Geologic Evaluation of the Tucson Basin for Carbon Dioxide Sequestration Potential

Brian F. Gootee
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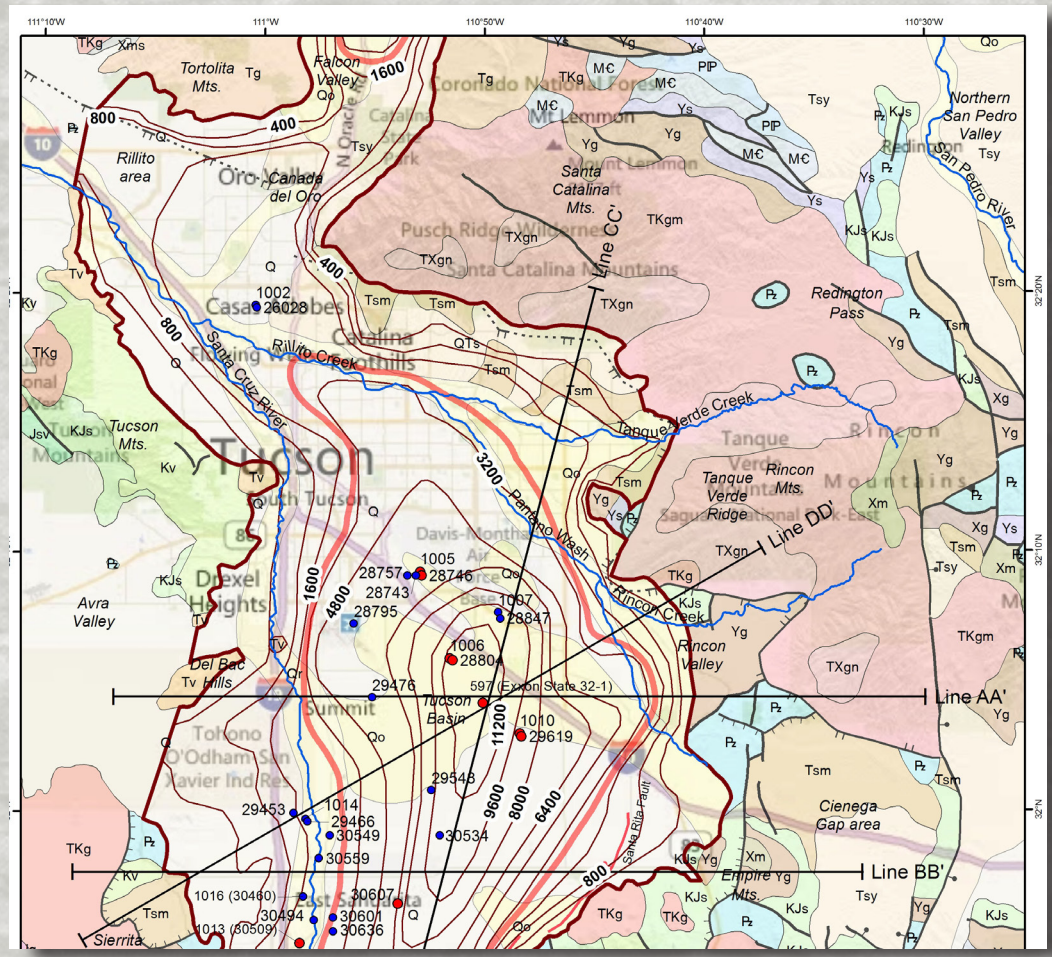

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by

Brian F. Gootee

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1.0 Introduction

The Department of Energy (DOE), including its National Energy Technology Laboratory and West Coast Regional Carbon Sequestration Partnership (WESTCARB), have established national programs to evaluate the technical feasibility of long-term subsurface geologic storage of carbon dioxide (CO_2) produced by industrial activity. The WESTCARB is a consortium of seven western U.S. States and one Canadian Province that is one of seven regional North American partnerships established to evaluate technical aspects of high-volume CO_2 capture and sequestration. Collaborative WESTCARB research programs have included more than 90 public agencies, private companies, and non-profit organizations. The Arizona Geological Survey (AZGS) began work in 2010 on *WESTCARB Phase III – Arizona Geological Characterization* (California Energy Commission Agreement Number 500-10-024).

As part of *WESTCARB Phase III*, the AZGS is evaluating the potential for CO_2 sequestration in geologic formations that are below a level of 800 meters (m) (2,625 feet (ft)) depth below land surface (bls). This evaluation is directed at porous and permeable geologic formations with impermeable sealing strata in Cenozoic sedimentary basins in the Basin and Range Province, and Paleozoic sedimentary formations of the Colorado Plateau. An initial screening of Cenozoic sedimentary basins with significant depth and volume below the 800 m (2,625 ft) bls level resulted in 10 candidate basins from a total of 88 basins (Spencer, 2011). This report represents ongoing WESTCARB assessment of CO_2 storage potential in the Tucson basin, one of 10 Cenozoic basins in Arizona identified during the preliminary evaluation, and is part of Tasks 2 and 3 of Arizona WESTCARB Phase III. Task 2 consists primarily of characterizing basin structure, stratigraphy, lithology, and the nature of seals or a cap rock. This task also includes determining the storage capacity of permeable sediments below 800 m (2,625 ft) depth (Spencer, 2011). Task 3 is to determine if, and at what depth, saline groundwater approaches 10,000 milligrams per liter (mg/L) of total dissolved solids (TDS), characterized in a separate salinity study (Gootee et al., 2012). This concentration represents the threshold above which water is considered non-potable and unsuitable as drinking water (United States Environmental Protection Agency 1991). Based on the extent of permeable strata underlying impermeable strata, saturated with saline groundwater above 10,000 mg/L, the CO_2 storage volume below 800 m (2,625 ft) can be revised from earlier estimates (Spencer, 2011).

The Tucson basin is a north-south trending Cenozoic basin within the southern Basin and Range Province of Arizona. The Tucson basin is part of the Tucson Active Management Area (AMA), also referred to as the Upper Santa Cruz subbasin by Arizona Department of Water Resources (ADWR). The Tucson basin includes several subbasins totaling 3,303 square kilometers (km^2) (1,275 mi^2). The largest and deepest subbasin is referred to as the Tucson subbasin and represents the majority of basin-sediment volume below the 800-m target depth, and underlies the Tucson metropolitan area (Plate 1). The area of the Tucson subbasin occupied by basin-fill sediments below 800 m (2,625 ft) is approximately 780 km^2 (300 mi^2), or 24 % of the greater Tucson basin. The Tucson subbasin has a maximum basin depth of 3,658 m (12,001 ft), which represents a structural basin with a thick assemblage of Tertiary and Cretaceous sedimentary and igneous strata. A thick accumulation of early-Miocene and younger basin-fill sediments represent the primary basin-filling units in the Tucson subbasin.

2.0 Approach and Methods

The DOE National Energy Technology Laboratory and Regional Carbon Sequestration Partnerships have developed methodologies for characterizing CO_2 sequestration potential in sedimentary basins, especially where pore space is occupied by saline groundwater (>10,000 ppm TDS) (DOE, 2010). In this report we analyze and interpret collected data that meet basic criteria for characterizing the potential for carbon dioxide capture and storage (CCS) in the Tucson basin. Although basalt is being considered for future opportunities in CCS, and may be present at depth in the Tucson basin, basalt is not the focus of this characterization. Furthermore, no attempt was made to consider the population or infrastructure of the Tucson metropolitan area as part of this assessment.

Collection, compilation and quality assurance/quality control of well-log databases and relevant water-quality data were a major effort in this assessment. In addition, numerous published and unpublished previous works were screened for applicability, acquired, scanned to PDF and georeferenced into ArcMap project files. These data sets were used to modify the existing depth-to-bedrock contours and build two- and three-dimensional datasets for constructing geologic cross-sections and three-dimensional geologic models. Subsurface geologic data were incorporated into cross-sections, which aided in analysis of basin stratigraphy at target depths below 800 m (2,625 ft) bls. Additional methodology is included in a previous report on the Safford basin, the first basin evaluated for the WESTCARB Phase III project (Gootee, 2012).

3.0 Subsurface Data

Well Data

Of the approximately 7,000 wells in the greater Tucson basin, a total of 36 deep wells were used in this evaluation (Appendix A). A well depth greater than 518 m (1,700 ft) bls was chosen as initial screening criteria. Wells were also screened for the presence of halite, gypsum, and volcanic rocks noted in drillers logs which resulted in two additional wells included in the initial screening. A total of 24 ADWR wells-35 and 12 Arizona Oil and Gas (OG) wells were used in this study and are listed in Appendix A. Borehole-log lithology and stratigraphy were reviewed and assigned hydrogeologic-unit IDs for inclusion in the Aquaveo toolset used to create cross-sections. Log information and assigned units are listed in Appendix B.

During the Tucson basin research, ADWR supplied the AZGS with a database of wells with borehole stratigraphic formation top and bottom elevation picks, compiled from ADWR well records and USGS stratigraphic test hole logs (Strat-logs). These formation picks were based on nomenclature from Anderson (1987) and were used in the Tucson AMA groundwater flow model (Mason and Bota, 2006), updated in 2012 (ADWR, unpublished, 2012). ADWR also used these data to modify depth-to-bedrock contours from Richard et al. (2007), discussed further below. Work by Houser et al. (2004) established a more thorough assessment and baseline for distinguishing geologic units based on multiple log data, including age and density constraints which resulted in reclassifying basin-fill stratigraphy from Davidson (1973) and Anderson (1987). The ADWR and USGS Strat-log formation picks are considered to be superseded by Houser et al. (2004) in this study. Nonetheless, stratigraphic picks from the ADWR-USGS data were helpful and are included in the comments field in Appendix B.

Depth-to-Bedrock

Depth-to-bedrock contours in the Tucson basin were modified from Richard et al. (2007) and ADWR (unpublished, 2012), which in turn was based largely on gravity data reported and modeled by Oppenheimer and Sumner (1981). Calculated depth to bedrock is based on estimated sediment

densities, and on the assumption that density increases abruptly at the base of middle to upper Cenozoic strata, with greater density for underlying bedrock that largely lacks porosity and permeability. The abrupt downward transition from basin filling sediments to bedrock is an aspect of Basin and Range geology that is not characteristic of many other basins in the United States. It results from the fact that, at the end of the Laramide orogeny (at about 55 Ma), what is now the Basin and Range province was a mountain range, with erosional incision and removal of exposed rock and exhumation of deeper igneous and metamorphic rocks (Spencer and Reynolds, 1989). When Basin and Range extension began at about 25-30 Ma (Dickinson, 1991; Spencer et al., 1995), rocks that subsided to form the structural base of extensional basins were largely igneous and metamorphic rocks. A primary geologic impediment to accurate modeling of basin depth is the presence of high density basaltic volcanic rocks within basin-filling sedimentary sequences. Furthermore, buried, moderate-density felsic volcanic rocks may be modeled as basin-filling sedimentary strata, but in fact have little permeability or porosity and should be considered as bedrock. As a result of these factors, depth to bedrock calculations based entirely on gravity should be considered as approximations, with greater uncertainty for greater calculated basin depths.

Rystrom (2003) modeled depth-to-bedrock to the base of the intermediate-density, Oligo-Miocene Pantano Formation from gravity data, but the gravity data did not provide basin-wide coverage for the Tucson basin. Both Richard et al. (2007) and Rystrom (2003) determined depths based on differing scenarios, which are compared in cross-section AA'. Because the map for the base of the Pantano Formation defining the sedimentary basin for Tucson is incomplete, CO_2 storage estimates for the Tucson basin by Spencer (2011) represent a volume estimate within the structural basin which may or may not include Pantano Formation strata. The storage estimates are not revised in this evaluation. Also, although well 579 was thought to have bottomed in granite, U-Pb geochronologic analysis of individual zircon grains from well cuttings that had been identified as the basal granite revealed a diverse set of U-Pb dates characteristic of middle Tertiary sedimentary rocks rather than granite (Jon Spencer, written communication, 2012). Furthermore, it is not entirely clear that overlying strata identified as Cretaceous Bisbee Group are not in fact Tertiary sedimentary rocks (Jon Spencer, written communication, 2012).

The 122 m (400 ft) and 244 m (800 ft) depth-to-bedrock contours in the greater Tucson area were modified by ADWR based on recent well data, and were adopted for use in this study. ADWR considered the poorly defined base of the Pantano Formation to represent the top of bedrock, and excluded depth-to-bedrock determinations below 975 m (3,200 ft) bls for modeling groundwater in the Tucson AMA study. Based on an assessment of data from a cluster of deep wells used in this study, AZGS made minor modifications to the 488 m (1,600 ft), 975 m (3,200 ft) and 1,463 m (4,800 ft) depth-to-bedrock contours from Richard et al. (2007) that were believed to represent the base of the Pantano Formation. These contours were moved closer to the mountain front west of the Twin Buttes area, near the towns of Sahuarita and Green Valley, which resulted in a slight increase in depth-to-bedrock. Contours below 1,463 m (4,800 ft) were not modified from Richard et al. (2007), and are considered to largely represent pre-Miocene volcanic and sedimentary rocks contained within the structural trough of the Tucson basin.

Multiple seismic-reflection lines transect the Tucson basin and are the basis of stratigraphic and structural interpretations (Eberly and Stanley, 1978; Johnson and Loy, 1992; Wagner and Johnson, 2006). It was difficult to reconcile differences in depths to stratigraphic horizons between gravity and seismic models. The greatest difference between the gravity and seismic models results was related to areas beyond seismic lines along the basin margin; however, lithological data from relatively shallow wells along the basin margin have been used to define the base of the Pantano Formation (ADWR, unpublished, 2012). A combination of these data were used to help construct the cross-sections.

The Tertiary sedimentary basin-fill unit mapped as Tsm (Plate 1) were correlated basin-fill units observed in some wells along the basin margin. Exposures of basin-fill units mapped by Pearthree et al. (1988) and Dickinson (1999) within the Tucson basin were also added to the cross-sections.

4.0 Geologic Characterization

Geologic Setting

The Tucson basin lies within the highly extended Basin and Range tectonic and physiographic Province. The Tucson basin is bound by the Santa Catalina, Rincon Mountains, Empire and Santa Rita Mountains to the north, east and southeast, respectively (Plate 1). The Tucson and Sierrita Mountains border the western half of the Tucson basin. The Catalina core complex makes up the Santa Catalina and Rincon Mountains, an assemblage of various pre-Tertiary rocks. The Catalina core complex initially developed during mid-Tertiary (Oligocene to early Miocene) extension along a low-angle fault referred to as the Catalina Detachment Fault, separating rock assemblages into an upper-plate hanging wall and lower-plate footwall (Spencer and Reynolds, 1989). During extension associated with movement along the Catalina Detachment Fault between 28 and 20 Ma (Dickinson, 1991), interbedded volcanic and sedimentary deposits accumulated in an actively subsiding basin that is approximately coincident with the present extent of the Tucson basin. The earlier sequence of interbedded volcanic and sedimentary rocks are mapped locally as Tv, followed by a sequence of sedimentary rocks referred to as the Pantano Formation (unit Tp) (Plate 1). Voluminous and widespread mid-Tertiary volcanism occurred during the initial extension and basin-formation in the region, thus, Tertiary volcanic and sedimentary rocks (unit Tv) are considered to be the oldest proto-basin-filling rocks (Wagner and Johnson, 2006). However, the associated Tertiary Pantano Formation is considered to represent the base of an initial sedimentary basin in which sedimentary deposits accumulated in the Tucson subbasin. Thus, in addition to the younger basin-fill units, the Pantano Formation is also considered in this evaluation. This is consistent with the fact that, in the Cienega Gap area east of the Tucson Basin, the Pantano Formation is well exposed and consists primarily of clastic sedimentary rocks (Dickinson, 1991, Figure 55).

Following mid-Tertiary extension and initial development of the Tucson basin, renewed extension during the late Miocene caused uplift of mid- and pre-Tertiary rocks in the area of the Catalina core, and subsidence of the Tucson basin (Davis et al., 2004). This period of extension is referred to as the Basin and Range disturbance. Portions of mid-Tertiary basin-fill units (Tv and Tp) eroded from the uplifted Catalina core area and accumulated in the adjacent Sonoita basin to the east, and Tucson basin to the west. This period of extension, uplift and subsidence is considered to represent initial deposition of the Lower Basin Fill (LBF) (Wagner and Johnson, 2006). Seismic reflection profiles and well log data indicate that deposition of the LBF was accompanied by uplift and subsidence associated with Basin and Range faulting, marked by numerous intra-basin unconformities and faults (Wagner and Johnson, 2006; Houser et al., 2004). High-angle normal faulting associated with the Basin and Range extension commenced approximately 13 Ma and continued until approximately 5 Ma (Pearthree and Calvo, 1987; Menges and Pearthree, 1989; Houser et al., 2004).

Following deposition of the LBF, periodic uplift along the eastern basin margin exposed portions of older basin-fill strata. Sediment eroded from basin margins accumulated toward basin centers, which represented initial deposition of the Upper Basin Fill (UBF). Deposition continued from the latest Miocene (?) to early Pleistocene during a relatively quiescent tectonic period, where sediments in the UBF overlapped onto older basin-fill strata.

Structure

The Tucson basin is largely controlled by geologic structures, primarily faults and fault-related structures closely related to its complex tectonic history. The Tucson basin and its bordering subbasins are separated by bedrock saddles or ridges seen in modeled gravity (Plate 1). The basin trough and intervening saddles are interpreted to correspond to synform and antiform "grooves", respectively, formed along the inferred direction of transport in the Catalina detachment fault (Houser et al., 2004, Fig. 3).

The shape of the Tucson basin is largely asymmetric, with basin-fill units tilted gently towards the main range-bounding structures north, east, and southeast of the Tucson basin (see cross-sections AA', BB' and DD' in Plates 1 and 2). Portions of the Catalina detachment fault are exposed along the Catalina and Rincon mountain fronts adjacent to the Tucson basin. The Catalina detachment fault is eroded along the basin margin, adjacent to basin-fill sediments; however, the Catalina detachment fault projects underneath basin-fill sedimentary and volcanic rocks (Plates 2 and 3) (Johnson and Loy, 1992; Wagner and Johnson, 2006). Miocene-age extensional faults such as the fault at the foot of the northern Santa Rita Mountains (Pearthree and Calvo, 1987) appear to have merged with the master Catalina Detachment Fault in a listric fashion, and in some places cross-cut the Catalina Detachment Fault (Davis et al., 2004). Multiple lines of evidence point to syn-extensional deposition of sediments in the hanging wall along Miocene normal faults in the eastern Tucson basin, whereby sediments were progressively tilted against the fault plane (Wagner and Johnson, 2006; Johnson and Loy, 1992; Dickinson, 1991). Deformation in the upper plate, subsequently, was likely restricted to the Miocene LBF and underlying Pantano Formation. Deformation in these two sedimentary sequences consists of faults, tilted bedding and gentle folds (Davis et al., 2004). Numerous synthetic and antithetic faults are inferred to merge downward into the master detachment fault (Dickinson, 1991). Basin-fill strata in the hanging wall tilts toward the detachment fault, and the strike of bedding perpendicular to the inferred direction of transport along the detachment fault. Analysis of OG well 597 by Houser et al. (2004) identify numerous high-angle faults in the LBF, some with little displacement and other with much larger displacement. Bedding in the LBF is commonly tilted as much as 10 to 15 degrees in outcrop, and likely greater near faults in the subsurface. Likewise, the Pantano Formation is complexly tilted along basin margins, and is inferred to dip as much as 30 degrees in the subsurface, especially near faults.

The Pliocene UBF is generally flat-lying to nearly flat-lying and has few faults with little displacement. Known faults in the UBF are poorly constrained by well log data alone and appear to be limited to basin margins as evidenced by seismic reflection data (Johnson and Loy, 1992; Houser et al., 2004; Wagner and Johnson, 2006). Gently folded strata visible in seismic lines are inferred to possibly represent doming from mobile salt deposits in the lower part of the UBF (Wagner and Johnson, 2006); however, no salt has been reported in well logs in the Tucson basin.

Quaternary fault scarps border the eastern piedmont of the Tucson and Upper Santa Cruz basins (Drewes, 1977) (Plate 1). The Santa Rita Fault is a low angle normal fault, capable of generating an earthquake magnitude between 6.7 and 7.6 (Pearthree and Calvo, 1987; Johnson and Loy, 1992). The Santa Rita Fault dips approximately 19 degrees (true dip) to the northwest in the vicinity of section BB'. The Santa Rita Fault is interpreted to lie in the upper plate of the Catalina Detachment Fault. Whether the Santa Rita Fault cuts or merges with the Catalina Detachment Fault is unknown (Johnson and Loy, 1992).

Stratigraphy

Stratigraphy of basin-fill units in the Tucson basin dating from Oligo-Miocene through early Pleistocene, has been difficult to classify due to lack of age constraints, few high-quality well records, and difficulty correlating surface outcrops to stratigraphy in the subsurface. Nomenclature used to

constrain basin-fill strata in outcrop and the subsurface has improved since work by Pashley (1966), and continues to be refined based on field relations (Dickinson, 1999) and additional well analysis by Houser et al. (2004).

The most comprehensive record of basin-fill stratigraphy in the Tucson basin is represented in OG well 597 (Exxon State 32-1) drilled into the deep basin trough (see Plates). This study adopts nomenclature used by Houser and others (2004) to differentiate basin-fill units above the Pantano Formation and is considered to supersede nomenclature used by Davidson (1973) and Anderson (1987). The upper and lower basin fills and the underlying Pantano Formation are the primary basin-filling units in the Tucson basin, with the LBF and Pantano Formation representing the two primary basin-fill units near and below the 800-m depth.

Upper Basin Fill

The UBF is interpreted to represent the final stage of basin-filling in the Tucson basin, and is thought to pre-date integration of the Santa Cruz River (Davidson, 1973; Anderson, 1987; Dickinson, 1991). The UBF was deposited in a closed basin during a generally tectonically quiescent period during Pliocene to early (?) Pleistocene (~ 6 to 2 Ma). The UBF is widely exposed throughout the Tucson basin, where its original depositional surfaces are truncated and capped by overlying Quaternary deposits of variable thickness and age (Pearthree et al., 1988).

Thickness of the UBF ranges from less than 100 m (330 ft) along basin margins to as much as 1,250 m (4,100 ft) near the basin center, and averages between 500 and 700 m (1,640 and 2,300 ft) between basin margins (Plates 2 and 3). The UBF gradually thins towards basin margins, where it can be seen to truncate underlying facies within both basin-fill units (Wagner and Johnson, 2006). Facies thicken basinward and generally decrease in grain size into very fine sand and silt along distal fan toes and playa margins.

Bedding in the UBF is laterally continuous, flat-lying or nearly so, with few faults of relatively little displacement. Sediment generally consists of unconsolidated to weakly consolidated gravel, sand, silt, and clay mixed with gypsum and anhydrite (Houser et al, 2004), representing alluvial fan deposits along basin margins grading basinward into fine-grained and evaporite playa deposits near the basin center. Lacustrine deposits are relatively uncommon in well logs and do not appear to be laterally continuous between wells.

This UBF is composed mainly of detritus from weathered granitoid terrains, although volcanic and sedimentary clasts make up a minor portion. Minerals common consist of abraded quartz sand with mica and feldspar. Playa and playa-margin deposits vary laterally and vertically within the UBF as indicated in driller logs and seismic-reflection facies. Evaporite deposits are generally disseminated with fine-grained clastic deposits, generally present in the UBF between ~ 500 and 1,000 m (1,640 and 3,280 ft) depth. Selenite gypsum stringers and nodular anhydrite interspersed with mudstone and fine siltstone are also reported in logs (e.g., 35-29476 and OG well 10-06). Geophysical logs indicate that connate saline groundwater is associated with playa deposits (Houser et al., 2004). The presence of evaporite deposits is also suggested by deformation of overlying sediment near the middle portion of the UBF, seen in seismic-reflection profile near the eastern portion of seismic line D2 (cross-section AA' in Plate 2), and is hypothesized to be a result of upward-migrating salt deposits or domes. Late-Miocene salt and dome structures are reported in the Luke Basin and other basins in Arizona (Eberly and Stanley, 1978).

The UBF is interpreted to rest unconformably on the LBF. The contact between the two units is interpreted to represent a significant period of non-deposition associated with an increase in compaction, cementation, and bulk density (Houser et al., 2004). The contact between the upper and

lower basin fills is not well constrained basin wide, and is difficult to discern in well log data; however, the contact may correlate with a reflector seen in seismic lines (between facies MP4 and MP5 in Wagner and Johnson, 2006). The contact in OG well 597 is represented by a down-hole increase in bulk density, decrease in sonic transit time, and decrease in conductivity (see logs depicted in cross-section AA' in Plate 2).

Lower Basin Fill

The LBF is similar in extent and thickness to the UBF, and was also deposited under similar depositional settings. However, the LBF was deposited prior to and during active Basin and Range extension between approximately 13 and 6 Ma (Houser et al., 2004; Dickinson, 1999). The LBF is more consolidated and more deformed than the UBF. Thickness of the LBF averages approximately 900 to 1,100 m (2,950 to 3,600 ft) across the basin, thinning abruptly near faults and fault blocks, and to less than 100 m (330 m) near outcrops along basin margins. Over the structurally low part of the basin, depths to the LBF range from 700 to 900 m (2,300 to 2,950 ft) bls. South of the Tucson basin, the LBF is considered to be the equivalent to the Nogales Formation (Gettings and Houser, 1997). The Pantano Formation and overlying lower basin-fill deposits are an important aquifer, particularly in areas where these formations are near the surface along upthrown blocks (Mason and Bota, 2006).

The LBF generally consists of moderately well-indurated calcareous sandstone, mudstone, siltstone, and clay with some conglomerate. Because few wells were drilled to depths that penetrated the LBF, the most detailed stratigraphy for this unit is described in deep OG well 597 (Houser et al., 2004). Houser et al. (2004) subdivided the LBF into two units (C and D) in OG well 597. Unit C is approximately 260 m (850 ft) thick and consists of fine sandstone and siltstone interpreted to be a fluvial deposit. Sand and conglomerate is micaceous with fragments of moderately-rounded grains from granitoid sources, with minor volcanic and limestone, similar to the UBF. Mineral grains consist of quartz, feldspar, muscovite, biotite, chlorite and magnetite. Small amounts of gypsum and anhydrite are present throughout. Bedding in the upper part of the LBF appears to vary considerably, interpreted to represent a sandy braidplain. An 18-m (60-ft) thick conglomerate zone (~1,150 to 1,170 m (3,770 to 3,840 ft) depth bls) at the base of Unit C suggest a significant unconformity exists with the underlying Unit D. Unit D is approximately 700 m (2,300 ft) thick, and consists of calcareous mud, siltstone, sandstone, and conglomerate. This unit is poorly to moderately indurated with similar lithic clast components to the upper basin-fill deposits. Deposits in Unit D are inferred to represent a medial to distal fan. Geophysical logs indicate a high degree of variability in bedding and consolidation, probably attributed to by differences between unconsolidated calcareous mud interbedded with moderately consolidated siltstone, sandstone and conglomerate beds (Houser et al., 2004).

The LBF exhibits numerous facies changes, unconformities, faults and tilted bedding, especially near faults in the subsurface (Houser et al., 2004; Wagner and Johnson, 2006). Unconformities in the LBF are indicated by abrupt truncations of seismic facies, indicating that periods of subsidence and uplift have altered depositional patterns locally within the basin. Numerous faults with variable displacements are seen in seismic, and indicated by wash-out zones in geophysical logs, interpreted to be lined with soft, clay gouge, although some faults appear to be recemented (Houser et al., 2004; Wagner and Johnson, 2006).

Exposed along basin margins, the LBF is gradational to paraconformable with the underlying Pantano Formation. In the subsurface, the LBF is often seen to truncate tilted Pantano Formation, representing a considerable hiatus in deposition. The main difference between the two units is the presence of abundant volcanic fragments in the Pantano Formation, whereas, the LBF has relatively minor volcanic detritus.

Pantano Formation

The mid-Tertiary Pantano Formation is a thick sedimentary sequence that accumulated in actively subsiding proto-basins in the vicinity of the Tucson basin. The Pantano Formation is exposed along the east and north basin margins, and in wells within the Tucson basin, and represents similar depositional environments: alluvial fans, playas, rock avalanches, and interbedded volcanic flows. This formation is generally tilted and truncated by the overlying LBF, thus its true thickness is unknown and varies from less than 100 m (330 ft) along basin margins to several hundred meters near the basin center (see cross-sections AA' through DD').

The Pantano Formation is uniformly well consolidated and cemented; however, it is also considered an aquifer along basin margins (Mason and Bota, 2006). Driller logs report harder drilling in indurated sediments, typically dark red, gray and purple conglomerate cemented with clay. Mudstone and fine sandstone are commonly interbedded with conglomerate. Intervals of gypsiferous and calcareous mudstone are also present, representing playa deposits. Conglomerate clasts are generally angular and poorly sorted, consisting of various granitoid rocks, intermediate-composition volcanics and rare limestone.

The Pantano Formation rests unconformably on a thick sequence of middle-Tertiary interbedded volcanic and volcaniclastic rocks, exposed on the western margin of the Tucson basin, and in OG well 597. This assemblage of volcanic rocks may be more widespread and underrepresented within the structural basin, but are not evaluated in this study. However, it is worth noting the relative thickness of lithology penetrated by OG well 597, that consists of 540-m (1,770-ft) thick sequence of diverse rocks such as mafic dikes, intermediate- and felsic-composition flows, conglomerate, and limestone conglomerate. These rocks are discussed further in detail by Houser et al. (2004).

Sealing Conditions

No obvious impermeable bodies or extensive sealing conditions appear to be present near or below 800 m (2,625 ft) depth in the Tucson basin. The UBF is unconfined in general, but semi-confined conditions are present in the upper and middle portions of the UBF (Mason and Bota, 2006). It is conceivable that gypsiferous sediment in the lower portion of the UBF represents confining and relatively impermeable conditions, but these deposits do not appear to represent an impermeable seal, and are discontinuous vertically and laterally within the basin. Similarly, clay is present in the upper and lower basin fill, but is generally mixed with clastic sand and gravel without well-defined boundaries vertically or laterally. Both clay and mudstone at fan margins and evaporite deposits near playa centers grade laterally into coarser-grained sediment towards basin margins; however, it is evident in seismic-reflection and well log data that these facies shift laterally and vertically throughout the basin (Wagner and Johnson, 2006). A thick, basinwide seal or caprock near or below 800 m (2,625 ft) is not evident in the Tucson basin; this inference is based on correlation between relatively few deep wells and could be inaccurate for unrepresented sections of the basin.

Salinity

Groundwater quality data below 800 m (2,625 ft) in the Tucson basin are scarce; no saline groundwater above 5,000 mg/L has been reported (Gootee et al., 2012). Based on a statewide query from water quality databases, OG well 10-10 has measured salinity that may represent groundwater conditions below 800 m (2,625 ft) depth (see blue triangle and well on section AA'). A value of 540 mg/L TDS was reported; however, no screened interval for this well could be found, so its relationship to formation groundwater is uncertain.

Evaporite deposits are thought to be largely interspersed with clastic sediments in the basin, but whether or not saline water is associated with them is unknown. No wells reported salt or halite, and only one well in the western-central portion of the basin (35-29476) reported 9 m (29 ft) of "hard gypsum" at ~ 400 m (1,310 ft) depth. In OG well 597, saline groundwater is interpreted from geophysical logs, and is associated with lime mudstone disseminated with gypsum between 600 to 800 m (1,980 to 2,640 ft) bls in UBF (Houser et al., 2004). In the same well, a poorly consolidated muddy evaporite interval in the Pantano Formation, including a 3.7-m (12-ft) thick bed of anhydrite, is interpreted to contain connate saline water, between 2,158 to 2,188 m (7,080 to 7,180 ft) bls.

5.0 Conclusions

A preliminary evaluation of the storage potential for CO_2 in saline-permeable strata below an impermeable caprock in the Tucson basin is inconclusive. This is primarily due to the dearth of deep well data in the basin. Permeable strata below 800 m (2,625 ft) depth is sufficiently thick and potentially favorable for CO_2 sequestration; however, the lack of salinity data for deep aquifers precludes an adequate assessment of storage volumes in saline formations below 800 m. Based on available data, the presence of an extensive seal or capping unit near or below 800 m (2,625 ft) depth could not be identified.

Additional well log data of high quality and geophysical log suites would be needed to correlate stratigraphic horizons in basin-fill units, especially to the base of the Pantano Formation. Acquisition and analysis of additional existing seismic data, coupled with well data, would be a valuable and practical tool for furthering research of deep basin-fill stratigraphy in the Tucson basin for the purposes of evaluating CO_2 storage potential.

6.0 Bibliography

ADWR, 2011, Arizona Well Registry Distribution Database (Wells 35- and 55-): Phoenix, Arizona Department of Water Resources, MS Access database and ESRI shapefiles.

ADWR, 2012 (unpublished, in review), Updated regional groundwater flow model of Tucson Active management Area after Mason and Bota (2006), Tucson, Arizona.

Anderson, S.R., 1987, Cenozoic stratigraphy and geologic history of the Tucson basin, Pima County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 87-4190, 20 p., scale 1:250,000.

Davidson, E.S., 1973, Geohydrology and water resources of the Tucson basin, Arizona, U.S. Geological Survey Water Supply Paper 1939-E, 81p.

Davis, G.H., Constenius, K.N., Dickinson, W.R., Rodriguez, E.P., and Cox, L.J., 2004, Fault and fault-rock characteristics associated with Cenozoic extension and core-complex evolution in the Catalina-Rincon region, southeastern Arizona. GSA Bulletin, v. 116, no. 1/2, pp. 128-141.

Department of Energy, 2010, Summary of the Methodology for Development of Geologic Storage Estimates for Carbon Dioxide in the Third Edition of the Carbon Sequestration Atlas of the United States and Canada. 42p.

Dickinson, W.R., 1991, Tectonic setting of faulted Tertiary strata associated with the Catalina core complex in southern Arizona: Geological Society of America Special Paper 264, 106 p., scale 1:125,000.

Dickinson, W.R., 1999, Geologic framework of the Catalina foothills, outskirts of Tucson, Pima County, Arizona: Tucson, Arizona Geological Survey Contributed Map CM-99-B, 31 p., scale 1:24,000.

Drewes, HD., 1977, Geologic map and sections of the Rincon Valley Quadrangle, Pima County, Arizona: US. Geological Survey Miscellaneous Investigations Series Map 1-997, scale 1:48,000.

Eberly, L.D., and Stanley, T.B., Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, v.89, p.921-940.

Gettings, M.E., and Houser, B.B., 1997, Basin geology of the upper Santa Cruz Valley, Pima and Santa Cruz Counties, southeastern Arizona: U.S. Geological Survey Open-File Report 97-676, 40 p., 6 pls.

Gootee, B.F., 2012, Geologic Evaluation of the Safford Basin for Carbon Dioxide Sequestration Potential, Arizona Geological Survey Open-File Report OFR-12-01, 71 p., 1 plate.

Gootee, B.F., Mahan, M.K., and Love, D.S., 2012, A Summary of Reported Elevated Salinity Concentrations for Groundwater Samples Collected in Arizona, AZGS Open-File Report 12-26, 23 p.

Houser, B.B., Peters, L., Esser, R.P. and Gettings, M.E., 2004, Stratigraphy and tectonic history of the Tucson Basin, Pima County, Arizona, based on the Exxon State (32)-1 well: U.S. Geological Survey Scientific Investigations Report 2004-5076, 33 p.

Johnson, R.A. and Loy, K.L., 1992, Seismic reflection evidence for seismogenic low-angle faulting in southeastern Arizona. Geology, v.20, pp. 597-600.

Mason, D.A. and Bota, L., 2006, Regional Groundwater Flow Model of the Tucson Active Management Area, Tucson, Arizona. Arizona Department of Water Resources Model Report No. 13, 112 p.

Menges, C.M., and Pearthree, P.A., 1989, Late Cenozoic tectonism in Arizona and its impact on regional landscape evolution, in Jenny, J.P. and Reynolds, S.J., eds., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest XVII, p. 649-680.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range Province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115, 1 sheet, scale 1:1,000,000.

Pashley, E.F., Jr., 1966, Structure and stratigraphy of the central, northern and eastern parts of the Tucson Basin, Pima County, AZ, PhD dissertation U of A, pp. 273, Plates 1-5.

Pearthree, P.A., and Calvo, S.S., 1987, The Santa Rita fault zone: Evidence for large magnitude earthquakes with very long recurrence intervals, Basin and Range Province of southeastern Arizona: Seismological Society of America Bulletin, v. 77, p. 97-116.

Pearthree, P.A., McKittrick, M.A., Jackson, G.W., Demsey, K.A., 1988, Geologic map of Quaternary and upper Tertiary deposits, Tucson 1° x 2° quadrangle, Arizona: Tucson, Arizona Geological Survey Open-File Report 88-21, scale 1:250,000.

Richard, S.M., Reynolds, S.J., Spencer, J.E. and Pearthree, P.A., 2002, Digital Graphics Files for the Geologic Map of Arizona, a representation of Arizona Geological Survey Map 35, v. 1.0., Arizona Geological Survey Digital Geologic Map Series DGM-17.

Richard, S.M., Shipman, T.C., Greene, Lizbeth, Harris, R.C., 2007, Estimated Depth to Bedrock in Arizona: Tucson, Arizona Geological Survey Digital Geologic Map 52 (DGM-52), version 1.0, 1 Adobe Acrobat (PDF) file (8 p., 1 sheet), design scale 1:1,000,000.

Rystrom, V.L., 2003, Structure of the Tucson Basin, Arizona, From Gravity and Aeromagnetic Data. USGS Open-File Report 03-116, 80 p.

Spencer, J.E., 2011, Preliminary Evaluation of Cenozoic Basins in Arizona for CO_2 Sequestration Potential, Arizona Geological Survey, Open-File Report OFR 11-05, 15 p.

Spencer, J.E., and Reynolds, S.J., 1989, Middle Tertiary tectonics of Arizona and adjacent areas, in Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest XVII, p. 539-574.

Spencer, J.E., Richard, S.M., Reynolds, S.J., Miller, R.J., Shafiqullah, M., Grubensky, M.J., and Gilbert, W.G., 1995, Spatial and temporal relationships between mid-Tertiary magmatism and extension in southwestern Arizona: Journal of Geophysical Research, v. 100, p. 10,321-10,351.United State

Environmental Protection Agency (USEPA), 1991. Title 40 CFR Drinking Water Act, Ch.1, SubCh D, Part 143, National Secondary Drinking Water Regulations, Sect. 143.3 Secondary MCLs.

Wagner, F.H. III, and Johnson, R.A., 2006, Coupled basin evolution and late-stage metamorphic core complex exhumation in the southern Basin and Range Province, southeastern Arizona. Tectonophysics, v.420, pp. 141-160.

Well Type	Well ID	Other ID	Other Name	Basin	Elev. (m)	Elev. (ft)	UTMX NAD83	UTMY NAD83	Well Depth (ft)	Well Depth (m)	Log Type	Comments from Data Source. [Comments by author]
OG	597		Exxon (Humble Oil and Refining Co.) State-32 No. 1	Tucson Basin	880	2886	515525	3548134	12571	3831	AMSTRAT, S	Reviewed Well File (60pgs). Formation at TD = Tertiary granite monzonite
OG	10-02	35-26028	USGS No. 01. Tucson, Test Hole No. 1	Tucson Basin	716	2350	499317	3576548	1811	552	none	Reviewed Well file (3 pgs)Formation at TD= NA. OG well 10-02 location and elevatioin used over 35 well.
OG	10-05	35-28746	Tucson Gas & Elec. 07	Tucson Basin	841	2760	511063	3557488	3145	959	D	Reviewed Well file (5 pgs); Formation at TD= NA
OG	10-06		Tucson Hole No. 3. D1514-25ADD	Tucson Basin	845	2772	513180	3551314	2998	914	RES, SP, S	Reviewed Well File (3 pgs);Formation at TD= NA. Additional logs and well data obtained from Tucson Water by Diane Love on 1/25/12. Has same location and similar depth as well 35-28804.
OG	10-07	35-28847	USGS No. 04	Tucson Basin	866	2840	516631	3554618	1842	561	CDL, IEL,SL, S, N	Reviewed Well File (4 pgs);Formation at TD= Pantano
OG	10-10	35-29619	USGS No. 02. Tucson. D16-15-10CCC. Tucson Exploration Hole No. 2.	Tucson Basin	906	2973	518170	3545952	2640	805	SP, R, S	Reviewed Well File (3pgs);Formation at TD= NA. Additional logs and well data obtained from Tucson Water by Diane Love on 1/25/12.
OG	10-13	35-30509	Anaconda No. 1 Continental	Tucson Basin	850	2790	502445	3530992	2786	849	D, IEL	Reviewed Well File (3 pgs); Formation at TD= Mesozoic
OG	10-14	35-29466	Pima Mining No. 4	Tucson Basin	818	2684	502889	3539861	2133	650	IEL	Reviewed Well File (3 pgs);Formation at TD= NA
OG	10-15	35-31562-(?)	Anaconda No. 2. D-18-13-10CDB	Tucson Basin	917	3010	499386	3526344	2064	629	IEL	Reviewed Well File (3 pgs); converted to water well,Formation at TD= NA. Similar to 35-31562 well in TD and completion date. No drillers log for 10-15 well; however, 35-well has a log approximatley 2.1 miles to northeast.
OG	10-16	35-30460	Anaconda No. 3 Continental	Tucson Basin	836	2742	502713	3534305	1798	548	IEL	Reviewed Well File (3 pgs);Formation at TD= NA. [Similar depth to 35-30460 and location; however, 30460 lat/long approximately is 270m (0.16 mi) to SE. OG-well 10-16 well location used. Surface elevation is based on 35-well, survey grade of land surface]
OG	11-19		Continental Oil 2 ORC	Tucson Basin	1090	3576	506854	3611286	3220	981	N	Reviewed Well File (5 pgs), Formation at TD= Precambrian (Oracle quartz monzonite)
OG	11-20		Continental Oil 1 ORC	Tucson Basin	1073	3520	506861	3609704	3293	1004	N	Reviewed Well File (5 pgs),Formation at TD= Precambrian (Whitetail Conglomerate)
ADWR 35-	26028	OG 10-02	D-13013003CDB. Test Hole No. 1	Tucson Basin	721	2366	499413	3576352	1813	553	D	TEST HOLE ONLY
ADWR 35-	28743		D-15014002CAC	Tucson Basin	813	2667	510748	3557236	2500	762	D	
ADWR 35-	28746	OG 10-05	D-15014002DBC	Tucson Basin	817	2680	511156	3557230	3145	959	D	
ADWR 35-	28757		D-15014003DAD	Tucson Basin	807	2648	510135	3557243	2505	764	D	
ADWR 35-	28795		D-15014017DCB	Tucson Basin	792	2599	506320	3553790	1925	587	G	[no logs found]
ADWR 35-	28804		D-15014025ADD	Tucson Basin	845	2772	513363	3551188	2993	912	None	Similar depth and location to OG well 10-06
ADWR 35-	28847	OG 10-07	D-15015016CBB	Tucson Basin	868	2848	516768	3554167	1843	562	None	
ADWR 35-	29453	72449	D-16013035AAA	Tucson Basin	830	2723	502018	3540295	830	253	D	[andesite noted at TD]
ADWR 35-	29466	OG 10-14	D-16013036ACC	Tucson Basin	818	2684	503015	3539690	2133	650	D	
ADWR 35-	29476	Well No. SC-15	D-16014004BAA	Tucson Basin	815	2674	507626	3548538	1800	549	D	Gravel packed with 200 yds of 1/8" to 1/2" gravel, land surface elevation 2670'.
ADWR 35-	29548		Tucson Water well SC-19, D-16014025BBB	Tucson Basin	856	2809	511850	3541908	2500	762	D, SP, R	Measurement was made form top of 1-in pipe attached to pump column. Top of 1" pip was 6.8 ft. above land surface. Land surface elevation is approximately 2,800 ft.
ADWR 35-	29619	OG 10-10	D-16015010CCC	Tucson Basin	907	2976	518284	3545758	2998	914	None	test well #2
ADWR 35-	30460	OG 10-16	D-17013013CDD	Tucson Basin	836	2743	502827	3534060	1735	529	D	
ADWR 35-	30494	30017	D-17013024DDB	Tucson Basin	836	2743	503453	3532635	2000	610	D	
ADWR 35-	30509		D-17013025CCD	Tucson Basin	847	2779	502451	3530824	2786	849	D	
ADWR 35-	30534		D-17014001BAA	Tucson Basin	865	2838	512465	3538684	1545	471	D	[abundant gypsum noted in logs]
ADWR 35-	30549	39804	D-17014006ABB	Tucson Basin	816	2677	504599	3538692	2000	610	D	
ADWR 35-	30559		D-17014007BBB	Tucson Basin	819	2687	503813	3537068	1923	586	D	
ADWR 35-	30601	28042	D-17014019DBD	Tucson Basin	841	2759	504834	3532831	2000	610	D	

Well Type	Well ID	Other ID	Other Name	Basin	Elev. (m)	Elev. (ft)	UTMX NAD83	UTMY NAD83	Well Depth (ft)	Well Depth (m)	Log Type	Comments from Data Source. [Comments by author]
ADWR 35-	30607	OG 10-06-(?)	City of Tucson Test Well No. 3. D-17014022ABB	Tucson Basin	866	2841	509460	3533817	2993	912	S	Identical log and completion date to OG well 10-06; however, 30607 is located two townships south. 30607 location may be inaccurate.
ADWR 35-	30636		D-17014030ACA	Tucson Basin	843	2766	504841	3531821	2440	744	G	[no logs found]
ADWR 35-	31553	25944	D-18013001AAB	Tucson Basin	852	2795	503461	3528992	1800	549	D	cable tool drill from 0'-1150', rotary drilled from 1150'-1800', measured from top of casing
ADWR 35-	31562	OG 10-15-(?)	D-18013001CBC	Tucson Basin	855	2805	502257	3527994	2064	629	D	measured at ground level, approximate elevation @ 2795.59'
ADWR 35-	31674	28659	D-18014006DBA	Tucson Basin	874	2868	504849	3528183	2004	611	D	measured from top of casing

D = Drillers log
G = Geologist log
S = samples
CAL = caliper log
RES = resistivity log
SP = spontaneous potential log
CN = compensated neutron -formation density log
GAM = gamma ray log
T = temperature log

Well Type	Well ID	Elev. (m)	Elev. (ft)	From Depth (ft)	To Depth (ft)	From Depth (m)	To Depth (m)	Top Elev. (m)	Bottom Elev. (m)	HGUID	HGU Code	Lithology	Log Type	Comments [by author]
35	26028	716	2350	0	140	0	43	716	674			Unknown	S	Descriptions from a driller-time log, with descriptions at intermittent intervals. Summarized by BFG.
35	26028	716	2350	140	1813	43	553	674	164			Overall coarse sand and gravel with intervals of silt and mud, generally consolidated and "hard". Clastics predominantly granitic and volcanic with lesser gneiss.	S	Logs reported to have been run in notes: Mud log, resistivity, spontaneous potential, gamma ray, sonic and caliper.
35	28743	813	2667	0	20	0	6	813	807	1	UBF	coarse granitic sand and gravel	D	
35	28743	813	2667	20	40	6	12	807	801	1	UBF	same	D	
35	28743	813	2667	40	60	12	18	801	795	1	UBF	same - some fine sand & clay	D	
35	28743	813	2667	60	80	18	24	795	788	1	UBF	granitic sand and gravel, quartz sand	D	
35	28743	813	2667	80	100	24	30	788	782	1	UBF	same - 1% magnetite present	D	
35	28743	813	2667	100	120	30	37	782	776	1	UBF	same - mostly quartz	D	
35	28743	813	2667	120	140	37	43	776	770	1	UBF	granitic and volcanic sand and gravel - very little magnetite	D	
35	28743	813	2667	140	160	43	49	770	764	1	UBF	same	D	
35	28743	813	2667	160	180	49	55	764	758	1	UBF	granitic sand and gravel with some volcanic and some metamorphic particles	D	
35	28743	813	2667	180	200	55	61	758	752	1	UBF	same - more fine grain quartz sand	D	
35	28743	813	2667	200	220	61	67	752	746	1	UBF	caliche, clay and some quartz sand	D	
35	28743	813	2667	220	240	67	73	746	740	1	UBF	same - more sand	D	
35	28743	813	2667	240	260	73	79	740	734	1	UBF	same - some gravel	D	
35	28743	813	2667	260	280	79	85	734	728	1	UBF	granitic sand and gravel with some thin layers of caliche	D	
35	28743	813	2667	280	300	85	91	728	721	1	UBF	same	D	
35	28743	813	2667	300	320	91	98	721	715	1	UBF	clay, some caliche, some sand	D	
35	28743	813	2667	320	340	98	104	715	709	1	UBF	same - a little gravel	D	
35	28743	813	2667	340	360	104	110	709	703	1	UBF	clay with layers of fine grain sand	D	
35	28743	813	2667	360	380	110	116	703	697	1	UBF	same some gravel	D	
35	28743	813	2667	380	400	116	122	697	691	1	UBF	same - more sand and gravel	D	
35	28743	813	2667	400	420	122	128	691	685	1	UBF	alternating layers of coarse sand and clay, some caliche	D	
35	28743	813	2667	420	440	128	134	685	679	1	UBF	same	D	
35	28743	813	2667	440	460	134	140	679	673	1	UBF	sand and gravel. Subrounded granitic and schistose particles. Few pieces of quartzite	D	
35	28743	813	2667	460	480	140	146	673	667	1	UBF	amen as above but more fine sand	D	
35	28743	813	2667	480	500	146	152	667	660	1	UBF	same	D	
35	28743	813	2667	500	520	152	158	660	654	1	UBF	same one garnet in quartz, few volcanics, feldspars weathered	D	
35	28743	813	2667	520	540	158	165	654	648	1	UBF	same, with few pieces lime-cemented fine - grained sandstone	D	
35	28743	813	2667	540	560	165	171	648	642	1	UBF	same	D	
35	28743	813	2667	560	580	171	177	642	636	1	UBF	same, with lime-cemented sandstone more abundant same, with lime-cemented sandstone more abundant	D	
35	28743	813	2667	580	600	177	183	636	630	1	UBF	same as 580 but more quartzite and epidote	D	
35	28743	813	2667	600	620	183	189	630	624	1	UBF	same, but more black sand, fine and rounded.	D	
35	28743	813	2667	620	640	189	195	624	618	1	UBF	same as 580	D	
35	28743	813	2667	640	660	195	201	618	612	1	UBF	same	D	
35	28743	813	2667	660	680	201	207	612	606	1	UBF	alternating layers of quartz sand and clay	D	
35	28743	813	2667	680	700	207	213	606	599	1	UBF	clay, caliche and some subrounded quartz sand	D	
35	28743	813	2667	700	720	213	219	599	593	1	UBF	same - more sand	D	
35	28743	813	2667	720	740	219	226	593	587	1	UBF	same - more sane	D	
35	28743	813	2667	740	760	226	232	587	581	1	UBF	same	D	
35	28743	813	2667	760	780	232	238	581	575	1	UBF	same - a few volcanic particles	D	
35	28743	813	2667	780	800	238	244	575	569	1	UBF	clay, caliche and granitic sand	D	
35	28743	813	2667	800	820	244	250	569	563	1	UBF	same, less sand	D	
35	28743	813	2667	820	840	250	256	563	557	1	UBF	clay and caliche with some fine grained subrounded quartz sand	D	
35	28743	813	2667	840	860	256	262	557	551	1	UBF	clay and fine grained subrounded quartz sand	D	
35	28743	813	2667	860	880	262	268	551	545	1	UBF	clay and fine sand with some lime-cemented sandstone layers. Sand is subrounded clear to white quartz. A few schistose grains	D	
35	28743	813	2667	880	900	268	274	545	539	1	UBF	same with more larger grains and black sand grains	D	
35	28743	813	2667	900	920	274	280	539	532	1	UBF	same	D	

Well Type	Well ID	Elev. (m)	Elev. (ft)	From Depth (ft)	To Depth (ft)	From Depth (m)	To Depth (m)	Top Elev. (m)	Bottom Elev. (m)	HGUID	HGU Code	Lithology	Log Type	Comments [by author]
35	28743	813	2667	920	940	280	287	532	526	1	UBF	same	D	
35	28743	813	2667	940	950	287	290	526	523	1	UBF	same, a few grains with epidote, some larger grains	D	
35	28743	813	2667	950	960	290	293	523	520	1	UBF	same	D	
35	28743	813	2667	960	970	293	296	520	517	1	UBF	same	D	
35	28743	813	2667	970	980	296	299	517	514	1	UBF	same	D	
35	28743	813	2667	980	990	299	302	514	511	1	UBF	same	D	
35	28743	813	2667	990	1000	302	305	511	508	1	UBF	same, considerable black sand	D	
35	28743	813	2667	1000	1010	305	308	508	505	1	UBF	same	D	
35	28743	813	2667	1010	1020	308	311	505	502	1	UBF	same	D	
35	28743	813	2667	1020	1030	311	314	502	499	1	UBF	same	D	
35	28743	813	2667	1030	1040	314	317	499	496	1	UBF	same, some larger grains	D	
35	28743	813	2667	1040	1050	317	320	496	493	1	UBF	same	D	
35	28743	813	2667	1050	1060	320	323	493	490	1	UBF	MISSING	D	
35	28743	813	2667	1060	1070	323	326	490	487	1	UBF	same, more poorly cemented, a few larger grains	D	
35	28743	813	2667	1070	1080	326	329	487	484	1	UBF	same	D	
35	28743	813	2667	1080	1090	329	332	484	481	1	UBF	same	D	
35	28743	813	2667	1090	1100	332	335	481	478	1	UBF	coarse sand and a little limey clay. Sand is mostly subrounded white quartz with some schistose grains	D	
35	28743	813	2667	1100	1110	335	338	478	475	1	UBF	same as 880 with a few coarse grains	D	
35	28743	813	2667	1110	1120	338	341	475	471	1	UBF	same as 880	D	
35	28743	813	2667	1120	1130	341	344	471	468	1	UBF	same, with a few grains of epidote, more lime	D	
35	28743	813	2667	1130	1140	344	347	468	465	1	UBF	coarse sand and limey clay, a little gravel, sand is subrounded white quartz with some schistose grains.	D	
35	28743	813	2667	1140	1150	347	351	465	462	1	UBF	fine - medium sand with limey clay layers. Sand is rounded to subrounded, mostly white quartz	D	
35	28743	813	2667	1150	1160	351	354	462	459	1	UBF	same	D	
35	28743	813	2667	1160	1170	354	357	459	456	1	UBF	same, a few coarse grains	D	
35	28743	813	2667	1170	1180	357	360	456	453	1	UBF	same, less cementation	D	
35	28743	813	2667	1180	1190	360	363	453	450	1	UBF	same	D	
35	28743	813	2667	1190	1200	363	366	450	447	1	UBF	same, a few caliche pebbles	D	
35	28743	813	2667	1200	1210	366	369	447	444	1	UBF	same	D	
35	28743	813	2667	1210	1220	369	372	444	441	1	UBF	same	D	
35	28743	813	2667	1220	1230	372	375	441	438	1	UBF	limey clay and fine sand layers	D	
35	28743	813	2667	1230	1240	375	378	438	435	1	UBF	same	D	
35	28743	813	2667	1240	1250	378	381	435	432	1	UBF	same, a few caliche pebbles	D	
35	28743	813	2667	1250	1260	381	384	432	429	1	UBF	MISSING	D	
35	28743	813	2667	1260	1270	384	387	429	426	1	UBF	same	D	
35	28743	813	2667	1270	1280	387	390	426	423	1	UBF	same	D	
35	28743	813	2667	1280	1290	390	393	423	420	1	UBF	same, a little coarser material	D	
35	28743	813	2667	1290	1300	393	396	420	417	1	UBF	same, a little sand	D	
35	28743	813	2667	1300	1310	396	399	417	414	1	UBF	same	D	
35	28743	813	2667	1310	1320	399	402	414	411	1	UBF	same, more sand	D	
35	28743	813	2667	1320	1330	402	405	411	407	1	UBF	same	D	
35	28743	813	2667	1330	1340	405	408	407	404	1	UBF	same	D	
35	28743	813	2667	1340	1350	408	411	404	401	1	UBF	same, more fine sand, less cementation	D	
35	28743	813	2667	1350	1360	411	415	401	398	1	UBF	same	D	
35	28743	813	2667	1360	1370	415	418	398	395	1	UBF	mostly clay with thing stringers of fine grained rounded quartz sand	D	
35	28743	813	2667	1370	1380	418	421	395	392	1	UBF	same	D	
35	28743	813	2667	1380	1390	421	424	392	389	1	UBF	same	D	
35	28743	813	2667	1390	1400	424	427	389	386	1	UBF	same	D	
35	28743	813	2667	1400	1410	427	430	386	383	1	UBF	same, few pieces gypsum in clay	D	
35	28743	813	2667	1410	1420	430	433	383	380	1	UBF	fine sand with thin clay layers. Sands rounded.	D	
35	28743	813	2667	1420	1430	433	436	380	377	1	UBF	same	D	
35	28743	813	2667	1430	1440	436	439	377	374	1	UBF	same	D	
35	28743	813	2667	1440	1450	439	442	374	371	1	UBF	fine-medium sand with thin clay layers. Sands rounded	D	

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35	28743	813	2667	1450	1470	442	448	371	365	1	UBF	fine sand with thin clay layers	D	
35	28743	813	2667	1470	1480	448	451	365	362	1	UBF	same	D	
35	28743	813	2667	1480	1490	451	454	362	359	1	UBF	sand, rounded with thin clay layers and few gravel	D	
35	28743	813	2667	1490	1500	454	457	359	356	1	UBF	fine sand with clay layers	D	
35	28743	813	2667	1500	1510	457	460	356	353	1	UBF	sand, rounded with thin clay layers	D	
35	28743	813	2667	1510	1520	460	463	353	350	1	UBF	same	D	
35	28743	813	2667	1520	1530	463	466	350	347	1	UBF	same	D	
35	28743	813	2667	1530	1540	466	469	347	343	1	UBF	medium to fine sand with limey clay layers. Sand is mostly white to clear quartz, rounded to subrounded.	D	
35	28743	813	2667	1540	1550	469	472	343	340	1	UBF	MISSING	D	
35	28743	813	2667	1550	1560	472	475	340	337	1	UBF	same	D	
35	28743	813	2667	1560	1570	475	479	337	334	1	UBF	same, with some caliche	D	
35	28743	813	2667	1570	1580	479	482	334	331	1	UBF	same, less sand	D	
35	28743	813	2667	1580	1590	482	485	331	328	1	UBF	same	D	
35	28743	813	2667	1590	1600	485	488	328	325	1	UBF	same with thin caliche layers.	D	
35	28743	813	2667	1600	1610	488	491	325	322	1	UBF	MISSING	D	
35	28743	813	2667	1610	1620	491	494	322	319	1	UBF	same	D	
35	28743	813	2667	1620	1630	494	497	319	316	1	UBF	same	D	
35	28743	813	2667	1630	1640	497	500	316	313	1	UBF	same	D	
35	28743	813	2667	1640	1650	500	503	313	310	1	UBF	same, a little gravel	D	
35	28743	813	2667	1650	1660	503	506	310	307	1	UBF	same	D	
35	28743	813	2667	1660	1670	506	509	307	304	1	UBF	same	D	
35	28743	813	2667	1670	1680	509	512	304	301	1	UBF	same	D	
35	28743	813	2667	1680	1690	512	515	301	298	1	UBF	same	D	
35	28743	813	2667	1690	1700	515	518	298	295	1	UBF	same	D	
35	28743	813	2667	1700	1710	518	521	295	292	1	UBF	same	D	
35	28743	813	2667	1710	1720	521	524	292	289	1	UBF	same	D	
35	28743	813	2667	1720	1730	524	527	289	286	1	UBF	same	D	
35	28743	813	2667	1730	1740	527	530	286	283	1	UBF	same	D	
35	28743	813	2667	1740	1750	530	533	283	279	1	UBF	same	D	
35	28743	813	2667	1750	1760	533	536	279	276	1	UBF	MISSING	D	
35	28743	813	2667	1760	1770	536	540	276	273	1	UBF	same	D	
35	28743	813	2667	1770	1780	540	543	273	270	1	UBF	same	D	
35	28743	813	2667	1780	1790	543	546	270	267	1	UBF	same	D	
35	28743	813	2667	1790	1800	546	549	267	264	1	UBF	same	D	
35	28743	813	2667	1800	1810	549	552	264	261	1	UBF	same, clay is less limey	D	
35	28743	813	2667	1810	1820	552	555	261	258	1	UBF	same	D	
35	28743	813	2667	1820	1830	555	558	258	255	1	UBF	MISSING turned over by wind	D	
35	28743	813	2667	1830	1840	558	561	255	252	1	UBF	same, more sand	D	
35	28743	813	2667	1840	1850	561	564	252	249	1	UBF	BLANK	D	
35	28743	813	2667	1850	1855	564	565	249	247	1	UBF	same partial sample	D	
35	28743	813	2667	1855	1870	565	570	247	243	1	UBF	light brown shale with layers of well rounded and frosted quartz sand, fine to medium grained	D	
35	28743	813	2667	1870	1880	570	573	243	240	1	UBF	same, more clay	D	
35	28743	813	2667	1880	1890	573	576	240	237	1	UBF	same, less clay, a little coarser sand	D	
35	28743	813	2667	1890	1900	576	579	237	234	1	UBF	more clay than 1870', and sand grains less rounded	D	
35	28743	813	2667	1900	1910	579	582	234	231	1	UBF	medium to coarse sand, well rounded with thin layers light brown shale	D	
35	28743	813	2667	1910	1920	582	585	231	228	1	UBF	same	D	
35	28743	813	2667	1920	1930	585	588	228	225	1	UBF	same with more clay and more schist particles in sand.	D	
35	28743	813	2667	1930	1940	588	591	225	222	1	UBF	mostly clay with very fine-grained quartz sand.	D	
35	28743	813	2667	1940	1950	591	594	222	218	1	UBF	alternating layers of fine-medium sand and brown shale	D	
35	28743	813	2667	1950	1960	594	597	218	215	1	UBF	same	D	
35	28743	813	2667	1960	1970	597	600	215	212	1	UBF	same	D	
35	28743	813	2667	1970	1980	600	604	212	209	1	UBF	same	D	

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35	28743	813	2667	1980	1990	604	607	209	206	1	UBF	same	D	
35	28743	813	2667	1990	2000	607	610	206	203	1	UBF	same	D	
35	28743	813	2667	2000	2010	610	613	203	200	1	UBF	same	D	
35	28743	813	2667	2010	2020	613	616	200	197	1	UBF	same with more dark quartzite grains	D	
35	28743	813	2667	2020	2030	616	619	197	194	1	UBF	same	D	
35	28743	813	2667	2030	2040	619	622	194	191	1	UBF	same with more shale	D	
35	28743	813	2667	2040	2050	622	625	191	188	1	UBF	same as before with still more dark quartzite grains	D	
35	28743	813	2667	2050	2060	625	628	188	185	1	UBF	same	D	
35	28743	813	2667	2060	2070	628	631	185	182	2	LBF	same, with more micaceous shale. A few grains of lavas.	D	
35	28743	813	2667	2070	2080	631	634	182	179	2	LBF	shale or clay with thin layers of very fine-grained quartz sand, well rounded. Several grains of red garnet.	D	
35	28743	813	2667	2080	2090	634	637	179	176	2	LBF	same	D	
35	28743	813	2667	2090	2100	637	640	176	173	2	LBF	Layers of sandstone and shale. Sand grains contain still more dark quartzite, some more lavas, and some chert.	D	
35	28743	813	2667	2100	2110	640	643	173	170	2	LBF	same as 2100 but more sand. More dark grains of schist, quartzite and lavas. More chert and more phosphorescent limestone	D	
35	28743	813	2667	2110	2120	643	646	170	167	2	LBF	clay with some fine to medium grained sand	D	
35	28743	813	2667	2120	2130	646	649	167	164	2	LBF	same as 2110	D	
35	28743	813	2667	2130	2140	649	652	164	161	3	Tp	more broken fragments, cemented conglomerate, but same materials.	D	[distinction between basin fill and Pantano not clear]
35	28743	813	2667	2140	2150	652	655	161	158	3	Tp	same	D	
35	28743	813	2667	2150	2160	655	658	158	154	3	Tp	same, one worm tube or rot cast. Calcite center.	D	
35	28743	813	2667	2160	2170	658	661	154	151	3	Tp	cemented conglomerate of quartz and schist, quartzite and lavas. Some chert and phosphorescent limestone. Considerable rounded sand grains of same material.	D	
35	28743	813	2667	2170	2180	661	664	151	148	3	Tp	same	D	
35	28743	813	2667	2180	2190	664	668	148	145	3	Tp	same, but more clay	D	
35	28743	813	2667	2190	2200	668	671	145	142	3	Tp	same	D	
35	28743	813	2667	2200	2210	671	674	142	139	3	Tp	same as 2170 but more conglomerate. Sample contains many pieces knocked off side of hole in changing bits and side-wall coring.	D	
35	28743	813	2667	2210	2220	674	677	139	136	3	Tp	same as 2200	D	
35	28743	813	2667	2220	2230	677	680	136	133	3	Tp	same as 2210	D	
35	28743	813	2667	2230	2240	680	683	133	130	3	Tp	same	D	
35	28743	813	2667	2240	2250	683	686	130	127	3	Tp	SAMPLE LOST. SAME AS 2240	D	
35	28743	813	2667	2250	2260	686	689	127	124	3	Tp	SAME AS 2240	D	
35	28743	813	2667	2260	2270	689	692	124	121	3	Tp	clay-cemented conglomerate. Fragments much more angular than above but same type. Percent dark increasing.	D	
35	28743	813	2667	2270	2280	692	695	121	118	3	Tp	layers of conglomerate and layers of brown shale. Fine grains moderately rounded but large fragments angular.	D	
35	28743	813	2667	2280	2290	695	698	118	115	3	Tp	layers of conglomerate and layers of brown shale or clay. Clay micaceous and manganiferous. Conglomerate moderately cemented with lime and/or clay. Fine grains rounded, coarse grains angular. Mostly quartz but considerable gneiss, schist and granite q	D	
35	28743	813	2667	2290	2295	698	700	115	113	3	Tp	same as 2290 with more clay	D	
35	28743	813	2667	2295	2300	700	701	113	112	3	Tp	same as 2290, but much less clay and more rounding.	D	
35	28743	813	2667	2300	2310	701	704	112	109	3	Tp	same as 2295	D	
35	28743	813	2667	2310	2320	704	707	109	106	3	Tp	same as 2300	D	
35	28743	813	2667	2320	2340	707	713	106	100	3	Tp	same as 2290	D	
35	28743	813	2667	2340	2350	713	716	100	97	3	Tp	same as 2310	D	
35	28743	813	2667	2350	2360	716	719	97	94	3	Tp	same as 2290	D	
35	28743	813	2667	2360	2370	719	722	94	90	3	Tp	same as above but more clay.	D	
35	28743	813	2667	2370	2378	722	725	90	88	3	Tp	same as 2290 but more conglomerate, less rounding.	D	
35	28743	813	2667	2378	2390	725	728	88	84	3	Tp	same as above but mostly clay and shale. White, kaolinized feldspars appear.	D	
35	28743	813	2667	2390	2400	728	732	84	81	3	Tp	same as above but more white feldspar. Very little rounding.	D	
35	28743	813	2667	2400	2410	732	735	81	78	3	Tp	same as above	D	

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35	28743	813	2667	2410	2420	735	738	78	75	3	Tp	very hard, angular conglomerate.	D	
35	28743	813	2667	2420	2430	738	741	75	72	3	Tp	same as above	D	
35	28743	813	2667	2430	2440	741	744	72	69	3	Tp	same as 2430 with few thin shale layers	D	
35	28743	813	2667	2440	2450	744	747	69	66	3	Tp	same as above. Some rounding on lava fragments	D	
35	28743	813	2667	2450	2460	747	750	66	63	3	Tp	same as 2450	D	
35	28743	813	2667	2460	2470	750	753	63	60	3	Tp	same as above but more rounding on fine quartz grains	D	
35	28743	813	2667	2470	2480	753	756	60	57	3	Tp	same as 2470	D	
35	28743	813	2667	2480	2490	756	759	57	54	3	Tp	same as 2470	D	
35	28743	813	2667	2490	2500	759	762	54	51	3	Tp	same as 2470, some thin shale layers.	D	
35	28746	817	2680	0	35	0	11	817	806	1	UBF	caliche clay and sand	D	Same as OG well 10-05
35	28746	817	2680	35	50	11	15	806	802	1	UBF	gravel and rocks	D	Same as OG well 10-05
35	28746	817	2680	50	74	15	23	802	794	1	UBF	gravel rocks and some clay	D	Same as OG well 10-05
35	28746	817	2680	74	300	23	91	794	725	1	UBF	sand and clay streaks	D	Same as OG well 10-05
35	28746	817	2680	300	479	91	146	725	671	1	UBF	sand and clay with gravel streaks	D	Same as OG well 10-05
35	28746	817	2680	479	491	146	150	671	667	1	UBF	rocks caliche and some sand	D	Same as OG well 10-05
35	28746	817	2680	491	540	150	165	667	652	1	UBF	sand and clay streaks	D	Same as OG well 10-05
35	28746	817	2680	540	586	165	179	652	638	1	UBF	sandy clay	D	Same as OG well 10-05
35	28746	817	2680	586	1840	179	561	638	256	1	UBF	sandy clay with streaks of sand and gravel	D	Same as OG well 10-05. [ADWR (2012) pick for top of Middle Tinaja is ~1,220 ft-elev.]
35	28746	817	2680	1840	2038	561	621	256	196	2	LBF	cemented conglomerate with hard clay streaks	D	Same as OG well 10-05
35	28746	817	2680	2038	2142	621	653	196	164	2	LBF	cemented conglomerate with streaks of hard clay	D	Same as OG well 10-05
35	28746	817	2680	2142	2580	653	786	164	30	2	LBF	cemented conglomerate with streaks of hard clay	D	Same as OG well 10-05
35	28746	817	2680	2580	2653	786	809	30	8	2	LBF	cemented conglomerate	D	Same as OG well 10-05
35	28746	817	2680	2653	2684	809	818	8	-1	2	LBF	sandy clay	D	Same as OG well 10-05
35	28746	817	2680	2684	2895	818	882	-1	-66	2	LBF	cemented conglomerate with some clay	D	Same as OG well 10-05
35	28746	817	2680	2895	2912	882	888	-66	-71	2	LBF	sandy clay	D	Same as OG well 10-05
35	28746	817	2680	2912	3145	888	959	-71	-142	2	LBF	cement conglomerate with some clay	D	Same as OG well 10-05
35	28757	807	2648	0	25	0	8	807	799	1	UBF	caliche	D	
35	28757	807	2648	25	44	8	13	799	794	1	UBF	coarse sand and gravel	D	
35	28757	807	2648	44	56	13	17	794	790	1	UBF	coarse sand, gravel and clay	D	
35	28757	807	2648	56	62	17	19	790	788	1	UBF	clay, some sand and gravel	D	
35	28757	807	2648	62	79	19	24	788	783	1	UBF	clay and some sand	D	
35	28757	807	2648	79	90	24	27	783	780	1	UBF	clay some gravel	D	
35	28757	807	2648	90	1050	27	320	780	487	1	UBF	sandy clay with streaks of coarse sand and gravel	D	
35	28757	807	2648	1050	1480	320	451	487	356	1	UBF	sandy clay	D	
35	28757	807	2648	1480	1660	451	506	356	301	1	UBF	sandy clay with hard sand streaks	D	
35	28757	807	2648	1660	1880	506	573	301	234	1	UBF	medium sand with some clay	D	
35	28757	807	2648	1880	2005	573	611	234	196	1	UBF	sand and small gravel with clay streaks	D	
35	28757	807	2648	2005	2505	611	764	196	44	2	LBF	cemented conglomerate with thin clay streaks	D	
35	29453	830	2723	0	280	0	85	830	745	1	UBF	decomposed granite, sand and clay	D	
35	29453	830	2723	280	455	85	139	745	691	1	UBF	conglomerate, gravel and clay	D	
35	29453	830	2723	455	508	139	155	691	675	1	UBF	conglomerate gravel and small boulders	D	
35	29453	830	2723	508	820	155	250	675	580	1	UBF	conglomerate, gravel and clay	D	
35	29453	830	2723	820	830	250	253	580	577	4	Tv	andesite	D	
35	29466	818	2684	0	14	0	4	818	814	1	UBF	topsoil	D	
35	29466	818	2684	14	102	4	31	814	787	1	UBF	gravel	D	
35	29466	818	2684	102	1138	31	347	787	471	1	UBF	sand	D	
35	29466	818	2684	1138	1320	347	402	471	416	1	UBF	shale	D	
35	29466	818	2684	1320	1412	402	430	416	388	1	UBF	sand	D	
35	29466	818	2684	1412	1418	430	432	388	386	1	UBF	shale	D	
35	29466	818	2684	1418	1460	432	445	386	373	1	UBF	sand	D	
35	29466	818	2684	1460	1470	445	448	373	370	1	UBF	shale	D	
35	29466	818	2684	1470	1508	448	460	370	358	1	UBF	sand	D	
35	29466	818	2684	1508	1560	460	475	358	343	1	UBF	shale	D	

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35	29466	818	2684	1560	1620	475	494	343	324	1	UBF	sand	D	
35	29466	818	2684	1620	1724	494	525	324	293	1	UBF	shale	D	
35	29466	818	2684	1724	1840	525	561	293	257	1	UBF	sand	D	
35	29466	818	2684	1840	1920	561	585	257	233	1	UBF	shale	D	
35	29466	818	2684	1920	1930	585	588	233	230	1	UBF	sand	D	
35	29466	818	2684	1930	1948	588	594	230	224	1	UBF	shale	D	
35	29466	818	2684	1948	1998	594	609	224	209	1	UBF	sand	D	
35	29466	818	2684	1998	2016	609	614	209	204	1	UBF	shale	D	
35	29466	818	2684	2016	2032	614	619	204	199	1	UBF	sand	D	
35	29466	818	2684	2032	2048	619	624	199	194	1	UBF	shale	D	
35	29466	818	2684	2048	2094	624	638	194	180	1	UBF	sand	D	
35	29466	818	2684	2094	2133	638	650	180	168	1	UBF	conglomerate	D	
35	29476	815	2674	0	22	0	7	815	808	1	UBF	sand and gravel	D	
35	29476	815	2674	22	45	7	14	808	801	1	UBF	clay and gravel	D	
35	29476	815	2674	45	52	14	16	801	799	1	UBF	gravel	D	
35	29476	815	2674	52	93	16	28	799	787	1	UBF	clay and gravel	D	
35	29476	815	2674	93	112	28	34	787	781	1	UBF	clay and gravel with hard streaks	D	
35	29476	815	2674	112	188	34	57	781	758	1	UBF	sand and gravel, layers of clay, hard streaks	D	
35	29476	815	2674	188	203	57	62	758	753	1	UBF	hard sand and gravel, streaks of caliche	D	
35	29476	815	2674	203	229	62	70	753	745	1	UBF	clay and gravel streaks	D	
35	29476	815	2674	229	241	70	73	745	742	1	UBF	sand and clay streaks	D	
35	29476	815	2674	241	278	73	85	742	730	1	UBF	clay and hard sand streaks	D	
35	29476	815	2674	278	302	85	92	730	723	1	UBF	sand and sandy clay	D	
35	29476	815	2674	302	370	92	113	723	702	1	UBF	sand and hard streaks	D	
35	29476	815	2674	370	471	113	144	702	671	1	UBF	sand and gravel with streaks of clay, hard layers	D	
35	29476	815	2674	471	490	144	149	671	666	1	UBF	hard sand and streaks of lime with sand and gravel	D	
35	29476	815	2674	490	499	149	152	666	663	1	UBF	hard shale and sand streaks	D	
35	29476	815	2674	499	515	152	157	663	658	1	UBF	sand and hard streaks	D	
35	29476	815	2674	515	565	157	172	658	643	1	UBF	shale and sand and slate streaks	D	
35	29476	815	2674	565	574	172	175	643	640	1	UBF	sand	D	
35	29476	815	2674	574	583	175	178	640	637	1	UBF	shale	D	
35	29476	815	2674	583	610	178	186	637	629	1	UBF	sand and sandy shale	D	
35	29476	815	2674	610	642	186	196	629	619	1	UBF	shale and sand streaks	D	
35	29476	815	2674	642	672	196	205	619	610	1	UBF	shale	D	
35	29476	815	2674	672	876	205	267	610	548	1	UBF	red shale	D	
35	29476	815	2674	876	920	267	280	548	535	1	UBF	shale and layers of sandstone	D	
35	29476	815	2674	920	946	280	288	535	527	1	UBF	shale and sand streaks	D	
35	29476	815	2674	946	953	288	290	527	525	1	UBF	hard sand and gravel	D	
35	29476	815	2674	953	996	290	304	525	511	1	UBF	shale, hard streaks and sand streaks	D	
35	29476	815	2674	996	1015	304	309	511	506	1	UBF	sand	D	
35	29476	815	2674	1015	1030	309	314	506	501	1	UBF	shale	D	
35	29476	815	2674	1030	1093	314	333	501	482	1	UBF	shale and streaks of sand and hard layers	D	
35	29476	815	2674	1093	1155	333	352	482	463	1	UBF	shale and sand streaks	D	
35	29476	815	2674	1155	1161	352	354	463	461	1	UBF	gypsum and quartz	D	[UBF-B?]
35	29476	815	2674	1161	1176	354	358	461	457	1	UBF	gypsum and hard shale	D	
35	29476	815	2674	1176	1197	358	365	457	450	1	UBF	gypsum and hard shale and quartz	D	
35	29476	815	2674	1197	1232	365	376	450	439	1	UBF	hard shale	D	
35	29476	815	2674	1232	1253	376	382	439	433	1	UBF	gypsum and silt beds, some sand	D	
35	29476	815	2674	1253	1264	382	385	433	430	1	UBF	hard shale and gypsum	D	
35	29476	815	2674	1264	1280	385	390	430	425	1	UBF	shale and sand streaks	D	
35	29476	815	2674	1280	1291	390	394	425	421	1	UBF	hard shale and streaks of gypsum	D	
35	29476	815	2674	1291	1303	394	397	421	418	1	UBF	shale and sand streaks	D	
35	29476	815	2674	1303	1308	397	399	418	416	1	UBF	gypsum and hard shale	D	
35	29476	815	2674	1308	1354	399	413	416	402	1	UBF	shale and streaks of hard sand	D	

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35	29476	815	2674	1354	1383	413	422	402	393	1	UBF	hard gypsum	D	
35	29476	815	2674	1383	1410	422	430	393	385	1	UBF	gypsum and silt beds, little fine sand	D	
35	29476	815	2674	1410	1418	430	432	385	383	1	UBF	gypsum and silt beds	D	
35	29476	815	2674	1418	1446	432	441	383	374	1	UBF	shale and streaks of gypsum	D	
35	29476	815	2674	1446	1493	441	455	374	360	1	UBF	shale and streaks of sand and gypsum	D	
35	29476	815	2674	1493	1506	455	459	360	356	1	UBF	sand	D	
35	29476	815	2674	1506	1516	459	462	356	353	1	UBF	shale and streaks of sand	D	
35	29476	815	2674	1516	1550	462	472	353	343	1	UBF	shale, streaks of sand and hard streaks	D	
35	29476	815	2674	1550	1649	472	503	343	312	1	UBF	shale and sand streaks	D	
35	29476	815	2674	1649	1661	503	506	312	309	1	UBF	shale and gravel and streaks of sand	D	
35	29476	815	2674	1661	1693	506	516	309	299	1	UBF	shale and sand streaks	D	
35	29476	815	2674	1693	1729	516	527	299	288	1	UBF	shale and sandy shale	D	
35	29476	815	2674	1729	1790	527	546	288	269	1	UBF	fine to coarse sand with some silt and gravel	D	
35	29476	815	2674	1790	1805	546	550	269	265	1	UBF	gravel quartz and sand streaks	D	gypsum referred to in this log from 1155-1493' is predominantly anhydrite, stringers of anhydrite from 1493-1805'. Gypsum at 690' and throughout hole
35	29548	856	2809	0	7	0	2	856	854	1	UBF	clay	D	Qf (USGS)
35	29548	856	2809	7	55	2	17	854	839	1	UBF	gravel, boulders, and sand streaks	D	Qf (USGS)
35	29548	856	2809	55	65	17	20	839	836	1	UBF	clay and gravel	D	Qf (USGS)
35	29548	856	2809	65	103	20	31	836	825	1	UBF	clay and sandy clay	D	Qf (USGS)
35	29548	856	2809	103	228	31	69	825	787	1	UBF	sand, gravel, and clay	D	Qf (USGS)
35	29548	856	2809	228	313	69	95	787	761	1	UBF	sand and gravel, streaks of shale	D	Qf (USGS)
35	29548	856	2809	313	407	95	124	761	732	1	UBF	shale and hard sand and gravel	D	Qf (USGS)
35	29548	856	2809	407	475	124	145	732	711	1	UBF	shale, sand streaks, and gravel	D	Ts1 (USGS)
35	29548	856	2809	475	494	145	151	711	706	1	UBF	shale and sandy shale	D	Ts1 (USGS)
35	29548	856	2809	494	524	151	160	706	696	1	UBF	sandy shale and sand	D	Ts1 (USGS)
35	29548	856	2809	524	538	160	164	696	692	1	UBF	hard shale	D	Ts1 (USGS)
35	29548	856	2809	538	553	164	169	692	688	1	UBF	shale and sand streaks	D	Ts1 (USGS)
35	29548	856	2809	553	575	169	175	688	681	1	UBF	sand and hard streaks	D	Ts1 (USGS)
35	29548	856	2809	575	600	175	183	681	673	1	UBF	shale and sand streaks	D	Ts1 (USGS)
35	29548	856	2809	600	641	183	195	673	661	1	UBF	hard shale and gravel	D	Ts1 (USGS)
35	29548	856	2809	641	651	195	198	661	658	1	UBF	shale, sand streaks, and gravel	D	Ts1 (USGS)
35	29548	856	2809	651	694	198	212	658	645	1	UBF	shale, sandy shale	D	Ts1 (USGS)
35	29548	856	2809	694	720	212	219	645	637	1	UBF	shale, and sand layers	D	Ts1 (USGS)
35	29548	856	2809	720	734	219	224	637	632	1	UBF	shale, and sand streaks	D	Ts1 (USGS)
35	29548	856	2809	734	808	224	246	632	610	1	UBF	gravel, shale	D	Ts1 (USGS)
35	29548	856	2809	808	870	246	265	610	591	1	UBF	shale, sandy streaks	D	Ts2 and Ts3 (USGS). Lower Tinaja (ADWR, 2012)
35	29548	856	2809	870	922	265	281	591	575	1	UBF	hard shale	D	Ts2 and Ts3 (USGS). Lower Tinaja (ADWR, 2012)
35	29548	856	2809	922	959	281	292	575	564	1	UBF	brown shale	D	Ts2 and Ts3 (USGS). Lower Tinaja (ADWR, 2012)
35	29548	856	2809	959	1137	292	347	564	510	1	UBF	brown shale and hard streaks	D	Ts2 and Ts3 (USGS). Lower Tinaja (ADWR, 2012)
35	29548	856	2809	1137	1418	347	432	510	424	1	UBF	brown shale	D	Ts2 and Ts3 (USGS). Lower Tinaja (ADWR, 2012)
35	29548	856	2809	1418	1534	432	468	424	389	1	UBF	shale and hard streaks	D	Ts2 and Ts3 (USGS). Lower Tinaja (ADWR, 2012)
35	29548	856	2809	1534	1698	468	518	389	339	1	UBF	hard brown shale, hard streaks of gypsum	D	Ts2 and Ts3 (USGS). [Good correlation with Exxon well and gypsum in UBF-B]
35	29548	856	2809	1698	1854	518	565	339	291	1	UBF	shale, hard shale, streaks of gypsum	D	Ts2 and Ts3 (USGS)
35	29548	856	2809	1854	1975	565	602	291	254	1	UBF	shale and hard streaks of gypsum	D	Ts2 and Ts3 (USGS)
35	29548	856	2809	1975	2190	602	668	254	189	1	UBF	hard shale and streaks of gypsum	D	Ts2 and Ts3 (USGS)
35	29548	856	2809	2190	2282	668	696	189	161	1	UBF	brown shale, gypsum	D	Ts2 and Ts3 (USGS)
35	29548	856	2809	2282	2500	696	762	161	94	1	UBF	hard shale, streaks of gypsum	D	Ts2 and Ts3 (USGS)
35	30494	836	2743	0	30	0	9	836	827	1	UBF	silt and sand	D	
35	30494	836	2743	30	250	9	76	827	760	1	UBF	gravel with streaks of sand	D	

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35	30494	836	2743	250	460	76	140	760	696	1	UBF	gravel with streaks of clay	D	
35	30494	836	2743	460	660	140	201	696	635	1	UBF	gravel with streaks of boulders	D	
35	30494	836	2743	660	1280	201	390	635	446	1	UBF	gravel with streaks of boulders, lightly cemented	D	
35	30494	836	2743	1280	1580	390	482	446	354	1	UBF	gravel, some boulders	D	
35	30494	836	2743	1580	1740	482	530	354	306	1	UBF	gravel with streaks of sand	D	
35	30494	836	2743	1740	2000	530	610	306	226	1	UBF	gravel with streaks of sand, lightly cemented and finer	D	
35	30509	847	2779	0	350	0	107	847	740	1	UBF	clay sand and gravel	D	
35	30509	847	2779	350	480	107	146	740	701	1	UBF	sand	D	
35	30509	847	2779	480	500	146	152	701	695	1	UBF	sand and gravel	D	
35	30509	847	2779	500	615	152	187	695	660	1	UBF	sand	D	
35	30509	847	2779	615	730	187	223	660	624	1	UBF	conglomerate	D	
35	30509	847	2779	730	750	223	229	624	618	1	UBF	sand and clay	D	
35	30509	847	2779	750	790	229	241	618	606	1	UBF	conglomerate	D	
35	30509	847	2779	790	800	241	244	606	603	1	UBF	conglomerate and clay	D	
35	30509	847	2779	800	820	244	250	603	597	1	UBF	sand and clay	D	
35	30509	847	2779	820	860	250	262	597	585	1	UBF	conglomerate	D	
35	30509	847	2779	860	870	262	265	585	582	1	UBF	sand and clay	D	
35	30509	847	2779	870	1110	265	338	582	509	1	UBF	conglomerate and clay	D	
35	30509	847	2779	1110	1210	338	369	509	478	1	UBF	sand and clay	D	
35	30509	847	2779	1210	1270	369	387	478	460	1	UBF	sand and gravel	D	
35	30509	847	2779	1270	1300	387	396	460	451	1	UBF	conglomerate	D	
35	30509	847	2779	1300	1520	396	463	451	384	1	UBF	sand and gravel	D	
35	30509	847	2779	1520	2780	463	847	384	0	1	UBF	sand and clay	D	[Conductivity decrease at 1,750 feet, similar to OG well 597, possibly the base of unit A in the upper basin fill]
35	30509	847	2779	2780	2786	847	849	0	-2	1	UBF	hard sand	D	
35	30534	865	2838	0	10	0	3	865	862	1	UBF	clayey gravel	D	
35	30534	865	2838	10	50	3	15	862	850	1	UBF	sand	D	
35	30534	865	2838	50	70	15	21	850	844	1	UBF	clay	D	
35	30534	865	2838	70	244	21	74	844	791	1	UBF	sand	D	
35	30534	865	2838	244	268	74	82	791	783	1	UBF	gravelly sand	D	
35	30534	865	2838	268	310	82	94	783	771	1	UBF	clay	D	
35	30534	865	2838	310	315	94	96	771	769	1	UBF	gravel	D	
35	30534	865	2838	315	320	96	98	769	767	1	UBF	clayey sand	D	
35	30534	865	2838	320	350	98	107	767	758	1	UBF	clay	D	
35	30534	865	2838	350	360	107	110	758	755	1	UBF	gravelly sand	D	
35	30534	865	2838	360	375	110	114	755	751	1	UBF	sandy clay	D	
35	30534	865	2838	375	395	114	120	751	745	1	UBF	clay	D	
35	30534	865	2838	395	406	120	124	745	741	1	UBF	sandy clay	D	
35	30534	865	2838	406	416	124	127	741	738	1	UBF	gravelly sands	D	
35	30534	865	2838	416	427	127	130	738	735	1	UBF	sandy clay	D	
35	30534	865	2838	427	434	130	132	735	733	1	UBF	gravelly sands	D	
35	30534	865	2838	434	456	132	139	733	726	1	UBF	clay	D	
35	30534	865	2838	456	466	139	142	726	723	1	UBF	clayey sand	D	
35	30534	865	2838	466	503	142	153	723	712	1	UBF	sandy clay	D	
35	30534	865	2838	503	508	153	155	712	710	1	UBF	sand	D	
35	30534	865	2838	508	517	155	158	710	707	1	UBF	clay	D	
35	30534	865	2838	517	540	158	165	707	700	1	UBF	sand	D	
35	30534	865	2838	540	555	165	169	700	696	1	UBF	sandy clay	D	
35	30534	865	2838	555	560	169	171	696	694	1	UBF	sand	D	
35	30534	865	2838	560	566	171	173	694	692	1	UBF	sandy clay	D	
35	30534	865	2838	566	587	173	179	692	686	1	UBF	sand	D	
35	30534	865	2838	587	606	179	185	686	680	1	UBF	sandy clay	D	
35	30534	865	2838	606	618	185	188	680	677	1	UBF	clayey sand	D	
35	30534	865	2838	618	641	188	195	677	670	1	UBF	clay	D	

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35	30534	865	2838	641	645	195	197	670	668	1	UBF	clayey sand	D	
35	30534	865	2838	645	675	197	206	668	659	1	UBF	clay	D	
35	30534	865	2838	675	705	206	215	659	650	1	UBF	sandy clay	D	
35	30534	865	2838	705	710	215	216	650	649	1	UBF	gravelly sand	D	
35	30534	865	2838	710	715	216	218	649	647	1	UBF	sand	D	
35	30534	865	2838	715	734	218	224	647	641	1	UBF	clay	D	
35	30534	865	2838	734	739	224	225	641	640	1	UBF	clayey sand	D	
35	30534	865	2838	739	773	225	236	640	629	1	UBF	clay	D	
35	30534	865	2838	773	778	236	237	629	628	1	UBF	clayey sand	D	
35	30534	865	2838	778	793	237	242	628	623	1	UBF	sandy clay	D	
35	30534	865	2838	793	800	242	244	623	621	1	UBF	sand	D	
35	30534	865	2838	800	805	244	245	621	620	1	UBF	clay	D	
35	30534	865	2838	805	820	245	250	620	615	1	UBF	sandy clay	D	
35	30534	865	2838	820	860	250	262	615	603	1	UBF	clay	D	
35	30534	865	2838	860	870	262	265	603	600	1	UBF	cemented sand and gravel	D	
35	30534	865	2838	870	920	265	280	600	585	1	UBF	clay	D	
35	30534	865	2838	920	1075	280	328	585	537	1	UBF	gypsum with clay	D	
35	30534	865	2838	1075	1250	328	381	537	484	1	UBF	gypsum with clay	D	
35	30534	865	2838	1250	1400	381	427	484	438	1	UBF	gypsum with clay	D	
35	30534	865	2838	1400	1460	427	445	438	420	1	UBF	clay - dark brown	D	
35	30534	865	2838	1460	1545	445	471	420	394	1	UBF	dark brown clay with some gypsum	D	
35	30549	816	2677	0	20	0	6	816	810	1	UBF	surface silt and sand	D	
35	30549	816	2677	20	400	6	122	810	694	1	UBF	loose pea sized gravel, some boulders	D	
35	30549	816	2677	400	640	122	195	694	621	1	UBF	mostly gravel, streaks of boulders	D	
35	30549	816	2677	640	1020	195	311	621	505	1	UBF	mostly clay with streaks of gravel	D	
35	30549	816	2677	1020	1260	311	384	505	432	1	UBF	gravel, some boulders, small streaks of clay	D	
35	30549	816	2677	1260	1390	384	424	432	392	1	UBF	very good gravel, a few boulders	D	
35	30549	816	2677	1390	2000	424	610	392	206	1	UBF	lightly cemented basaltic boulders	D	
35	30559	819	2687	0	20	0	6	819	813	1	UBF	surface sand and silt	D	
35	30559	819	2687	20	300	6	91	813	728	1	UBF	boulders and gravel	D	
35	30559	819	2687	300	920	91	280	728	539	1	UBF	good gravel with streaks of clay	D	
35	30559	819	2687	920	1464	280	446	539	373	1	UBF	gravel with streaks of boulders	D	
35	30559	819	2687	1464	1800	446	549	373	270	1	UBF	gravel, small streaks of clay	D	
35	30559	819	2687	1800	1923	549	586	270	233	1	UBF	same as above, beginning to cement fine and tight.	D	
35	30601	841	2759	0	490	0	149	841	692	1	UBF	no entry	D	
35	30601	841	2759	490	539	149	164	692	677	1	UBF	gravel	D	
35	30601	841	2759	539	1112	164	339	677	502	1	UBF	gravel with streaks of clay	D	
35	30601	841	2759	1112	1509	339	460	502	381	1	UBF	gravel with streaks of boulders	D	
35	30601	841	2759	1509	1642	460	500	381	340	1	UBF	gravel	D	
35	30601	841	2759	1642	1718	500	524	340	317	1	UBF	clay with streaks of gravel	D	
35	30601	841	2759	1718	2000	524	610	317	231	1	UBF	mostly gravel with streaks of clay	D	
35	30636	840	2755	0	50	0	15	840	824	1	UBF	[unknown]	G	[Formation picks from ADWR-USGS Strat Logs]
35	30636	840	2755	50	240	15	73	824	767	1	UBF	[Upper Tinaja]	G	
35	30636	840	2755	240	300	73	91	767	748	1	UBF	[unknown]	G	
35	30636	840	2755	300	1750	91	533	748	306	3	Tp	[Pantano Fm.]	G	
35	30636	840	2755	1750	2450	533	747	306	93	6	B	[basement]	G	
35	31553	852	2795	0	250	0	76	852	776	1	UBF	rock & clay	D	
35	31553	852	2795	250	295	76	90	776	762	1	UBF	sandy clay	D	
35	31553	852	2795	295	445	90	136	762	716	1	UBF	rocky clay	D	
35	31553	852	2795	445	500	136	152	716	699	1	UBF	conglomerate	D	
35	31553	852	2795	500	535	152	163	699	689	1	UBF	sticky clay & rock	D	
35	31553	852	2795	535	595	163	181	689	671	1	UBF	sticky conglomerate	D	
35	31553	852	2795	595	635	181	194	671	658	1	UBF	clay & rock	D	

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35	31553	852	2795	635	760	194	232	658	620	1	UBF	conglomerate	D	
35	31553	852	2795	760	770	232	235	620	617	1	UBF	rock & sand	D	
35	31553	852	2795	770	1070	235	326	617	526	1	UBF	conglomerate	D	
35	31553	852	2795	1070	1076	326	328	526	524	1	UBF	sand	D	
35	31553	852	2795	1076	1150	328	351	524	501	1	UBF	conglomerate	D	
35	31553	852	2795	1150	1175	351	358	501	494	1	UBF	sand & gravel	D	
35	31553	852	2795	1175	1180	358	360	494	492	1	UBF	sand	D	
35	31553	852	2795	1180	1185	360	361	492	491	1	UBF	sand & gravel	D	
35	31553	852	2795	1185	1195	361	364	491	488	1	UBF	sand, gravel & clay	D	
35	31553	852	2795	1195	1205	364	367	488	485	1	UBF	sand, gravel & rock	D	
35	31553	852	2795	1205	1230	367	375	485	477	1	UBF	sand, gravel, clay & rock	D	
35	31553	852	2795	1230	1353	375	412	477	439	1	UBF	sand, gravel & rock	D	
35	31553	852	2795	1353	1415	412	431	439	421	1	UBF	sand & gravel	D	
35	31553	852	2795	1415	1440	431	439	421	413	1	UBF	sand, gravel, clay & rock	D	
35	31553	852	2795	1440	1445	439	440	413	411	1	UBF	sand & rock	D	
35	31553	852	2795	1445	1465	440	447	411	405	1	UBF	sand, gravel & rock	D	
35	31553	852	2795	1465	1470	447	448	405	404	1	UBF	sand, gravel, clay & large rocks	D	
35	31553	852	2795	1470	1590	448	485	404	367	1	UBF	sand, gravel & rock	D	
35	31553	852	2795	1590	1635	485	498	367	354	1	UBF	sand & gravel	D	
35	31553	852	2795	1635	1650	498	503	354	349	1	UBF	rock	D	
35	31553	852	2795	1650	1700	503	518	349	334	1	UBF	rock & sand	D	
35	31553	852	2795	1700	1705	518	520	334	332	1	UBF	sand & gravel	D	
35	31553	852	2795	1705	1730	520	527	332	325	2	LBF	hard rock	D	[LBF?]
35	31553	852	2795	1730	1735	527	529	325	323	2	LBF	hard rock & sand	D	
35	31553	852	2795	1735	1759	529	536	323	316	2	LBF	hard rock	D	
35	31553	852	2795	1759	1775	536	541	316	311	2	LBF	rock & clay	D	
35	31553	852	2795	1775	1800	541	549	311	303	2	LBF	rock	D	
35	31562	855	2805	0	62	0	19	855	836	1	UBF	sand & gravel	D	
35	31562	855	2805	62	148	19	45	836	810	1	UBF	sand, gravel with fine clay streaks	D	
35	31562	855	2805	148	330	45	101	810	754	1	UBF	clay, gravel & sand streaks	D	
35	31562	855	2805	330	524	101	160	754	695	1	UBF	coarse sand & gravel	D	
35	31562	855	2805	524	770	160	235	695	620	1	UBF	sand & gravel	D	
35	31562	855	2805	770	793	235	242	620	613	1	UBF	conglomerate	D	
35	31562	855	2805	793	879	242	268	613	587	1	UBF	sand & gravel	D	
35	31562	855	2805	879	940	268	287	587	568	1	UBF	conglomerate	D	
35	31562	855	2805	940	1295	287	395	568	460	1	UBF	sand & gravel	D	
35	31562	855	2805	1295	1324	395	404	460	451	1	UBF	conglomerate	D	
35	31562	855	2805	1324	1379	404	420	451	435	1	UBF	sandy clay conglomerate	D	
35	31562	855	2805	1379	1454	420	443	435	412	1	UBF	conglomerate of sand & gravel	D	
35	31562	855	2805	1454	1484	443	452	412	403	1	UBF	conglomerate & clay	D	
35	31562	855	2805	1484	1836	452	560	403	295	1	UBF	coarse sand & gravel	D	
35	31562	855	2805	1836	1908	560	582	295	273	2	LBF	hard sand & gravel	D	[LBF?]
35	31562	855	2805	1908	2064	582	629	273	226	2	LBF	hard sand & gravel with clay streaks	D	
35	31674	874	2868	0	85	0	26	874	848	1	UBF	rock & sand	D	
35	31674	874	2868	85	110	26	34	848	841	1	UBF	boulders	D	
35	31674	874	2868	110	120	34	37	841	838	1	UBF	clay & sand	D	
35	31674	874	2868	120	145	37	44	838	830	1	UBF	sand & gravel	D	
35	31674	874	2868	145	172	44	52	830	822	1	UBF	clay	D	
35	31674	874	2868	172	190	52	58	822	816	1	UBF	sand & gravel	D	
35	31674	874	2868	190	202	58	62	816	813	1	UBF	clay & sand	D	
35	31674	874	2868	202	245	62	75	813	799	1	UBF	sand & gravel	D	
35	31674	874	2868	245	300	75	91	799	783	1	UBF	clay with streaks of sand & gravel	D	
35	31674	874	2868	300	315	91	96	783	778	1	UBF	clay	D	
35	31674	874	2868	315	335	96	102	778	772	1	UBF	rock & sand	D	

Well Type	Well ID	Elev. (m)	Elev. (ft)	From Depth (ft)	To Depth (ft)	From Depth (m)	To Depth (m)	Top Elev. (m)	Bottom Elev. (m)	HGUID	HGU Code	Lithology	Log Type	Comments [by author]
35	31674	874	2868	335	375	102	114	772	760	1	UBF	sand & clay	D	
35	31674	874	2868	375	405	114	123	760	751	1	UBF	sand & rock	D	
35	31674	874	2868	405	430	123	131	751	743	1	UBF	sand & clay	D	
35	31674	874	2868	430	449	131	137	743	737	1	UBF	sand & rock	D	
35	31674	874	2868	449	455	137	139	737	735	1	UBF	clay & sand	D	
35	31674	874	2868	455	479	139	146	735	728	1	UBF	sand, rock & clay	D	
35	31674	874	2868	479	598	146	182	728	692	1	UBF	clay & sand	D	
35	31674	874	2868	598	755	182	230	692	644	1	UBF	sand with clay	D	
35	31674	874	2868	755	776	230	237	644	638	1	UBF	sand, rock & clay	D	
35	31674	874	2868	776	825	237	251	638	623	1	UBF	sand, gravel, rock & clay	D	
35	31674	874	2868	825	830	251	253	623	621	1	UBF	clay with sand	D	
35	31674	874	2868	830	995	253	303	621	571	1	UBF	rock & clay	D	
35	31674	874	2868	995	1157	303	353	571	521	1	UBF	sand with clay	D	
35	31674	874	2868	1157	1460	353	445	521	429	1	UBF	sand, gravel & clay	D	
35	31674	874	2868	1460	1482	445	452	429	422	1	UBF	gravel, sand & rock	D	
35	31674	874	2868	1482	1512	452	461	422	413	1	UBF	sand with clay	D	
35	31674	874	2868	1512	2004	461	611	413	263	1	UBF	sand & rock with some gravel & a little clay	D	
OG	597	880	2886	0	1856	0	566	880	314	1	UBF	Upper Basin Fill, Unit A: Loose volcaniclastic conglomerate, interbedded sandy conglomerate, pebbly sandstone, sandy siltstone, and unconsolidated calcareous sandy mud. Medial alluvial-fan, distal alluvial-fan and alluvial-plain facies.	G	Summarized from AMST and driller logs and quoted from Houser et al., 2004. Saline water noted from 1,650 to ~1,840 feet.
OG	597	880	2886	1856	2980	566	908	314	-29	1	UBF	Upper Basin Fill, Unit B: (1) an upper gypsiferous sandy lime mud between 566 and 686 m (1,856-2,250 ft), (2) sandy lime mud with sparse gypsum from 686 to 805 m (2,250-2,640 ft), and (3) from 805 to 908 m (2,640-2,980 ft), sandy lime mud and poorly indurated muddy sandstone with minor pebble conglomerate beds. Interpreted to represent a (1) playa, (2) playa margin, and (3) distal alluvial-fan facies. Gypsum (disseminated) noted from 1,850 to 2,250 feet.	G	Saline water noted between 1,980 to 2,640 feet.
OG	597	880	2886	2980	3840	908	1170	-29	-291	2	LBF	Lower Basin Fill, Unit C: interbedded sandstone and siltstone from 908 to 994 m (2,980 to 3,260 ft), (2) mostly sandstone with minor siltstone from 994 to 1,140 m (3,260 to 3,740 ft), (3) interbedded sandstone and siltstone from 1,140 to 1,152 m (3,740 to 3,780 ft), and (4) conglomerate from 1,152 to 1,170 m (3,780 to 3,840 ft). Interpreted to represent fluvial braided sandy plain. Minor anhydrite and gypsum. Faulting and tilted bedding is likely in this unit.	G	
OG	597	880	2886	3840	6170	1170	1881	-291	-1001	2	LBF	Lower Basin Fill, Unit D: consists of calcareous mud, siltstone, sandstone, and conglomerate that vary from poorly to moderately indurated over short intervals. The depositional setting is inferred to be medial to distal alluvial fan, similar to the upper part of Unit A. Lithics in the cuttings consist of abundant granite and quartz and rare quartzite, limestone, and volcanics.	G	
OG	597	880	2886	6170	8256	1881	2516	-1001	-1637	3	Tp	Pantano Fm: (1) a 449-m-thick (1,472-ft) well-consolidated gypsiferous, muddy conglomerate (1,880-2,329m [6,170-7,642 ft]) containing an andesite(?) flow in the lower half; and (2) a 187-m-thick (614-ft) sequence we infer to be a composite rock-avalanche deposit composed chiefly of intermediate-composition volcanic rocks (2,329-2,516 m [7,642-8,256 ft]). The overall color of the cuttings darkens gradually from pale red (5 R 6/2) at 1,880 m (6,170 ft) to grayish-red (5 R 4/2) by 2,225 m (7,300 ft). Lower Miocene and Upper Oligocene (?).	G	Saline water noted in Pantano Fm. Between 7,000 and 7,200 ft, also associated with a 10-foot thick anhydrite bed in this interval.
OG	597	880	2886	8256	10026	2516	3056	-1637	-2176	4	Tv	Middle Tertiary volcanic an sedimentary rocks: This 540-m-thick (1,770-ft) interval consists of a diverse group of rocks with uncertain correlation to surface units. It contains the following rock units (figs. 4, 11): (1) lamprophyre(?) dike or sill, (2) intermediate-composition lava flow, (3) conglomerate, (4) crystal-lithic ash-flow tuff, (5) limestone conglomerate, and (6) pyroxene trachyte flow. Miocene (?) to Oligocene (?).	G	Oldest basin-filling units (Wagner and Johnson, 2006)
OG	597	880	2886	10026	12001	3056	3658	-2176	-2778	5	Kb	Bisbee Group: shale, sandstone, thin-bedded limestone, and conglomerate. Lower Cretaceous and Upper Jurassic.	G	

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OG	597	880	2886	12001	12556	3658	3827	-2778	-2948	6	B	Granitoid rock: equigranular granitoid crystalline rock. Pre-Upper Jurassic.	G	
OG	1006	845	2772	0	30	0	9	845	836	1	UBF	Terrace gravel	D	
OG	1006	845	2772	30	40	9	12	836	833	1	UBF	Gravel, orange brown, pebbles of ofine-grained white granite, light colored volcanic rocks, greenish andesite, pink quartzite, pink chert.	S	Summary log of cuttings samples
OG	1006	845	2772	40	260	12	79	833	766	1	UBF	Gravel to sand, light orange brown, pebbles of light colored volcanic rocks, gray to white quartzite, pink quartzite, white micaceous gneiss (Catalina gneiss), pinkish white granite, white granite, black basalt, dark sandstone, few miscellaneous dark volcanic rocks; granitic, light volcanic and various metamorphic rocks are dominant pebble types.	S	
OG	1006	845	2772	260	593	79	181	766	664	1	UBF	Sand, pebbly gray brown, components similar to 40-260 feet, sandy siltstone at 360, 460-490 feet.	S	End of "Q Basin Fill"
OG	1006	845	2772	593	890	181	271	664	574	1	UBF	Sandstone, silty, light brown, scattered pebbles of granite, quartzite, light volcanic rocks, andesite; at 600 feet is contact between light orange brown sand with calcite crystal-filled vugs above and harder silty sandstone with solid cemented matrix below (soil zone?).	S	Top of "T Basin Fill upper"
OG	1006	845	2772	890	1420	271	433	574	412	1	UBF	Siltstone, brown, gypsum from 980 to 1420, purplish brown units at 940-990, 1210-1300.	S	Middle Tinaja (ADWR, 2012)
OG	1006	845	2772	1420	2100	433	640	412	205	1	UBF	Siltstone to claystone, purplish brown to light brown, gypsiferous, anhydrite from 1590-2100, few pebbles of granite, dark sandstone, quartzite	S	Middle Tinaja (ADWR, 2012)
OG	1006	845	2772	2100	2700	640	823	205	22	1	UBF	Siltstone, light to dark reddish brown, firmly indurated, few 1/8 inch stringers of very fine grained sandy siltstone, 1-5%, 1/8 to 1/2 inch nodules of anhydrite and 3/4 inch crystals of selenite gypsum.	S	Middle Tinaja (ADWR, 2012)
OG	1006	845	2772	2700	2970	823	905	22	-60	1	UBF	Sandy siltstone, interbedded brown and light reddish brown, brown laminate are very fine-grained to fine-grained silty sandstone, reddish brown laminae is sandy siltstone; contains few 1/2 inch pebbles of granite and quartzite; contains trace to 1% anhydrite nodules and gypsum crystals as 2100-2700. Pebbles of granite increase from 2990 to 2993 but are probably cave from higher levels in the hole.	S	Middle Tinaja (ADWR, 2012)
OG	1006	845	2772	2970	2993	905	912	-60	-67	2	LBF	Siltstone, reddish brown (see core at 2995), hard, few flattened crystals of gypsum.	S	"surely Tertiary Pantano"
OG	1007	866	2840	0	40	0	12	866	853	0	FL	Quaternary alluvium	N	From AZGS Oil and Gas CC records, p.3; summary of formations encountered. No driller or geologist logs found. A collection of cutting samples indicated.
OG	1007	866	2840	40	310	12	94	853	771	0	FL	Ft. Lowell Fm	N	
OG	1007	866	2840	310	1450	94	442	771	424	1	UBF	Tertiary Tinaja	N	
OG	1007	866	2840	1450	1842	442	561	424	304	1	UBF	Tertiary Pantano Fm.	N	[logs indicate Upper Basin Fill to TD - BFG]
OG	1010	906	2973	30	350	9	107	897	799	1	UBF	Basin fill - granular sand with pebbles from 30 to 180 feet, mudstone in the sand from 180 to 300, sandy gravel from 300 to 350. Electric and lithologic break at 350 feet.	S	Descriptions based on summary from core samples and electric log.
OG	1010	906	2973	350	740	107	226	799	681	1	UBF	Tertiary basin fill - gravel, sand and siltstone. Electric log break at 790.	S	Base of Upper Tinaja (ADWR, 2012)
OG	1010	906	2973	740	1280	226	390	681	516	1	UBF	Sandstone and gravel. Electric log break at 1280	S	
OG	1010	906	2973	1280	2480	390	756	516	150	1	UBF	Sandstone. No definite break in electric log.	S	[Top of Lower Tinaja beds from ADWR, 2012]
OG	1010	906	2973	2480	2660	756	811	150	95	1	UBF	Conglomerate and sandstone. Break in electric log at 2660 between sandstone above and conglomerate below.	S	[Break at 2,660' added by BFG; coincides with ADWR top of Pantano or LBF]
OG	1010	906	2973	2660	2998	811	914	95	-8	2	LBF		N	[estimated from OG well 597]
OG	1016	836	2742	0	65	0	20	836	816	1	UBF	sand and gravel	D	
OG	1016	836	2742	65	73	20	22	816	813	1	UBF	boulders and large gravel	D	
OG	1016	836	2742	73	137	22	42	813	794	1	UBF	hard sand, gravel and clay streaks	D	
OG	1016	836	2742	137	165	42	50	794	785	1	UBF	sand gravel and clay streaks	D	
OG	1016	836	2742	165	232	50	71	785	765	1	UBF	sandy clay, clay and gravel streaks	D	
OG	1016	836	2742	232	255	71	78	765	758	1	UBF	clay	D	
OG	1016	836	2742	255	287	78	87	758	748	1	UBF	clay, course sand and gravel	D	

Well Type	Well ID	Elev. (m)	Elev. (ft)	From Depth (ft)	To Depth (ft)	From Depth (m)	To Depth (m)	Top Elev. (m)	Bottom Elev. (m)	HGUID	HGU Code	Lithology	Log Type	Comments [by author]
OG	1016	836	2742	287	327	87	100	748	736	1	UBF	clay and gravel	D	
OG	1016	836	2742	327	400	100	122	736	714	1	UBF	course sand and gravel	D	
OG	1016	836	2742	400	420	122	128	714	708	1	UBF	clay, sand and gravel	D	
OG	1016	836	2742	420	455	128	139	708	697	1	UBF	course sand and gravel	D	
OG	1016	836	2742	455	533	139	162	697	673	1	UBF	sand, gravel and sticky clay	D	
OG	1016	836	2742	533	627	162	191	673	645	1	UBF	course sand and gravel	D	
OG	1016	836	2742	627	724	191	221	645	615	1	UBF	course sand	D	
OG	1016	836	2742	724	784	221	239	615	597	1	UBF	course sand and gravel	D	
OG	1016	836	2742	784	810	239	247	597	589	1	UBF	course sand (hard)	D	
OG	1016	836	2742	810	860	247	262	589	573	1	UBF	hard sand and gravel	D	
OG	1016	836	2742	860	934	262	285	573	551	1	UBF	hard sand and streaks of gravel	D	
OG	1016	836	2742	934	950	285	290	551	546	1	UBF	hard sand	D	
OG	1016	836	2742	950	1020	290	311	546	525	1	UBF	course sand	D	
OG	1016	836	2742	1020	1050	311	320	525	516	1	UBF	sand, gravel and hard streaks	D	
OG	1016	836	2742	1050	1070	320	326	516	509	1	UBF	hard sand and gravel	D	
OG	1016	836	2742	1070	1090	326	332	509	503	1	UBF	sand and gravel	D	
OG	1016	836	2742	1090	1173	332	358	503	478	1	UBF	course sand and gravel	D	
OG	1016	836	2742	1173	1255	358	383	478	453	1	UBF	course sand	D	
OG	1016	836	2742	1255	1325	383	404	453	432	1	UBF	sand gravel and hard streaks	D	
OG	1016	836	2742	1325	1410	404	430	432	406	1	UBF	sand and gravel	D	
OG	1016	836	2742	1410	1492	430	455	406	381	1	UBF	sand and fine gravel	D	
OG	1016	836	2742	1492	1558	455	475	381	361	1	UBF	sand and gravel	D	
OG	1016	836	2742	1558	1606	475	490	361	346	1	UBF	course sand and gravel	D	
OG	1016	836	2742	1606	1723	490	525	346	310	1	UBF	sand and gravel (hard)	D	
OG	1016	836	2742	1723	1739	525	530	310	306	3	Tp	hard red rock and sand	D	[based on apparent increase in consolidation and proximity to seismic line P3 in Wagner and Johnson, 2006.
OG	1016	836	2742	1739	1753	530	534	306	301	3	Tp	hard sand, red rock and gravel	D	
OG	1016	836	2742	1753	1764	534	538	301	298	3	Tp	hard purple rock	D	
OG	1016	836	2742	1764	1777	538	542	298	294	3	Tp	hard rock and gravel	D	
OG	1016	836	2742	1777	1792	542	546	294	289	3	Tp	hard rock and sand	D	
OG	1119	1090	3576	0	3200	0	975	1090	115	1	UBF	Basin fill	N	Taken from a letter 3/21/1972.
OG	1119	1090	3576	3200	3220	975	981	115	108	6	B	Precambrian (Oracle quartz monzonite)	N	Taken from a letter 3/21/1972.
OG	1120	1073	3520	0	3090	0	942	1073	131	1	UBF	Basin fill	N	Taken from a letter 3/21/1972.
OG	1120	1073	3520	3090	3293	942	1004	131	69	6	B	Precambrian (Oracle quartz monzonite)	N	Taken from a letter 3/21/1972.

HGUID	HGU Code
0	FL (Fort Lowell Formation)
1	UBF (upper basin-fill)
2	LBF (lower basin-fill)
3	Tp (Pantano Formation)
4	Tv (Tertiary volcanics)
5	Kb (Cretaceous Bisbee Group rocks)
6	B (basement, pre-Cretaceous rocks)