Geologic Map of the Tule Wash 7 ½' Quadrangle, Mohave County, Arizona

by

Brian F. Gootee and Bradford J. Johnson

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Arizona Geological Survey
University of Arizona
1955 East Sixth Street, Suite 205, Tucson, Arizona 85721

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Unit Descriptions

BIG SANDY RIVER DEPOSITS

Qy3r - Active floodplain banks and terrace deposits (late Holocene~~, recent~~) - Active river channel, shallow bar floodplain deposits. Unconsolidated, moderately to poorly sorted sand with some gravel. Clast lithologies consists of various granitoids, volcanics, schist and rare quartzite. Vegetation generally absent in active channels. Channel banks consists of mesquite, cottonwood, tamarisk, willow, ash and dense shrubs.

Qy2r – Low floodplain river terraces (late Holocene) – Unconsolidated gravel, sand, silt and some clay found adjacent to active river channel and floodplain deposits. Surfaces are about 2 to 3 m above the active channel and have well-developed bar and swale microtopography. Vegetation is light to moderate with commonly willow and juvenile mesquite and tamarisk. Soil is absent to weakly developed. Qy2r surfaces typically persist during flooding events, although can be eroded or abandoned, and in some areas of the floodplain Qy2r has at least two subunits although were not differentiated, rather meandering scrolls were outlined within Qy2r where former channels were.

Qy1r – Low river terraces along modern floodplain margin (Holocene) – Low river terrace deposits consisting of unconsolidated gravel, sand, silt and some clay found 2 to 5 m above modern floodplain, and more heavily vegetated than younger deposits. Vegetation consists of a chapparal of cottonwood, mesquite, creosote, acacia, yucca, prickly pear, shrub, and grasses. Deposits consist of sand, moderately well sorted, micaceous and loamy, with slight undulating microtopography. Some salt encrustations where shallow groundwater is present. Gullies are common along Qy1r banks formed from headward erosion adjacent to the river floodplain. Qy1r deposits interfinger with Qy1 deposits, and Qy3 tributary deposits commonly form poorly developed alluvial fans on Qy1r surfaces.

Qi3r – Lowest-intermediate river terraces and alluvium (late Pleistocene) - Low-lying terraces along modern Big Sandy River consisting of unconsolidated to lightly consolidated boulders, gravel, sand and silt with minor to moderate clay. Unit Qi3r terrace deposits form linear, flat terraces elevated 5 to 10 m above the modern river, with minimal dissection, and are commonly capped by Qi3 deposits. Locally, this unit can be divided into similar landforms separated by 1 to 3 m elevation. Qi3r deposits exhibit light to moderate argillic and calcic soil development and are up to 5 m thick. Locally, residences are developed on Qi3r surfaces along the river corridor and tributary mouths, and deposits have been locally mined for aggregate.

Qi2r – Low to high intermediate river terraces and alluvium (Pleistocene) – Unconsolidated to weakly consolidated boulders, gravel, sand, silt and minor clay found in terrace deposits elevated 15 to 25 m above the modern Big Sandy River. Clasts consist of primarily Proterozoic crystalline lithologies and Cenozoic volcanics. Qi2r deposits are commonly capped by Qi2 piedmont deposits and are found up to 1.6 km (1 mile) east of the modern river. At least two divisions of Qi2-age deposits are recognized, with older Qi2r deposits representing aggradational terrace fill deposits 15 to 18 m thick. Younger Qi2-age deposits and accompanying Qi2r deposits

are commonly strath terrace deposits 2 to 5 meters thick positioned lower in the landscape relative to earlier Qi2 deposits. Clasts include diverse lithologies and are well-rounded relative to local piedmont alluvium.

Qi1r – High-intermediate river alluvium (Pleistocene) – Limited to one exposure in the quadrangle near the mouth of Burro Wash (261,814 E, 3,852,360 N) approximately 55 m above the modern wash. Unconsolidated to weakly consolidated silt, sand, gravel and boulders, with minor clay. Deposits are generally light orange brown and clasts are moderately sorted, subrounded to rounded, with moderate sphericity. Qi1r deposits overlie tilted basin-fill deposits. Clast lithology consists of varied granites, pegmatitic and vein quartz, some metamorphic rocks, and felsic and mafic volcanic rocks derived from Aquarius Mountains. Soil development poorly preserved although likely stage IV+ based on piedmont deposits.

PIEDMONT DEPOSITS

Qy3 – Active channel, bar, and low terrace deposits (late Holocene) – Moderate to poorly sorted, unconsolidated silt, sand and gravel deposits of active ephemeral washes and alluvial fans on the piedmonts east and west of Big Sandy River. Characterized by fluvial channels and bars composed of locally derived gravel. Terrace margins are typically elevated about 0.5 to 1 m above active washes and mantled with fine sand and silt, where soil development is absent to lightly developed. Lightly vegetated except along channel margins, bar islands, and low terraces. Channels are prone to flooding during moderate to large precipitation events with scouring and bar deposition and lateral erosion of banks.

Qy2 – Low terrace deposits along larger active washes (late Holocene) – Alluvial deposits and surfaces related to active ephemeral washes that are frequently active or relatively recently abandoned and not laterally extensive. Deposits are composed of poorly to moderately sorted and bedded coarse sand and gravel and commonly capped by silt and sand elevated 1 to 2 m above active washes with paired and unpaired terraces common. Well-preserved depositional micro-topography and fabric, with no varnish, no clay accumulation, and weak carbonate accumulation in places. Vegetation includes creosote, and dwarf palo verde, ironwood and mesquite.

Qy1 – Low terrace deposits along inactive portions of active channels (Holocene) – The youngest, likely fully abandoned alluvial deposits and surfaces elevated about 1 to 3 m above active washes. Unconsolidated, poorly to moderately sorted sand and gravel. Surfaces may or may not have relict depositional micro-topographic bars and channels and hosts weakly integrated networks of very small distributary channels with thin active sheetflood deposits. In upper piedmont terraces Qy1 deposits are coarser and occasionally have debris flow channel and levee morphology with light varnish development. Soil development is weak with incipient carbonate accumulation, very minor clay accumulation with possible light varnish on large gravel. Vegetation consists of predominantly creosote with some saguaro, ironwood, ocotillo, cholla and dwarf palo verde, mesquite and acacia.

Qi3 – Low-intermediate piedmont deposits (late Pleistocene) – Unconsolidated to weakly consolidated gravel, sand and silt with minor clay, forming generally wide, planar surfaces about

5 to 10 m above modern washes. Surfaces are commonly inset below older surficial deposits, broad when overlying basin fill, and relatively narrow in bedrock canyons. Qi3 deposits are about 1 to 4 m thick and exhibit light to moderate, stage II to III-soil development with a light to moderate argillic horizon with moderate varnish and light pavement. Vegetation includes cholla, acacia, creosote, and dwarf mesquite.

Qi2 – Low to high intermediate piedmont deposits (Pleistocene) – Unconsolidated to weakly consolidated gravel, sand and silt found 15 to 30 m above modern washes as broad, moderate to deeply dissected remnant planar alluvial surfaces. Qi2 deposits are 15 to 18m thick in places, which are thought to represent fill terraces, with younger Qi2 and Qi3 deposits inset into older Qi2 fill deposits. Soil development on surface remnants exhibit moderate to strong argillic accumulation and stage III to IV calcic development. Along the river corridor Qi2 interfingers with Qi2r deposits and are locally up to 18 m thick and Qi2 commonly caps Qi2r.

Qi1 – High-intermediate piedmont deposits (Pleistocene) – Unconsolidated to weakly consolidated boulders, gravels, sand and minor silt and clay, forming well-rounded, linear alluvial deposits elevated 50 to 70 m above modern washes. Qi1 deposits are equivalent to Qi1r deposits and exhibit moderate to strong argillic and calcic soil development, stage III+ to IV.

Qi–Intermediate piedmont deposits, undivided (Pleistocene) – Unconsolidated to weakly consolidated deposits of silt, sand, and gravel with rare boulders. Deposits comprise abandoned terraces and alluvial fan remnants of uncertain age formed on bedrock, basin fill and older river deposits.

Qo –Highest old pedogenic deposits associated with Nbs (Pleistocene to Pliocene?) – High-standing remnant alluvial deposits and pedogenic development associated with underlying Big Sandy basin margin deposits (Nbc) along upper Boner Wash in the southeast corner of the quadrangle. Qo overlying Qor deposits exhibits a remnant planar surface that dips gently to the west-southwest, with small active low-relief channels. Qo surface has a strong calcic accumulation, eroding into caliche plates and blocks up to 10 cm thick. Soil development is estimated is 2 to 5 m thick. An argillic horizon is absent, although a Holocene soil is locally up to 20 cm thick (5YR 3/2 to 3/4). Clasts consist of mostly basalt with some vein quartz and feldspar grains (grus), packed into a moderate to well-developed pavement. Weathering rinds on basalt are up to 2 mm thick. Vegetation is diminished relative to adjacent slopes and consists of prominent crucifixion thorn trees with up to 1 m diameter, 4 m height, lechuguilla yucca clusters, sagebrush, creosote, prickly pear, and less common or sparse cholla, small cacti, and acacia with rare saguaro and single-stalk agave.

OTHER SURFICIAL DEPOSITS

d – Disturbed areas (recent) – Heavily disturbed ground due to extensive excavation, construction of earth dams and berms, road shoulders, berms and paved Highway 93.

Qtc – Hillslope deposits (Quaternary) – Unconsolidated to moderately consolidated colluvium and talus hillslope deposits with varying degrees of soil development on moderate to steep slopes that typically overlie basin-fill and bedrock map units.

QNls –Landslide deposits associated with Tbsf (Pliocene to Quaternary) – Slides and large blocks of talus derived from Big Sandy conglomerate (unit Nbc) containing pebbles, cobbles, and small boulders of plutonic rocks in a light-tan matrix dominated by sand- and granule-sized grains. These deposits include coherent blocks tens of meters across, groups of uniformly tilted blocks several meters to tens of meters across, and chaotic blocks with nonuniform bedding attitudes. The first two types are tilted toward the highlands of autochthonous Nbc from which they originated.

BASIN FILL UNITS

The Big Sandy Formation was formally described by Sheppard and Gude (1972) as consisting chiefly of lacustrine deposits occupying an area of approximately 70 km^2 in southern Big Sandy Valley. Sheppard and Gude (1972) defined the Big Sandy Formation as a lacustrine facies consisting of mudstone, with silt and sand components found primarily in the Wikieup quadrangle, and in the southern part of the Tule Wash quadrangle. They recognized a marginal conglomerate lithofacies that laterally grades into the lacustrine facies, but did not include the coarse-grained facies as part of the formation definition or extent. Other researchers made similar observations that lacustrine facies graded into marginal sandy and conglomeratic facies (Morrison, 1940; Dickinson, 2008), although their distribution and extent was not mapped. Our mapping delineates three distinct lithofacies in the Tule Wash quadrangle as part of the redefined Big Sandy Formation, which can be continuously traced farther north of this map area.

Based on our mapping of lithofacies equivalent to the Big Sandy Formation in the Wikieup quadrangle and farther north, the southern Big Sandy Valley was a terminal closed-basin depocenter for primarily fine-grained siliciclastic deposition in a shallow, groundwater-fed alkaline lake, punctuated by shallow lacustrine carbonate deposition. Sediment and water were locally supplied from the Hualapai Mountains, Aquarius Mountains, and the Poachie Range, and from ancestral drainages supplied from roughly the area near the confluence of Knight Creek, Cane Springs Wash and Trout Creek north of the Tule Wash quadrangle. Sediment of the Big Sandy Formation in the southern depocenter aggraded up to a maximum-filling surface before spilling across a bedrock sill further south, integrating Big Sandy and Greenwood valleys that resulted in the formation of the Big Sandy River. Incision of the Big Sandy River into fine-grained Big Sandy Formation deposits resulted in a series of off-lapping or prograding alluvial fans that tracked basin incision during the Pliocene and Quaternary.

Big Sandy Formation

Nbc – Conglomerate lithofacies (Miocene and Pliocene) – Tan to gray, poorly to moderately consolidated gravel, sand and silt with minor clay, found generally adjacent to mountain ranges, deeply dissected by modern washes. Clasts consist of very poorly sorted pebbles, cobbles and boulders derived from Proterozoic basement, primarily of granitic composition (Xg); also includes Cretaceous igneous rocks, mid-Cenozoic volcanic rocks and older Tule Wash basin fill

lithologies. Unit Nbc is matrix-and clast-supported and has bedding ranging from thin, crude to massive with multidirectional trough cross bedding common. Nbc erodes into well-rounded ridges capped with a gravel lag, with boulders up to several meters across. Carbonate cementation is common near its base in contact with finer-grained Tule Wash basin sediments. Basal beds in this unit fill erosional paleotopography in older bedrock and Tule Wash basin fill deposits, locally several tens of meters but basinwide the base of unit Nbc can be traced from high elevations in the Aquarius Mountains down to the valley floor, and in most places below the modern river corridor in the subsurface.

Nbs – Sandy lithofacies (Miocene and Pliocene) – Tan, massive, well-sorted, unconsolidated to moderately consolidated sand and silt with subordinate clay and gravel located along the valley axis. This facies grades laterally east into coarser Nbc facies and finer west and south into muddy facies of Nbm and commonly has bedding characteristics of both, including subordinate marker limestone beds, and clay and gravel zones. Bedding is laterally continuous and planar-tabular with ripples, flutes occasional pea and pebble intraclasts. Primarily exposed in washes and in low-relief hills underneath Quaternary piedmont deposits. Poorly preserved teepee structures and soft sediment deformation present locally. Fine-sand and silt dominated commonly weathers to "badland" topography. A representative section of Nbs is well-represented in badlands east of River Rd and northeast of Pump Station Rd in the southern part of the map area. Maximum exposed thickness is ~20 m.

Nbm – Muddy lithofacies (Miocene and Pliocene) – Olive gray (5GY 5/1) to light to medium reddish brown (5YR 5/3) fine sand, silt and clay exposed east of the modern river in the southernmost mapping area along the valley axis. This facies represents the northernmost extent of the fine-grained Big Sandy Formation (Sheppard and Gude, 1972). Bedding is horizontal to very gently west-dipping and has variable thickness in the subsurface and is everywhere unconformably overlain by Quaternary river and piedmont deposits. Mudstone is very fine-grained and generally consolidated to moderately indurated with silica and carbonate cement. Mud beds are generally greenish gray and red-brown although white, dark gray and purple gray are locally present. Nbm lithofacies grade laterally into sandy lithofacies Nbs, and conglomeratic lithofacies (Nbc) to the north. Muddy lithofacies generally overlie coarser beds and strata in many but not all outcrops, suggestive of a fining-upwards sequence. The muddy lithofacies commonly has sand and limestone interbeds, planar tabular and continuous to discontinuous between separate exposures. Primary bedforms in mud and clay beds are generally laminated and planar but are often deformed by soft-sediment deformation (tee-pee and dissolution-collapse) subsequently overlain by non-deformed bedding. Maximum exposed thickness is approximately 20 to 30 m in the map area. Mineralization in this lithofacies has been explored for lithium, uranium and other heavy elements (Scarborough and Wilt, 1979).

Tule Wash formation

Worley (1979) assigned tilted Miocene strata of the eastern Big Sandy Valley to three formations: Bull Canyon, Tule Wash, and Burro Wash. Doing so facilitated description and sedimentological interpretation of the strata, but Worley noted that stratigraphic relationships between the three units were uncertain. We have abandoned two of those unit names and have assigned all of the units to an informal "Tule Wash formation". Some stratigraphic relationships

remain uncertain, therefore our map units within the Tule Wash formation are based on lithofacies rather than interpretation of stratigraphic position. There are several representative or reference sections of this formation and its lithofacies: Tule Wash (Scarborough and Wilt, 1979; Worley, 1979), upper Big Wash, Burro Wash, and Bull Canyon (Worley, 1979), and Boner Canyon.

Nts – Sandstone lithofacies (Miocene) – Light to medium orange-brown to olive gray to light tan, thin- to thick-bedded, fine- to coarse-grained sandstone, moderately to very well sorted and commonly micaceous. Beds are tabular and most commonly medium- to thick-bedded, with internal structure ranging from massive to finely laminar, locally with small-scale crossbedding and ripple lamination. Unit Nts is commonly light orange-brown in aerial imagery. Interbeds can include olive and red-brown mud, granule and pebble gravel of clasts sourced from Aquarius Mountains, and local eolian planar and wedge-planar beds. Near the bedrock/basin-fill margin sandstone beds appear more massive and may be related to wind-blown sand ramps reworked from basin margin sediments. Some thick beds are poorly sorted, internally massive, and exhibit reverse coarse-tail grading with dispersed granules and very coarse sand increasing in abundance toward the tops of beds, suggesting deposition by debris flows. At least three known beds of rock avalanche breccia are interbedded with Nts, ranging from 2 to 8 m thick, with chaotic and folded intrabeds, and very coarse boulders to fine blocks (2 to 8 m in length) of auto-brecciated monolithologic intraclasts of mostly granite and diorite and some feldspar porphyry. In one avalanche bed, paleoflow indicators indicate a westerly source, which suggests a highly asymmetric valley axis along the eastern basin-fill/bedrock margin. This finding is also supported by multiple indicators from mapping in progress north of the Tule Wash quadrangle.

Ntm – Mudstone lithofacies (Miocene) – Light olive gray micaceous mud and fine sand with locally abundant secondary selenite gypsum seams up to 10 cm thick subparallel to bedding. Anhydrite is locally present intermixed with selenite. Muddy portions form soft greenish-gray to yellow-tan slopes. Interbeds of sandstone and gray crystalline limestone form erosion-resistant steps and local hogbacks along tilted sections. Alluvium interbeds form light orange-tan beds and slopes.

Ntc – Conglomerate lithofacies (Miocene) – Moderately consolidated, crudely and unevenly bedded, poorly to moderately sorted, sand- to clast-supported conglomerate containing angular to subangular clasts of granite, granodiorite, schist, vein quartz, rare rhyolite, and locally minor basalt. Sandstone like unit Nts is interbedded with the conglomerate, forming <50% of the map unit. Where proximal to limestone and mud-dominated deposits, selenite gypsum occurs in fractured Ntc. Unit Ntc is greenish gray in arial imagery.

Ntl – Limestone lithofacies (Miocene) – The characteristic rock of this lithofacies is light gray to white, thin- to medium-bedded, wavy laminated, cherty, crystalline limestone. Thin chert layers, lenses, and nodules are common, forming up to 50% of the rock in some intervals, and are generally weathered brown. Tepee structures with up to 20 cm of relief are present, typically in lower parts of limestone successions. Pisolite beds typically are present higher in the section. The limestone forms ledges a few meters thick alternating with less-resistant intervals in which limestone is interbedded with sandstone and shale. The sandstone is medium- to thin-bedded, olive green to light gray to light-tan, fine- to medium-grained, and is associated with olive-gray

siltstone and shaly mudstone. Thinly interbedded white limestone, olive-green to gray shale, and orange-pink mudstone form intervals several meters thick that have a distinctive pinkish color. This lithofacies has been explored for uranium potential (Granger and Raup, 1962; Worley, 1977; Scarborough and Wilt, 1979).

Ntt – Tuff (Miocene) – Silicic vitric tuff forms distinctive white, thin-to medium-bedded, planar-laminated units <1 to 6 m thick, composed of coarse ash that appears to be mainly glass shards with <2% grains of biotite and feldspar (<0.5 mm) and rare pumice lapilli. In the section north of the head of Boner Canyon, a light-gray tuff unit contains 20-50% pumice lapilli (with phenocrysts of biotite and rare feldspar), lithic grains, and subrounded quartz grains in a vitric ash matrix.

Ntb – Basalt (Miocene) – Mafic lava flows with gray- to dark-brown-weathered massive cores and well-developed carapace breccias. Most flows contain 5-8% olivine phenocrysts <1 to 3 mm (partially replaced by serpentine or iddingsite) and amygdules lined with zeolites, calcite, or epidote in a dark-gray to purple-gray aphanitic groundmass. Some flows contain phenocrysts of pyroxene and 10-25% plagioclase needles <1 mm long, and may range to basaltic andesite in composition.

Ntu – Tule Wash formation, undivided – basin fill units of the Tule Wash formation constrained by stratigraphic and structural relationships, although largely concealed beneath talus and colluvium.

PROTEROZOIC ROCKS

Yp -Pegmatite and leucogranite (Mesoproterozoic) – Dikes of pegmatite and aplitic leucogranite intrude Paleoproterozoic rocks throughout the map area, on average forming 15-20% of the Proterozoic rocks. The dikes range from less than 1 m to more than 10 m thick and dip moderately north, with strikes ranging from 250 to 290 and dips between 30 and 60 degrees. Some dikes coalesce and bifurcate along strike. Areas designated as unit Yp include individual large dikes and dense swarms of dikes with up to 50% country rock between them. Pegmatite-aplite dikes are present throughout unit Xg (the Aquarius pluton), but form less than 20% of that unit and are generally less densely concentrated than in unit Yp. The dikes are composed of pegmatite and leucogranite in alternating zones that are parallel to the dike margins and that give the dikes a layered appearance. The leucogranite is fine-to medium-grained and contains muscovite, locally abundant garnet (trace to 5%), and tourmaline (<1 mm, trace to 1%). The pegmatite contains tourmaline and coarse-grained muscovite, and perthitic microcline crystals 10 cm and larger are common.

Xg -Aquarius pluton (Paleoproterozoic) – Medium- to coarse-grained monzogranite to quartz monzonite containing K-feldspar megacrysts up to 5 cm long in a groundmass of plagioclase, K-feldspar, quartz, biotite, and hornblende. The granite typically has 5-35% perthitic K-feldspar megacrysts 1-4 cm long and contains 15-25% mafic minerals. Fine- to medium-grained biotite is the predominant mafic mineral in most parts of the pluton, forming aggregates with variably epidotized hornblende that increases in abundance with increasing overall mafic content. Fine-

to medium-grained dioritic enclaves are locally abundant. The margins of enclaves are commonly irregular and ragged, and grade into cm-sized mafic aggregates in the host granite that are mineralogically and texturally similar to the margins of the enclaves and that were clearly derived from them. Some enclaves occur in swarms that grade into approximately tabular masses of diorite, which evidently were emplaced before full crystallization of the host granitic magma and were partly assimilated by it. However, swarms of xenolithic enclaves are locally present as well.

Compositional and textural variations are present in the Aquarius pluton, but zonation is not readily mappable because exposure of this unit outside of canyons is poor. A mafic-rich (melanocratic) phase is common and widespread. Aggregates of fine-grained, green, epidotized hornblende and fine- to medium-grained biotite form 20-50% of this rock. Dioritic enclaves and disseminated fine-grained epidote are common and K-feldspar megacrysts are normally abundant. A mafic-poor (leucocratic) monzogranite is uncommon. This phase is composed of medium-grained plagioclase and quartz, medium- to coarse-grained K-feldspar, and 8-10% fine- to medium-grained biotite. The texture ranges from generally medium-grained, with many K-feldspar crystals in the 5-7 mm range and <1% in the 1-2 cm range, to porphyritic, with 20% of the K-feldspar >1 cm long and a few up to 3 cm. The medium-grained variety of the leucocratic phase has been observed in sharp contact with the melanocratic phase. The porphyritic variety has been observed swirled together and mingled along gradational contacts with the "typical" (mesocratic) granite. Contacts between the typical mesocratic granite and the melanocratic phase are gradational and appear to reflect different amounts and degrees of assimilation of dioritic enclaves.

The pluton locally displays layering defined by relatively quartzofeldspathic and mafic-rich domains a few cm thick, preferred orientation of K-feldspar megacrysts and flattened or disc-shaped diorite enclaves, and grain-size variation in quartzofeldspathic domains. Biotite does not show preferred orientation, although concentrations of biotite define layering. Enclaves in some layered zones grade into tabular masses of diorite that are oriented parallel to the layering but display no layering themselves. However, rare dioritic xenoliths exhibit an older tectonic foliation that in some cases lies at a high angle to the layering in the granite. The layering is interpreted as a primary magmatic fabric, although in some places it may have been modified by a younger tectonic foliation.

Xd -Diorite (Paleoproterozoic) – Small pods of diorite occur throughout the Aquarius pluton, but only larger ones are shown separately. The diorite is medium-to fine-grained and composed of approximately 50% plagioclase (+ minor quartz and K-feldspar) and 50% hornblende + fine-grained epidote + fine-grained biotite. In the medium-grained zones, the mafic component is almost all hornblende.

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