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EXTENSIVE ICHNOFOSSIL ASSEMBLAGE AT THE BASE OF THE PERMIAN ABO FORMATION, CARRIZO ARROYO, NEW MEXICO

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Abstract.— The Carrizo Arroyo section of central New Mexico exposes an ~100-m-thick section of intercalated clastic rocks and limestones of the Virgilian Red Tanks Member of the Bursum Formation immediately overlain by siliciclastic red beds of the Wolfcampian Abo Formation. New Mexico Museum of Natural History locality 5123 at the base of the Abo Formation contains an abundant but low diversity ichnofauna of the *Cruziana* ichnofacies that consists of two ichnogenera, *Palaeophycus* Hall, 1852 and *Protovirgularia* M'Coy, 1850. The fossiliferous interval is a 1.6-m-thick, multistoried, ripple-laminated sandstone interpreted as having been deposited on an estuarine sand flat. Two burrowed horizons are present in this sandstone: (1) at its base, immediately above estuarine shale, where the bedding plane bioturbation index is 40%; and (2) a surface 33 cm above its base, where burrow size is smaller, and the bioturbation index is 10% to 25%. The burrowed surfaces are extensive and can be traced on strike for at least three kilometers. We interpret them as a low diversity example of the *Cruziana* ichnofacies, indicative of a marginal marine estuary. Locality 5123 thus documents brackish water deposition at the base of the Abo Formation, and it suggests a locally conformable contact of the Abo with the underlying Red Tanks Member of the Bursum Formation.

INTRODUCTION

The ichnogenus *Palaeophycus* Hall ranges in age from Proterozoic to Holocene (Häntzschel, 1975) and is found in virtually all sedimentary facies (Pemberton and Frey, 1982). However, apart from one record of *Palaeophycus* from the Permian Cutler Group in the northwest part of the state (McDowell and Miller, 2001), there are no recorded occurrences from New Mexico. Here, we record an extensive and abundant occurrence of *Palaeophycus striatus* Hall from New Mexico Museum of Natural History (NMMNH) locality 5123 at the base of the Abo Formation (early Wolfcampian) in Carrizo Arroyo, central New Mexico (Fig. 1). A less common ichnospecies, *Palaeophycus alternatus* Pemberton and Frey, is also present, as is *Protovirgularia dichotoma* M'Coy, and it, too, has previously been unknown from New Mexico. Locality 5123 thus documents a low diversity occurrence of the *Cruziana* ichnofacies. This suggests brackish marine conditions at the onset of deposition of the Abo Formation at Carrizo Arroyo, best explained if the base of the Abo Formation is locally conformable on the Red Tanks Member of the Bursum Formation.

SITE DESCRIPTION

Carrizo Arroyo is located on the eastern edge of the Colorado Plateau, 50 km southwest of Albuquerque in central New Mexico (Fig. 1). An approximately 100-m thick section of intercalated clastic rocks and limestones exposed in Carrizo Arroyo is assigned to the Red Tanks Member of the Bursum Formation (Lucas and Krainer, 2002). Siliciclastic red beds of the Abo Formation overlie the Red Tanks Member at Carrizo Arroyo. Regionally, the Abo Formation is primarily of fluvial (freshwater) origin and is assigned a Wolfcampian age, largely due to interfingering with the Wolfcampian marine Hueco Group to the south (Cook et al., 1998).

NMMNH locality 5123 is in the basal 40 cm of the Abo Formation at UTM zone 13, 308643E, 3850200N, NAD 27 (Figs. 1-2). This burrowed horizon is extensive, and we were able to trace it at least three km south along the western wall of Carrizo Arroyo. The ichnofossils at NMMNH locality 5123 occur in an extensive, thin, tabular sandstone bed that has sharp contacts with underlying siltstone and overlying mudstone. The sandstone lacks rip-up clasts and its dominant bedform is ripple lamination. This bedform and the geometry of the bed suggest it represents nonchannelized surface overbank flow of sand that formed a

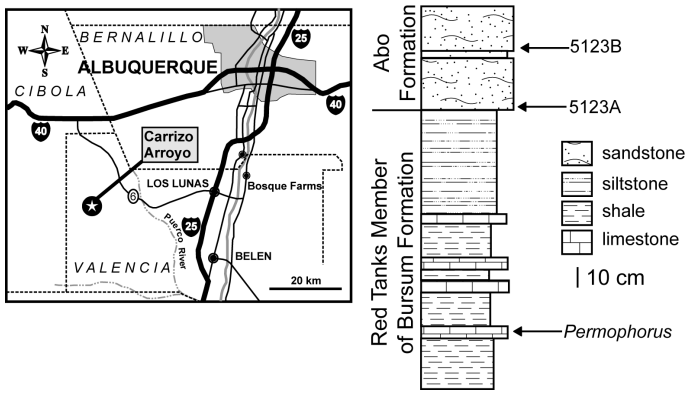

FIGURE 1. Index map showing location of Carrizo Arroyo and measured section at NMMNH locality 5123.

sandflat (cf. McKee et al., 1967; Williams, 1971; Harms et al., 1975; Turnbridge, 1981; Soegaard and Caldwell, 1990). A traditional interpretation of this sandflat would suggest it was freshwater, but the trace fossils reported here indicate the presence of brackish water. The burrowed sandstone at the base of the Abo Formation rests directly on estuarine siltstones and shales of the Red Tanks Member of the Bursum Formation (Figs. 1-2). Therefore, the trace fossils suggest a continuation of estuarine conditions across the Bursum-Abo boundary, which is most reasonably viewed as locally conformable.

At locality 5123, the burrows are in two horizons (Fig. 1). The lower horizon (5123A: Fig.1) is in the basal sandstone bed of the Abo Formation, which is 27 cm thick and has a sharp contact on underlying, grayish red micaceous siltstone at the top of the Red Tanks Member of the Bursum Formation (Figs. 1-2). The burrows (of *Palaeophycus striatus, P. alternatus* and *Protovirgularia dichotoma*) are preserved in convex hyporelief on the underside of this sandstone bed (Fig. 3A). The bedding plane bioturbation index (Miller and Smail, 1997) is 40%, and the burrows are of similar size, of uneven distribution and almost exclusively belong to *Palaeophycus striatus* (Fig. 3A)

A second burrowed horizon (5123B: Fig. 1), ~ 33 cm higher, is at the base of the next ripple-laminated sandstone of the Abo Formation (Fig. 1). This bed is ~ 26 cm thick and essentially identical to the lower

FIGURE 2. Ouctop view of NMMNH locality 5123.

burrowed sandstone. However, the bioturbation index of this upper horizon is much lower, only 10 to 25%, though *Palaeophycus striatus* still dominates the ichnofossil assemblage (Fig. 3B). Indeed, no other ichnotaxa other than *P. striatus* appeared to be preserved at this level.

SYSTEMATIC ICHNOLOGY

Ichnogenus *Palaeophycus* Hall, 1847

Palaeophycus striatus Hall, 1852

Fig. 3A-D

Referred specimens: Eleven slabs, NMMNH P-37902, 37903, 37904, 37905, 37906, 37907, 37908, 37909, 37913 (Fig. 3C), 37914, 37915, and 37925, each containing numerous specimens.

Description: The specimens are preserved in convex hyporelief. Burrow courses are straight to curved, with a maximum observed length of 130 mm. The orientation of the burrows to the bedding plane ranges from horizontal to oblique. There is no evidence of burrow collapse. Frequent crosscutting and interpenetration is seen between specimens. Systematic branching is absent, although successive branching occurs. The burrow walls exhibit essentially parallel, longitudinal striations. Linings are very thin where present. The burrow fill is identical to the surrounding matrix, with no evidence of the fill having been processed or sorted. Burrow diameters are cylindrical to elliptical and range from 4 to 19 mm.

Remarks: *Palaeophycus* has had a complex and confusing taxonomic history. A systematic review by Pemberton and Frey (1982) recognized five valid ichnospecies. They distinguished *Palaeophycus* from *Planolites* by the presence of wall linings and by *Palaeophycus* having a burrow fill identical to the surrounding matrix. *Palaeophycus striatus* was recognized as a thinly lined burrow sculpted by fine, continuous, parallel, longitudinal striae. Specimens from NMMNH locality 5123 are assigned to *Palaeophycus striatus* based on this emended diagnosis.

Palaeophycus represents passive sedimentation within open dwelling burrows (domichnia) constructed by a predaceous or suspension feeding animal (Pemberton and Frey, 1982). Osgood (1970) posited predaceous polychaetes as a modern analog of the tracemaker of *Palaeophycus*. The burrow wall sculpture of *P. striatus* is considered to be the result of interior scraping or digging by the bristles or setae of the vermiform tracemaker (Pemberton and Frey, 1982).

There have been several important publications about *Palaeophycus* following Pemberton and Frey's (1982) review (e.g., Fillion and Pickerill, 1990; Keighley and Pickerill, 1995; Buckman, 1995; Uchman, 1998). Most recently, Mángano et al. (2002) provided an overview of this ichnogenus and reported that *Palaeophycus* has been recorded from non-marine, marginal marine, shallow-marine, and deep marine settings, as well as from tidal-flats. The age of this ichnotaxon ranges from Proterozoic to Holocene.

Ichnogenus *Palaeophycus* Hall, 1847

Palaeophycus alternatus Pemberton and Frey, 1982

Fig. 3D

Referred specimens: Two slabs, NMMNH P-37926 (Fig. 3D) and 37927, containing two specimens.

Description: The specimens are preserved in convex hyporelief. Burrow courses are straight and mostly horizontal. There is no branching or burrow collapse. Linings are very thin where present. Each specimen preserves a section that is distinctly annulate and that alternates with longitudinal striae along the burrow length. There are three annulations per 10 mm. The burrow diameters are cylindrical, and range from 5 to 6 mm in diameter. There is a decrease in diameter where the annulations occur.

Remarks: Pemberton and Frey (1982) established the ichnospecies *Palaeophycus alternatus* for thinly lined burrows that are alternately striate and annulate. They argued that the change from predominantly striate to predominantly annulate parts of burrows results from a change from direct locomotory to peristaltic movements by the trace maker, so it is a significant and distinctive ethologic pattern. They found *P. alternatus* to be less common than other ichnospecies of *Palaeophycus*. This is consistent with the low abundance of this ichnospecies when compared to *P. striatus* at NMMNH locality 5123. We assign specimens to *Palaeophycus alternatus* based on Pemberton and Frey's original diagnosis.

Several authors subsequently described annulate material referred to *Palaeophycus*. Buckman (1995) erected a new ichnospecies, *Palaeophycus crenulatus,* for forms with distinct, axially continuous annulations and reviewed the position of annulate *Palaeophycus.* He considered previously described annulate ichnospecies of *Palaeophycus* (*P. annulatus* Badve; *P. anulatus* McCann and Pickerill; *P. serratus* McCann) to be *nomina dubia,* with the exception of *Palaeophycus alternatus.*

Ichnogenus *Protovirgularia* M'Coy, 1850

Protovirgularia dichotoma M'Coy, 1850

Fig. 3E-F

Referred specimens: Six slabs, NMMNH P-37910, 37911 (Fig. 3E), 37912, 37928, 37929 and 38967 (Fig. 3F), containing 24 specimens.

Description: The specimens are preserved in convex hyporelief. Traces are unbranched with mostly straight, horizontal courses. The maximum trace length is 55 mm; and the maximum trace width is 6 mm. A faint median furrow is intermittently present. Paired, bilaterally symmetrical chevron markings form V-angles of 90-110 degrees where optimally preserved. There are several traces that vary from a symmetrical chevron-type form and exhibit a plaited morphology. The maximum lateral chevron appendage length is 3 mm; and the maximum chevron appendage width is 1 mm. The chevron appendage spacing is typically 1 mm. There is no association of these trails with *Lockeia*-type structures.

Remarks: Han and Pickerill (1994) revised the ichnotaxonomy of *Protovirgularia*, reviewed several ichnospecies of *Protovirgularia* (*P. harknessi* Lapworth; *P. nereitarum* Richter; *P. mongruensis* Chiplonkar and Badve) and concluded that only the type, *Protovirgularia dichotoma* M'Coy, is valid. We assign specimens from NMMNH locality 5123 to *Protovirgularia dichotoma* based on Han and Pickerill's (1994) emended diagnosis, though subsequent authors have rejected the conclusion that *Protovirgularia* is monospecific (see below).

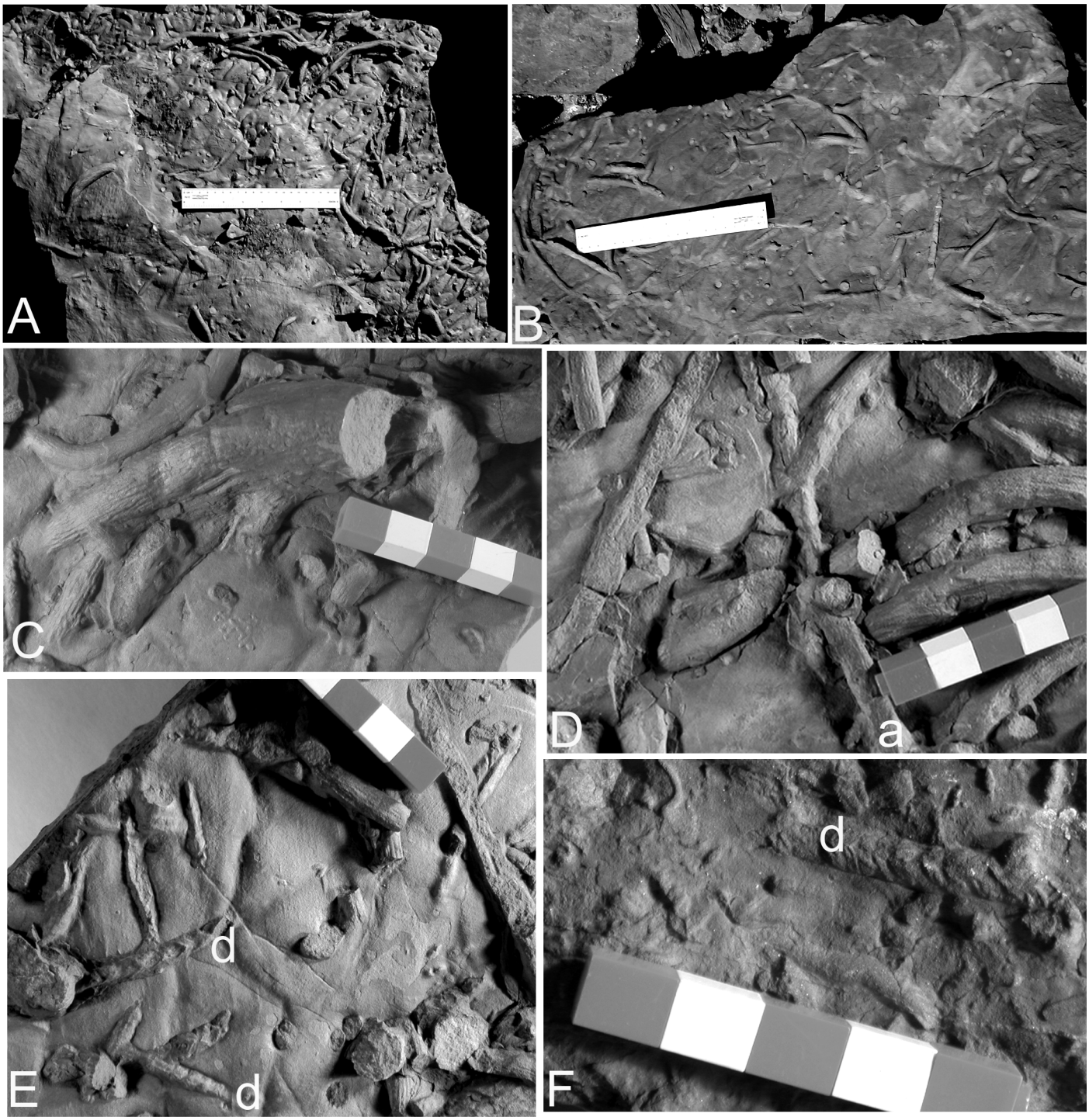

FIGURE 3. Selected ichnofossils from NMMNH locality 5123. **A,** Field photograph of intensively bioturbated slab from lower horizon, showing domination of bedding plane surface by *Paleophycus striatus*. Ruler scale in cm. **B,** Field photograph of less intensively bioturbated slab from upper horizon, showing domination of bedding plane surface by *Paleophycus striatus*. Ruler scale in cm. **C,** *Palaeophycus striatus*, NMMNH P-37913; broken burrow edge shows that burrow fill is same as lining. **D,** *Paleophycus alternatus*, NMMNH P-37926, indicated by "a," surrounded by specimens of *P. striatus*. **E,** *Protovirgularia dichotoma*, NMMNH P-37911, indicated by "d," among specimens of *P. striatus*. **F,** *Protovirgularia dichotoma*, NMMNH P-38967, indicated by "d," among specimens of *P. striatus*.

Ethologically, *Protovirgularia dichotoma* is a locomotion trace (repichnia). The most likely tracemakers are cleft-foot bivalves (Seilacher and Seilacher, 1994;Uchman, 1998; Mángano et al., 1998, 2002). Recently, Mángano et al. (2002) named a new ichnospecies, *Protovirgularia bidirectionalis,* for traces showing V-shaped markings oriented in opposite directions, and also provided a detailed overview of this ichnogenus. They reported that *Protovirgularia* has been recorded from deep-marine facies, shallow open-marine and marginal-marine facies, as well as from tidal-flat facies. Age ranges given are from Ordovician to Holocene. The record of *Protovirgularia* documented here is thus a strong indicator that deposition at NMMNH locality 5123 was not in a strictly freshwater habitat, but instead in a brackish water setting.

DISCUSSION

The trace fossil assemblage at the base of the Abo Formation in

Carrizo Arroyo is extremely unusual in its high degree of bioturbation and great lateral extent. Since its discovery, we have made an effort to locate similar assemblages in outcrops of the Abo Formation and its correlative, the Cutler Formation (Group), at various localities in New Mexico. Outcrops of the Abo/Cutler in the Joyita Hills (Socorro County), at Abo Pass (Valencia County) and in the Jemez Mountains (Sandoval County) do have many low density occurrences of *Palaeophycus*, particularly near the base of the Abo/Cutler. However, none of these occurrences remotely approaches the intense bioturbation and great lateral extent of NMMNH locality 5123. This locality is thus a unique trace fossil assemblage from the Lower Permian red beds of New Mexico.

We initially regarded the ichnofossil assemblage at NMMNH locality 5123 as freshwater. Miller et al. (2002) and Miller and Labandeira (2002) have pointed out that the infauna of Paleozoic stream and lake deposits is meager. Locality 5123, with a bedding plane bioturbation index of as much as 40%, would thus be an unusual record according to their analysis, as such a high degree of bioturbation is rare in late Paleozoic nonmarine rocks. There are good theoretical and empirical reasons to accept the premise that the invertebrate infauna did not fully invade terrestrial environments until the Mesozoic (Buatois and Mángano, 1993; Buatois et al., 1998). However, the discovery of sites such as locality 5123 might suggest that much more remains to be learned about nonmarine Paleozoic ichnofaunas, and that at least some of their apparent lack of abundance may be due to a lack of field study and discovery.

Much progress has been made recently in refining our understanding of nonmarine ichnofacies. Buatois and Mángano (1995) defined the *Mermia* ichnofacies as an association of nonmarine, fully aquatic trace fossils dominated by horizontal to subhorizontal feeding traces produced by mobile deposit feeders. Abundance is high, locomotion traces are absent and grazing patterns show a low degree of specialization. The *Mermia* ichnofacies is considered to be characteristic of fine-grained sediments in well-oxygenated, low energy, permanently subaqueous zones of lacustrine systems. If *Protovirgularia* could be made by a nonmarine bivalve, then Locality 5123 could represent a low diversity (impoverished) example of the *Mermia* ichnofacies. However, its occurrence in deposits of a fluvial sandflat would extend the *Mermia* ichnofacies into yet another lithofacies.

A more parsimonious interpretation of NMMNH locality 5123, first suggested to us by Luis Buatois (written commun., 2003), is that it is an example of a low diversity assemblage of the *Cruziana* ichnofacies. The *Cruziana* ichnofacies is a trace fossil association characteristic of soft-sediment habitats in the sublittoral (shallow subtidal) zone (Ekdale et al., 1984). Low diversity assemblages of the *Cruziana* ichnofacies are particularly characteristic of lagoonal and estuarine settings. *Protovirgularia* can be regarded as characteristic of the *Cruziana* ichnofacies (e.g., Mángano et al., 2002), though *Palaeophycus* has a much wider ichnofacial range.

Therefore, based on the presence of *Protovirgularia*, we assign NMMNH locality 5123 to the *Cruziana* ichnofacies. As noted above, this indicates brackish water deposition at the base of the Abo Formation, and it suggests a locally conformable contact of the Abo with the underlying Red Tanks Member of the Bursum Formation.

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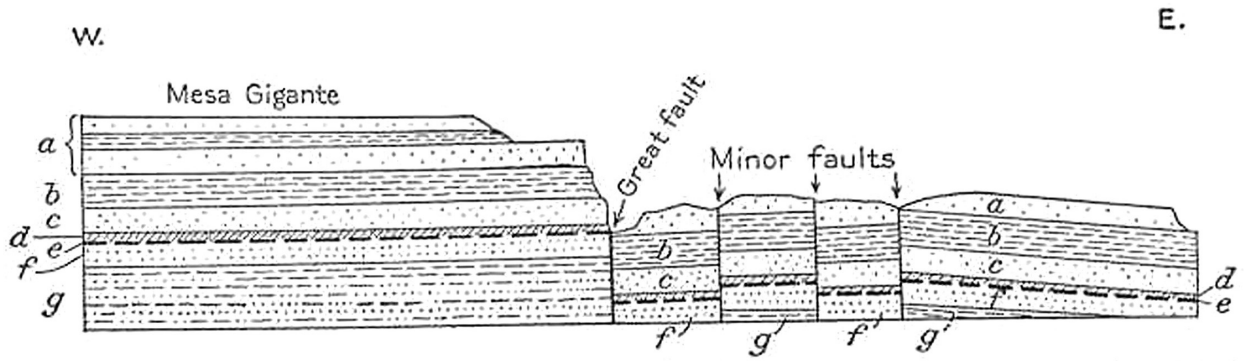

FIGURE 40.—Section north and east of Suwanee, looking north, showing relations of faults. *a*, Dakota (?) and overlying Cretaceous sandstone and shales; *b*, Morrison shale; *c*, Navajo sandstone with a lower red member; *d*, *e*, Todilto formation (gypsum on limestone); *f*, Wingate sandstone; *g*, Red shale and sandstone. The Mesa Gigante is projected south 4 miles or more

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