred to most of the rocks in the Tombstone area as the Bisbee Formation (undifferentiated) because no significant intervals of limestone are found in this area. However, after Creasy (1967), and Archibald (1987) mapped and described the Mural Limestone in the Whetstone Mountains to the north, it became clear that the Mural Limestone interval was either never deposited or was deposited and then later removed by erosion in the Tombstone area. Just to the north of the map area, Shipman and Ferguson (2005) reinterpreted a limestone that had been mapped as Epitaph dolostone (Gilluly, 1956; Moore, 1993) as Mural Limestone. Minor thin limestone units with sparse molluscan fauna are present within the Bisbee Group in the Tombstone Hills (Butler et al., 1938; Gilluly, 1956; Force, 1996), but no serious attempt has been made to correlate these rocks with the Mural Limestone. Based on poorly preserved fossils and regional arguments, Stoyanow (1949) believed that the Bisbee Group of the Tombstone Hills was all part of the uppermost unit of the Bisbee Group, the Cintura Formation. Force (1996) divided the Bisbee Group of the Tombstone area into informal upper and lower divisions with a lower division consisting primarily of coarse-grained breccia and conglomerate, a unit that Gilluly (1956) correlated with the Glance Conglomerate.

Bisbee Group in the map area is mapped simply as undifferentiated siliciclastic Bisbee Group (Ks). The base is not exposed and the upper contact is an angular unconformity. The Bisbee Group in the study area is strongly folded and was probably deeply eroded prior to deposition of Upper Cretaceous volcanics. It is therefore possible that all of the upper Bisbee Group in this area, including the Mural and Cintura formations was removed. In support of this interpretation, just to the north of this map area a sequence of Bisbee Group siliciclastic strata is overlain by Mural Formation (Shipman and Ferguson, 2005) and correlated with the Morita Formation.

The Bisbee Group of the study area consists of complexly intertonguing sequences of thin- to thick-bedded, cross-stratified and plane-bedded, quartz sandstone, feldspathic quartz sandstone, and lithic-feldspathic quartz sandstone interbedded with gray-green to red siltstone, mudstone, silty mudstone and shale, locally with abundant calcareous nodules and irregularly thin- to medium-bedded, discontinuous impure limestone, and limestone pebble conglomerate. Two lithofacies, ranging in thickness from 5 to 150 m, are recognized, each representing approximately 50% of the map unit, and each characterized by the dominance of specific lithologies: 1) gray-green mudstone and lithic-feldspathic-quartz sandstone, and 2) red shale or mudstone and quartz sandstone. The two lithofacies occur in repeating cycles with the red shale and quartz sandstone units typically sharply overlying the lithic-feldspathic-quartz sandstone and dark mudstone units. Sparse, rounded to well-rounded, clast-supported and matrix-supported, medium- to thick-bedded, sandy matrix, pebble-cobble conglomerate beds are associated with both lithofacies. Clasts in the conglomerate consists of quartzite, argillite, vein quartz, with sparse granitoid, limestone, and felsic volcanics.

The gray-green mudstone and lithic-feldspathic quartz sandstone lithofacies is characterized by thin- to medium-bedded, moderately to moderately poorly-sorted, grayish green, argillaceous sandstone interbedded with dark colored mudstone and siltstone. Sandstone is typically massive, but may include ripple-laminated intervals. The lithofacies is interpreted as a distal alluvial to deltaic and distributary channel depositional environment. Some of the sandstone units may be turbidites.

The red shale and quartz sandstone lithofacies typically consist of moderately to well-sorted, light colored, less argillaceous, commonly complexly cross-stratified sandstone interbedded with reddish siltstone, mudstone and shale. Sandstone is typically quartzose with quartz cement. Calcareous nodules, irregularly bedded impure limestone, and limestone pebble conglomerate beds are found almost exclusively associated with the red shale and mudstone. The red shale and quartz sandstone lithofacies are interpreted as alluvial deposits grading into marginal marine and/or lacustrine high-energy beach sequences. The associated pedogenic carbonate units suggest a semi-arid environment.

Upper Cretaceous volcanics. Upper Cretaceous volcanic rocks overlie the Bisbee Group with pronounced angular unconformity and form a gently northwest-dipping pile several hundred meters thick. The lower part of the sequence consists of andesitic lava overlain and intruded by rhyolite lava and lithic tuff that was collectively referred to as the Brunckow volcanics by Gilluly (1945; 1956). The only part of this sequence exposed in the map area is the andesitic lava. To the north, these rocks are overlain by a sequence of rhyolite lava, the tuff of Charleston, and the Uncle Sam Tuff, a phenocryst-rich ash-flow tuff of quartzite latite composition that forms resistant rounded peaks and ridges. The andesitic volcanics form low, rounded hills, and the rocks are pervasively altered. Propylitic alteration is ubiquitous with pervasive chloritic alteration of mafic phenocrysts, and abundant epidote-coated joints and fractures.

Andesite lava and a probable andesitic intrusive complex, mapped collectively as unit Ka, directly overlie and intrude the Bisbee Group in the northern part of the map area. These rocks correlate with the andesite portion of the Brunckow Hill volcanics of Gilluly (1956). The southernmost exposures of these rocks represent a intrusive complex composed of andesitic flows interspersed with a confusing array of Bisbee Group sandstone and argillite blocks most of which are oriented as if they were not significantly disrupted relative to nearby exposures of Bisbee Group outcrops. The contact between the Bisbee Group and the andesite is characterized by large areas of sedimentary rock intruded by andesitic dike swarms that coalesce into zones dominated by andesite with scattered sandstone and argillite blocks. This intrusive complex is intruded by a complex series of younger andesitic dikes of various composition, and by a relatively massive stock of andesite porphyry (Kap) that is in turn sparsely intruded by additional fine-grained andesitic dikes (Kai). The andesite porphyry stock was mapped as part of the Uncle Sam Porphyry by Gilluly (1956), and as a dacite lava by Moore (1993). Farther north and up-section through the andesite lava sequence, dikes become less abundant.

The andesite lava forms a monotonous pile of amalgamated flows locally with thin mafic pyroclastic and volcaniclastic sandstone and conglomerate interbeds. Attempts to map individual flows and sequences of similar lavas are severely hampered by complex interfingering of different flow types, cross-cutting dikes of varying composition, poor exposure, and uncertain structural relationships. The resulting map depicts the entire unit as undifferentiated andesite lava, a solution required by the scope of this mapping project. Detailed field descriptions of the rocks are available as part of a digital database accompanying this map and may be of use to investigators working on specific problems or using smaller scale maps. Petrographically, the andesite lavas are characterized by small (<2 mm) mafic phenocrysts that are usually altered beyond recognition and therefore of little use for differentiating flows. Where recognizable, the mafic phenocrysts are dominated by hornblende, but pyroxene phenocrysts are also present.

Individual outcrops of the andesite unit are subdivided into three general types based on the abundances and size ranges of the plagioclase phenocrysts. Field descriptions in the database identify these rocks using these three types: The symbols and general descriptions are: Kfx) fine-grained, phenocryst-rich andesite containing >10%, but usually >25%, 0.5-2.0 mm, but usually <1.0 mm plagioclase phenocrysts, Kfp) fine-grained, phenocryst-poor andesite containing <10%, but usually <5%, 0.5-2.0 mm, but usually <1.0 mm plagioclase phenocrysts, and Kmx) flows with discrete blocks or zones of the Kfx and Kfp types mixed with medium-grained, moderately phenocryst-rich andesite containing 10-25%, 1.5-3.0 mm plagioclase phenocrysts. In the northern part of the lava field, flows of the fine-grained phenocryst-poor and phenocryst-rich andesite lava dominate with only thin intervals of the Kmx type, but to the south, Kmx dominates in an area that includes abundant blocks ranging in size from 1 to 100 m of Bisbee Group sedimentary rocks. In some areas, the andesite and sedimentary rock are so intimately swirled together that descriptive units, Kmx-s or Kfx-s are used in the database. These zones probably represent vent complexes. In general, to the north, flows of the fine-grained phenocryst-poor and phenocryst-rich andesite (Kfx and Kfp) dominate. To the south, the medium-grained andesite (Kmx) dominates in an area that appears to be an intrusive complex.

Intrusive units and intrusive relationships

The principal intrusive units in the study area are two quartz monzonite stocks (Kgs and Kg), and a swarm of northeast-striking coarse-grained andesite porphyry dikes (Kad).

Quartz monzonite of Brunckow Hill and the quartz monzonite of Government Draw

Two quartz monzonite stocks herein informally named the quartz monzonite of Brunckow Hill and quartz monzonite of Government Draw intrude the andesite volcanics (Ka). The quartz monzonite of Brunckow Hill has a K/Ar biotite age of 76.30 ± 1.80 Ma (Marvin and Cole, 1978). Despite the fact that this date is nearly 3 million years older than a K/Ar biotite age of 73.5 ± 2.80 Ma (Marvin et al., 1973) for the Uncle Sam Tuff, the stock at Brunckow Hill and the Scheffelin Granodiorite (dated at 76.3 ± 3 Ma by Creasy and Kistler (1962)) are both interpreted to be younger than the Uncle Sam Tuff (Lipman and Sawyer, 1985; Moore, 1993). Neither stock is known to intrude the Uncle Sam Tuff. In addition, a clast of medium-grained quartz monzonite similar to the Brunckow Hill stock was observed within a rhyolite tuff breccia (Kra) that is overlain by the Uncle Sam Tuff in the northerly adjacent Fairbank map area (Ferguson et al., 2005). Because of this, we believe that one or both of the quartz monzonite of Brunckow Hill and the Scheffelin Granodiorite might predate emplacement of the Uncle Sam Tuff. The tuff of Charleston which underlies the Uncle Sam Tuff in the northerly adjacent Faribank map area (Ferguson et al., 2005) is for the most part a megabreccia unit, and this raises the possibility that the quartz monzonite of Brunckow Hill might be related to an older caldera and that the K/Ar dates are not in error.

The quartz monzonite of Government Draw (found only on the Lewis Springs 7.5' map sheet) is differentiated from the stock at Brunckow Hill because of slight petrographic differences and because it appears to be correlative with an extensive swarm of northeast-striking coarse-grained andesite porphyry dikes that intrudes all other igneous rocks in the Tombstone Hills - Charleston area including the Scheffelin Granodiorite. None of these dikes intrude the Government Well stock. Of critical importance to this discussion are conflicting reports regarding the cross-cutting relationship between the stock at Brunckow Hill (Kg) and the andesite porphyry dikes (Kad). Gilluly (1956) shows a prominent dike of the andesite porphyry intruded by the stock at Brunckow Hill, a relationship that would require the stock to postdate all rocks intruded by the andesite porphyry dike swarm (including the Uncle Sam Tuff). This interpretation may have lead previous workers to conclude that the K/Ar dates of this stock and the Uncle Sam Tuff were in error. The dike in question clearly intrudes the stock, a relationship shown by Newell (1974) and confirmed during our mapping of this critical area.

Coarse-grained andesite porphyry dikes

The coarse-grained andesite porphyry (Kad) forms a swarm of distinctive, northeast-striking dikes and a small stock (along the east edge of the northerly adjacent Fairbank map sheet) that intrudes all other know igneous units in the Tombstone Hills - Charleston area except for the quartz monzonite of Government Draw. The dikes dip steeply to the southeast and intrude a swarm of similarly oriented normal faults in the area. Some of the dikes are composite with granitic interiors and porphyritic margins, and the granitic interiors are petrographically similar to the quartz monzonite of Government Draw. The eastern intrusive contact of the quartz monzonite of Government Draw displays similar relationships with a porphyritic border phase (similar to the andesite porphyry dike unit) intruded by granitic material similar to the rest of the stock. The dikes and the stock are therefore correlated temporally, and since the dikes intrude the Uncle Sam Tuff, the quartz monzonite of Government Draw is interpreted to be the only granitic rock in the area that is known to be older than Uncle Sam Tuff. The dikes and the stock at Government Draw have not been dated.

Structural Geology

Bisbee Group strata in the study area where folded in large wavelength northeast-striking close to open folds. Along the northeast edge of the map area, a weakly developed slatey cleavage is folded by these folds (the cleavage – bedding intersection is folded).

Upper Cretaceous volcanics overlie the folded Bisbee Group with angular unconformity, and are tilted gently to the northeast throughout the area. The northwest tilting is attributed to a set of steeply to moderately southeast-dipping normal faults that transect the San Pedro valley from southwest to northeast directly north of the map area.

Alteration and mineralization

Alteration in country rock associated with emplacement of the quartz monzonite stocks of Government Well and Brunckow Hill is relatively minor. Rocks older than the Uncle Sam Tuff are pervasively propylitically altered, but show no sign of increased altered or mineralization adjacent to the granitic stocks. Thin, northeast-striking quartz-sericite-pyrite veinlets with less than 5cm thick potassic envelopes are present in the stock at Brunckow Hill. These are cut by zones of argillic alteration, calcite, and MnO veins associated with northeast-striking faults and the coarse-grained andesite porphyry dike swarm.

Alteration associated with the northeast-striking coarse-grained andesite porphyry dikes is intense and these dikes appear to be the main source of fluid migration and alteration in the Charleston mining district directly north of the map area. Wall rocks are typically strongly argillic altered with extensive networks of MnO and quartz-calcite veinlets. At depth, in the Charleston Lead Mine, alteration associated with these dikes is reported to produce coarse-grained seriticic alteration. Unpublished Anaconda data reported in Reynolds et al. (1986) report a K/Ar sericite age of 76.40 ± 3.0Ma from a vein in the Charleston Lead Mine. It is worthwhile noting that the Charleston Lead Mine lies at the point where a pair of greater than 10m-thick coarse-grained andesite porphyry dikes intersect the west-facing caldera margin for the tuff of Charleston, and the base of the Uncle Sam Tuff (Ferguson et al., 2005).

Recognition that emplacement of medium-grained, phaneritic texture granitic rocks of the Scheffelin Granodiorite, and the quartz monzonite stock at Brunckow Hill might be related to volcanic rocks older than the Uncle Sam Tuff raises the possibility that alteration and mineralization in the Charleston district is more complex than previously thought.

Map Unit Descriptions

Other Units

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

d - Disturbed ground – Much of the quadrangle has been disturbed by human activities, particularly agricultural activities. This unit designation is used only in areas of substantial excavation or anthropogenic deposition, for example, sewage treatment facilities or gravel pits.

Qtc - Quaternary hillslope talus and colluvium – Thin, steeply to moderately sloping, weakly bedded hillslope deposits mantling the middle and lower slopes of bedrock hills. Deposits are locally derived and very poorly sorted, consisting of angular to subangular basalt cobbles and boulders with a matrix of sand, silt and clay. Older hillslope deposits have darkly varnished cobble and boulder mantles and relatively clay-rich soils.

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 7 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 during 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.

Qy_3r - Historical river terrace deposits – Terrace deposits that occupy elevations from 1 to 2 meters above Qycr 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. These terraces have developed in the past century as the active channel has narrowed and vegetation has increased on adjacent terraces. 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 Qy_3r surfaces is possible during lower flow events.

Qy_2r - Latest Holocene to historical river terrace 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). Qy_2r deposits are associated with broadly planar surfaces that locally retain the shape of historical river meanders. Qy_2r 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 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 Qy_2r 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. Qy_2r deposits are subject to catastrophic bank failure due to undercutting and lateral erosion during flow events. Distal piedmont fan deposits (Qy_2 ,Qyaf, and Qys) onlap onto Qy_2r deposits although an interfingering relationship likely exits in the subsurface.

Qy_1r – 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 are up to 7 meters above the active channel in highly incised locales and typically are less than 1.5 m higher than adjacent Qy2r surfaces. These terraces typically are covered with fine-grained floodplain deposits, but relict gravel bars and lenses are common.

Qi_3r - Late Pleistocene river terrace deposits – Deposits associated with low intermediate terraces inset about 5 m above the Holocene floodplain of the San Pedro River. Deposits consist of sand, silt, and gravel, with weak to moderate soil carbonate (Stage I-II) accumulation. Terrace surfaces typically are smooth and slightly reddened and are covered with gravel and finer-grained deposits.

Qi_2r – Middle to late Pleistocene river terrace deposits – Higher intermediate terraces about 10 to 15 m above the Holocene floodplain of the San Pedro River. Terrace surfaces typically are fairly smooth to sloping remnants perched on eroded St. David Formation deposits. Terrace deposits are a mix of river sand, gravel, and silt and clay, but surfaces typically are covered with relict gravel deposits. Soil development is moderate because surfaces are not extensive, consisting primarily of weak clay accumulation and reddening and stage II to III calcic horizons.

Qi_1r - Early to middle Pleistocene river terrace deposits – Isolated deposits associated with the highest possible river terraces along the San Pedro River. Terrace surfaces are fairly flat but have undoubtedly been substantially modified by erosion. Well-rounded gravel is evident at the surface and terrace surfaces are typically covered with litter from underlying calcic soil horizons. Terrace surfaces range from about 20 to 25 m above the active river channel.

Qir - Pleistocene river deposits, undifferentiated

Piedmont alluvium and surficial deposits

Quaternary piedmont deposits derived from the Huachuca Mountains to the west cover the western 2/3 of the Lewis Springs quadrangle; deposits on the eastern fringe of the map were derived from local hills or the Mule Mountains to the east. This alluvium was deposited primarily by larger tributary streams that head to beyond the limits of the quadrangle; these larger streams and smaller streams that in this quadrangle have eroded and reworked some of these deposits. Deposits range in age from modern to early(?) Quaternary. Abbreviations are ka, thousands of years before present, and Ma, millions of years before present.

Qy_c – Modern stream channel deposits - Active channel deposits composed of very poorly-sorted sand, pebbles, and cobbles with some boulders to moderately-sorted sand and pebbles.

Channels are generally incised 1 to 2 m below adjacent Holocene terraces and alluvial fans, but may be incised 10 m or more below adjacent Pleistocene deposits. Channel morphologies generally consist of a single thread high flow channel or multi-threaded low flow channels with gravel bars. Channels are extremely flood prone and are subject to deep, high velocity in moderate to large flow events, and severe lateral bank erosion.

Qy$_3$ – Latest Holocene alluvium - Recently active piedmont alluvium located primarily along active drainages including floodplain, low-lying terrace, and overflow channels. Qy$_3$ 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 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.

Qy$_2$ - Late Holocene alluvium - Young deposits in floodplains, low terraces and small channels that are part of the modern drainage system. Along the larger drainages, unit Qy$_2$ sediment is generally poorly to very poorly sorted silt, sand, pebbles, and small cobbles; floodplain and terrace surfaces typically are mantled with sand and finer sediment. On lower piedmont areas and in smaller tributary washes young deposits consist predominantly of moderately sorted sand and silt, with some pebbles and cobbles in channels. Soils are pale brown in color (10 YR), and soil development is very weak, consisting of slight carbonate accumulation. Channels generally are incised less than 1 m below adjacent terraces, but locally incision may be as much as 2 m. Channel morphologies generally consist of a single-thread high flow channel or multi-threaded low flow channels with gravel bars adjacent to low flow channels. Channels are flood prone and may be subject to deep, high velocity flows in large flow events. Potential lateral bank erosion is severe, and flood flows may significantly change channel morphology and flow paths. Local relief varies from fairly smooth channel bottoms to undulating bar-and-swale topography that is characteristic of coarser deposits. Terraces have planar surfaces, but small channels are common.

Qy$_1$ – Older Holocene alluvium - Terrace deposits found mostly along the margins of incised drainages throughout the study area. Qy$_1$ surfaces are higher than adjacent Qy$_2$ surfaces and are generally not subject to inundation. Qy$_1$ terraces are planar to gently undulating, with local surface relief up to 1 m where gravel bars are present. Qy$_1$ surfaces are < 3 m above adjacent active channels. Surfaces typically are sandy but locally have unvarnished open fine gravel lags or pebble and cobble deposits. Qy$_1$ soils typically are brown in color (7.5YR) with weakly developed stage I calcium carbonate accumulation (see Machette, 1985, for description of stages of calcium carbonate accumulation in soils).

Qys - Fine-grained Holocene alluvium derived from the St. David Formation - Thin, fine-grain Holocene alluvial deposits formed in swales on ridges of mid-Pleistocene fan deposits. These deposits are very thin, typically less than 0.5 m thick, but locally may be up to 1 m thick. Sediment is mainly silt and sand, with occasional deposits of open, unvarnished, fine gravel lag. Soil development is minimal. Where it has developed soil is typically a brown (7.5YR) sandy loam with substantial disseminated carbonate but no visible carbonate accumulation.

Qy - Holocene alluvial deposits, undifferentiated

Qyi - Holocene to late Pleistocene alluvial fan and terrace deposits - Thin, relatively fine-grained alluvial fan deposits mantling lower slopes of St. David Formation near the San Pedro River.

Qi_3 - Late Pleistocene alluvial fan and terrace deposits - Unit Qi_3 is composed of slightly to dissected terraces and alluvial fans. Active channels are incised up to about 3 m below Qi_3 surfaces. Qi_3 fans and terraces are slightly lower to much lower in elevation than adjacent older surfaces. Qi_3 deposits consist of pebbles, cobbles, and finer-grained sediment. Qi_3 surfaces commonly are fairly smooth with local bar and swale topography and loose to pebble and cobble lags. Surface clasts typically exhibit weak rock varnish. Qi_3 soils are moderately developed, with brown to reddish brown loamy (7.5 to 5 YR) near-surface horizons and stage I to II calcium carbonate accumulation.

Qi_{23} – Middle to late Pleistocene alluvium, undifferentiated

Qi_2 - Middle to late Pleistocene alluvial fan and terrace deposits - Unit Qi_2 is composed of moderately dissected relict alluvial fans and terraces with moderate to strong soil development found throughout the map area. Qi_2 surfaces are drained by moderately incised tributary channel networks; channels are typically 1-2 meters below adjacent Qi_2 surfaces. Well-preserved, planar Qi_2 surfaces are smooth with pebble and cobble lags; surface color is reddish brown; surface clasts are moderately varnished. More eroded, rounded Qi_2 surfaces are characterized by scattered, cobble and pebble lags with broad ridge-like topography. Soils associated with planar surface remnants typically contain reddened (5 YR), clay loam argillic horizons, with clay skins and subangular blocky structure. Underlying soil carbonate development is typically stage II with areas to stage III.

Qi_1 – Early to middle Pleistocene alluvial fan and terrace deposits - Unit Qi_1 is composed of moderately to deeply dissected relict alluvial fans with strong soil development. Qi_1 surfaces are drained by broad swales and well-developed, moderately to deeply incised tributary channel networks. Well-preserved, relatively planar Qi_1 surfaces are smooth with pebble and cobble lags; surface color is red, and surface clasts are moderately to strongly varnished. More eroded, rounded Qi_1 surfaces are characterized by strongly varnished, scattered, cobble to cobble and pebble lags with broad ridge-like topography. Soils associated with well-preserved Qi_1 surfaces are reddish brown to red and very clay-rich with strong subangular to angular blocky structure. Calcic horizon development is quite variable, but ranges from stage II to stage IV.

Qi –Pleistocene alluvial deposits, undifferentiated

Qo – Early Pleistocene alluvial fan deposits - Moderately to deeply dissected relict alluvial fan deposits with moderate to strong calcic soil development. These deposits typically cap eroded ridges or high mesas, depending on local preservation. Deposits consist of cobbles, pebbles, and sand in the middle piedmont and fine slightly toward the basin axis. Surface soil horizons are locally moderately clay-rich and reddened, but more typically are calcareous even at the surface with stage IV to V calcic horizons. These deposits may represent alluvial fans that were graded to the highest levels of the St. David Formation in the valley axis, or may just post-date the St. David formation.

Tertiary Basin Fill Alluvium

QTsd - Pliocene to early Pleistocene St. David Formation – Relatively thick sequences of red to green siltstone and claystone, white limestone, and buff sandstone. This unit is typically relatively erodible and is poorly exposed on slopes below capping Quaternary gravels. Limestone and sandstone beds are typically more resistant and form ledges. Most exposures in the Lewis Springs quadrangle probably belong to the middle member of the St. David formation (Lindsay et al, 1990), which is dominated by fine-grained floodplain deposition associated with a north-flowing axial drainage. Limestone beds may represent local marsh or lacustrine environments. Deposits in the western part of the quadrangle are coarser and probably represent distal fan environments. Local zones of substantial clay and carbonate accumulation near the modern valley axis may represent moderately developed buried soils.

Bedrock Units

Kgs - Quartz monzonite of Government Draw (Upper Cretaceous) –Medium-grained, slightly plagioclase-porphyritic, 10% biotite-hornblende, quartz monzonite. The quartz monzonite contains 1-10%, 1-10cm, rounded irregular fine-grained dioritic inclusions and is very similar to the quartz monzonite of Brunckow Hill and the Schefflien Granodiorite. The quartz monzonite of Government Draw is distinquished by its location, by a contact phase that is very similar to the coarse-grained andesite porphyry dikes (Kad), and because it contains locally abundant fine- to medium-grained leucogranite dikes. The quartz monzonite of Government Draw is thought to be younger than other plutons in the area because coarse-grained andesite porphyry dikes which appear to be derived from it intrude the other plutons.

Kg - Quartz monzonite of Brunckow Hill (Upper Cretaceous) – Medium-grained, slightly plagioclase-porphyritic, 10% biotite-hornblende, quartz monzonite. The quartz monzonite contains 1-10%, 1-10cm, rounded irregular fine-grained dioritic inclusions, and is very similar in appearance to the quartz monzonite of Grovernment Draw and the Schefflien Granodiorite. Marvin and Cole (1978) report a K/Ar biotite age of 76.30 ± 1.80 Ma for this unit.

Kai - Fine-grained andesite dikes (Cretaceous) – Andesite dikes containing <5%, <1mm plagioclase phenocrysts in very fine-grained matrix. The dikes probably represent feeders for andesite flows higher in the section.

Kad - Coarse-grained andesite porphyry dikes (Upper Cretaceous) – Dark gray, crystalline matrix, northeast-striking, steeply southeast-dipping, 0.2 to 8m thick, andesite porphyry dikes containing 12-30% 2-5mm euhedral plagioclase phenocrysts, and a few % altered mafic phenocrysts. The porphyry also contains sparse quartz phenocrysts (1-4mm), and locally up to 15% 1-10cm, fine-grained dioritic inclusions. Rocks very similar to the coarse-grained andesite porphyry dike map unit are also present along the southeastern intrusive contact of the quartz monzonite of Government Draw (CAF-2-11213) suggesting that the two units are closely related. A dike of this unit also occurs in this area but does not cut the quartz monzonite of Government Draw. Dikes of this unit intrude the quartz monzonite of Brunckow Hill and the Schefflien Granodiorite near Tombstone suggesting that the quartz monzonite of Government Draw is younger.

Kap - Andesite porphyry (Cretaceous) – A distinctive, hypabyssal andesite porphyry containing 10-25%, 1-3mm, euhedral plagioclase phenocrysts in a fine-grained crystalline matrix. Altered mafic phenocrysts (<1.5mm) comprise <5% of the rock.

Ka - Andesite (Cretaceous) – Amalgamated, andesite lava flows intruded by a myriad of dikes characterized by relatively fine-grained (<3.0mm and usually <2.0mm), euhedral to subhedral plagioclase phenocrysts. The andesite is pervasively propylitically altered with abundant epidote coated fractures and veinlets. Plagioclase phenocrysts ranging in size from <1mm to 3mm are present in abundances ranging from 1% to 30%. In most flows plagioclase phenocrysts are consistent in terms of size and abundance, but heterogenous zones are also present that probably represent andesite flows intruded by complex dike networks.

Ks - Bisbee Group (Lower Cretaceous) – Complexly intertonguing sequences of thin- to thick-bedded, cross-stratified and plane-bedded, quartz sandstone, feldspathic quartz sandstone, and lithic-feldspathic quartz sandstone, gray-green to red siltstone, mudstone, silty mudstone and shale, locally with abundant calcareous nodules and irregularly thin- to medium-bedded, discontinuous impure limestone, and limestone pebble conglomerate. Sparse, clast-supported and matrix-supported, medium- to thick-bedded sandy matrix, rounded to well-rounded, pebble-cobble conglomerate beds are also present. Clasts in the conglomerate consists of quartzite, argillite, vein quartz, with sparse granitoid, limestone, and felsic volcanics.

Acknowledgments. The Fort Huachuca Military Reservation permitted access to the fort and provided the 1987 color aerial photographs for use in our mapping efforts. Digital orthophoto quadrangles were produced by the U.S. Geological Survey and were obtained from the Arizona Regional Image Archive (ARIA) of the University of Arizona.

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