

Stratigraphic analysis of the Yates #2 La Mesa well and implications for southern Española Basin tectonic history

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Abstract

The Neogene Española Basin of the Rio Grande rift has been alternatively interpreted as overlapping an Eocene Laramide basin or as representing inversion of a Laramide uplift. The stratigraphy of the rocks penetrated by the Yates #2 La Mesa well near Santa Fe, New Mexico, is essential to the interpretation of the subsurface geology and to resolving this controversial aspect of the tectonic history of the basin. Petrographic analysis of 46 thin sections from well cuttings, as well as general examination of cuttings and geophysical logs, addresses these problems.

Limestone and clastic sedimentary rocks overlying Precambrian granite were previously interpreted as Tertiary basin fill, but petrographic examination of limestone cuttings reveals many fragments with diagnostic late Paleozoic marine fossils. Along with the absence of typical local Eocene red beds, the Paleozoic fossils require reassignment of this 462-m-thick (1,516-ft-thick) interval to the Pennsylvanian section.

Volcanic and volcanoclastic rocks overlying the Paleozoic strata were previously assigned to the Oligocene Espinaso Formation. Only the lower 307 m (1,007 ft) of this succession consist of latitic detritus characteristic of the Espinaso Formation. Mafic lava flows and arkosic sedimentary strata compose the upper 318 (1,043 ft) m of the volcanic interval. The mafic lava flows correlate to upper Oligocene–lower Miocene basalts and basanites seen in nearby outcrops, and the sedimentary layers resemble overlying rift-basin fill.

The results of this study support formation of the Española Basin by inversion of a Laramide uplift. The well cuttings provide no evidence for Eocene syn-Laramide basin-fill sedimentary deposits. Oligocene volcanoclastic rocks buried the uplift that was denuded of all Phanerozoic cover strata except for a partial Paleozoic section. Basalts erupted onto an alluvial surface that was already accumulating rift-basin fill.

Introduction

This study focuses on lithologic and stratigraphic interpretation of subsurface layers penetrated by the Yates #2 La Mesa well located within the southern Española Basin, west of Santa Fe, New Mexico (Fig. 1). This petroleum exploration well was drilled in 1985 to a depth of 2,350 m (7,710

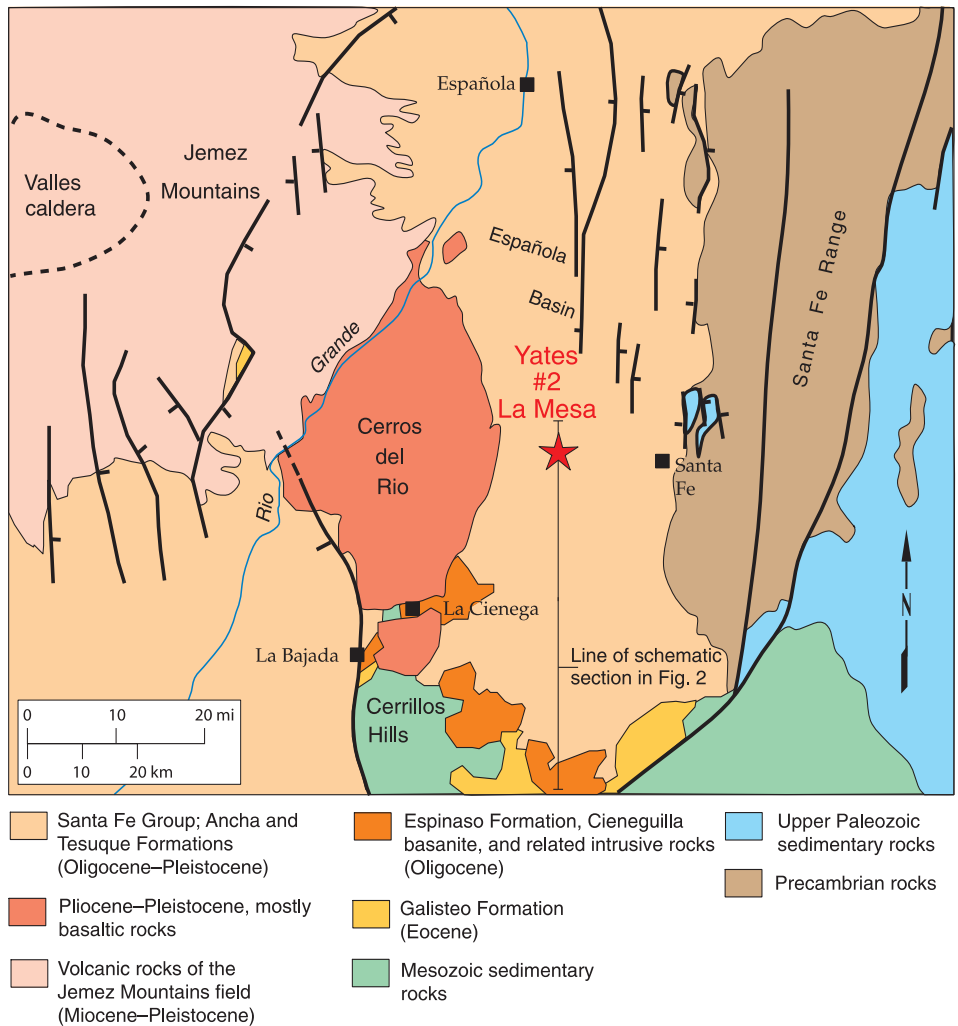


FIGURE 1—Location map of the study area. The Yates #2 La Mesa well is located approximately 30 km (18.6 mi) west of Santa Fe, New Mexico, in the middle of the southern Española Basin.

ft). Most workers (Cather 1992; Biehler et al. 1991; Ferguson et al. 1995) agree that the Yates #2 La Mesa well was drilled into Precambrian basement. If true, then this well is critical as a stratigraphic control point for interpreting seismic reflection data that bear on the entire Phanerozoic history of the region (Baldrige et al. 2001).

The interpretation of seismic data and previous studies of the subsurface geology in the Yates #2 La Mesa well have produced conflicting interpretations. These differences need to be resolved in order to understand fully the geology and the tectonic history of the Española Basin. We

undertook this study to resolve these controversies about the subsurface geologic and tectonic history of the southern Española Basin with an emphasis on petrographic data collected from well cuttings.

Alternative interpretations

Previous workers offered contrasting interpretations of the strata that underlie rift-basin fill in the lower part of the well (between 1,200 and about 2,350 m [3,937–7,710 ft]). The three parts of the stratigraphy of most concern are (1) an interval of volcanic and volcanoclastic

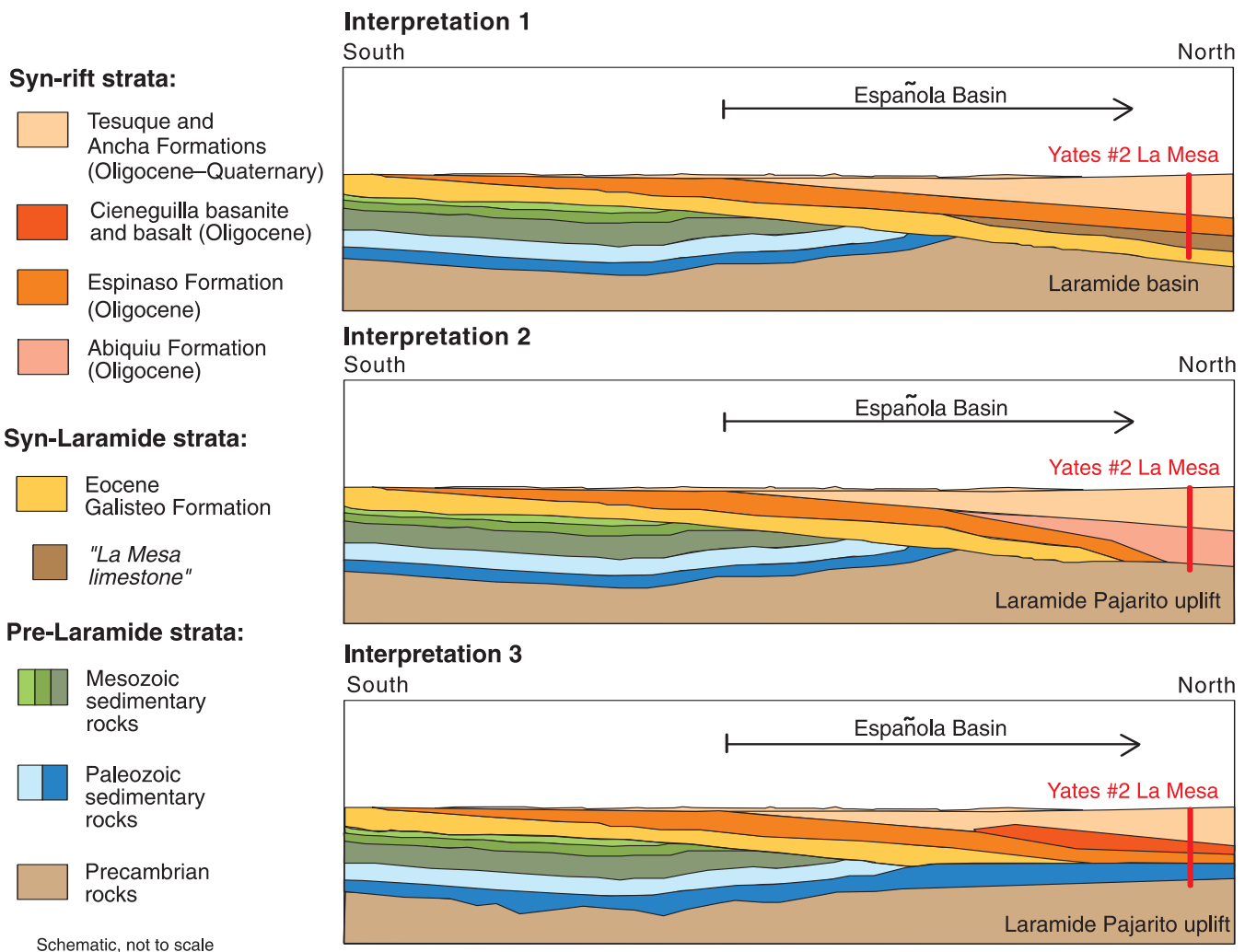


FIGURE 2—Contrasting interpretations of the subsurface geology of the southern Española Basin; see Figure 1 for the location of the schematic unscaled profiles. In interpretation 1 (Biehler et al. 1991; Ferguson et al. 1995; Grant 1999) the Yates #2 La Mesa well penetrates Eocene basin fill that includes the lacustrine “La Mesa limestone.” Paleozoic strata pinch out below an unconformity to the south, and the well may bottom in Galisteo Formation (Grant 1999). Interpretation 2 (Cather 1992) suggests the

presence of the Pajarito uplift during the Eocene. Limestone is interpreted to be within Oligocene volcanoclastic strata of the Abiquiu Formation, and the Eocene Galisteo Formation is truncated south of the well as it approaches the flank of the Pajarito uplift. Interpretation 3, explored in this paper, attributes the limestone-bearing interval to regional Pennsylvanian strata. The thick Espinaso Formation of interpretation 1 is replaced by a thinner section of Espinaso and a younger interval of Oligocene basalt.

rocks, (2) a limestone-bearing sedimentary section below the volcanic interval, and (3) the rocks penetrated at the bottom of the well. The section of volcanic-rich cuttings has been interpreted as either a part of the Miocene Abiquiu Formation (Cather 1992) or the Oligocene Espinaso Formation (Biehler et al. 1991; Grant 1999). The sequence of sedimentary rocks below the volcanic interval, which yielded a high percentage of limestone fragments, was assigned to the Eocene Galisteo Formation (Biehler et al. 1991; Ferguson et al. 1995; Grant 1999) without consideration of correlation to Paleozoic strata. Cather (1992) attributed the limestone to the Abiquiu Formation because limestone and volcanic-rock cuttings are mixed in some intervals. The base of the Yates #2 La Mesa well was determined to be either Precambrian basement rock (Biehler et al. 1991; Cather 1992; Ferguson et al. 1995) or the Eocene Galisteo Formation (Grant 1999).

Conflicting interpretations of tectonic history in this area hinge on these contrasting interpretations of the well cuttings: the Española Basin coincides with either an uplift or a basin during the Eocene Laramide orogeny (Fig. 2). If this area was a basin during the Eocene it would have collected sediment of this age, but if there was an uplift present, the well location would have undergone erosion to provide detritus into adjacent basins.

Previous interpretations of stratigraphic units

The bottom of the Yates #2 La Mesa well was considered to be basement rock by the site geologist, which was supported by the seismic data from the SAGE project (Biehler et al. 1991). Contrastingly, Grant (1999) projected the top of the Precambrian rocks below the bottom of the well. He attributed the lowest cuttings in the well to “granite wash” in the Eocene Galisteo Formation. Consistent with the Laramide-

basin hypothesis (Biehler et al. 1991; Ferguson et al. 1995), Grant (1999) suggested that the Precambrian basement dipped northward, just below the bottom of the Yates #2 La Mesa well, and that the well bottomed in Eocene basin fill.

The limestone-rich section penetrated in the Yates #2 La Mesa well was named the lacustrine “La Mesa limestone” and was correlated to the Galisteo Formation (Biehler et al. 1991; Ferguson et al. 1995; Grant 1999), even though this limestone interval has no outcrop equivalent within regional Eocene strata. Upper Paleozoic limestone was interpreted to pinch out south of the Yates #2 La Mesa well (Biehler et al. 1991; Ferguson et al. 1995; Grant 1999), although subsequent reinterpretation relaxes that requirement (J. Ferguson, pers. comm. 2003). Grant (1999) supported the Eocene age for the limestone because of the stratigraphic placement of the limestone within the well below the Espinaso

Formation and above the Galisteo Formation, which he interpreted at the bottom of the well. Outcrops of the Galisteo Formation contain sparse, thin beds of freshwater limestones (Stearns 1953b; Grant 1999), so it was thought possible for the "La Mesa limestone" to be a thicker correlative of these thin calcareous intervals of the Galisteo Formation.

Cather (1992) hypothesized that the limestone-bearing section, as well as the volcanoclastic interval stratigraphically above it, were a part of the Abiquiu Formation with alternating limestone and volcanoclastic beds. He based his argument on the driller's logs because the cuttings had not yet been made public at the time of his study, and the logs showed a mixture of volcanic and limestone fragments in the same samples. Cather (1992) also noted loose fossil bone and wood fragments recovered from these cuttings during drilling that suggested a Tertiary age. In outcrops near La Bajada, the strata correlated to the Abiquiu Formation by Stearns (1953b) contain thin limestone beds that Cather (1992) tentatively correlated to what later became known as the "La Mesa limestone" (Biehler et al. 1991; Ferguson et al. 1995; Grant 1999). The mixed volcanic and sedimentary rock types and included fossils could alternatively be attributed to caving and mixing of cuttings from various levels of the well during the drilling process.

The interval of volcanic rock cuttings has been correlated to the Abiquiu Formation (Cather 1992) or interpreted as an unusually thick section of the Espinaso Formation (Biehler et al. 1991; Grant 1999). The Espinaso Formation is an Oligocene volcanoclastic sedimentary rock succession with local interbedded lava flows (Stearns 1953b; Sun and Baldwin 1958; Erskine and Smith 1993). Although it is thicker in the Yates #2 La Mesa well than seen in outcrop, the seismic data and driller's logs supported the interpretation that this interval is the Espinaso Formation.

Interpretations of tectonic history

The interpretation of an Eocene basin in the southern Española Basin relies on the interpretation of a body of water where lacustrine limestone accumulated (Biehler et al. 1991; Ferguson et al. 1995; Grant 1999). Uplift, tilting, and erosion of underlying Phanerozoic rocks (Fig. 2) would have occurred during an earlier phase of Laramide deformation before deposition of the Galisteo Formation. Oligocene deposition of volcanoclastic Espinaso Formation followed deposition of the Eocene units (Stearns 1953b; Sun and Baldwin 1958; Ingersoll et al. 1990; Biehler et al. 1991; Grant 1999). As seen in Figure 2, the Eocene sediments would have thickened toward the north, which is further evidence for a basin in this area at this time (Grant 1999).

TABLE 1—Point-counting categories and descriptions of grains.

Category	Description	
Quartz:	Monocrystalline	Single-domain quartz grain.
	Polycrystalline	Multiple quartz grains within one fragment; includes chert and quartzite.
Feldspar:	Plagioclase feldspar	Grains of feldspar with albite twinning.
	Potassium feldspar	Grains of microcline and orthoclase feldspar, some displaying albite-pericline twinning.
Calcite:		Single highly birefringent calcite grains.
Lithic fragments:	Metamorphic fragment	Mostly polycrystalline quartz with undulose extinction and aligned micas; few quartz-amphibole aggregates.
	Sandstone/mudstone fragment	Multigranular, lithified sandstone and mudstone fragments.
	Carbonate fragment without fossils	Micrite ± microspar limestone.
	Carbonate fragment with fossils	Micrite with fossils; typically brachiopods, mollusks, bryozoans, and fusulinids.
	Intermediate volcanic rock fragment	Phenocrysts of feldspar, hornblende, pyroxene, or biotite in a light-colored, feldspar-rich groundmass.
	Mafic volcanic rock fragment	Phenocrysts of olivine (typically iddingsite replaced), plagioclase, and pyroxene in an intergranular to intersertal groundmass of plagioclase and pyroxene. Some zeolite and carbonate replacement and vesicle fillings.
	Vitric volcanic fragments	Opaque black (tachylite) or transparent brown (sideromelane) glass; in some cases with calcite- or zeolite-filled vesicles.
Calcite replaced volcanic fragments		Volcanic, textured rock fragments with pervasive replacement by fine-grained calcite, in some cases accompanied by unidentified zeolites.
	Plutonic rock fragment	Large interlocking euhedral grains of quartz, feldspar, opaque minerals, and some mica.

Alternatively, if the modern Española Basin coincides with the Laramide Pajarito uplift (Cather 1992), then there should be no Eocene deposits in the well (Fig. 2). In this interpretation, the Yates #2 La Mesa well should not bottom in Eocene lacustrine limestone and the limestone-rich section, and the volcanoclastic strata above could be part of the Abiquiu Formation (Cather 1992). Alternatively, the limestone-bearing interval could correlate to Paleozoic marine strata resting on Precambrian basement. In either of these interpretations of the limestone-bearing interval, the Eocene Galisteo Formation pinches out on the uplift flank south of the well (Fig. 2). If all of the volcanoclastic strata correlate to the Espinaso Formation, then it raises a question about the presence or absence of regionally known Oligocene basalt and basanite (Cieneguilla limburgite of Stearns 1953a). Mafic lava flows are present both west (Stearns 1953a,b; Sun and Baldwin 1958) and east (Read et al. 2000) of the well, so presumably should also be penetrated by the well.

Methods

A selection of 46 cutting samples, distributed throughout the well (see Appendix for depths), were thin-sectioned. Two hundred fifty grains were point-counted on each thin-section slide with use of an automated stage and counter. If the microscope cross hairs intersected above an identifi-

able rock fragment, then the grain was counted as that rock type. If the cross hairs intersected above a single mineral grain, it was counted as that mineral type. Table 1 summarizes the categories used to identify the rock fragments. Vertical variations in petrographic composition permitted designation of stratigraphic units. Petrographic data were integrated with results of a cursory examination of cuttings and with geophysical logs to further define the boundaries of these units.

Results of petrographic analysis

Appendix reports the point-counting results of the Yates #2 La Mesa well. Figure 3 displays these data along with designation of lithostratigraphic units based on well-cutting compositions.

When the Yates #2 La Mesa well was drilled, the driller's log referred to a large amount of caving from the upper basin-fill sediment. These cavings mixed with cuttings throughout the well during the drilling process. The mixing of cuttings, which is evident in Figure 3, made it difficult to accurately locate contacts between units based on cuttings alone, as well as to determine the exact composition of the intervals in the deeper subsurface. Lithologic changes of stratigraphic significance were recognized by the first down-hole appearance of new rock types within the cuttings and by the dominant rock type within an interval.

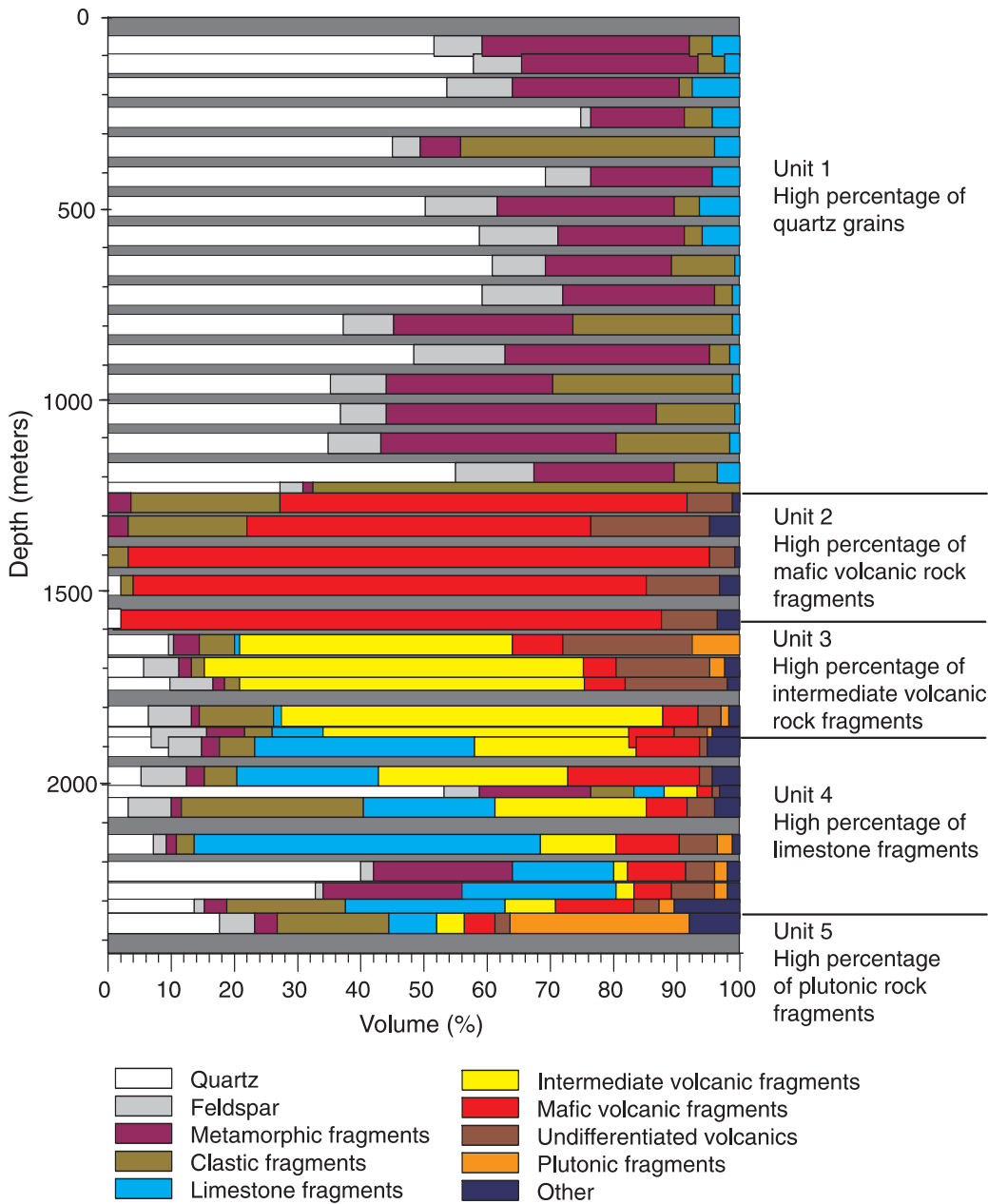


FIGURE 3—Summary of petrographic data. Each horizontal bar represents the percentages of different mineral grains or rock fragments at a particular depth in the well. We interpret the wide variety of rock types in each thin section as partly due to the caving in and mixing of cuttings during the drilling process. Therefore, each unit was identified by the down-hole first appearance of a new, dominant rock type.

Unit #1

The first penetrated unit occupies the uppermost 1,210 m (3,970 ft) of the well and is mostly sub-arkosic sand and mudstone. The loose sand and sandstone fragments contain high abundances of quartz and feldspar with some fragments of metamorphic rock, which are mostly foliated quartz-muscovite aggregates or quartzite (Fig. 3). Paleozoic marine fossils are present in many of the scarce limestone fragments present in this interval.

Unit #2

Progressing downward in the well, unit #2 consists mostly of mafic volcanic rocks that

are present between 1,210 and 1,528 m (3,970–5,013 ft) below the surface. The lava flow fragments contain phenocrysts of clinopyroxene, iddingsite-replaced olivine, and plagioclase within a fine-grained, dark groundmass of pyroxene and plagioclase (Fig. 4 left). A small percentage of these fragments have a groundmass replaced by calcite or zeolite, and these minerals also fill vesicles. There are also vitric pyroclastic fragments present in this succession with varying degrees of calcite or zeolite replacement. These vitric fragments include both transparent sideromelane glass and vesicular opaque tachylite.

A few of the thin sections from this inter-

val include a high percentage of clastic rock fragments and quartz and feldspar grains similar to unit #1 (Fig. 3, Appendix), but mafic rock fragments consistently dominate this section. Well logs show varying responses through this interval that are consistent with the presence of arkosic layers between lava flows, rather than requiring that all of the quartz and feldspar fragments are mixed from higher levels in the well.

Unit #3

From 1,528 m down to 1,835 m (5,013–6,020 ft) is a section of dominantly intermediate volcanic or volcanoclastic rock fragments (Fig. 3). Unit #3 contains fragments of both porphyritic hornblende latite and augite latite. These rock fragments have phenocrysts of plagioclase feldspar, hornblende, pyroxene, and biotite (Fig. 4 right). The large variety of textures and mineral contents visible among fragments within individual cutting samples implies that these volcanic fragments are derived from volcanoclastic sedimentary rocks, rather than representing lava flows.

Unit #4

Thin sections for samples from the interval from 1,835 m to 2,297 m (6,020–7,536 ft) below the surface are dominated by limestone fragments with subordinate fragments of clastic sedimentary rocks. Many limestone fragments contain fossils of late Paleozoic marine fauna such as crinoids, brachiopods, bryozoans, fusulinids, and bivalves (Fig. 5 left and right). Sparse volcanic rock cuttings in this interval (Fig. 3) are interpreted as cavings from the overlying strata.

Unit #5

The lowermost unit in the Yates #2 La Mesa well is present from 2,297 m to 2,350 m (7,536–7,710 ft) below the surface. We examined only one thin section representing unit #5, and it shows a high percentage of plutonic (granitic) rock fragments as compared to thin sections from other units (Fig. 3). There is also a significant abundance of single grains of angular quartz and feldspar that resemble the minerals within the plutonic rock fragments. The cuttings from unit #5 also include fragments that correlate to each of the overlying intervals (Fig. 3) and these fragments are interpreted to represent mixing of fragments from caved parts of the well.

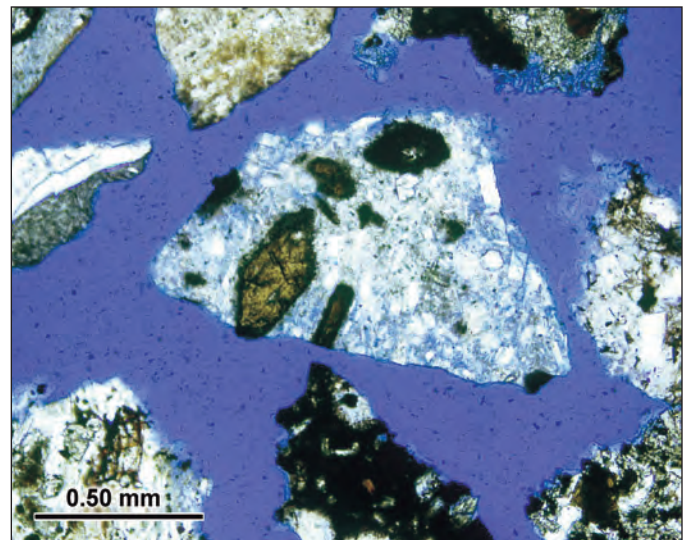
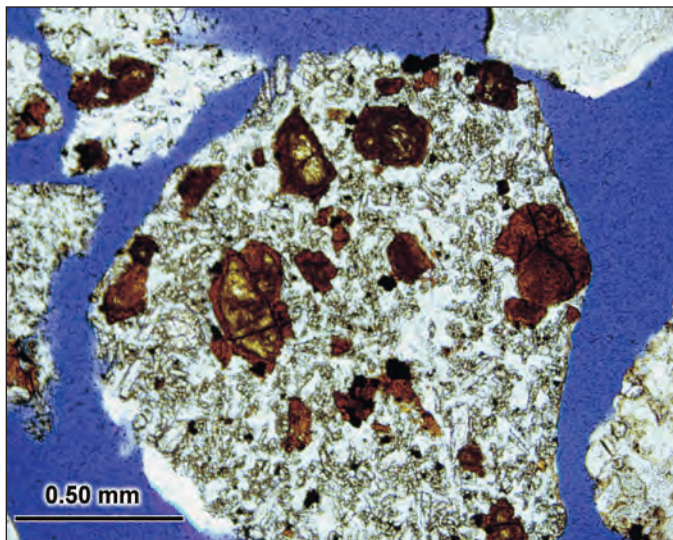


FIGURE 4—Photomicrographs of volcanic rock cuttings in units #2 and #3. **Left**—Lava flow cuttings from unit #2 containing clinopyroxene

and iddingsite-replaced olivine. **Right**—Highly porphyritic hornblende-lattice fragments from unit #3.

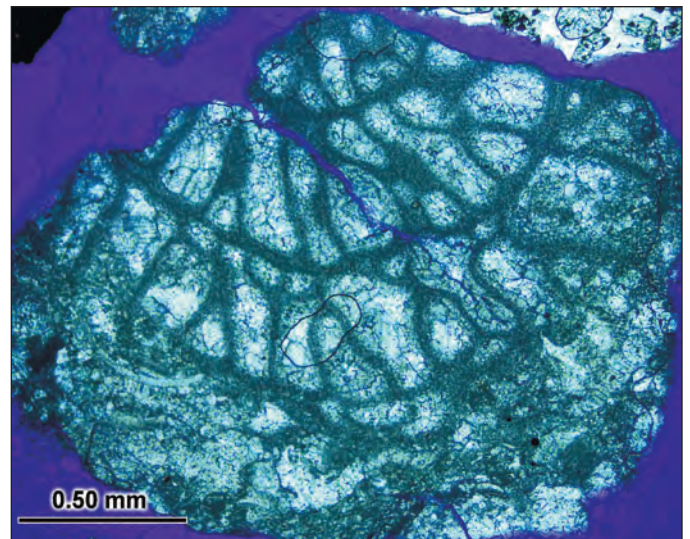
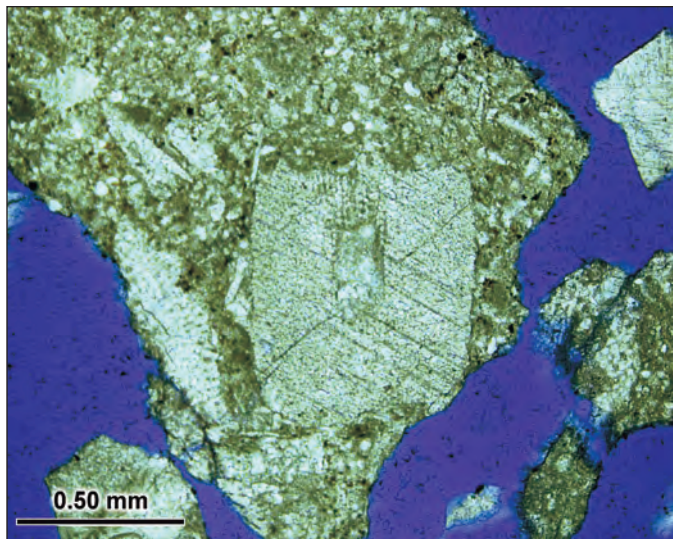


FIGURE 5—Photomicrographs of fossils in limestone cuttings from unit #4. Crinoid fragments (left), fusulinid tests (right) along with brachiopod, bryozoan, and mollusk fragments not illustrated here all

reveal a Paleozoic age for the limestones previously attributed to deposition in an Eocene lake.

Stratigraphic correlation

Figure 6 displays a stratigraphic column for the well that is consistent with the petrographic descriptions of the cuttings.

The uppermost unit in the well is the Santa Fe Group. This undisputed rift-basin fill section is present down to 1,210 m (3,970 ft) into the well. The Pliocene–Quaternary Ancha Formation is present at the surface in this area and is similar in composition to the underlying Tesuque Formation (Shroba et al. 2005; Koning and Read 2004). Because the Ancha Formation is relatively thin in this area, the first sampled well cuttings were retrieved from the Tesuque Formation of the Santa Fe Group, which is attributed to unit #1. The abundance of quartzite fragments and scattered Paleozoic limestone grains imply that most or all of the Tesuque Formation in the well

correlates to lithosome S of Koning et al. (2004). The composition of this sediment implies deposition by an ancestral Santa Fe River with a watershed that included that of the modern upper Pecos River (Smith 2004).

From 1,210 m to 1,835 m (3,970–6,020 ft) below the surface is a succession of dominantly volcanic rocks, previously interpreted as one thick volcanic unit (e.g., Biehler et al. 1991; Grant 1999). Our petrographic data (Fig. 3) show that this interval consists of a younger mafic interval (unit #2) and an older succession of intermediate composition (unit #3).

Unit #2 correlates to the Cieneguilla basanite (Sawyer et al. 2002; previously called the Cieneguilla limburgite by Stearns 1953b), consisting of Miocene to Oligocene basanite and olivine basalt seen in outcrops near La Cienega (Stearns

1953a,b; Sun and Baldwin 1958). Correlative basalt flows are present in the lower Tesuque Formation north of Santa Fe (Read et al. 2000; Baldrige et al. 1980; Smith 2004) and as far west as the southeastern Jemez Mountains (WoldeGabriel et al. 2003; Wolff et al. 2005). The presence of vitric pyroclastic rock fragments among the cuttings suggests the possibility that the well is located close to a vent. Gibson et al. (1993) attributed these regional mafic lavas to lithospheric mantle decompression melting during early stages of rift extension.

Arkosic grains similar to the Tesuque Formation that are present among the basalt cuttings are most likely not only from caving in of younger strata. High gamma-ray response on geophysical logs suggests that the lower part of the basaltic interval includes intervals of sedimentary

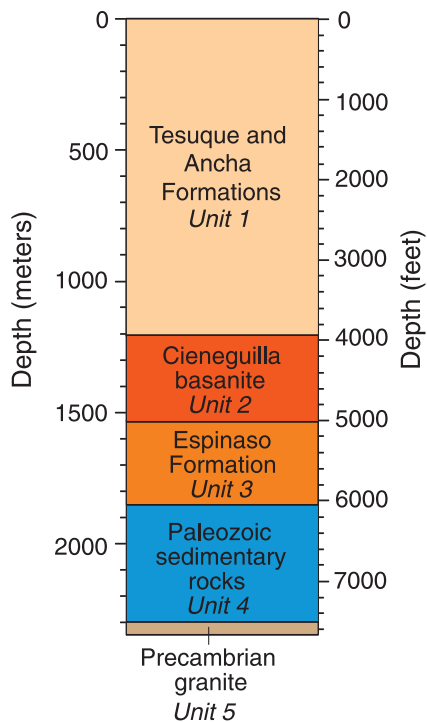


FIGURE 6—Interpreted stratigraphy of the Yates #2 La Mesa well. The compositional units interpreted in Figure 3 are correlated to previously identified lithostratigraphic units that are present in outcrop near the location of the Yates #2 La Mesa well.

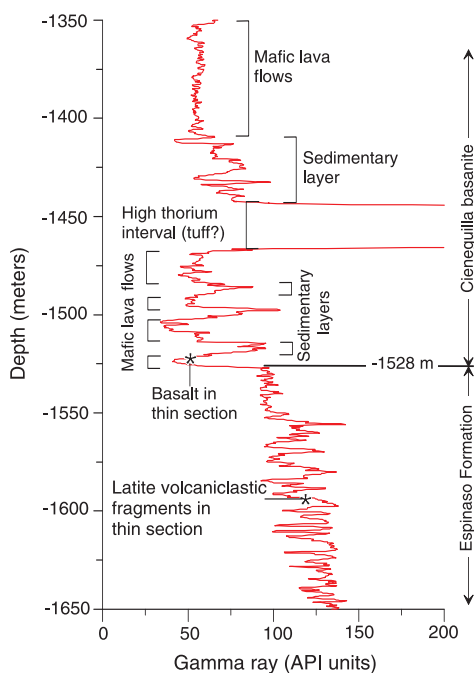


FIGURE 7—Gamma-ray log typical of the volcanic interval of the well. We interpret the shift in the log curve at 1,528 m (5,013 ft) to represent the contact between Cieneguilla mafic lavas and more potassic, latitic volcanoclastic detritus of the Espinaso Formation. Variable log response within the mafic lava interval reveals the presence of sedimentary interbeds and radiogenic horizons that may represent altered tuff.

TABLE 2—Compositional comparison of Espinaso Formation and Cieneguilla basanite.

	Espinaso Formation		Cieneguilla basanite	
	alkaline latite ¹ wt %	calc-alkaline latite ¹ wt %	basalt ² wt %	basanite (limburgite) ² wt %
SiO ₂	54.42 ± 5.24	59.25 ± 2.74	45.81	40.18
Al ₂ O ₃	16.89 ± 1.65	17.13 ± 0.85	14.08	11.7
FeO	7.12 ± 2.52	5.83 ± 1.32	7.41	6.68
MgO	2.54 ± 1.23	1.95 ± 0.58	8.79	14.3
CaO	6.48 ± 2.05	5.57 ± 0.64	9.45	13.28
Na ₂ O	3.8 ± 0.73	3.97 ± 0.46	2.49	3.48
K₂O	3.97 ± 0.77	2.65 ± 0.64	0.86	0.76
TiO ₂	1.41 ± 1.09	0.73 ± 0.18	1.63	2.66
P ₂ O ₅	0.42 ± 0.26	0.25 ± 0.06	0.28	0.68
MnO	0.18 ± 0.03	0.15 ± 0.03	0.19	0.08

¹Data from Erskine and Smith 1993

²Data from Sun and Baldwin 1958

deposits alternating with intervals of lava (Fig. 7). The interfingering of lava flows and sedimentary beds implies that rift-basin subsidence coincided with basalt eruption. This interpretation is consistent with local accumulation of more than 400 m (1,300 ft) of Tesuque Formation below likely correlative basalt near Santa Fe (Smith 2004).

The driller's logs mention periods of slower drilling rates while penetrating zones of the basalt flows that coincide with thin intervals of green clays. These clays are not present in the cuttings archived at the New Mexico Bureau of Geology and Mineral Resources, but these intervals coincide with spikes in the gamma-ray log indicating high thorium content and may coincide with layers of altered tuff. Stearns (1953a) described green tuffaceous clay in outcrop near La Cienega that may correlate to the clay layers in the well.

The intermediate-composition volcanic interval composing unit #3 resembles the latitic Espinaso Formation (Erskine and Smith 1993). The diverse mineral contents and textures of unit #3 cuttings support a correlation to the Espinaso latitic lava flows and sedimentary deposits, which are exposed as close to the well as La Cienega (Stearns 1953a,b; Sun and Baldwin 1958; Grant 1999).

The contact between the Cieneguilla basanite and Espinaso Formation was not identified by previous workers or in the driller's log, so these two formations were previously considered as one lithostratigraphic unit. The gamma-ray log abruptly shifts to higher gamma values at 1,528 m (5,013 ft) below the surface (Fig. 7). We interpret this shift as the contact between the two different volcanic intervals. Table 2 shows that an average sample of the Cieneguilla mafic lavas has 0.86 wt% K₂O, whereas the Espinaso Formation averages 3.97 wt% K₂O (Sun and Baldwin 1958; Erskine and Smith 1993). This contrast in K₂O contents explains the gamma-ray log response.

Biehler et al. (1991) and Grant (1999) interpreted the entire sequence of volcanic

and volcanoclastic rocks as a thick section of the Espinaso Formation. In the Yates #2 La Mesa well this sequence is 625 m (2,051 ft) thick, which is much thicker than is seen anywhere in outcrop for the Espinaso Formation (cf. Sun and Baldwin 1958; Stearns 1953a). Distinguishing between the Cieneguilla basanite and Espinaso Formation within the well leads to stratigraphic thicknesses (318 m [1,043 ft] of Cieneguilla mafic lavas and 307 m [1,007 ft] of Espinaso Formation) that are comparable to what appears in outcrops.

We correlate unit #4, previously interpreted as the Eocene "La Mesa limestone" lake deposit (Biehler et al. 1991; Grant 1999), to the Pennsylvanian Madera Group and possibly unidentified Mississippian strata (Fig. 6). The presence of Paleozoic marine fossils precludes the presence of an Eocene lacustrine deposit. The possibility that the fossiliferous cuttings are only fragments of Paleozoic clasts within Eocene clastic sediment seems unlikely to us, because although polyolithic fragments of cemented grains are present in the cuttings there are no observed instances where limestone grains are cemented to other grains. This implies that the limestone cuttings derive from drilling through limestone rather than clastic strata containing limestone clasts. The rock types in the cuttings correspond to the interbedded Paleozoic limestone and clastic sedimentary rocks seen elsewhere along the margins of and below the Española Basin. Cather (1992) suggested that the limestones were interbedded with volcanic rocks, but we interpret the presence of both limestone and volcanic rock cuttings to represent mixing of cavings from different well intervals.

A comparison of geophysical logs in the Yates #2 La Mesa well to the Shell Santa Fe Pacific #1 well (drilled near Rio Rancho, New Mexico) further supports correlation of unit #4 to the Pennsylvanian section (Fig. 8). It is not realistic to make specific bed-by-bed correlations between the two wells because of dramatic lateral facies variations in Pennsylvanian strata (e.g.,

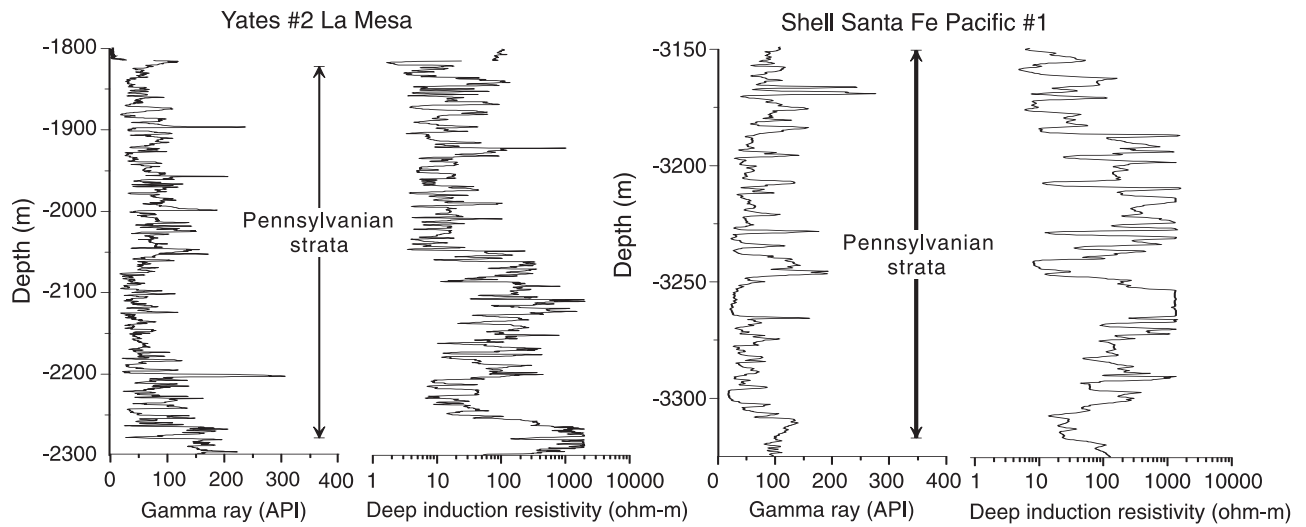
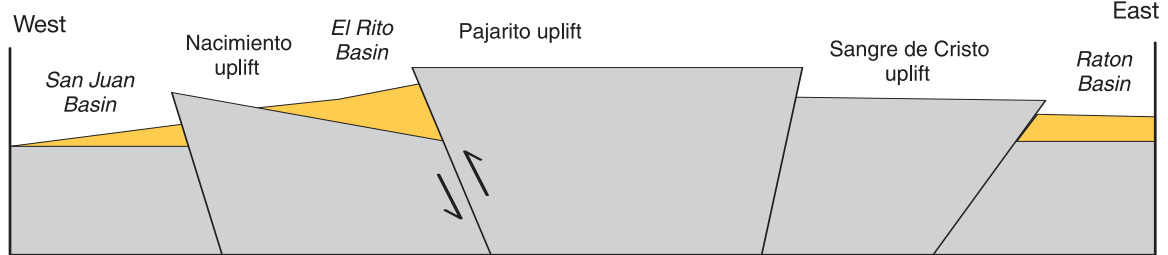


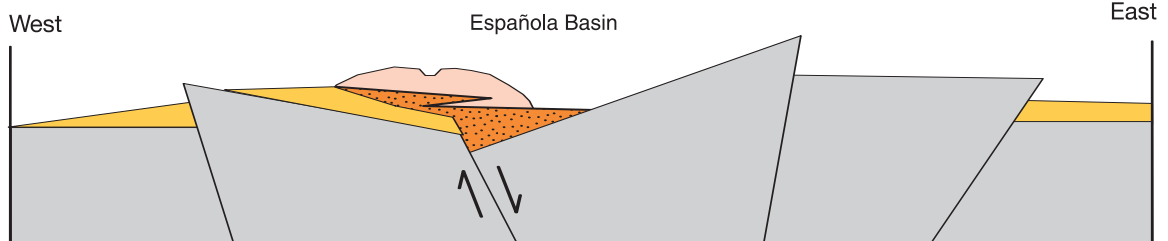
FIGURE 8—Comparison of gamma-ray and resistivity logs for the Yates La Mesa #2 and the Shell Santa Fe Pacific #1 wells. The vertical scales are adjusted for comparison purposes and are different

between the wells because the Pennsylvanian section in the Shell Santa Fe Pacific #1 well is much thinner.

Eocene – Laramide orogeny



Miocene – Rio Grande rift



(not to scale)

Pre-Tertiary rocks	Laramide sedimentary rocks
Rift-basin fill	Jemez volcanic rocks

FIGURE 9—Tectonic history of the southern Española Basin. Laramide shortening formed the Pajarito uplift. During Oligocene-Miocene extension, stresses reversed the throw on

reverse faults to invert the Pajarito uplift to form the Española Basin (after Cather 1992).

Baltz and Myers 1999), and the section is much thinner in the Shell Santa Fe Pacific #1. However, the geophysical expression of the Pennsylvanian section in these two wells is very similar. The lower half of this section in each well is characterized by an upward increase in resistivity to values greater than 500 ohm-m, which shows the upward transition from the clastic sediments of the Sandia Formation into the limestone-rich lower part of the Madera Group. The upper half of the section in each well also shows variability in both the gamma and resistivity signals that reflects

the interbedding of limestone, shale, and sandstone in the upper part of the Madera Group. The Shell Santa Fe Pacific #1 well shows more limestone than the Yates #2 La Mesa well, which is expected because the Shell well is more distant from contemporaneous clastic sediment sources.

The Yates #2 La Mesa well bottoms in Precambrian basement rock (unit #5), present below 2,297 m (7,536 ft). Rock fragments with large interlocking grains typical of plutonic rocks dominate the examined thin section.

Conclusions

If the southern Española Basin was also a Laramide basin, there would be Eocene deposits present in the Yates #2 La Mesa well, but there are none present (Fig. 6). The well bottoms in Precambrian granite and is overlain by a Paleozoic sedimentary succession previously correlated to the Eocene Galisteo Formation. The presence of Paleozoic strata in the well also implies earlier misidentification of seismic reflectors, which led to the previous exclusion of Paleozoic rocks from the well. The absence

of Eocene Galisteo Formation supports the Pajarito uplift interpretation of Cather (1992) and subsequent inversion of the uplift to form the Española Basin, as schematically illustrated in Figure 9.

Two volcanic and volcanoclastic formations are present in the well rather than just one, as previously reported. Stratigraphically above the Paleozoic strata is the Oligocene Espinazo Formation overlain by mafic lava flows interbedded with arkosic sedimentary rocks that represent the earliest rift-basin fill.

Acknowledgments

Steve Cather of the New Mexico Bureau of Geology and Mineral Resources encouraged this study and provided the thin sections used for analysis. Myer's work was supported by the Caswell Silver Foundation at the University of New Mexico. We thank David Sawyer (USGS) for discus-

sions about the geology in the well and for providing digitized well logs. Brian Brister provided helpful instruction on correlating the driller's logs, geophysical logs, and cutting samples. Reviewers Tien Grauch and Steve Cather contributed important insights that permitted us to improve the paper.

References

- Baldrige, W. S., Damon, P. E., Shafiqullah, M., and Bridwell, R. J., 1980, Evolution of the central Rio Grande rift, New Mexico—new potassium-argon dates: *Earth and Planetary Science Letters*, v. 51, pp. 309–321.
- Baldrige, 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 Española Basin (Rio Grande rift) and flank uplift adjacent to the La Bajada fault: *Geological Society of America, Abstracts with Programs*, v. 33, no. 5, p. A61.
- Baltz, E. H., and Myers, D. A., 1999, Stratigraphic framework of upper Paleozoic rocks, southeastern Sangre de Cristo Mountains, New Mexico, with a section on speculations and implications for regional interpretation of Ancestral Rocky Mountain paleotectonics: *New Mexico Bureau of Mines and Mineral Resources, Memoir* 48, 269 pp.
- Biehler, S., Ferguson, J., Baldrige, W. S., Jiracek, G. R., Aldern, J. L., Martinez, M., Fernandez, R., Romo, J., Gilpin, B., Braile, L. W., Hersey, D. R., Luyendyk, B. P., and Aiken, C. L. V., 1991, A geophysical model of the Española Basin, Rio Grande rift, *New Mexico: Geophysics*, v. 56, pp. 340–353.
- Cather, S. M., 1992, Suggested revisions to the Tertiary tectonic history of north-central New Mexico; *in* Lucas, S. G., Kues, B. S., Williamson, T. E., and Hunt, A. P. (eds.), *San Juan Basin IV: New Mexico Geological Society, Guidebook* 43, pp. 109–122.
- Erskine, D. W., and Smith, G. A., 1993, Compositional characterization of volcanic products from a primarily sedimentary record; the Oligocene Espinazo Formation, north-central New Mexico, with supplemental data 9325: *Geological Society of America, Bulletin*, v. 105, no. 9, pp. 1214–1222.
- Ferguson, J. F., Baldrige, W. S., Braile, L. W., Biehler, S., Gilpin, B., and Jiracek, G. R., 1995, Structure of the Española Basin, Rio Grande rift,

Appendix

Point-count data (percentages based on 250 points counted per thin section). Categories described in Table 1.

Slide #1	Unit	Mono-crystalline quartz	Poly-crystalline quartz	Plagioclase feldspar	Potassium feldspar	Metamorphic rock fragments	Sandstone fragments	Mudstone fragments	Limestone fragments w/fossils	Limestone fragments w/o fossils	Intermediate volcanic rock fragments
2-150	1	51.2	0.4	3	4.6	32.8	3.6	0	0.8	3.6	0
2-300	1	57.4	0.4	2.2	5.4	28	4.2	0	1.2	1.2	0
2-500	1	53.6	0	2.8	7.6	26.4	2	0	3.2	4.4	0
2-750	1	74.4	0.4	1.2	0.4	14.8	4.4	0	1.6	2.8	0
2-1000	1	44.2	0.8	0	4.4	6.4	40.2	0	2.2	1.8	0
2-1250	1	69.2	0	1.2	6	19.2	0	0	2.8	1.6	0
2-1500	1	49.8	0.4	3.2	8.2	28	4	0	2.8	3.6	0
2-1750	1	58.4	0.4	2	10.4	20	2.8	0	5.4	0.6	0
2-2000	1	60.8	0	0.8	7.6	20	10	0	0.4	0.4	0
2-2250	1	59.2	0	1.2	11.6	24	2.8	0	0	1.2	0
2-2500	1	36.8	0.4	1.2	6.8	28.4	17.6	7.6	0	1.2	0
2-2750	1	48.4	0	1.2	13.2	32.4	1.6	1.6	1.2	0.4	0
2-3000	1	35.2	0	1.2	7.6	26.4	6	22.4	0.4	0.8	0
2-3250	1	36.8	0	0.4	6.8	42.8	9.2	3.2	0.4	0.4	0
2-3500	1	34.8	0	0.8	7.6	37.2	5.2	12.8	0.4	1.2	0
2-3750	1	54.6	0.4	1.2	11.2	22.2	4.8	2	2	1.6	0
2-3910	1	26	1.2	0.8	2.8	1.6	5.2	62.4	0	0	0
2-4000	2	0	0	0	0	3.6	23.6	0	0	0	0
2-4200	2	0	0	0	0	3.2	18.8	0	0	0	0
2-4460	2	0	0	0	0	0	3.2	0	0	0	0
2-4700	2	2	0	0	0	0	2	0	0	0	0
2-4990	2	0.8	0	0	0	0	0	0	0	0	0
2-5200	3	9.6	0	0.8	0	4	5.6	0	0.4	0.4	43.2
2-5390	3	5.6	0	5.6	0	2	2	0	0	0	60
2-5500	3	9.8	0	6.8	0	1.8	2.4	0	0	0	54.6
2-5800	3	6.4	0	2.8	4	1.2	11.8	0	0	1.2	60.4
2-5980	3	6.8	0	6.8	2	6	4.4	0	2.4	5.6	48.4
2-6060	4	9.6	0	4.8	0.4	2.8	5.6	0	11.6	23.2	25.6
2-6310	4	5.2	0	5.2	2	2.8	5.2	0	4	18.4	30
2-6470	4	53.2	0	4.8	0.8	17.6	6.8	0	0.4	4.4	5.2
2-6570	4	3.2	0	5.2	1.6	1.6	28.8	0	4.6	16.2	24
2-6880	4	7.2	0	2	0	1.6	2.8	0	40	14.8	12
2-7110	4	40	0	2	0	22	0	0	10.2	5.8	2.2
2-7290	4	32.8	0	1.2	0	22	0	0	14.4	10	2.8
2-7430	4	13.6	0	0	1.6	3.6	18.8	0	17.2	8	8
2-7550	5	17.6	0	5.6	0	3.6	17.6	0	4	3.6	4.4

¹ The last four digits of the slide number record the depth, in feet, below ground surface.

