Geologic Map of the Wintersburg 7.5' Quadrangle and parts of the Arlington, Gillespie, and Tonopah Quadrangles, Maricopa County, Arizona

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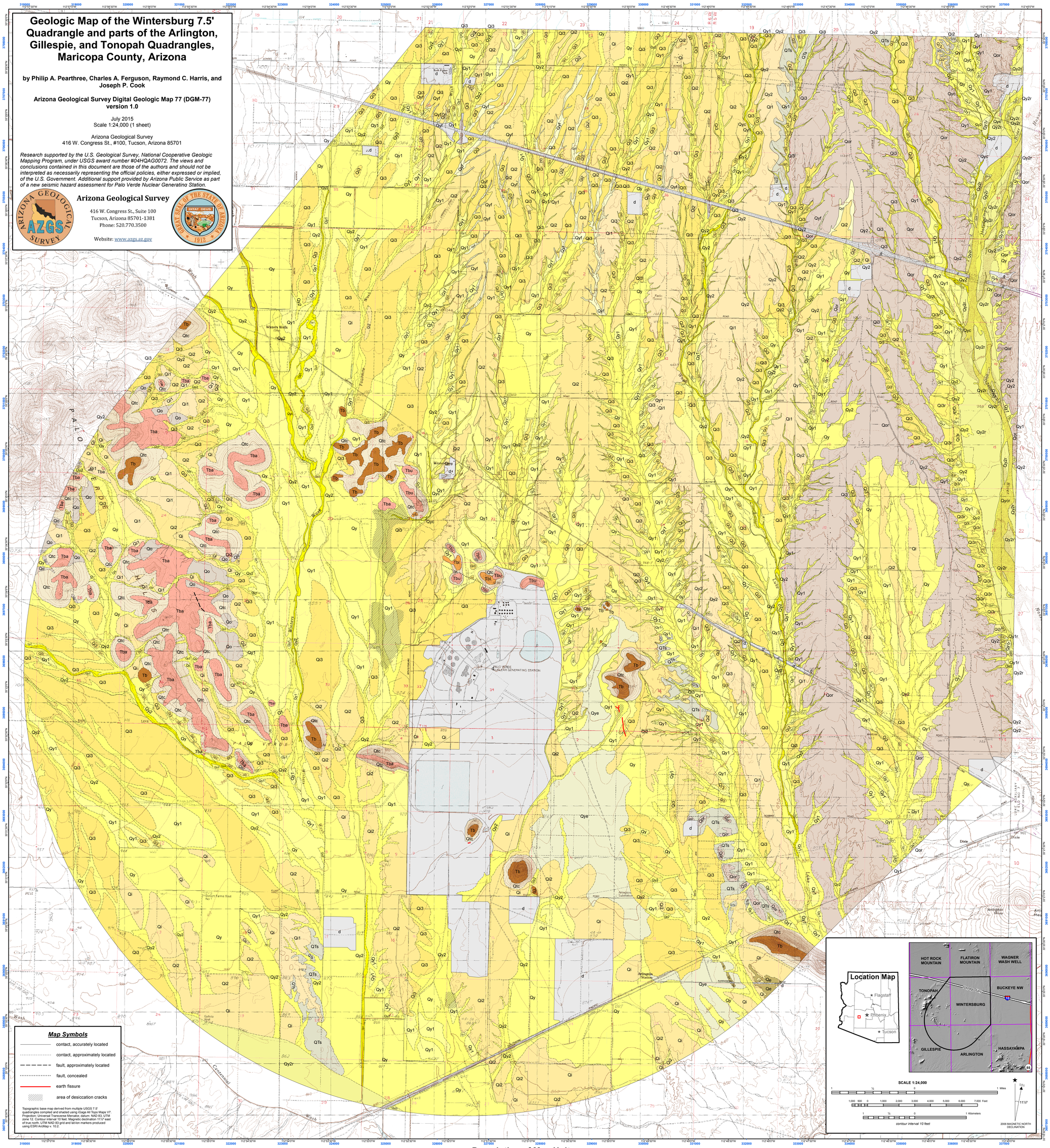

Introduction

The area covered by this geologic map includes all of the Wintersburg 7 ½' quadrangle and parts of the adjacent Arlington, Gillespie and Tonopah quadrangles surrounding the Palo Verde Nuclear Generating Station (PVNGS). The map area is located 40 to 55 miles (70-90 km) west of downtown Phoenix. The map area covers the piedmont between the Palo Verde Hills and the Hassayampa River and a 7 mile (11 km) reach of the Hassayampa River. The quadrangle includes the PVNGS, Interstate Highway 10, and numerous Maricopa County roads. It has experienced some suburban development associated with the PVNGS and is currently on the outer fringe of the greater Phoenix metropolitan area, so more development is likely in the future. The small bedrock hills in the southwestern quarter of the quadrangle were mapped by Charles Ferguson in the spring of 2005. Surficial deposits that cover most of the quadrangle were mapped by Philip Pearthree using color aerial photos from 1979, high-resolution digital color orthophotos provided by the Flood Control District of Maricopa County, National Agricultural Inventory Program (NAIP) photos from 2010 and 2013, and topographic information from U.S. Geological Survey maps and Google Earth. Field checking was done in the spring, summer and fall of 2005, with additional fieldwork in the fall of 2013 and the winter and spring of 2014. The mapping in 2005 was done in conjunction with geologic mapping of the Flatiron Mountain 7 ½' quadrangle (Spencer et al, 2005) to the north, and this quadrangle map is one of eight 1:24,000 scale geologic maps covering most of the Hassayampa Valley that have been produced in 2004 - 2006. This mapping was completed under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992. The additional mapping completed in 2014 was done in cooperation with Lettis Consultants International (LCI) as part of an investigation of seismic hazards for the PVNGS. Funding for this mapping was provided by Arizona Public Service.

Surficial Geology

The map area is predominantly covered with surficial deposits laid down by the Hassayampa River and numerous smaller tributary stream systems. These surficial deposits were mapped primarily using stereo pairs of color aerial photos taken in 1979 for the Bureau of Land Management, high-resolution digital orthophotos from the FDCMC and the NAIP, and topographic information obtained from the 7 ½' U.S. Geological Survey quadrangle maps. Mapping interpretations were verified by field observations during the spring, summer and fall of 2005; additional field observations were made in 2013-14. Unit characteristics were described and unit boundaries were spot-checked in the field. The physical characteristics of Quaternary alluvial surfaces (channels, alluvial fans, floodplains, stream terraces) evident on aerial photographs and in the field were used to differentiate their associated deposits by age and source. This mapping was compiled over NAIP digital orthophoto bases. Mapping was done in a GIS format and the final linework was generated from the digital data.

Several characteristics evident on aerial photographs and on the ground were used to differentiate various alluvial surfaces and deposits associated with them by age and source. The color of alluvial surfaces is primarily controlled by soil color, desert pavement development and rock varnish, and vegetation type and density. Significant soil development begins beneath an alluvial surface after it becomes isolated from active flooding and deposition (Gile et al., 1981, Birkeland, 1999). Holocene soils typically have relatively subtle horizons and generally are brown or gray in the field and on aerial photographs. More distinct, relatively obvious soil horizons develop over thousands to tens of thousands of years. Typical soil horizons in Pleistocene alluvial sediments of Arizona are reddish brown argillic horizons (zones of clay accumulation) and white calcic horizons (zones of calcium carbonate and silica accumulation). In arid areas such as the lower Hassayampa Valley, clay accumulation and reddening associated with argillic horizon development tend to be relatively weak even on old alluvial surfaces. On color aerial photographs and on the ground, older alluvial surfaces characteristically appear slightly redder or distinctly whiter (on more eroded surfaces) than younger surfaces. Dark rock varnish and gravel pavements also develop with time on stable alluvial surfaces, so well-preserved older surfaces typically have a dark brown color. Differences in the drainage patterns between surfaces also provide clues to surface age. Young alluvial surfaces commonly display distributary (branching downstream) or anastomosing (branching and rejoining) channel patterns. Areas adjacent to active channels commonly have little channel development because unconfined shallow flooding predominates. Dendritic tributary (joining downstream) drainage patterns are characteristic where modern drainages are incised into older surfaces. 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 surfaces are minimally dissected and are less than 1 m above channel bottoms. Active channels are entrenched 1 to 5 m below Pleistocene alluvial surfaces, and the older surfaces typically have been moderately to severely rounded by erosion. Ages of various surficial deposits of the map area were roughly estimated based on regional correlations to similar surficial deposits in southern Arizona.

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, areas adjacent to the Hassayampa River are moderately to deeply dissected. The highest terrace remnants of the Hassayampa River (unit Qorh) record the level of the river bed in the early to middle Quaternary. Qorh terraces rest atop a several hundred meter thick aggradational sequence that was deposited during late Tertiary to early Quaternary (units QTs) (Shoustra et al., 1976). Adjacent piedmont areas to the west and north were aggrading in the late Pliocene and early Quaternary as well (unit QTs). At that time the river was probably was depositing sediment across a fairly broad floodplain in the eastern part of the quadrangle, and distal alluvial fans on both sides of the river were interfingering with the river floodplain. Since then the Hassayampa River has downcut 10 to 15 m, with incision increasing slightly to the north. Preservation of Pleistocene river terraces recording intermediate levels of the Hassayampa River is poor. The valley bottom along the Hassayampa River consists almost entirely of modern channel deposits (unit $Qy_{1}r$) and late Holocene floodplain deposits ($Qy_{2}r$). Tributary washes immediately west and east of the Hassayampa River have downcut in response to incision of the river, and late Quaternary deposits are quite limited in extent along these drainages.

In the western 90% of the map area, piedmont washes drain to the south to the Gila River or Centennial Wash, a sizable tributary of the Gila River. Much of this piedmont is mantled by Pleistocene tributary deposits (units Qi_1, Qi_2, or Qi_3). Older Pleistocene deposits (Qi_1) have been eroded into broadly rounded. The relatively small tributary washes that drain this area are incised a few meters or less below adjacent Pleistocene alluvial surfaces. Even though the amount of net incision is modest, there is enough topographic confinement of active fluvial systems that late Pleistocene deposits typically are found on the fringes of the eroded middle Pleistocene ridges, and Holocene deposits are found on valley bottoms. Agricultural activity, more recent residential development, aggregate pits and the PVNGS have modified the landscape to greater or lesser degrees. Areas are mapped as "disturbed" where the surficial deposits are profoundly altered (gravel pits, nuclear plant, interstate highway); surficial deposits other areas with less profound disturbance are depicted as more general units with approximate contacts.

Geologic Hazards and Aggregate Resources

The geomorphology and surficial geology of the quadrangle provide clues to the extent and character of flood hazards and the availability of aggregate resources. Geologically young fluvial deposits (units Qy_{1}, Qy_{2}, and locally Qy_{1} along tributary washes and units $Qy_{1}r$, $Qy_{2}r$ along the Hassayampa River) record recent fluvial activity. The Hassayampa River is incised and flooding is restricted to the valley bottom. The fact that the valley bottom is covered almost entirely by late Holocene deposits strongly suggests that the valley bottom is the floodplain, and all portions of it have been subjected to recent inundation and deposition. Flooding is restricted to the valley bottom. The fact that the valley bottom is covered almost entirely by late Holocene deposits strongly suggests that the valley bottom is the floodplain, and all portions of it have been subjected to recent inundation and deposition. Flooding is restricted to relatively narrow corridors along the incised tributary washes that drain directly to the Hassayampa. Flood-prone areas are somewhat more extensive in the western 2/3 of the quadrangle where incision is modest. Valley bottoms covered with young deposits but channels are quite small, implying that shallow sheet flooding and bank erosion along channels are the principal flood hazards. Although valley bottoms are fairly wide, there are no major distributary channel networks or active alluvial fans on the piedmont.

Aggregate resources were extracted from several small pits in piedmont surficial deposits near Interstate Highway 10, probably for construction of the highway. Two larger aggregate operations are currently active along the Hassayampa River north of I-10. These operations are apparently mining aggregate primarily from Holocene river deposits, but they may be drawing upon older river deposits as well. The potential for useful aggregate resources in older river deposits that flank the modern floodplain is not known because the thickness of these deposits is uncertain.

Both earth fissures (AZGS, 2015) and giant desiccation cracks (Harris, 2003) have been recognized in the southwestern portion of the map area. An earth fissure opened in the summer of 2000 about 3 miles (5 km) southeast of Wintersburg. The fissure trends nearly north-south and is about 1,150 ft (350 m) long. In two locations the fissure is en echelon, with NW-SE steps. A complex of new earth fissures totaling 620 ft (190 m) opened approximately 400 ft (120 m) to the north-northwest of the initial fissure in the fall of 2014. These new fissures appear to be an extension of the initial fissure and also exhibit en echelon cracks that splay into a y-shaped arrangement at the northern end. There is no discernable vertical offset across any of the fissures. The location of the fissures, at the edge of the Palo Verde basin and somewhat in line with the trend of a small hill, suggests that a shallow buried bedrock ridge may extend south of the hill beneath the trace of the fissures. If this scenario is correct, the crack may represent fissuring due to compaction and subsidence on either or both sides of the buried ridge. An area of shallow giant desiccation cracks lies between the earth fissure zones. These cracks appeared at the same time as the initial earth fissure. Alignments of established vegetation in some portions of the polygonal desiccation crack network demonstrate that cracking has occurred periodically in the past. Additional areas of giant desiccation cracks were mapped by Harris (2003), and more were identified recently and are included on this map.

Two approximate or inferred faults are depicted that displace Miocene volcanic rocks. We found no evidence that these faults have been active during the Quaternary, nor did we find any other evidence of Quaternary fault activity in the map area.

Mapping Responsibility

Pearthree is responsible for all of the surficial geologic mapping in the map area. Ferguson mapped the bedrock geology of the Wintersburg quadrangle (Pearthree et al., 2006). Bedrock geologic units for all areas outside of the Wintersburg quadrangle are based on the compilation map of Reynolds and Skotnicki (1993), but map unit boundaries were modified by Pearthree using high-resolution orthophotography and topography. Earth fissures were originally mapped by Harris; some additional fissures were mapped by Cook in 2015.

Bedrock Geology

Mafic lavas of the 16.9 to 20.7 Ma (Shoustra et al., 1976;) Palo Verde Hills lava field constitute the only bedrock exposed in the area. The volcanic strata are gently dipping and show no sign of major deformation. A minor down-to-the-southwest normal fault offsets the lavas in the hills just north of the PVNGS (Pearthree et al., 2006), but these kinds of faults are common throughout the Basin and Range province of southwestern Arizona and there is little or no reason to suppose that this or other faults like it that are probable also present in the area have been recently active, or that that they ever will be in the future.

Based on extensive geochemical analyses of mafic lavas in the area, Shoustra et al. (1976) recognized two kinds of mafic lava: basaltic andesite and basalt, and as a result defined two bedrock map units: basalt (Tb), and a combined unit of basalt, basaltic andesite, and minor tuff and volcaniclastic rocks (Tba). Later, more detailed mapping by Pearthree et al. (2006) in an area confined to the Wintersburg 7.5' quadrangle showed that, in the immediate vicinity of the PVNGS, basaltic andesitic lava overlies basaltic lava along a gently northeast-dipping contact that is probably depositional (the contact is exposed in a hill in the north-central part of section 27, T1N, R6W. It should be noted that Shoustra et al.'s (1976) definition of basalt versus basaltic andesite (geochemistry) differs from the more recent study (Pearthree et al., 2006) which was based on petrology of the lavas. In the Pearthree et al. (2006) classification, lavas with fairly abundant plagioclase phenocrysts were identified as basaltic andesitic, and those with sparse or minor plagioclase phenocrysts were classified as basaltic. When the Wintersburg quadrangle map (Pearthree et al., 2006) was combined with the mapping of Shoustra et al. (1976) to produce this map, no attempt was made to reconcile the different definitions of the mafic rocks. Because of this, we show the basalt and basaltic andesite lavas in the immediate vicinity of the PVNGS as map units Tbl and Tbu respectively and do not attempt to extend these units elsewhere on the map.

Mafic lavas in the hills directly east of the PVNGS are basaltic based on both study's classifications, but since they show no stratigraphic relationship to the basaltic andesitic rocks (Tbu map unit) adjacent to the PVNGS, they are correlated with the more generic Tb map unit. The Tb lavas in this area were dated by Shafiqullah et al. (1980) as the oldest in the area, which suggests that they may correlate with the Tbl (older) unit. However, as noted by Pearthree et al. (2006), the lava flows in sections 35 and 36, T1N, R6W appear to dip moderately to the southwest and they might be a different (older or younger) age than those near the PVNGS. The difference in stratigraphic tilt of the volcanic strata near the PVNGS (northeast), with the southwest-tilted strata in the aforementioned hills indicates that an anticlinal tilt-domain boundary exists in the vicinity of the PVNGS. This should not be taken as evidence of any sort of structural instability however, since tilt-domain boundaries of this sort are present throughout the Basin and Range province of the American southwest (eg. Stewart, 1980). In this and nearly all other instances like it, structures related to tilt-domain boundaries in the Basin and Range province have been inactive for millions of years.

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Description of Map Units

Surficial Map Units - Piedmont Alluvium

Quaternary and late Tertiary piedmont deposits from the Belmont Mountains to the north and the Palo Verde Hills to the west cover the western 90 percent of the map area. This alluvium was deposited primarily by larger tributary streams that head to the north of the quadrangle and smaller tributaries that drain the Palo Verde Hills; these larger streams and smaller streams that head in this quadrangle have eroded and reworked some of these deposits. Clast lithologies include basalt and felsic volcanic rocks and mixed granitic and metamorphic rocks. Deposits range in age from modern to early Pleistocene or late Pliocene. Abbreviations used are ka, thousands of years before present, and Ma, millions of years before present.

Qyc **Qyc – 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 0.5 to 4 m below adjacent Holocene terraces and alluvial fans, but may be incised as much as 8 m below adjacent Pleistocene deposits. Channel morphologies generally consist of a single thread, relatively deep channel or multi-threaded smaller, shallower channels with gravel bars. Channels are extremely flood prone and are subject to deep, high velocity flow in moderate to large flow events. Areas adjacent to Qy_2 deposits may be prone to lateral bank erosion.

Qy_2 **Qy_2 - Late Holocene alluvium.** Young, typically fine-grained deposits in floodplains, low terraces and small channels. 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 fine 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 minimal to very weak, consisting at most of slight carbonate accumulation. Channels generally are incised less than 1 m below adjacent young surfaces, but locally incision may be as much as 2 m. Channel morphologies generally consist of a single- or multi-threaded 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. Substantial lateral bank erosion may occur in these deposits, 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 **Qy_1 - Holocene alluvium.** Older Holocene terrace deposits found mostly along the margins of incised drainages throughout the map area, and are quite extensive along some of the larger washes. Qy_1 surfaces are higher than adjacent Qy_2 surfaces and generally are not subject to flooding. Qy_1 terraces are generally planar but local surface relief may be up to 1 m where gravel bars are present. Qy_1 surfaces are 1-4 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 (7.5 to 10 YR) with weakly developed stage I calcium carbonate accumulation (see Machette, 1985, for description of stages of calcium carbonate accumulation in soils).

Qyf **Qyf - Fine-grained Holocene alluvium.** 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 1 m or more thick. Sediment typically is brown (7.5YR) mainly silt and sand, with occasional deposits of open, unvarnished, fine gravel lag. Soil development is minimal, with substantial disseminated carbonate but little visible carbonate accumulation.

Qye **Qye - Mixed young eolian deposits and alluvium**. Weak, limited gravel lag deposits with small coppice dunes and discontinuous small channels; the extent of gravel surface lags and the abundance of small channels varies substantially, some areas are composed mostly of small dunes with limited pavements and few channels. Vegetation is very sparse and small on flat areas; desert shrubs, mainly creosote bush, are common on coppice dunes. Surfaces are generally brown to tan on aerial photos, and they commonly have striped appearance.

Qy **Qy - Holocene alluvial deposits, undifferentiated.**

Qi_3 **Qi_3 - Late Pleistocene alluvium.** Unit Qi_3 is composed of slightly to moderately dissected relict alluvial fans and terraces. Active channels are incised up to about 1-2 m into Qi_3 surfaces, and Qi_3 fans and terraces are 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 weak bar and swale topography and open to moderately tight pebble and cobble pavements. Locally, pavements are tight. Surface gravel clasts typically exhibit weak to moderate brown rock varnish but some surfaces in the northern part of the quadrangle that are mainly composed of fine-grained volcanics are more darkly varnished. Qi_3 soils are moderately developed, with brown loamy (7.5 YR) near-surface horizons with minor clay and stage II calcium carbonate accumulation.

Qi_2 **Qi_2 – Middle to late Pleistocene alluvium.** Unit Qi_2 is composed of moderately dissected relict alluvial fans and terraces with moderate soil development. Qi_2 surfaces are drained by broad swales and well-developed, moderately incised tributary channel networks; channels are typically 1-2 meters below adjacent Qi_2 surfaces. Well-preserved, planar Qi_2 surfaces are fairly smooth with pebble and cobble pavements; where the surface gravel is cobbly, surfaces typically retain some evidence of depositional bars. Surface color is reddish brown; surface gravel clasts are moderately to strongly varnished. More eroded, rounded Qi_2 surfaces are characterized by strongly varnished, scattered, cobble to pebble lags. Soils associated with planar surface remnants typically contain reddened (5 to 7.5 YR), clay loam argillic horizons, with clay coatings and subangular blocky structure. Underlying soil carbonate development is typically stage III with areas as strong as stage IV. Carbonate is abundant through at least 1 m of the soil profile. In more eroded locations, argillic horizons have been removed and soils are calcic throughout.

Qi_1 **Qi_1 – Middle Pleistocene alluvium.** Unit Qi1 is composed of moderately dissected, generally rounded relict alluvial fan surfaces. Qi1 surfaces form planar remnants and broadly rounded ridges that are 1-2 m higher than adjacent Qi2 surfaces. Drainage networks include broad swales on the ridge tops and tributary channels incised 3 to 4 m. Underlying eroded QTs deposits are occasionally exposed along some ridge slopes and wash banks. Well-preserved Qi1 surfaces are limited in extent, but have moderately to tightly packed cobble, boulder, and pebble lag. Surface clasts are variably varnished and commonly have carbonate rinds up to 2 mm thick, and rubble from underlying petrocalcic horizons are fairly common on Qi1 surfaces. More eroded, rounded Qi1 surfaces are characterized by variably varnished, scattered, cobble and boulder lags with locally exposed laminar carbonate horizons. Where well preserved, Qi1 soils calcic throughout, with underlying stage IV to weak stage V petrocalcic horizons.

Qi **Qi – Middle and late Pleistocene alluvial deposits, undifferentiated.**

Qo **Qo – Early Pleistocene alluvium.** Unit Qo is composed of moderately to deeply dissected, planar relict alluvial fan surfaces with broadly rounded margins. Qo surfaces form planar remnants and broadly rounded ridges that are 2-10 m higher than adjacent washes. Drainage networks on broad Qo surfaces typically are weakly developed and minimally incised, but locally washes draining the margins of these surfaces are incised 5-10 m. Well-preserved Qo surfaces have abundant calcium carbonate cemented petrocalcic rubble. Surface clasts are variably varnished, but basalt and basaltic andesite clasts commonly are very darkly varnished. Rounded margins of Qo surfaces are characterized by variably varnished cobble and boulder lags with exposed laminar carbonate horizons. Where well preserved, Qo soils calcic throughout, with moderate to strong stage V petrocalcic horizons.

QTs **QTs - Early Pleistocene to Pliocene alluvium.** Unit QTs is composed of eroded generally fine-grained basin deposits, locally overlain by younger Quaternary units. QTs deposits typically are poorly exposed on ridge slopes, in wash banks, and in channels as strath terraces. The thickness of QTs deposits is variable, but certainly is at least tens of meters (Shoustra et al., 1976). In the shallow subsurface, unit QTs includes an extensive clay-rich unit (the Palo Verde clay) that is older than 2 Ma (Shoustra et al., 1976). Surface exposures of QTs include weakly to moderately indurated, cross-bedded, red, pebbly sandstones, silt and clay deposits, and buried paleosols.

Hassayampa River Alluvium

Quaternary and late Tertiary piedmont deposits associated with the Hassayampa cover the eastern margin of the Wintersburg quadrangle. Clast lithologies are quite diverse, but are principally mixed fine-grained volcanic rocks and granite. Clasts range from well-rounded to subangular in shape. Deposits range in age from modern to Pliocene.

Qycr **Qycr - Active river channel deposits.** Moderately to poorly sorted sand, gravel and minor silt in recently active channels and lightly vegetated bars of the Hassayampa River. Gravel consists mainly of pebbles with some cobbles; clasts range from subangular to well-rounded.

Qy_2r **Qy_2r - Late Holocene floodplain deposits.** Sand, silt, and gravel deposits associated with the floodplain and low terraces along the Hassayampa River. Qy_2r surfaces typically are smooth and are less than 2 m above the active channel. Terrace surfaces typically are covered with fine-grained floodplain deposits, but relict gravel bars and lenses are common.

Qy_1r **Qy_1r - Older Holocene river terrace deposits.** Sand, silt, and gravel deposits associated with slightly higher terraces along the Hassayampa River. Terrace surfaces typically are flat but rounded around their margins and are less than 3 m above the active channel. Terrace surfaces typically are covered with a fine gravel lag where well-preserved but are quite fine-grained where eroded.

Qi_3r **Qi_3r - Late Pleistocene river terrace deposits.** Deposits associated with low intermediate terraces inset about 3 m above the Holocene floodplain of the Hassayampa River. Deposits consist of sand, silt, and gravel, with weak to moderate soil carbonate (Stage I-II) accumulation. Terrace surfaces typically are smooth and are covered with fine-grained floodplain deposits, but relict gravel bars and lenses are found locally.

Qi_2r **Qi_2r – Middle Pleistocene river terrace deposits.** High intermediate terraces about 5 m above the Holocene floodplain of the Hassayampa River. Terrace surfaces typically are dissected by small tributary drainages but are smooth away from the drainages. 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 moderately strong, consisting primarily of stage II to III calcic horizons.

Qorh **Qor - Early to middle Pleistocene river deposits.** Deposits associated with the highest terraces along the Hassayampa River that record the maximum aggradation of the river. Terrace surfaces are broadly rounded, and the deposits are moderately to deeply dissected by tributary drainages and the river and have been substantially modified by erosion. Exposures are poor, but subangular to well-rounded gravel is evident at the surface. Terrace surfaces are also typically covered with litter from underlying indurated stage IV petrocalcic soil horizons. Qorh terrace surfaces are more extensive than any of the younger Pleistocene terraces. Terrace surfaces range from about 10 to 15 m above the active river channel, and rise slightly to the north across the map area. They are at approximately the same topographic level as adjacent Qi1 tributary fan surfaces, and thus must be of similar age

Other Units

Qe **Qe - Quartz-rich dune sand and sand sheet deposits**. Minimal gravel pavements between dunes, which range in height up to about 5 ft, but are commonly less than 3 ft high. Dune areas typically have sparse to moderately dense vegetation, with small desert shrubs and grasses.

Qtc **Qtc - Quaternary hillslope talus and colluvium**. Thin, steeply to moderately sloping, weakly bedded hillslope deposits mantling the middle and lower slopes of basalt 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.

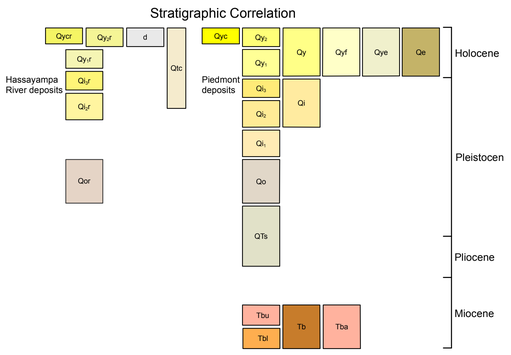
d **d - Disturbed areas.** Much of the quadrangle has been disturbed by human activities, particularly agricultural activities. This unit designation is used only in areas of substantial excavation or anthropogenic deposition, for example, major flood-control levees.

Bedrock Units

Tbu **Tbu - upper basalt**. Basalt lava containing 3-7% -2mm mafic phenocrysts (pyroxene and/or iddingsite altered olivine), and 5-10% 1-4mm plagioclase phenocrysts (samples: CAF-2-10637, 10638, 10639, 10643, 10649, 10650, 11343, 11344, 11345, 11346, and 11348)

Tbl **Tbl - lower basalt**. Basalt lava containing 3-7%, 1-3mm mafic phenocrysts (pyroxene and/or iddingsite altered olivine), and sparse 1-2mm plagioclase phenocrysts (samples: CAF-2-10640, 10644, 10646, 10648)

Tb **Tb - basalt lava, undifferentiated**. Basalt lava containing 2-7%, 0.5-3mm mafic phenocrysts (pyroxene and/or iddingsite altered olivine) with sparse plagioclase phenocrysts <2mm (samples: CAF-2-10622, 10626, 10631, and 10635). Shafiqullah et al. (1980) report a whole rock, K/Ar age of 20.7 + 0.6 Ma for this unit, making it the oldest known lava from the Palo Verde lava field.

Tba **Tba – basalt, basaltic andesite, tuff, and volcaniclastic sediments.**

Stratigraphic Correlation