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Abstract

A sedimentary sequence penetrated in the lower part of the Grober-Fuqua #1 well in the southeastern Albuquerque Basin has previously been interpreted as either Triassic or Eocene in age. Paleomagnetic study of three specimens from two core fragments yielded a 54.5° mean inclination of remanent magnetization relative to bedding. This inclination is like that expected in Tertiary time and is distinct from an expected low-angle Triassic inclination. Although the data are very few, when considered in combination with stratigraphic relations and the presence of a gravity low in this southeastern part of the basin, the paleomagnetic evidence favors a Tertiary age for strata in the lower part of the Grober-Fuqua #1 well.

Introduction

The Albuquerque Basin is part of the Rio Grande rift, which extends from Colorado to Mexico. Basin subsidence was most active from late Oligocene through Miocene time (Chapin and Cather, 1994), resulting in large accumulations of syn-rift sedimentary deposits of the Santa Fe Group. The Santa Fe Group varies in thickness from approximately 1,000 to 2,000 m (3,280 to 6,560 ft) along the basin margins to more than 4,270 m (14,000 ft) in the basin centers (Lozinsky, 1994; May and Russell, 1994). Throughout most of the Albuquerque Basin, the thickest sections of Santa Fe Group correspond to areas of deep lows on gravity maps (Cordell, 1976; Birch, 1982). An apparent exception is located in the southeastern part of the Albuquerque Basin east of the Rio Grande (eastern part of the Belen sub-basin), where an extensive, north-south elongated, >20-mGal gravity low was intersected by the 1,920-m- (6,300-ft-) deep Grober-Fuqua #1 petroleum exploration well (Fig. 1). Interpretations of well data (Fig. 2) indi-

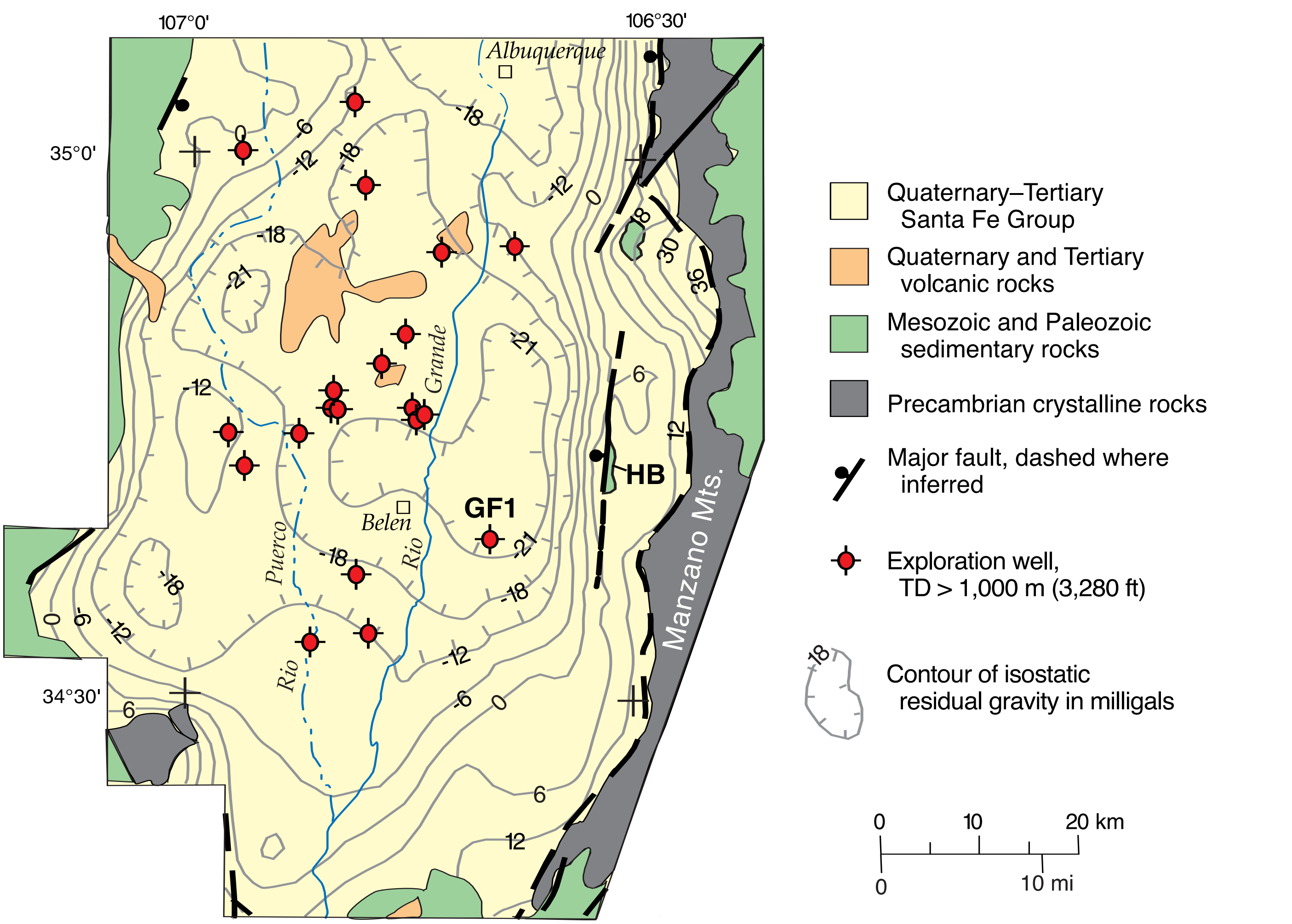

FIGURE 1—Generalized geology of the southern Albuquerque Basin from Kelley (1977), showing locations of oil exploration wells completed to >1,000 m (3,280 ft) total depth (TD; Black, 1982, 1999). **GF1** = Grober-Fuqua #1 well. Isostatic residual gravity from Gillespie et al. (2000). Contour interval = 6 milligals. **HB** = Hubbell Bench, where Triassic rocks were sampled by Lozinsky (1988).

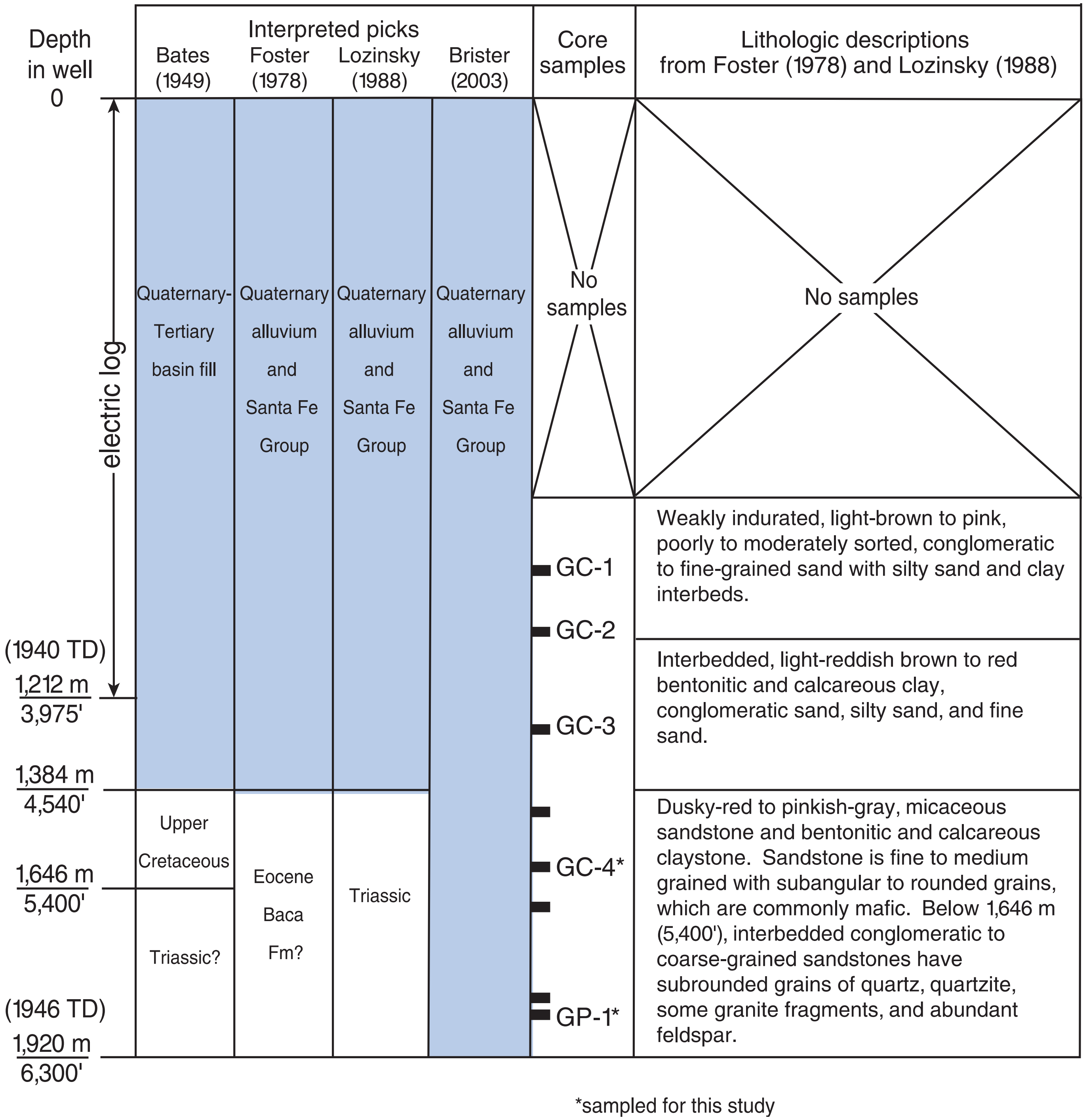

FIGURE 2—Schematic diagram of lithology, interpreted picks, and depths of core samples from the Grober-Fuqua #1 well. Interpreted picks are from R. L. Bates, as reported in Reiche (1949, p. 1204), Foster (1978), Lozinsky (1988), and Brister (written comm. 2003). The two completion depths (TD) from 1940 and 1946 and the limited depth extent of the electric log are also shown. Lithologic descriptions are from Foster (1978 and unpublished notes) and Lozinsky (1988). Horizons where core samples are available in the lower part of the well and those (GC samples) used in Lozinsky's (1988, 1994) analysis of sandstone petrology are marked with thick black ticks. One specimen from GC-4 and two specimens from GP-1 were used in this study.

cate the Santa Fe Group is 1,384 m (4,540 ft) thick (Foster, 1978; Lozinsky, 1988, 1994). This thickness contradicts gravity models that indicate a Santa Fe Group thickness considerably greater than 2,000 m (6,560 ft; Cordell, 1976; Birch, 1982; Grauch et al., 1999). Coverage of published seismic data is minimal in this area (Russell and Snelson, 1994).

One way to reconcile the apparent contradiction is by altering the gravity models to provide for low-density salt within units underlying the Santa Fe Group, as argued by Grauch et al. (1999). However, estimating the amount of salt and speculating on its geologic significance hinge on correct identification of the older units penetrated by the well. Cuttings from below 1,384 m (4,540 ft) in the Grober-Fuqua #1 well have been identified in the literature alternatively as pre-rift sedimentary deposits of early Tertiary age (Baca Formation?, Foster, 1978) or Triassic clastic sedimentary rocks (Lozinsky, 1988). If the units are Triassic in age, gravity models would require an extensive amount of salt, which most likely was deposited during the Permian. For example, a preferred gravity model of Grauch et al. (1999) incorporated salt as 30% of a 2–3-km- (1.2–1.8-mi-) thick Paleozoic basin-fill sequence. If the units are early Tertiary in age instead, gravity models would not require as much salt, and the salt may have been deposited irregularly in syn-basin playa lakes. Thus, a correct age determination of these units is important for understanding the significance and tectonic implications of the gravity low.

In an attempt to resolve the age controversy, we have applied paleomagnetic methods to two core fragments taken from the lower part of the Grober-Fuqua #1 well. Paleomagnetic study of these samples can discriminate between the two ages because directions of geomagnetic fields at the well site were much different in Tertiary time than in Triassic time. This difference is well expressed in the expected inclination of the field, which was 50°– 60° for Tertiary time and less than 10° for Triassic time (Fig. 3). Although the two core samples from the Grober-Fuqua #1 well are unoriented, bedding is recognized. Inclination of remanent magnetization is determined relative to this paleohorizontal marker.

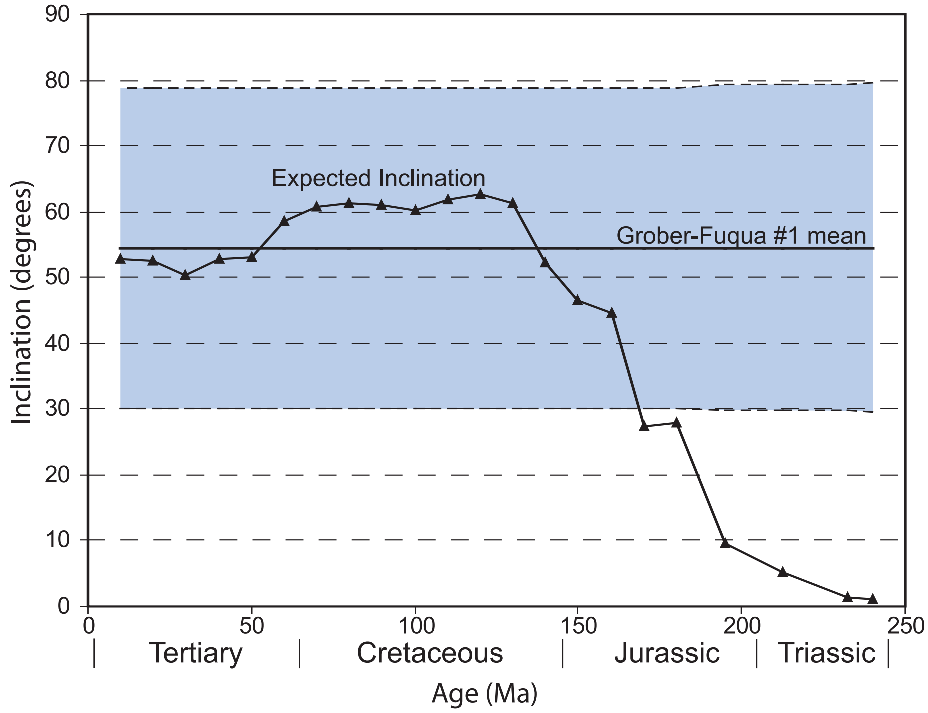

FIGURE 3—Plot of expected inclination versus age and inclination results for the Grober-Fuqua #1 well. Inclinations are calculated from poles of Besse and Courtillot (1991) for ages of 10 Ma to 180 Ma and from the North American craton poles of Molina-Garza et al. (1998) for Early Jurassic through Triassic ages. Also shown is the mean 54.5° inclination for the Grober-Fuqua #1 well samples and the 95% confidence limits (shaded) for its comparison to the expected inclinations.

Lithology of the Grober-Fuqua #1 well

A drilling summary (scout card), drillers' logs, several lithologic logs, a geophysical electric log (limited in depth), well cuttings, and core fragments from the Grober-Fuqua #1 well are available at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) petroleum library. The well was drilled to a total depth of 1,212 m (3,975 ft) in 1940. In 1946 it was redrilled to a depth of 1,920 m (6,300 ft). Cuttings and core at various intervals were collected below 802 m (2,630 ft) during drilling. Small, bagged samples from the cuttings and fragments of some of the core remain at NMBGMR.

Previous workers collectively have identified the first 1,384 m (4,540 ft) of sediments in the well as Quaternary alluvium and Santa Fe Group (Fig. 2). Interpretation on the interval below 1,384 m (4,540 ft) has changed with time (Fig. 2). This interval has been interpreted to represent Upper Cretaceous and Triassic rocks (R. L. Bates, reported in Reiche, 1949, p. 1204); pre-Santa Fe Tertiary units, possibly equivalent to the Baca Formation of Eocene age (Foster, 1978); and entirely Triassic rocks (Lozinsky, 1988).

The Triassic interpretation by Lozinsky (1988) came out of his study of sandstone petrology from cores and surface rocks from throughout the Albuquerque Basin. He observed that sandstone from core sample GC-4 (Fig. 2) differed significantly from the sandstone petrology of the Santa Fe Group, the Baca Formation, and other pre-Santa Fe Tertiary units that he had observed. Instead, petrology of GC-4 matched that of a sandstone sample from Triassic rocks mapped by Kelley (1977) at the Hubbell Bench (Fig. 1) that Lucas (1991) correlated with basal units of the Triassic section. The lithologic descriptions of the lower part of the well also resemble descriptions of outcrops of Triassic rocks on the flanks of the basin (Stewart et al., 1972; Lucas and Hayden, 1989; Lucas and Heckert, 1994, 1995). Notable Triassic lithologic similarities include abundant mica, bentonitic clays, subangular to subrounded grains, and the presence of conglomerates.

Paleomagnetism

Inspection of available samples from the Grober-Fuqua #1 well revealed that only core fragments from the GC-4 and GP-1 horizons (Fig. 2) were both sufficiently large for rock magnetic analysis and had visible bedding laminations. Roughly cube-shaped specimens of approximately 1 cc volume were cut from these core fragments and oriented in specimen coordinates so that bedding was horizontal. The GC-4 specimen, from the 1,541–1,544 m (5,057–5,064 ft) interval, is pale reddish-brown (10R 5/4), laminated, very fine to fine-grained sandstone. Two specimens were obtained from GP-1, from the 1,837–1,838 m (6,026 – 6,031 ft) interval; they are pale-red (10R 6/2), very fine to medium-grained sandstone with laminations of grayish-red (10R 4/2) shale.

The specimens were subjected to progressive thermal and alternating-field demagnetization to isolate characteristic magnetization components and assess their origin. Remanent magnetization of the specimens was measured using a spinner magnetometer with a sensitivity of about 1E-4 A/m; two measurements were made and then averaged for each specimen at each demagnetization step. Thermal demagnetization of the GC-4 specimen isolated one component of magnetization above 395° C with an unblocking range extending as high as 675° C (Fig. 4A). Principal component analysis (Kirschvink, 1980) of these demagnetization data yielded an inclination of 58.2° for this remanent magnetization component with an associated maximum angular deviation (MAD) of 4.2°. Thermal demagnetization behavior for the GP-1 specimen was more complex. A moderately inclined component of remanent magnetization (61.1°, MAD of 8.2°) was isolated over 350°–560° C (Fig. 4B), but at higher temperatures the directions and magnitudes of magnetization varied in an erratic manner and no coherent magnetization component was isolated. Alternating-field demagnetization of the second specimen from the GP-1 horizon isolated a magnetization of moderate inclination (44.3°, MAD of 7.5°) over peak inductions of 25 mT to 100 mT (Fig. 4C).

For GC-4 the unblocking temperatures as high as 675° C indicate a hematite carrier for the characteristic component, whereas for the GP-1 specimens the removal of the characteristic component over ranges

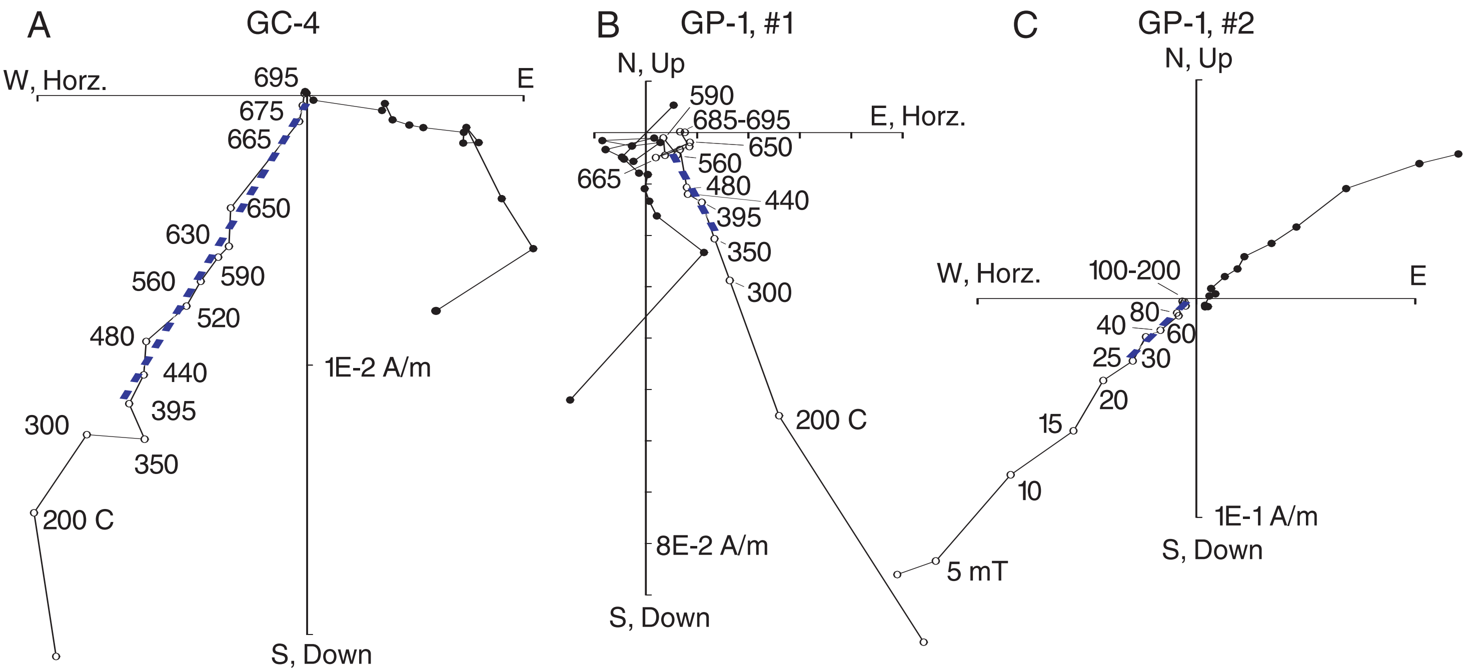

FIGURE 4—Orthogonal vector diagrams (Zijderveld, 1967) for progressive demagnetization results of the GC-4 and GP-1 specimens. Solid symbols are projections of remanent magnetizations after each demagnetization step on the horizontal plane, and they represent arbitrary declinations. Open symbols are projections of remanent magnetizations after each demagnetization step on the vertical plane, and they represent inclinations relative to horizontal. Values for GC-4 and GP-1 #1 are demagnetization temperatures (°C); values for GP-1 #2 are peak inductions (mT). Dashed lines are mean inclinations determined over the selected demagnetization ranges for the characteristic magnetization component of each specimen.

of 300°–560° C and 25–100 mT indicates a low-Ti titanomagnetite carrier. These conclusions were supported by isothermal remanent magnetization (IRM) acquisition experiments (Fig. 5). In IRM experiments, titanomagnetite acquires large magnetizations at inductions as high as 0.3 T, but at higher inductions it becomes saturated and acquires no additional IRM (Dunlop, 1986). The GP-1 specimens acquired at least 90% of their IRM by inductions of 0.3 T, consistent with a main titanomagnetite carrier (Fig. 5). In contrast, the GC-4 specimen acquired 64% of the IRM at inductions above 0.3 T, requiring a high-coercivity carrier like hematite.

Based on statistical procedures of McFadden and Reid (1982), the mean inclination of the three specimens is 54.5° ± 32.4°. We include both specimens from GP-1 in the mean calculation because their inclination range is greater than their difference with the GC-4 inclination. The associated 95% confidence limit for the mean inclination is large due to the small number of samples available. To assess the age of the magnetization we compared the mean inclination for the Grober-Fuqua #1 well samples to expected inclinations at the site calculated from North American reference poles. For Triassic through Early Jurassic times we used the North American craton poles of Molina-Garza et al. (1998) for reference. For Late Jurassic and younger times we used the North American poles from Besse and Courtillot (1991). Uncertainty limits for the inclination differences are 24°–25°, calculated using the flattening parameter of Demarest (1983). Thus the 54.5° mean inclination for the Grober-Fuqua #1 well samples is similar to values expected for Tertiary and Cretaceous times, and it is statistically distinct from expected Triassic inclinations (Fig. 3).

Interpretation of the inclination data to indicate a Tertiary age for the sedimentary rocks in the lower Grober-Fuqua #1 well requires two principal assumptions: (1) that bedding preserved in the core samples was horizontal when the rocks acquired their remanent magnetization, and (2) that the age of the remanent magnetization approximates the age of the sedimentary sequence. Hypothetically, a properly oriented primary dip of bedding (e.g., cross-bedding) could cause a low-inclination Triassic magnetization to appear to have a steeper inclination when the bedding is oriented horizontally. To produce the 54.5° inclination, however, the primary dip from both well horizons must have been high (45°–50°) and directed opposite to a recorded Triassic paleofield declination (generally north-northwest or south-southeast). These circumstances seem unlikely.

If the moderately inclined remanent magnetization measured in the well resulted from remagnetization of Triassic rocks, this remagnetization event was likely recorded in other Triassic rocks in the region. Remanent magnetizations in nearby Triassic sections were examined by Molina-Garza et al. (1991) and Molina-Garza and Geissman (1999). Molina-Garza et al. (1991) isolated low-inclination Triassic magnetizations carried by hematite in most samples of Moenkopi and Chinle Formations from rift-flank uplifts to the northeast, west, and south of the Grober-Fuqua #1 well. For example, from their Tables 2 and 3, they included results from 281 of 351 demagnetized samples (79%) from 53 sites used in their calculation of Triassic mean directions. The Triassic magnetization component was typically unblocked over 580°–680° C. Secondary magnetizations of moderate to steep inclination also were recognized at several locations, and these were concentrated above the basal disconformity with Permian strata (Molina-Garza and Geissman, 1999). The secondary magnetizations are either pretilting reversed-polarity components or post-tilting normal polarity components, and they are carried by goethite or fine-grained hematite. These secondary components typically unblocked over lower and more distributed temperature ranges than the primary low-inclination components.

For the Grober-Fuqua #1 well samples, the finding that magnetite carries the characteristic magnetization in the GP-1 horizon is an important consideration. The reddish color of this sample suggests that it was never subjected to a reducing geochemical environment that could precipitate authigenic magnetite. Thus the magnetite in GP-1 is most likely detrital in origin, and it probably acquired a detrital or post-detrital magnetization at or soon after sediment deposition. Later thermoviscous remagnetization of this early-formed magnetite remanence seems unlikely because it would require a thermal pulse of approximately 525° C for 10 m.y. to remagnetize the magnetite that unblocks as high as 560° C in laboratory demagnetization (Pulliah et al., 1975). For GC-4, the remanent magnetization carried by hematite is probably a chemical remanent magnetization formed after sediment deposition. Its unblocking as high as 675° C is more like that expected for coarse specular hematite rather than for fine-grained hematite that Molina-Garza et al. (1991) interpreted to typically carry secondary magnetizations in Triassic rocks. The hematite remanence in GC-4 may well have formed within a few million years after deposition, as is common in red bed sequences (Butler, 1992).

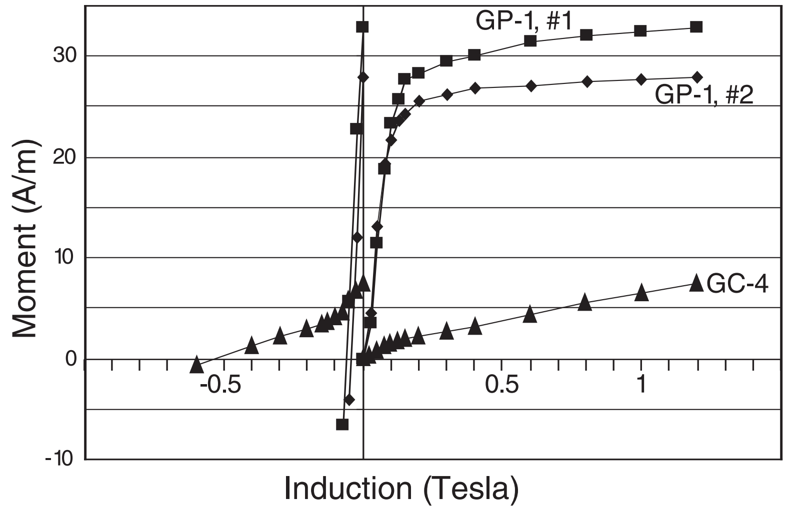

FIGURE 5—Acquisition of isothermal remanent magnetization of Grober-Fuqua #1 well core samples. Backfield demagnetization of remanence acquired at 1.2 T gives coercivity of remanence values that are indicative of hematite for the GC-4 horizon (triangles) and magnetite for the GP-1 horizon (squares and diamonds).

Discussion

The paleomagnetic results support a Tertiary age for rocks penetrated in the lower part of the Grober-Fuqua #1 well, but we interpret the data with caution because they are based on so few samples. However, in combination with several regional geologic considerations, the results argue against a Triassic age. First, the depth range of the lower interval in the well would require a Triassic section of more than 536 m (1,760 ft) thick (Fig. 2). This is unreasonable considering the maximum thickness of the Triassic section thins from 480–500 m (1,575–1,640 ft) on the northern and northeastern flanks of the Albuquerque Basin (Lucas and Heckert, 1995; Lucas et al., 2001) to less than 270 m (886 ft) in south-central New Mexico (Lucas, 1991). Second, Jurassic or Cretaceous sandstones typically overlie Triassic rocks from the western to the southeastern sides of the Albuquerque Basin (Lucas and Heckert, 1994; Lucas, 1991). The absence of these distinctive units in the well unreasonably implies that Tertiary units rest directly on Triassic rocks (S. Lucas, written comm. 2003). Finally, the Triassic pick in the well requires surprising explanations for the presence of the extensive gravity low in the area (Fig. 1), leading inevitably to the conclusion that a significant volume of low-density salt exists within the normally dense Mesozoic–Paleozoic sedimentary sequence (Grauch et al., 1999). Although the presence of Permian salt is not unreasonable, large quantities probably would have mobilized into diapirs through time, particularly during Laramide shortening. No evidence of salt tectonism is known in the region.

Choosing among the previously published interpretations for the lower part of the Grober-Fuqua #1 well (Fig. 2), several arguments favor Foster's (1978) interpretation that the strata are correlative with the Eocene Baca Formation. First, it is reasonable to expect that Baca Formation associated with the Eocene Carthage–La Joya Basin, exposed as near as 40 km (25 mi) to the south in the Joyita Hills, would extend northward into the area of the Grober-Fuqua #1 well (Cather and Johnson, 1984; Cather et al., 1994). Second, the Manzano Mountains (Fig. 1) were high and undergoing denudation during Eocene time, as was the Hubbell Bench but to a lesser degree (Kelley et al., 1992). These areas could have served as nearby sources of Triassic-rock detritus.

On the other hand, if the lithology of the lower part of the Grober-Fuqua #1 well is no longer considered to be diagnostic of a Triassic or an early Tertiary age, this interval could be a continuation of the Santa Fe Group of Miocene or late Oligocene age. In a recent reexamination of the well cuttings and core fragments, B. Brister (written comm. 2003) has favored a Santa Fe Group identity for the lower well sequence (Fig. 2) based on an assemblage of lithic fragments that includes plutonic and metamorphic types of probable Precambrian provenance and basaltic and ash-flow tuff types of likely Oligocene or Miocene age. This hypothesis is also consistent with the paleomagnetic data (Fig. 3), and it would be favored by previous gravity inversions that inferred rift-fill thickness in excess of 2,000 m (6,560 ft) in the southeastern part of the Albuquerque Basin (Cordell, 1976; Birch, 1982; Grauch et al., 1999).

Conclusions

Although the available samples are few, inclinations of remanent magnetization determined from the lower part of the Grober-Fuqua #1 well are like those expected for Tertiary time, and they are distinct from those expected for Triassic time. Coupled with the recognition that the penetrated stratigraphic section in the lower part of the well is abnormally thick for an expected Triassic section and also with the presence of a gravity low in this southeastern part of the basin, the paleomagnetic data provide support for a Tertiary age for sandstones in the lower part of the Grober-Fuqua well.

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