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SUBSURFACE STRATIGRAPHY IN THE SOUTHERN SAN LUIS BASIN, NEW MEXICO

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ABSTRACT.—Subsurface lithologic and geophysical data from a series of municipal, exploratory, subdivision, and domestic wells are used to delineate variations in thickness and extent of Tertiary through Quaternary sediments and Pliocene basalt flow sequences in the southern San Luis Basin. Servilleta basalts increase in thickness from south to north within the Taos Valley; they are absent in BOR1, present as a single thin flow in BOR3, and present as three multiple-flow sequences at BOR4, K3, RP2500, and the Airport well. The Ojo Caliente Sandstone Member varies in apparent thickness from thin or absent at BOR1 and BOR2/3 to greater than 1000 ft (300 m) at RP2500 to 340 ft (100 m) at the Airport well. The apparent thickness of the Ojo Caliente is greatest along the Rio Pueblo, suggesting deposition in a depression, possibly an ancestral Rio Hondo or Rio Pueblo drainage, during mid-to-late-Miocene time. The Ojo Caliente sand may have been derived from the west, accumulating against Chama-El Rito alluvial fans building off the eastern mountain front. Data from the drilling program are also used to identify and constrain offset on several intrabasin faults and a mountain front graben bounded on the west by the Seco Fault, across which the Servilleta Formation is offset 950 ft (290 m), and on the east by the Town Yard fault. The average subsidence rate within the graben is estimated as approximately 0.1mm/yr (0.3 ft/1000yr). Down-to-the west offset across the Town Yard Fault is > 1390 ft (420 m).

INTRODUCTION

Subsurface data collected from drilling programs conducted during the past 15 years are utilized to evaluate the subsurface stratigraphy in the southern San Luis Basin. Of particular importance are a series of exploratory wells drilled to depths ranging from 1000 ft (300 m) to 2990 ft (910 m) below ground surface (bgs), as part of a cooperative exploratory drilling program conducted by the Town of Taos and Taos Pueblo, with funding from the US Bureau of Reclamation (BOR). Data from the drilling program were compiled, and preliminary correlations were made between deep wells to provide a stratigraphic framework for an evaluation of the hydrology of the basin fill aquifer system (see Drakos et al., 2004, this volume). The area of this study includes the region between the Sangre de Cristo mountain front on the east and the Rio Grande on the west, the Rio Hondo on the north and the Rio Grande-Rio Pueblo de Taos confluence on the south (Fig. 1).

METHODOLOGY

Numerous studies (e.g. Baldridge et al., 1984; Dungan et al., 1984; Lipman and Mehnert, 1979) have defined syn-rift Tertiary sedimentary and volcanic units in the general vicinity of the study area. Well log data from this study, particularly from several deep exploratory and production well borings, are used to constrain the subsurface extent of and relationships between rift-related sedimentary and volcanic units. Because the subtle differences between basin-fill units can be difficult to discern in drill cuttings and due to the relative paucity of data points, the stratigraphic inferences and subsurface correlations presented in this paper are preliminary. Data from thirteen wells greater than 1000 ft (300 m) deep, including lithologic logs of cuttings and geophysical logs (electric logs, neutron, natural gamma, and caliper), are used to identify lithologic and geophysical signatures of the basin-fill units. These data are utilized to determine which stratigraphic unit each well is completed into, and are used to explore the stratigraphic framework and shallow structures of the Taos Valley.

GEOLOGIC SETTING

The study area is situated in the Taos Valley within the southern San Luis Basin (Fig. 1). The San Luis Basin is situated in the northern Rio Grande rift, a generally north-south trending series of fault-bounded basins extending from Colorado to Mexico (Hawley, 1978; Chapin and Cather, 1994). Rifting in the San Luis Basin dates from approximately 30-27 Ma and has resulted in approximately 8-12% extension, primarily along north-south trending, down to the west normal faults (Tweto, 1979; Brister and Gries, 1994; Chapin and Cather, 1994; Kluth and Schaftenaar, 1994). The southern San Luis Basin in the vicinity of Taos is a deep graben with predominant down-to-the-west faulting along the east margin (Bauer and Kelson, 2004, this volume). In the San Luis Basin near Alamosa, Tertiary and Quaternary sedimentary deposits exhibit average dips of 0° to 12° to the east (Chapin and Cather, 1994).

DESCRIPTION OF STRATIGRAPHIC UNITS

From oldest to youngest, the units underlying the basin discussed in this study are: 1) Pennsylvanian Alamitos Formation, 2) Tertiary Picuris Formation, 3) Tertiary Santa Fe Group, 4) Tertiary Servilleta Formation, and 5) Quaternary Alluvium. Galusha and Blick (1971) subdivided the Santa Fe Group in the Española Basin into the Tesuque Formation and the overlying Chamita Formation. The Tesuque Formation is further subdivided into the Chama-El Rito Member and the overlying Ojo Caliente Sandstone

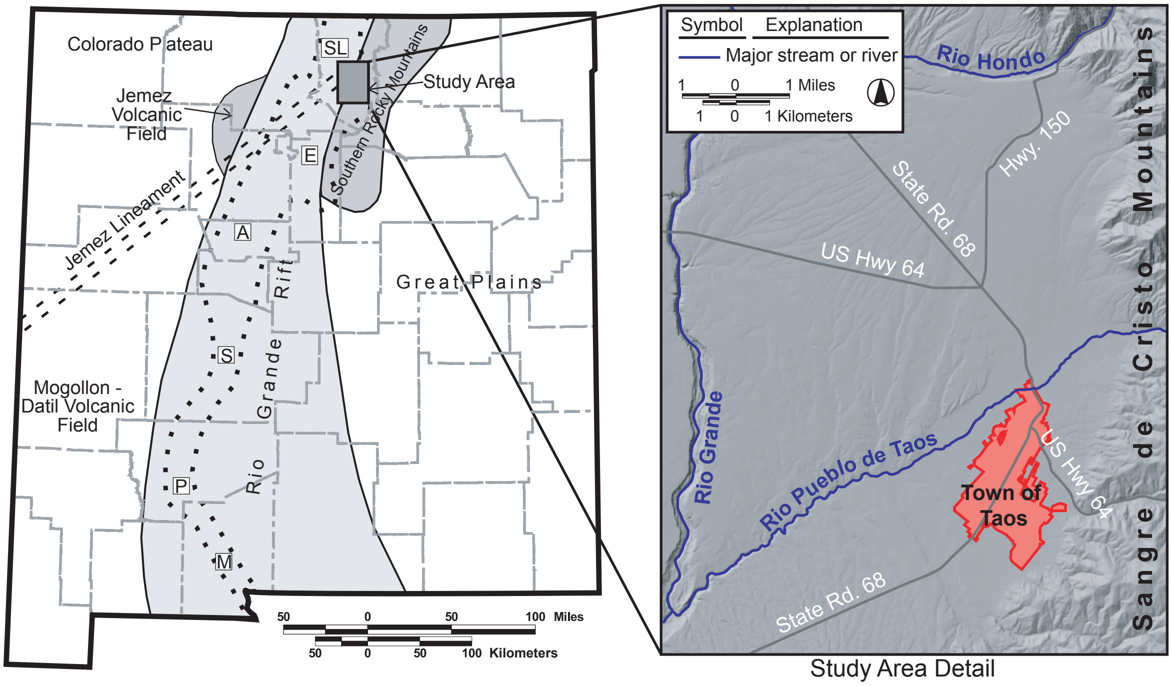

FIGURE 1. Location map – schematic map of New Mexico showing study area and the approximate limits of various physiographic provinces and geographic features. Major basins in the Rio Grande rift from north to south are: SL=San Luis, E = Española, A = Albuquerque, S = Socorro, P = Palomas, M = Mimbres. (state map modified from Sanford et al., 1995 and Keller and Cather, 1994).

Member (Fig. 2; Galusha and Blick, 1971). Although extending this Santa Fe Group stratigraphic nomenclature into the southern San Luis Basin may be problematic, it is used as an initial framework for this investigation. Some revision of stratigraphic units may be required as additional surface and subsurface data become available.

Along the basin margin on the east side of the study area, the Tertiary deposits are in fault and depositional contact with older sedimentary and crystalline rocks within the Sangre de Cristo Mountains. While not discussed in detail in this paper, the crystalline rocks include Proterozoic plutonic and gneissic complexes in the Taos Range in the northern part of the study area, and metasedimentary rocks (quartzite, schist, and phyllite) in the northern Picuris Mountains located in the southern part of the study area (Bauer et al., 1999). Paleozoic sedimentary rocks overly the metasedimentary rocks in the southern portion of the study area, south of the Rio Pueblo de Taos, and includes the Pennsylvanian Alamitos and underlying Flechado Formations. The Flechado Formation is comprised of a clastic-dominated sedimentary section (shale, siltstone, sandstone, and conglomerate beds) and is overlain by the more limestone-rich Alamitos Formation (Bauer et al., 1999).

Alamitos Formation (ℙa)

One well in the study area (Taos Town Yard) penetrated limestone of the Pennsylvanian Alamitos Formation at a depth of 720 ft (220 m) below ground surface (bgs) (Drakos and Lazarus, unpubl. report to the Town of Taos, 1997). In the Town Yard well the Alamitos Formation consists of interbedded gray limestone, tan, white, and brown fine-grained sandstone beds and shale beds, with limestone beds representing approximately 50% of the penetrated section. The shallow depth at which the Paleozoic section was encountered in the Town Yard well is attributed to offset on the Town Yard fault (Figs. 3 and 4; Drakos and Lazarus, unpubl. report to the Town of Taos 1997; Bauer et al., 1999; Drakos et al., 2001).

Picuris Formation (Tp)

The oldest Tertiary unit encountered is the Oligocene to Miocene Picuris Formation, which is penetrated in the BOR2 deep piezometer and the BOR3 production well (located at the same site, 36 ft [11 m] from one another) (Fig. 4; Drakos et al., unpubl. report to the Town of Taos, 2002). The Picuris Formation is subdivided into an upper fine-grained, ash-rich member and a generally coarser-grained lower member that includes a distinctive quartzite-rich basal conglomerate (Bauer et al., 1999). The upper and lower members are separated by the Llano Quemado volcanic breccia, clasts of which have been dated to 28.4 Ma (Bauer et al., 1999). The upper Picuris Formation is composed of predominantly volcanic clasts and grains and is interpreted to be derived from pre-rift and early rift volcanic centers in the San Juan volcanic field to the north and northwest.

It is inferred that the Picuris Formation was encountered in well nest BOR2/3 from 1810 to 2110 ft (552 to 643 m) bgs. At the BOR2/3 well nest, the Picuris Formation comprises fine-grained silty sediments with minor reworked ash from 1810 to 1945 ft (552 to 593 m) bgs overlying interbedded coarse sandy gravel, including clasts of pink, white, and green quartzite, fossiliferous

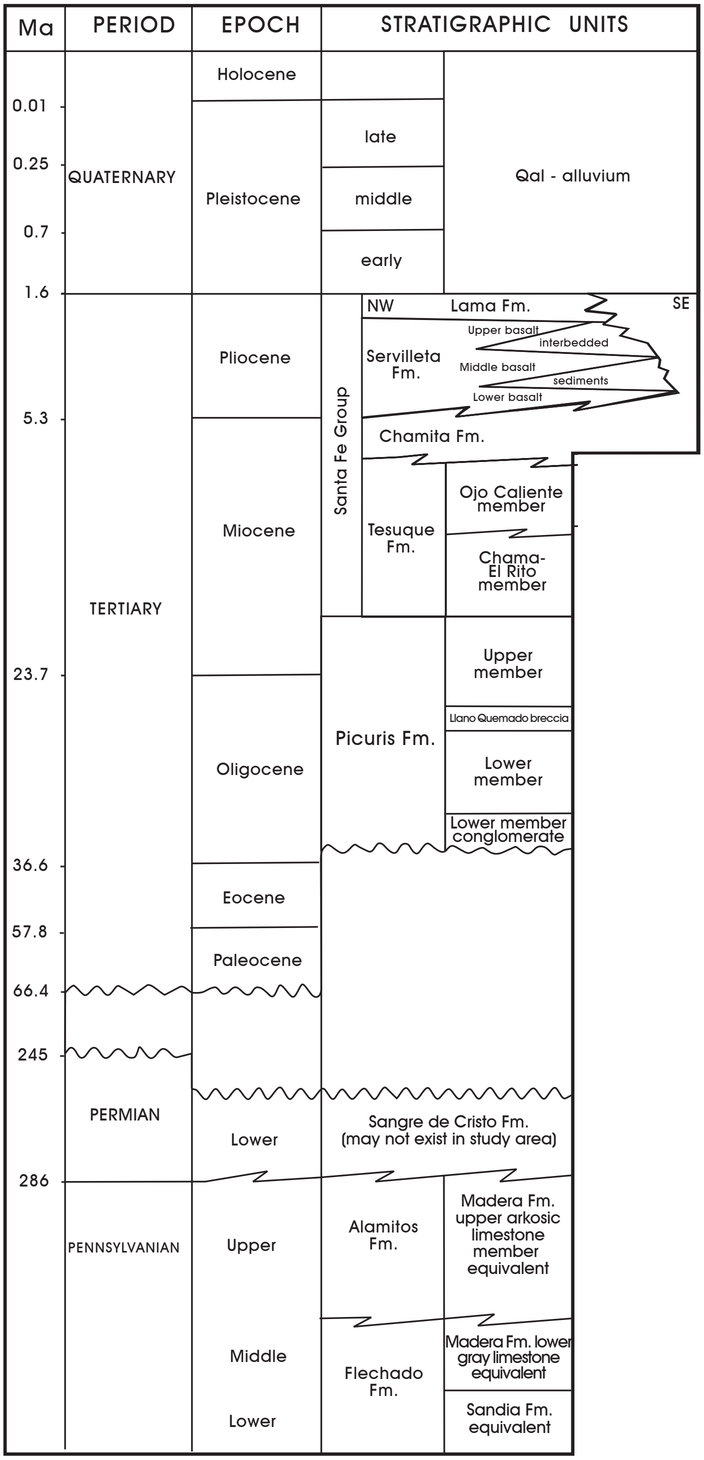

FIGURE 2. Taos Valley Stratigraphic Nomenclature (modified from Bauer et al., 1999)

limestone and sandstone, and clayey silt with reworked ash layers (?) from 1945 to 2110 ft (593 to 643 m) bgs, the total depth of the well. Based on the quartzite-rich gravel penetrated near the bottom of the BOR2/3 wells, the lower stratigraphic sequence encountered is interpreted to be the lower Picuris Formation and the upper Picuris Formation is absent (Fig. 4).

Chama-El Rito Member of the Tesuque Formation (Ttce)

Five wells in this study are completed primarily in the Chama-El Rito Member of the Tesuque Formation. The Chama-El Rito Member consists of subequal proportions of interbedded conglomerate and sandstone, with minor mudstone beds (Steinpress, 1981; Bauer and Kelson, 1998). Conglomerate beds contain a predominance of volcanic clasts with subordinate Precambrian granitic and quartzite clasts. Locally (in the vicinity of BOR2/3), volcanic clasts are subordinate to sedimentary clasts. This is interpreted to be the result of locally uplifted Paleozoic strata that provided a proximal source of coarse material. The Chama-El Rito Member has a thickness of up to 1575 ft (480 m) (Bauer and Kelson, 1998).

Ojo Caliente Sandstone Member of the Tesuque Formation (Ttoc)

Five wells in the study area are completed primarily in the Ojo Caliente Sandstone Member of the Tesuque Formation (well nests at RP2000/RP2500 and at BOR4/BOR6 are considered as single wells for this study). The Ojo Caliente Sandstone Member is a buff to light brown, fine to very fine-grained, poorly consolidated eolian sandstone with large-scale tabular cross-beds (Bauer and Kelson, 1998). While the Ojo Caliente is absent at the BOR2/3 location, it is identified in both drill cuttings and geophysical logs at the Airport well and the RP2500 well. At RP2500, the Ojo Caliente is differentiated from the overlying Chamita Formation on the basis of sorting and grain size. Fine-grained, well-rounded, well-sorted, unconsolidated tan sand with moderate oxidation and a distinct geophysical signature (relatively low-API gamma ray log values and generally parallel 16” and 64” resistivity logs; Fig 6) was encountered from 1305 ft to 2527 ft (398 to 770 m) bgs. Reddened layers overlying carbonate horizons, apparent Bt-Bk soil horizons, and intervals containing carbonate nodules were also observed during drilling in this interval. A well-developed soil with Bt and Bk horizons encountered between 1305 and 1315 ft (398 to 401 m) bgs is interpreted to mark the top of the Ojo Caliente. Based on subsurface data, the Ojo Caliente Sandstone Member varies in thickness from thin or absent on the south end of the Taos basin (BOR2/3) to greater than 1000 ft (305 m) along the Rio Pueblo de Taos (RP2500) to 340 ft (104 m) at the Taos Airport.

Chamita Formation (Tc)

The Tesuque Formation is overlain by the Miocene - Pliocene Chamita Formation (Fig. 2), which was originally defined in the Española Basin as the uppermost formation in the Santa Fe Group (Galusha and Blick, 1971). In the study area, the Chamita Formation consists of moderately to poorly sorted sandstone beds with clasts of intermediate volcanic rock, quartzite, and other metamorphic rocks (Bauer and Kelson, 1998). At locations where the Ojo Caliente Sandstone Member is absent, it is difficult to differentiate the Chamita Formation from the Chama-El Rito Member of the Tesuque Formation in drill cuttings. Similarly, where the Servilleta Formation (see below) is absent, it is also very difficult to determine the contact between the Chamita Formation and the overlying Lama formation. Based on Glorieta Geoscience Inc. subsurface lithologic and borehole geophysical data (Drakos and Hodgins, unpublished report to the Town of Taos, 2001; Drakos et al., unpublished report to the Town of Taos, 2002) and thickness estimates from Bauer et al. (1999), Chamita Formation thickness ranges from 0 (at BOR 2/3) to 890 ft (271 m) at RP2500. The well log from RP2500 shows that the Chamita Formation may interfinger with the underlying Ojo Caliente Sandstone Member at that location.

Servilleta Formation (Ts)

Interbedded basalt flows and sediments comprise the Servilleta Formation, which underlies either Quaternary alluvial deposits or the Lama formation, where present. Some previous workers (Dungan et al, 1984; Lipman and Mehnert, 1979) have separated the basalt flows and sediments into separately named units, while other researchers (e.g. Lambert, 1966) have grouped the interbedded sequence of three basalt units and sediments together as the Servilleta Formation. For purposes of this study, the Servilleta Formation is treated as a single unit that comprises up to three basalt flow members, each consisting of one or more individual flows (where present), interbedded sediments, fine-grained sediments at the top of the Servilleta Formation above the upper basalt flow member, and the baked zone (generally red clay) below the lower basalt flow member. The basalts are interlayered with gravel, sand and clay of mixed metamorphic, igneous and volcanic lithologies, with predominantly quartzite clasts. The sediments between the upper and middle Servilleta basalt flows include a fluvial deposit of rounded sand and quartzite-dominated gravel approximately 40 ft (12 m) thick that, together with fractured basalt at some locations, are a thin but moderately productive aquifer referred to informally as the “Agua Azul” aquifer (Drakos and Lazarus, 1998). The basalt flows range in age from 2.8 to 4.8 million years (Appelt, 1998; Lipman and Mehnert, 1979; Manley, 1976). The thickness of the entire Servilleta Formation (basalt flows and sediments included) ranges from 0 to 650 ft (198 m) (Dungan et al., 1984), with thinning/pinching out towards the Sangre de Cristo mountain front to the east and the Embudo fault zone to the south.

Quaternary Alluvium (Qal)

Alluvium overlying the upper Servilleta basalt flow member includes Quaternary alluvial-fan deposits that interfinger with fluvial deposits of the Rio Grande, Rio Hondo, and Rio Pueblo de Taos stream systems. The high terrace surfaces throughout the Taos basin record the culmination of aggradation along the Rio Grande during the Middle Pleistocene (Pazzaglia and Wells, 1990). The Plio-Pleistocene rift fill sequence underlying younger alluvium in the Taos basin has been informally named the Lama formation (Pazzaglia and Wells, 1990) or has been included as part of the Chamita Formation (Bauer et al., 1998). This unit includes distinctive weathered mud flow deposits observed in samples from boreholes and along Blueberry Hill road on the west side of Taos that have been referred to as the Blueberry Hill mudflows (Sorrel and Banet, unpubl. BIA Report, 1993). The Lama formation is likely correlative with the Plio-Pleistocene Ancha Formation, previously identified in the Española Basin (Galusha and Blick, 1971; Koning et al., 2002; Spiegel and Baldwin, 1963). Because the Lama formation is indistinguishable from Quaternary alluvium in drill cuttings and has been inferred at only one location based on geophysical logs (BOR 5; Drakos et al., 2001) the Lama formation is grouped with overlying alluvial deposits in this study. Total thickness of alluvium (± Lama formation) overlying the Servilleta Formation ranges from less than 100 ft (30 m) at Colonias Point to approximately 1500 ft (460 m) at BOR5 (Figs. 3 and 4).

DISCUSSION

Subsurface Correlations and Interpretations Based on Well Log Data

Lithologic and geophysical data from the Town wells (RP2500, RP2000, BOR2, BOR3, and the Taos Town Yard Exploratory Boring) and the BIA wells (BOR4/BOR6, BOR-5, BOR7, and K2/3) were used to delineate variations in thickness and extent of the basalt flows of the Servilleta Formation and underlying Tertiary basin fill sediments in the Taos area of the southern San Luis Basin (Figs. 4 and 5). The cross sections were constructed based on correlations from geophysical logs and from lithologic descriptions (Fig. 6).

Servilleta basalts increase in thickness from south to north within the Taos Valley; they are absent in BOR1, present as a single thin flow in BOR3, and present as three multiple-flow sequences at BOR4, K3, RP2500, and the Airport well. Servilleta basalts can be traced eastward in BIA wells K3, Tract B Tip site (BOR4/BOR6), and BOR5, where the upper Servilleta basalt is downdropped approximately 950 ft (290 m) within a mountain front graben, which is bounded on the west by the Seco fault and on the east by the Town Yard fault (Fig. 3). The average subsidence rate within the graben is approximately 0.1mm/yr (0.3 ft/1000yr) based on an age of approximately 3 Ma for the upper Servilleta basalt (Appelt, 1998). This subsidence rate is similar to the slip rate along the nearest segment of the Mountain Front fault calculated by Menges (1988, 1990). Down-to-the west offset across the Town Yard Fault is > 1390 ft (420 m), based on the depth at which Paleozoic sedimentary rocks were encountered in the Town Yard well (720 ft or 220 m), and the absence of pre-Tertiary sediments in BOR3, drilled to a depth of 2110 ft (640 m).

In the majority of wells drilled to date, Tertiary fluvial sediments appear to show small and large scale fining upward sequences, indicating deposition in an environment relatively free of tectonic influences. However, sediments in BOR3 and BOR5 are generally much coarser grained and appear to show small and large scale coarsening upward sequences, indicating that deposition may have been controlled by motion on the Town Yard and Seco faults (Figs. 3, 4, and 5).

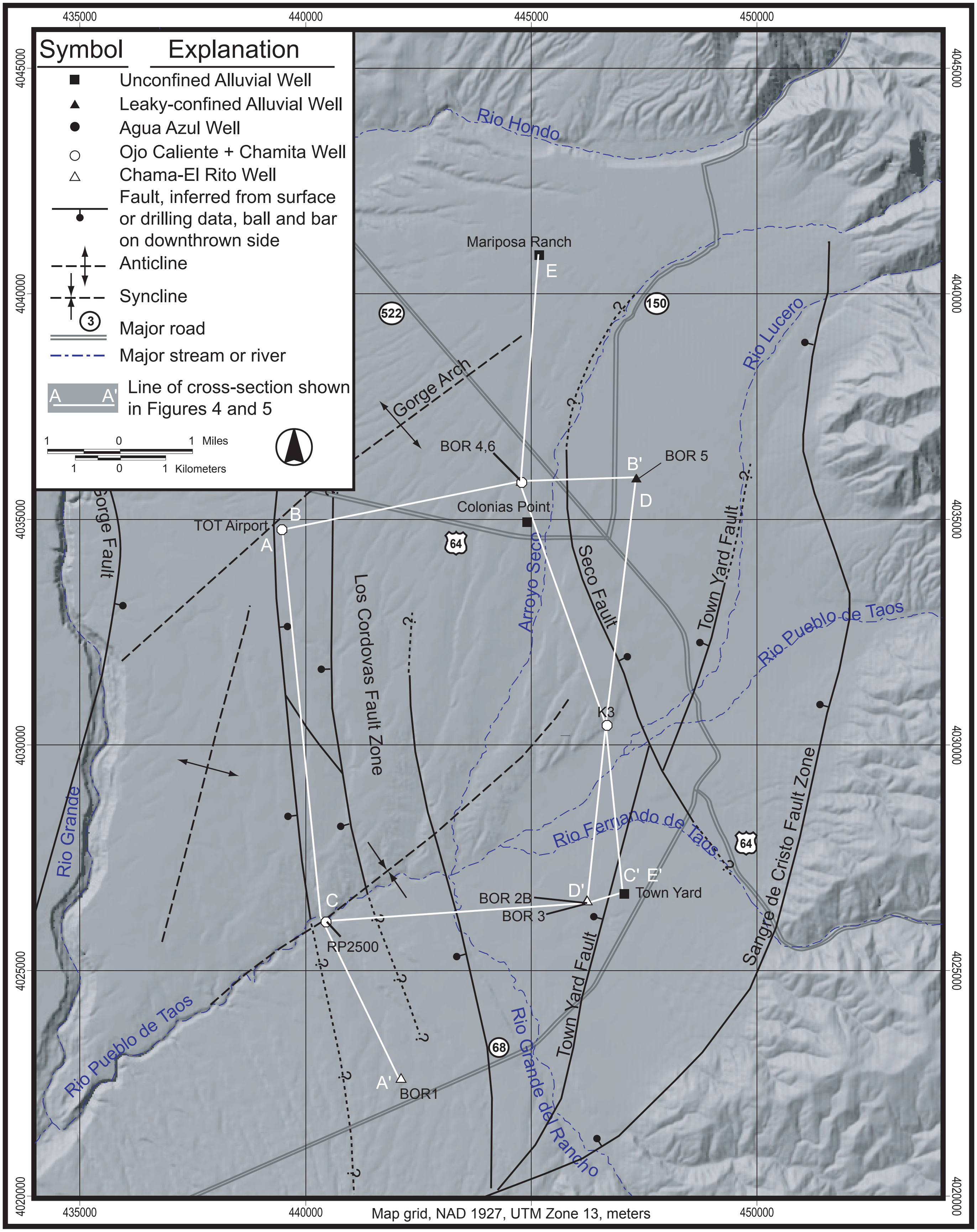

FIGURE 3. Map of study area showing cross section locations

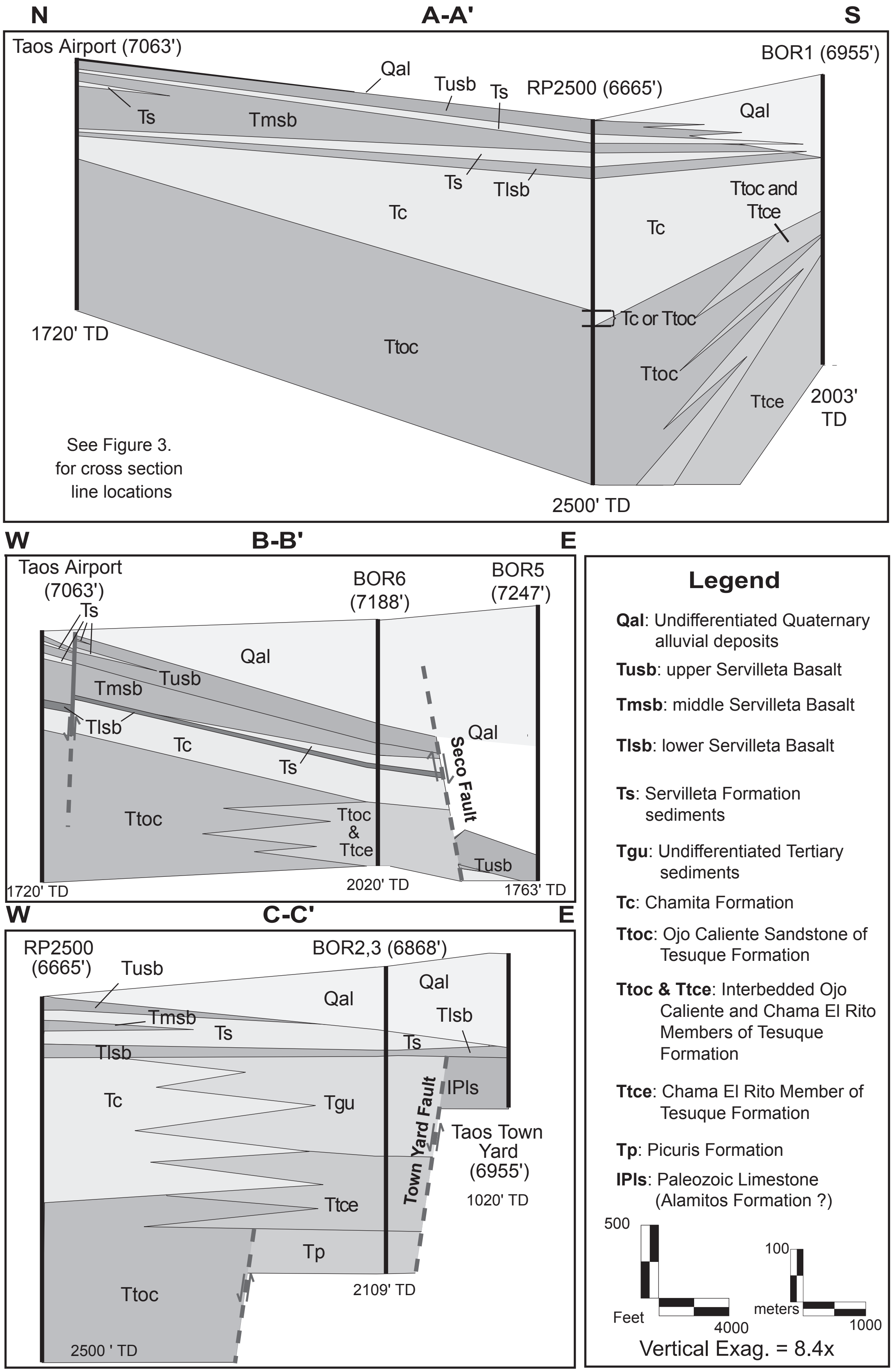

FIGURE 4. Cross sections through selected Taos area wells

Eolian sand of the Ojo Caliente Sandstone Member of Tesuque Formation is the most distinctive sedimentary unit in the basin and is identifiable in both well cuttings and geophysical logs (Fig. 6). The apparent thickness of the Ojo Caliente is greatest along the Rio Pueblo de Taos, suggesting deposition in a depression, possibly an ancestral Rio Hondo or Rio Pueblo, during mid-to-late-Miocene time. The Ojo Caliente sand may have been derived from the west, accumulating against the Chama-El Rito (see above) alluvial fans building off the eastern mountain front. This would account for the interfingering of these two members observed in BOR6 and BOR1 (Figs. 4 and 5).

CONCLUSIONS

Data from the drilling program helped to identify and constrain offset on several intrabasin faults. Servilleta basalts can be traced eastward in BIA wells K3, Tract B Tip site (BOR4/BOR6), and BOR5, where the upper Servilleta basalt is downdropped approximately 950 ft (290 m) within a mountain front graben. This graben is bounded on the west by the Seco fault and on the east by the Town Yard fault. The Town Yard fault projects into the present day Rio Lucero drainage, and the Seco fault projects into the Arroyo Seco drainage. The Town Yard fault was identified by drilling into the Paleozoic sedimentary rocks at the Town Yard well at 720 ft, whereas the nearby BOR3 well was drilled to a total depth of 2100 ft entirely in basin fill deposits.

Stratigraphic nomenclature developed for Tertiary sedimentary deposits in the Española Basin by Galusha and Blick (1971) is utilized for this study; however, revision of stratigraphic units may be required after additional surface and subsurface data become available. An eolian deposit interpreted as the Ojo Caliente Sandstone Member of Tesuque Formation was identified in cuttings and geophysical logs from several wells in the basin, where it ranged in thickness from thin or absent at BOR2/3 to greater than 1000 ft (305 m) along the Rio Pueblo de Taos (RP2500) to 340 ft (104 m) at the Taos Airport. The apparent thickness of the Ojo Caliente is greatest along the Rio Pueblo de Taos, suggesting deposition in a depression, possibly an ancestral Rio Hondo or Rio Pueblo, during mid-to-late-Miocene time. Where the Ojo Caliente is absent, identifying the contact between

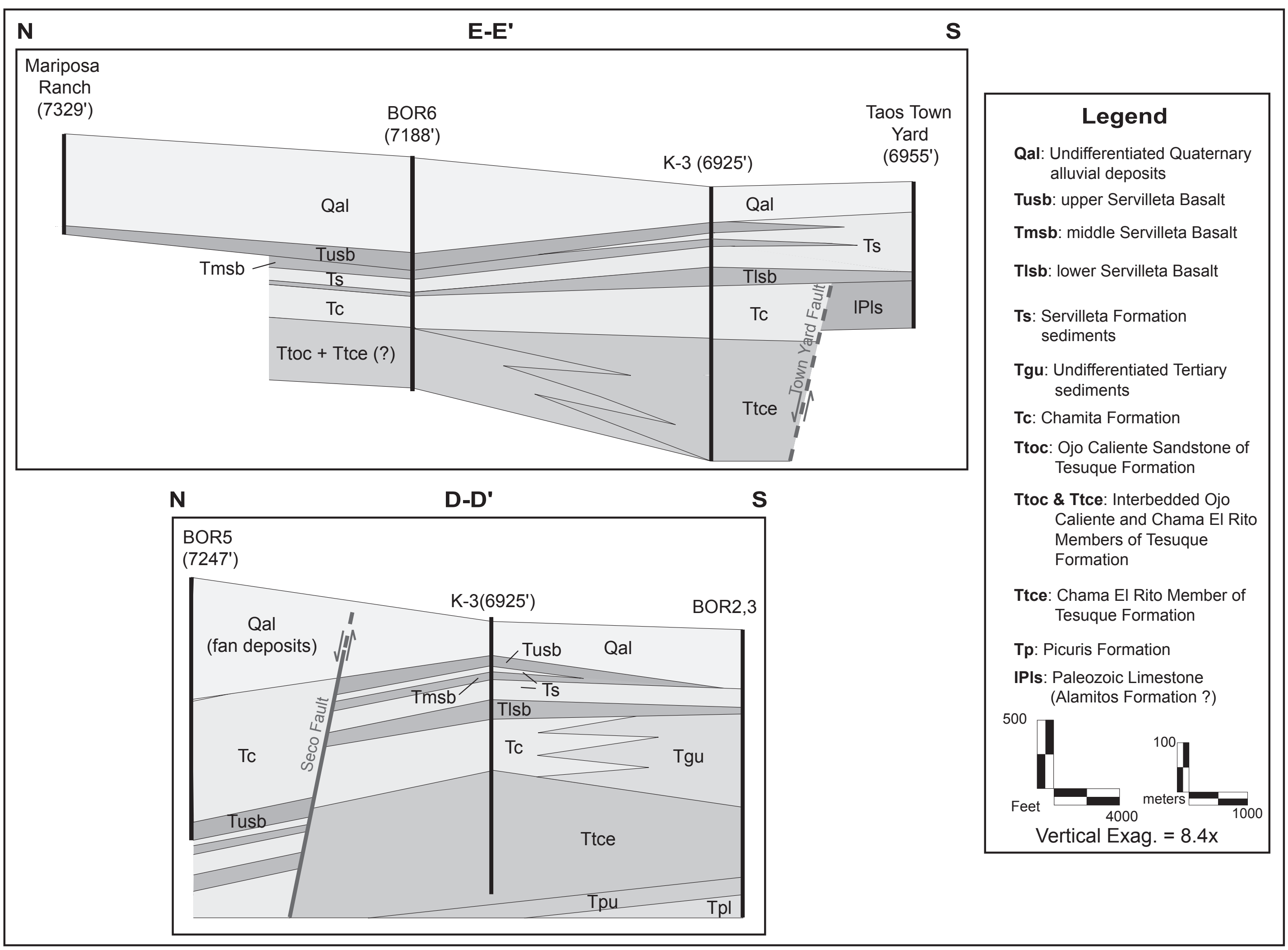

FIGURE 5. Cross sections through selected Taos area wells

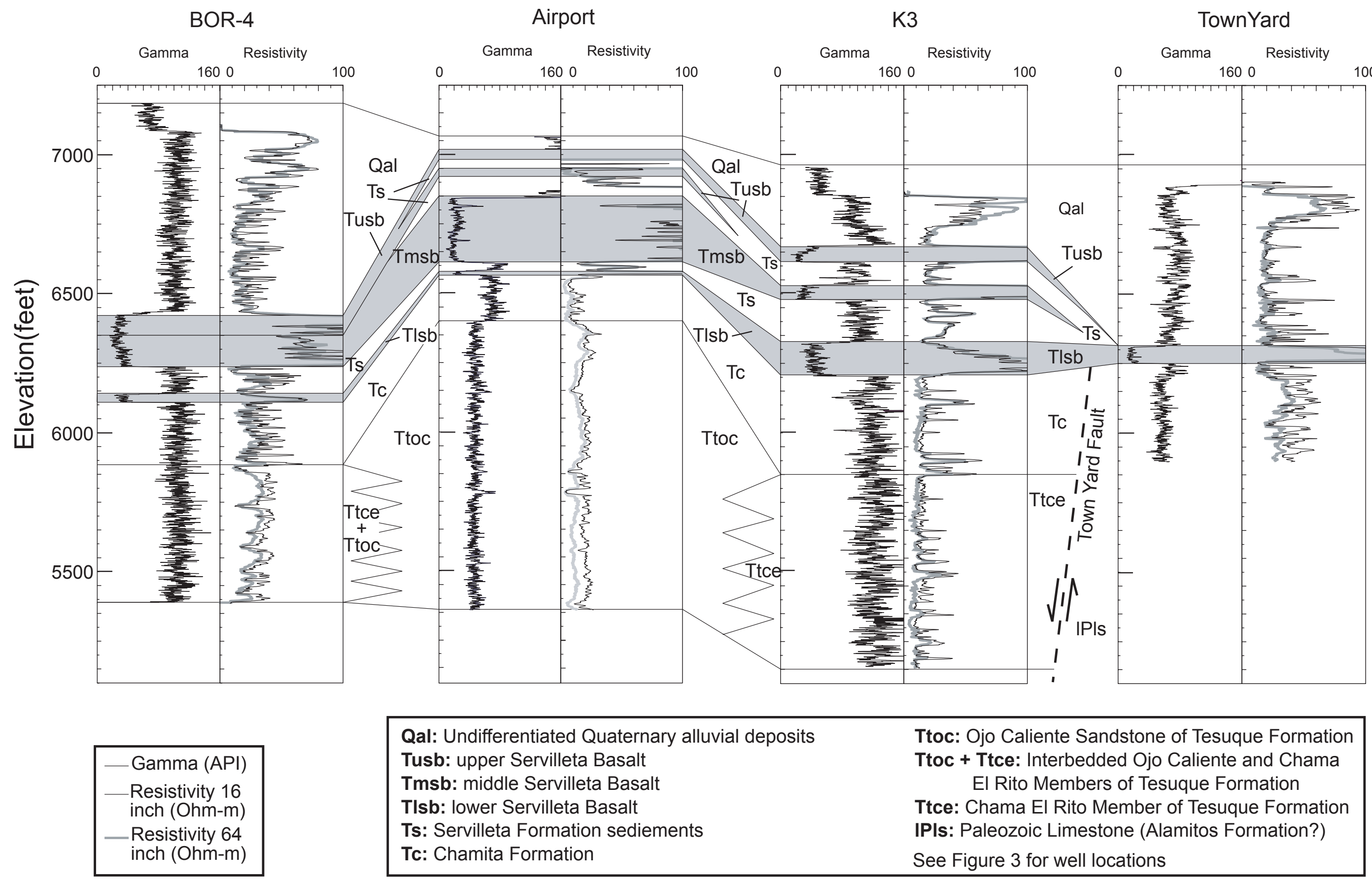

FIGURE 6. Correlation of units based on geophysical log interpretations

Chamita Formation and Chama-El Rito Member deposits based on drill cuttings and geophysical logs is difficult. However, a maximum Chamita Formation thickness of 890 ft (271 m) was identified at RP2500, suggesting that in most areas the Chamita - Chama-El Rito contact will be less than 900 feet below the top of the Chamita Formation. A coarse-grained gravel-dominated Chama-El Rito Member (?) deposit with abundant limestone and sandstone clasts observed at BOR2/3 is interpreted to represent deposition adjacent to Paleozoic strata uplifted along the Town Yard fault.

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APPENDIX A

WELL LOCATIONS FOR TAOS AREA WELLS CITED IN THIS STUDY

	UTM NAD 27, zone 13, m.			UTM NAD 27, zone 13, m.	
WELL NAME	Easting	Northing	WELL NAME	Easting	Northing
BOR2B/2C	446240	4026553	BJV #1	441230	4023480
BOR3	446247	4026541	BOR 1	442124	4022604
BOR5	447345	4035906	BOR 4 Deep	444766	4035805
BOR7	444280	4038930	BOR 6 #1	444797	4035805
K2 - K3	446688	4030429	BOR 6 #2	444797	4035805
RP 2000 Deep	440380	4026000	BOR2A	446247	4026541
RP 2500	440462	4026069	Town Taos Airport	439480	4034760
UNM/Taos	441310	4022260	Town Yard	447060	4026680