GSA DR Item **2013139** accompanies Koning, D.J., Grauch, V.J.S., Connell, S.D., Ferguson, J., McIntosh, W., Slate, J.L., Wan, E., and Baldridge, W.S., 2013, Structure and tectonic evolution of the eastern Española Basin, Rio Grande rift, north-central New Mexico, *in* Hudson, M.R., and Grauch, V.J.S., eds., New Perspectives on Rio Grande Rift Basins: From Tectonics to Groundwater: Geological Society of America Special Paper 494, p. 185–219, https://doi.org/10.1130/2013.2494(08).

APPENDIX A. STRATIGRAPHY OF THE TESUQUE AND CHAMITA FORMATIONS

This appendix reviews stratigraphic relations and nomenclature for the Tesuque and Chamita Formations. Strata of these formations were deposited in three main depositional environments (Figure A-1): 1) a west-sloping, eastern alluvial slope (piedmont) along the foot of the Sangre de Cristo Mountains (Smith, 2000a; Kuhle and Smith, 2001); a south-sloping basin-floor, and 3) a south- to southeast-sloping western alluvial slope (piedmont) -- the latter two areas reached headward into the San Luis Basin. These depositional environments resulted in three distinct lithofacies assemblages that grade laterally with one another, which we call the eastern alluvial slope, basin-floor, and western alluvial slope lithofacies assemblages. Two smaller depositional areas include upper Oligocene-lower Miocene alluvial fans flanking the Cerrillos Uplift and upper Miocene-Pliocene alluvial fans flanking the Jemez Mountains (Figure A-1).

In the Española Basin, the pre-Pliocene part of the Santa Fe Group has been subdivided into the Tesuque Formation (Spiegel and Baldwin, 1963) and a somewhat coarser-grained, overlying Chamita Formation (Galusha and Blick, 1971), as illustrated in Figure A-2. The Tesuque Formation has been subdivided into several members by Galusha and Blick (1971) that include the Nambé, Skull Ridge, and Pojoaque Members in the eastern part of the Española Basin, and the Chama-El Rito Member in the central and western part of the basin (including the western part of the eastern half-graben). The Chama-El Rito Member consists of the aforementioned western alluvial slope lithofacies assemblage, in which relatively coarse volcaniclastic sediment, derived from dacitic-andesitic volcanoes in the San Luis Basin, is interbedded with orange, quartz-rich sand (May, 1980; 1984; Ekas et al., 1984; Ingersoll et al., 1990). The other three members were defined more by biostratigraphic criteria than lithostratigraphic criteria, and cut

across the basin-floor and eastern alluvial slope lithofacies assemblages (Figure A-2). Cavazza (1986) informally called pre ~13.1 Ma Tesuque Formation sediment deposited on the basin-floor and eastern alluvial slope as lithosomes B and A, respectively (Figures A-1 and A-2). Lithosome B is gray to pink in color, contains significant felsic-intermediate volcanic and Paleozoic sedimentary rock detritus, and was deposited by south- to southwest-flowing streams. Lithosome A is orange to pink in color, consists of arkosic sand and granite-and quartzite-bearing gravel, and was deposited by a plethora of streams flowing west out of the granite-cored Sangre de Cristo Mountains. Interbedded in these strata are three tephra zones consisting of fine, white and gray ashes, listed from bottom to top: 1) the Nambé white ash zone (16.6-16.2 Ma) near the top of the Nambé Member that only consists of white ashes; 2) the Skull Ridge ash zone (15.8 to 15.1 Ma) in the Skull Ridge and Chama-El Rito Members, which includes all of the ashes mapped in the Skull Ridge Member by Galusha and Blick (1971) and Koning et al. (2002) except for the No. 1 white ash bed; and 3) the Pojoaque white ash zone (14.0-13.2 Ma) in the Pojoaque and Chama-El Rito Members (Figure A-1; age control discussed in Appendix B).

Defining the base of the Santa Fe Group has become more problematic because of recent observations of lower basin-fill strata 7-13 km northeast of downtown Santa Fe. From bottom to top, basin-fill units found here include: 1) a limestone- and granite-bearing sandy conglomerate that is locally over 400 m-thick (Smith, 2000b); 2) white to light gray, tuffaceous, silty-clayey sand and pebbly sand with latitic clasts; 3) reddish pebble- to cobble-conglomerate composed almost wholly of granite clasts. The lowest unit has been called the Nambé Member of the Tesuque Formation by previous workers (e.g., Spiegel and Baldwin, 1963; Smith, 2000b), and the middle unit has been called the Bishops Lodge Member of the Tesuque Formation (Brewster, 1956; Spiegel and Baldwin, 1963) or part of the Picuris Formation (Cabot, 1938; Galusha and

Blick, 1971). However, recent interpretations demonstrate that the Bishops Lodge Member is a distal equivalent of the Espinaso Formation (Smith, 2000b; Smith, 2004). The Espinaso Formation southwest of Santa Fe mostly consists of proximal, debris-flow dominated alluvial fan deposits of volcaniclastic conglomerate and sandstone, with minor latite, quartz latite, and andesite flows erupted from vents in what is now the Cerrillos Hills (Stearns, 1953; Kautz et al., 1981; Smith et al., 1991). The Espinaso Formation and correlative intrusions under its eroded source vents range in age from 36-26 Ma (Baldridge et al., 1980; Sauer, 1999; Sawyer et al., 2002), and generally is considered to underlie the Santa Fe Group (Spiegel and Baldwin, 1963; Kautz et al., 1981), as evident in the Yates #2 well (Figure A-3). In this paper, we agree with Smith (2004) and include the Bishops Lodge Member in the Espinaso Formation.

The upper unit (i.e., reddish conglomerate) constitutes the basal part of what we informally refer to as the "lower coarse unit" of the Tesuque Formation (unit Ttan1 of Koning et al., 2002). This unit is composed of pebbly sandstone, conglomerate, and sandstone. The lower coarse unit can be followed northwards to the Chimayo area, but its upper contact is gradational and indistinctive. Cross-sections and inspection of cuttings from the Kelley Federal well 3.5 km southeast of Chimayo indicate a thickness of 380-460 m (Figure A-4; Plate 1). The basal age of the lower coarse interval is constrained at 25.5-26.0 Ma based on a $^{40}Ar/^{39}Ar$ age of 25.52 ± 0.07 Ma from a tephra ~18 m above its base (Table 1 of manuscript, sample SET-26). The upper age limit of this interval is probably around 18 Ma because it underlies the upper, fine-grained part of the Nambe Member; these upper strata have been assigned an approximate age range of 16-18? Ma based on fossil data and geomagnetic polarity studies (Tedford and Barghoorn, 1993; Barghoorn, 1981 and 1985).

An unit informally called lithosome E by Koning and Johnson (2006) is found in the subsurface southwest of Santa Fe. Lithosome E consists of pebbly sand and clayey pebbly sand of latite and basalt detritus. It overlies the Cieneguilla basanite and also interfingers with it (Figure A-3). Sediment of lithosome E is interpreted to have been eroded from the Cieneguilla basanite and Espinaso Formation on the eastern flanks of the Cerrillos Uplift (Koning and Johnson, 2006; Figure A-1).

The distinctive Ojo Caliente Sandstone Member of the Tesuque Formation is found in the west-central and northwestern parts of the Española Basin (Figure A-1). This eolianite consists of fine- to coarse-grained sand that is commonly tangential cross-stratified (Koning et al., 2005a). The unit coarsens slightly up-section and interfingers southward with the Vallito Member of the Chamita Formation. It interfingers eastward with the upper Pojoaque and the Cejita Members of the Tesuque Formation (Koning et al., 2005a; Cejita and Vallito Members introduced below). Based on geochemical correlations of Slate et al. (2013), the upper Pojoaque white ash zone is likely present in the lower part of the Ojo Caliente Sandstone (~13.5-13.2 Ma; Appendix B). Probable Trapper Creek ashes are found in the middle and upper part of the sandstone (ages of 12.17 ± 0.3 Ma and 11.3 ± 0.10 Ma, respectively) on the western flank of the Velarde graben (Koning et al., 2011; Slate et al., 2013). We suspect that preserved Ojo Caliente Sandstone is older than 11 Ma over much of the Abiquiu embayment to the west.

An important coarsening event at 13.1-13.2 Ma (Koning, 2002; Koning et al., 2005a and 2007; Appendix B) is used to subdivide Miocene-age, Santa Fe Group strata (Figure A-2). In the coarser upper unit, the Cuarteles Member (Koning et al., 2005a; Koning and Aby, 2005) encompasses the eastern alluvial slope lithofacies assemblages (equivalent to lithosome A lower in the section) and the Cejita Member (Manley, 1976, 1977, 1979) includes deposits derived

from the Peñasco embayment. Both these members extend from the Tesuque Formation east of the Rio Grande into the Chamita Formation west of the Rio Grande, as allowed by the stratigraphic code (North America Commission on Stratigraphic Nomenclature, 2005; Koning and Aby, 2005; Koning et al., 2005a). The Cejita Member interfingers westward with sand (and minor silt-clay and pebbles) derived from the San Luis Basin and Abiquiu embayment, called the Vallito Member of the Chamita Formation, which in turn interfingers westward with gravel, sand, and silt-clay deposited by an ancestral Rio Chama, called the Hernandez Member of the Chamita Formation (Figure A-2; Koning and Aby, 2005). The Hernandez Member interfingers westward with alluvial fans consisting of felsic-intermediate volcanic detritus derived from the Jemez Mountains (not shown on Figure A-2). In addition to their overall coarser texture, these post 13.1-13.2 Ma strata are also distinctive in that coarse tephra are more common than fine tephra. These upper tephra beds include, from bottom to top: the lower coarse white ash zone (12.0-13.0 Ma), the main Española tephra zone (poorly constrained age of 10.2-12.0 Ma; not shown on Figure A-2), the Alcalde tephra zone (9.0-10.0 Ma), the Chamita lower tuffaceous zone (8.1-8.7 Ma), and the Chamita upper tuffaceous zone (6.8-6.9 Ma), which is correlative to the Peralta Tuff (McIntosh and Quade, 1995; Koning and Aby, 2003; Koning et al., 2004; 2005a and 2007). These coarse tephra are almost certainly a product of abundant felsic-intermediate volcanism in the nearby Jemez Mountains. This volcanism formed the flows, intrusions, and proximal volcaniclastic deposition of the Keres Group. An exception is the main Española tephra zone, which includes beds of black volcanic grains, interpreted to be basalt or basaltic andesite, possibly derived from early activity of the Lobato volcanic field in the northeast Jemez Mountains.

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Figure A-1

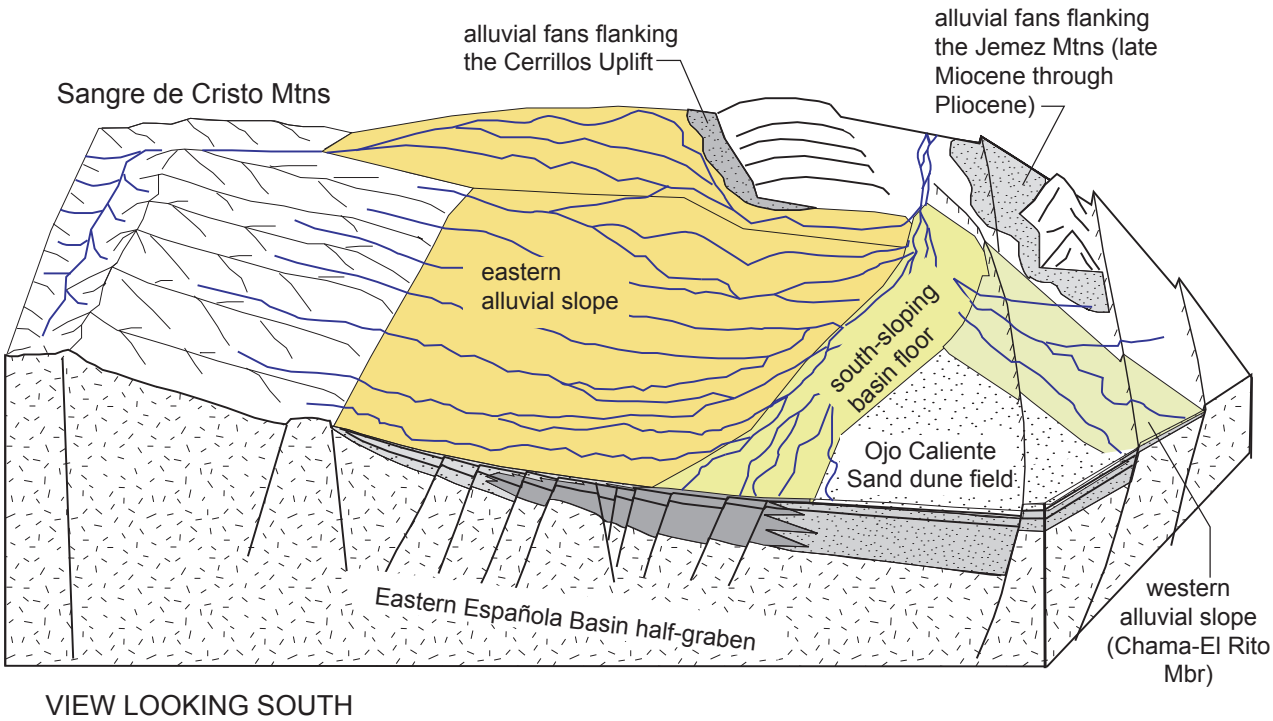

Figure A-1. Schematic block diagram illustrating depositional environments during Santa Fe Group deposition in the late middle Miocene. Late Miocene alluvial fans in the southwest basin are also included.

Figure A-2 (next page). Diagram illustrating ages and spatial stratigraphic relations of various units of the Santa Fe Group (schematically, from west to east across the Española Basin). Note that lithofacies of the Tesuque Formation (i.e., western alluvial slope, basin-floor, and eastern alluvial slope deposits, as explained in Appendix A) are shown in yellow and orange shades. The Nambé, Skull Ridge, and Pojoaque Members defined by Galusha and Blick (1971), which extend across the eastern alluvial slope-basin floor boundary, are delineated by blue lines. Tephra zones are depicted using cross-shaped stippled patterns. Age control derived primarily from the following works: Izett and Obradovich, 2001; McIntosh and Quade, 1995; Barghoorn, 1981, using the revised geomagnetic polarity time-scale of Ogg and Smith, 2004; Tedford and Barghoorn, 1993; Koning et al., 2005a, 2005b; Smith, 2000b; Kempter et al., 2007; Dethier et al., 1986; Aldrich and Dethier, 1990).

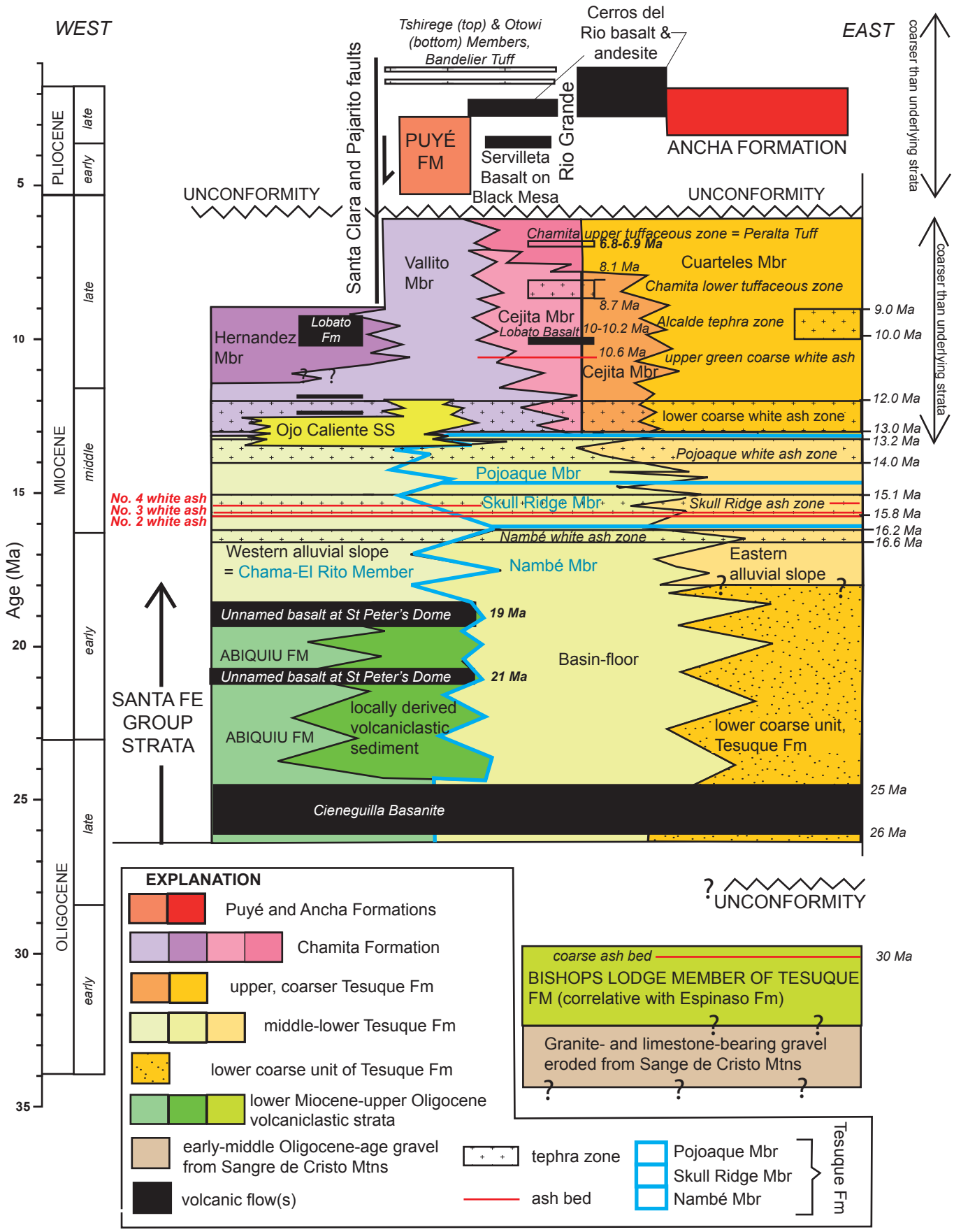
WEST
EAST
Age (Ma)
PLIOCENE
MIOCENE
OLIGOCENE
late
early
middle
5
10
15
20
25
30
35
Tshirege (top) & Otowi (bottom) Members, Bandelier Tuff
Cerros del Rio basalt & andesite
Santa Clara and Pajarito faults
PUYÉ FM
Servilleta Basalt on Black Mesa
Rio Grande
ANCHA FORMATION
UNCONFORMITY
UNCONFORMITY
coarser than underlying strata
coarser than underlying strata
Chamita upper tuffaceous zone = Peralta Tuff
6.8-6.9 Ma
Vallito Mbr
8.1 Ma
Cuarteles Mbr
Chamita lower tuffaceous zone
8.7 Ma
Cejita Mbr
Lobato Basalt
10-10.2 Ma
Alcalde tephra zone
9.0 Ma
10.0 Ma
Hernandez Mbr
Lobato Fm
10.6 Ma
upper green coarse white ash
Cejita Mbr
12.0 Ma
lower coarse white ash zone
Ojo Caliente SS
13.0 Ma
13.2 Ma
Pojoaque white ash zone
14.0 Ma
Pojoaque Mbr
15.1 Ma
No. 4 white ash
No. 3 white ash
No. 2 white ash
Skull Ridge Mbr
Skull Ridge ash zone
15.8 Ma
16.2 Ma
Nambé white ash zone
16.6 Ma
Western alluvial slope = Chama-El Rito Member
Nambé Mbr
Eastern alluvial slope
Unnamed basalt at St Peter's Dome
19 Ma
ABIQUIU FM
Basin-floor
Unnamed basalt at St Peter's Dome
21 Ma
SANTA FE GROUP STRATA
locally derived volcaniclastic sediment
ABIQUIU FM
lower coarse unit, Tesuque Fm
25 Ma
Cieneguilla Basanite
26 Ma
? UNCONFORMITY
30 Ma
coarse ash bed
BISHOPS LODGE MEMBER OF TESUQUE FM (correlative with Espinaso Fm)
Granite- and limestone-bearing gravel eroded from Sange de Cristo Mtns
EXPLANATION
Puyé and Ancha Formations
Chamita Formation
upper, coarser Tesuque Fm
middle-lower Tesuque Fm
lower coarse unit of Tesuque Fm
lower Miocene-upper Oligocene volcaniclastic strata
early-middle Oligocene-age gravel from Sangre de Cristo Mtns
volcanic flow(s)
tephra zone
ash bed
Pojoaque Mbr
Skull Ridge Mbr
Nambé Mbr
Tesuque Fm

Figure A-3

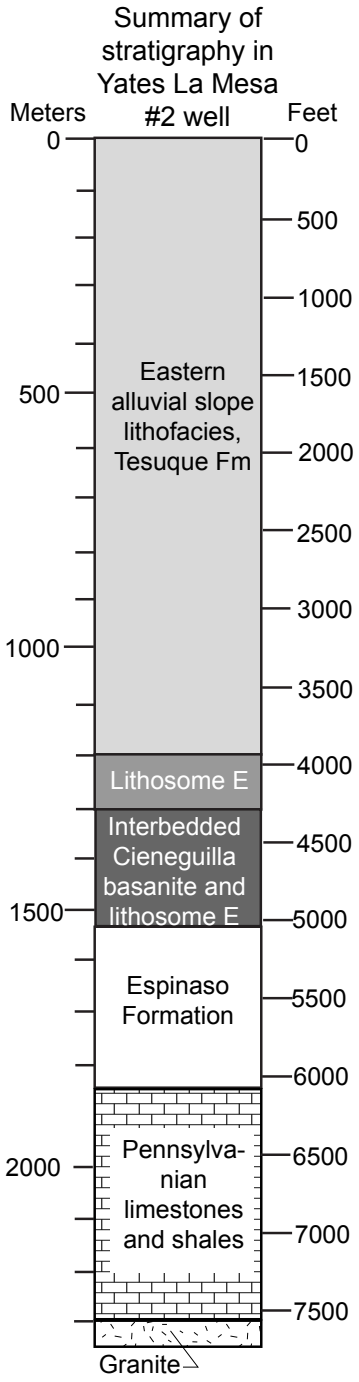

Figure A-3. Summary of stratigraphy of the Yates La Mesa No. 2 well. The well is located 8-9 km west of downtown Santa Fe (Plate 1, Figures 1 and 5 of manuscript). Figure modified slightly from Myer and Smith (2006) according to unpublished observations by Daniel Koning and David Sawyer (U.S. Geological Survey).

Figure A-4

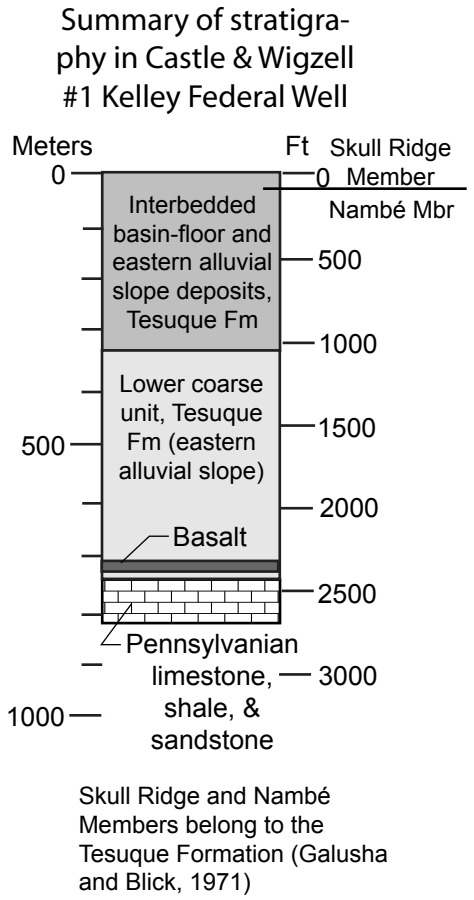

Figure A-4. Summary of stratigraphy of the Castle and Wigzell No. 1 Kelly Federal well, located 3.5 km southeast of Chimayo (Plate 1). Subsurface interpretations are from Koning et al. (2002) and David Sawyer (U.S. Geological survey; personal commun., 2005). The basalt at the base of the Santa Fe Group is correlated to the Cieneguilla basanite based on its stratigraphic position, but it does not match the composition of the Cerro Piñon basalt flow dated by Baldridge et al. (1980) (Nelia Dunbar, N.M. Bureau of Geology, written commun, 2007).