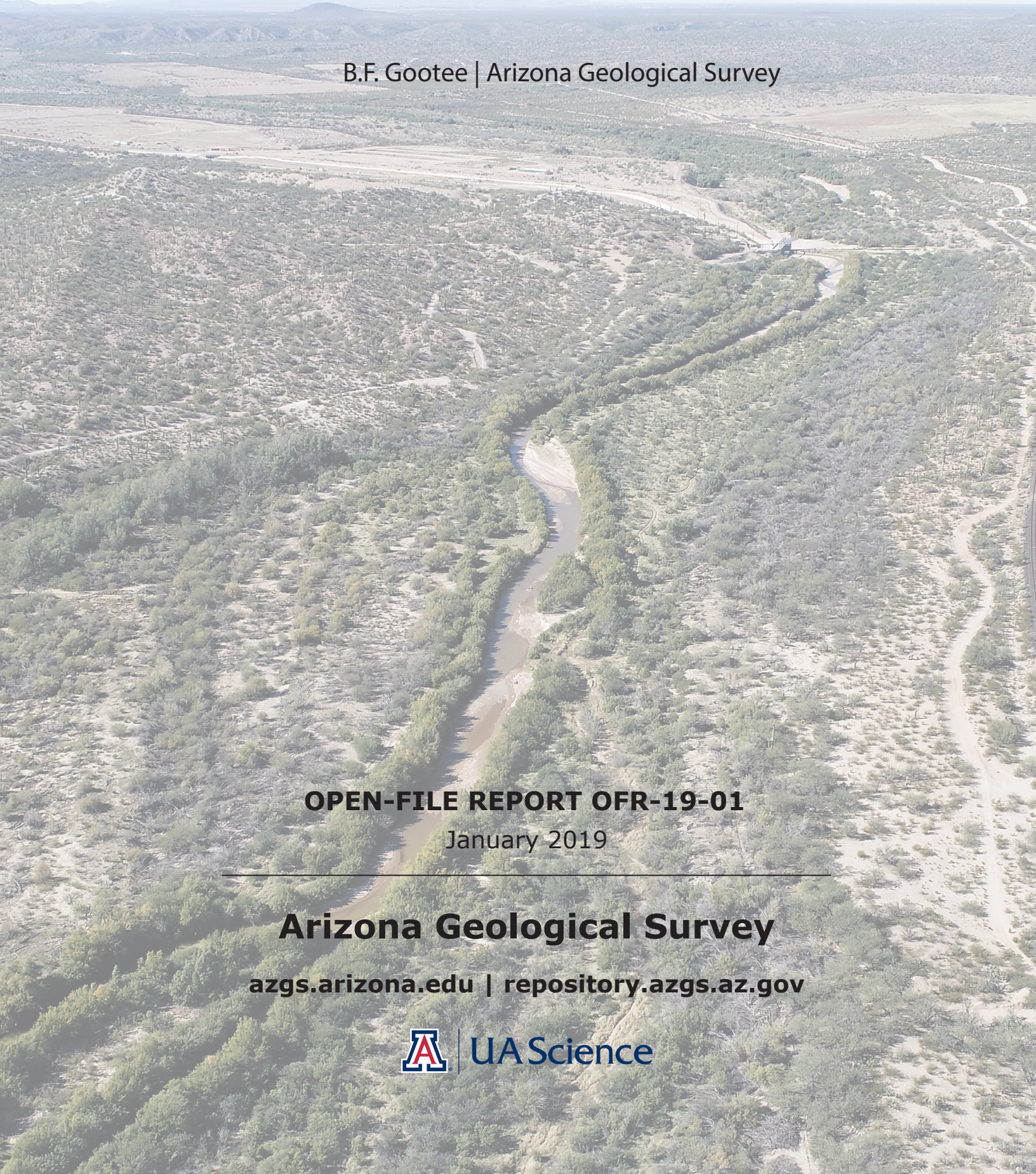
Revised depth-to-bedrock and depth-to-base of Gila River deposits along the southern Higley and northern Picacho Basin boundary, Pinal County, Arizona

B.F. Gootee | Arizona Geological Survey



OPEN-FILE REPORT OFR-19-01

January 2019

Arizona Geological Survey

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Manuscript approved for publication in January 2019
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Recommended Citation: Gootee, B.F., 2019, Revised depth-to-bedrock and depth-to-base of Gila River deposits along the southern Higley and northern Picacho Basin boundary, Pinal County, Arizona. Arizona Geological Survey Open-File Report OFR-18-01, 18 p.

This study represents the southward continuation of a hydrogeologic investigation in the eastern Higley basin or Superstition Vistas Planning Area that resulted in AZGS Special Paper 11, and was funded primarily by Salt River Project (SRP). We thank SRP management and staff for their support, teamwork and vision in this project.

Cover image: Aerial view looking west at the Middle Gila River entering Basin and Range Province east of Florence, AZ. The Ashurst-Hayden diversion dam seen in upper right at the end of the riparian corridor, is located at the approximate boundary of the Elephant Butte fault and easternmost boundary of Basin and Range province. Knob in middle-ground near the horizon is part of the Florence Military Reservation, and Estrella Mountains is seen on far horizon.

INTRODUCTION

This report summarizes revisions to the Depth-to-Bedrock (DTB) contour map after Richard et al. (2007) along the boundary between the southeastern Higley basin near Queen Creek, AZ, and the northeastern Picacho basin near the town of Florence (Figure 1). This study represents a southward continuation of recent modifications to DTB in the eastern Higley basin or Superstition Vistas Planning Area (Gootee et al., 2017). The thickness and subsurface extent of Gila River deposits in the Florence area was updated in this study to help identify subsurface relationships to adjacent basin fill units and to understand history of Gila River integration.

GEOLOGIC SETTING

The Higley-Picacho study area lies between the eastern Santan Mountains and western Mineral Mountain/North Butte mountains, and the eastern Higley and northeastern Picacho structural/groundwater basins (Figure 1). Bedrock in the study area is mapped as early Miocene volcanic rocks (25-15 million years ago [Ma]), Tertiary/Cretaceous intrusive igneous rocks (80-30 Ma), and Proterozoic plutonic and metamorphic rocks (1,500-1,000 Ma) (Ferguson and Skotnicki, 1995 and 1996; Richard and Spencer, 1997; Skotnicki, 1999; Spencer et al., 1996). The earliest known basin fill sequence linked to groundwater basins is defined as Miocene alluvium (gravel, sand, silt and clay) (about 16 to about 3 Ma) interbedded with late Miocene (8 to 6 Ma) andesitic basalts (Nason et al., 1982; Huckleberry, 1993; Pearthree et al., 2012). DTB is also referred to as the depth to base of the Lower Alluvial Unit (LAU). The Gila River flows from bedrock-dominated valleys east of Florence to the west across thick basin fill deposits in the study area, and roughly along the boundary between the Higley and Picacho basins. The Gila River probably arrived in the Florence area about 3 Ma, although the precise mechanism of integration is unknown, and the subsurface extent of river deposits is not well defined.

METHODS

Depth to Bedrock

Revisions to depth-to-bedrock (DTB) and the base of Gila River deposits are primarily based on existing publications and well data from Arizona Department of Water Resources (2018), with some data obtained from personal communication and unpublished data. DTB in the study area mapped by Richard et al. (2007) was derived primarily from Oppenheimer and Sumner (1980), which was based on 2 wells and 3 gravity profiles used to model bedrock. DTB in this area is equivalent to the base of the Lower Alluvial Unit after Corkhill et al. (1993) and Gootee et al. (2017). This study relied primarily on existing data from about 700 wells (primarily groundwater wells with some exploratory borings), shallow and deep seismic-reflection surveys, and to a lesser extent historical gravity and aeromagnetic data.

Well log data were used to classify the type of basin fill, presence of interbedded basalt and bedrock type. These data were recorded and classified into ArcGIS shapefiles. The presence of basalt in wells greatly helped to identify potential horizons that could be used to determine dip of flows or underlying topography, and most importantly to identify minimum constraints on pre-basin fill bedrock depth. Geologic map data supplemented subsurface information on bedrock and basin-fill deposits pertinent to this study. In many cases well data, outcrops and other subsurface data, especially interpretations from existing sources, conflicted with each other. Thus, all data and an understanding of regional and historical geology were used to help determine and refine DTB. Three cross-sections created or updated in Higley and Picacho basins are discussed further below. All datasets were used to construct the cross sections, although just data pertinent to this study are shown in the sections.

Gila River deposits

Well data were also used to determine the depth of deposits interpreted to be sourced from Gila River deposits. Surficial geologic mapping in the study area between North Mountain and eastern Gila River Indian Community (GRIC) was primarily derived from Huckleberry (1992, 1993, and 1996), Pearthree et al. (2015), and field observations made during this study. A preliminary assessment of clast distribution and provenance of Gila River deposits was conducted on Gila River deposits of various ages to help determine relationships between mapped units and well data for correlation and to determine aspects of the evolution of the Gila River in this area. The relative percentage of clasts lithology was counted (regardless of diameter) similar to other clast counts conducted on major drainages in the Basin and Range (Pearthree et al., 2015; Dickinson, 2008; Gootee, unpublished data; and Skotnicki, unpublished data). Well data were compiled from ADWR, USGS, AZ Oil & Gas, Bureau of Reclamation, San Carlos Irrigation Project (SCIP) and private unpublished sources. Many of these sources overlapped as duplicates (USGS & ADWR for example).

Figure 1. Higley-Picacho study area, Pinal County, Arizona.

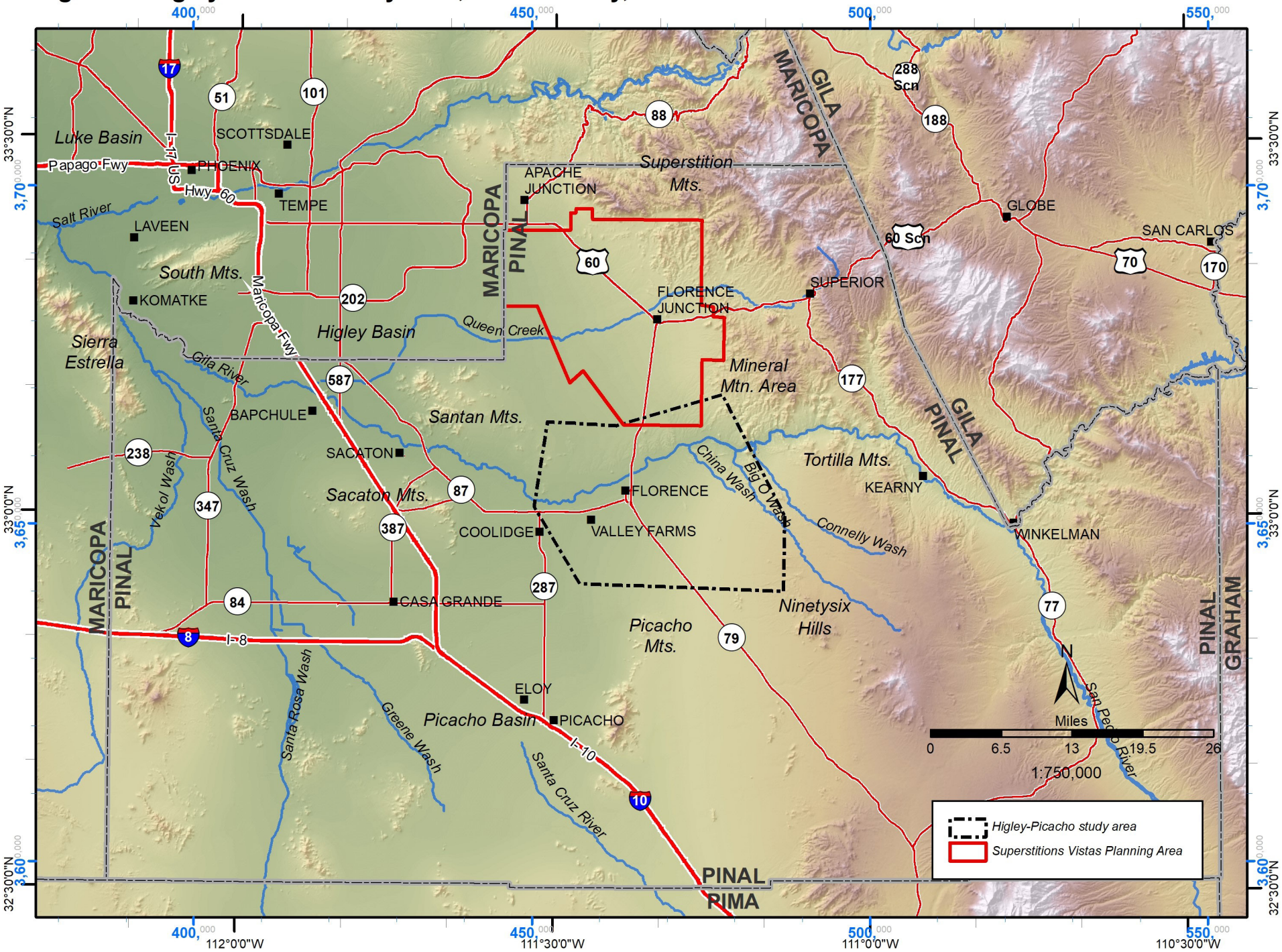

Figure 1. Regional location map of Higley-Picacho study area (heavy dashed black polygon). Superstition Vistas Planning Area (Gootee et al., 2017) (heavy red polygon) north of this study area. Major tributaries to Gila River are blue lines.

RESULTS

Depth to Bedrock

Significant changes to the DTB contours were made compared with those of Richard et al. (2007); the new contours are shown in Figure 2. A total of 293 wells with lithologic data were used to aid in constraining bedrock depth. A total of 64 wells encountered bedrock, mostly in granite. DTB contours were reconciled with DTB contours immediately to north in southern Higley basin (Superstition Vistas Planning Area (SVPA); Gootee et al., 2017, Fig. 9) and converted to depth below land surface and elevation in feet above sea level (Figures 3 and 4).

Two new cross sections were made in the northern Picacho basin, sections AA' and CC' (Figures 2 and 5). A third cross section from AZGS (2008) and Gootee (2013), section BB', was updated using results from SVPA in the Higley basin (Gootee et al., 2017) and new findings and data from this study, shown in Figure 5.

The two new geologic cross sections in Picacho basin were made to illustrate differences in DTB, basin geometry, basalt flows and horizons, faults, and select wells pertinent to this study (Figure 5). The shape of DTB contours represent in general northwest-southeast trending lineaments thought to represent faulted basin-fill strata. Faults or fault zones (multiple faults) are interpreted to coincide with closely-spaced contour lines. Widely-spaced contours are thought to represent non-deformed basin-fill mantled on bedrock between faulted areas, although some areas may coincide with areas lacking well data, which has the effect of spacing contours evenly.

Basalt is exposed at the surface in Higley and Picacho basins between bedrock mountains, found interbedded with basin-fill deposits, and overlying bedrock paleotopography. The presence or absence of basalt encountered in wells was a major contributor in constraining the minimum depth of basin-fill deposits (bedrock). All well logs were sorted into wells in which basalt was recorded, possibly encountered based on indicators in the log, or was not noted. Logs from some wells noted thick sequences of cinder, which may indicate the presence of a cinder cone or fissure vent nearby (plotted in Figure 2).

Basin-fill deposits

Basin-fill deposits (pre-Gila River deposits) generally consist of a mix of alluvial deposits (clay, silt, sand and gravel) derived from the Santan and Mineral Mountain/North Butte bedrock source areas. In cross-sections AA' and CC' in Picacho basin, basin fill was not differentiated into Middle Alluvial Unit (MAU) and Lower Alluvial Unit (LAU); rather, these units were lumped into pre-Gila basin-fill deposits because DTB was the main focus of these sections. In general, the MAU is likely present in the western portion of both sections that does not include interbedded basalt flows, and is labeled "fine-grained basin-fill" in both sections. A contact between MAU and LAU in this area could not be determined based on well data, but also because criteria to define the two are not well defined, or there is no clear boundary between the two. In general, many wells to the west reported fine-grained clay and silt, where as wells to the east are coarser grained. We interpret this coarser-grained domain to be equivalent to parts of MAU and LAU, or just coarse-grained basin fill with an upper boundary defined by Gila River deposits where present and lower boundary defined as hydrogeologic bedrock at depth.

A detailed description of mineral or lithologic constituents in alluvial deposits were insufficient towards identifying particular source areas, although granite and felsic-bearing lithologies are most commonly reported. Identifying lithologic facies within the basin-fill sequence was outside the scope of this work.

Results from the SVPA study (Gootee et al., 2017) were used to update the southeast-northwest trending BB' in Higley-Picacho basin (Figure 6). Depths to the base of the Upper Alluvial Unit (UAU), MAU and LAU were extracted into BB'. Queen Creek deposits and its adjacent mineral facies were also incorporated; they appear to extend into the LAU an unknown depth. This assertion is primarily based on the presence of Queen Creek mineral facies documented in exploratory borings C1 and A3a, to depths of about 1,450 and 1,500 ft-bls, respectively, upstream of section line BB' approximately 4 and 8 miles respectively (Gootee et al., 2017). Based on these relationships, Queen Creek deposits are believed to pre-date both Gila and Salt River deposits, although the location of the depocenter that Queen Creek fed into prior to the development of the Gila and Salt Rivers is unknown. Gila River deposits, discussed later, are found at the modern topographic divide between Picacho and Higley basins. These deposits appear to extend into Higley basin subsurface, although

Figure 2. Depth to base of Lower Alluvial Unit (bedrock)

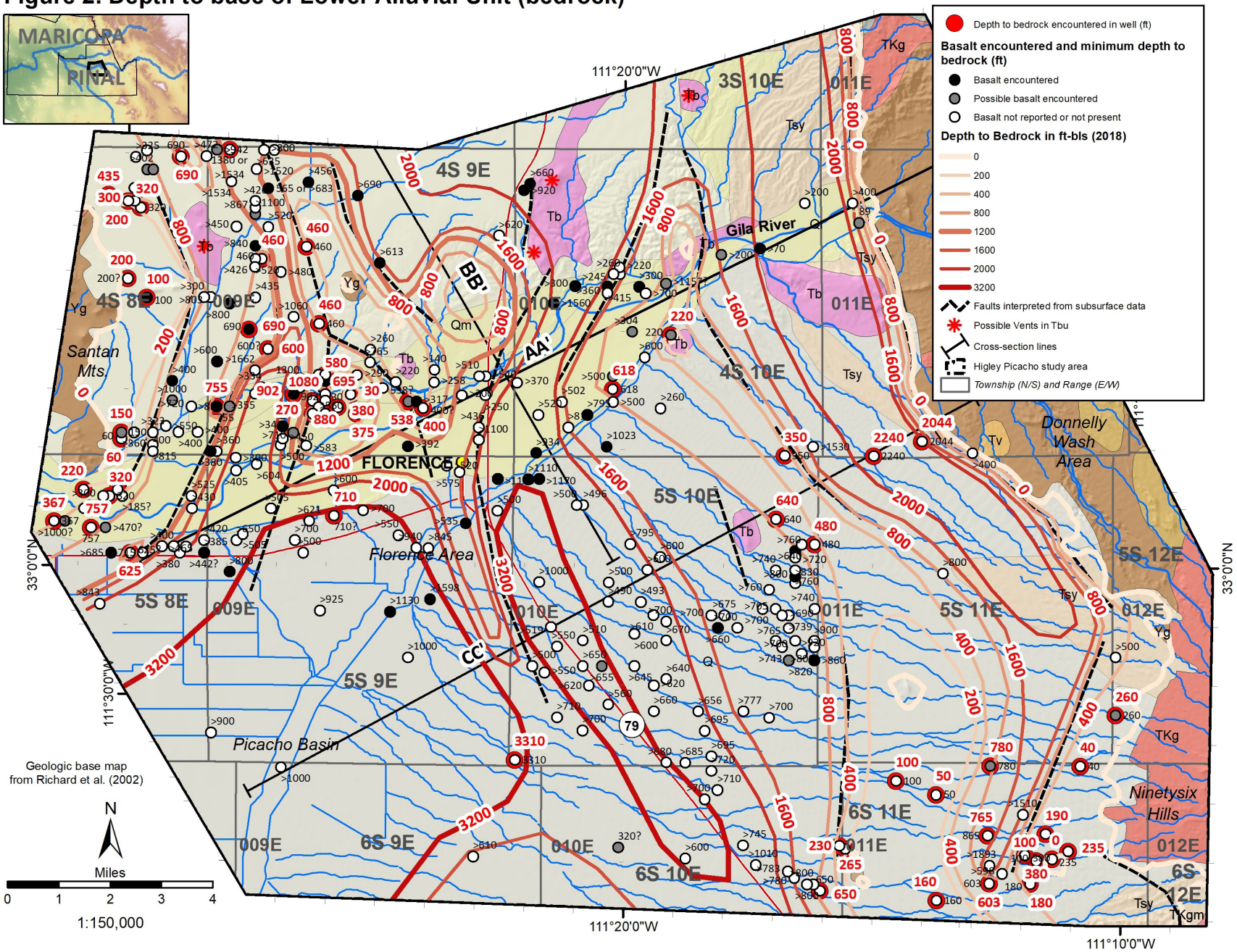

Figure 2. Depth to base of Lower Alluvial Unit (hydrogeologic bedrock) in the Higley-Picacho study area. Northeast-southwest oriented cross-sections AA' and CC' from this study (Figure 2). Geologic cross-section BB' updated from AZGS (2008) and Gootee (2013) with data from this study. Full extent shown in Figure 3. Contour lines and line segments include notations about data source, error and other notes in GIS layer data.

this possibility needs to be explored further by mineral analysis from future well drilling.

Interbedded basalt

Basalt flows are interbedded within the basin-fill sequence. Basalt is mapped in several places at the surface as either interbedded with basin fill deposits, or directly overlying bedrock (Figure 2). Basalt was found to directly overly bedrock in only two wells, near where basalt was mapped overlying bedrock at the surface north of Florence. In all other areas where basalt was encountered in wells, basalt was found to be interbedded with basin-fill sand and gravel, and less commonly, in brown clay and fine sand. Variation in thickness, lateral extent and lithology underlying flows suggest some paleotopography was present when lava vents erupted at the land surface, but the details of the paleotopography are not well-constrained.

Where basalt flows were found to be interbedded with basin fill, thickness of individual flows encountered in wells ranged from 13 to 75 ft, which is typical for basalt flows. Actual flow thicknesses might be less if the sequence is tilted. Wells drilled in the Florence Copper mine area encountered basalt is several wells and show thicknesses of 50 to 75 ft thick. Whether this is one or multiple flows is not clear.

Basalt in wells is generally dark gray to black, but reddish-brown, purple and bluish colors are commonly reported. Basalt flows are thought to be crudely bedded, fractured, and jointed. Texture is generally massive, but vugs and vesicles are commonly present and often filled with calcite, quartz and possibly zeolite minerals. Bright reddish-brown deposits in basaltic sequences are interpreted to be cinder deposits found near vent sources, especially in wells drilled through sequences several hundred feet thick of varying hardness, color and lithology. Based on these findings and remnant morphology of basalt exposures the locations of possible vents are indicated in Figure 2. Basalt is commonly jointed and fractured and many wells report fluid loss during drilling.

Determining the vertical and lateral extent of basalt flows and their orientation was especially difficult based on the variety of log quality and well spacing. In some cases, two relatively closely-spaced wells could be used to infer the dip of individual flows. In T4S, R9E, Section 31B, between wells 35-17946/47 and 35-17945, the dip of basalt was calculated to have an apparent dip of 7° to 9° to the east. Two other wells (35-18752 and 35-18949) encountered basalt that, if the same flow, dips an apparent 7° to 8° to the east (Figure 5, Section A-A'). Florence Copper Inc. reported flat-lying basalt interbedded with poorly-indurated basin-fill (US EPA, 2013), but elevations between boreholes suggest basalt dipping 13° to the west (US EPA, 2014, their C-C').

Based on these relationships, it appears that basaltic volcanoes erupted onto a landscape of generally low relief consisting of a bedrock pediment and a basin-fill surface at the eastern toe of the Santan Mountains; this surface sloped to the north toward the town of Queen Creek. Another gentle paleosurface slope toward the south and west onto fine sand and mud flats in the northern Picacho basin prior to development of the Gila River. Bedrock nobs of generally low relief were present in both areas. There apparently was a low paleo-divide in the general area between the present-day Higley and Picacho basins prior to the arrival of the Gila River. Faulting, discussed further in the next section, appears to have occurred prior to volcanism, as indicated by a relatively deep half-graben or graben in the hanging wall of the Elephant Butte fault, as well as during and following volcanism. Emplacement of basalt fissures, vents and cinder cones probably occurred along faults, fault zones or intersecting faults. Basin-fill, basalt flows and bedrock are exposed in a few places near Florence (Figure 2). Gila River deposits are inset into these older deposits, which indicates the arrival of the Gila River post-dates faulting and volcanism.

Faults

Faults in the study area have been identified from surface mapping (Ferguson and Skotnicki, 1995, 1996; Richard and Spencer, 1997), seismic imaging (Laney and Pankratz, 1987; Warren, 2009; Gootee et al., 2017), and exploratory drilling (BOR, 1970s; Bronco Exploration, 2012; US EPA, 2013, 2014). A detailed assessment of faulting is relevant for the purposes of defining DTB and hydrogeologic boundaries and zones.

There are at least two major faults and several other suspected faults in the study area generally trending north-northwest/south-southeast (Figures 2 and 5). The Elephant Butte fault is a major west-dipping normal fault along the eastern portion of the study area. One exposure of this fault is in the SE corner of section 33

Figure 3. Depth to base of LAU, SVPA and Northern Picacho Areas

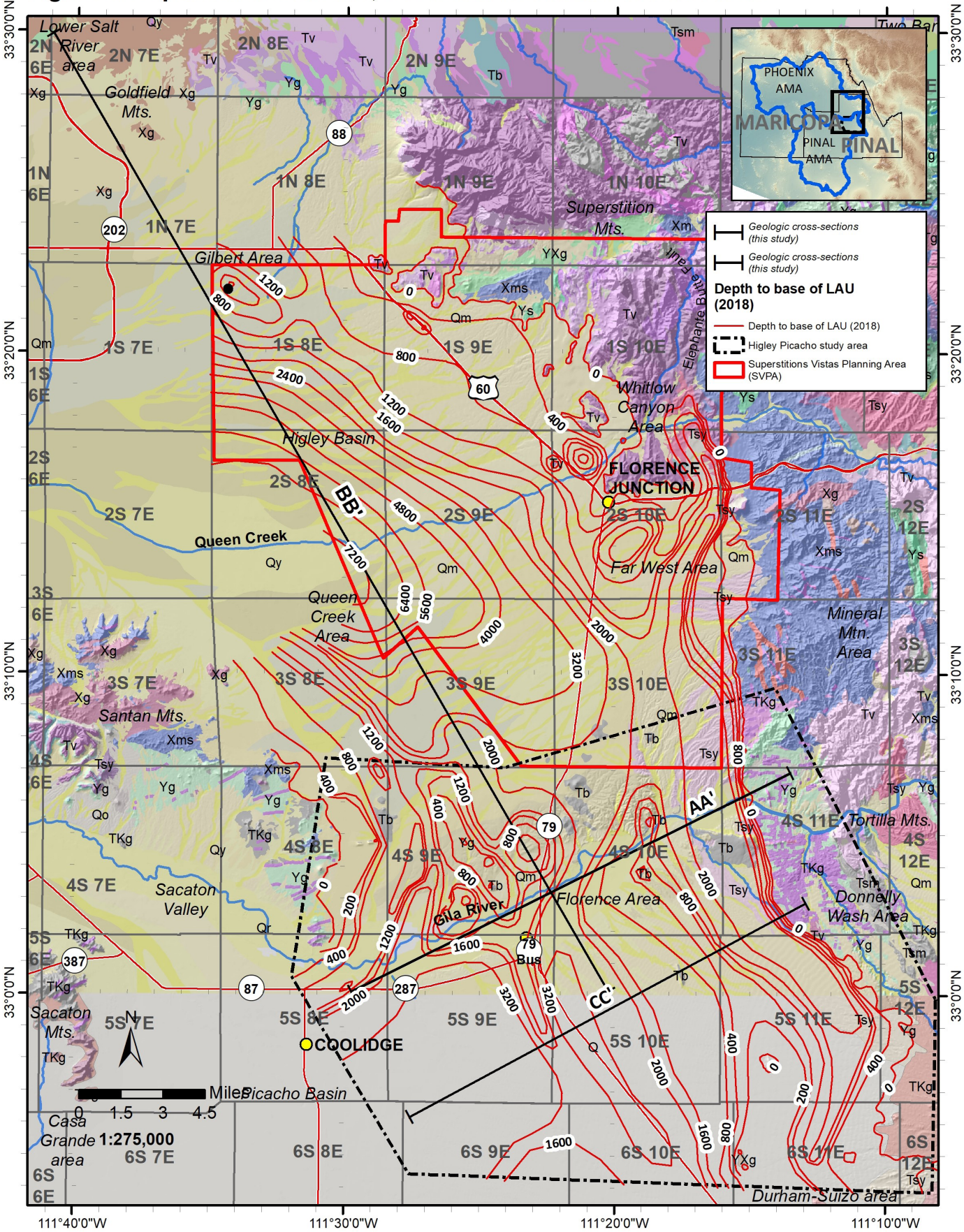

Figure 3. Depth to base of Lower Alluvial Unit in feet below land surface in Superstition Vistas Planning Area (SVPA, Gootee et al., 2017) and Higley-Picacho study area (this study). Northwest-southeast cross-section BB' modified from AZGS (2008) and Gootee (2013) with results from this study and Gootee et al. (2017) (Figure 5). Geology basemap from Richard et al. (2007) and Pearthree et al. (2015).

in T. 4S, R. 11E. Here it dips 72° to the west, similar to the major west-dipping Cochran fault mapped about 8 to 10 miles east of the Elephant Butte fault (Richard and Spencer, 1997). The Elephant Butte fault was also identified further north on the eastern margin of the Higley basin and indicated by the presence of deep basin-fill juxtaposed with tilted bedrock ridges (Gootee et al., 2017). Similarly, Bronco Creek Exploration (unpublished data, 2012) tested for mineralized bedrock beneath basin-fill deposits in the Ninetysix Hills and Cactus Flat areas in the southeastern part of the study area (T6S, R11E and eastern portion of section B-B', Figure 5). They encountered relatively deep basin-fill deposits juxtaposed against older volcanic and basement bedrock. These data indicate a similar northwest-southeast trending faulted relationship between basin-fill and bedrock. In the hanging wall of the Cochran fault (east and outside the study area) basin-fill deposits are gently west-dipping into a broad syncline. This relationship may also be present in basin-fill/basalt sequence west of China Wash south of the Gila River (Figure 2 and cross-section A-A', Figure 5).

On the eastern margin of the Santan Mountains the Higley fault was identified from vintage seismic data as a major east-dipping fault (Warren, 2009). This fault is thought to be much older than the Elephant Butte fault, although faulting concurrent with west-dipping faults cannot be ruled out. The Higley fault is estimated to dip 35° to 40° to the east (Warren, 2009). The major evidence for the Higley fault close to exposed bedrock in the eastern part of T4S, R8E are well records, especially from wells cased in basalt and conglomerate >800 to >1,000 feet depths. Steep gradients between basin-fill and pre-basin fill rocks support faulting along a fault similar to the strike of the Higley fault. If so it may be likely that east-dipping "old" faults were reactivated during faulting related to the main west-dipping Elephant Butte fault and related faults.

Exploration of copper resources in the Florence Copper mine area identified two major west-dipping faults, the Sidewinder fault with ~1,200 ft offset of pre-basin fill rocks, and the Party Line fault with about 1,000 ft displacement of similar-age rocks (US EPA, 2013, 2014). There are dozens of other synthetic west-dipping faults as well. Based on these studies the relationship between these major faults and the overlying basin-fill is not clear. Detailed well-lithology suggests that faulting is at least partially involved in basin-fill below younger alluvium. Faults in this area also explain relatively thick sequences of basin-fill next to shallow bedrock projecting with a north-south strike (Figure 2). It should be noted that based on the projection of faults shown in Figure 2, intersecting faults are likely present which could be future drilling target areas or zones with potentially high secondary porosity.

Gila River Deposits

The extent of Gila River deposits was evaluated in the study area to determine their width, depth and thickness in the subsurface, and its relationship with underlying basin-fill units (Figure 7). Surficial mapping was largely done by Huckleberry (1992, 1993) and Richard and Spencer (1997), with subsequent compilations and modifications by Spencer et al. (1996) and Pearthree et al. (2015). Map units shown in Figure 7 are representative of the relative age range of Gila River deposits, although their thickness and extent in the subsurface is not as well-delineated or has been described only in general in the Florence area (e.g. Pool et al., 2001).

Thickness and extent

The portion of the Gila River between San Carlos Reservoir and the confluence with the Salt River is referred to as the Middle Gila River. The Florence area portion of the Middle Gila immediately west of Ashurst-Hayden Dam (section 8 in T4S, 11E, Figure 7) is important because the Gila River exits the Transition Zone and enters the Basin and Range Physiographic Province. Upstream of the study area the Gila River is generally less than a mile wide and constrained to bedrock-cored, v-shaped valleys with thin alluvial terraces flanking the sides of the river channel overlying bedrock. West of Ashurst-Hayden Dam Gila River deposits are considerably more extensive, 5 to 7 miles wide, are thicker, and overlie some bedrock but mostly basin-fill deposits. Gila River deposits upstream and downstream of the study area were incorporated into the study area to constrain the maximum depth-to-base and height of Gila River deposits. The Florence area is also important because it is a portion of the Gila River that closely coincides with a hydrologic divide between the Higley basin to the north and Picacho basin to the south in which the Gila currently resides. An understanding of these deposits in relation to underlying

Figure 4. Elevation to base of LAU, SVPA and Northern Picacho Areas

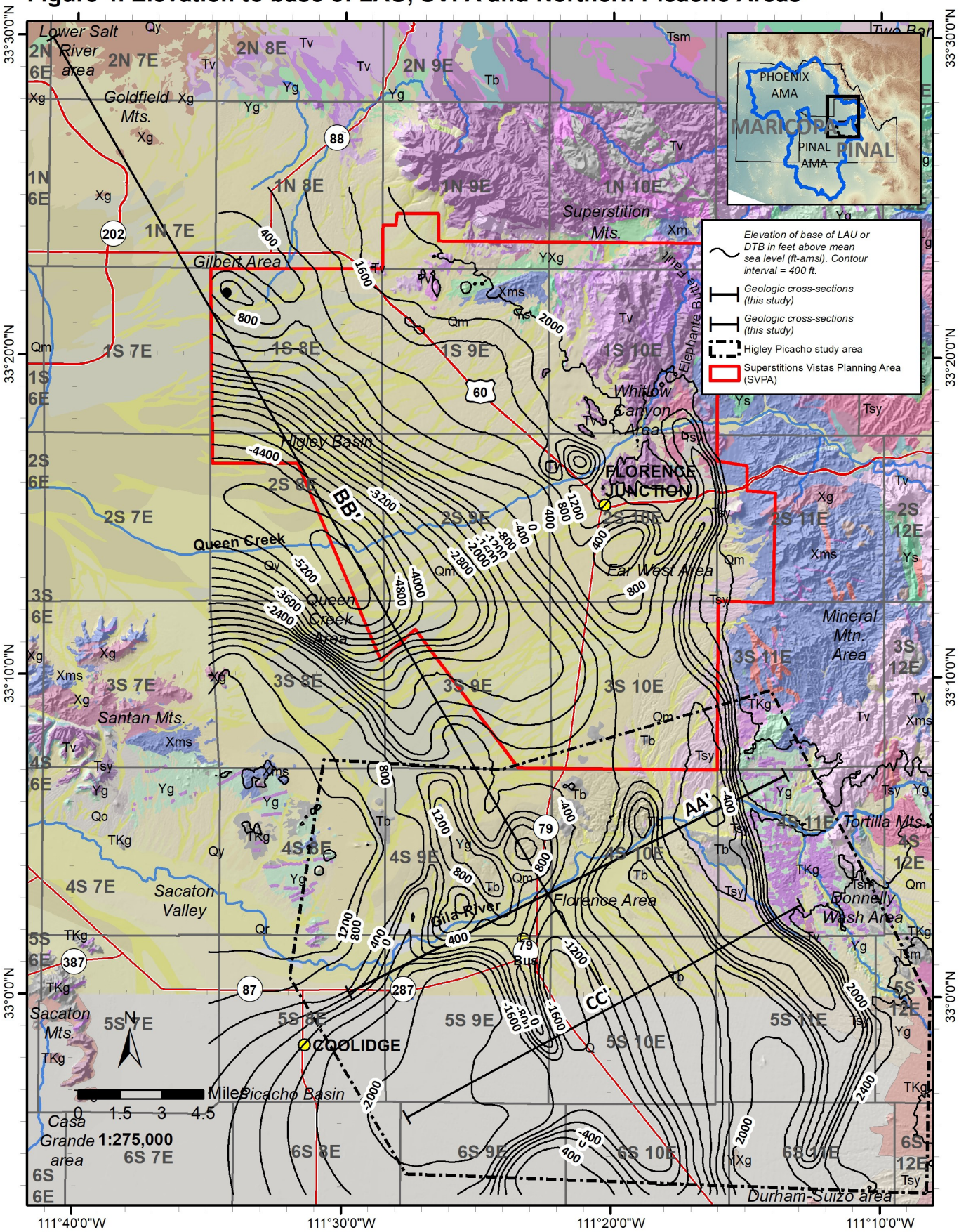

Figure 4. Elevation to base of Lower Alluvial Unit in feet above mean sea level in Superstition Vistas Planning Area (SVPA, Gootee et al., 2017) and Higley-Picacho study area (this study).

deposits may help to identify potential subsurface groundwater flow between the two basins.

The presence or absence of Gila River deposits were identified in a total of about 290 wells in the study area (Figure 7). Gila River deposits were identified and their depth below land surface was labeled certain, queried if uncertain, or "0" if likely not present. Gila River deposits consist of coarse-grained boulder and cobble channel gravel deposits several feet or 10's of feet thick with little or no fine silt or clay; fine-grained (silt, clay and sandy clay) overbank deposits several feet or 10's of feet thick; or a mix of these deposits. Channel and overbank lithologies were commonly reported in more detailed well logs. Variation in lithology made determining a drillers log especially difficult and subject to collective or incremental bias. Other criteria were used as much as possible to determine Gila River from non-Gila River deposits, such as deposits reported as being several hundred feet of clay or silt and sand (likely not Gila River deposits), context to surface geology, adjacent wells, and provenance of grains or clasts. Depth to the base of Gila River deposits below land surface in wells as interpreted in this report ranged from 15 ft to 245 ft, but the transition from Gila to pre-Gila deposits was confirmed in only one well by mineral analysis (Skotnicki, 2018, personal communication). Many wells with Gila River deposits within this depth range have highly variable thickness laterally. Pool et al. (2001), reports thickness of the Gila River deposits are no more than 100 ft and 50 to 70 ft thick in the Florence area. Wells reviewed in this study showed similar thicknesses based on the predominantly coarse-grained boulders, cobbles and sand. Similar deposits, however, were also observed below about 100 ft, although with more diverse lithology (a mix of fine- and coarse-grained deposits). Some detailed wells in the 100 to 200 ft depth range indicated deposits consistent with alternating channel and overbank fluvial-like deposits, but whether those deposits were deposited by Gila River could not be determined. We interpret the wide range in variable thickness to represent a shifting river system during periods of aggradation (building up) of river deposits onto older deposits and erosion into older deposits. Due to the quality of well logs and apparent variable thickness, it was not feasible to confidently construct a thickness-contour map.

Gila River deposits do appear to abruptly overlie surficial and subsurface pre-Gila River geologic units (bedrock and basin-fill units). Basin-fill interpreted to correlate with LAU and MAU both were found in the study area; however, the MAU does not appear to be present east of the town of Florence. East of Florence Gila River deposits appear to rest abruptly on faulted and gently-tilted LAU and may also bury some portion of pre-Gila low-relief topography where the MAU is not present or is not fine-grained. In this area, logs typically record "gravels, boulders, sand" on "cemented gravel, conglomerate, and volcanic rock". Fine-grained deposits below Gila River deposits immediately west of Florence appear to be more characteristic of the active area of deposition during MAU time prior to arrival of the Gila River; typical logs report several hundred feet of clay and silty clay below Gila River-like lithologies. Some alluvial fans may be sourced from eroding LAU deposits during MAU time. The exact boundary between MAU and LAU in the subsurface below Gila River deposits is not well defined, but in general this boundary is inferred from well data and shown in Figure 7. Based on these relationships, saturated Gila River deposits may hydraulically connect Higley and Picacho underflow depending on the gradient of hydraulic head, which was not evaluated in this study.

The subsurface geology in the Florence Copper mine area was evaluated for mineral resource potential and extraction (US EPA, 2013, 2014). Florence Copper Inc. did not focus on Gila River deposits or basin-fill in particular; however, they document Gila River deposits generally shown as uniformly 50 to 80 ft thick "alluvium" on an Upper Basin Fill Unit (UBFU) interbedded with "flat-lying" basalts. We also document these deposits but interpret the Gila River deposits to have much more variability in thickness. We interpret their underlying basin-fill deposits with interbedded basalt (at least in the areas north, east and south of Florence) to correlate with the gently-tilted LAU.

The overall morphology or shape of all Gila River deposits in the study area appears to be about 5 to 7 miles wide. The highest (and probably oldest) deposits are on the north and south flanks of the Gila River (mapped as Qorg, Figure 7). The maximum amount of topographic relief between the highest river deposits (elevation 1,800 ft) and lowest depth in the subsurface (about 1,300 ft elevation) at the same part of the river is about 500 ft. However, the thickest river deposits at any location do not appear to exceed more than 200 to 250 ft in the study area. Gila River gravels south of 33° N in Figure 7 have not been mapped, and while their presence in the subsurface are indicated by well logs, the southernmost extent of these deposits is not well

Figure 5. Geologic cross-sections in Florence and northern Picacho areas, Southeastern Santan Mountains to Mineral Mountain/North Butte area

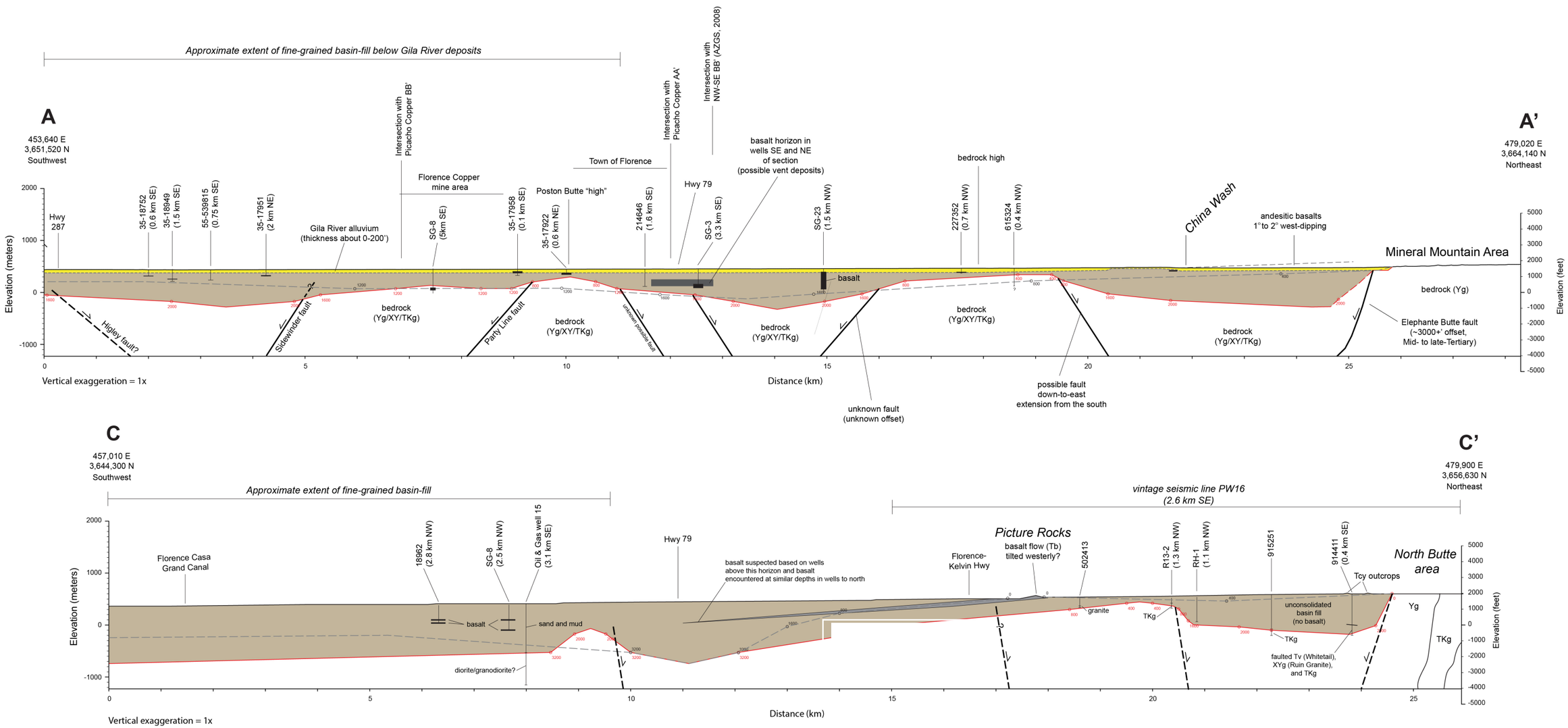

Figure 5. Cross-sections AA' and CC' from Figure 2. Depth to base of Lower Alluvial Unit or hydrogeologic bedrock, and depths in feet from Figure 2 shown as red line with depths in red text. Previous depth-to-bedrock from Richard et al. (2007) shown as dashed gray line. Gila River deposits thickness estimated in general, about 200 ft thick. Pre-Gila fine-grained basin-fill deposits correlating to "Middle Alluvial Unit" not differentiated in sections. Well data in section CC' not sufficient to differentiate syn- and post-Gila tributary deposits, but these tributary deposits graded to ancestral and modern Gila River probably do not extend below maximum thickness of Gila River deposits, about 200 ft depth, in western half of CC'. The eastern half of section CC' probably represented topographic highlands during Gila time.

defined. Likewise, Qorg deposits as far north as the Military target range (section 6, T4S, R10E) may indicate a northern extension into Higley basin, however the presence/absence of Gila River deposits is not clear from existing well log data in the southern Higley basin. Mineral analysis from wells north and south of known Gila River deposits shown in the study area are needed to support or refute possible extensions into the Higley and Casa Grande areas.

Tributaries to Gila River

Many aspects of tributary deposits graded to the Gila River in the Florence area are noteworthy. Tributary deposits within this study area from numerous small unnamed washes, larger drainages like China Wash, and washes north of Ashurst-Hayden dam probably interfinger with Gila River deposits along floodplain margins. Tributaries should also have a record of aggradation and degradation similar to the Gila River as the washes tracked the margins of ancestral river floodplains. Thus, it is possible that this phenomenon could affect hydraulic conductivity of sediment surrounding the juxtaposition of Gila and tributary boundaries. The unnamed tributary watershed draining into the Gila River (northeast portion of T4S, R10E) used to drain into the Higley basin (supported by boring C3a1 [Gootee et al., 2017]). Qorg deposits are sharply cut off by this drainage suggesting Qorg originally covered this area. Following deposition of Qorg, the Gila River began to incise and erode down, resulting in piracy of the west-flowing drainage. The late-Pleistocene Florence terrace is deposited in a post-Qorg pirated drainage which helps define relative ages in the system. Similarly, opposite of the old Qorg deposits, but on the south side of the river, tributaries graded to the ancestral Gila River appear to have been superimposed on Qorg deposits and then cut down, creating the map pattern of isolated Qorg ridges (Figure 7). The modern Gila River clearly controls base level for active tributaries south of the river. However, prior to arrival of the Gila River, tributaries to the south probably drained to a different base level, likely low centers to the west where extensive fine-grained deposits are buried. This hypothesis cannot be tested directly since older tributaries are buried, but hydraulic conductivities in pre-Gila River tributary deposits may have heterogeneity unlike the modern landscape. Mineral facies from tributaries sourced from the north should be rich in detritus from Pinal Schist and volcanic rocks, and sourced from the south and southeast should be rich in granitic minerals.

Longitudinal profile

Gila River deposits appear to be thickest along the main stem of the river and are significantly thicker than Gila River deposits upstream of Ashurst-Hayden dam. Curiously, the oldest Gila River deposits (Qorg) are found at this transition and exhibit the steepest river gradient. A longitudinal profile of the main stem was constructed to assess and determine the maximum thickness of river deposits from well data and their relationship to elevated river terraces, gravel pits, bedrock geology, upstream and downstream constraints, and underlying basin-fill deposits (Figure 8). In addition, clasts were collected from gravel pits, the modern river channel, and river terraces as part of previous and ongoing research by AZGS into evolution of the Gila River. Clast counts represent a percent distribution of clast lithologies which provide clues to changes in source areas (provenance) over time in the Gila River system. Clast counts also help to develop a depositional model for initial integration of the Gila River in the Florence area. One clast count was provided for comparison by Skotnicki (2018, unpublished) from a gravel pit in Gila River deposits at Arizona Ave. The following observations can be made from the longitudinal profile in Figure 8:

1. Gila River deposits are thinner upstream - less than 100 ft thick near Ashurst-Hayden Dam - and thicken downstream.

2. The maximum depth of Gila River deposits (blue well sticks) is approximately 200 feet in the study area and is up to 300 ft west of Sacaton.

3. Ancestral Salt River Deposits (ASRD) (Skotnicki et al., 2016) are within an “envelope” of Gila River deposits assuming little to no deformation of basal Gila River deposits, which suggests the Gila River was present prior to the arrival of the Salt River.

4. Older Gila stream terraces have steeper gradients (0.4-0.5%) than younger terraces and the modern channel (0.15-0.20%).

5. Gila River deposits abruptly overlie thick (typically several hundred feet) fine-grained sand, silt and clay-dominated deposits west of Highway 79 near Florence.

6. Provenance of all Gila River deposits are generally similar along the length of the Middle Gila River, and over time (Qorg to Qy). We interpret this to represent an integration event with the upper Gila River source areas (upstream of Winkelman or San Carlos) that has remained apparently constant over time. Some variation in percent lithology is present, which is discussed more below.

Figure 6. Geologic cross-section BB' Superstition Mountains to Florence, View to Northeast

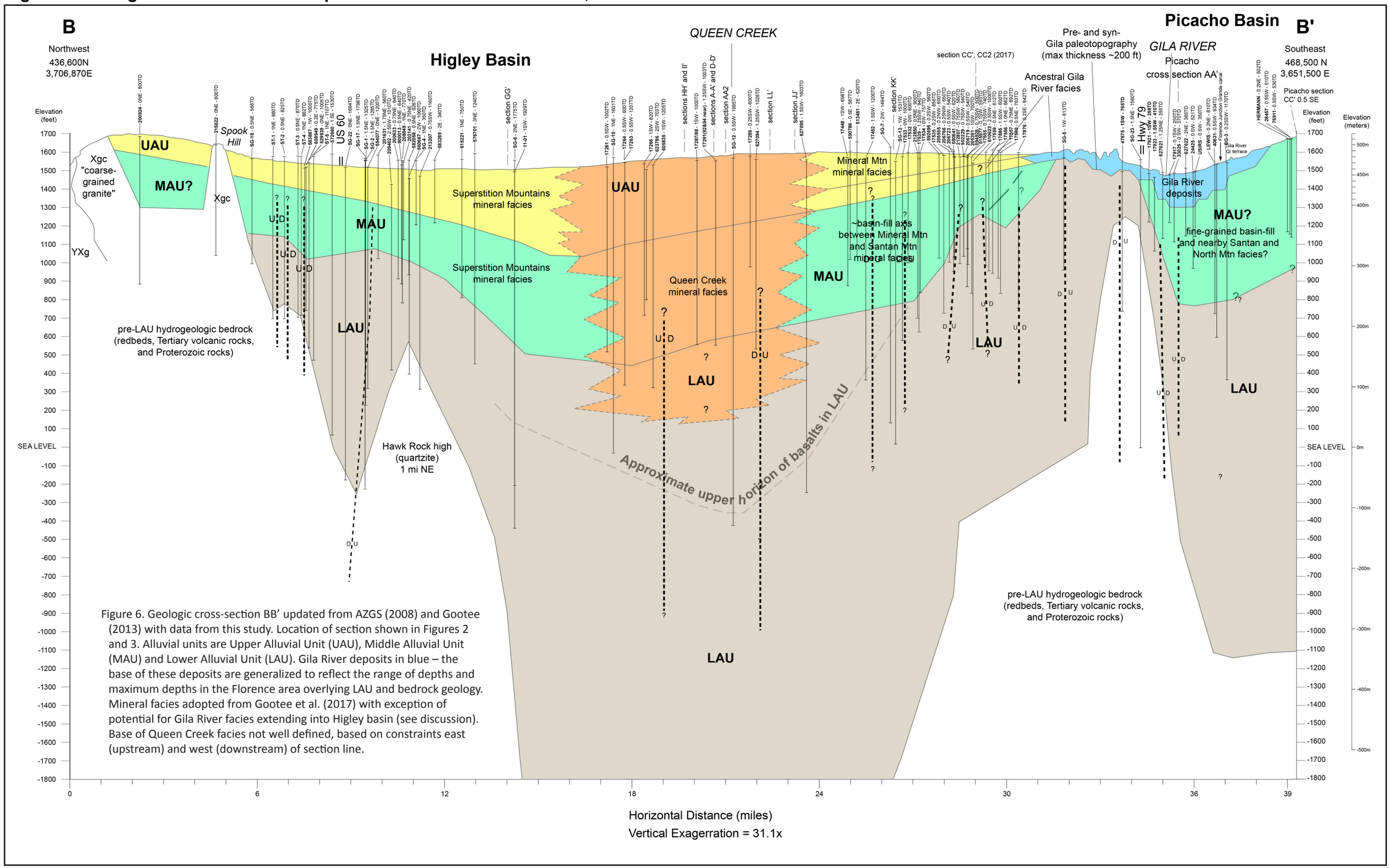

Figure 6. Geologic cross-section BB' updated from AZGS (2008) and Gootee (2013) with data from this study. Location of section shown in Figures 2 and 3. Alluvial units are Upper Alluvial Unit (UAU), Middle Alluvial Unit (MAU) and Lower Alluvial Unit (LAU). Gila River deposits in blue – the base of these deposits are generalized to reflect the range of depths and maximum depths in the Florence area overlying LAU and bedrock geology. Mineral facies adopted from Gootee et al. (2017) with exception of potential for Gila River facies extending into Higley basin (see discussion). Base of Queen Creek facies not well defined, based on constraints east (upstream) and west (downstream) of section line.

Figure 7. Depth to base of Gila River Deposits

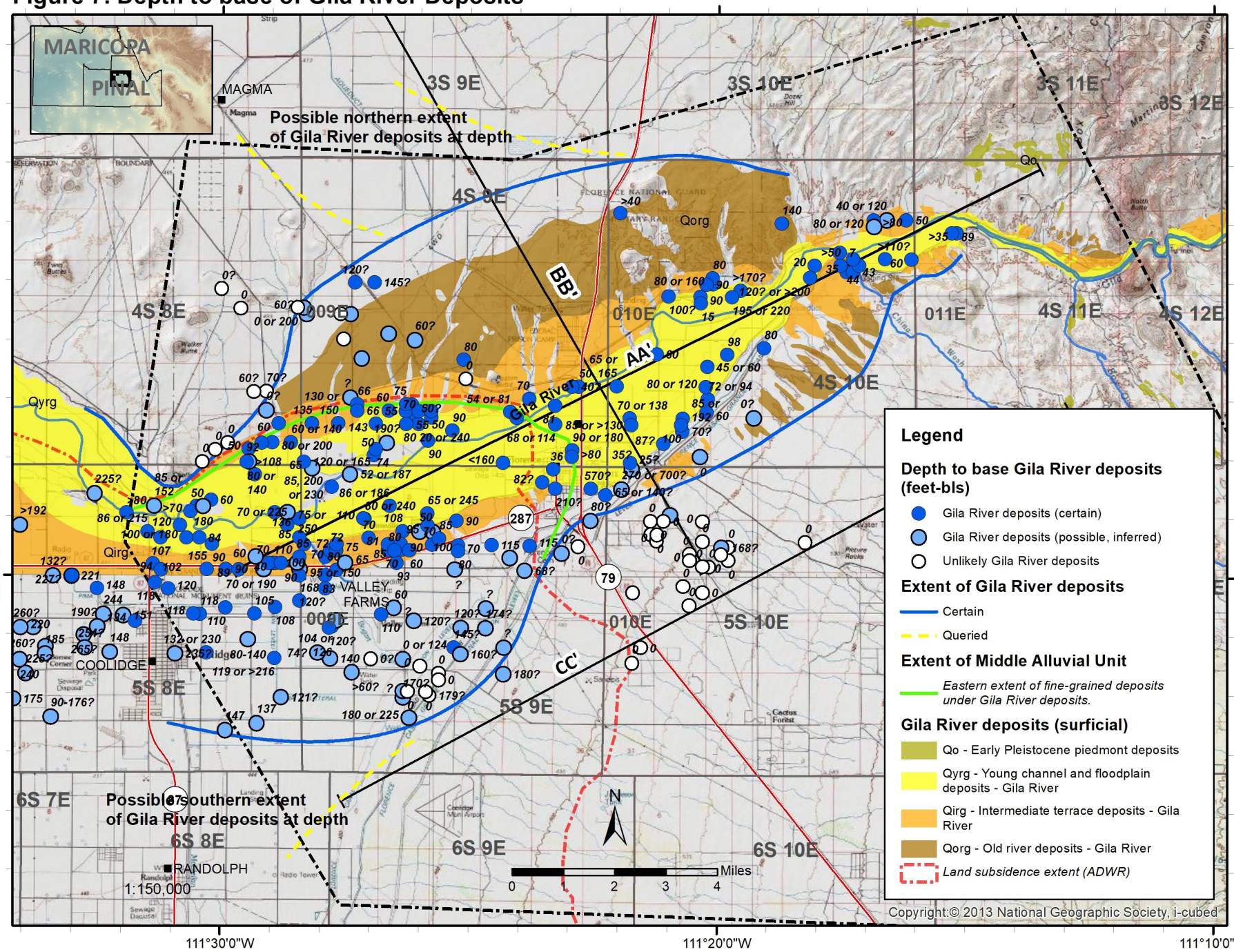

Figure 7. Higley-Picacho study area showing location and depth to base of Gila River deposits. Depths in feet below land surface coincide with mostly well locations and a few surface exposures. Surficial Gila River deposits mapped by Huckleberry (1992, 1993), but unmapped south of 33 degrees North. Solid blue line represents known extent of Gila River deposits at surface and subsurface. Dashed yellow lines represent possible but unknown ancestral pathways of the Gila River.

7. The base of Gila River deposits farther west is determined by a well in Avondale about 6 miles west of the modern confluence of the Gila and Salt Rivers, at 599 ft-elevation. Steve Skotnicki (2018, personal communication) performed mineral analysis of this well and confirmed river deposits he interpreted to represent Gila River gravels. This is consistent with a continuation of the Gila River tread to this location.

8. Preservation of terrace surfaces and gradients lack noticeable tectonic deformation such as uplift or subsidence. However, a subsidence feature is present west of, up to, and slightly east of Florence (ADWR, 2018) (between miles 48 and 68 in Figure 8). It is possible that the oldest Gila River deposits have experienced subsidence since deposition, although the resolution and quality of well data are insufficient to show this.

Gila River integration

Several discoveries and insights during this study have significantly contributed to our present understanding of the relative age, history and evolution of Gila River in the Phoenix area. Based on this study, we hypothesize the following sequence of events in the Florence area involving basin-fill and the Gila River:

1. ~8 to ~3 Ma: Santan and Mineral Mountains were topographic highlands like today, with the lowest depocenters in Higley to the north/northwest, and Picacho to the south/southwest. Several cinder cones and basalt flows erupted east, north and south of Florence between Santan and Mineral Mountains between 8 and 6 Ma, creating a volcanic field of positive topographic relief, flowing towards areas of lower relief. Drainages during this time formed alluvial fans adjacent to mountainous areas and the volcanic area, eroded older deposits and created some additional topographic relief. Faulting along Higley and Elephant Butte also created some topographic relief after or around 6 Ma. Basalt flows and basin-fill deposits were gently tilted, allowing low-lying areas to accumulate additional basin-fill deposits draining to the west into playa flats.

2. ~3 Ma: The Gila River arrived into the Florence area at an elevation of about 1,600 ft-elevation at a steeper gradient than modern deposits, with clasts derived from Dripping Springs Valley area (see Figure 1). These rocks were also mixed with abundant schist we interpret as being derived from basin-fill in the immediate vicinity of Florence area, we informally refer to as the “Florence megafan”. Timing of this event may coincide with spillover from the Safford basin when lacustrine or basin-fill deposition ended around 3 Ma (Jungers and Heimsath, 2016). The Gila River aggraded up to 1800 ft-elevation to create the megafan or “Target terrace” (Huckleberry, 1996). Because Gila River deposits are not deformed by tilting, faulting probably ended before this time.

3. ~3 to 2.5 Ma: An estimated 500 ft of vertical incision through megafan deposits from 1,800 ft-elevation to around 1,300 ft-elevation. The Gila River adjusted (eroded) 65 mi downstream in west Phoenix to an elevation of about 600 ft (a gradient of about 0.2%.). Some terraces upstream of Ashurst-Hayden dam may have tracked this incision.

4. ~2.5 to 0.5 Ma: Arrival of Ancestral Salt River Deposits (ASRD) between South Mountain and Santan Mountains around 2.5 Ma integrated with the Gila River (Skotnicki et al., 2017). Aggradation of ASRD causes Gila River to aggrade over 100 ft thickness up to about 1,060 ft-elevation near Arizona Ave. Around 550 ka, the Salt River integrates across Papago Buttes in Tempe into the Luke basin (Seong et al., 2016).

5. 0.5 Ma to present: Salt and Gila rivers both aggrade, possibly due to the Salt River continuing to aggrade, an additional ~100 ft up to the Salt River’s Mesa terrace (Péwé, 1978), possibly equivalent to the Gila’s Florence terrace (Huckleberry, 1993). More work is needed to support or refute this idea. The Mesa terrace appears to have been abandoned around 90 ka (Larson et al., 2016). Multiple terraces and fill-cut terraces are recorded above and below this terrace horizon but are considered relatively subordinate to the sequence of events described here. The modern Gila River is interpreted to have degraded into older Gila River fill-terrace deposits which may correlate to a horizon seen in multiple gravel pits along the Gila River (Cal Portland, 2018, personal communication).

SUMMARY

A revised DTB contour map was constructed along the boundary between the southeastern Higley basin near Queen Creek, AZ, and the northeastern Picacho basin near the town of Florence, and between the eastern

Santan and western Mineral/North Butte mountains (Figures 1-3). Data used to constrain DTB came primarily from well records used in conjunction with other data types and sources. Two geologic cross-sections were constructed to illustrate DTB contour lines and other geologic relationships mapped in the Florence area (Figure 8). Based on findings and interpretations made in this study, DTB, also referred to as depth to base of Lower Alluvial Unit (LAU), was reconciled and modified in the southern SVPA after Gootee et al. (2017). The compiled DTB for both study areas is shown in Figure 3 and included along with GIS layer data. A third geologic cross-section, northwest-southeast trending cross-section BB', was updated from recent work in the Superstition Vistas area (AZGS, 2008; Gootee, 2012; Gootee et al., 2017) and this study (Figure 6).

In most parts of this study area DTB was increased from Richard et al. (2007). A strong northwest-southeast trend in contours reflects multiple faults and fault zones where basin-fill deposits occupy fault grabens and half-grabens, probably in a fanning-dip sequence. Bedrock nobs and ridges separate the linear troughs. Both west-dipping and east-dipping normal faults were identified, although the spatial and temporal relationships between the two orientations is not well understood and is likely complex.

Basalt flows interbedded with basin-fill apparently are common and widespread in the Florence area. Volcanism is interpreted to have accompanied faulting into a generally low-relief landscape between Mineral Mountains to the east and Santan Mountains to the west, with isolated bedrock nobs and lava-capped mesas, and playa deposition in Higley basin to the north and Picacho basin to the south. Basalt appears to have been emplaced along faults as fissures, erupted as vents and cinder cones, and as flows north toward the town of Queen Creek and south into Picacho basin. The full extent of these volcanic deposits is not known but it is likely that flows occupied and possibly filled and spread out into low-lying areas. Faulting appears to have tilted the youngest basalt flows in multiple orientations; older deposits are inferred to have greater tilts.

Gila River deposits in the Florence area are about 5 to 7 miles wide and range from several 10's of feet thick to as much as 200 to 250 ft thick, found at a maximum elevation of 1,800 ft at the surface and minimum elevation of 1,300 ft in the subsurface. Gila River deposits typically consist of coarse channel gravel (boulders, cobbles, pebbles) and sand, mixed with finer-grained overbank silt and clay. Gila River deposits overlie a mix of older deposits (granite bedrock, coarse-grained basin fill, basaltic volcanic rocks, and fine-grained basin-fill) and preexisting erosional topography over those deposits, which may explain the variation in thickness of river deposits. Tributary deposits draining into ancestral Gila River deposits at depth should also share the same thickness, but this could not be confirmed. The distribution and extent of Gila River deposits indicate that the Gila River arrived in the Florence area with a provenance like today's, which we interpret as an event of top-down spillover river integration between Safford and Picacho basins around 3 Ma. Early integration of the Gila River in the Florence area occurred up to an elevation of 1,800 ft as a megafan, which may suggest the possibility that the Gila River extended for an unknown time and distance into Higley and/or southern Picacho basins, although this could not be confirmed without provenance analysis from well cuttings. Early Gila River appears to have graded to an elevation that coincides with the base of or below Ancestral Salt River Deposits (ASRD) in the Sacaton area, which indicates the Gila River arrived before the Salt River. Since that time Gila River appears to have aggraded up to the Florence terrace which defines much of the known extent of surficial river deposits. Queen Creek may have been graded to the Sacaton area prior to arrival of the Gila, although this relationship is unknown. These relationships between Gila River deposits and underlying deposits, especially basin-fill deposits, may help to delineate groundwater conditions in the Florence area.

RECOMMENDATIONS FOR FURTHER CONSIDERATION

Results from this assessment highlight several aspects of future research to help resolve problems or reduce uncertainties. Problems included correlating basalt flows or provenance of basin-fill deposits. With few rare exceptions, drillers and geologists did not report clast mineralogy or source areas. Conducting clasts counts at the surface of basin-fill exposed along the Gila River, and mineral analysis of drill cuttings would greatly improve the ability to correlate between wells and source areas. Mineral analysis in boreholes would be especially useful above and below basalt flows interbedded with basin fill. Determining the orientation of bedding in basin-fill exposed on the north side of the Gila River will be very helpful for structural control.

Due to the abundance and complexity of faults, any attempt to estimate the amount of offset vertically and laterally will aid in unravelling fault mechanics and history. Previous researchers estimate a significant amount of lateral offset (up to 1,000 meters) along the

Figure 8. Distribution of Middle Gila River deposits between Salt River and Florence

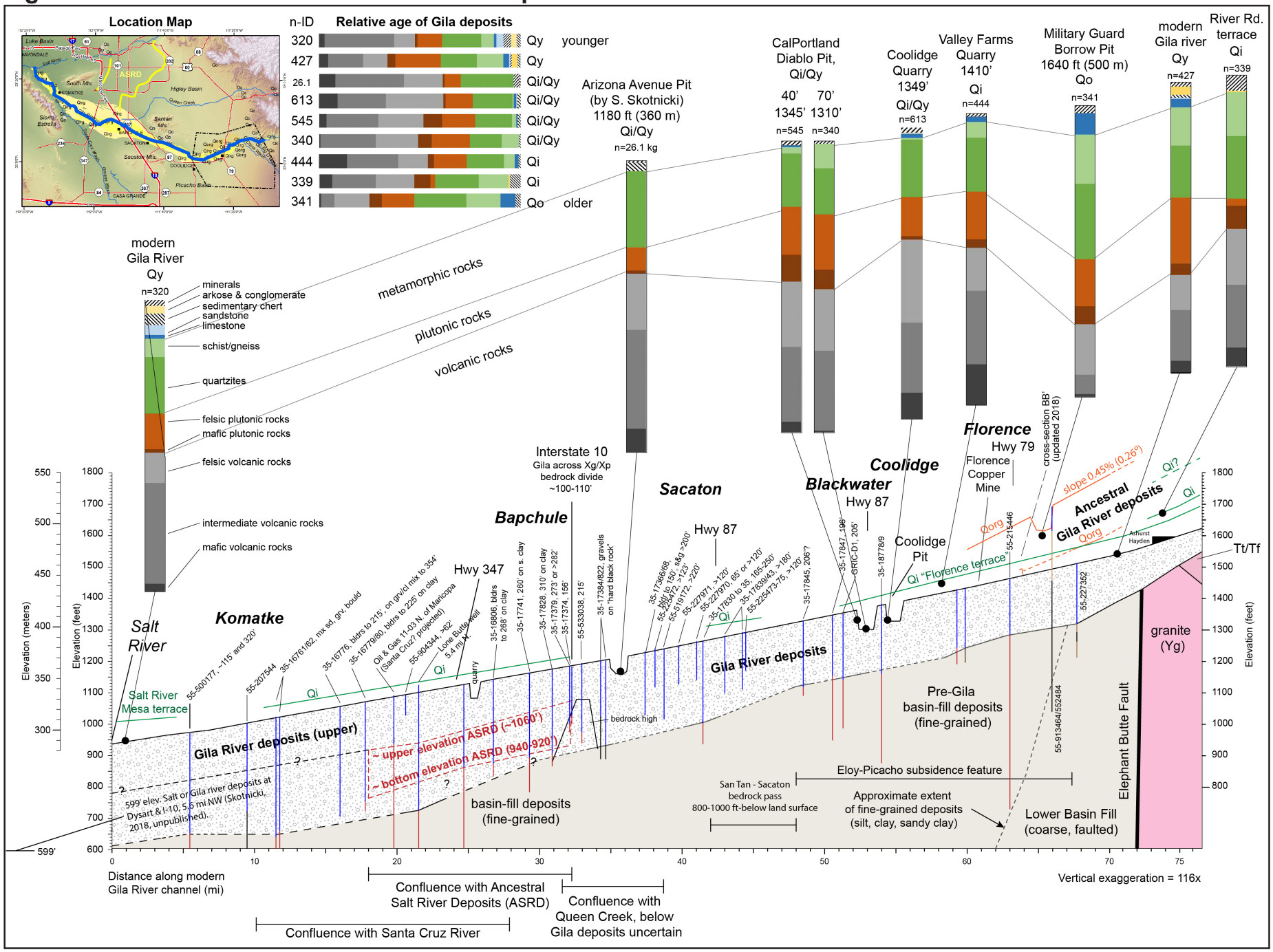

Figure 8. Longitudinal profile of Middle Gila River between confluence with Salt River in Avondale and east of Florence above Ashurst-Hayden dam. Index map of Middle Gila profile (thick blue line), Higley-Picacho study area (black dashed line), Gila River surficial deposits (yellow polygons), and Ancestral Salt River Deposits (ASRD) between yellow lines. Surficial and subsurface Gila River deposits shown along the profile in relation to its tributaries (Salt River, ancestral Salt River, Santa Cruz, and Queen Creek). Pre-Gila basin-fill deposits shown as light brown. Clast count locations shown as black circles.

Elephant Butte fault; additional data to support or refute that would be important.

Provenance analysis from well cuttings north and south of Florence can support or refute the possibility of ancestral Gila River deposits in the subsurface. In addition, the same methods applied to wells along the modern Gila River channel will help to delineate Gila River deposits further. And water chemistry and groundwater isotopic methods can be used to identify connections between Gila River deposits and adjacent basins, which might have implications involving groundwater recharge potential.

ACKNOWLEDGEMENTS

We thank Salt River Project for financial support. Tom Lowry with CalPortland provided access to gravel pits and sample collection for clast counts. Bronco Exploration provided unpublished geologists logs for the eastern portion of the study area. We are especially grateful to Steve Skotnicki for unpublished mineral and lithologic analysis from selected wells and gravel pits, and for productive discussion of geology in the region. Discussions of regional geology and river integration was extremely valuable thanks to Ron Dorn (Arizona State University), Phil Pearthree and Ann Youberg (AZGS), Jersy DePonty (SRP), and John Douglass (Paradise Valley Community College), Phillip Larson (Minnesota State University) and Yeong Seong (Korean Institute of Science and Technology).

GIS DATA

Layer files for DTB contours, wells used for DTB, faults, and cross-sections. Metadata are included in some layered shapefiles and well data.

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