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New Mexico Geology, v. 4, n. 3 pp. 39-41, 48, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v4n3.39

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Structural history of Pajarito fault zone in the Española Basin, Rio Grande rift, New Mexico

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Introduction

The central section of the Rio Grande rift consists of three distinct, north-trending en echelon basins that step to the right. These three basins are from south to north: the Albuquerque–Belen, Española, and San Luis Basins. Individual basins are approximately 60 km wide, fault bounded, and asymmetric, with valley-fill sediments tilted oppositely in each successive basin (Kelley, 1979). Sediments within the Española Basin are tilted to the west.

The border faults of the Española Basin are poorly exposed. Moreover, the eastern edge of the Española Basin is not marked by a single major fault (fig. 1) but is defined by the both depositional and faulted contact of the basin fill (Santa Fe Group) with the Precambrian rocks of the Sangre de Cristo uplift. The western margin of the Española Basin is marked by a series of northeast-trending, down-to-the-east faults. However, part of this fault zone is covered by young volcanics, indicating inactivity in the past few m.y.

Manley (1979) defined the central intrarift Velarde graben within the Española Basin. Stratigraphic relations indicate that the Velarde graben began forming in early Pliocene time; detectable seismicity (Jiracek, 1974) and crustal subsidence (Reilinger and York, 1979) indicate that it is still active. Manley (1979) mapped the eastern border of the Velarde graben as a zone of prominent yet partially obscured north-trending, west-side-down faults that cut the Santa Fe Group at least 20 km to the west of the eastern margin of the Española Basin. The western edge of the Velarde graben is defined by the Pajarito fault zone which exhibits predominantly down-to-the-east displacements. In the Jemez Mountains, this fault zone cuts a 1.1-m.y.-old ash-flow tuff (Doell and others, 1968), producing a prominent fault scarp (Golombek, 1981). The objectives of this study are to define the kinematics, timing, and tectonics of the Pajarito fault zone by means of detailed mapping and structural analysis, thereby providing new insight into the evolution of this portion of the Rio Grande rift. Complete discussion of these results is reported in Golombek (1982).

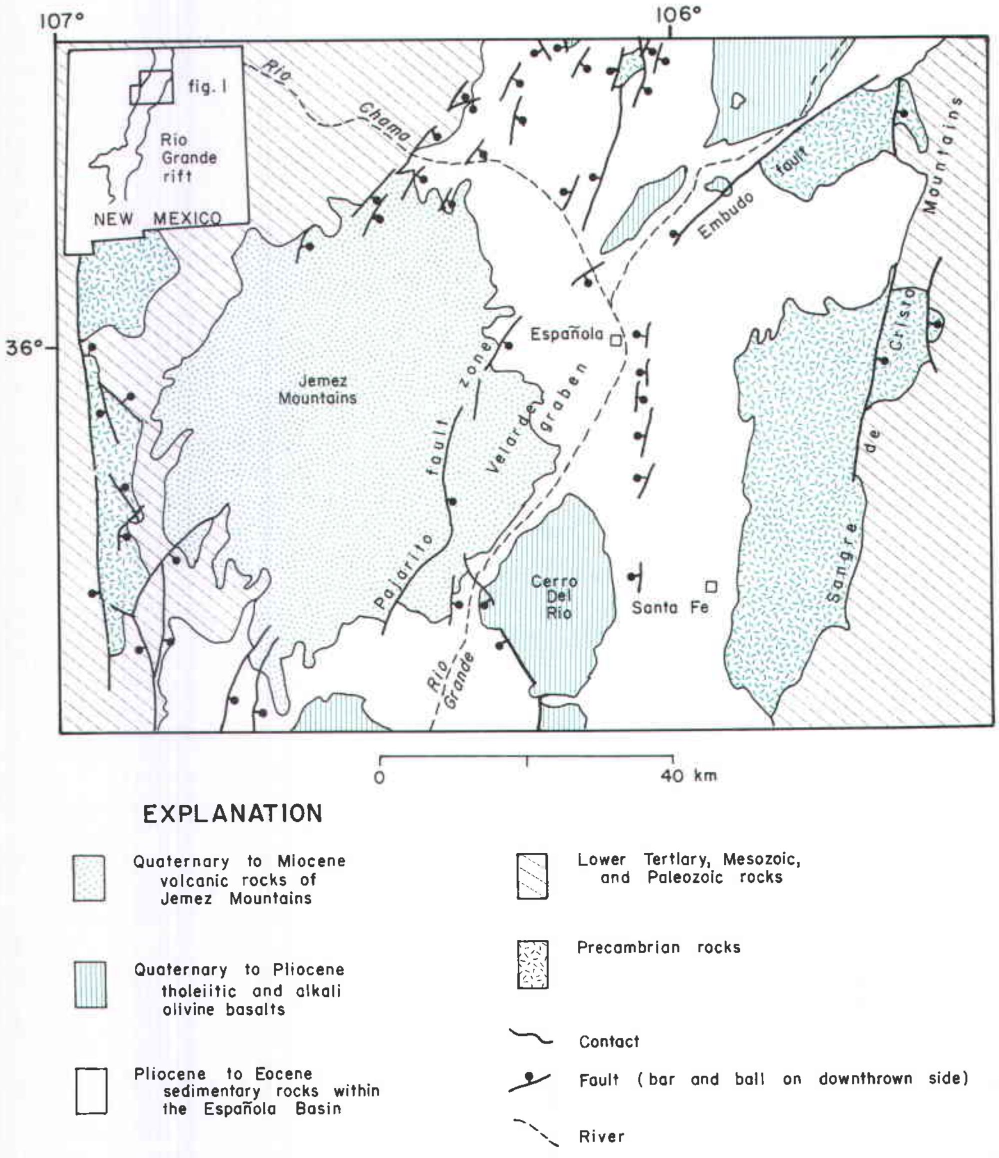


FIGURE 1—GENERALIZED GEOLOGIC MAP OF ESPAÑOLA BASIN, RIO GRANDE RIFT, NEW MEXICO (from Manley, 1979, with modifications).

Stratigraphy

Volcanic rocks of the Jemez Mountains have been combined into three groups (Bailey and others, 1969; Smith and others, 1970; Griggs, 1964): the oldest Keres Group (age dates of 9.1–8.5 m.y.; Dalrymple and others, 1967) found as highlands in the southern Jemez Mountains, the intermediate-age Polvadera Group (age dates of 7.4–3.7 m.y.; Dalrymple and others, 1967) found as highlands in the northern Jemez Mountains, and the youngest Tewa Group (age dates of 1.4–0.4 m.y.; Doell and others, 1968) erupted from central calderas in the Jemez Mountains and found within and flanking them as broad, gently dipping plateaus (fig. 2). Beneath the volcanic rocks are the formations of the Santa Fe Group (Galusha and Blick, 1971), a predominantly Miocene, fossiliferous, sedimentary sequence that accumulated during rifting. The Santa Fe Group rests unconformably on the Galisteo Formation, which was deposited in prerift Eocene basins (Stearns, 1943).

General characteristics

The Pajarito fault zone extends in a north-northeast direction along the east flank of the Jemez Mountains (fig. 1). Marked changes occur in both the stratigraphic sections of volcanic rocks and the character of the fault zone along strike. These structural and stratigraphic changes permit subdivision of the fault zone into segments (fig. 2). These segments are, from north to south:

1) SANTA CLARA SEGMENT—single large fault scarp 100–200 m high; fault cuts intermediate-age Polvadera Group rocks and derived volcaniclastic sediments;
2) GUAJE MOUNTAIN SEGMENT—complex zone of small faults with displacements down both to the east and west; fault zone disrupts intermediate-age Polvadera Group rocks and derived volcaniclastic sediments;

3) PAJARITO PLATEAU SEGMENT—prominent 100-m fault scarp in youngest Bandelier Tuff which underlies the gently eastward-sloping Pajarito Plateau; and
4) ST. PETER'S DOME SEGMENT—wedge-shaped zone of two faults; Keres Group rocks on upfaulted side adjacent to 30–100-m fault scarp.

Displacements

Where the fault zone cuts the 1.1-m.y.-old Bandelier Tuff it has produced a prominent 50–100-m-high fault scarp (Golombek, 1981). Correlation of ash-flow beds across the fault indicate that in most places the scarp height is equal to the stratigraphic displacement. Displacements of rock units older than the Bandelier Tuff were estimated using standard techniques that utilize knowledge of the stratigraphy. These estimates of the total displacement across the fault during its 5-m.y. history are between 200–600 m. Rates of displacement for the time periods 0–5, 0–1.1, and 1.1–5 m.y. ago range from .020 to .136 mm/year. The lack of significant east-side-down displacements in the Guaje Mountain segment (fig. 2) implies that the west side of the Velarde graben locally ramps up. An east-side-down fault is present (fig. 1) along the east side of the Velarde graben at this latitude (Manley, 1979), suggesting the entire Velarde graben floor ramps up.

Because total displacement across the Pajarito fault zone has been from 200 to 600 m during its entire history (5 m.y. ago–present; Manley, 1979), central depressions (indicated by gravity minima; Cordell, 1979) filled with 2–2.5 km of low-density sediments were probably formed by old faults that became inactive by middle Miocene and are not presently visible on the surface. The relative contribution of prerift and synrift sediments to this gravity minima is unknown. However, in at least one place along the Pajarito fault zone (St. Peter's dome), prerift sedimentary rocks probably contribute significantly to the anomaly (Golombek, 1982).

Controls on the location and trend of the Pajarito fault zone

Abrupt facies changes between older volcanics and volcaniclastic sediments of the Jemez Mountains appear to have controlled the local position, trend, and character of the Pajarito fault zone. Erosion during the active life of a volcanic dome would result in the deposition of volcaniclastic sediments in an apron around the dome. Thus, the periphery of a volcanic dome would be characterized by interfingering of volcanics and volcaniclastic sediments. If the periphery of a dome remained in about the same place during its active life, then the stratigraphic record at the periphery would show an abrupt change from mostly igneous rocks to mostly volcaniclastic sediments in a direction radially away from the volcanic center. This rapid facies change between Keres and Polvadera Group volcanics and volcaniclastic sediments appears to have controlled the position and trend of the Pajarito fault zone. The fault zone bows and/or steps eastward where two large volcanic complexes are present in the St. Peter's dome and Guaje Mountain segments, but the zone is found further west in between and at either end of the volcanic complexes. One complex in the Guaje Mountain segment was sufficiently massive to interfere with the development of the Velarde graben, causing the graben to ramp up.

Extensional Tectonics

Mesoscopic fracture data were collected at 30 stations, most of which are in the Tshirege Member of the Bandelier Tuff. Slickensides on mesoscopic faults in the Tshirege Member are typically well developed with very smooth and polished surfaces. Displacements were invariably pure dip-slip and normal, indicating extension approximately perpendicular to the strike of the fault. Fig. 3 illustrates the trace of the Pajarito fault zone, the extension directions for each station in the Bandelier Tuff, and composite plots for each domain (area with similarly striking mesoscopic faults and derived extension directions). Every domain has an extension direction oriented approximately perpendicular to the local trend of the fault zone. These extension directions could result from reorientation of the regional east-west extension by the Pajarito fault zone to a direction perpendicular to the fault zone in each segment.

In addition, most domains have extension directions oriented approximately parallel to subparallel to the local trend of the fault zone. These extension directions could be because of stress release parallel to the intermediate stress direction which will be locally parallel to the fault if the direction of maximum extension has been reoriented so as to be approximately perpendicular to the fault zone. This implies that both the intermediate and minimum stress directions were tensional.

Tectonic and geologic history of Española Basin in Pajarito fault zone area

In the area of the Pajarito fault zone, the early development of the Rio Grande rift was marked by the deposition of Santa Fe Group sediments (early Miocene) directly on flat-lying, prerift Galisteo Formation and did not involve pervasive faulting or tilting. Localized faulting created central depressions, indicated by gravity minima, in the Española Basin. Sedimentation concomitant with faulting allowed accumulation of thick deposits (2–2.5 km) of Santa Fe Group within the central depressions (fig. 4a). Faulting ended by middle Miocene, when filling of the Española Basin was completed in the study area (approximately 10 m.y. ago); these faults are not presently visible on the surface.

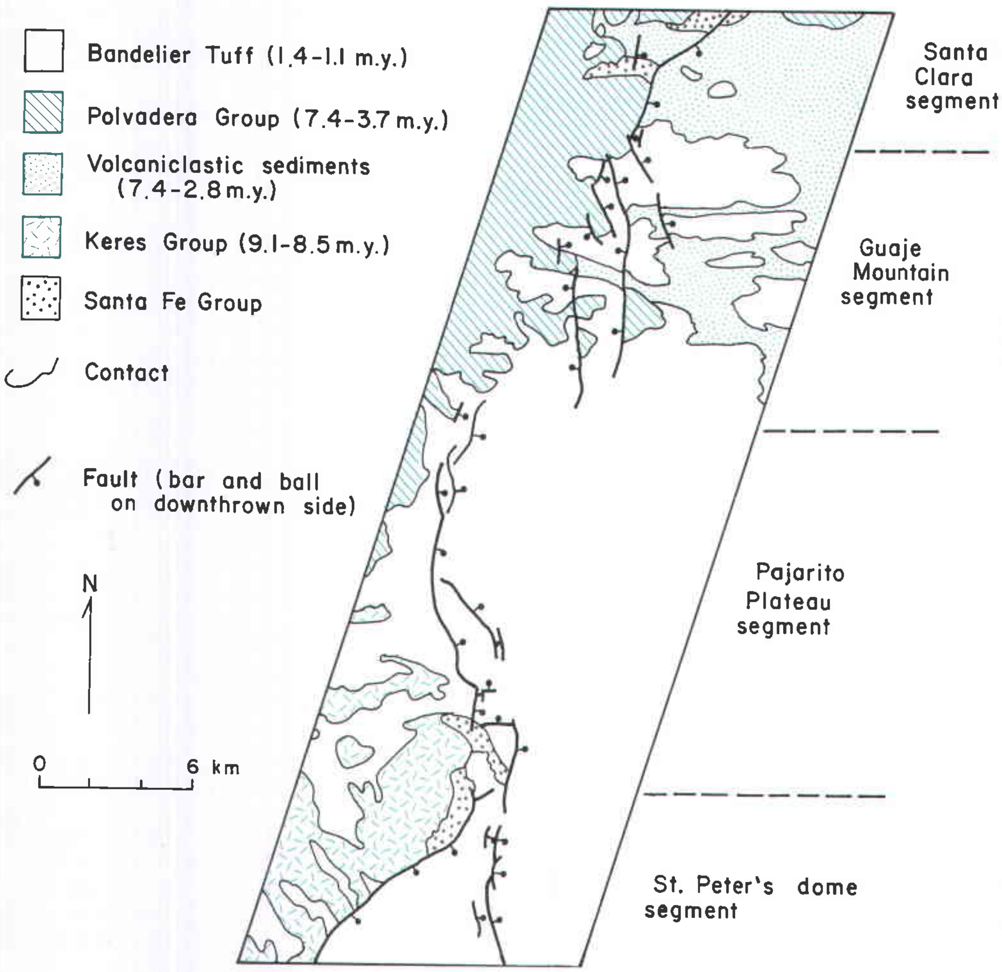


FIGURE 2—SEGMENTS OF PAJARITO FAULT ZONE.

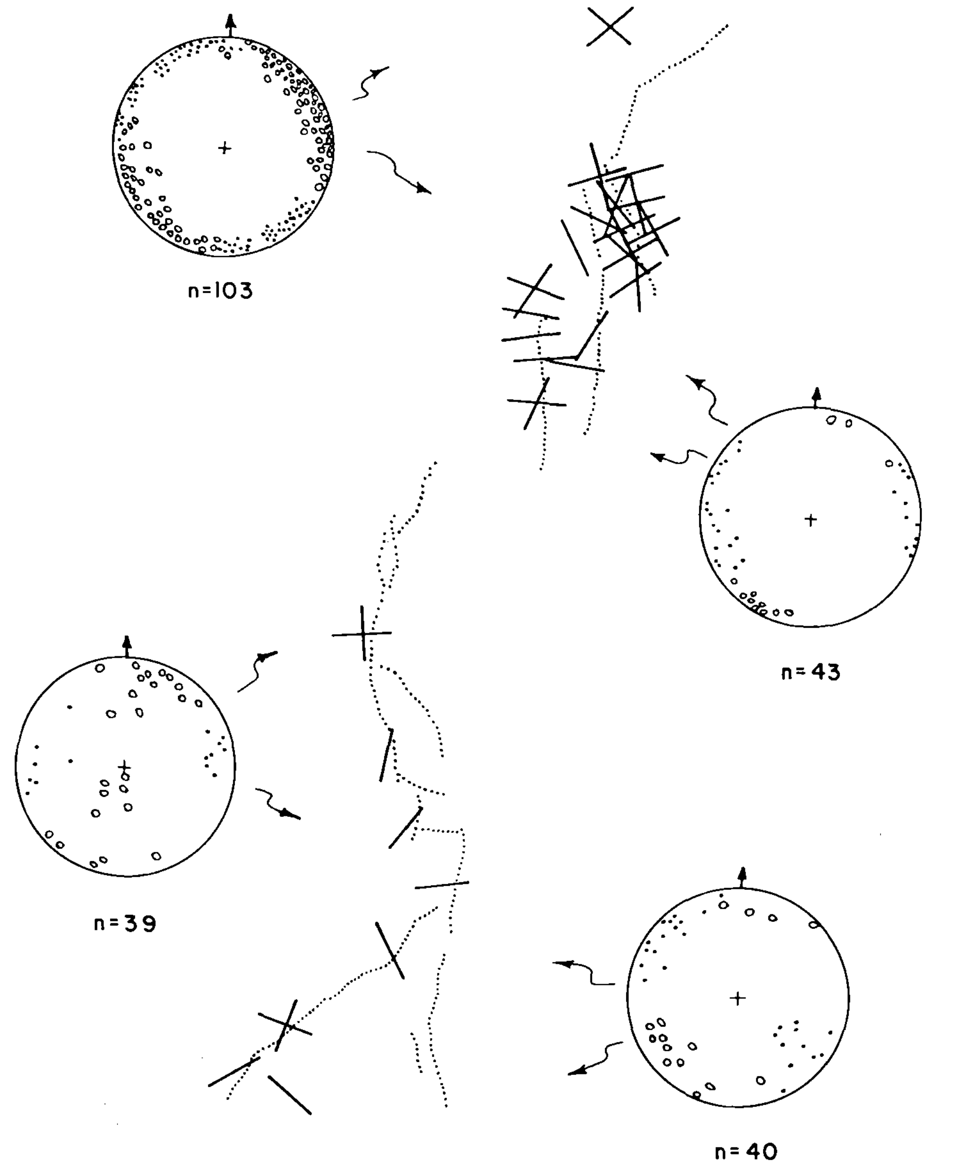
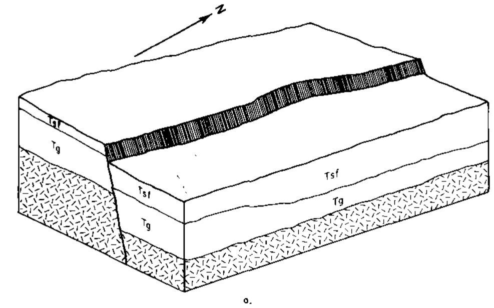
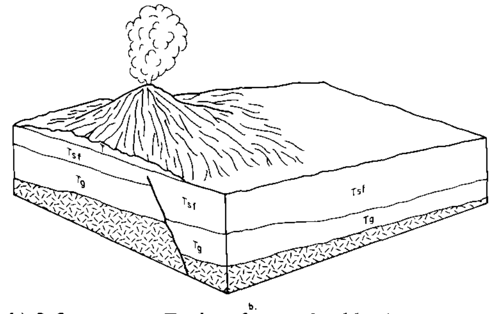


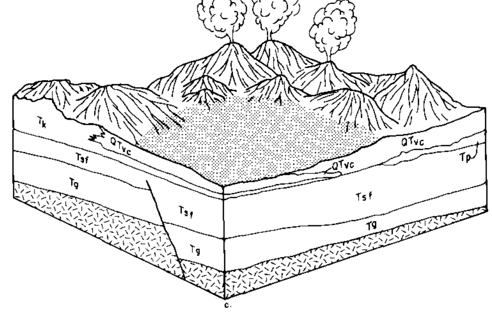
FIGURE 3—KINEMATICS OF PAJARITO FAULT ZONE. Dotted line is trace of major faults of Pajarito fault zone; solid lines indicate extension directions for all stations in Bandelier Tuff. Composite fracture-domain plots on lower hemisphere equal area projection; n = number of faults for indicated stations. Because faults at many stations cluster into two distinct sets indicating two extension directions, faults have been coded into two sets: solid dots are poles to faults that cluster into sets that strike north to east, open circles are poles to faults that cluster into sets that strike north to west. Domains are, from north to south: Santa Clara segment and northern Guaje Mountain segment, southern Guaje Mountain segment, Pajarito Plateau segment, and St. Peter's dome segment. Extension directions perpendicular to local trend of fault zone are due to reorientation of regional east-west extension by Pajarito fault zone. Extension directions parallel (northern Guaje Mountain segment) and parallel to subparallel (Pajarito Plateau and St. Peter's dome segments) to local trend of fault zone are thus parallel to intermediate stress direction if reorientation occurs as suggested above, thus *implying that both minimum and intermediate stress directions are tensional.* North-northeast-extension directions in southern Guaje Mountain segment do not fit proposed pattern.



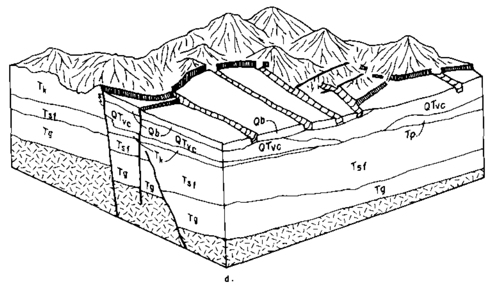
a) EARLY MIOCENE TIME. Fault depicted allowed accumulation of 2–2.5 km of low-density sedimentary fill (Santa Fe Group) in central subbasin within Española Basin.



b) 8–9 M.Y. AGO. Faults of central subbasin have become inactive. West tilting, due to movement on faults defining western margin of Española Basin, has occurred after eruption of Keres Group volcanics in St. Peter's dome area.



c) JUST PRIOR TO 5 M.Y. AGO. Volcanism has shifted to north depositing Polvadera Group. **QTvc** are eroded volcaniclastic sediments from Keres and Polvadera Groups.



d) PRESENT. Pajarito fault zone formed about 5 m.y. ago with movement continuing to present displacing Bandelier Tuff. Canyons eroded through Pajarito Plateau.

Volcanism was underway by 10 m.y. ago, about when the western margin border faults became active. West tilting of sediments and old volcanics (Keres Group) occurred from 8.5 to 7.5 m.y. ago. Because Santa Fe Group sediments on the upthrown side of the Pajarito fault zone are tilted to the west at the same (or larger) angle than Santa Fe Group sediments on the downthrown (east) side, faults responsible for the west tilting must be located to the west, probably along the western border of the Española Basin (fig. 4b). With eruption of the Polvadera Group, volcanic activity shifted northward. Volcaniclastic sediments were shed off the volcanic constructs in the north and south (fig. 4c).

The Pajarito fault zone and Velarde graben subbasin formed about 5 m.y. ago. Volcanism in the north slowed by 3 m.y. ago and shifted to the center of the Jemez Mountains, culminating with the eruptions of the Bandelier Tuff 1.4 and 1.1 m.y. ago. The last volcanic activity occurred about 0.4 m.y. ago, but faulting along the Pajarito fault zone has continued to the present, offsetting the Bandelier Tuff as much as 100 m in the past 1.1 m.y. (fig. 4d).

(*continued on p. 48*)

FIGURE 4—EVOLUTIONARY BLOCK DIAGRAM OF PAJARITO FAULT ZONE AREA. Symbols for geologic units: **Qb**—Bandelier Tuff, **QTvc**—volcaniclastic sediments, **Tp**—Polvadera Group, **Tk**—Keres Group, **Tsf**—Santa Fe Group (synrift deposits), **Tg**—Galisteo Formation (prerift deposits), pattern—pre-Galisteo rocks.

Pajarito fault zone

(continued from p. 41)

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Late Cretaceous leaf locality

(continued from p. 45)

APPENDIX A *(continued)*

Total thickness—16.84 m (55.9 ft)

Unit No.	Description	Thickness (cm)	*(inches)*
010	White sandstone, medium-grained; with large plant fragments up to 5 cm²; well indurated and forms characteristic popcorn surface texture upon weathering; some hoodoo (columns or pinnacles) development	89	*36*
009	White sandstone, fine-grained; about 5% plant debris concentrated in laminae. Undulating bedding finely developed; well indurated with fine laminations and mud partings	60	*24*
008	Dark gray-green mudstone with 15–20% plant debris up to 3.5 cm²; coarsens upward	30	*12*
007	Gray-green mudstone with about 5% plant fragments and stems; grades upward into 008	28	*11*
006	Sandstone, white, medium-grained; with large fragments of plants up to 5 cm²; about 10% plant content	25	*10*
005	Mudstone, gray-green; with approximately 10% carbonaceous debris; coarsens upwards into 006	61	*24*
004	Carbonaceous mudstone, dark-gray; up to 40% plant debris is up to 2 cm² poorly sorted; coarsens upwards; becomes much less carbonaceous laterally (about 10%)	28	*11*
003	Olive sandstone, medium-grained; with some iron staining along bedding planes; 5–10% plant debris	117	*47*
002	Gray siltstone; 5% plant debris; iron staining in fractures	18	*7*
001	White sandstone; fine-grained lenses of sand rich in carbonized plant debris and silt lacking plant debris; lenses subparallel to bedding; fines upward into 002; much lateral variation in plant debris content (5–20%)	30	*12*

APPENDIX B—MEASURED SECTION.

Unit No.	Description	Thickness (cm)	*(inches)*
A	Concretion, dark-brown; siderite with veins of barite; rare, poorly preserved leaf impressions extend laterally 1.8 m (5.9 ft)	35.6	*14.2*
B	Siltstone, gray-green; scattered subrounded plant fragments; well-sorted, averaging 5 mm (.2 inches) in diameter	15.2	*6.1*
C	Mudstone, gray-green; a few scattered stem fragments; poorly sorted up to 3 x 5 cm (1.2 x 2 inches)	3.8	*1.5*
D	Mudstone, gray-green; occasional horizons with leaves 3 cm (1.2 inches) in length and also horizons of poorly sorted stems up to 1.3 x 2 cm (.5 x .8 inches)	22.8	*9.1*
E	Mudstone, gray-green; many jumbled leaves, many of which overlap; leaves subcomplete 2–5 cm (.8–2 inches) in length, small fragments up to 5 mm (.2 inches) in length; poorly sorted stem fragments 1–5 cm (.4–2 inches) in length and up to .75 cm (.3 inches) wide; slickensides up to 39 cm (16 inches) in length, leaves on laminae averaging .3 cm (.12 inches) apart	17.8	*7.1*
F	Mudstone, gray-green; scattered leaves few in number: (a), lens of few scattered complete leaves grades laterally into stems and poorly sorted small plant fragments, but no leaves; stems 5–10 cm (2–4 inches) long and up to 1 cm (.4 inches) wide, fragments are subrounded 2–.25 mm (.08–.01 inches) in diameter; (b) same as lateral, stem-rich portion of (a), sharp contact with plant-rich portion of (a)	a) 7.6 b) 5.0	*3.0* *2.0*
G	Lateral from (a) and (b) siltstone, yellow-green; few broken plant fragments (no leaves); lens-shaped cross section 7 x 60 x 15 cm (2.8 x 24 x 6 inches)	7.0	*2.8*
H	Mudstone, gray-green; full of overlapping complete leaves that cover 100% of surface on laminae about every .5 cm (.2 inches); intervening layers produce complete leaves not overlapping	7.7	*3.1*
I	Mudstone, gray-green; large stems 5–10 cm (2–4 inches) long and 1 cm (.4 inches) wide, also many small stem pieces, subrounded from 3 to 8 mm (.12 to .32 inches) in diameter	15.2	*3.1*
J	Grades down with less stem to subrounded fragments less than 2 mm (.08 inches) in diameter to unfossiliferous gray-green mudstone	45.9	*18.4*

□

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