Hydrogeologic Framework of the La Bajada Constriction Area, New Mexico—Integration of Subsurface and Surface Geology

By David A. Sawyer and Scott A. Minor

Chapter G of

The Cerrillos Uplift, the La Bajada Constriction, and Hydrogeologic Framework of the Santo Domingo Basin, Rio Grande Rift, New Mexico

Edited by Scott A. Minor

Professional Paper 1720–G

U.S. Department of the Interior
U.S. Geological Survey

Contents

Figures

Table

Hydrogeologic Framework of the La Bajada Constriction Area, New Mexico—Integration of Subsurface and Surface Geology

By David A. Sawyer and Scott A. Minor

Abstract

Summary results of multidisciplinary investigations of the La Bajada constriction presented in this report are synthesized in this chapter. In the area of the constriction, where only sparse information exists regarding the subsurface hydrogeology, an integrated geologic and geophysical approach allows development of a geologic framework model that can provide input for regional ground-water flow models. The combination of surface geology based on new geologic mapping (chapters A, B, C, and E, this volume), airborne geophysics (aeromagnetic and time-domain electromagnetic surveys; chapters D and F, this volume), ground geophysical measurements (gravity and magnetotelluric surveys; chapters D and F, this volume), and data from the few wells in the area (this chapter) provides new constraints on the hydrogeologic framework of the La Bajada constriction area.

Data of differing quality from more than 60 water wells were used to generate a water-level contour map of the La Bajada constriction area, but only a few of these wells provided subsurface geologic constraints. The subsurface geology of the constriction area is depicted in a series of interpretative cross sections that allow three-dimensional visualization of the geologic framework. The northern flank of the Cerrillos uplift, bordering the east side of the La Bajada constriction, consists of north- to northeast-dipping Oligocene and Eocene volcanic and sedimentary deposits underlain by thick Cretaceous and older sedimentary rocks. These rocks form a northeast-facing monoclinal ramp beneath the Cerros del Rio volcanic field that drops into the southwestern Española Basin. The northern tip of the Cerrillos uplift is probably truncated by a northeast-striking fault or fault zone that is structurally linked with the Tetilla fault zone to the southwest. In the structurally low La Bajada constriction and overlapping northeastern Santo Domingo Basin, rift-basin sediments of the Santa Fe Group are interlayered with volcanic deposits from the Jemez and Cerros del Rio volcanic fields. These basin-fill deposits are cut by numerous, mostly north-northwest-striking, normal faults that are inferred to have growth-fault histories that produce increased amounts of dip-slip displacement with increasing depth. The southwest part of the La Bajada constriction is subdivided into three structural blocks separated from one another by prominent intrabasin faults of Miocene and younger age: (1) the eastern La Majada graben, between the La Bajada fault zone and Sanchez fault; (2) the central Reservoir horst, between the Sanchez and Cochiti faults; and (3) the western Cochiti graben, between the Cochiti and South Pajarito faults. The northwest border of the La Bajada constriction consists of the northeast-striking Pajarito fault zone and its uplifted footwall Saint Peters Dome block, composed chiefly of Jemez volcanic rocks and underlying pre-rift sedimentary rocks.

We conclude that through-going aquifers consisting of ancestral Rio Grande axial-river sand and gravel and coarse western-piedmont gravel form the predominant ground-water pathways through the La Bajada constriction between Española and Santo Domingo Basins. Eastern-piedmont sand and silty sand deposits that probably form fair to moderately good aquifers likely extend through the constriction beneath the entire northern Cerros del Rio volcanic field. On the southeast side of the La Bajada constriction within the Cerrillos uplift, thick, clay-rich Cretaceous marine shales of low hydraulic conductivity form a pervasive regional confining unit. Numerous, dominantly north-northwest-striking, intrabasin faults that project part way across the La Bajada constriction may locally partition or compartmentalize and deflect ground-water flow into fault-parallel directions. Complex interfingering of the sedimentary fill and volcanic rocks within the La Bajada constriction and Santo Domingo Basin, together with intrabasin faults that commonly juxtapose hydrologically contrasting geologic layers, result in a matrix of laterally and vertically variable hydrogeologic compartments.

Introduction

Studies by the U.S. Geological Survey were begun in 1996 to improve understanding of the geologic framework of the Albuquerque composite basin and adjoining areas, in order that more accurate hydrogeologic parameters could be applied to new hydrologic models. The ultimate goal of this multidisciplinary effort has been to better quantify estimates of future water supplies for northern New Mexico's growing urban centers, which largely subsist on aquifers in the Rio Grande rift basin (Bartolino and Cole, 2002). From preexisting hydrologic models it became evident that hydrogeologic uncertainties were large in the Santo Domingo Basin area, immediately up gradient from the greater Albuquerque metropolitan area, and particularly in the northeast part of the basin referred to as the La Bajada constriction (see chapter A, this volume, for a geologic definition of this feature as used in this report). Accordingly, a priority for new geologic and geophysical investigations was to better determine the hydrogeologic framework of the La Bajada constriction area. This chapter and the other chapters of this report present the results of such investigations as recently conducted by the U.S. Geological Survey.

The combination of surface geology based on new geologic mapping (chapters A, B, C, and E, this volume), airborne geophysics (aeromagnetic and time-domain electromagnetic surveys) (chapters D and F, this volume), ground geophysical measurements (gravity and magnetotelluric surveys) (chapters D and F, this volume), and data from a few critical wells (this chapter) provide new constraints on the hydrogeologic framework of the La Bajada constriction area. These lines of evidence can be used to help determine the subsurface distribution of aquifers and confining units of the Rio Grande ground-water flow system, which hydraulically connects the Española and Santo Domingo Basins. In the La Bajada constriction area, where only sparse information exists regarding the subsurface hydrogeology, this integrated geologic and geophysical approach provides the best geologic input available for regional ground-water flow models.

Direct subsurface geologic observations in the area of the La Bajada constriction are restricted to a relatively small number of water wells. No petroleum exploration wells have been drilled in the Santo Domingo Basin or the La Bajada constriction area. This situation contrasts with the considerable quantitative physical-property information available from a modest number of petroleum exploration wells drilled in the adjacent northern Albuquerque Basin and in the Hagan and Santa Fe embayments. The La Bajada constriction represents a critical hydrologic link in the regional Rio Grande aquifer system between the poorly constrained Santo Domingo Basin and the better studied Española Basin. Although sparse subsurface information from the northeast part of the Santo Domingo Basin suggests pronounced changes in regional water elevations across the La Bajada constriction, the large distances between wells and the lack of adequate quantitative geologic and geophysical data preclude accurate characterization of these changes.

In this chapter we first describe the limited subsurface water elevation and geologic information that is available from wells in the area of the La Bajada constriction. We then integrate these well data with regional surface geologic data and geophysical data described in the preceding chapters of this report to construct geologic cross sections and derive a more complete hydrogeologic framework model of the constriction area.

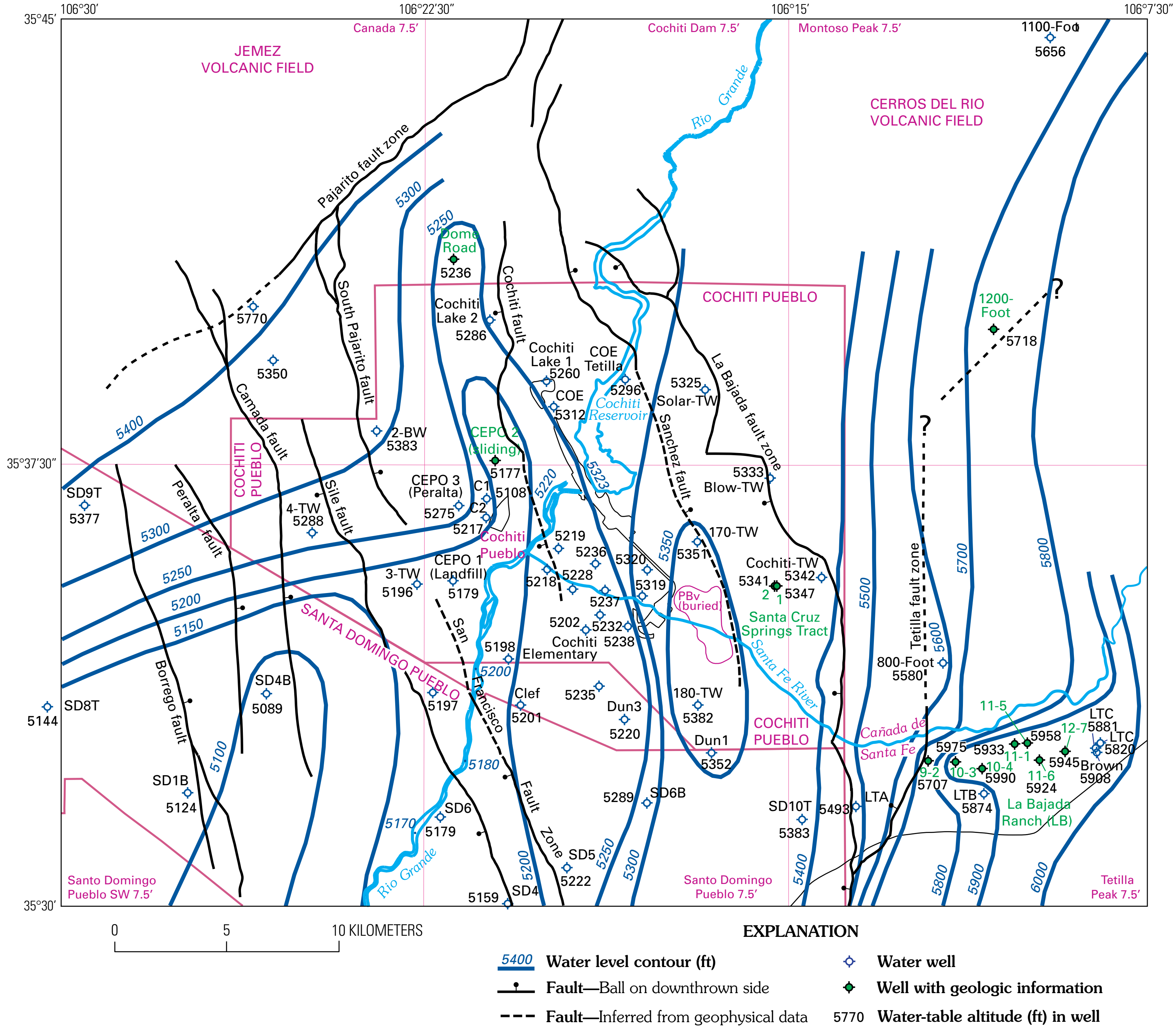
Subsurface Hydrologic and Geologic Data

Water Elevations in the La Bajada Constriction Area

The distribution of wells in the La Bajada constriction area and water-elevation contours based on those wells are displayed in figure G1. Those wells shown in figure G1 for which geologic information is available are keyed to table G1*A*, *B*. Well information for the Cochiti Pueblo area (table G1*A*) includes data derived from L.M. Bexfield (U.S. Geological Survey (USGS), written commun., 1999) and from the water level compilation of Bexfield and Anderholm (2000). Well data presented in table G1*B* were obtained from a variety of sources; some of the wells listed in this table are less accurately located than those listed in table G1*A*. Water elevations south of Cochiti Dam on the east side of the Rio Grande (fig. G1) were measured during a reservoir seepage study conducted after the dam was completed in 1973 (Blanchard, 1993). The wells south of Cañada de Santa Fe and east of the La Bajada fault (fig. G1) were drilled or compiled for a hydrogeologic study of the proposed La Bajada Ranch subdivision (Peery and Pearson, 1994). A few water levels were obtained from well permits on file at the New Mexico Office of State Engineer in Albuquerque. Water levels in the southern and southwestern parts of the area shown in figure G1 were provided by the New Mexico District, Albuquerque Office of the USGS Water Resources Division (J.M. Kernodle, USGS, written commun., 1995; L.M. Bexfield, USGS, written commun., 1999; Bexfield and Anderholm, 2000).

Although they are drawn on the basis of data derived from a variety of sources, the water-elevation contours in the La Bajada constriction area indicate a fairly uniform water-table configuration that generally slopes down to the west and south (fig. G1). Water elevations decrease toward the Rio Grande from the east, north, and northwest, conforming to the overall drop in elevation and natural stream-flow gradient within the Santo Domingo valley. Within the southern Cochiti Pueblo area the water table forms a trough that is centered on the Rio Grande and opens southward into the Santo Domingo Basin (figs. A2, G1). Local deviations from this overall pattern can be detected in areas where more closely spaced

Figure G1. Regional water table (contoured at 50 ft intervals), water wells, and major faults in the La Bajada constriction area. Water table generally consistent with compilations of Titus (1961), Shomaker (1995), and Bexfield and Anderholm (2000). Water elevations not necessarily measured within the same aquifer or confining unit. Data from water wells shown on map summarized in table G1*A*, *B*. In table G1*B* and in text, the prefix "LB" precedes the number assigned to La Bajada Ranch wells southeast of Cañada de Santa Fe in the southeast part of map.



EXPLANATION

5400 **Water level contour (ft)**

Fault—Ball on downthrown side

Fault—Inferred from geophysical data

◇ **Water well**

◆ **Well with geologic information**

5770 **Water-table altitude (ft) in well**

Table G1*A*. Water table elevations in the Cochiti Pueblo area.

[UTM, Universal Transverse Mercator; total depth, as reported by driller. Sources of data: L.M. Bexfield, U.S. Geological Survey (unpublished data, 1999); Chamberlin and others (1999); Michael Quintana, Cochiti Environmental Protection Office (written commun., 1996); John Sorrell, Bureau of Indian Affairs (written commun., 1996); Spiegel and Baldwin (1963); and unpublished records of the New Mexico Office of State Engineer. Data source abbreviations: CEPO, Cochiti Environmental Protection Office; DAS, D.A. Sawyer; NMBGMR, New Mexico Bureau of Geology and Mineral Resources; OSE, New Mexico Office of State Engineer; USGSWSP, U.S. Geological Survey Water-Supply Paper]

Quadrangle	SWL (ft)	UTM east (m)	UTM north (m)	Well name	Collar elevation (ft)	Total depth (ft)	Depth to water (ft)	Data source	Local well number
Santo Domingo Pueblo									
	5,347	386347	3939102	Santa Cruz Springs 1	5,501	875	154	DAS, 1998 Mar 13	
	5,341	386312	3939096	Santa Cruz Springs 2	5,494	545	153	DAS, 1998 Mar 13	
	5,202	380370	3937815	Cochiti Elementary	5,362	300	160	Bexfield, 1999 Feb 03	16N.06E.32.224
	5,179	376306	3939370	Landfill well CEPO 1	5,239	130	60	CEPO	
	5,177	377650	3943183	Sliding well CEPO 2	5,379	400	123	Bexfield, 1999 Feb 03	16N.06E.07
	5,351	383867	3940508	170–T Windmill	5,458	170	110	CEPO	
	5,382	383849	3935366	180–T Windmill	5,527	180	145	CEPO	
	5,217	377369	3941337	Cochiti 2 (C2)	5,284		67	CEPO	
Santo Domingo Pueblo SW									
	5,275	376523	3941720	Peralta well CEPO 3	5,335	401	60	CEPO	
	5,383	374004	3944135	Cochiti 2B Windmill	5,533	290	150	Bexfield, 1999 Feb 03	16N.05E.10.2
	5,196	375165	3939312	3–T Windmill	5,330	170	134	CEPO	
	5,288	371913	3940981	4–T Windmill	5,877	630	589	CEPO	
Cochiti Dam									
	5,108	377356	3941984	Cochiti 1 (C1)	5,298	250	190	Bexfield, 1999 Feb 03	16N.06E.18.311
	5,260	379293	3945594	Cochiti Lake 1	5,525	805	265	Bexfield, 1999 Feb 03	16N.06E.05.132
	5,286	377567	3947556	Cochiti Lake 2	5,639	1,142	353	CEPO	
	5,312	379500	3944807	Corps of Engineers	5,579	400	267	CEPO	
	5,296	381761	3945607	Corps of Engineers Tetilla	5,556	400	260	CEPO	
	5,333	386168	3942517	Blow–T Windmill	5,591	350	258	CEPO	
	5,325	384240	3945245	Solar–T Windmill	5,858	650	533	CEPO	
	5,236	376462	3949468	Dome Road	5,818	1,312	582	Chamberlin; NMBGMR	17N.05E.24.344
Tetilla Peak									
	5,342	387721	3939328	Cochiti–T Windmill	5,628	360	286	CEPO	
	5,580	391515	3936625	800-Foot well	6,175	795	595	USGSWSP 1525	16N.07E.33.444
Montoso Peak									
	5,718	393235	3946980	1200-Foot well	6,725	1,207	1,007	OSE	

Table G1*B*. Water table elevations in the La Bajada constriction area.

[All quadrangles are 7.5 minute quadrangles. SWL, elevation of static water level as reported by driller. Primary sources of well data: L.M. Bexfield, U.S. Geological Survey (written commun., 1999 and 2001); P.J. Blanchard, U.S. Geological Survey (Blanchard, 1993); J.M. Kernodle, U.S. Geological Survey (written commun., 1996); John Shomaker and Associates, La Bajada Ranch subdivision report (Shomaker, LBR; Peery and Pearson, 1994); and well-permit records of the New Mexico Office of the State Engineer (OSE)]

Quadrangle	SWL (ft)	Well name	Collar elevation (ft)	Total depth (ft)	Depth to water (ft)	Aquifer unit	Data source	Local well number	Owner	Date measured
Tetilla Peak										
	5,707	LB09–2	6,110	700	403	Km	Shomaker, LBR	15N.07E.09.4312	W. Thompson	1994 Jul 07
	5,975	LB10–3	6,135	640	160	Km	Shomaker, LBR	15N.07E.10.3143	W. Thompson	1994 Aug 09
	5,990	LB10–4	6,145	640	155	Km	Shomaker, LBR	15N.07E.10.4314	W. Thompson	1994 Aug 09
	5,932	LB11–1	6,125	360	193	Tg/QTa	Shomaker, LBR	15N.07E.11.1431	W. Thompson	1994 Aug 09
	5,958	LB11–5	6,122	475	164	Tg/QTa	Shomaker, LBR	15N.07E.11.1442	W. Thompson	1994 Aug 09
	5,924	LB11–6	6,133	470	209	Tg/QTa	Shomaker, LBR	15N.07E.11.4141	W. Thompson	1994 Aug 09
	5,945	LB12–7	6,085	460	140	Tg	Shomaker, LBR	15N.07E.12.3121	W. Thompson	1994 Aug 09
	5,908	Brown	5,940	54	32		Shomaker, LBR	15N.07E.12.421	Brown	1962 Dec 02
	5,493	LTA	5,668	440	175	QTa	Shomaker, LBR	15N.07E.17.310	L. Thompson	1983 Apr 25
	5,874	LTB					Shomaker, LBR	15N.07E.15.23242	L. Thompson	1994 Jul 15
	5,881	LTC	5,913	55	32	QTa	Shomaker, LBR	5314001653400	L. Thompson	1975 Apr 29
	5,820	LTD	5,900	405	80		Shomaker, LBR	15N.07E.12.24	L. Thompson	1990 Apr 02
Montoso Peak										
	5,656	1100-Foot	6,636		980		Spiegel and Baldwin, 1963			
Canada										
	5,770		5,920		150		OSE			
	5,350		5,970		620		OSE			
Santo Domingo Pueblo SW										
	5,377	SD9T	6,375		998		J.M. Kernodle, 1996			
	5,144	SD8T	5,855		711		J.M. Kernodle, 1996			
	5,089	SD4B	5,635		546		L.M. Bexfield, 1999, 2001	15N.05E.05.243		
	5,124	SD1B	5,124				J.M. Kernodle, 1996			
	5,179	SD6	5,185		6		J.M. Kernodle, 1996; L.M. Bexfield, 2001.			
Santo Domingo Pueblo										
	5,159	SD4	5,360		201		J.M. Kernodle, 1996; L.M. Bexfield, 2001.			
	5,222	SD5	5,275		53		J.M. Kernodle, 1996			
	5,289	SD6B	5,440		151		J.M. Kernodle, 1996			
	5,383	SD10T	5,600		217		J.M. Kernodle, 1996			
	5,219	4–4					Blanchard, 1993			
	5,218	3–2					Blanchard, 1993			
	5,236	18–7					Blanchard, 1993			
	5,228	13–6					Blanchard, 1993			
	5,237						Blanchard, 1993			
	5,320	18–4					Blanchard, 1993			
	5,319	13–8					Blanchard, 1993			
	5,238	13–9					Blanchard, 1993			
	5,232	13–10					Blanchard, 1993			
	5,201	Clef			24		Blanchard, 1993			
	5,235				250		OSE			
	5,220	Dun3			271		OSE			
	5,352	Dun1			138		OSE			
	5,198				72		OSE			

water-elevation data exist. For example, a narrow north-northwest-trending water-table trough is identified in an area west of the Rio Grande extending from the Cochiti Pueblo settlement northwest through the town of Cochiti Lake (fig. G1, area of Cochiti Lake wells 1 and 2 and Dome Road well). This trough may be due to increased water usage in the area, although no water was pumped near the Dome Road well before it was drilled in 1998. Relatively high water levels west of the river at the CEPO 3 Peralta well and Cochiti 2–BW and 4–TW windmills (fig. G1, table G1*A*), provide evidence that the water-table trough west of the Rio Grande bends into a southwest trend beneath Santo Domingo Pueblo lands. The westward shift of the trough relative to the Rio Grande has been noted in previous studies of the regional hydrology and hydrogeology of the area (Titus, 1961; Smith and Kuhle, 1998c; Bexfield and Anderholm, 2000; Smith, McIntosh, and Kuhle, 2001). These studies postulated that the shift is due to higher hydraulic conductivity in sediments west of the Rio Grande than directly beneath it. An anomalously high water-table level (5,770 ft) in the northwesternmost well in the Cochiti Pueblo area (fig. G1), northwest of Tent Rocks National Monument (fig. A4), may be due to a perched water table in the volcanic-rock aquifer (or aquifers) flanking the Jemez Mountains.

East of the Rio Grande the water table generally slopes to the west (fig. G1, Bexfield and Anderholm, 2000), although this part of the basin is not tightly constrained by wells that penetrate the unconfined aquifer system in basin fill. However, data from windmills on the La Majada Mesa surface (pl. 1) suggest a small area of slightly higher water-table elevations southeast of Cochiti Dam. These higher elevations appear to define a water-table mound 10–35 ft above the surrounding water table. Wells surrounding this mound include the 180–TW windmill, 170–TW well, and Dun1 well (fig. G1, table G1*A, B*). Wells that have lower water elevations east and north of the 180–TW well include the Cochiti–TW windmill, the Santa Cruz Springs Tract wells, the Blow–TW windmill, and the farther north and topographically higher Solar–TW windmill. The water-table mound is bounded to the east by a small but persistent water-table trough along the base of the La Bajada fault-zone escarpment (fig. G1). We discuss possible geologic controls of the water-table mound later in this chapter.

Water table measurements in the easternmost La Bajada constriction come from a few deep wells that penetrate rocks of the Cerros del Rio volcanic field and intersect the water table in underlying basin-filling sediments of the Santa Fe Group. North of Cañada de Santa Fe, only three wells have been measured: the 1100-Foot, the 1200-Foot , and 800-Foot wells. On the basis of water elevations in these three wells of 5,656 ft, 5,718 ft, and 5,580 ft, respectively (Spiegel and Baldwin, 1963), the water table can be projected with a relatively smooth gradient down to the 5,400 ft water elevation contour at the base of the La Bajada escarpment (fig. G1). The configuration of the water table in the eastern area is consistent with the configuration shown on previous water-table maps of the surrounding region (Titus, 1961; Spiegel and Baldwin, 1963; Shomaker, 1995; Grant, 1997, 1999; and Bexfield and Anderholm, 2000). At present, no hydrologic evidence suggests any discontinuities in the water-table surface beneath the Cerros del Rio volcanic field (Titus, 1961; Spiegel and Baldwin, 1963) that could be attributed to hydrologic barriers such as basaltic feeder dikes. Numerous intrusive feeder systems likely are associated with the dozens of individual vent areas in the Cerros del Rio volcanic field. However, existing water-elevation data are so sparse in the area of the Cerros del Rio that we are unable to resolve the effect of any specific structures (for example, dikes or faults) on the regional water table.

South of Cañada de Santa Fe and east of the La Bajada fault zone, a number of water table measurements are summarized in a report on the proposed La Bajada Ranch subdivision (Peery and Pearson, 1994). In that study seven new wells were drilled through the Mesita de Juana volcano, the southernmost volcanic vent of the Cerros del Rio volcanic field (pl. 2, fig. A4), and existing well records at the New Mexico Office of State Engineer were compiled (summarized in fig. G1, table G1*B*). The water-elevation and exploratory hydrogeologic information produced by this investigation markedly improved upon that available to Spiegel and Baldwin (1963) in this area. A local higher altitude water-table plateau between 5,900 and 6,000 ft elevation is defined by these well data, suggesting that the associated aquifer may not be connected with the regional hydrologic flow system. The middle and eastern La Bajada Ranch wells penetrate saturated Tuerto Gravel (Koning and others, 2002), which forms the uppermost part of the regional Santa Fe Group aquifer system in the Española Basin. The Tuerto is unsaturated in the westernmost drill holes, and water elevations measured in rocks of subjacent Espinaso Formation, Galisteo Formation, and Mancos Shale provide no clear evidence of ground-water connection with the regional Santa Fe Group aquifer system (Peery and Pearson, 1994).

Subsurface Geologic Constraints From Wells

Despite the existence of more than 20 wells in the Cochiti Pueblo area (fig. G1, table G1*A*) and more than 10 additional wells to the east (table G1*B*; summarized by Peery and Pearson, 1994), only a few of these wells provide subsurface geologic constraints that supplement the surface geologic and geophysical data used in the development of regional hydrogeologic models. Below we discuss these few important wells in the context of Santo Domingo Basin architecture and La Bajada constriction terranes outlined in this report. Geologic well data are discussed from east to west, first for the Cerros del Rio and Cerrillos uplift area, next for the northeast part of the Santo Domingo Basin, and finally for the Saint Peters Dome block.

Cerros del Rio Volcanic Field and Cerrillos Uplift

The eastern boundary of the La Bajada constriction is concealed beneath the Cerros del Rio volcanic plateau (CDRVF) in the footwall block of the La Bajada fault zone

(LB) (fig. A2). In the downthrown block of the Tetilla fault zone (TT, fig. A2), east of the La Bajada fault zone, 2.5–2.7-Ma basalts of the Cerros del Rio volcanic field basalts overlie Santa Fe Group basin-fill sedimentary rocks. The 800-Foot well is located just east of the buried north-striking projection of the Tetilla fault zone (discussed in chapter E of this volume and later in this chapter) which forms part of the eastern border of the constriction (pl. 2, fig. G1). Unfortunately, there is no geologic information available for this well, which was drilled by the Soil Conservation Service before 1938 (Spiegel and Baldwin, 1963). Nonetheless, magnetotelluric station MT–4 (chapter F, this volume; Williams and Rodriguez, 2003; pl. 2; section C-C′, pl. 6) is located just north of this well, and it was used to determine a depth of 240 m to a regional electrical conductor (the Mancos Shale). This result provides evidence to interpret the northernmost extent of the Cerrillos uplift where it is located at shallow depth beneath relatively thin (80 m) thick basalts of the Cerros del Rio volcanic field.

The 1200-Foot well, located north of the 800-Foot well in the central part of the Cerros del Rio volcanic field (pl. 2, fig. G1), was originally drilled by the Soil Conservation Service in the early 1900s and redrilled by the U.S. Forest Service in 1961. A detailed driller's lithologic log was obtained from the well-permit files of the Office of State Engineer in Albuquerque; it is summarized in figure G2. It indicates that the hole penetrated a sequence of basalt flows, each ranging from 26 to 157 ft thick, interbedded with sediments down to a depth of 840 ft. The interflow sediments are clay rich or silt rich, range from 26 to 107 ft thick, and include variable amounts of basaltic cinders. The uppermost basalt is overlain by 50 ft of clay of variable hardness. The strong lithologic contrast in drilling characteristics between the hard basalt flows and softer interbedded sediments increases the likelihood that the driller's log is accurate. The base of the basaltic interval (256 m or 840 ft depth) corresponds closely with the 270±30 m (886±96 ft) thickness of basalt determined at nearby magnetotelluric station MT–5 (sections B-B′ and E-E′; pls. 2, 6; fig. F2*B*). Below the basalt is interbedded clay and gravel from 840 to 880 ft depth and 108 ft of dry sand and gravel. The water table lies at a depth of 1,007 ft in a sandy silt and gravel zone, and the main water-producing zone extends from 1,054 ft depth to the bottom of the hole at 1,207 ft (fig. G2). The most hydrologically conductive interval is a sand zone extending from 1,115 to 1,163 ft depth, bounded above and below by moderately productive sandy silt and interbedded gravel.

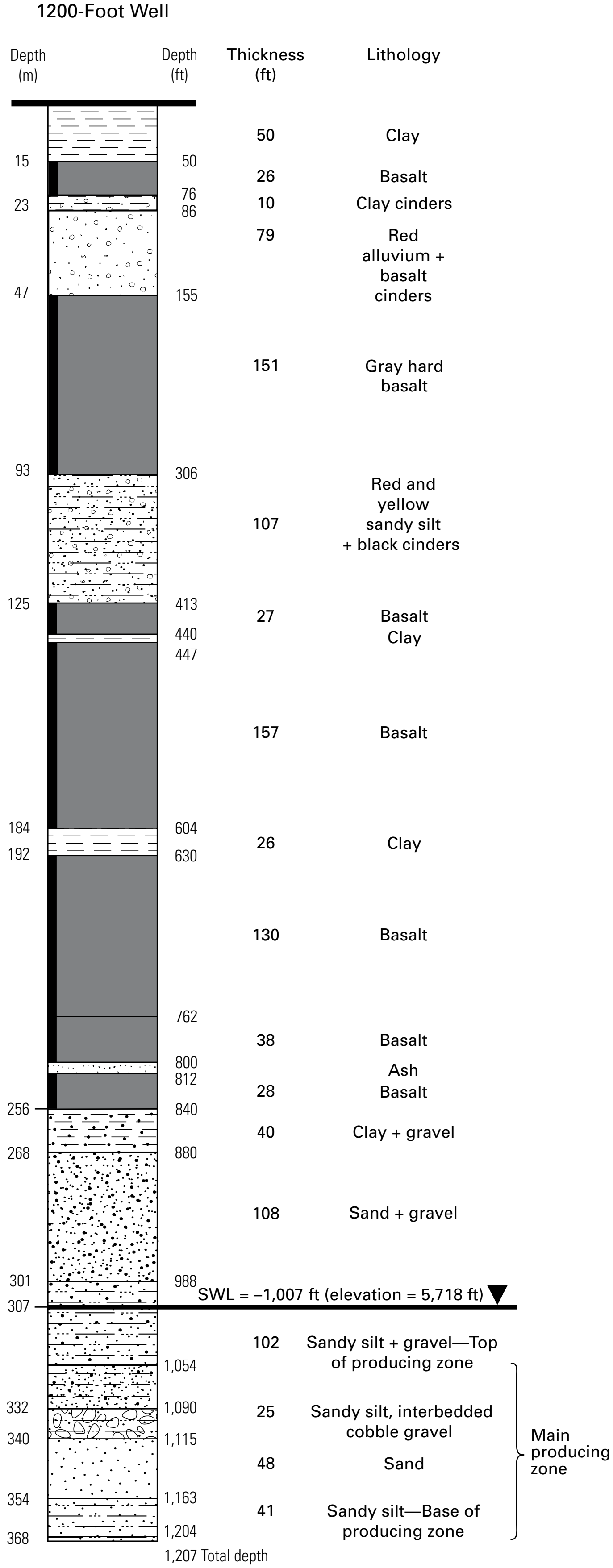


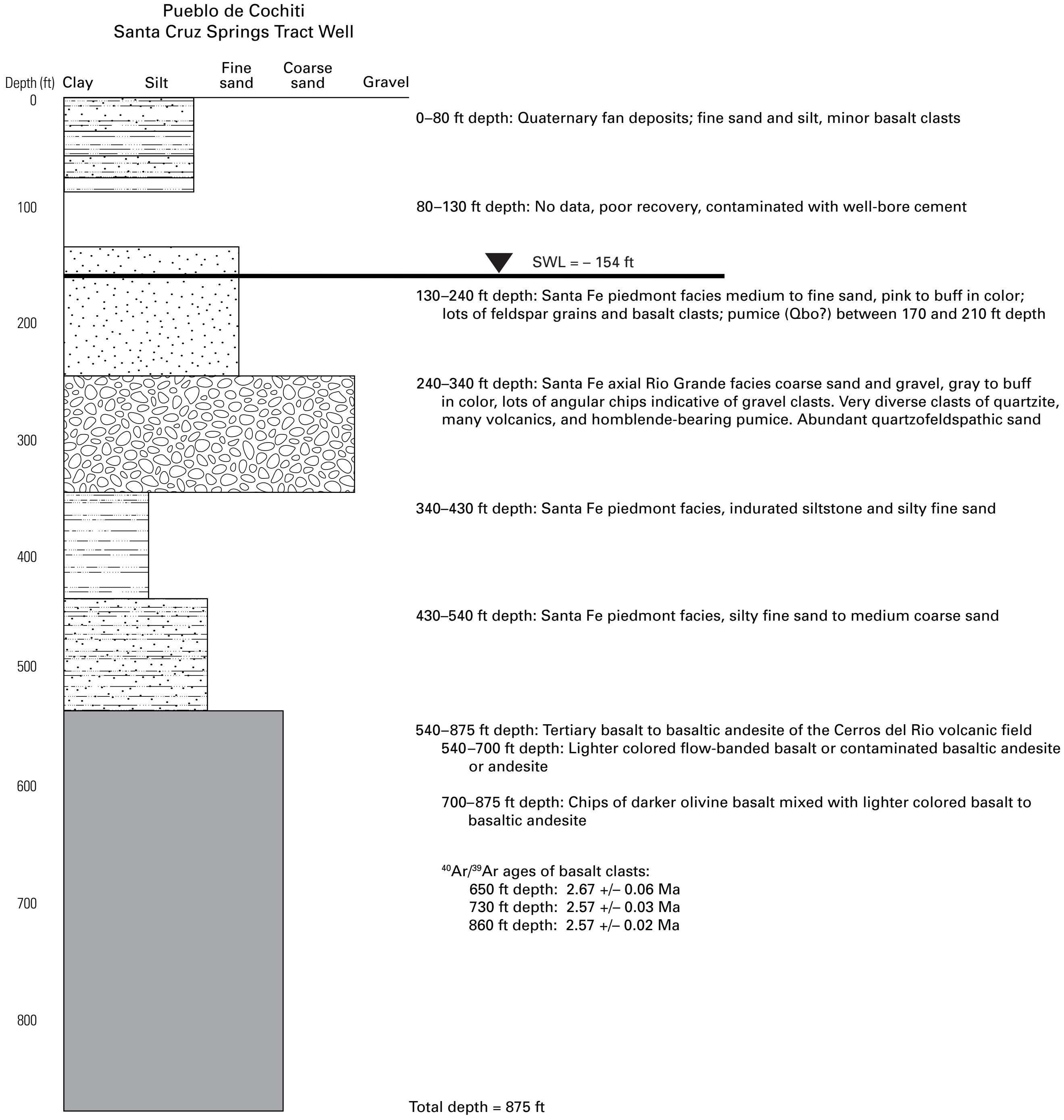
Figure G2. Lithologic column of 1200-Foot well, northeastern La Bajada construction; column based on driller's log obtained from New Mexico Office of State Engineer, Albuquerque. Well cuts at least six basalt flows (gray shading) interbedded with clastic sediments that overlie Santa Fe Group sediments; top of Santa Fe Group is 256 m deep. SWL, static water level.

Subsurface geologic constraints from the Cerrillos uplift area south of Cañada de Santa Fe include data from the seven wells drilled in the proposed La Bajada Ranch subdivision (fig. G1) (Peery and Pearson, 1994) beneath the northern flank of the Mesita de Juana volcano (pl. 2, fig. A4). Lithologic descriptions of cuttings from these wells are briefly summarized here and the water elevations measured in the wells are summarized in table G1*B*. The eastern part of section D-D′ of plate 6 shows our interpretation of the rock units and structures intersected by the La Bajada Ranch wells; it is simpler than the complex stratigraphy and structure interpreted by Peery and Pearson (1994) beneath the surface basalt. The stacked flows of basalt of Mesita de Juana (unit Tbj, pl. 2) range from 60 to 182 ft in total thickness and are largely unsaturated, on the basis of the well cuttings and measured water elevations. Unconsolidated sand and gravel of the Tuerto Gravel (unit QTt) (Koning, Pazzaglia, and McIntosh, 2002; called Ancha Formation in Peery and Pearson, 1994) form the most productive aquifer and compose the upper 40 to 60 ft of the saturated zone in these wells. These sediments were reassigned to the Tuerto based on the dominantly monzonitic provenance of their clasts (Koning, Pazzaglia, and McIntosh, 2002). Beneath the Tuerto, the Eocene Galisteo Formation (unit Tg), consisting of interbedded sandstone and siltstone, forms the major aquifer in the three eastern wells (LB12–7, LB11–5, and LB11–6 (table G1*B*)). Peery and Pearson (1994) interpreted complex stratigraphic juxtapositions within the three central wells (LB11–1, LB10–4, and LB10–3 (table G1*B*)) as owing to faulting. Alternatively, we explain the complexity as owing to unconformities and abrupt stratigraphic thickening and pinch-outs of sedimentary and volcanic or intrusive units (section D-D′, pl. 6). For example, sediments of the Tuerto Gravel have a saturated thickness of almost 165 ft in LB11–1 and overlie the Galisteo Formation. In contrast, Tuerto sand and gravel in the two wells immediately west of LB11–1 (wells LB10–4 and LB10–3) are markedly thinner (<50 ft thick) and overlie 100–150 ft of Espinaso Formation (unit Te) volcaniclastic sediments that contain a vesicular basaltic lava flow and, in turn, overlie the Cretaceous Mancos Shale (unit Km). The westernmost La Bajada Ranch well, LB09–2, penetrates less than 100 ft of the basalt of Mesita de Juana and 40 ft of Tuerto Gravel that rests directly on Mancos Shale. In this well, the water table was penetrated at depth of 403 ft, much deeper than in the other wells (table G1*B*). Tuerto sand and gravel pinches out toward the west before reaching the La Bajada escarpment. Thus, it appears likely that there is little or no hydrologic connection between the shallow Tuerto aquifer in the eastern and central wells and the deeper water level found in the Mancos in the westernmost hole (section D-D′, pl. 6).

La Bajada Constriction

The north-northwest-trending La Majada graben, located between the newly defined southern extension of the Sanchez fault and the La Bajada fault zone, obliquely transects the La Bajada constriction in the northeast part of the Santo Domingo Basin (SC, LB, figs. A4, E9). The Santa Cruz Springs Tract well provides the only subsurface geologic constraints within the La Majada graben (section C-C′, pl. 6; fig. G1). Basalt, basaltic andesite, and andesite lava flows of the Cerros del Rio volcanic field were measured in this well from 540 ft to the bottom of the hole at a depth of 875 ft (fig. G3). The upper 160 ft (540–700 ft depth) of the lava is lighter colored, contains flow bands, and ranges in composition from basaltic andesite to andesite (G.A. Smith, University of New Mexico, written comm., 2001). An age determined for the upper lava, sampled from homogeneous cuttings at a depth of 630 ft, is 2.67±0.06 Ma (Smith, McIntosh, and Kuhle, 2001). Cuttings of the lower basalt lava (700–875 ft depth) consist of darker olivine basalt mixed with lesser amounts of lighter-colored basalt to basaltic andesite. Two argon ages were determined for this interval, 2.57±0.03 Ma (730 ft depth) and 2.57±0.02 Ma (860 ft depth) (Smith, McIntosh, and Kuhle, 2001). These latter two, very precise, ages are indistinguishable. The older age obtained above concordant younger ages is stratigraphically problematic, but it may be that the upper lavas in the hole are derived from landsliding of basaltic rock off the nearby La Bajada fault scarp. This process is pervasive along the modern La Bajada escarpment (Sawyer and others, 2001).

Santa Fe Group basin-fill sediments above the basalts of the Cerros del Rio volcanic field in the Santa Cruz Springs Tract well record distinctive changes in geologic environment in the past 2.5 million years. From 540 to 430 ft depth, generally unconsolidated Santa Fe Group sediments consist of dominantly silty fine sand, interbedded with medium-coarse sand of the eastern piedmont facies of the Sierra Ladrones Formation; from 430 to 340 ft depth, these sediments are overlain by a dominantly fine grained cemented silt facies (fig. G3; (G.A. Smith, University of New Mexico, written comm., 2001). The upper silt facies appears in the time-domain electromagnetic survey (chapter F, this volume) as a low-resistivity zone (section C-C′, pl. 6; figs. F7*E*; F10; F11*D;* F12*C*, *D*), extending undisturbed from the La Majada graben westward across the Sanchez fault zone and into the central Reservoir horst (fig. A4). Overlying these fine-grained deposits are ancestral Rio Grande axial river gravels of the Sierra Ladrones Formation at depths of 240–340 ft. These hydrogeologically important deposits contain abundant coarse sand and gravel; cuttings are derived from a diverse suite of gravel clasts that include quartzite, many types of volcanic rock, and hornblende-bearing pumice (G.A. Smith, University of New Mexico, written commun., 2001). Hydraulically conductive quartzofeldspathic sand is also abundant in this interval. Eastern piedmont facies deposits overlie the axial gravels from depths of 130–240 ft. From depths of 170–210 ft, these sediments include pumice interpreted as the 1.61-Ma Otowi (lower) Member of the Bandelier Tuff. This pumice correlates with outcrops of the Otowi Member exposed at the surface south of the well on the north side of Galisteo Creek (unit Qbo, pl. 2; fig. A4). These upper eastern piedmont facies sediments are pink to buff in color and contain many potassium-feldspar grains as well as basalt clasts derived from basalts of the Cerros del Rio volcanic field in the



0–80 ft depth: Quaternary fan deposits; fine sand and silt, minor basalt clasts

80–130 ft depth: No data, poor recovery, contaminated with well-bore cement

130–240 ft depth: Santa Fe piedmont facies medium to fine sand, pink to buff in color; lots of feldspar grains and basalt clasts; pumice (Qbo?) between 170 and 210 ft depth

240–340 ft depth: Santa Fe axial Rio Grande facies coarse sand and gravel, gray to buff in color, lots of angular chips indicative of gravel clasts. Very diverse clasts of quartzite, many volcanics, and hornblende-bearing pumice. Abundant quartzofeldspathic sand

340–430 ft depth: Santa Fe piedmont facies, indurated siltstone and silty fine sand

430–540 ft depth: Santa Fe piedmont facies, silty fine sand to medium coarse sand

540–875 ft depth: Tertiary basalt to basaltic andesite of the Cerros del Rio volcanic field
540–700 ft depth: Lighter colored flow-banded basalt or contaminated basaltic andesite or andesite

700–875 ft depth: Chips of darker olivine basalt mixed with lighter colored basalt to basaltic andesite

^{40}Ar/^{39}Ar ages of basalt clasts:
650 ft depth: 2.67 +/– 0.06 Ma
730 ft depth: 2.57 +/– 0.03 Ma
860 ft depth: 2.57 +/– 0.02 Ma

Total depth = 875 ft

Figure G3. Lithologic column of Santa Cruz Springs Tract well, eastern Cochiti Pueblo. Lithologic descriptions are based on description of cuttings by G.A. Smith (University of New Mexico, written commun., 2001; Smith, McIntosh, and Kuhle, 2001) and on well data provided by John Sorrell (Bureau of Indian Affairs, written commun., 1996). Axial gravels in the well (240–340 ft depth) provide evidence of eastward lateral migration of the Rio Grande nearly to the La Bajada fault zone between 2.5 and 0.5 Ma. Beneath the axial gravel, a silt-rich interval (340–430 ft depth) probably corresponds with a high-electrical-conductivity unit above basalt in magnetotelluric section 630 (chapter F, this volume). ^{40}Ar/^{39}Ar ages of basalt clasts from the 650–860 ft depth interval reported in Smith, McIntosh, and Kuhle (2001). The well was drilled for Cochiti Pueblo by the Bureau of Indian Affairs before 1996. SWL, static water level.

footwall block of the La Bajada fault zone. The water table was intersected at a depth of 154 ft within sediments having a mixed arkosic and basaltic provenance characteristic of the eastern piedmont facies. No cuttings were recovered from the 80–130 ft depth interval, and Quaternary surficial deposits consisting of fines form the uppermost interval from 80 ft depth to the surface.

The Santa Cruz Springs Tract well provides evidence for the subsidence history of the southern part of the La Majada graben after deposition of the Cerros del Rio basalts (that is, after 2.5 Ma). More than 540 ft of sediment was deposited in the southern La Majada graben during its development. No evidence has been found to indicate fault offset on middle and upper Pleistocene surficial terrace deposits. Thus, most movement along the Sanchez and La Bajada fault zones bordering the southern La Majada graben occurred before 0.5 Ma (Machette and others, 1998; Smith, McIntosh, and Kuhle, 2001; Sawyer and others, 2001). Fault movement in the northern part of the graben may have continued after deposition of the 55-ka El Cajete tephra that appear to be cut by the Sanchez fault just west of the Rio Grande (D.P. Dethier, oral commun., 1999) (chapter E, this volume). The 2.5–0.5 Ma main episode of graben subsidence coincides with the time of major rhyolite eruptions that formed the Valles caldera. The 1.61-Ma Bandelier Tuff pumice at 210–170 ft depth in the Santa Cruz Springs Tract well (fig. G3) indicates that nearly 60 percent of the sediment was deposited in the first million years after the main volume of basalts of the Cerros del Rio volcanic field had erupted. Lateral migration of the ancestral Rio Grande to the eastern margin of the northeast part of the Santo Domingo Basin during this time was likely coeval with peak tectonic activity along the central part of the La Bajada fault zone (Smith, McIntosh, and Kuhle, 2001). This activity was followed by westward migration of the Rio Grande to a more central position within the northeast part of the Santo Domingo Basin as movement along the central La Bajada fault zone waned during the past 0.5 million years.

The near-surface geology west of the Sanchez fault in the Reservoir horst (pl. 2, fig. A4) is characterized by relatively thin, shallow basalts (units Tb, Tbpb, pl. 2) that form the western edge of the Cerros del Rio volcanic field (sections A-A′, B-B′, C-C′, pl. 6). The axial gravel facies of the Sierra Ladrones Formation (unit QTsa) is widespread beneath the basalts. None of the wells located in this structural block have geophysical logs or geologic descriptions of cuttings. Many of the shallow volcanic rocks underlying the horst, however, have distinctive magnetic and electrical resistivity signatures that are discussed in more detail in chapters D and F (this volume), respectively, and later in this chapter.

The geology of the western La Bajada constriction is made up of volcanic rocks from the proximal Jemez volcanic field to the northwest that interfinger with basin-fill sediments of the Santa Fe Group (sections A-A′, B-B′, C-C′, pl. 6). The Santa Fe Group basin-fill sediments include the western piedmont Cochiti Formation (unit QTc) volcaniclastic facies, and the axial-river (unit QTsa) and eastern piedmont (unit QTsp) facies of the Sierra Ladrones Formation (pl. 2). The main structural feature in this part of the constriction is the Cochiti graben, located between the east-dipping South Pajarito and west-dipping Cochiti faults (pl. 6; fig. A4). Wells drilled in the Cochiti graben include the Cochiti 2–BW and 3–TW windmills, several production wells that supply the Cochiti Pueblo settlement (Cochiti wells 1 and 2; C1 and C2, fig. G1), the monitoring CEPO 1 (Landfill) and CEPO 3 (Peralta) wells, and the Cochiti Golf Course (Cochiti Lake 2) production well (fig. G1, table G1*A*). No subsurface geologic or borehole geophysical data are available for these seven wells, and subsurface geology in the area can only be interpreted from surface geology and geophysical imaging of the subsurface (chapters D and F, this volume). Within the Cochiti graben, geophysical logs and geologic data are available only for the Dome Road and the CEPO 2 (Sliding) wells (fig. G1); they are summarized below.

In the CEPO 2 (Sliding) well, geophysical logs were run down to the completion depth of 400 ft (fig. G4, table G1*A*). This monitoring well was drilled just north of the Cochiti Pueblo town site, where it was collared in Quaternary alluvium at the surface. No geologic descriptions of cuttings or samples were obtained at the time of drilling. Volcaniclastic sediments of the Cochiti Formation interfinger with ancestral Rio Grande axial gravel deposits in outcrops near the well (pl. 2). Resistivity, gamma-ray, neutron, spontaneous potential, and caliper logs were obtained from the well. The gamma-ray and long-normal (64-in.) resistivity logs for the hole are shown in figure G4, against which is plotted our interpretation of sediment grain size. Relatively low gamma-ray values and very high resistivities (generally 150–250 ohm-m) that were recorded above the static water table (123 ft depth) probably correlate with sand and perhaps with some gravel. A very high resistivity zone (200–365 ohm-m) at 80–98 ft depth is probably gravel.

Below the water table, gamma-ray values increase in many discrete thin beds to more than 90 GR API and correspond with a pronounced decrease in resistivity to less than 25 ohm-m (fig. G4). These petrophysical characteristics are most consistent with clay-rich sediments. At 140–269 ft depth, geophysical logs indicate a thick sequence of clay-rich sediments comprising as many as 40 separate clay horizons. These clay-rich beds, most greater than 105 GR API, are interspersed with siltstone and only very minor sandy silt lenses, which are inferred on the basis of the coupled response of gamma-ray and resistivity values, the latter of which are mostly less than 10 ohm-m. This sequence of clay-rich beds was likely deposited in a lacustrine setting, although lake beds have not yet been identified at the surface within the Cochiti Formation.

The lower 130 ft of the well consists of two packages of very high resistivity sediments, probably gravel, interfingering with sand and thinner, low-resistivity and high-gamma-ray, clay-rich intervals (fig. G4). The resistivity of the thicker gravel intervals (40–45 ft) ranges from 50 to 75 ohm-m, very high values compared with resistivities measured for saturated Santa Fe Group sediments by magnetotelluric and time-domain

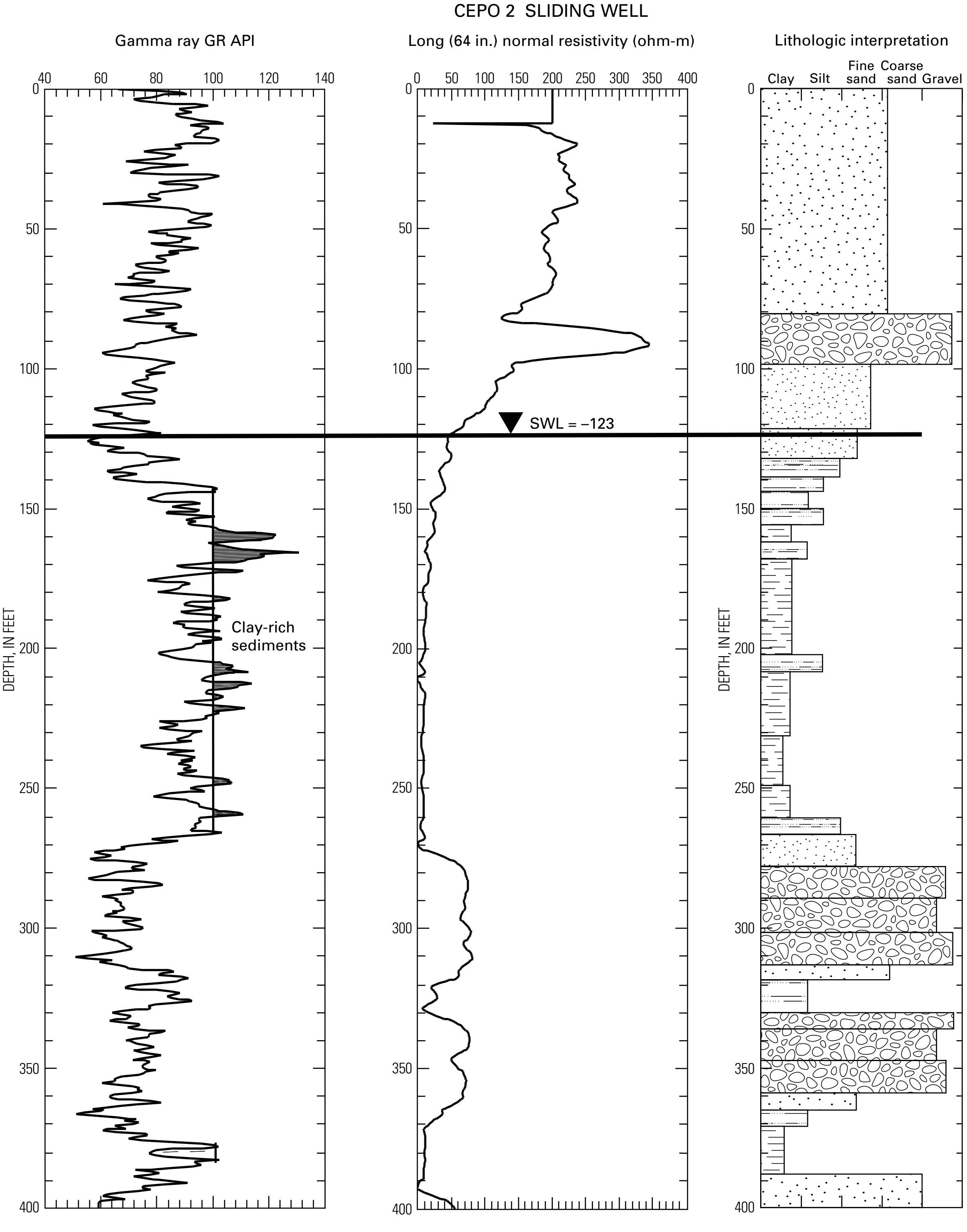


Figure G4. Gamma ray and long-normal resistivity logs and lithologic interpretation of CEPO 2 (Sliding) well in Cochiti Pueblo. The thick, low-resistivity sequence and corresponding high gamma-ray values at depths of 140–269 ft interpreted to represent a thick, clay-rich, probably lacustrine deposit. The well was drilled for Cochiti Environmental Protection Office (CEPO) in September 1996 by Rodgers Drilling and logged by Southwest Geophysical Services. Well data were provided by Jacob Pecos, Gary Valdo, and Michael Quintana of the Cochiti Environmental Protection Office and were digitized by Center Line Data as part of this investigation. SWL, static water level.

electromagnetic surveys (chapter F, this volume). A likely depositional setting of this lower well sequence is a river environment, where the thinner clay-rich zones represent thin overbank muds. As described in chapter F (this volume), the thick, low-resistivity lacustrine(?) zone is widespread west of the Rio Grande in the shallower parts of the saturated zone. Interestingly, it is enough of an electrical conductor in the time-domain electromagnetic survey (chapter F, this volume) to mask the high-resistivity gravels that lie below it in the CEPO 2 well.

The Dome Road well in the northern part of the Cochiti graben was drilled in August and September 1998 by the USGS Water Resources Division, in cooperation with the New Mexico Office of State Engineer. The New Mexico Bureau of Mines and Mineral Resources (Chamberlin, Jackson, and Connell, 1999) provided a geologic description and summary of the geophysical logs of the well. The well was sited on the Cañada de Cochiti Grant, north of Cochiti Pueblo in the west-central part of the Cochiti Dam quadrangle (fig. G1). The well was collared in the basal part of the Otowi Member of the Bandelier Tuff. The base of the tuff was visible in the mud pit only 2 ft below the ground surface. Below the tuff, the entire well was in volcaniclastic gravel and sand of the Cochiti Formation (fig. G5, modified from Chamberlin, Jackson, and Connell, 1999). Chamberlin, Jackson, and Connell (1999) interpreted sediments in the upper part of the hole as equivalent to the gravel of Lookout Park. However, D.P. Dethier (unpub. maps, 2000) did not find this unit as he mapped, and according to G.A. Smith (University of New Mexico, written commun., 2004) it is not present.

The lithologic log from the Dome Road well (fig. G5) indicates at a depth of 545 ft a change in grain size from volcaniclastic pebble gravel above to volcaniclastic sand and gravelly sand below that continues to the completion depth of 1,312 ft (400 m). Geophysical logs (resistivity, gamma-ray, density, density porosity, or neutron porosity) coupled with geologic samples for the Dome Road well (fig. G5, modified from Chamberlin, Jackson, and Connell, 1999) indicate homogeneous deposits of coarse-grained gravel and sand, with little vertical distinction in the interpreted lithology. The grain-size break interpreted from cuttings in the lithologic log is not evident in the borehole geophysical logs. High gamma-ray values (100–150 GR API) are probably related to high U, Th, and K associated with the dominantly rhyolitic clast composition of the Cochiti Formation. Induction resistivity ranged from 30–60 ohm-m throughout the Cochiti Formation without distinctive intervals. Chamberlin, Jackson, and Connell (1999) interpreted the water table in this well to be at a depth of 583 ft, on the basis of the abrupt decrease in sonic log travel time (fig. G5). The volcanic sand, gravelly to silty sand, and minor gravel lenses intersected in the hole below 545 ft are interpreted to have high hydraulic conductivity. Correlation of this well with surface geologic exposures of Cochiti Formation (pl. 2) mapped and described by Smith and Kuhle (1998c) and Smith, McIntosh, and Kuhle (2001) indicates that the Cochiti Formation in this area consists of fairly homogeneous coarse sand and gravel.

Figure G5 (facing page). Geophysical and lithologic logs of Dome Road well, northwest part of La Bajada constriction, based on Chamberlin, Jackson, and Connell (1999). The entire well is in gravel and sand of the western piedmont facies of the Santa Fe Group (Cochiti Formation). Although logs indicate high lithologic variability on a small scale (10–30 ft), resistivity and especially gamma-ray geophysical log responses are broadly similar throughout the entire well. Gamma-ray and neutron logs probably are affected by chemical composition of rhyolite volcanic material and thus deviate from typical simple log responses of mixtures of nonvolcanic clastic sand and clay. Geophysical log abbreviations: Av C Den, average compensated density; Delta-T, travel time; Den Por, density porosity; Ind Res, induction resistivity; Neut Por, neutron porosity; SP, spontaneous potential. SWL, static water level.

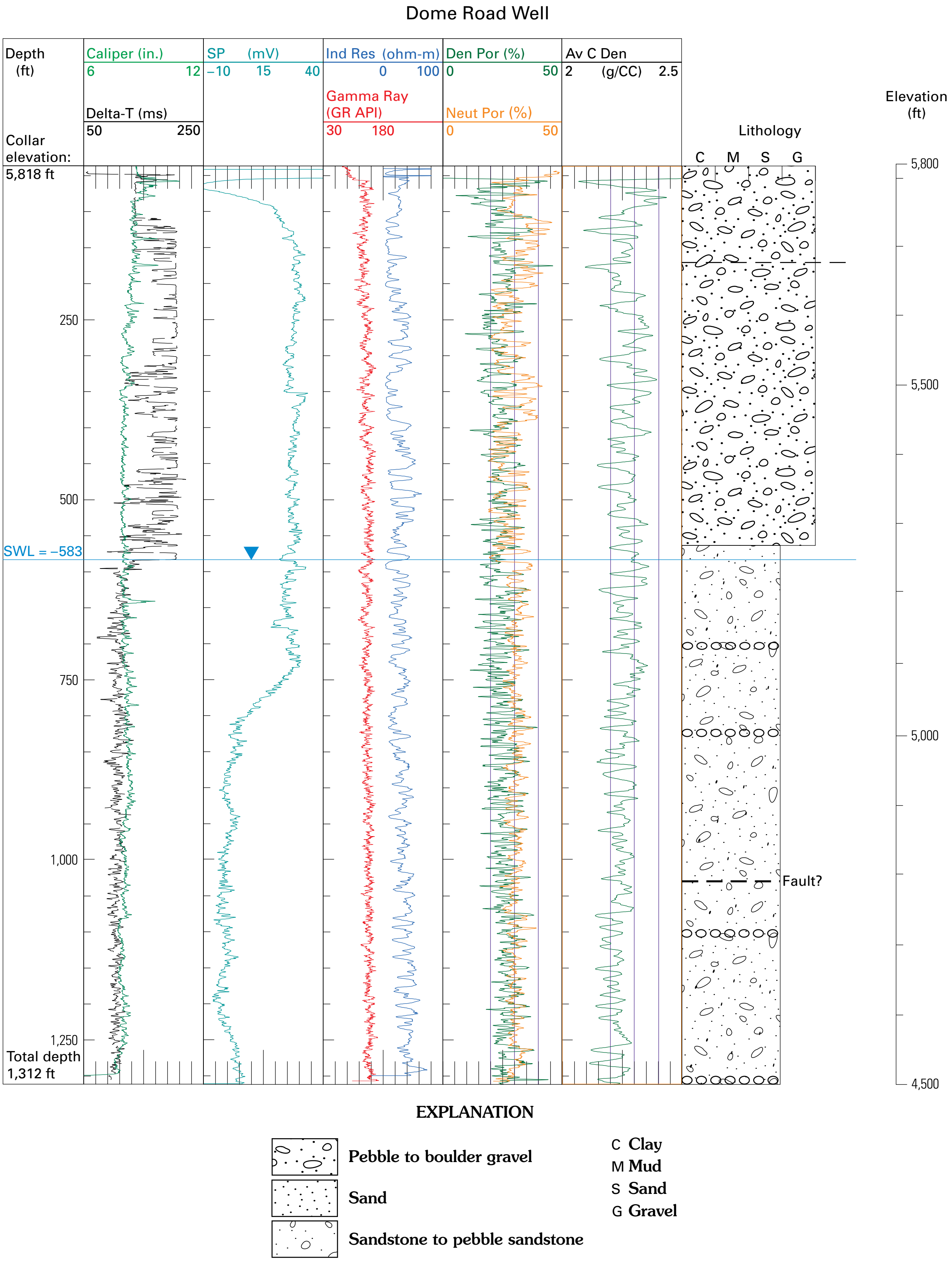
Saint Peters Dome Block

Subsurface constraints on geology derived from the Saint Peters Dome block adjacent to the La Bajada constriction are quite limited. No wells with geologic or geophysical logs are drilled in the block west of the northeast-striking segment of the Pajarito fault zone north of Tent Rocks National Monument (pl. 2; figs. A4, G1), and no subsurface geologic information is available from nearby wells east of the southwest projection of the fault zone, including the 5,350 ft water-elevation well and the Cochiti 2–BW windmill (fig. G1).

Subsurface Hydrogeologic Framework of the La Bajada Constriction Area

Introduction

In this section the subsurface geologic framework of the La Bajada constriction and bounding uplifts is described to identify principal geologic factors that may influence groundwater flow between the Española and Santo Domingo Basins. Serial cross sections were constructed to depict subsurface geologic interpretations of the La Bajada constriction area and to facilitate three-dimensional visualization of the hydrogeologic framework of the area. The sections were constructed principally by using the following sources of information: the map compilation of surface geology shown in plate 2; subsurface constraints from the aeromagnetic, gravity, and electromagnetic survey data presented in chapters D and F (this volume); and subsurface hydrologic and geologic data from wells described earlier in this chapter. Below approximately 300 m depth, most geologic relations shown, in particular the interfingering relations of the various facies of the Santa Fe Group (that is, unit QTsp, eastern piedmont deposits of the Sierra Ladrones Formation; unit QTsa, axial gravel deposits of the Sierra


Dome Road Well
Depth (ft)
Collar elevation: 5,818 ft
Caliper (in.)
6
12
Delta-T (ms)
50
250
SP (mV)
−10
15
40
Ind Res (ohm-m)
0
100
Gamma Ray (GR API)
30
180
Den Por (%)
0
50
Neut Por (%)
0
50
Av C Den
2 (g/CC) 2.5
Lithology
C M S G
Elevation (ft)
5,800
5,500
5,000
4,500
250
500
750
1,000
1,250
SWL = −583
Total depth 1,312 ft
Fault?
EXPLANATION
Pebble to boulder gravel
Sand
Sandstone to pebble sandstone
C Clay
M Mud
S Sand
G Gravel

Ladrones Formation; and unit QTc, Cochiti Formation, western piedmont deposits; discussed in Chapter B, this volume), are schematic and conceptual. The cross sections, shown in plate 6 (here referred to as sections A-A′, B-B′, and so forth), follow the profile lines shown on plate 2 and figure G6. Figure G6 summarizes our synthesis of the geologic configuration of the La Bajada constriction as discussed throughout the remainder of the chapter.

Cerrillos Uplift: Southeastern Boundary of the La Bajada Constriction

The La Bajada constriction is bounded on the southeast by the Cerrillos uplift (Kelley, 1952, 1977, 1978, 1979; Baltz, 1978), a bedrock structural high that is largely covered by rocks of the Cerros del Rio volcanic field. Surface geologic evidence for the uplift is largely limited to the gently east-tilted (10°–14°) hogback of Jurassic and Cretaceous sedimentary rocks in the footwall block of the La Bajada fault zone in the southeast part of the study area (pl. 2) (Maynard, Sawyer, and Rogers, 2001). The uplift projects eastward and northward below rocks of the Cerros del Rio volcanic field (sections B-B′, C-C′, D-D′, pl. 6). The Cerrillos uplift is viewed as a rift-flank uplift (Roy and others, 1999) bordering the Santo Domingo Basin of the Rio Grande rift. It is structurally analogous to the paired Sandia Mountains uplift–Hagan embayment bounding the northeast side of the Albuquerque composite basin (fig. A1). However, unlike the Sandia uplift, it was not uplifted as high and remains largely buried beneath younger Pliocene and Pleistocene volcanic and sedimentary rocks.

The Cerrillos uplift limited the depositional thickness and areal extent of Santa Fe Group basin-fill sediments in the area of the eastern La Bajada constriction. Along the northernmost cross section (A-A′, pl. 6), the constriction extends from the northeast part of the Santo Domingo Basin eastward beneath rocks of the Cerros del Rio volcanic field and includes Santa Fe Group basin-fill sediments that are probably continuous, and hydraulically connected, with correlative strata in the adjacent Española Basin. The true nature of interfingering between Cochiti Formation western piedmont sediments (unit QTc in cross section) and Sierra Ladrones Formation eastern piedmont (unit QTsp) and axial gravel (unit QTsa) sediments likely differs from that depicted on the section, but no subsurface data exists in this area to constrain the depositional geometry of these coeval sedimentary facies.

The cross-sectional structural geometry of the buried Cerrillos uplift is depicted in east-west sections B-B′, C-C′, and D-D′ (pl. 6). The northeast flank of the Cerrillos uplift consists of north- to northeast-dipping Cretaceous Mancos Shale (unit Km in sections) and underlying undivided Pennsylvanian, Permian, Triassic, and Jurassic sedimentary rocks (unit J₸P). These dipping strata likely form part of a northeast-verging monoclinal flexure (see east part of section B-B′) that ramps down into the southwestern part of the Española Basin (that is, the Santa Fe embayment) beneath cover rocks of the Cerros del Rio volcanic field (CDRVF, fig. A2). The existence of such a flexure at depth is supported by gravity-defined east-southeast-trending structure contours on the base of the Tertiary basin-fill sedimentary rocks along the northeast flank of the Cerrillos uplift (figs. D4, G6; pl. 2 of Grauch and Bankey, 2003). Spiegel and Baldwin (1963) postulated a down-to-east Cienega fault zone near the inferred flexure, but surface geologic studies have not confirmed its existence despite permissive geophysical evidence (Grauch and Bankey, 2003). Along the northeast flank of the uplift from section B-B′ south through C-C′ to D-D′ (pl. 6), the Mancos Shale is overlain by an increasing thickness of pre-rift Tertiary sedimentary and volcanic rocks that consist of Eocene Galisteo Formation (unit Tg) and Eocene and Oligocene Espinaso Formation (unit Te) and Cieneguilla Basanite (unit Tc). These strata strike northwest and dip 15°–20° NE. beneath Miocene-Pliocene basin-fill sediments of the Santa Fe Group where exposed at the east end of Cañada de Santa Fe (pl. 2) (Sun and Baldwin, 1958; Sawyer and others, 2001). A westward change to a more westerly strike and northerly dip is clearly indicated by the gravity gradient expressed by structure contours at the base of the basin fill (figs. D4, G6; pl. 2 of Grauch and Bankey, 2003).

The pre-Tertiary sedimentary sequence thins markedly from south to north along the axis of the Cerrillos uplift (section E-E′, pl. 6), on the basis of magnetotelluric and audiomagnetotelluric soundings discussed in chapter F (this volume). Pre-Tertiary sedimentary rocks in the core of the Cerrillos uplift at magnetotelluric station MT–4 are interpreted to consist of about 700 m of Cretaceous marine Mancos Shale (unit Km) underlain by 1,700 m of Permian, Triassic, and Jurassic continental sedimentary rocks (unit J₸P) (fig. F11*F*, *D*), consistent with regional stratigraphic thicknesses for these units (table A1). This pre-Tertiary sequence thins owing to an erosional unconformity at the base of Eocene Galisteo Formation that cuts downsection northward (section E-E′, pl. 6). The unconformity gradually cuts downsection through the Mancos Shale sequence so that it is 500–600 m thick in MT–4 and MT–8, only 200 m thick in MT–11, and absent in MT–5 and MT–10 (section E-E′, pl. 6; fig. F11*B*, *D*). Only the thinned subjacent Permian-Jurassic section is present at the north end of the Cerrillos uplift in MT–5 and MT–10. The unconformity likely represents a buried post-Laramide erosional surface on the southern flank of the Laramide Brazos–Pajarito–Sangre de Cristo uplift (Cather, 1992, 2004), an interpretation supported by petroleum-industry seismic data (Black, 1984; Baldridge and others, 2001).

Cretaceous and older strata are upwarped from Cañada de Santa Fe southward (southern part of section E-E′, pl. 6). Such local uplift was probably caused by emplacement of Oligocene monzonite intrusions that deformed their cover rocks, similar to intrusion-related deformation exposed to the south and east in the Cerrillos Hills and at Cerro Seguro and the adjoining Las Tetillitas (pl. 1). The strong magnetic signature of the overlying Cerros del Rio volcanic field masks the subsurface extent of the monzonite intrusions. A northeast-trending gravity gradient

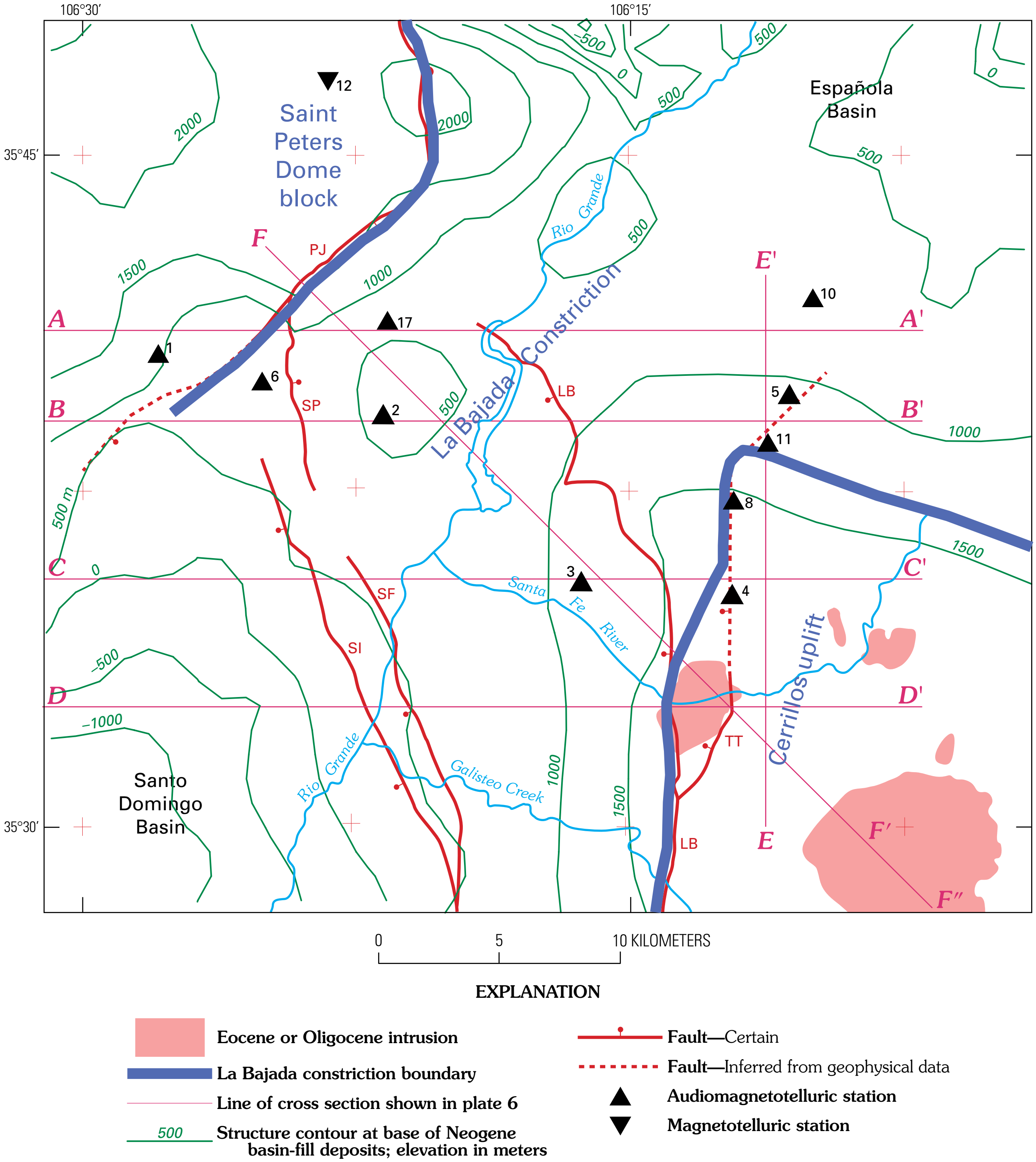


Figure G6. La Bajada constriction area showing its boundaries and gravity-derived structure contours on base of Neogene basin-fill deposits, as described in the text. The boundary of the Cerillos uplift, buried beneath cover rocks of the Cerros del Rio volcanic field, is based on the gravity model cited in chapter D (this volume), magnetotelluric and audiomagnetotelluric data at MT and AMT stations 4, 5, 8, and 11; surface geology; and interpretation of aeromagnetic data. The La Bajada constriction is the locus of downgradient flow of ground water in Santa Fe Group basin-fill aquifers as it passes from the Española Basin into the Santo Domingo Basin. Fault and fault zone abbreviations: LB, La Bajada; PJ, Pajarito; SF, San Francisco; SI, Sile; SP, South Pajarito; TT, Tetilla.

maximum (chapter D, this volume) is located near Cañada de Santa Fe (between station MT–4 and the Santa Fe River; fig. D1) and south of where basin fill abruptly thickens near MT–5 (that is, between MT–11 and MT–8 in section E-E′, pl. 6). This southward shift of the gravity gradient relative to the zone of thickened basin fill probably results from the considerable decrease in structural elevation of the pre-Tertiary rocks between the Cerrillos Hills and the north end of the Cerrillos uplift.

The north flank of the Cerrillos uplift is truncated by an inferred northeast-striking fault or zone of faults that, to the southwest, may structurally link with the Tetilla fault zone (pl. 2; sections B-B′, E-E′, pl. 6; TT, figs. A2 and G6). The existence of this fault zone is most clearly displayed by magnetotelluric soundings (chapter F, this volume). The data indicate a shallow depth (<250 m) to pre-Tertiary rocks at MT stations 4 and 8, a moderate depth (300 m) to these rocks at MT–11, and much greater depth (1,200 m) to them at MT stations 5 and 10. These changing depths require that strata are offset by about 650 m of fault throw in the narrow zone between MT stations 11 and 5 (pl. 2; section E-E′, pl. 6). The local N. 45° E. “electromagnetic” strike direction reported in chapter F (this volume) in the area of these stations (fig. F2*A*, *B*) suggests that the inferred fault or fault zone strikes northeast (pl. 2; figs. A2, G6). This structure may be analogous to the northeast-striking portion of the Tetilla fault zone exposed south of Cañada de Santa Fe (fig. E4) and may transfer extensional strain between the Santo Domingo and Española Basins (chapter E, this volume).

The Cerrillos uplift is bounded on its northwest edge by the inferred northeast-striking fault or fault zone described above (section B-B′, pl. 6), on the west by the north-striking projection of the Tetilla fault zone (section C-C′), and farther south by the north-striking La Bajada fault zone (section D-D′, pl. 6; figs. A2, A4). These fault structures together represent the southeast boundary of the La Bajada constriction as defined in this report (fig. G6), across which the thickness of Santa Fe Group basin-fill deposits increases to greater than 250 m. North of Cañada de Santa Fe, where the La Bajada fault zone (LB) bends northwest, the boundary of the La Bajada constriction as defined by thick basin fill curves northeastward into the footwall block of the La Bajada fault zone (pl. 2; figs. A2, A4, G6). It resumes a northward trend where it intersects the northern projection of the Tetilla fault zone (TT, figs. A2, A4, G6). The uplift and constriction boundary is inferred to continue northward along the projected Tetilla fault zone and curve into the geophysically defined northeast-striking fault or zone of faults described above.

Comparison of the aeromagnetic signature of the Eocene and Oligocene Cerrillos intrusions (pl. 4) with the area of the Cerrillos uplift based on gravity (pl. 3, fig. A3) indicates that the area of the uplift is much larger than the area of the intrusions. The overall geometry of the Cerrillos uplift reflects a basement-cored uplift (Roy and others, 1999) rather than local deformation around individual stocks of the Cerrillos intrusive center (Maynard, Sawyer, and Rogers, 2001; Maynard, 2005). Uplift of the Cerrillos block tilted and arched rocks as young as the Eocene and Oligocene Espinaso Formation and, on the east flank, the lower Miocene Tesuque Formation (Koning and others, 2006). Two dates have been obtained from pre-Tertiary sediments in the footwall block of the La Bajada fault zone that further constrain the timing of uplift of the block: an apatite fission track cooling age of approximately 31 Ma and an apatite (U-Th)/He age of 20 Ma (S.A. Kelley, New Mexico Institute of Mining and Technology, oral commun., 2001; House, Kelley, and Roy, 2003). The fission track age is indistinguishable from the 28–31 Ma Ar isotopic ages of the nearby Cerrillos intrusions (chapter C, this volume; Maynard, 2005). The younger apatite (U-Th)/He age is similar to Miocene ages obtained for uplift of the Sandia Mountains block about 40 km to the south (House, Kelley, and Roy, 2003). Apatite fission-track ages from the Sandia Mountains reported by Kelley and others (1992), Kelley and Chapin (1995), and House, Kelley, and Roy (2003) indicate that uplift continued in the Sandia block into the middle Miocene (as young as 10–12.5 Ma). Presumably the Cerrillos uplift also continued to rise during the middle Miocene owing to rift-flank uplift accompanying extensional faulting.

La Bajada Constriction

The La Bajada constriction in the northeast part of the Santo Domingo Basin is underlain in the shallow subsurface by rift-basin sediments of the Santa Fe Group that are interlayered with volcanic deposits from the Jemez and Cerros del Rio volcanic fields. Pre-Miocene units are not exposed within the basin, and their lithologic characteristics and structural configuration can be inferred only from geophysical data and limited exposures on the uplifted flanks of the rift. The basin-fill deposits are cut by numerous, mostly north-northwest-striking, normal faults that are inferred to have growth-fault histories, resulting in increased amounts of dip-slip displacement with increasing depth (pl. 6). As described in chapters A and E (this volume), the central La Bajada constriction is subdivided into three structural blocks or domains that are separated from one another by prominent intrabasin and basin-border faults of Miocene and younger age: the eastern La Majada graben, between the Sanchez fault and La Bajada fault zone; the central Reservoir horst, between the Cochiti and Sanchez faults; and the western Cochiti graben, between the South Pajarito fault zone and Cochiti fault (figs. A4, E9). Late Miocene and younger temporal patterns of sedimentation in response to growth faulting, fault-related “seesaw” subsidence (Smith, McIntosh, and Kuhle, 2001), possible inward migration of active rift faulting (chapter E, this volume), and areally restricted volcanism have generated different stratigraphic packages in each of these and surrounding structural blocks. Below we describe, from east to west, the salient geologic features of the following parts of the La Bajada constriction: the northwest Cerros del Rio volcanic field (that is, the area northeast of the La Bajada fault zone and west of the Cerrillos uplift), and each of the three intrabasin structural blocks (that is, La Majada graben, Reservoir horst, and Cochiti graben) (fig. A4).

Northwestern Cerros del Rio Volcanic Field

Tongues of Sierra Ladrones Formation axial river gravels (unit QTsa, pl. 2) likely extend eastward into the footwall block of the La Bajada fault zone beneath cover rocks of the northwestern Cerros del Rio volcanic field, on the basis of limited exposures of such gravels along the La Bajada escarpment (chapter B, this volume; sections A-A′ and B-B′, pl. 6). Assuming that the down-to-west Cochiti Cone fault was an active basin-bounding fault between 2.6 and 1.1 Ma (chapter E, this volume), axial river gravels and eastern piedmont facies sediments (unit QTsp) probably interfinger at least as far east as this fault. Northward, toward the Española Basin, axial river gravels are predicted to extend progressively farther east under the Cerros del Rio volcanic rocks such that lenses or tongues of axial gravel may project well into the footwall block of the Cochiti Cone fault. More certain is the presence of basin-fill piedmont facies sediments beneath the entire northern part of the volcanic field (unit QTsp in sections A-A′ and B-B′, pl. 6). Such buried deposits are predicted north of the Cerrillos uplift where the La Bajada constriction widens and merges with the southwest part of the Española Basin (figs. A2, G6). A network of faults and feeder dikes associated with the Cerros del Rio volcanic units likely cut or intrude basin-fill sediments underlying the volcanic plateau (chapter C, this volume), but the geometry and spatial distribution of such features are unconstrained.

La Majada Graben

The north-northwest trend of the La Majada graben, situated between the northern La Bajada fault zone and the Reservoir horst (figs. A4, E9), is oblique to and cuts across the overall north-northeast trend of sedimentary facies boundaries within the northeast part of the Santo Domingo Basin (pl. 2). As a result, the dominant facies of basin-fill sediments within the graben gradually changes from axial river gravels in the northern part of the block to eastern piedmont sediments in the southern part (compare sections A-A′, C-C′, and F-F″, pl. 6). Given the growth-fault history of the bounding faults, it is likely the ancestral Rio Grande intermittently occupied and flowed along the La Majada graben.

The La Majada graben formed primarily between about 2.5 and 0.5 Ma, during and following eruption of the Pliocene basalts of the Cerros del Rio volcanic field and eruption of andesites during the second phase of the Santo Domingo Basin subsidence, as described by Smith McIntosh, and Kuhle (2001). This period of peak subsidence of the La Majada graben and movement along the La Bajada fault zone coincided with the main caldera-forming eruptions in the Valles caldera within the Jemez volcanic field (Nielson and Hulen, 1984).

Erosion and mass wasting of the La Bajada fault-zone escarpment provided abundant piedmont sediment that was deposited in the graben, which includes Cerros del Rio basalt-derived sedimentary breccias and landslide deposits (Smith, Bailey, and Ross, 1970). Arkosic piedmont facies sediments are also common in the graben, which were derived from the Sangre de Cristo Range east of the Santa Fe embayment. Basaltic lavas of the Cerros del Rio volcanic field are displaced down into the La Majada graben along the La Bajada fault zone and, in the southern part of the graben, basalt flows are overlain by younger basin-fill sediments (sections A-A′, B-B′, and C-C′, pl. 6).

Relatively small displacement, north-northwest-striking, synthetic and antithetic normal faults are common in the northern part of the La Majada graben, whereas larger displacement, more widely spaced faults associated with the scalloped La Bajada fault zone cut obliquely across the southern part of the graben (pl. 2; east-west sections A-A′, B-B′, C-C′, F-F″, pl. 6). The latter faults may serve structurally to compartmentalize and close off the southern end of the graben, which may inhibit the southerly flow of ground water within the block. Stratal dips within the La Majada graben are gentle, generally just a few degrees to the east. However, eastward dips appear to increase southward where they locally exceed 10°.

Reservoir Horst

The north-northwest-trending Reservoir horst is a relatively uplifted structural block located between the Cochiti graben on the west and the La Majada graben on the east (figs. A4, E9). Santa Fe Group basin-fill sediments underlying the horst consist primarily of ancestral Rio Grande axial gravels (unit QTsa, pl. 6), although subordinate amounts of interfingering eastern piedmont facies (unit QTsp) are also present. The lack of geologic data from wells in the horst prevents determination of the subsurface distribution of axial gravels at depth. Similar to the La Majada graben, the Reservoir horst trends obliquely across basin-fill facies boundaries such that, in the north, western piedmont sediments of the Cochiti Formation (unit QTc) are present in the west part of the horst and in the south part of the horst eastern piedmont sediments encroach on the river gravels from the east (compare sections A-A′, B-B′, C-C′, pl. 6). The axial gravel facies becomes more sand rich (unit Tsls) beneath the basalt of Peña Blanca (unit Tbpb), along the east bank of the Rio Grande, at the south end of the horst (chapter B, this volume; pl. 2; section D-D′, pl. 6) (Smith and Kuhle, 1998a, b). In the same area local lacustrine deposits of clay-rich sediment and limestone (units Tslm, Tsll) interfinger with the axial sand and gravel deposits (Smith and Kuhle, 1998b).

Faulted basaltic flows along the western edge of the Cerros del Rio volcanic field (unit Tb, pls. 2, 6) are locally present at the surface or at relatively shallow depth within the northern part of the Reservoir horst (sections A-A′, B-B′, pl. 6). The horst also contains aeromagnetically expressed buried basalt related to the basalt of Peña Blanca (unit Tbpb, pl. 6; feature C4, fig. D7). Distal layers of Otowi Member of the Bandelier Tuff (unit Qbo) are also preserved at the surface within the horst. Only basin-fill sediments (mainly axial gravel, unit QTsa) are predicted in the horst below about 100 m within the depth range of sections A-A′ and B-B′ (pl. 6). Further south, however, the basalt of Peña Blanca is present down to depths of nearly 300 m, which reflects the southward increase in throw of the La Bajada fault zone (sections C-C′ and F-F″, pl. 6).

Internally, the Reservoir horst is a relatively undeformed block containing only minor faults that strike subparallel to its overall trend. Gentle (<10°) eastward stratal dips are typical throughout the length of the horst (see east-west sections A-A′, B-B′, C-C′, D-D′, pl. 6), in contrast to the moderate northwestward dip of underlying pre-Tertiary sedimentary rocks indicated in the gravity-constrained regional section F-F″ of plate 6 (see also chapter D, this volume). The westward stratigraphic thickening of older, pre-rift Tertiary sedimentary rocks at depth within the horst (unit Tg(?), section F-F″, pl. 6) presumably reflects deformation related to the Laramide Brazos–Pajarito–Sangre de Cristo uplift (Cather, 1992, 2004) and Cerrillos uplift.

Cochiti Graben

The north-northwest-trending Cochiti graben is bounded on the east by the Reservoir horst and on the west by the Saint Peters Dome block and, farther south, by a contiguous unnamed domain of small fault blocks (sections A-A′, B-B′, C-C′, and F-F″, pl. 6; figs. A4, E9). As in the structural blocks to the east, the type and relative volume of basin-fill sedimentary facies gradually change along the length of the graben owing to the oblique trend of the graben relative to the facies boundaries. Basin-fill sediments in the northern part of the graben consist dominantly of western piedmont deposits of the Cochiti Formation (unit QTc, section A-A′; see also description of Dome Road well, fig. G5), whereas at the southern end gravelly axial-river deposits of the Sierra Ladrones Formation prevail (unit QTsa, section C-C′). Western piedmont sediments interfinger with axial-river deposits in gradually shifting proportions along the entire length of the graben (compare east-west sections A-A′, B-B′, C-C′, D-D′). The Cochiti Formation (Smith and Lavine, 1996) is characterized by gravel and coarse sand in the northern part of the Cochiti graben, but the percentage of gravel and the average size of sand grains decrease southward away from the volcanic field (Smith and Kuhle, 1998c).

Rocks of the Jemez volcanic field zone are downdropped into the northern and central parts of the Cochiti graben along faults of the Pajarito and South Pajarito fault zones (pl. 2; sections A-A′, B-B′, and F-F″, pl. 6). These volcanic units are present at several depth intervals, reflecting the broad age range of the east flank of the Jemez volcanic field (Miocene to 1.22 Ma; chapter C, this volume); volcanic deposits and flows include the 1.61- and 1.22-Ma members of the Bandelier Tuff (units Qbt, Qbo, pl. 2), the 7- to 6-Ma units of the Bearhead Rhyolite (units Tbr, Tbp), and older (~10–7 Ma) Keres Group rocks (units Tkpa, Tkct, Tkvs).

Lacustrine sediments are inferred to be present in the shallow subsurface (between about 50 and 150 m depth) in the northern part of the Cochiti graben (unit QTcl, section B-B′, pl. 6) largely on the basis of a localized, electrically conductive interval detected by the time-domain electromagnetic surveys (chapter F, this volume; fig. F7*C–E*). This conductive body is as much as 5 km wide and 10 km long in plan view and extends from Peralta Canyon on the southwest to at least the Sanchez fault on the northeast. At present no samples of lacustrine rocks have been recovered from any wells in the area of the conductive body, so information about texture, mineralogy, and grain size are based on indirect geophysical downhole logging methods. Borehole geophysical data from the CEPO 2 (Sliding) well suggest that as much as 130 ft (40 m) of clay-rich lacustrine sediment was penetrated by the well (fig. G4). Given the large areal dimensions of this body (fig. F7*C–E*) and a thickness of as great as 100 m, the lacustrine sediments may act as a local subhorizontal barrier to ground-water flow. Development of a lake system in this area was likely due to damming by one or more of three mechanisms: basaltic maar volcanism on the floodplain of the Rio Grande (Self and others, 1996), scarp formation along one or more nearby faults, or landsliding off high-relief volcanic landforms or fault escarpments. It is not certain whether the east boundary of the inferred clay-rich body near section B-B′ (pl. 6) is at the Cochiti fault, as depicted in the section, or slightly farther east.

The Cochiti graben dies out just south of lower Peralta Canyon and the village of Cochiti Pueblo (pl. 1), where the bordering South Pajarito and Cochiti faults end near the overlapping Sile and San Francisco faults (figs. A4, E9). The graben also dies out to the north where the Cochiti fault ends south of the northeast-striking segment of the Pajarito fault zone and Saint Peters Dome. Thus, the Cochiti graben is structurally open on both ends. The graben contains several internal north-striking faults that have shorter trace lengths and smaller throws in surface exposures (tens of meters) than the bounding faults (pl. 2; sections A-A′, B-B′, and F-F″, pl. 6). In contrast to the La Majada graben, the Cochiti graben does not appear to be segmented by any large cross faults.

Saint Peters Dome Block: Northwestern Boundary of the La Bajada Constriction

The northwestern border of the La Bajada constriction is formed by the Saint Peters Dome structural block, a basement-cored uplift composing the footwall block of the northeast-striking Pajarito fault zone (PJ, fig. A2) (Kelley, 1952; Goff, Gardner, and Valentine, 1990; Cather, 1992; Abbott, Cather, and Goodwin, 1995). The uplift is evident in gravity data and required by gravity modeling (figs. A3, D1, D6). The surface trace of the block-bounding Pajarito fault zone dies out where the north-striking South Pajarito fault zone merges with it (figs. A2, G6); there is no evidence that the fault offsets sediments of the Cochiti Formation (unit QTc, pl. 2) or the overlying gravel of Lookout Park (unit Tglp) to the southwest. The northeast-striking Pajarito fault zone is aligned, however, with a prominent northeast-trending gravity gradient extending southwest from Saint Peters Dome block that is coincident with the northwest side of Santo Domingo Basin (pl. 4; fig. D1). These observations suggest that a buried older Miocene (pre-7-Ma Peralta Tuff Member), basin-bounding Pajarito fault segment may continue in the subsurface to the southwest (fig. A2). To the north, the Pajarito fault zone and adjacent Saint Peters Dome block continue northward where they form the western boundary of the deep Pajarito (or southern Velarde) subbasin or graben (Ferguson and others, 1995) of the Española Basin (figs. A2, D1, G6).

The stratigraphic history of the Saint Peters Dome block is complex owing to Miocene and younger rift-flank uplift and proximity to source vents of the Jemez volcanic field. Upper Miocene through Quaternary volcanic rocks, pyroclastic deposits, and associated sediments of the southeastern Jemez volcanic field dominate the upper 1 km of the block (pl. 2; sections A-A′, B-B′, F-F″, pl. 6). Unconformably underlying the Bandelier Tuff cap rock (units Qbt, Qbo, pl. 2) are the Cochiti Formation (unit QTc), the Bearhead Rhyolite (unit Trb) and associated Peralta Tuff Member (unit Tbp), and older Miocene Keres Group volcaniclastic sediments (units Tkvs, Tku of pl. 6 only) intercalated with varied volcanic domes, tuffs and lava flows (units Tkpa, Tku). In the subsurface one or more fingers of axial-river gravels extend westward into the footwall block of the Pajarito fault zone in the southeastern part of the Saint Peters Dome block (Smith, McIntosh, and Kuhle, 2001). The synvolcanic Bearhead Basin, which accumulated at least 500 m of interlayered Peralta Tuff Member pyroclastic and sedimentary deposits between 7 and 6 Ma, may greatly affect the volcanic hydrogeology and structural framework in the southwest part of the Saint Peters Dome block (Smith, 2001). The west edge of this basin is bounded by northern projections of the down-to-east Peralta and Camada faults (pl. 2). As much as 100 m of middle Santa Fe Group basin-fill sedimentary rocks are exposed in the footwall block of the Pajarito fault zone near Saint Peters Dome (unit Tsf, section F-F″), and similar rocks may underlie the Jemez volcanic sequence elsewhere in the Saint Peters Dome block as well as at deeper levels in the northwest part of the La Bajada constriction (Goff and others, 1990).

The Pajarito fault zone bounding the Saint Peters Dome block accommodates greater than 100 m of down-to-the-east offset of the 1.22-Ma upper Bandelier Tuff (unit Qbt) (Goff, Gardner, and Valentine, 1990). Unconstrained fault offsets of older rocks present at depth in the Pajarito hanging-wall block are likely much greater (200–1,000 m), assuming a growth-fault history (sections A-A′, B-B′, F-F″, pl. 6). Large angular unconformities in the footwall between strata of the Eocene Galisteo Formation (dip, 45° W.), the Miocene Santa Fe Group (dip, 10° SW.), and Pliocene and Pleistocene Cochiti Formation and Bandelier Tuff (3°–5° NW. to SE.) reflect episodic uplift and back tilting of the Saint Peters Dome block in Tertiary and Quaternary time. This and other lines of evidence indicate that the Pajarito was an active zone of major normal faulting along the western border of the Española and Santo Domingo Basins from the late Miocene through the Pleistocene. Internally, the Saint Peters Dome block is generally little deformed, although some smaller displacement faults (<25 m) cut pre-Bandelier Tuff rocks (pl. 2).

Implications for Ground-water Flow Between Española and Santo Domingo Basins

Ancestral Rio Grande axial gravel and sand deposits of the upper Miocene to Pleistocene Sierra Ladrones Formation are the most productive aquifers in northern New Mexico (Kernodle and others, 1995). Evidence of high transmissivity of Miocene gravels is provided by deep production wells on the Pajarito Plateau in the western Española Basin northwest of the study area (Purtymun, 1995; Reneau and Dethier, 1996). Similar Miocene and Pliocene deposits are widely distributed in the central part of the La Bajada constriction between the Española and Santo Domingo Basins (Dethier, 1999; Chapter B, this volume), although existing subsurface data do not constrain the eastern extent of axial Rio Grande gravels beneath rocks of the Cerros del Rio volcanic field north and northwest of the Cerrillos uplift. Also, the deepest extent of these highly conductive sediments has not been characterized by any deep water wells in the northeastern or main parts of the Santo Domingo Basin. Nevertheless, ancestral Rio Grande fluvial gravel and sand extend at least from Española on the north southward through the entire Santo Domingo Basin and into the Albuquerque Basin (fig. A1) such that it probably conveys the largest amounts of ground water by underflow from the Española Basin through the Santo Domingo Basin. We conclude that through-going axial river sand and gravel and coarse western piedmont gravel aquifers form the predominant ground-water pathways through the La Bajada constriction.

Western piedmont facies gravel and sand deposits of the Cochiti Formation probably form a substantial aquifer unit in the northwest part of the La Bajada constriction south of Saint Peters Dome, owing to their coarse grain size and inferred moderately high permeability (Smith and Kuhle, 1998c). However, the permeability of these deposits may gradually decrease southward on account of the reduction of their average grain size from gravel to sand away from their Jemez volcanic field source rocks. Eastern piedmont facies sand and silty sand deposits probably form a fair to moderately good aquifer, depending locally on the amount of interbedded silt and clay. The City of Santa Fe's Buckman well field, immediately east of the Rio Grande at the north tip of the Cerros del Rio volcanic field (pl. 1), is perhaps typical of the water supply available from this aquifer unit (Black and Veatch, 1978; Lewis and West, 1995). Other than information gathered in this well field, little is known of the hydrologic characteristics of Santa Fe Group eastern piedmont deposits concealed beneath rocks of the volcanic field.

Cerros del Rio basalt lava flows probably form good fracture-flow aquifers in the subsurface of the La Majada graben and Reservoir horst, given the common presence of cooling joints within such rocks and their tendency to deform by distributed extensional fracturing (Minor and Hudson, 2006). Hydrologic results from the Santa Cruz Springs Tract well (John Sorrell, U.S. Bureau of Indian Affairs, unpub. data, reported in Smith and Kuhle, 1998c) support this inference. Little is known of the hydrostratigraphy of Santa Fe Group sediments beneath the basalts of the Cerros del Rio volcanic field in the La Majada graben, but it probably includes hydraulically conductive axial Rio Grande gravels that form good aquifers similar to those exposed in the footwall of the La Bajada fault zone. The slight water table trough just west of and parallel to the La Bajada fault zone at the south end of the graben (fig. G1) may reflect a zone of increased hydraulic conductivity in the La Majada graben-fill section, perhaps owing to the combined effects of concentrated axial gravel and enhanced permeability near and parallel to the fault zone.

Poorly consolidated sediments of the Santa Fe Group that are deposited in the late Cenozoic Rio Grande rift basins have high to very high hydraulic conductivity compared with most of the older rocks forming the uplifted blocks that bound the basins. On the southeast side of the La Bajada constriction, low-conductivity clay-rich Cretaceous marine shales form a regional confining unit within the Cerrillos uplift. These shales are at least 600 m thick and are tilted gently to moderately eastward (unit Km, section C-C′, pl. 6), opposite to the regional water table that slopes west toward the modern Rio Grande (fig. G1). These Cretaceous rocks have not completely exchanged their saline marine pore fluids with ground water in the past 80 million years, as implied by the poor water quality recorded in several wells (Lewis and West, 1995). In addition to poor water quality, these clay-rich rocks contain only meager amounts of water. The bulk hydraulic conductivity of the Cretaceous sedimentary rocks is probably further reduced where Eocene and Oligocene stocks and plugs have intruded (units Tmi, Tmh, section F-F″, pl. 6) and contact metamorphosed them. Overlying lower Tertiary sedimentary and volcaniclastic rocks of the Galisteo and Espinaso Formations in the Cerrillos uplift probably have somewhat greater hydraulic conductivity than the Cretaceous shales, but their conductivity is still markedly lower than most of the basin-fill sediments owing to their much greater degree of compaction and induration.

In the Saint Peters Dome block on the opposite, northwest, side of the constriction, flows, domes, and pyroclastic rocks of the Jemez volcanic field have not been studied to determine their hydrologic properties. Local aquifer units may exist where competent volcanic rocks have been intensely fractured during cooling or later deformation. Compared with the Cerrillos uplift, discrete volcaniclastic sedimentary aquifer units are more likely in the Saint Peters Dome block, particularly within volcanic rocks that intertongue with the Cochiti Formation and Keres Group volcaniclastic sediments (units QTc, Tkvs, sections A-A′, B-B′, and F-F″, pl. 6).

The abundant, dominantly north-northwest-striking, intrabasin faults in the La Bajada constriction (pl. 2, fig. E9) may locally partition or compartmentalize ground-water flow (chapter E, this volume) and deflect it into a mainly south-southeast fault-parallel direction. Given the common along-strike persistence of clay cores and cemented damage zones and mixed zones with the intrabasin fault zones, most faults probably impede across-fault flow of ground water (Minor and Hudson, 2006; chapter E, this volume). In contrast, along-fault flow may be enhanced in the tens-of-meters-wide damage zones surrounding the fault cores in protoliths where fracturing, rather than cataclasis (that is, grain-size reduction), was the dominant mode of deformation and where those fractures were not later cemented. Another important consequence of faulting on the regional ground-water flow system is the structural juxtaposition of units with differing bulk hydraulic conductivity within the rift basin-fill sequence. Given the complex interfingering lithostratigraphy of the sedimentary fill of the La Bajada constriction and Santo Domingo Basin, intrabasin faults commonly juxtapose hydrologically contrasting lithologic layers, resulting in laterally and vertically variable fault-zone hydrologic properties. This juxtaposition of dissimilar lithologies is especially pronounced toward the margins of the basin where the lithologically more diverse piedmont facies prevail and interfinger with distal axial river gravels (east-west sections A-A′, B-B′, C-C′, D-D′, pl. 6). In addition, cross faults and fault-zone reactivation can locally alter the permeability along and across intrabasin fault zones and, in some cases, result in fault holes and leakage (for example, Caine and others, 2002). However, other than in the La Majada graben, cross faults striking obliquely with respect to the overall north-northwest structural grain do not appear to be common in the La Bajada constriction area, and most intrabasin faults appear to have been relatively inactive since the middle Pleistocene (Machette and others, 1998).

References Cited

Abbott, J.C., Cather, S.M., and Goodwin, L.B., 1995, Paleogene synorogenic sedimentation in the Galisteo Basin related to the Tijeras-Canoncito fault system: New Mexico Geological Society 46th field conference, Geology of the Santa Fe Region, Guidebook, p. 271–278.

Baldridge, W.S., Ferguson, J.F., Braile, L.W., Biehler, S., Jiracek, G.R., Gilpin, B.E., Alumbaugh, D.L., Gratwick, D.S., Richards, T.L., and Hasterok, D.P., 2001, Architecture of the southern Espanola Basin (Rio Grande rift) and flank uplift adjacent to the La Bajada fault [abs]: Geological Society of America Abstracts with Programs, v. 33, no. 5, p. 61.

Baltz, Elmer, 1978, Resume of the Rio Grande depression in north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 163, p. 210–228.

Bartolino, J.R., and Cole, J.C., 2002, Ground-water resources of the Middle Rio Grande Basin, New Mexico: U.S. Geological Survey Circular 1222, 132 p.

Bexfield, L.M., and Anderholm, S.K., 2000, Predevelopment water-level map of the Santa Fe Group aquifer system in the Middle Rio Grande Basin between Cochiti Lake and San Acacia, New Mexico: U.S. Geological Survey

Water-Resources Investigations Report 00–4249, 1 map sheet with text, scale approximately 1:400,000.

Black, B.A., 1984, Hydrocarbon potential of the Española Basin—A progress report: New Mexico Geological Society 35th field conference, Rio Grande Rift—Northern New Mexico, Guidebook, p. 223–226.

Black and Veatch, 1978, Construction and testing report, Buckman well no. 2 (New Mexico RG 20516–5–6): Denver, Black and Veatch Consulting Engineers project 6607.002, prepared for Public Service Company of New Mexico, Santa Fe, 36 p.

Blanchard, P.J., 1993, Ground-water-level fluctuations in the Cochiti Dam–Peña Blanca area, Sandoval County, New Mexico, 1976–89: U.S. Geological Survey Water-Resources Investigations Report 92–4193, 72 p.

Caine, J.S., Minor, S.A., Grauch, V.J.S., and Hudson, M.R., 2002, Potential for fault zone compartmentalization of ground-water aquifers in poorly lithified, Rio Grande rift-related sediments, New Mexico [abs.]: Geological Society of America Abstracts with Programs, v. 34, no. 4, p. 59.

Cather, S.M., 1992, Suggested revisions to the Tertiary tectonic history of north-central New Mexico: New Mexico Geological Society 43d field conference, San Juan Basin IV, Guidebook, p. 109–122.

Cather, S.M., 2004, Laramide orogeny in central and northern New Mexico and southern Colorado, in Mack, G.H., and Giles, K.A., eds., The geology of New Mexico, A geologic history: New Mexico Geological Society Special Publication 11, p. 203–248.

Chamberlin, R.M., Jackson, Patricia, and Connell, S.D., 1999, Field logs of borehole drilled for monitoring well at Dome Road site, Cañada de Cochiti Grant, Sandoval County, New Mexico: New Mexico Bureau of Geology and Mineral Resources Open-file Report 444c, 30 p.

Dethier, D.P., 1999, Quaternary evolution of the Rio Grande near Cochiti Lake, northeast part of the Santo Domingo Basin, New Mexico: New Mexico Geological Society 50th field conference, Albuquerque Geology, Guidebook, p. 371–378.

Ferguson, J.F., Baldridge, W.S., Braile, L.W., Biehler, S., Gilpin, B., and Jiracek, G.R., 1995, Structure of the Española Basin, Rio Grande rift, from SAGE seismic and gravity data: New Mexico Geological Society 46th field conference, Geology of the Santa Fe Region, Guidebook, p. 105–110.

Goff, Fraser, Gardner, Jamie, and Valentine, Greg, 1990, Geologic map of the St. Peters Dome area, Jemez Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 69, scale 1:24,000.

Grant, P.R., 1997, Subsurface geology and related hydrologic conditions, Santa Fe embayment and contiguous areas, New Mexico: New Mexico State Engineer Office Technical Report 97–5, 53 p., 3 plates.

Grant, P.R., 1999, Subsurface geology and related hydrologic conditions, Santa Fe embayment and contiguous areas, New Mexico: New Mexico Geological Society 50th field conference, Albuquerque Geology, Guidebook, p. 425–435.

Grauch, V.J.S., and Bankey, Viki, 2003, Aeromagnetic interpretations for understanding the hydrogeologic framework of the southern Española Basin, New Mexico: U.S. Geological Survey Open-File Report 03–124, 44 p.

House, M.A., Kelley, S.A., and Roy, Mousumi, 2003, Refining the footwall cooling history of a rift flank uplift, Rio Grande rift, New Mexico: Tectonics, v. 22, no. 5, p. 1060, doi:101029/2002TC001418 [internal pagination: p. 14–1 to 14–18].

Kelley, V.C., 1952, Tectonics of the Rio Grande depression of central New Mexico: New Mexico Geological Society 3d field conference, Rio Grande Country, Guidebook, p. 92–105.

Kelley, V.C., 1977, Geology of Albuquerque Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 33, 60 p.

Kelley, V.C., 1978, Geology of the Española Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 48, scale 1:125,000.

Kelley, V.C., 1979, Tectonics, Middle Rio Grande rift, New Mexico, in Riecker, R.E., ed., Rio Grande rift—Tectonics and magmatism: American Geophysical Union, p. 57–70.

Kelley, S.A., and Chapin, C.E., 1995, Apatite fission-track thermochronology of Southern Rocky Mountain–Rio Grande rift–Western High Plains provinces: New Mexico Geological Society 46th field conference, Geology of the Santa Fe Region, Guidebook, p. 87–96.

Kelley, S.A., Chapin, C.E., and Corrigan, J., 1992, Late Mesozoic to Cenozoic cooling histories of the flanks of the northern and central Rio Grande rift, Colorado and New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 145, 39 p.

Kernodle, J.M., McAda, D.P., and Thorn, C.R., 1995, Simulation of ground-water flow in the Albuquerque Basin, central New Mexico, 1901–1994, with projections to 2020: U.S. Geological Survey Water-Resources Investigations Report 94–4251, 114 p.

Koning, D.J., Pazzaglia, F.J., and McIntosh, W.C., 2002, Redefinition of the Ancha Formation and Plio-Pleistocene deposition in the Santa Fe embayment, north-central New Mexico: New Mexico Geology, v. 24, p. 75–87.

Koning, D.J., Read, A.S., Grauch, V.J.S., and Minor, S.A., 2006, Late Oligocene-Miocene structures in and near the Santa Fe embayment, N.M., and inferences regarding tectonism and paleo-topography [abs.], *in* McKinney, K.C., ed., Geologic and hydrogeologic framework of the Española Basin, Española Basin Workshop, 5th, Santa Fe, New Mexico, March 7–8, 2006, Proceedings: U.S. Geological Survey Open-File Report 2006–1134, p. 36.

Lewis, A.C., and West, Francis, 1995, Conceptual hydrologic systems for Santa Fe County: New Mexico Geological Society 46th field conference, Geology of the Santa Fe Region, Guidebook, p. 299–305.

Machette, M.N., Personius, S.F., Kelson, K.I., Haller, K.M., and Dart, R.L., 1998, Map of Quaternary faults and folds in New Mexico and adjacent areas: U.S. Geological Survey Open-File Report 98–0521, 1 sheet, scale 1:750,000, text 367 p.

Maynard, S.R., 2005, Laccoliths of the Ortiz porphyry belt, Santa Fe County, New Mexico: New Mexico Geology, v. 27, no. 1, p. 3–21.

Maynard, S.R., Sawyer, D.A., and Rogers, J., 2001, Preliminary geologic map of the Madrid 7.5’ quadrangle: New Mexico Bureau of Mines and Geology Open-file Report DM–40, scale 1:24,000, 26 p. text.

Minor, S.A., and Hudson, M.R., 2006, Regional survey of structural properties and cementation patterns of fault zones in the northern part of the Albuquerque Basin, New Mexico—Implications for ground-water flow: U.S. Geological Survey Professional Paper 1719, 000 p.

Nielson, D.L., and Hulen, J.B., 1984, Internal geology and evolution of the Redondo dome, Valles caldera, New Mexico: Journal of Geophysical Research, v. 89, p. 8695–8711.

Peery, R.L., and Pearson, J.W., 1994, Hydrogelogy and water-resource assessment, proposed La Bajada subdivision, Santa Fe County, NM: John Shomaker & Associates consultant report, 33 p.

Purtymun, W.D., 1995, Geologic and hydrologic records of observation wells, test holes, test wells, supply wells, springs and surface water in the Los Alamos area: Los Alamos National Laboratory Report LA–12883–MS, 339 p.

Reneau, S.L., and Dethier, D.P., 1996, Pliocene and Quaternary history of the Rio Grande, White Rock Canyon and vicinity, New Mexico: New Mexico Geological Society 47th field conference, Jemez Mountains Region, Guidebook, p. 317–324.

Roy, Mousumi, Karlstrom, K.E., Kelley, S.A., Pazzaglia, F.J., and Cather, S.M., 1999, Topographic setting of the Rio Grande rift, New Mexico—Assessing the role of “rift-flank” uplift in the Sandia Mountains: New Mexico Geological Society 50th field conference, Albuquerque Geology, Guidebook, p. 167–174.

Sawyer, D.A., Shroba, R.R., Minor, S.A., and Thompson, R.A., 2001, Geologic map of the Tetilla Peak quadrangle, Santa Fe and Sandoval Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF–2352, scale 1:24,000.

Self, Stephen, Heiken, Grant, Sykes, M.L., Wohletz, Kenneth, Fisher, R.V., and Dethier, D.P., 1996, Field excursions to the Jemez Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 134, 72 p.

Shomaker, J.W., 1995, Hydrogeology of the Ortiz Mountains and vicinity: New Mexico Geological Society 46th field conference, Geology of the Santa Fe Region, Guidebook, p. 313–318.

Smith, G.A., 2001, Development of a pyroclastic apron adjacent to rhyolite domes in a subsiding basin—Upper Miocene Peralta Tuff, Jemez Mountains, New Mexico, *in* Crumpler, L.S., and Lucas, S.G., eds., Volcanology in New Mexico: New Mexico Museum of Natural History and Science Bulletin 18, p. 85–96.

Smith, G.A., and Kuhle, A.J., 1998a, Geologic map of the Santo Domingo Pueblo quadrangle, Sandoval County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Digital Map OFDM 26, scale 1:24,000.

Smith, G.A., and Kuhle, A.J., 1998b, Geologic map of the Santo Domingo Pueblo SW quadrangle, Sandoval County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Digital Map OF–DM–26, scale 1:24,000.

Smith, G.A., and Kuhle, A.J., 1998c, Hydrostratigraphic implications of new geologic mapping in the Santo Domingo Basin, New Mexico: New Mexico Geology, v. 20, p. 21–27.

Smith, G.A., and Lavine, Alex, 1996, What is the Cochiti Formation?: New Mexico Geological Society 47th field conference, Jemez Mountains Region, Guidebook, p. 219–224.

Smith, G.A., McIntosh, William, and Kuhle, A.J., 2001, Sedimentologic and geomorphic evidence for seesaw subsidence of the Santo Domingo accommodation-zone basin, Rio Grande rift, New Mexico: Geological Society of America Bulletin, v. 113, p. 561–574.

Smith, R.L., Bailey, R.A., and Ross, C.S., 1970, Geologic map of the Jemez Mountains, New Mexico: U.S. Geological Survey Miscellaneous Investigations Map I–571, scale 1:125,000.

Spiegel, Zane, and Baldwin, Brewster, 1963, Geology and water resources of the Santa Fe area: U.S. Geological Survey Water-Supply Paper 1525, 258 p.

Sun, Ming-Shan, and Baldwin, Brewster, 1958, Volcanic rocks of the Cienega area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 54, 80 p.

Titus, Frank, Jr., 1961, Ground-water geology of the Rio Grande trough in north-central New Mexico, with sections on the Jemez caldera and the Lucero uplift: New Mexico Geological Society 12th field conference, Albuquerque Country, Guidebook p. 186–192.

Williams, J.M., and Rodriguez, B.D., 2003, Magnetotelluric data in the southwest Española Basin, northern New Mexico: U.S. Geological Survey Open-File Report 03–199, 128 p.

Published in the Central Region, Denver, Colo.
Manuscript approved for publication February 10, 2006
Graphics by authors
Photocomposition by Mari L. Kauffmann (Contractor, ATA Services)
Edited by Mary-Margaret Coates (Contractor, ATA Services)