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REVERSAL MAGNETOSTRATIGRAPHY AND RADIOISOTOPIC GEOCHRONOLOGY OF THE PLIO-PLEISTOCENE CAMP RICE AND PALOMAS FORMATIONS, SOUTHERN RIO GRANDE RIFT

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Abstract—Alluvial-fan and axial-fluvial sediment deposited during the most recent stage of crustal extension in the Rio Grande rift of southern New Mexico is referred to as the Palomas Formation in the Palomas Basin and the Camp Rice Formation in basins to the south. These formations can be accurately dated and correlated by (1) radioisotopically dated basalt flows, fallout ashes, and pumice-clast conglomerates interbedded within or inset against the formations, and (2) high-resolution reversal magnetostratigraphy, some sections of which incorporate dated volcanic rocks as chronologic tie points. The base of the formations correspond to either the Gauss (late Pliocene) or Gilbert (early Pliocene) geopolarity chrons, depending upon position within the basins, and the ancestral Rio Grande may have arrived in southern New Mexico as early as 5 Ma. The age of the top of the formations, corresponding to the La Mesa and Cuchillo geomorphic surfaces and to the initiation of downcutting by the ancestral Rio Grande and its tributaries, is at or very near the Matuyama-Brunhes geopolarity chron boundary, at 0.78 Ma.

INTRODUCTION

The sedimentary record of the most recent phase of crustal extension in the southern Rio Grande rift of New Mexico is the Palomas Formation in the Palomas Basin and the Camp Rice Formation in basins to the south (Fig. 1; Strain, 1966; Seager et al., 1982, 1987; Lozinsky and Hawley, 1986a,b). Like most continental sediment, the Camp Rice and Palomas Formations are not easily dated and correlated. Vertebrate fossils have been discovered within the formations, corresponding to parts of the Blancan and Irvingtonian land mammal stages, but they are rare and widely scattered and do not provide the biostratigraphic control necessary to accurately date the base and top of the formations nor correlate between sections (Strain, 1966; Hawley et al., 1969; Tedford, 1981; Lucas and Oakes, 1986; Repenning and May, 1986; Morgan et al., this guidebook). The most successful approach to dating the Camp Rice and Palomas Formations is reversal magnetostratigraphy, using radioisotopically dated volcanic and volcaniclastic rocks intercalated with the formations as chronologic tie points to the geopolarity time scale (Mack et al., 1993, 1996; Leeder et al., 1996). We present here a summary of paleomagnetic and radioisotopic data, along with new data recently collected. Of particular interest are constraints on (1) the age of the base of the formations, (2) the time of first appearance of the ancestral Rio Grande in southern New Mexico, and (3) the age of the constructional top of the formations.

GEOLOGIC SETTING

The Camp Rice and Palomas Formations are exposed beneath mesas that flank the modern Rio Grande valley (e.g., West Mesa, Fig. 1) and in deeply incised tributary arroyos, such as Rincon Arroyo and Percha Creek (Fig. 1). In addition, the constructional top of the formations is preserved over a large area of southern New Mexico and has been mapped by Seager et al. (1982, 1987). This surface is referred to as the Cuchillo surface in the Palomas Basin (Lozinsky, 1986) and the La Mesa surface above axial-fluvial strata and Jornada I surface above piedmont strata of the Camp Rice Formation (Gile et al., 1981). These geomorphic surfaces are directly underlain by a stage IV and V petrocalcic paleosol several meters thick, which makes them resistant to erosion. The constructional surfaces represent the surface of deposition of alluvial fans or the floodplain of the ancestral Rio Grande just prior to the initial phase of regional incision by the river and its tributaries. The process of incision and partial backfilling has placed the river approximately 100 m below the Cuchillo, La Mesa, and Jornada I

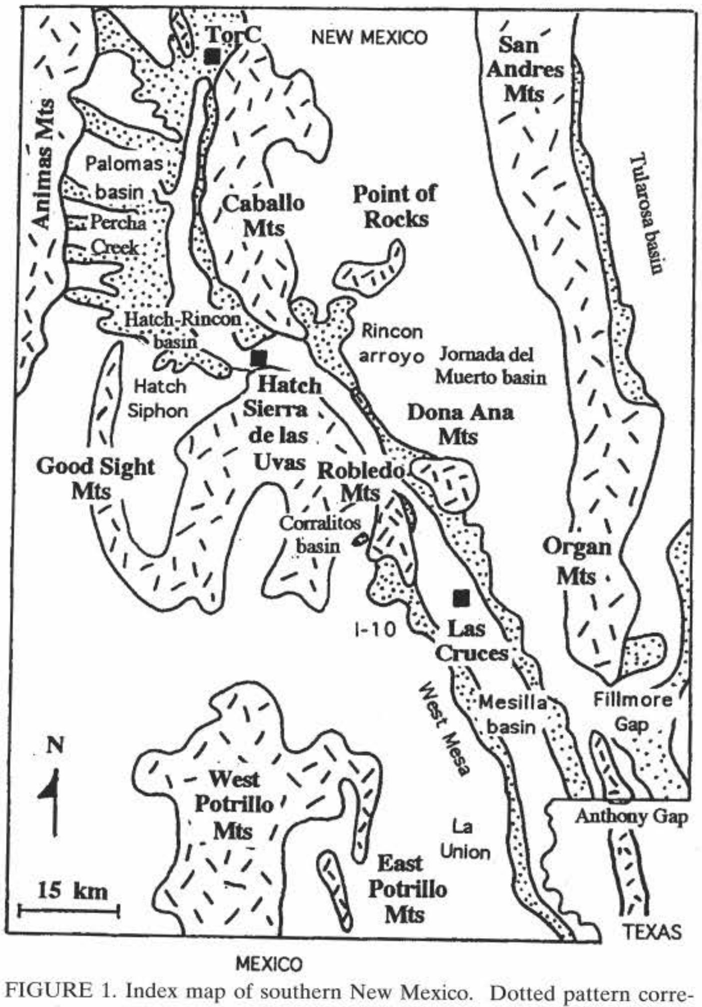

FIGURE 1. Index map of southern New Mexico. Dotted pattern corresponds to exposures of the Plio-Pleistocene Camp Rice and Palomas Formations.

surfaces and has produced a series of stepped geomorphic surfaces inset against the Camp Rice and Palomas Formations (Ruhe, 1962, 1967; Gile et al., 1981).

The maximum exposed thickness of the Camp Rice and Palomas Formations is about 135 m, although most sections are between 40 and 100 m thick. Alluvial-fan sediment is primarily gravel/conglomerate, with minor amounts of sand/sandstone and brown mudstone. Alluvial-fan detritus is locally well lithified, especially along the eastern margin of the Palomas Basin (Seager and Mack, 1991; in press). Channel facies deposited by the ancestral Rio Grande is primarily pebbly sand/sandstone exhibiting trough and planar crossbeds, horizontal laminae, and ripple cross-laminae. Generally unconsolidated, the channel facies is well lithified on the south side of the Robledo Mountains (Box Canyon), near San Diego Mountain, and along the east side of the Rincon Hills (Fig. 1). In each case, cementation appears to be related to local geothermal activity. Also deposited on the floodplain of the ancestral Rio Grande were very fine sand and red-brown mudstone, some of which display calcic paleosols (Mack and James, 1992). Axial-fluvial sediment of the ancestral Rio Grande is very widespread in southern New Mexico, having occupied six contiguous basins (Palomas, Hatch-Rincon, Jornada del Muerto, Corralitos, Mesilla, Tularosa Basins). The processes responsible for the spillover of the river between basins are described by Ruhe (1962), Hawley et al. (1969), and Mack et al. (1997).

VOLCANIC AND VOLCANICLASTIC ROCKS WITHIN THE CAMP RICE AND PALOMAS FORMATIONS

Radioisotopically dated volcanic and volcaniclastic rocks within the Camp Rice and Palomas Formations provide important chronologic constraints on the age of the formations, as well as critical chronologic tie points to the geopolarity time scale (Fig. 2). Three different types of volcanic rocks within or inset against the Camp Rice and Palomas Formations have been dated: (1) basalt lava flows, (2) pumice-clast conglomerates, and (3) fallout ashes. In addition, several fallout ashes that have been identified within the formations, but have not yet been radioisotopically dated, will also be discussed.

Basalt flows

Very few basalt flows within or inset against the Camp Rice and Palomas Formations have been dated. Among the oldest are two flows located within the Palomas Basin. One of the flows, dated by the K-Ar method at 4.5 ± 0.1 Ma by Seager et al. (1984), is located near the western pinchout of the hanging wall-derived sediment of the Palomas Formation. Although below or within the lowermost part of the Palomas Formation, this basalt does not necessarily define the lower limit for the age of the formation, because the sediment along the western margin of the basin may have onlapped the

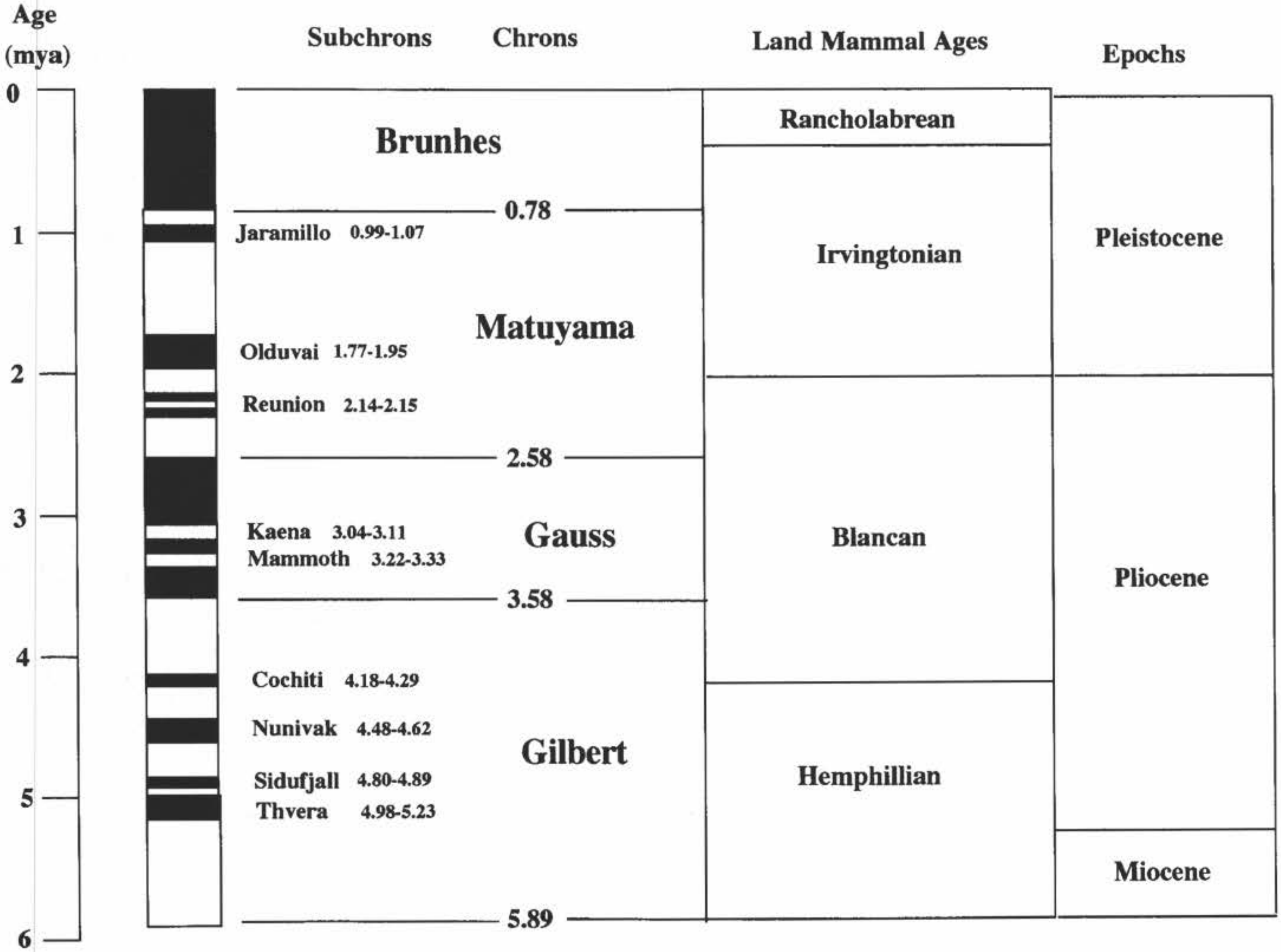

FIGURE 2. Pliocene and Quaternary chronology, adapted from Berggren et al. (1995).

hanging wall dip slope of the Palomas half graben some considerable time after initiation of the basin (cf. Leeder and Gawthorpe, 1987). The second basalt flow is interbedded with footwall-derived alluvial-fan conglomerates of the Palomas Formation on the eastern margin of the Palomas Basin, and has been dated by the K-Ar method at 3.1 ± 0.1 Ma by Seager et al. (1984). These two basalt flows indicate that at least part of the Palomas Formation is Pliocene, but they have not been used as chronologic markers for magnetostratigraphy.

The youngest dated basalt flows are located southwest of Las Cruces on the West Mesa, where they overlie the constructional top of the Camp Rice Formation. These basalts include Aden Crater, the Afton volcanic field, and cinder cones and their associated lava flows that erupted near the rim of the mesa and flowed onto inset terraces. Using the K-Ar method, Seager et al. (1984) dated the lava lake of Aden Crater at 0.53 ± 0.04 Ma, the Afton flow at 0.53 ± 0.03 Ma, a flow two kilometers west of the mesa rim at 0.49 ± 0.03 Ma, and the Santo Tomas flow at 0.55 ± 0.03 Ma. In contrast, the basalts that occupy inset surfaces were also dated by the K-Ar method to be around 0.2 Ma (Hoffer, 1971), and Anthony and Poths (1992) used ^{3}He surface exposure dating to obtain ages of the Afton flows ranging from 81 to 72 ± 4 ka, of the Aden complex from 18.2 to 15.7 ± 2-3 ka, and for one of the cones near the edge of the West Mesa from 69 to 85 ± 4–7 ka. Given the wide disparity in these dates, they are of limited value in providing an upper limit for the age of the Camp Rice Formation.

Pumice-clast conglomerates

At least four times in Pliocene and early Pleistocene time explosive eruptions in the Jemez volcanic field of northern New Mexico choked the ancestral Rio Grande with pumice. The resultant pumice floods moved geologically rapidly downstream at least as far as the Las Cruces area, where pumice-clast conglomerates 0.2 to 2.0 m thick were deposited within the Camp Rice Formation (Mack et al., 1996). The oldest pumice-clast conglomerate recognized to date in southern New Mexico is located near Hatch Siphon (Fig. 1). It is approximately 0.5 m thick and is composed almost exclusively of pebbles and small cobbles of pumice. An age of 3.12 ± 0.03 Ma was determined for the Hatch Siphon pumice bed by ^{40}Ar/^{39}Ar analysis of single crystals of sanidine taken from the pumice clasts (Mack et al., 1996). The Hatch Siphon pumice-clast conglomerate constitutes a chronologic tie point for a magnetostratigraphic profile of the same name (Fig. 3).

The most widespread pumice-clast conglomerate is present at four separate locations in southern New Mexico and has been dated at around 1.6 Ma (Mack et al., 1996), an age that makes it correlative with the lower Bandelier tuff of the Jemez volcanic field. The 1.6-Ma pumice conglomerate locally consists of two parts. The lower part, which is up to 0.5 m thick, is composed of pebbles, cobbles, and small boulders of pumice (Fig. 4). The upper part, which may exist by itself, consists of 1 to 2 m of crossbedded granule and pebble-sized pumice mixed with fluvial sand. The 1.6-Ma pumice conglomerate is an important chronologic tie point for

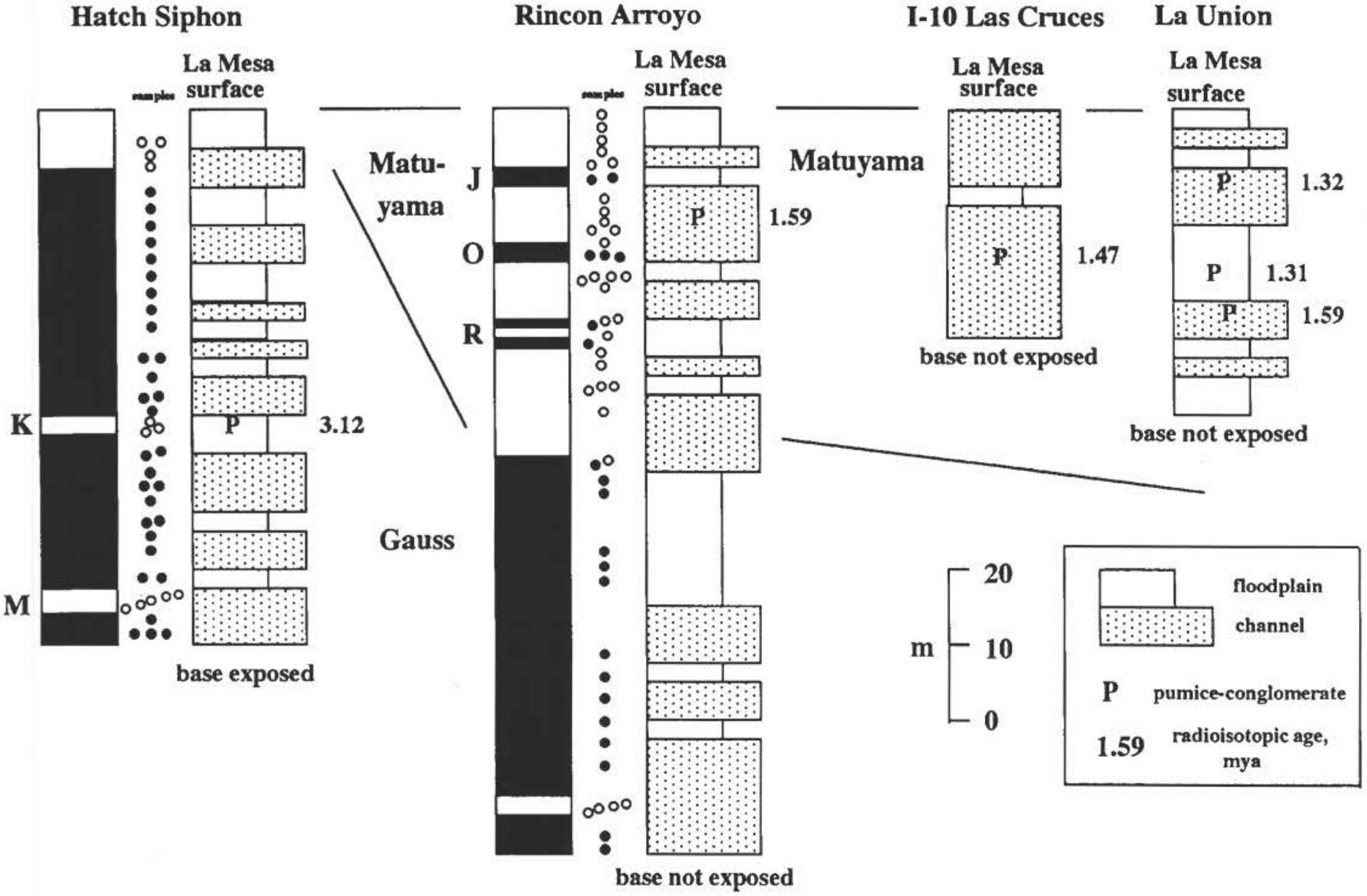

FIGURE 3. Measured sections of the Camp Rice Formation showing location of pumice-clast conglomerates (Mack et al., 1996) and reversal magnetostratigraphy (Mack et al., 1993). J = Jaramillo subchron; O = Olduvai subchron; R = Reunion subchrons.

FIGURE 4. Photograph of the pumice-clast conglomerate exposed at Rincon Arroyo. Hammer is 25 cm long.

the Rincon Arroyo magnetostratigraphic section, as well as providing age constraints on those stratigraphic sections that have not been sampled for magnetostratigraphy (Fig. 3). Among the other pumice-clast conglomerates present in southern New Mexico, two at La Union have been dated near 1.3 Ma and either represent the upper Bandelier eruption or eruptive events between the two Bandelier eruptions (Fig. 3; Mack et al., 1996). Finally, it is not known whether two other pumice-conglomerates, dated at 1.84 ± 0.26 and 2.22 ± 0.27, represent distinct events or the same event, because of the large standard deviations of the age (Mack et al., 1996). These pumice-conglomerates are not used as tie points for magnetostratigraphy.

Fallout ash

Three thin (<1 m) fallout ashes in southern New Mexico have been correlated with specific Pleistocene volcanic eruptions in the western United States, based primarily on their physical and chemical properties. There are two localities of the Bishop tuff, one interbedded with piedmont facies near the top of the Camp Rice Formation near Anthony Gap (Hawley, 1975; Kelley and Matheny, 1983), and the other exposed in the Grama railroad cut (Seager and Hawley, 1973). In addition to geochemical analysis, the ash at Grama has also been radioisotopically dated using fission tracks as 0.754 ± 0.2 Ma (Kortemeier, 1982), supporting correlation with the Bishop tuff, which has been dated at 0.74 Ma (Izett et al., 1988; Sarna-Wojcicki et al., 1991). The third Pleistocene fallout ash in the study area is exposed near the top of Ash Mesa in Selden Canyon (Seager et al., 1975) and has been correlated, based on its geochemical properties and on its normal geomagnetic polarity, with the 0.61 Ma Lava Creek B tuff of the Yellowstone caldera (Reynolds and Larson, 1972; Izett, 1981). The Bishop ash at Grama and the Lava Creek B ash at Ash Mesa were used as chronologic tie points in magnetostratigraphic sections by Mack et al. (1993)(Fig. 5).

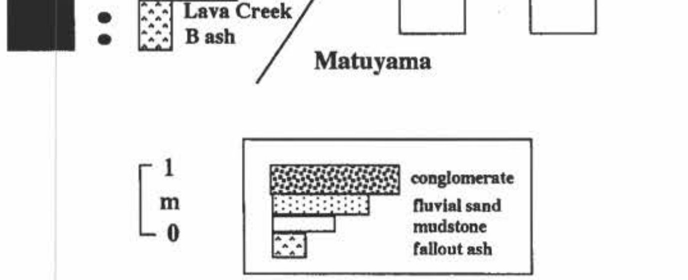

FIGURE 5. Magnetostratigraphy of ash-bearing sections at Ash Mesa and Grama (Mack et al., 1993).

In addition to the Pleistocene ashes described above, three other fallout ashes have been discovered along the eastern margin of the Palomas Basin, at Red Canyon (called the Las Palomas ash by Lozinsky and Hawley, 1986b), north of Ash Canyon, and Wildhorse Canyon (Figs. 6 and 7). The Las Palomas ash is 1.4 m thick, the Wild Horse Canyon ash is 2.5 m thick, and the North Ash Canyon ash is 4.6 m thick, and all three are laterally discontinuous. The ashes are white to light gray in color and are composed primarily of glass shards and secondarily of silt to fine sand-sized crystals of quartz, sanidine, plagioclase, and biotite. At Wild Horse and North Ash Canyons, the lower part of the ash is structureless and probably represents little modified air-fall tephra, whereas the upper part is well bedded and exhibits horizontal laminae and ripple cross-laminae, suggesting reworking by water or wind. The Las Palomas ash at Red Canyon has a thin (50 cm) structureless lower part with a thin (3 cm) shale parting, overlain by about 30 cm of well-bedded ash, followed by 60 m of structureless ash (Fig. 8). None of the three ash beds have been radioisotopically dated, but because of their great thickness and stratigraphic position within the Pliocene–early Pleistocene Palomas Formation were probably derived from eruptions in the Jemez volcanic field, perhaps corresponding to the Bandelier eruptions. Magnetostratigraphic sections include two of the ashes, the Las Palomas ash at Red Canyon and the ash at Wild Horse Canyon (Fig. 7).

MAGNETOSTRATIGRAPHY OF THE CAMP RICE AND PALOMAS FORMATIONS IN SOUTHERN NEW MEXICO

Twenty-five stratigraphic sections of the Camp Rice and Palomas Formations in southern New Mexico have been collected to determine polarity reversals. The majority of these have been collected by Mack et al. (1993) (13 sites), Leeder et al. (1996) (7 sites), and G. H. Mack (unpub. data) (1 section); ten of these magnetostratigraphic sections are shown here (Figs. 3, 5, 7, and 9). In addition, Vanderhill (1986) sampled three sections on the West Mesa near and south of La Union, and Repenning and May (1986) sampled one site near Truth or Consequences. Both Vanderhill (1986) and Repenning and May (1986) only sampled mudstones or well consolidated very fine sandstones, and there are large gaps in their profiles corresponding to thick sand channels. Moreover, neither Vanderhill (1986) nor Repenning and May (1986) had radioisotopically dated volcanic rocks as chronologic tie points to the geopolarity reversal time scale. However, the thin stratigraphic interval (20 m) sampled by Repenning and May (1986) yielded a Blancan vertebrate fauna.

The magnetostratigraphic sections of Mack et al. (1993) and Leeder et al. (1996) have an advantage over those of Vanderhill (1986) and Repenning and May (1986) because they involve a closer spacing of samples (0.5–2.0 m) and because not only mudstones and fine sand/sandstones were sampled, but coarser channel sands were sampled as well. Well-lithified sandstones and some well-lithified mudstones were sampled using standard drilling techniques, while unlithified sand, silt, and poorly lithified mudstones were sampled by pounding a nonmagnetic steel tube into the sediment and transferring the oriented sample into a quartz-glass tube, which was later cemented using sodium silicate and high-temperature alumina. Samples were demagnetized with a series of alternating field demagnetization steps, which removed the soft viscous remanent magnetization. This was followed by step-wise thermal demagnetization at several temperatures up to 675°C. The primary magnetic component in the samples is from magnetite.

The magnetostratigraphic sections of Mack et al. (1993) also have an advantage in that some contain radioisotopically dated volcanic rocks to act as chronologic tie points to the geopolarity time scale. These include pumice conglomerates at Hatch Siphon and Rincon Arroyo and the Bishop ash at Grama (Figs. 3 and 5). In addition, for many of the sections, the constructional top of the formations, either the La Mesa surface for the Camp Rice Formation or the Cuchillo surface for the Palomas Formation, provides an approximate time line for correlation of the sections (Figs. 3, 7, and 9).

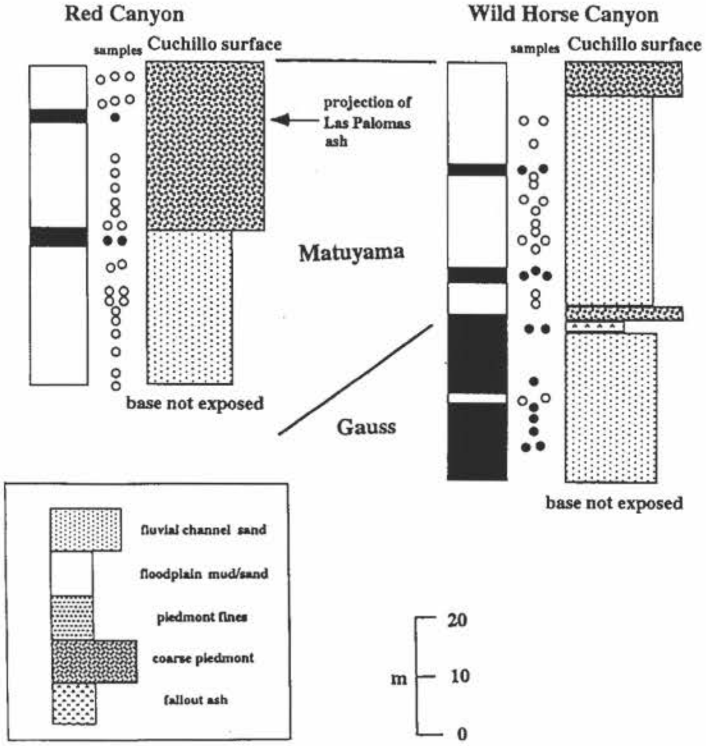

FIGURE 7. Magnetostratigraphc sections at Red Canyon and Wild Horse Canyon, along the eastern margin of the Palomas Basin.

DISCUSSION

The age of the Camp Rice and Palomas Formations in southern New Mexico is well constrained by a combination of radioisotopically dated basalts, volcanic ashes, and pumice-clast conglomerates within and inset against the formations, as well as by high-resolution reversal magnetostratigraphy. The lower part of the Camp Rice and Palomas Formations is Pliocene in age, as originally suggested by Hawley (1975, 1981). The Palomas Formation contains a 3.1 Ma basalt flow and the Camp Rice Formation contains the 3.12 Ma pumice-clast conglomerate at Hatch Siphon (Fig. 3). Moreover, there is ample evidence for sediment deposited during the Gauss geopolarity chron in both formations (cf. Fig. 2 and Figs. 3, 7, and 9). The best documented Gauss-age sediment is at Hatch Siphon, where the radioisotopically dated pumice-clast conglomerate (3.12 Ma) falls within the Kaena subchron (3.0–3.11 Ma)(cf. Figs. 2 and 3). Not surprisingly, the age of the base of the formations varies depending upon position within the basins. At Hatch Siphon (Fig. 3), as well as at other locations documented by Mack et al. (1993), the base of the Camp Rice Formation does not appear to cross the Gauss-Gilbert boundary, defining a lower limit of 3.58 Ma (Fig. 2). However, at the Garfield sections (Fig. 9), which correspond to a more basin-center position compared to Hatch Siphon, there is evidence of Gilbert-age sediment, perhaps including the three youngest subchrons (Cochiti, Nunivak, Sidufjall; cf. Fig. 2). Similarly, Repenning and May (1986) also suggested the existence of Gilbert-age sediment in the Palomas Formation, including the presence of the Nunivak subchron (4.48–4.62 Ma; Fig. 2). The Garfield West section also is important in determining the first appearance of the ancestral Rio Grande in southern New Mexico. The presence of three subchrons of the Gilbert Chron and reversed polarity beneath the lowest one (Sidufjall subchron) sets a lower limit for deposition of the axial-fluvial sediment of 4.98–5.23 (the top of the Thvera subchron) (cf. Figs. 2 and 9).

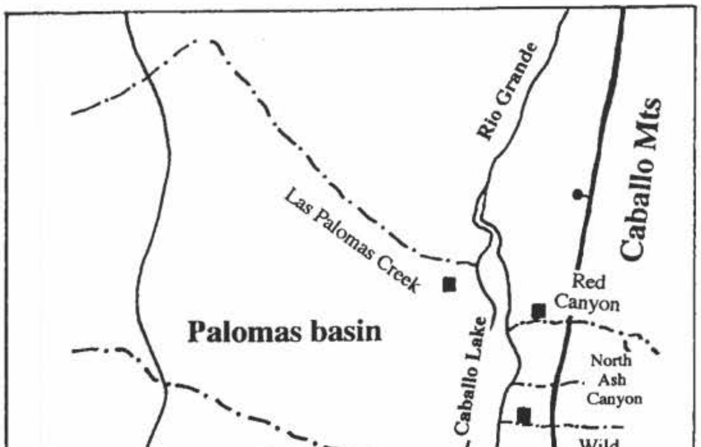

FIGURE 6. Index map of the Palomas Basin showing the location of magnetostratigraphic sections and/or the ash-bearing sections at Red Canyon (Las Palomas ash), North Ash Canyon, and Wild Horse Canyon. Heavy lines with ball and stick are range boundary normal faults, with ball on downthrown side.

The age of the upper part of the Camp Rice and Palomas Formations is latest Pliocene and early Pleistocene, corresponding to the Matuyama Chron. Pumice-clast conglomerates dated at around 1.6 and 1.3 Ma indicate an early Pleistocene age. The best documented Matuyama section is at Rincon Arroyo (Fig. 3), where all four subchrons were identified and corroborated by the 1.6 Ma pumice-clast conglomerate (Fig. 3). Although the other sections depicted in Figures 3, 7, and 9 do not contain radioisotopically dated volcanic rocks, the predominance of reversed polarity in the upper parts of these sections is consistent with a Matuyama age. Applying this reasoning, the undated thick fallout ash at Red

FIGURE 8. Photograph of the lower part of the Las Palomas ash at Red Canyon in the Palomas Basin. Hammer is 25 cm long.

Canyon (Las Palomas ash) is Matuyama in age, an interpretation consistent with its derivation from one of the Pleistocene Bandelier eruptions of the Valles caldera (Fig. 7). However, the undated ash at Wild Horse Canyon appears to be positioned near the top of the Gauss geopolarity chron, suggesting it may predate the Pleistocene Bandelier eruptions (Fig. 7).

The age of the constructional top of the formations, corresponding to the La Mesa and Cuchillo surfaces, appears to be at or very near the Matuyama-Brunhes boundary, 0.78 Ma (Fig. 2). The Rincon Arroyo section is again especially instructive because there is reversed polarity, but no normal polarity, above the Jaramillo subchron (Fig. 3). Indeed, for all of the sections that contain the constructional top, reversed polarity extends to the top of the sections, suggesting the Matuyama-Brunhes boundary was not crossed (Figs. 3, 7, and 9). Possible exceptions include the Lucero Arroyo section of Mack et al. (1993) and one of the three sections of Vanderhill (1986), both of which contain normal polarity at or near the top of the sections. However, the Lucero Arroyo section has a condensed Matuyama interval (only 12 m thick, compared to 50 m at Rincon Arroyo), and it is not clear if the normal polarity near the top corresponds to the Brunhes Chron or one of the subchrons in the Matuyama. It also is not clear how the normal polarity near the top of the section of Vanderhill (1986) should be interpreted, because of the large gaps in the spacing of the samples. The presence of the Bishop ash (0.74 Ma) within the Camp Rice Formation at Anthony Gap (Hawley, 1975; Kelley and Matheny, 1983), if properly correlated, suggests that at least locally deposition of the Camp Rice Formation continued past the Brunhes-Matuyama boundary. It is noteworthy that the Bishop ash at Anthony Gap is located very close to the mountain front, an area expected to be the last affected by headward erosion of a incising alluvial-fan channel.

The age of the top of the Camp Rice and Palomas Formations is also constrained by the ashes at Ash Mesa and Grama (Fig. 5). The Ash Mesa ash, which has been correlated with the Lava Creek B eruption at Yellowstone (0.61 Ma; Reynolds and Larson, 1972; Seager et al., 1975) is interbedded with sediment inset against the Camp Rice Formation (Mack et al., 1993). Thus, downcutting by the ancestral Rio Grande and its tributaries at Ash Mesa had begun prior to 0.61 Ma. At Grama, the Bishop ash (0.74 Ma) is positioned directly beneath inset gravels, but it is not clear whether

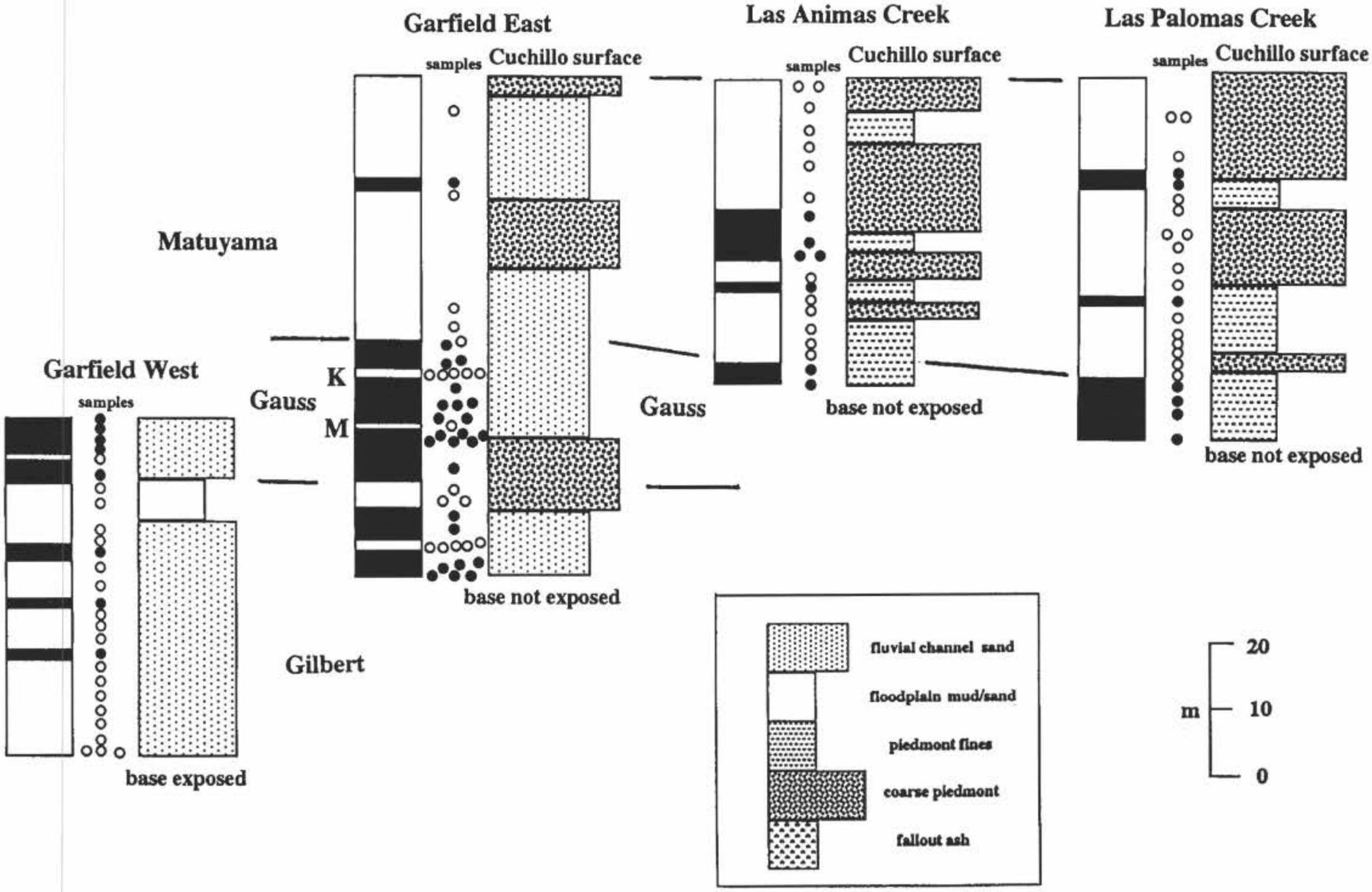

FIGURE 9. Magnetostratigraphic sections in the southern and western parts of the Palomas Basin (Mack et al., 1993; Leeder et al., 1996).

mudstone beneath the ash is inset alluvium or part of the Camp Rice Formation. If it is the former, then downcutting began during the latest Matuyama, and if the latter, then the top of the Camp Rice Formation at this location extended into the earliest Bruhnes. Either way, downcutting began very near or at the Matuyama-Brunhes boundary.

Finally, the ability to consistently pick chron boundaries allows correlation of the Camp Rice and Palomas Formations with a degree of accuracy not possbile by other techniques. The resultant detailed correlations permit basinwide comparison of depositional rates and processes (e.g., Mack et al., 1994a, 1997; Leeder et al., 1996), as well as provide the chronologic control for estimates of paleoclimatic change through the late Pliocene and early Pleistocene (Mack et al., 1994b).

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In the distance is the Sierra de las Uvas, composed primarily of Oligocene volcanic and volcaniclastic rocks. The badlands in the foreground are developed in axial-fluvial sediment of the Pliocene–early Pleistocene Camp Rice Formation. Photograph by Greg Mack.