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MAGNETOSTRATIGRAPHIC CORRELATION AND DATING OF WEST TEXAS AND NEW MEXICO LATE PERMIAN STRATA

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Abstract.—Ochoan formations in west Texas-New Mexico have been investigated magnetostratigraphically for the purpose of obtaining age information. The locally-named Dewey Lake Formation has been studied in two areas of northwest Texas and in southeastern New Mexico. The subjacent Alibates and Rustler formations also are being investigated in these areas. Data from the Magenta Dolomite Member of the Rustler Formation near Carlsbad, NM, indicate three magnetic polarity intervals, contained within 11 m of dolomitic strata. Only preliminary Magenta data are available at present; nevertheless, four stratigraphic sections in the member consistently indicate the three polarity intervals. Additionally and surprisingly, reliable paleomagnetic data have been obtained from the Castile Formation. The reconnaissance data show a relatively strong remanent magnetization which is stable to thermal demagnetization procedures. A probable reversed polarity Late Permian magnetization was obtained. Within the Dewey Lake Formation of west Texas, magnetostratigraphy shows that relative thickness of enclosed volcanic ash beds is not a reliable correlation tool; ash beds of similar thickness located 120 km apart lie in different magnetic polarity intervals. Magnetostratigraphy has shown that the 0.6 m ash layer at Dickens, TX, corresponds to a 0.02 m ash layer (the upper of two) at Caprock Canyons State Park. Magnetostratigraphy also demonstrates that fully one-half of the Dewey Lake Formation present in northwest Texas (Caprock Canyons) has been removed by pre-Late Triassic erosion in the more southerly localities. Late Permian, rather than Triassic, paleopoles are obtained from the Dewey Lake beds. The data of this study suggest a correlation of the Magenta Dolomite with the lower exposed portion of the Alibates strata of northwest Texas (Caprock Canyons State Park). A Late and Middle Permian magnetostratigraphic time scale is derived by combining all available magnetostratigraphic studies. The Dewey Lake-Alibates/Rustler magnetostratigraphic sequences correlate well with the global magnetic polarity pattern and suggest that the Alibates/Rustler strata may be latest Capitanian in age and that the Dewey Lake (Quartermaster) strata were deposited in the Wujiapingian and early Changsingian Stages of the Late Permian.

DEWEY LAKE (QUARTERMASTER) FORMATION

Introduction

The youngest Permian strata in North America are the red beds of the Permian Basin of west Texas and southeastern New Mexico. Numerous names have been applied to these strata , including Quartermaster, Pierce Canyon Redbeds, and Dewey Lake and Alibates (stratal relationships were reviewed by Lucas and Anderson, 1994). The age of these red bed strata is unknown due to an almost total absence of fossils, and has been speculated to be both Late Permian and Triassic. A rarely-occuring molluscan fauna suggested a Permian age (Roth et al.,1941), but Schiel (1987) favored a Triassic age. The red beds are commonly unconformably overlain by Upper Triassic (upper Carnian) sandstones of the basal Chinle Group.

For the purpose of age-dating, an intensive magnetostratigraphic study of both the Dewey Lake and the underlying, anhydrite-rich Alibates exposures was undertaken at Caprock Canyons State Park, near Quitaque, Texas (approximately 107 km NE of Lubbock, TX: Fig. 1). The Dewey Lake and Alibates are distinguished by the presence of bedded anhydrite within the Alibates and its absence in the Dewey Lake strata. The total section exposed and studied at Caprock Canyons (Steiner et al., in prep.) is nearly 140 m thick, 55 m of Alibates beds and 94 m of Dewey Lake strata. The Dewey Lake beds contain two volcanic ash beds, one about 4 m above the formation base defined by the absence of bedded anhydrite and a second about 20 m higher than the first. The lower ash bed is relatively thick, varying between 20 and 28 cm thickness over lateral exposures of 12 km. In sharp contrast, the higher ash bed is only 2 mm thick.

Another thick exposure of volcanic ash was observed (D. Cheney, pers. comm., 1997) in the Dewey Lake Formation near Dickens, Texas (90 km due east of Lubbock, TX). The Dickens exposure is approximately 120 km south-southeast of the Caprock Canyons exposure (Fig. 1), and the ash bed is 0.57 m thick. The thickness of exposure therefore greatly physically resembles the lower ash bed at Caprock Canyons. The need for rudimentary age control for paleoclimatic studies in the Early and Middle Permian exposures farther east of Dickens prompted a magnetostratigraphic investigation of the Dickens exposures of the Dewey Lake Formation. The intent was to establish a correlation of this ash bed with the one it resembles at Caprock Canyons, which is being dated radiometrically (Renne et al., 1996).

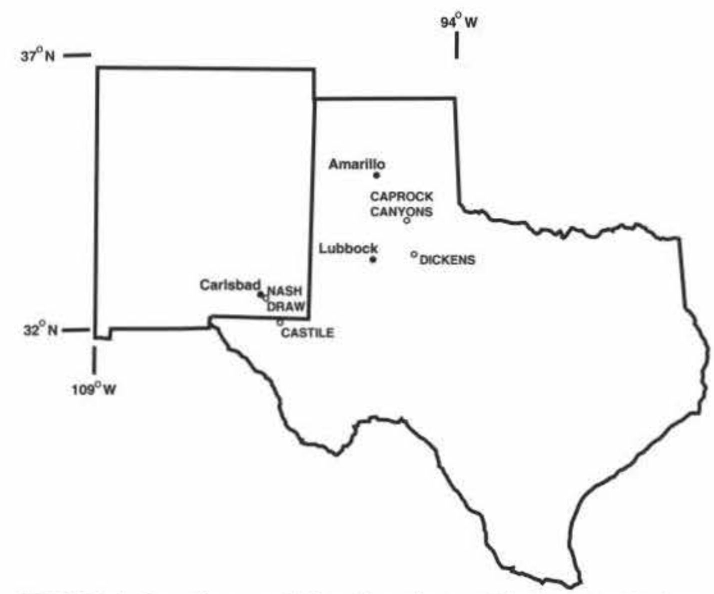

FIGURE 1. Location sampled sections discussed in the text. City locations are indicated by black dots and sampling localities by open symbols.

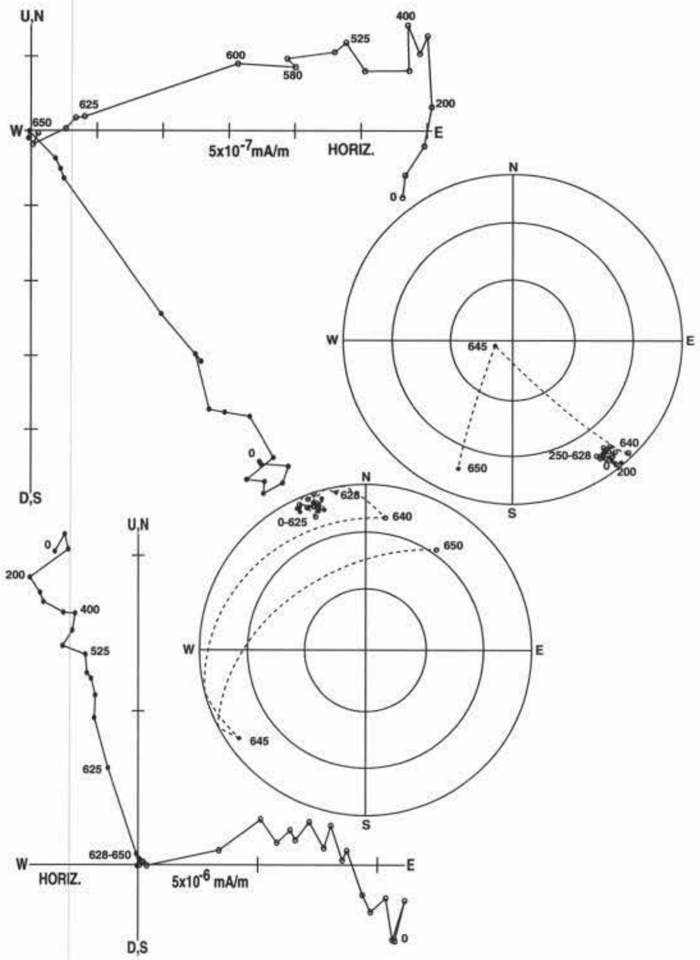

FIGURE 2. Typical demagnetization responses of the Dewey Lake samples from the Dickens locality. Equal area stereographic plots show lower (upper) hemisphere directions as solid (open) circles. Orthogonal axes plots show the horizontal projection of the magnetic vector (declination) as solid symbols and the vertical projection (inclination) as open symbols.

Magnetostratigraphy

Twenty-two oriented paleomagnetic samples were collected in a reconnaissance sampling of Dewey Lake exposures adjacent to US Hwy 82, at the rest stop approximately 4 km east of Dickens, TX. Two partial sections were sampled just south of the highway. At one exposure, the volcanic ash bed forms the top of the exposure, and 3 m of strata below the ash bed were sampled. Just east of this exposure, a gully exposes the section from the ash bed to the top of the formation. The formation is overlain unconformably by conglomeratic sands of the basal Camp Springs Formation of the Chinle Group. The reconnaissance sampling was preformed under stringent time constraints, so it was guided by an assumption that this ash bed corresponded to the lower of the two at Caprock Canyons. That assumption meant that the ash layer should be encompassed by a thick normal polarity interval, and therefore sampling aimed for the top of that polarity interval. Sampling in the gully began at about 8 m above the ash bed and continued in reconnaissance fashion to the top of the formation. Samples were collected with a battery-powered electric drill fitted with a diamond bit and using forced-air as a bit coolant.

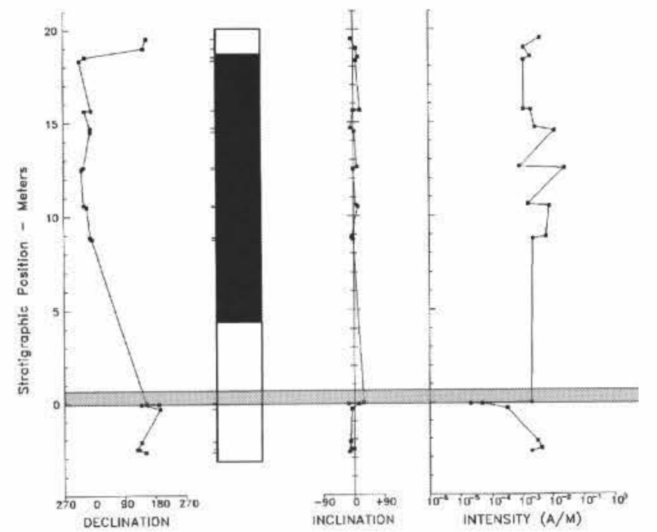

FIGURE 3. The magnetostratigraphy at Dickens; black indicates normal polarity. Grey band represents the volcanic ash bed.

The paleomagnetic samples were measured with a cryogenic magnetometer and progressively thermally demagnetized in 17 steps from 150° to 650° C. Like the Dewey Lake samples of the Caprock Canyons area, the magnetizations are remarkably uncomplicated by later secondary magnetizations, a rare phenomenon in paleomagnetic studies. Most samples decay univectorially to the origin of orthogonal axes plots after removal of a component between 150 ° and 300 ° C that is steeply inclined. Demagnetization response is illustrated by two examples (Fig. 2), one sample from below, and one from above the ash bed. The low temperature component from all samples comprises a quite scattered population of generally northerly directed, steeply inclined directions; the component is far steeper than the presently observed and theoretical axial dipole directions for this site, and its origin presently is unclear.

With such relatively uncomplicated magnetizations, the magnetostratigraphic interpretation is straightforward. The Dewey Lake magnetostratigraphy at Dickens (Fig. 3) consists of two intervals of reversed polarity separated by one of normal polarity. The volcanic ash bed lies within reversed polarity, unexpected because its thickness. Unfortunately, the sampling coverage is inadequate to fully define the reversed polarity interval containing the ash bed, although further samples will be taken. Despite the sampling gap, correlation of the Dewey Lake strata at Dickens and contained ash layers between Dickens and Caprock Canyons is clear and unambiguous, as will be shown.

RUSTLER FORMATION, MAGENTA MEMBER

The Magenta Member is one of five members of the Rustler Formation of extreme southeastern New Mexico and southwest-

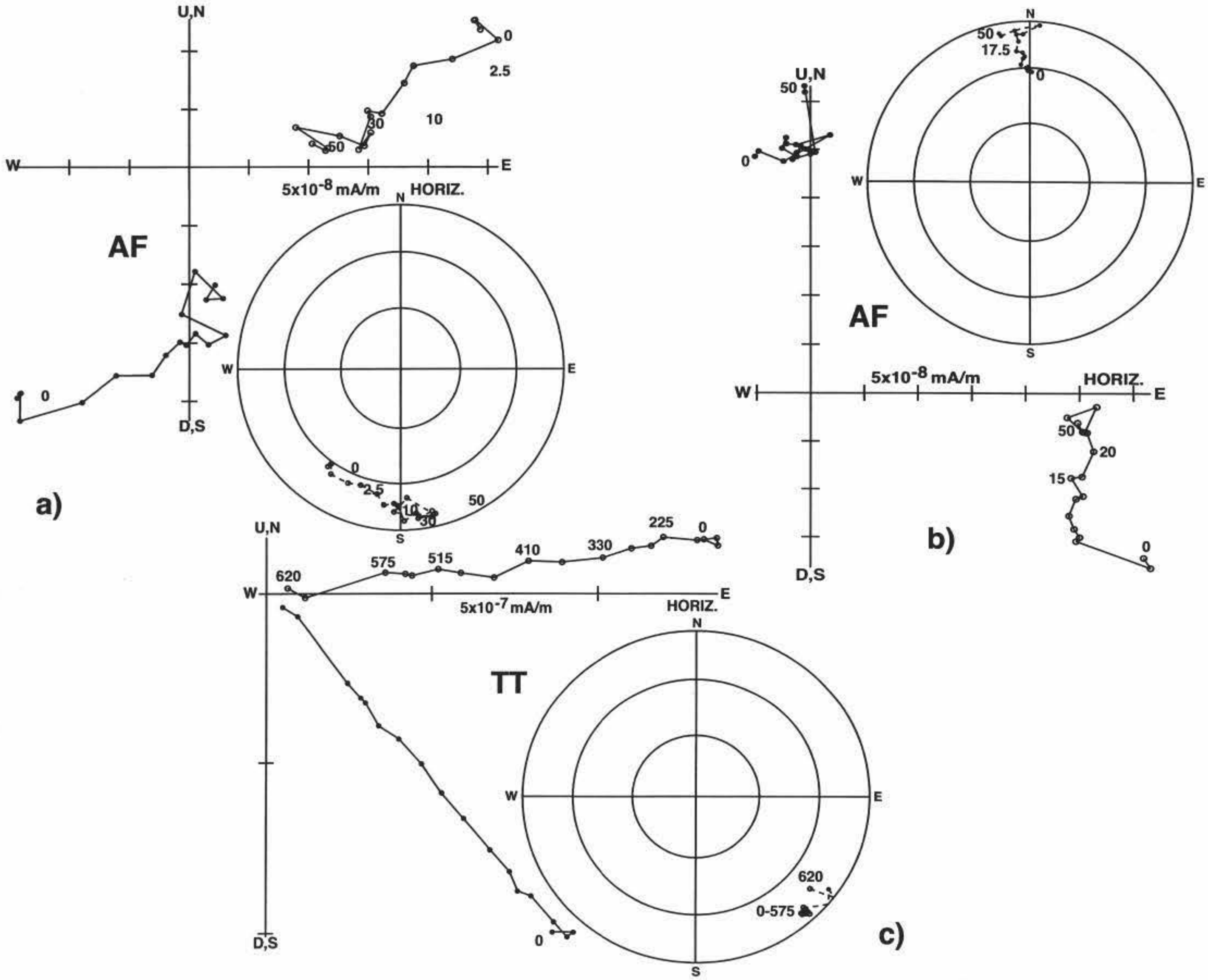

FIGURE 4. a) and b) Alternating field (AF) and c) thermal (TT) demagnetization of Magenta Dolomite samples from the Rustler Formation. Plots and symbols as in Fig. 2.

ern Texas. Pink dolomite characterizes the member; five collections were made from stream-cut exposures on the west side of Nash Draw (Fig 1); all from exposures accessed from NM Highway 31. One nearly complete section was sampled near an abandoned mine at the more northerly end of NM 31, near its intersection with US 62-180. This sampling spanned 11 m (of a probable 15 m thickness) at 0.5 to 1 m increments, yielding twenty four samples. Four other partial sections of the Magenta Member were sampled farther south on NM 31, in exposures created by a deeply incised creek that drains eastward from NM 31 out into Nash Draw. Most of these collections spanned 2.5 m, and one spanned 3.3 m of the Magenta Member, resulting in another 55 samples from the member.

The magnetic polarity of about 2/3 of the Magenta Member samples is readily apparent from the initial measurements (natural remanent magnetizations, or NRMs). As yet, only pilot samples have been demagnetized. Both alternating field (AF) and thermal demagnetization have been tested. AF demagnetization was successful in removing overprint magnetizations in some samples (Fig. 4a-b), but not in others. Thermal demagnetization was more successful than AF (Fig. 4c), and thermal demagnetization of the rest of the samples in progress.

However, four of the five sections are sufficiently free of overprinting magnetizations that their NRM directions indicate a polarity sequence; moreover, the four sequences suggest the same polarity succession, reversed polarity followed by a thin normal polarity interval, followed again by reversed polarity (Fig. 5). Data from the Magenta Member are reported here in the preliminary stage of their investigation because of a suggested correlation with the Alibates "Beds" of the Caprock Canyons sequence in Texas, and the constraint that that correlation provides on the age of the superjacent Dewey Lake strata.

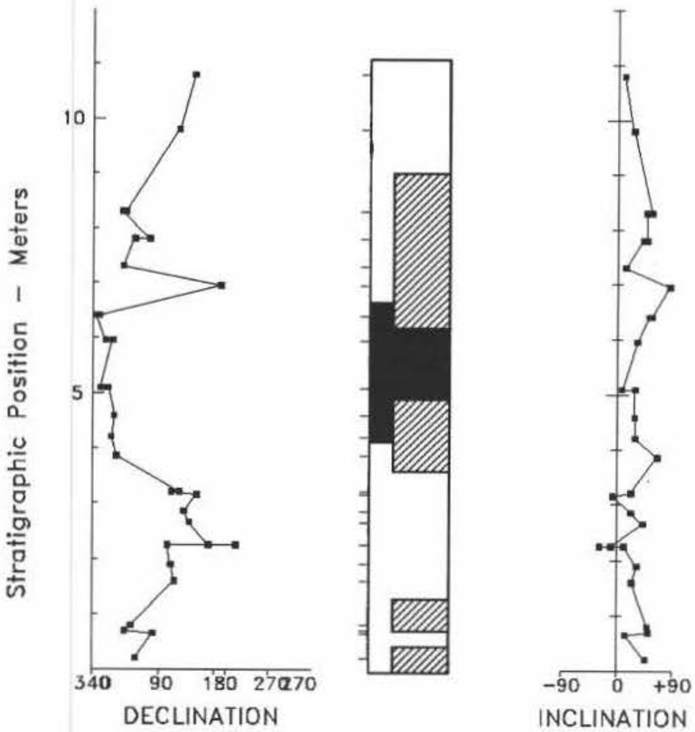

FIGURE 5. Preliminary Magenta Member magnetostratigraphy from the natural remanent magnetizations (NRMs).

CASTILE FORMATION

The Castile gypsum consists of alternate layers of white gypsum/anhydrite and dark layers. The dark color suggested the possibility that a detrital component may reside in these layers, and thus that magnetic components could be present. To test this possibility, a sample was taken from a block sample already in the possession of the author. The block consisted of thin (approximately 2 mm) alternating layers of black and pure white anhydrite. The insitu vertical direction of the block was known, but the azimuthal orientation was unknown.

Quite surprisingly, this sample was magnetic at the level of many chemical sedimentary rocks such as limestones and dolomites; initial magnetization values were about 1.5×10^{-7} mA/m. More significant than the unexpectedly strong magnetization, was the stability of the magnetization to demagnetization techniques. Both AF and thermal demagnetization were tested on samples from this block. Low-field AF demagnetization (1 to 7 mT) had little effect in changing the magnetization direction, but the intensity decayed dramatically (Fig. 6) until it was quickly at or below the resolution of a cryogenic magnetometer (5×10^{-9} mA/m). This suggests the presence of some amount of very "soft" (unstable) component of magnetization, such as equant magnetite of >1 micron size or an iron sulfide

In contrast, the magnetization direction remained unchanged by thermal demagnetization to 500° C. Moreover, the magnetic intensity decayed fairly linearly to a near-zero intensity by 500° C (Fig. 6). This behavior suggests either fine-grained magnetite, maghemite, or hematite; obviously, more detailed work on more samples is required to determine the actual magnetic carriers. The stability of the Castile sample to thermal demagnetization was a surprise, partly because of the unstable behavior in response to AF demagnetization. Moreover, predominantly gypsiferous sedimentary rocks incorporated in red beds usually have unstable magnetizations; additionally, sedimentary rocks possessing weak initial intensities not infrequently are unstable above about 300° C.

The stability of the Castile sample to 500° C rules out magnetic carriers in the iron sulfide solid solution series; that stability suggests magnetite or maghemite as a magnetic carrier, thus possible evidence of a detrital origin of the carrier. Further support of a detrital carrier is the found in the fact that the magnetic direction is similar to other Late Permian magnetizations for North America. Because the block was azimuthally unoriented, the compass direction of the remanence is unknown. But, the vertical orientation of the magnetic vector was known, thus the magnetization is referenced to the horizontal planes of the parallel dark and light laminations. A locus of all possible paleopoles that could correspond to this magnetization is generated by the distance of the site to the pole, information determined from the inclination component (the vertical component) of the magnetic vector obtained. This results in a circular track (Fig. 7) which is bracketed by two other circles representing the 95% confidence limits on the determination of the magnetic direction itself.

At 95% confidence, the Castile locus of poles statistically overlap with the slightly younger Alibates paleopole of northwest Texas (A in Fig. 7). Hence, if the Castile sample block and its magnetic direction were rotated about 120-130° in a counterclockwise sense, the Castile pole would agree well with the next younger Late Permian paleopole known from North America. Obviously, this Castile "pole" is from one sample only; the comparison is merely undertaken to show that the Castile Formation probably preserves a stable Late Permian magnetization.

DISCUSSION

Figure 7 also displays the paleopoles from the Dewey Lake strata at Dickens (DD) and at Caprock Canyons (CC). The CC data suite was divided into the Alibates portion (A), and a lower (DL) and upper (DU) portions of the Dewey Lake beds, and poles calculated for each (Steiner et al., in prep.). The reason for the division within the Dewey Lake strata is a significant facies change that occurs at 26 m, a change from very evenly bedded siltstones and claystones to medium grained fluvial sandstones and thick eolian sandstones. This lithologic change is accompanied by shift in magnetic direction and a degradation of the quality of magnetization preservation; the lower 26 m display extremely linear demagnetization trends to the origin of orthogonal axes plots above 300° C demagnetization, clearly indicating that no secondary magnetizations influence the magnetic direction above that treatment step. On the other hand, the upper sandstone samples display considerably less linear trends and consistently have higher errors associated with their characteristic directions. Further, the mean direction of the strata above 26 m is displaced from that of the lower strata (Fig. 7). Several possibilities could explain the difference (Steiner and Renne, in prep.): 1. The

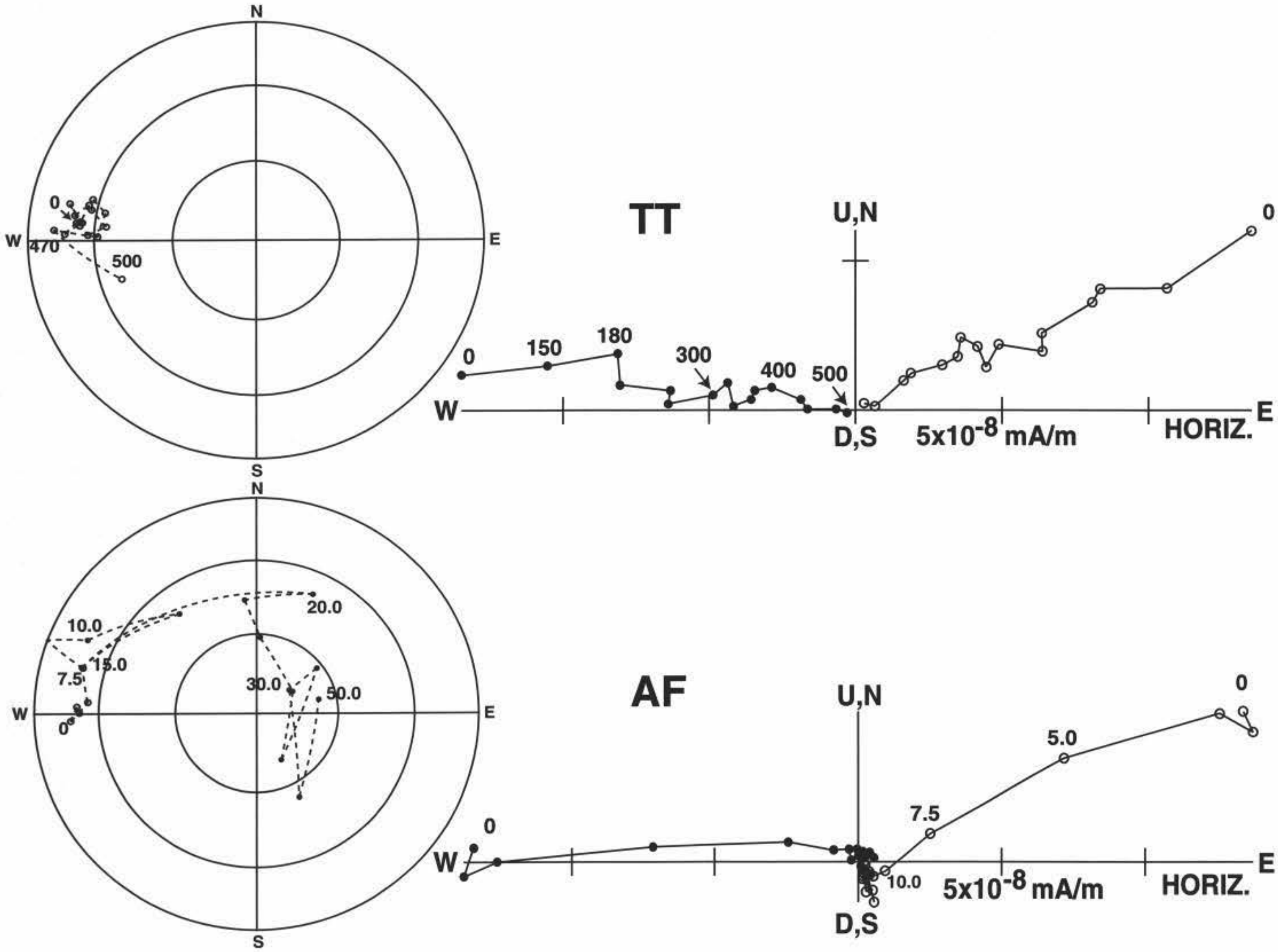

FIGURE 6. Castile reconnaissance sample demagnetization by alternating fields (AF) and thermal treatment (TT). Plots and symbols as in Figure 2.

porosity of the sandstones may have allowed additional magnetization in the sandstones during the time represented by the unconformity between the Dewey Lake and the overlying Chinle Group. For that reason, the paleopole for cratonic North America from the Late Triassic Chinle Group (C) is shown in Figure 7. The upper Dewey Lake strata appear biased towards the Late Triassic pole, possibly representing an unremoved overprint associated with the unconformity. 2. The lithologic change could represent a change in formation, hence somewhat younger strata (perhaps Early or Middle Triassic). In fact, the strata above 26 m in part physically resemble the Middle Triassic Moenkopi Formation (Anton Chico Member) of the area between Albuquerque and Santa Rosa, New Mexico. However, the absence of an unconformity or any change in age of the strata is demonstrated by a comparison of the Dewey Lake paleopoles between Dickens and Caprock Canyons.

The fine-grained, evenly bedded lithology of the Dewey Lake strata at Dickens is identical to that from the lower 26 m at Caprock Canyons (Fig. 8). The Dickens Dewey Lake paleopole (DD in Fig. 7) is statistically indistinguishable from that of the CC strata below 26 m (DL in Fig. 7). This means that the Dickens and lower Caprock Canyons strata are closely similar in age.

This paleopole agreement supports the stratigraphic correlation of the magnetic polarity sequences and correlation among the volcanic ash beds between the two sites, shown in Figure 8. The volcanic ash at Dickens has reversed polarity beds below and above it, suggesting that it correlates with the higher of the two ash beds at CC. The relative lengths of the overlying normal polarity interval at Dickens and CC support that correlation. Moreover, the relative position of the ash bed within the reversed polarity interval at Dickens matches that at CC, providing yet a third similarity in support of this correlation, making the proposed correlation between Dickens and Caprock Canyons quite probable.

The magnetostratigraphic and paleopole correlations between the Dewey Lake Formation at Dickens and Caprock Canyons also address the stratigraphic questions raised by the lithology and pole position change at the Caprock Canyons site. The similarity of the Dickens pole from magnetic polarity intervals Rc3 to Rd4 to that from the just older strata of Nb2 and the lower 3/4 of Rb2 polarity intervals at CC proves that the lithology change is simply

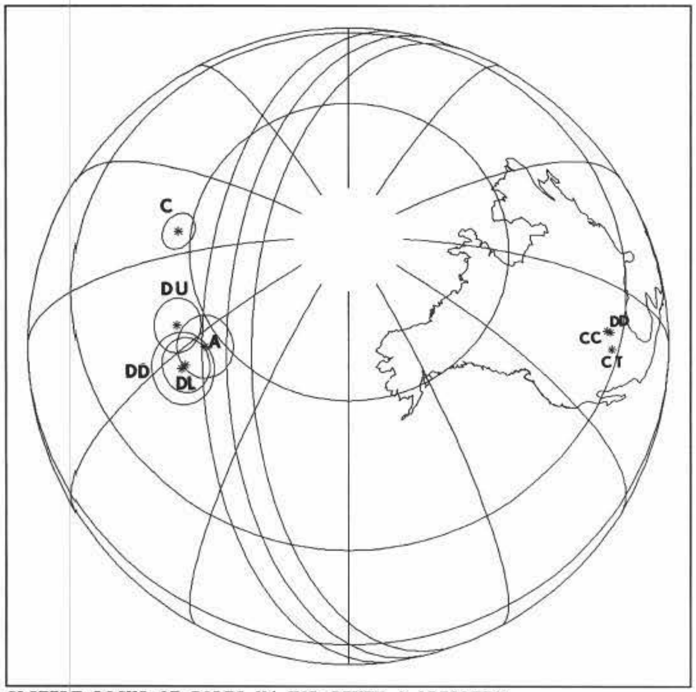

FIGURE 7. Paleomagnetic pole positions. The Dewey Lake Formation is represented by Caprock Canyons and Dickens localities; the Caprock Canyons sequence has been divided into the Alibates (A), lower Dewey Lake (DL) and upper (DU) Dewey Lake. The cratonic Chinle Group pole (C) is shown for reference. A locus of poles and their 95% confidence limits are shown for the Castile sample. Site locations are shown by asterisks (CT = Castile; CC = Caprock Canyons; DD = Dickens).

that; the same fine-grained, evenly laminated siltstone-mudstone facies at Dickens gives an identical paleopole to that of the fine-grained, evenly laminated but slightly older strata at CC, and not the same paleopole as magnetostratigraphically coeval fluvial and eolian sands comprising the upper 1/4 of Rc3-Nc3-Rd4 at CC. Because the magnetostratigraphy and ash correlations prove that these different lithologies represent the same time interval, this pole difference is strong evidence that the coarser and more porous lithology has influenced the characteristic direction of the strata, probably by being more susceptible to fluid penetration and overprinting by later magnetizations. The magnetostratigraphic match between the two sections and the display of identical paleopoles from the same lithology negates the possibility of an unconformity formational and age change in the Caprock sequence.

Figure 8 also shows a magnetostratigraphic sequence from the Dewey Lake beds at Nash Draw (Molina-Garza et al., 2000). Here the Dewey Lake beds rest on the Rustler Formation, whereas at Caprock Canyons, they lie on the Alibates 'Formation'. The proposed correlation of the Nash Draw Dewey Lake strata with the Dickens and CR exposures was guided by the relative position of the Nash Draw and CR magnetographies with respect to the base of the Dewey Lake beds at each locality.

The proposed magnetostratigraphic correlations of Figure 8 also were influenced by the apparent polarity sequence within the Magenta Member of the Rustler Formation. As shown in the figure, the Magenta magnetostratigraphic sequence closely resembles that of the lower beds of the Alibates Formation exposed at Caprock Canyons, in the display a polarity sequence containing a very short normal polarity interval enclosed by dominantly reversed polarity. Both that moderately distinctive polarity sequence and its position relative to the base of the Dewey Lake Formation at each locality suggest that the Rustler Formation correlates approximately to the Alibates Formation. The proposed correlation can be tested because it predicts that the upper member of the Rustler should contain entirely reversed polarity.

The experimentation on a single sample of the Castile Formation was a test to determine the possibility of magnetic remanence carriers in the formation. Similar tests were carried out on samples of the Salado Formation with negative results (Steiner, unpublished data). The single Castile sample suggests reversed polarity at that time. While not at all definitive, that suggestion is in agreement with global magnetostratigraphy (Fig. 9).

Figure 9a shows all magnetostratigraphic studies determined globally from Middle and Late Permian strata. The data shown are the magnetostratigraphic interpretations and ages quoted by the authors. Among the sequences, the Iranian section (Gallet et al., 2000) possesses the best combination of good marine faunal control and good magnetic characteristics indicative of a reliable magnetization record. The Pakistan sequence also is well-dated biostratigraphically, and has a similar magnetostratigraphic signature, but possesses slightly less pristine magnetizations. Using the assumption that the Iranian data present the best representation of geomagnetic field behavior for the Late Permian (Wujiapingian and Changsingian Stages), all other sequences have been adjusted to match this sequence in general polarity signature in Figure 9b.

The best Dewey Lake paleopoles definitely demonstrate that the Dewey Lake strata are Permian and not Triassic in age. Comparison of the Dewey Lake magnetostratigraphy (Caprock Canyons) with the Iranian and Pakistani sections (Fig. 9b) suggests that the age of the Dewey Lake strata is probably Wujiapingian and early Changsingian. The three reversed polarity intervals in the Dewey Lake magnetostratigraphy tentatively are inferred to correspond to the lower three reversed polarity intervals of the Iranian sequence. This interpretation implies that the upper Changsingian is missing in Texas.

One other conclusion follows from acceptance of the Iranian sequence as representative of Late Permian magnetic polarity. The lower part of the North American Ochoan Stage then becomes equivalent to the uppermost portion of the global Capitanian Stage. This implies that the top of the Capitanian Stage stratotype (as represented by the Tansill and Reef Trail formations) is older than the top of the global Capitanian Stage; that is, the uppermost North American Capitanian strata are several million years older than the oldest Wujiapingian or Djulfian strata of the Tethys. This is a seemingly inescapable conclusion at this point.

CONCLUSIONS

Five conclusions devolve from the above data and discussions.

1) Ash beds can dramatically change thickness along strike over distances of 100 km.

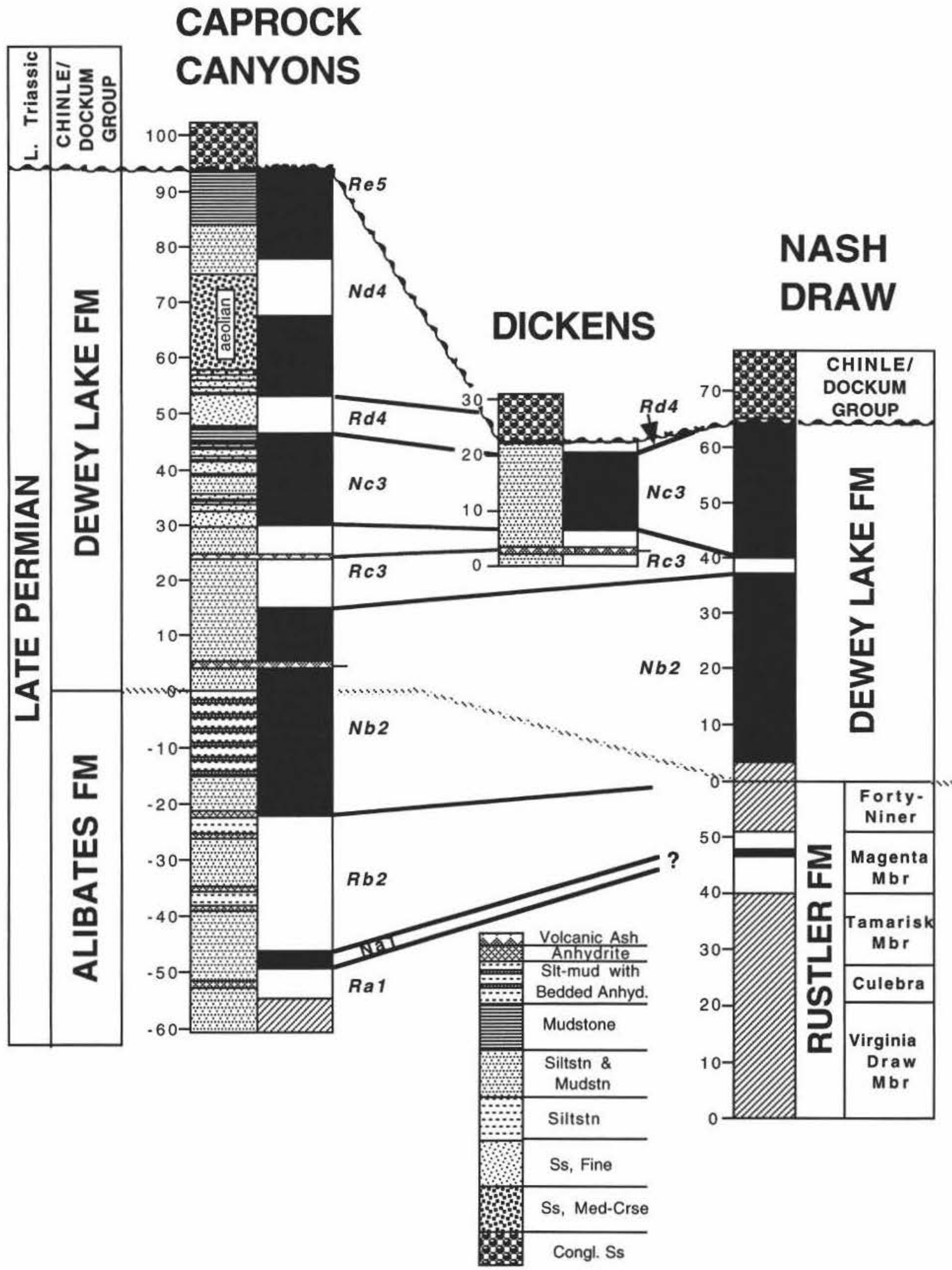

FIGURE 8. Correlation of Dewey Lake, Alibates and Rustler Formations from Caprock Canyons, Dickens and Nash Draw. Correlations are based on a combination of polarity interval boundaries, ash bed occurrences and the contact of the Dewey Lake Formation with the underlying formations in the various localities. Combinations of the letters R and N with other letters and numbers are used to designate individual polarity intervals for discussion. Thickness scales are in meters.

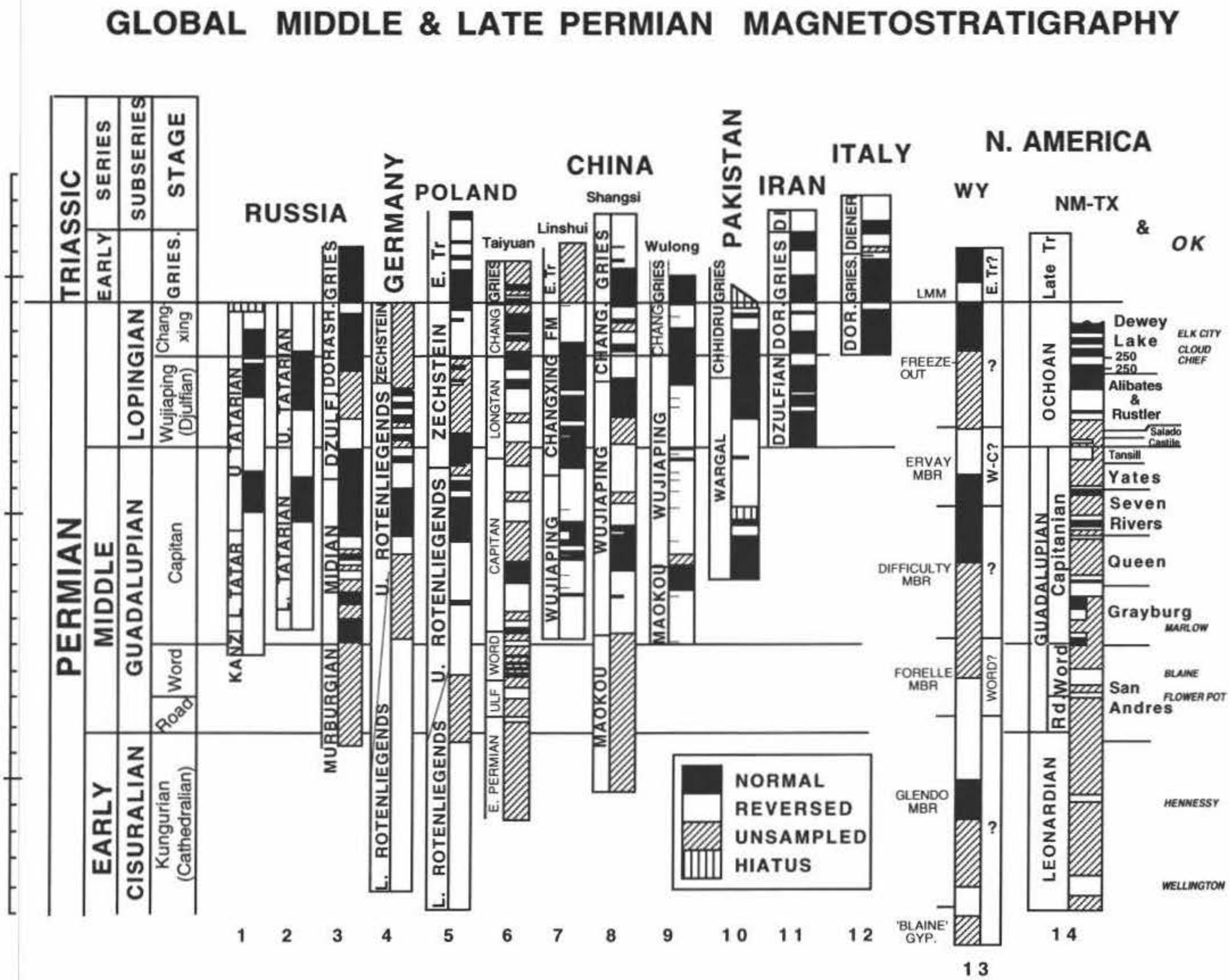

FIGURE 9a. The Dewey Lake, Alibates/Rustler, and Castile data are displayed with other Middle and Late Permian global magnetostratigraphic results. 1: Molostovsky (1983); 2: Gurevich and Stautsitays (1985); 3: Zakharov and Sokarev (1991) and Gialanella, et al. (1997); 4: Menning (1988); 5: Nawrocki (1999); 6: Embleton et al. (1996); 7: Heller et al. (1995); 8: Steiner et al. (1989); 9: Heller et al. (1995); 10: magnetostratigraphy of Haag and Heller (1991) biostratigraphic ages from Wardlaw and Pogue (1995); 11: Gallet et al. (2000); 12: Scholger et al. (2000); 13: Steiner, Hutna, and Lyford, in prep.; 14: This paper; Steiner, Christensen, and Parkin, in prep; and Peterson and Nairn, 1971.

2) Paleomagnetic poles and magnetostratigraphy demonstrate that the age of the Dewey Lake strata in northwestern Texas is probably early Late Permian, Wujiapingian Stage, through early late Late Permian, early Changsingian Stage.

3) A drastic change in lithology of the Dewey Lake strata at Caprock Canyons, northwest Texas, does not represent an unconformity or new formational boundary. As would be expected with the filling and desiccation of the Permian Basin, fluvial and aeolian deposits replaced tidal flat deposits in the northern reaches of the basin.

4) Magnetostratigraphy suggests that the Rustler Formation may correlate approximately to the Alibates Formation.

5) The Castile Formation is suitable for paleomagnetic and magnetostratigraphic study.

ACKNOWLEDGMENTS

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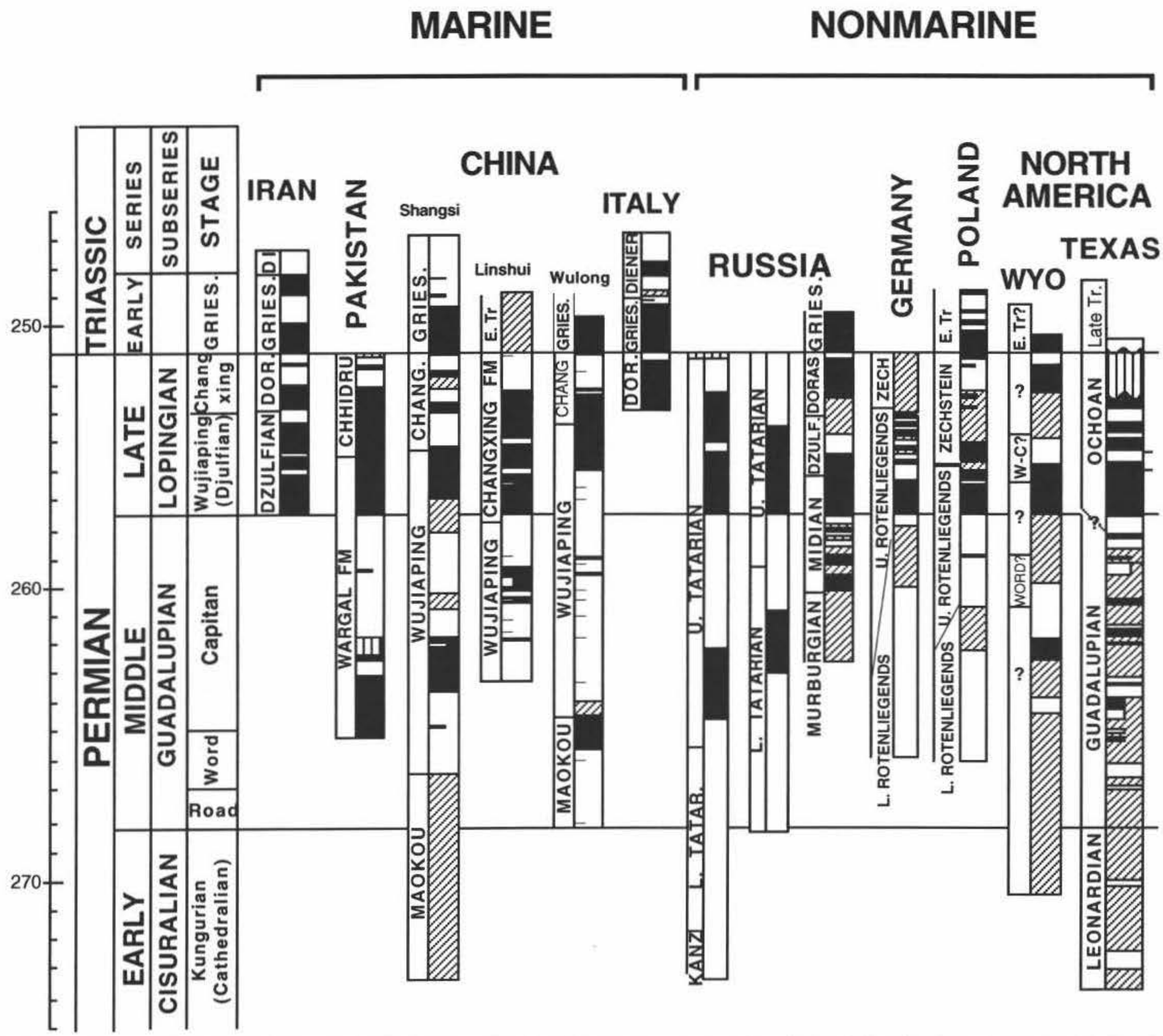

FIGURE 9b. All sequences have been adjusted in length such that their polarity sequences approximately match that of the Iranian sequence, considered to be the most representative (see text).

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