Geologic Map Database for Aggregate Resource Assessment in the Phoenix Metropolitan Area and Surrounding Regions, Arizona

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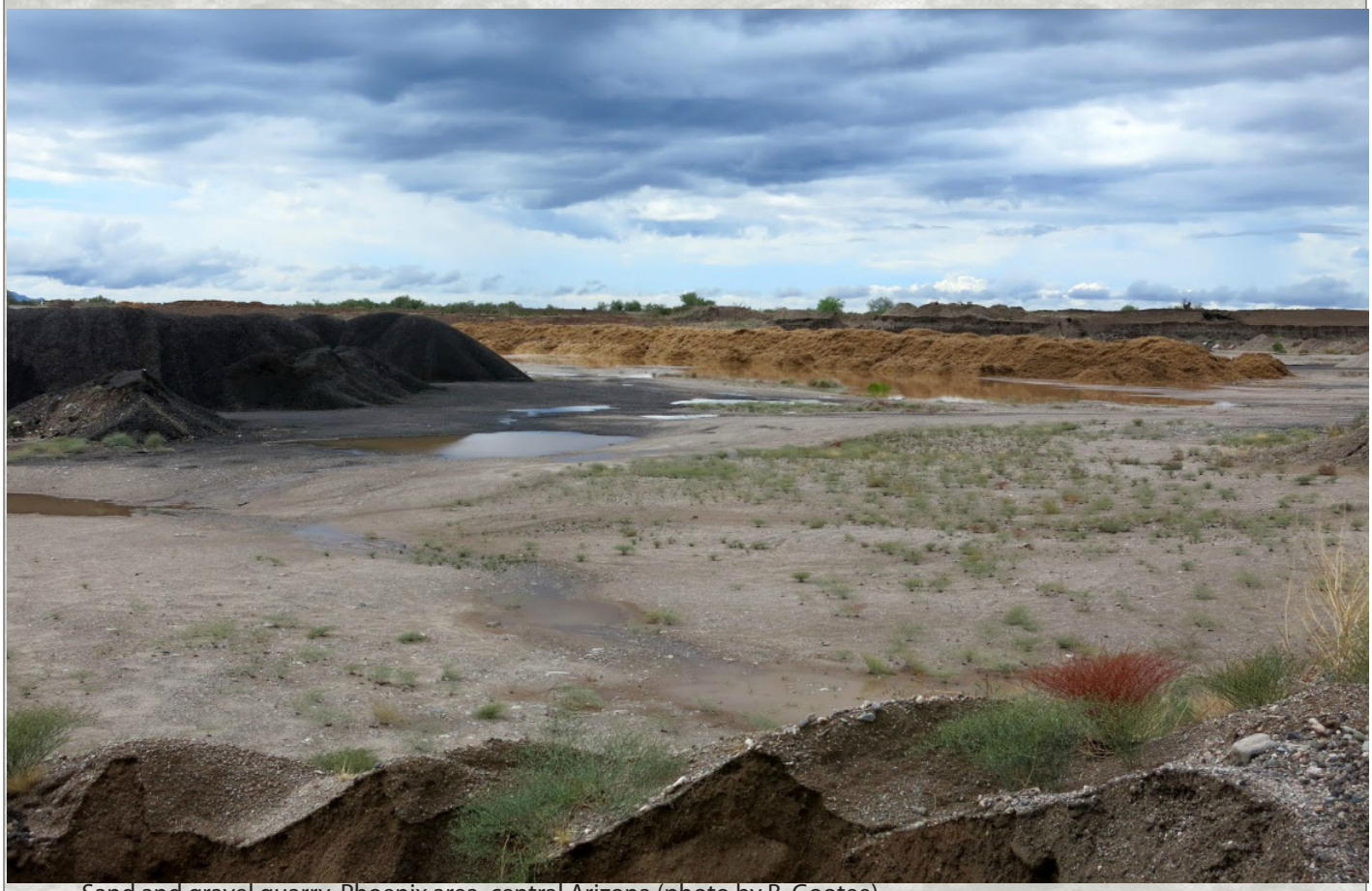
Arizona Geological Survey



Sand and gravel quarry, Phoenix area, central Arizona (photo by B. Gootee)

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Geologic Map Database for Aggregate Resource Assessment in the Phoenix Metropolitan Area and Surrounding Regions, Arizona

by

Philip A. Pearthree, Brian F. Gootee, Stephen M. Richard, and Jon E. Spencer

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May 2015

Contents of DI-43

(1) This report

(2) Map graphics – a pdf file representing data in graphical form.

(3) Shapefile of the map unit layer (polygons)

(4) ArcGIS Layer Package of map unit layer (polygons)

(5) ArcGIS Map Package of map unit layer, contacts and faults layer, and dikes and veins layer, plus a 1:250,000 scale topographic base map.

Introduction

This geologic map database and report represent a new geologic map compilation of the four 1:100,000 scale geologic maps that encompass the Phoenix metropolitan area. This compilation includes new mapping of the deposits associated with the major river systems (Salt, Gila, Verde, Agua Fria, and Hassayampa) and their largest tributaries (New River, and Skunk, Cave and Queen Creeks). In addition, mapping of deposits of smaller tributaries was improved in many parts of the map area. We made minor revisions of existing bedrock mapping, primarily along boundaries between previous compilation maps, and merged similar bedrock units into a simplified set of units.

The primary purpose of this compilation is to depict geologic units that have been and are being exploited for aggregate resources in a uniform and fairly simple manner. This supports efforts of local governments to include aggregate resources in their land management planning, as mandated by state law. These data should also serve as useful reconnaissance tools for aggregate producers when they evaluate potential future resources.

The map compilation scheme has separate young, intermediate, and old geologic units for the deposits of each of the 5 large rivers that traverse the metropolitan area. All of the major aggregate extraction activities are drawing upon the deposits of these rivers, and all produce generally high-quality aggregate products, but each has different characteristics and different gravel lithologies. Each of these rivers drains a large watershed with diverse types of bedrock; bed load deposited in the Phoenix area has commonly been transported for tens of miles or more. The proportion of less resistant lithologies is greatly diminished by this transport, which

results in a high-quality rock product for use in various types of aggregate. This map depicts the deposits associated with each of these rivers, with separate units for each river that reflect variations in rock type and gravel size. The largest of these rivers is the Gila, which traverses the southern part of the map area. All of the other watersheds in the region are tributaries of the Gila River. Because of proximity to the urban area and the amount of gravel in its deposits, however, we consider the Salt River to be the principal river system in the region, and group the Gila River with the Salt River below their confluence. The Agua Fria in the western part of the Phoenix area is another major source of aggregate, because of its proximity to the development activity in that area and the abundant gravel content of the deposits. The Verde River is a very large tributary on the eastern edge of the metropolitan area, with a diverse and coarse gravel bed load; one large aggregate operation is utilizing Verde River deposits. The primary limitation for the Verde River is the short alluvial reach below a bedrock canyon. The Hassayampa River is on the far western margin of the Phoenix area. The young deposits of much of the Hassayampa River are fairly fine, primarily sand and pebbles. Older river deposits contain more gravel, and may be an important source of aggregate in the future.

Deposits of the next smaller group of fluvial systems are mapped similarly by age and fluvial system. These moderately large drainages produce abundant gravel and sand, and have very extensive deposits. Their lithologic mixes are much less diverse, typically dominated by a few rock types. They have been exploited with a few moderate or large aggregate pits, but in general their deposits have been subject to development and only limited areas remain available as potential aggregate resources.

Bedrock

Bedrock map units were compiled largely from 1:24,000 scale maps, many of which were produced by the Arizona Geological Survey for the STATEMAP program (a joint State-Federal program to fund geologic mapping as specified in the National Geologic Mapping Act of 1992 and its reauthorizations). Important units include the unusually resistant Sierra Ancha diabase, hard, brittle, and chemically unreactive Proterozoic quartzites (primarily Mazatzal Quartzite, Dripping Spring Quartzite, and Troy Quartzite), and Mescal Limestone which may contain asbestos where it is in contact with Sierra Ancha diabase.

Databases

Three geodatabase layers are included in the database package that is part of this publication, as follows: (1) A polygon data layer that includes all surficial and bedrock map units. This is the primary product of this publication, and is intended to provide users with a guide to the types of geologic materials at the surface in the greater Phoenix metropolitan area. (2) A layer of geologic contacts and faults (arcs, or lines) that represent boundaries between different map units. Note that, for bedrock map units, polygons representing similar map units were merged, but the contacts between these units were not deleted. (3) A layer of dikes and veins (arcs, or lines). All three geodatabase layers are included in the database package file, whereas the polygon layer is also included as a layer package file and as a shapefile. Additional information is provided in the metadata associated with these files.

Major River Deposits

Major sources of aggregate for the Phoenix metropolitan area. All large active and recently active aggregate quarries have exploited these resources. Lithologic diversity is high, clast sizes are diverse and include abundant cobbles, pebbles and some boulders. Long sediment transport distances have diminished the abundance of lithologies that are more prone to weathering. Nearly all aggregate operations are located in or immediately adjacent to modern channels and overbank areas, but as pits are typically tens of feet deep, they may be exploiting pre-Holocene river deposits as well.

Salt River (including the Gila River below their confluence)

Qyrs - Young channel and floodplain deposits (Holocene), Young coarse gravel and sand in channels, and sand, silt and clay deposited in overbank areas by the Salt River. Deposits are dominated by cobbles and boulders in the east, but typical gravel size diminishes substantially downstream. Pebbles, cobbles and boulders are commonly clast-supported with a coarse sand matrix. Clasts are rounded to well-rounded, with moderate to high sphericity, and poorly sorted. Quartzite, intermediate to felsic volcanic rock and granite make up between 65 and 75% of clast lithology. Other common lithologies include basalt, diabase or gabbro, arkosic sandstone and conglomerate and limestone, and make up about 20 to 30%. Less common lithologies include gneiss, schist, chert and bulky minerals such as quartz and epidote, which make up between 5 and 15%. Quartzite and fine-grained volcanic rocks appear to be the most-resistant lithologies with the least amount of internal fracturing. Less-resistant rock types may be more abundant as pea gravel and smaller sizes. Weathering rinds are generally absent, although some coarse-grained lithologies exhibit rinds up to 1 cm thick. Chatter and percussion marks are common, especially on fine-grained rocks and quartzite. When broken or fractured granite appears to disintegrate. Also include abundant fine gravel and sand, and overbank areas typically are mantled with silt and clay.

In gravel pits the coarse-grained deposits with pebbles, cobbles and boulders are often massive to crudely-bedded, continuous, clast-supported and range from 1 to 5 or more meters thick. Clasts are often imbricated, with long-dimension sub-parallel to the river axis, dipping gently upriver. Faint large-scale cross-bedding is also present. Finer-grained deposits of predominantly coarse sand are discontinuous, crude to well-stratified, commonly exhibit cross-bedding and range from 0.5 to 1 meter thick, occasionally 2 to 3 meters thick.

Qirs - Intermediate terrace deposits (Pleistocene), Intermediate terrace deposits above the Holocene floodplain, but less than 100 feet above the modern channel. Includes lithologically diverse rounded gravel, sand, and fines. Moderate soil development and some weathering of susceptible clasts. Laterally extensive deposits commonly found on both sides of the river, but most of these terraces are intensely developed. Lithology of clasts are similar to those observed in the modern channel (Kokalis, 1971). The Blue Point and Mesa terraces are grouped in this unit (Pewe, 1978).

Qors - Old terrace deposits (Pleistocene-Pliocene) High, deeply eroded coarse gravel and sand deposits of the Salt-Gila River. Planar terrace surfaces are variable depending on preservation, some older deposits are deeply eroded. Strong calcic soils development on well-preserved surfaces, weathering of susceptible lithologies. Qors deposits are typically isolated from the corridor of modern river deposits and are of limited extent. Lithology of clasts are similar to those observed in the modern channel (Kokalis, 1971); however, more quartzite and less basalt

lithologies appear to differentiate the oldest terrace from younger ones (Larson et al., 2010). The Sawik and Stewart Mountain terraces are grouped in this unit (Pewe, 1978; Larson et al., 2010).

Gila River above the Salt-Gila confluence

Qyrg - Young channel and floodplain deposits (Holocene), Young sand, gravel, and silt deposits found on overbank areas along the Gila River. Deposits are dominated by pebbles and cobbles upstream, but typical gravel size diminishes substantially downstream. Pebbles and cobbles are clast-supported with a coarse sand matrix. Clasts are rounded to well-rounded, with moderate to high sphericity, and poorly to moderately sorted. Felsic volcanic rocks (dacite and rhyolite) make up nearly 50% of clast lithology, with quartzite the next most abundant, nearly 25%. Intermediate volcanic rock, granite and fine-grained metamorphic rocks make up ~15% of clast lithology. The remaining ~10% mix of lithologies include arkosic sandstone and conglomerate, diabase or gabbro, sedimentary chert, limestone and bulky minerals quartz and epidote. Quartzite and fine-grained volcanic rocks appear to be the most-resistant lithologies with the least amount of internal fracturing. Less-resistant rock types may be more abundant as pea gravel and smaller sizes, such as the Pinal Schist and similar fine-grained meta-sedimentary rocks. Weathering rinds are generally absent. These deposits also include abundant fine sand and silt overbank deposits, commonly blanketing the main channel and floodplain.

Qirg - Intermediate terrace deposits (Pleistocene), Sand, gravel, silt and clay deposits in intermediate river terraces. Moderate soil development, local eolian reworking of surficial sand deposits. Includes lithologically diverse rounded cobbles, pebbles, gravel and sand. Moderate soil development and some weathering of susceptible clasts, such as granite, vesicular basalt and poorly-indurated coarse-grained rocks.

Qorg - Old river deposits (Pleistocene-Pliocene), Old river deposits associated with high terrace remnants and deeply dissected landforms. Deposits are variably weathered; may have strong soil development or little soil development, depending on surface preservation.

Agua Fria River

Qyra - Young channel and floodplain deposits (Holocene), Recently active channel gravel and sand deposits, and sandy to silty floodplain deposits commonly underlain by older channel deposits. Deposits are dominated by cobbles and boulders upstream to the north and gradually diminish to predominantly coarse-grained pebbles and small cobbles intercalated with fine-grained sand downstream near the confluence with the Gila River. Clast size and angularity gradually decrease downstream, while degree of sphericity and sorting subtly increase. Clast lithologies include ~70 to 80% coarse-grained granitoid and volcanic rocks, with 20 to 30% diverse metamorphic rocks. Volcanic rocks are largely felsic to intermediate in composition, ranging from aphanitic to phaneritic. Granitoid rocks vary in composition, exhibiting equi-crystalline and mylonitic textures. Clasts are typically sub-rounded to rounded, low to moderate sphericity, and poorly sorted. Weathering rinds are generally absent, although some coarse-grained lithologies exhibit rinds up to 1 cm thick. Fractured granite and vesicular basalt tend to disintegrate, while fine-grained volcanic rocks (latite and rhyolite) are more competent.

In gravel pits the coarse-grained deposits with pebbles, cobbles and boulders are often massive to crudely-bedded, upstream, moderate to well-stratified further downstream. Bedding is generally continuous, clast- to matrix-supported and range from 10’s of cm to several meters

thick, as much as 15 meters thick. Clasts are very poorly to moderately imbricated. Finer-grained deposits of predominantly coarse sand are discontinuous, crude to well-stratified, commonly exhibit cross-bedding and range from a few cm's to 1 meter thick, occasionally 2 to 3 meters thick. In most cases fine- and coarse- strata are distinct with relatively sharp contacts, whereby coarse-grained deposits commonly cut-and-fill into underlying sand layers, and are abruptly overlain by sand. Some sandy layers exhibit a higher degree of reddening, perhaps due to age and degree of oxidized mafic minerals.

Qira - Intermediate terrace deposits (Pleistocene), Intermediate terrace deposits of the Agua Fria River. Primarily cobble, boulder, pebble gravel and sand, with variable sand, silt and clay layers. Clast lithologies are similar to those observed in the modern channel, dominated by coarse-grained plutonic and volcanic rock types. Clasts are generally poorly sorted, sub-rounded to rounded, with low to moderate sphericity. Deposits are generally clast-supported, with less-thick and discontinuous sand-supported strata. Moderate to strong soil development up to weak petrocalcic horizons, and clay-rich argillic horizons, minor to moderate clast weathering.

Qora - Old terrace and alluvial fan deposits (Pleistocene-Pliocene), High, deeply eroded coarse gravel and sand deposits of the Agua Fria River. Range from isolated terraces in the south to extensive terraces and a very large remnant alluvial fan in the north. Planar terrace surfaces are variable depending on preservation, some older deposits are deeply eroded. Clast lithologies are similar to those observed in the modern channel, dominated by coarse-grained plutonic and volcanic rock types. Strong calcic soils development on well-preserved surfaces, intense weathering of susceptible lithologies.

Verde River

Qyrv - Young channel and floodplain deposits (Holocene), Gravel, sand, silt and clay deposits in modern channels and floodplains. Lithology of clasts include predominantly basaltic rock types (26 to 46%), granitoid rocks (10 to 41%), quartzite (11 % average), and various other volcanic rocks (10 to 29%), and metamorphic rocks (5 to 26%) (Pope, 1974). The relative percentage of lithologic variety appears to be consistent with progressively older terraces along the Verde River. A subtle reduction in grain size is apparent between the oldest terraces and modern deposits (Pope, 1974). Deposits range from gravel to sandy gravel, predominantly clast-supported, poorly to very poorly sorted.

Qirv - Intermediate terrace deposits (Pleistocene), Sand, gravel, silt and clay deposits in intermediate river terraces. Moderate soil development. These deposits may be also present adjacent to the Verde River near its confluence with the Salt River, characterized by moderate to strong calcic soil development. Lithology of clasts are similar to those observed in the modern channel (Pope, 1974). Terraces include the Blue Point and Mesa terraces.

Qorv, Old high terrace deposits (Pleistocene-Pliocene), High, deeply eroded coarse gravel and sand deposits of the Verde River. Planar terrace surfaces are limited, deposits are typically deeply eroded. Strong calcic soils development on well-preserved surfaces, weathering of susceptible lithologies. Lithology of clasts are similar to those observed in the modern channel (Pope, 1974). These deposits may be also present adjacent to the Verde River near its confluence with the Salt River, characterized by moderate to strong calcic soil development. These terraces include the Sawik and Stewart Mountain terraces.

Hassayampa River

Qyrh - Young channel and floodplain deposits (Holocene), Sand and crystalline metamorphic rock, mafic and felsic volcanics, and quartz in fine gravel deposits of the modern channels and low terraces, with minor silt and clay.

Qirh - Intermediate terrace deposits (Pleistocene). Gravel and sand deposits on intermediate river terraces.

Qorh - Old terrace and alluvial fan deposits (Pleistocene-Pliocene). Higher dissected river gravel and sand deposits associated with high river terraces and a very old alluvial fan where the ancient Hassayampa River entered Hassayampa Valley. Gravel lithologies include crystalline metamorphic rocks, basalt, latite, and chert. Commonly cobbles and pebbles, with boulders abundant only in the northernmost outcrops. Variably weathered; strong petrocalcic surface soil if well preserved.

Intermediate River Deposits

Minor aggregate sources for the Phoenix metropolitan area. Less lithologic diversity, shorter transport distances, but older deposits are quite extensive.

New River

Qyrn - Young channel and floodplain deposits (Holocene), Channel cobbles, boulders, pebbles, and sand, with finer floodplain deposits.

Qirn - Intermediate terrace deposits (Pleistocene). Primarily cobble, boulder, pebble gravel and sand, with variable sand, silt and clay layers. Moderate to strong soil development, minor to moderate clast weathering,

Qorn - Old terrace deposits (Pleistocene). High, deeply eroded gravel and sand deposits of New River. Planar terrace surfaces are variable depending on preservation, some older deposits are deeply eroded. Strong calcic soils development on well-preserved surfaces, intense weathering of susceptible lithologies.

Skunk Creek

Qyrk - Young channel and terrace deposits (Holocene), Gravel dominated by basalt and metavolcanics, with minor granite, sand and finer grained deposits in active channels, low bars and adjacent low terraces.

Qirk - Intermediate terrace deposits (Pleistocene). Primarily cobble, boulder, pebble gravel and sand, with variable sand, silt and clay layers. Moderate to strong soil development, minor to moderate clast weathering.

Qork - Old terrace and alluvial fan deposits (Pleistocene). High, deeply eroded gravel and sand deposits. Planar terrace surfaces are variable depending on preservation, some older deposits are deeply eroded. Strong calcic soils development on well-preserved surfaces, intense weathering of susceptible lithologies.

Cave Creek

Qyrc - Young channel and terrace deposits (Holocene). Gravel dominated by basalt, andesite, and green metavolcanic clasts, with minor granite and crystalline metamorphic rocks, sand and finer grained deposits in active channels and on low terraces.

Qirc - Intermediate terrace and alluvial fan deposits (Pleistocene). Primarily cobble, boulder, pebble gravel and sand, with variable sand, silt and clay layers. Moderate to strong soil development, minor to moderate clast weathering

Qorc - Old terrace remnants (Pliocene to Pleistocene). High, deeply eroded gravel and sand deposits. Planar terrace surfaces are variable depending on preservation, some older deposits are deeply eroded. Strong calcic soils development on well-preserved surfaces, intense weathering of susceptible lithologies, but most gravel clasts appear to be quite resistant to weathering.

Queen Creek

Qyrq - Young channel and terrace deposits (Holocene), Gravel, sand and finer grained deposits in active channels and on the floodplain.

Qirq - Intermediate terrace and alluvial fan deposits - Queen Creek, Intermediate terrace and alluvial fan deposits - Queen Creek (Pleistocene), Pleistocene, Intermediate terrace deposits of Cave Creek. Primarily cobble, boulder, pebble gravel and sand, with variable sand, silt and clay layers. Moderate to strong soil development, minor to moderate clast weathering.

Qorq - Old terrace deposits - Queen Creek, Old terrace deposits - Queen Creek (Pleistocene), Pleistocene, High, deeply eroded gravel and sand deposits. Deposits are deeply eroded and poorly preserved. Strong calcic soils development locally, intense weathering of susceptible lithologies,

Lesser River Deposits

Deposits associated with moderately large tributaries that have not been substantially exploited for aggregate resources, and are not specifically identified for potential aggregate resources.

Qyr - Channel, floodplain and low terrace deposits (Holocene), Channels and low terrace deposits with weak soil development are mapped as unit Qyr. Several different levels of terraces are included in this map unit. This unit contains both channel (crudely bedded coarse sands, gravels, and cobbles) and overbank (finely laminated clays, silts, and fine sands) sediments. Soil development is limited to slight organic accumulation at the surface and some bioturbation.

Qir - Intermediate river terrace deposits (Middle to late Pleistocene), Includes intermediate terraces with moderate to strong soil development up to about 50 ft above the modern channel. Deposits are subrounded to angular gravel, with reasonable lithologic mix, sand, silt and clay. Soil development includes relatively thick argillic horizons with clay textures and abundant carbonate, but weak to no cemented petrocalcic horizons.

Qor - Old, high river terrace deposits (Early to middle Pleistocene), Old, very high, degraded river terrace remnants are mapped as Qor. Qor terraces exist as isolated remnants standing high above the modern stream channels. Because Qor terrace deposits have been exposed to erosion

for much of the Quaternary, they seldom retain their original terrace form and instead form a series of isolated ridges and hills. Qor deposits are coarse, with clasts ranging in size from pebbles to boulders. Coarse-grained rocks at the surface are highly pitted, and fine-grained rocks are commonly fractured. Qor soils are dominated by thick petrocalcic horizons with Stage IV-V morphology. Secondary silica incorporated within the petrocalcic horizons appears as light brown, thin laminae.

Piedmont Tributary Deposits

Qyc - Modern channel deposits (Holocene). Compilation unit for sand and gravel deposits of active, open channels, gravel and sand bars, and low terraces. This unit is composed of moderately-sorted sand, gravel, and pebbles with some cobbles in the lower piedmont areas to poorly-sorted sand, gravel, pebbles, and cobbles in the upper piedmont areas. Channels are generally incised less than 0.5 to 1 meter below adjacent Holocene terraces. Channel morphologies generally consist of a single thread deep high flow channel or multi-threaded shallow low flow channels with adjacent gravel bars. The channels are flood prone and are subject to deep, high velocity flow during moderate to large flood events. Channels are subject to scouring and bar deposition. Banks are subject to lateral erosion. There is no soil development in this fluvially active unit, and little or no vegetation within the channels.

Qy - Piedmont alluvium (Holocene), Mostly alluvium, locally includes some eolian deposits. This unit is characterized by unconsolidated, stratified, poorly to moderately sorted sand, gravel, cobble, and boulder deposits that underlie small active channels, low terraces, and alluvial fans. In some places this designation is used where the Qy1 and Qy2 surfaces are too intricately intermingled to map separately at this scale. These areas may be subject to occasional to frequent flooding. Terraces and alluvial fan surfaces are 0 to 2 m above active channels. Terrace surfaces are frequently mantled by sandy loam sediment. Alluvial surfaces exhibit bar-and-swale topography, with the ridges typically being slightly more vegetated. Surfaces have minimal or no rock varnish or desert pavement development. Late Holocene soils are minimally developed, but Middle and Early Holocene soils typically contain cambic horizons, weak calcic horizons (not more than Stage I), and are noticeably reddened. Surface colors are light brown to yellowish brown, with a slight reddening with depth due to oxidation. Surface soils are not indurated with clay or calcium carbonate, so surfaces have relatively high permeability and porosity.

Qyi - Mixed piedmont gravels (Holocene to Middle Pleistocene). Qyi is a composite map unit that contains both late Pleistocene (Qi3) and Holocene (Qy and Qyc) deposits. Qyi is used in a few piedmont areas where it is difficult to distinguish surfaces of different ages because they have complex, interfingering spatial relationships.

Qi3 - Young intermediate piedmont alluvium (Late to latest Pleistocene). Alluvial fan surfaces and terraces consisting of moderately sorted, clast-supported sandstone and conglomerate with abundant granitic or metamorphic gravel clasts in a tan to brown sandy to silty matrix. Surfaces are moderately incised by stream channels, but still contain constructional, relatively flat, interfluvial surfaces. Subdued bar and swale topography is common. Desert pavement and rock varnish development ranges from nonexistent to moderate. Surface colors are slightly more red (light brown to reddish yellow) than Qy surfaces. Qi3 soils are also more strongly developed than Qy soils. Qi3 soils commonly contain tan to red-brown argillic horizons that are weakly to

moderately strongly developed. These soils typically have Stage II-III calcium carbonate development.

Qi2 - Intermediate piedmont alluvium (Middle to late Pleistocene). Alluvial deposits that include sand, loamy sand, gravely sand and minor gravel, poorly sorted with sand- to boulder-sized clasts. Preserved depositional surfaces in the upper piedmont form flat ridges separated by incised channels in shallow valleys, and deposits tend to be coarsely textured given their proximity to mountain slopes. Qi2 surfaces are typically 2 to 10 m above modern channels. Desert pavement and rock varnish development is moderate to strong on stable surfaces, but variable to weak on highly eroded surfaces. Soils are thick and well developed with argillic, duric, and local petrocalcic horizons and brown to reddish brown surface colors. These soils typically contain reddish argillic horizons moderately to strongly enriched in pedogenic clay. Calcic horizon development is fairly strong (Stage II-IV), but soils generally do not have cemented petrocalcic horizons (caliche).

Qi - Middle to late Pleistocene piedmont alluvium, undivided. Moderately consolidated sand, sandy gravel, or gravel deposits underlying surfaces with some soil development, genererally redder than Qy soils, with less clay and carbonate accumulation than Qo soils. Surfaces slightly to moderately incised by active channels.

Qi1 - Older intermediate piedmont alluvium (Middle to early Pleistocene). Alluvium deposit located near the mountain front at the highest surfaces in the mapped areas, with moderately strong soil development. The deposits are composed of poorly sorted sand, pebbles, cobbles, and small boulders with minor silt and clay. Surfaces are planar with moderate bevelling near the edges and have dark, strongly developed pebble-cobble desert pavements. Washes are incised with 5-6 meters of relief. Soil development is mature to very mature and composed of clay loam with well developed stage IV to V laminar secondary carbonate, indurate, granular peds.

Qo - Old piedmont deposits (Early Pleistocene). Alluvial fan surfaces and deposits that consist of typically very poorly sorted cobbles to clay, including angular to subangular cobbles and pebbles and clay. Deposits typically are very poorly sorted, including angular to subangular cobbles and pebbles with sand and minor silt and clay. These deposits are moderately consolidated and commonly are indurated by soil carbonate. Surfaces are moderately to deeply dissected, with 2 to 10 m of relief between channels and ridgecrests. This unit occupies the highest topographic positions on the piedmonts. Original fan surfaces have been removed by erosion, so the characteristic topographic expression of these deposits are alternating ridges and valleys. Soil development is moderate to strong, depending on local preservation. Reddish-brown argillic horizons are moderately- to well-developed on planar, relatively well-preserved alluvial surface remnants. All soils are dominated by carbonate accumulation. Surfaces typically are littered by carbonate fragments derived from eroded or perturbed petrocalcic horizons; this gives

QTs - Sandstone, siltstone and conglomerate (Late Miocene to Quaternary. Consolidated to partly consolidated sedimentary rocks that flank bedrock exposures; includes pediment developed on Proterozoic schist (map unit Xs) fans and plains of alluvium considered to be basin fill. Thin soil horizons developed on alluvium are probably quaternary in age, and substantially younger than gently dipping, underlying material. Correlate with Tsy in region. In

southern Hieroglyphic Mountains, occurrs as remnant deposits capping ridges on the west side of the Agua Fria river valley.

Qs - Surficial deposits, (Quaternary),Undifferentiated surficial deposits, generally in mountain areas; includes talus, colluvium and various ages of alluvium.

Basin-Axis Deposits

Qyf - Fine-grained alluvial-fan and terrace deposits (Holocene). Qyf comprises the young, fine-grained deposits with minimal soil development that mantle much of the lowermost piedmonts. Extensive Qyf deposits typically surround young channel deposits (Qyc), and they tend to increase in width downslope, indicating that they fine-grained alluvial-fan/sheet-flood deposits associated with ephemeral drainages. Unit Qyf includes many small channels as well, and these commonly exhibit alternating entrenched and unentrenched reaches. Qyf deposits typically are composed of sand, silt and clay, with some fine gravel. Original depositional bedding may be preserved, but more typically bioturbation has obscured sedimentary structures. Soil development associated with Qyf deposits is weak, consisting mainly of eolian silt and minor (stage I) carbonate accumulation.

Qiyf - Fine-grained deposits (Holocene and Late Pleistocene). Complexly interfingered fine-grained Holocene and Pleistocene deposits. Little topographic relief and extensive agricultural development on these surfaces limit our ability to distinguish detailed relationships between young and old deposits. Because these surfaces are subject to sheetflooding, many of the deposits may be Holocene in age. However, soil survey maps and recent geologic mapping indicate that some soils within these low-relief areas have moderate development (Haplargids) indicative of a late Pleistocene age.

Qif - Old, fine-grained, basin-floor deposits (Late Pleistocene to Middle Pleistocene). Qif comprises fine-grained basin-floor deposits characterized by strong soil development indicative of some antiquity. Virtually all of these areas have been disturbed by agricultural activity or urban development, so the original surface morphology and drainage patterns have been obscured. Qif deposits are composed of sand, clay and silt, with some fine gravel. Areas mapped as Qif have minimal local topographic relief, generally less than 1 m. These areas are not topographically distinct from areas covered by younger deposits, and commonly grade into areas of younger deposits. Soils associated with unit Qif are strongly developed. Qif soils are classified as Haplargids-, with thick argillic horizons with clay or clay loam textures and moderate to strong calcic horizon development (stage III to IV). Surface colors typically are brown (7.5 YR), but argillic horizons are reddish brown (5 YR).

Miscellaneous Quaternary Units

d - Surface deposits related to human activity. Areas of significant recent surficial disruption due to various human activities. Includes dams, large cattle tanks, large canals.

da - Disturbed ground - aggregate quarry. Areas where active or recently active aggregate operations have altered the ground surface

wa - Lakes, reservoirs. Bodies of water that obscure underlying geology.

Qtc - Colluvium and talus (Holocene and Pleistocene). Unconsolidated to moderately consolidated colluvium and talus deposits on steeper hillslopes. These deposits are typically weakly bedded, subangular to angular, poorly sorted sand and gravel.

Qe - Eolian sand deposits (Holocene), Eolian sand deposits (Holocene). Eolian sand and silt deposits associated with active dunes; typically reworked river floodplain deposits

QTls - Landslide deposits (Holocene to Pliocene). Poorly consolidated to unconsolidated, very poorly sorted mud to large boulders, characterized by a hummocky surface littered with boulders. Landslides contain blocks of basalt, tuff, and volcaniclastic sandstone up to 50 meters diameter.

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