Geology

Comment and Reply on 'Reinterpretation of the depositional environment of the Yellowstone fossil forests' : COMMENT

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FORUM

Editor's Note: Geology *welcomes contributions to the Forum not exceeding four typed double-spaced pages.*

Comment and Reply on 'Tertiary tectonic denudation of a Mesozoic-early Tertiary(?) gneiss complex, Rawhide Mountains, western Arizona'

COMMENT

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In his excellent treatment of Tertiary denudation faulting in the Rawhide Mountains of Arizona, Shackelford (1980) concluded that (1) the autochthonous mylonitic gneisses reflect a tectonic event separate and older than that represented by the Rawhide (detachment) fault, and (2) denudation occurred through northeast-directed gravity gliding of upper-plate allochthonous rocks. Our Comment is based on observations made during several years of detailed mapping of upper-plate rocks in an area directly north of that mapped by Shackelford and extending toward the Colorado Plateau.

As mapped by Shackelford and by us, the Rawhide fault dips gently to the north and northeast in the direction of the Colorado Plateau, which is as close as 40 km. If the upper plate is an allochthon that has moved northeast, how does the plate—and the associated Rawhide fault—terminate in that direction? If one assumes that the Colorado Plateau is not allochthonous, then the Rawhide fault must end by shoaling, by offset along a transcurrent fault, or by decrease in displacement northeastward. We have searched for possible terminations of the upper plate and have found none. The Rawhide fault does not shoal upward. The Artillery fault, similar to other faults cutting upper-plate rocks, is not a continuation of the Rawhide fault. Upper-plate Tertiary rocks extend, in depositional contact, onto basement rocks of Colorado Plateau type northeast of the Aubrey lineament, which separates terranes that differ greatly in morphology, structure, and types of rocks present (Lucchitta and Suneson, 1979). The Sandtrap Wash fault, which Shackelford suggested might terminate the upper plate, is part of the lineament. Our mapping shows that displacement along this fault decreases rapidly northward, where the fault merges with a north-trending normal fault that bounds the McCracken Mountains on the east. We have found no evidence of strike-slip displacement.

These relations indicate that the upper plate cannot have moved northeastward by gravity gliding, as suggested by Shackelford (1980). Possible alternatives are few. We suggest the following model.

The areas mapped by Shackelford and by us are near the northeast edge of a terrane marked by metamorphic core complexes, extreme distension, and associated detachment faulting. Both metamorphism and faulting die out to the northeast, and the Rawhide fault terminates in that direction by decrease in displacement, feathering into many breaks, and changing into a zone of distributive shear.

The upper plate is anchored at its northeast end to autochthonous basement rocks of Colorado Plateau type. To the southwest, in the vicinity of the Rawhide Mountains, it has been stretched and attenuated by listric faulting, but, fundamentally, it is in place. Thus, it is autochthonous or nearly so. The lower, gneissic plate has moved southwestward, toward a culmination of the metamorphic-complex terrane, by nonbrittle underflow. Therefore, it is allochthonous. In such a tectonic regimen ("conveyor-belt tectonism" in our parlance), the upper plate merely goes along for the ride, being stretched and pulled apart in the process. Near the margins of the area affected by the process, this stretching is manifested mostly by brittle fracture (listric faults). In more central areas, where rock temperatures probably are more elevated, attenuation may occur by more ductile processes, as in the Big Maria Mountains (Hamilton, 1964).

The basal detachment fault (Rawhide fault) is a locus of stress concentration that is difficult to visualize as following preexisting structures, because it cuts the grain of such structures. We suspect that it is the locus of a change from brittle to nonbrittle deformation, as suggested by Armstrong and Dick (1974), associated at the time of deformation with a steep temperature gradient.

Although the model can accommodate Shackelford's interpretation that the formation of the mylonite gneiss was an early Tertiary event distinct from the late Tertiary detachment faulting, this interpretation does not explain the close spatial relation between the basal detachment fault and the gneiss, or the close coincidence in space of two kinematic events widely separated in time.

Another interpretation is that formation of the mylonite gneisses, movement on the Rawhide fault, volcanism, deposition of Tertiary rocks, and listric faulting in the upper plate all are products of the same tectonic disturbance and are nearly of the same age. This interpretation requires that the early Tertiary K-Ar ages on the gneiss result from incomplete expulsion of argon during metamorphism of a Precambrian protolith and thus are to be viewed as maximum ages.

We suggest that the area mapped by Shackelford and by us and containing the Rawhide fault and associated upper plate is at the northeastern margin of the tectonic disturbance. To the southwest, heating, metamorphism, structural disturbance, and uplift were much greater. Little beside lower-plate gneiss is present in that area today, but an indication of what once was there can be obtained from studying tectonic sheets that became interleaved with accumulating sediments of the upper plate. These sheets are gravity-glide blocks that came from the southwest. In places, they are stacked one on top of another, and collectively they form an inverted sequence consisting of greenschist facies metasedimentary and metavolcanic rocks at the base, then quartzite and marble, and finally sheared and biotite-rich granitic rocks at the top. They represent the carapace at the top of the gneiss complexes, removed by progressive unroofing of the complexes as they were being uplifted. The sheets formed in response to uplift. The Rawhide fault, in contrast, was formed by nonbrittle underflow that contributed to the uplift.

In summary, we suggest that the lower-plate mylonite gneiss and the Rawhide fault are two expressions of an intense Tertiary (Miocene) thermal and deformational event that included volcanism, extension, listric and detachment faulting, basin formation, and the emplacement of imbricate gravity-glide masses that slid northeastward from an uplifted metamorphic-complex terrane. This disturbance was restricted to the area southwest of the Colorado Plateau; thus, the degree of metamorphism, mylonitization, and displacement on the Rawhide fault decrease northeastward from the Rawhide Mountains. The origin of the Rawhide fault is not related to gravity gliding, as Shackelford (1980) suggested, but probably to nonbrittle underflow. However, both underflow and the gravity-glide emplacement of tectonic sheets within the upper plate are related to intumescence and distension of the area of the metamorphic core complexes.

REPLY

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Lucchitta and Suneson's detailed mapping in the area northeast of the Rawhide Mountains failed to find the termination of the Rawhide fault as would be predicted by a gravity slide model for the fault. Consequently, the large amount of upper-plate extension proposed for the Rawhide Mountains (Shackelford, 1976, 1980) is not readily obvious. I conducted reconnaissance investigations in the area mapped by Lucchitta and Suneson and recognized the problems of termination of the Rawhide fault raised by them (Shackelford, 1976). Some of the extension in the Rawhide Mountains may be accommodated by telescoping in the Rawhide Mountains and by slip along the Artillery fault (Davis and others, 1979; Shackelford, 1980; I agree with Lucchitta and Suneson that the Artillery fault is not a continuation of the Rawhide fault). However, as noted by me (Shackelford, 1976) and by Lucchitta and Suneson, there is no obvious termination of the Rawhide fault nor an easily recognizable means of accommodating the upper-plate extension in the Rawhide Mountains.

Lucchitta and Suneson (Comment above) propose two models for formation of the metamorphic and dislocational terrane in the Rawhide Mountains. Their models are similar to those of Davis (1977), Coney (1979), Davis and Coney (1979), and Rehrig and Reynolds (1980) for formation of the metamorphic core complexes in southern Arizona. Davis and others (1979, 1980) and Shackelford (1980) presented serious objections to these models on the basis of their studies in the Whipple-Buckskin-Rawhide terrane of southeastern California and western Arizona. In the Whipple-Bucksin-Rawhide terrane, field relations conclusively demonstrate that lower-plate mylonitic gneisses predate and were kinematically "dead" (cold, or at least cooling) at the onset of Miocene detachment faulting (see Davis and others, 1979, 1980, for a complete discussion). Clasts of mylonitic gneiss in the allochthonous Oligocene(?)–early Miocene Gene Canyon Formation have yielded a fission-track age (on sphere) of 83 m.y. (Dokka and Lindgrey, 1979). Lower-plate mylonitic gneisses consistently yield Late Cretaceous to early Tertiary Rb-Sr and K-Ar ages (Martin and others, 1980; Shackelford, 1980; G. A. Davis, 1980, personal commun.). A decrease in K-Ar ages upward toward the basal detachment fault has been noted in these mylonitic rocks (Martin and others, 1980). In the Whipple's lower plate, postmylonitization dike rocks yield K-Ar ages of 29 and 42 m.y. (G. A. Davis, 1980, personal commun.). The occurrence of northwest-striking, northeast-dipping listric normal faults in both plates indicates that the basal detachment fault (Rawhide and Whipple faults) is not the lower limit of brittle deformation during Miocene detachment faulting.

The data from the Whipple-Buckskin-Rawhide terrane thus unequivocally indicate that the development of lower-plate mylonitic gneisses is not kinematically related to younger, late Oligocene(?) to Miocene detachment faulting.

If one cannot call upon brittle distension of upper-plate rocks synchronous with ductile deformation of lower-plate rocks, how does one account for the observed upper-plate extension? Either gravity sliding has occurred (but termination of the slide complex is buried, has been eroded away, has not been recognized, and so forth) or some other mechanism (model) must be available to account for the observed phenomena. Lucchitta and Suneson raise serious constraints about a gravity-slide model for the Rawhide Mountains. However, I still believe that a gravity-slide model remains the most viable one available to account for the deformation in the Rawhide Mountains and associated terrane.

An outrageous hypothesis for formation of the Rawhide fault and associated upper-plate distension would be to suggest that the Rawhide fault underlies the area mapped by Lucchitta and Suneson *and* projects under the western Colorado Plateau. This would place all of the terrane from the Rawhides to the Colorado Plateau in the upper plate of the "slide" complex and account for Lucchitta and Suneson's failure to recognize the termination of the Rawhide fault. Upper-plate distension in the Whipple-Buckskin-Rawhide terrane was the result of relative northeastward movement of the Colorado Plateau above a master detachment surface, here represented by the Rawhide and Whipple faults. This hypothesis was first introduced to me by Brian Wernicke (March 1980, personal commun.) during a discussion on Tertiary detachment faulting. Such a model has profound geologic implications, and much more work would need to be done before one could seriously entertain such a hypothesis.

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Comment and Reply on 'Reinterpretation of the depositional environment of the Yellowstone fossil forests'

COMMENT

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In a recent study of the Eocene Lamar River Formation in Yellowstone National Park, Fritz (1980b) maintained that many of the horizons of petrified wood formerly regarded as fossil forests are accumulations of plant material transported down the flanks of volcanoes by mud flows and streams. His concept of the depositional environment of the Lamar River Formation appears to be well supported by the evidence of sedimentary structures, and many (especially horizontal and inclined) logs were obviously transported. It is also possible that tree stumps were transported and deposited in a vertical position. However, Fritz has not satisfactorily established what proportion (if any) of the numerous upright petrified stumps in the Lamar River Formation was transported and deposited in this way. As evidence that the horizons with vertical stumps are not paleosols, Fritz (1980b, p. 311) indicated that "no A, B, or C horizons can be distinguished, and the zones are very thin, are well laminated, have no decayed organic debris, and in places are draped over large boulders." These issues are all related to the degree of differentiation of the paleosols rather than to whether they were soils. A modern soil with the features described by Fritz would be regarded as immature and would be classified as an alluvial soil (in the classification of Stace and others, 1968) or an entisol (classification of Soil Survey Staff, 1975). Elsewhere, Fritz (1980b, p. 313) argued against interpreting the horizons of petrified stumps as paleosols because "no 'forest' or depositional layer exists that can be traced for any distance." This also is inconclusive evidence. Considering the likely hilly and gullied terrain of his depositional model, soils were probably eroded and truncated by streams, mud flows, and slumping. The real question is whether the vertical stumps are attached to extensive root systems in the rock below or whether their roots have been broken and waterworn before deposition. No evidence of this kind has been presented by Fritz. That upright petrified stumps in the Lamar River Formation were transported is thus a theoretical possibility not yet documented.

On the other hand, there are at least some cases of petrified tree stumps unquestionably in place—for example, the horizons at the 75- to 100-m interval on Specimen Ridge (Fritz, 1980a; 1980b, Fig. 1). I examined these horizons carefully during the summer of 1979 and found that these stumps are firmly attached to extensive root systems in paleosols that, compared to previous accounts, are surprisingly well differentiated. The profile with the large stump (identified as redwood by Dorf, 1964) is the best differentiated (Figs. 1, 2, 3). It has a clear A horizon of silicified, light-colored sandstone (an albic horizon, in the terminology of

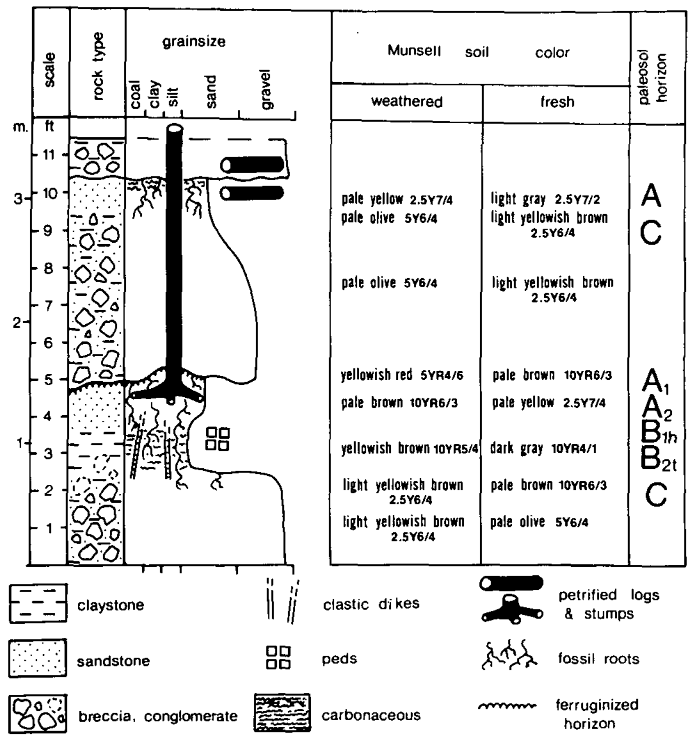

Figure 1. Well-differentiated paleosol, with large petrified tree stump in place, Eocene Lamar River Formation, Specimen Ridge (interval 90–94 m of Fritz, 1980b), northeastern Yellowstone National Park, Wyoming.

Figure 2. Large redwood stump in lower paleosol of Figure 1.

Figure 3. Paleosol horizons and redwood root in lower paleosol of Figure 1.

Soil Survey Staff, 1975). The B horizon is an erosion-resistant gray claystone (probably an argillic horizon) with characteristic soil-like structure (weak to moderate, very coarse, columnar peds) defined by sand-filled clastic dikes (silans in the sense of Brewer, 1964). The C horizon is the upper part of a mud-flow deposit, which appears more weathered than the lower part or other comparable units in the same outcrop. These horizons are all more or less gradational, and there are no abrupt discontinuities in the profile. The A_2 horizon is conspicuously thickened near the large petrified stump, as in basket podzols of modern soils (discussed by Buol and others, 1973, p. 142). Petrographic and geochemical data are needed before this paleosol can be accurately identified within a modern soil taxonomy.

Paleosols of the Lamar River Formation should be studied further because they will probably reveal much about the nature of Eocene vegetation and its location relative to sedimentary environments, about depth to water table, about water chemistry, about paleoclimate, and about rates of subsidence and uplift. Such studies may also provide conclusive answers to the main problem addressed by Fritz, the mixed climatic indications of fossil plants in the Lamar River Formation. Incorrect determinations, studies combining numerous different plant localities, or studies of single horizons of transported plant remains may all contribute to the mixed appearance of a fossil flora. Whether the "temperate" and "tropical" elements grew in mixed forests or in discrete communities or whether these fossil plants had the same ecological tolerances as their modern relatives is still to be determined, by studies of plant remains in place in as many well-differentiated fossil soils as can be found. Fritz and Fisk (1978, 1979) have made an admirable start in this direction by mapping and identifying fossil woods from a single level. It is hoped that future studies will also document the relationship between upright stumps and the underlying rock and the nature of likely fossil soils.

REPLY

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Retallack's interpretation of a paleosol on Specimen Ridge supports my depositional model for the Lamar River Formation and, if correct, adds valuable information toward a plausible understanding of the "fossil forests." One purpose of my work was to provide a stratigraphic base (Fritz, 1980a) to tie observations by workers like Retallack. Even though none of the organic zones I observed are unquestionably paleosols, I would expect discontinuous eroded soil horizons to occur in the Lamar River Formation. These paleosols should be most numerous and best developed in sections representing depositional lowlands where mud flows occurred sporadically. Specimen Ridge is such a section, and, like Retallack, I interpret the large trees at the 75- to 100-m interval (Fritz, 1980a; 1980b, Fig. 1; Retallack, Comment above, Fig. 2) to have been preserved where they grew (Fritz, 1980c, p. 15).

Caution should be used, however, in interpreting the organic zones as paleosols. Jensen (1931, p. 46), after examining the identical interval shown in Retallack's Figure 1, stated categorically that "the soil in which the trees grew is never preserved." Petrographic and geochemical studies, along with analyses of the clay mineralogy, are needed to confirm Retallack's paleosol identification. Retallack (Comment above, Fig. 1) bases his argument largely on color change and never indicates if the claystone designation in layer B refers to particle size or mineralogy or the type of clay, or if the clays are authigenic or depositional—all crucial questions for a paleosol designation. Rootlets like those shown in Retallack's Figure 3 do not provide critical evidence of a soil. I observed transported stymps with many small roots and associated organic debris in the mud flows of Mount

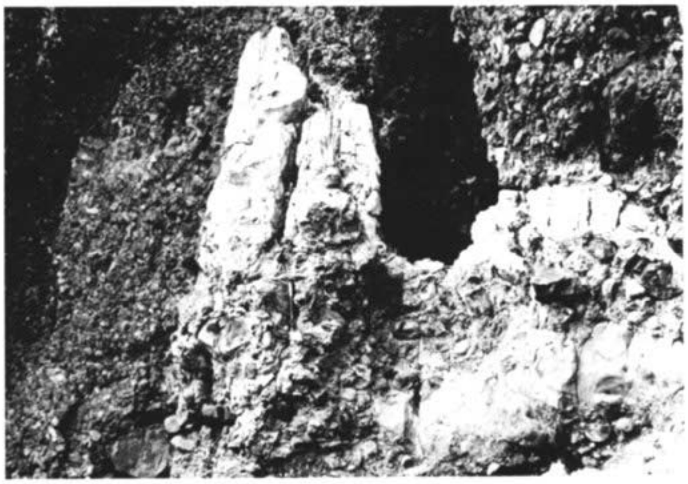

Figure 1. Upright transported stump with wide root system and short broken trunk, in Mount Hornaday section. Note absence of organic zone or weathering profile in entombing conglomerate.

Figure 2. Thinly laminated unweathered organic zone (outlined by arrows) draped over a large boulder on Amethyst Mountain.

St. Helens, an extant geologic environment directly comparable to the Yellowstone "fossil forests" (Fritz, 1980d). After burial these accumulations might be impossible to distinguish from immature soils. Therefore, until Retallack provides additional evidence, I believe the term "organic zone" most accurately describes organic concentrations in the Lamar River Formation.

Tall upright trees with unbroken trunks, narrow root systems, and intact roots penetrating the substrate were apparently preserved where they grew (Fritz, 1980c, p. 15, 68–71). Unlike the tall in situ trees, many upright stumps have short trunks and roots broken prior to burial in a conglomerate with no organic zone, weathering profile, or color change (Fig. 1 here; Fritz, 1980b, p. 312; 1980c, p. 15). The bark of these trees is rarely preserved, owing to abrasion by stream and mud-flow transport. Mount St. Helens mud flows transported similar upright stumps (Fritz, 1980d). It is thus likely that broken trees in the Lamar River Formation were transported and deposited upright in an analogous Eocene environment produced by Absaroka volcanic vents. Additional work is certainly needed to better document the percentage of transported stumps on each of the measured sections. However, preliminary data suggest that sections far from source areas have many in situ trees, whereas transported stumps and logs predominate in sections near a source (Fritz, 1980c). I would thus expect paleosols to be absent or poorly developed in sections near a source and best developed in the depositional lowlands. Figure 2 shows such a thin organic zone that, unlike the one described by Retallack, is probably not a paleosol.

My statement that "no 'forest' or depositional layer exists that can be traced for any distance" did not argue against interpreting the horizons as paleosols, as Retallack suggests. Instead, I was arguing that these layers do not represent true forests because they are a composite of upright, horizontal, and diagonal transported and in situ trees from several ecological habitats preserved in a complex alluvial environment. Even if paleosols exist in this type of assemblage, I believe the term "forests" gives a wrong impression of the depositional environment.

Although paleobotanical problems still exist in the Lamar River Formation, mixtures of temperate and tropical plant fossils have been well established at individual stratigraphic horizons by study of pollen, wood, and leaves (Fisk, 1976; Fritz, 1977; Aguirre, 1980). I hope this exchange will stimulate further investigations of the impressive Yellowstone fossil-wood deposits.

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