A Laramide age push-up block: The structures and formation of the Terlingua-Solitario structural block, Big Bend region, Texas: Discussion and reply

Discussion

CHARLES E. CORRY *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543*
JAMES B. STEVENS *Department of Geology, Lamar University, Beaumont, Texas 77710*
EUGENE HERRIN *Department of Geological Sciences, Southern Methodist University, Dallas, Texas 75222*

Erdlac (1990) has argued that the Terlingua-Solitario uplift represents a Laramide age "push-up" block. We would like to call attention to some weaknesses and inaccuracies in his paper pertaining to the rocks, timing, and structural evolution of the Terlingua-Solitario block based on our work in the area.

STRATIGRAPHIC PROBLEMS

The first problem we encounter in his paper is with his stratigraphic section (his Fig. 2). The figure is not attributed but, judging from the rock types illustrated and the thickness figures used, it appears to be based on any of Maxwell's publications from 1965 through 1972 (Maxwell and Dietrich, 1965, 1972; Maxwell and others, 1967; Maxwell, 1968) rather than original research on Erdlac's part.

Erdlac's Figure 2 is fundamental to the paper because of a lack of stratigraphic discussion in the text. Thus it is not possible to distinguish categories of stratigraphic units from his discussion; namely, (1) whether they are present in surface exposures, (2) whether they are present in the subsurface judging from regional relations, or (3) whether they are not present in the Terlingua and Solitario uplifts but are important to his story because of their regional distribution and relations. His section headed "Stratigraphic Setting" is almost entirely an opportunity to refer to his Figure 2, and that figure is not a useful guide to the first two categories given above.

We object to his use of the phrase "lower Tornillo (Javelina) Formations" (Erdlac, 1990, p. 1065). The Javelina Formation was established as the basal formation in the Tornillo Group by Maxwell and others (1967), and that usage has been widely accepted. Use of the term "Jeff Conglomerate" is also objectionable. Eifler's (1951) definition of the unit is acceptable for the Barrilla Mountains, but the name cannot be applied casually 140 km to the south, across major structural boundaries (Stevens and others, 1984; Stevens and Stevens, 1990).

Another problem concerns Erdlac's (1990, p. 1065–1067) brief discussion of the Chisos Formation and associated units at the Fresno Mine, and in the laccocaldera (a term defined by Henry and others, 1989) at Black Mesa, located on top of the Terlingua structure. Erdlac appears to view the Chisos Formation as having a stratigraphic simplicity comparable to the Buda Formation. In fact, the Chisos Formation is a complex unit consisting of five formally named members (Maxwell and others, 1967), and two informally named members (Stevens, 1969; Runkel, 1990), the whole aggregating to 323 m (east end, Lajitas Mesa; Maxwell and Dietrich, 1970) or 790 m (southwestern flank, Chisos Mountains; Maxwell and others, 1967) and deposited over a period of about 13–14 m.y. Identification of individual Chisos units is important to understanding the timing of uplift in the Terlingua area, and the discussion that Erdlac provides is inadequate for that task.

Erdlac claims that the structure we see today was uplifted by 50 Ma, the date he stated that the Laramide orogeny ended in this region (p. 1075). According to him, erosion had stripped the, by then, uplifted block to Santa Elena level by Devil's Graveyard time (p. 1073 and 1075), because he claims the uplift provided source material to the Devil's Graveyard basal conglomerate. Compositionally, as Erdlac (1990, p. 1065) correctly pointed out, these beds are probably derived from various Comanchean formations, although some of the pebbles and cobbles in the Junction facies of the basal Tertiary conglomerate of the Devil's Graveyard Formation may be Permian limestone, because they contain poorly preserved possible fusulinids. There is no material in the Devil's Graveyard Formation, however, that any sedimentologist or stratigrapher working with these units has ever suggested as being probably or possibly derived from the Terlingua uplift. The textures of the conglomerates and paleoflow indicators found in rocks of all kinds in the formation, particularly when considered together and geographically, are inconsistent with derivation from the Terlingua uplift. Conversely, the Chihuahua tectonic belt to the west remains a distinct possibility as a source for this unit, and it certainly has all of the upper Comanchean rock types exposed (Stevens, 1969; Stevens and others, 1984; Rigsby, 1986; Stevens and Stevens, 1990; Runkel, 1990).

McKnight (1970, p. 6) suggested that both the Terlingua uplift and Solitario dome were high by the time the basal conglomerate of the Devil's Graveyard Formation was deposited, and that the uplifts served as a source for the conglomerate. Stevens and others (1984), however, reported a K/Ar age of 46 Ma for a tuff in the variegated

The article discussed appeared in the *Bulletin*, v. 102, p. 1065–1076.

Geological Society of America Bulletin, v. 106, p. 553–559, 1 fig., April 1994.

beds that overlie the basal conglomerate on the northeast flank of the 38 Ma Solitario dome (Corry and others, 1990) in the type area of the Devil's Graveyard Formation. South of Hen Egg Mountain (east of the Terlingua uplift), and near the mouth of Contrabando Creek and at South Lajitas Mesa (west of the south end of the Terlingua uplift), Alamo Creek Basalt (47 Ma; Henry and others, 1986; Henry and McDowell, 1986; Price and Henry, 1988), or flows of the same age, are present in Devil's Graveyard Formation deposits. The basal Tertiary conglomerate is thus clearly older than the well-dated Solitario dome. Flow directions to the northwest in Fresno Canyon on the west flank of the uplift also suggest that the Terlingua structure was not the source for the conglomerate as Erdlac claims.

A significant part of Erdlac's argument for a Laramide contractile origin depends on understanding of the third stratigraphic category, regional relationships, particularly the absence of Black Peaks, Hannold Hill, and Canoe Formations from the Terlingua and Solitario uplifts through nondeposition, or erosion. Surprisingly, in early Tertiary time, he placed both Hannold Hill and Canoe Formations in his stratigraphic section. On the contrary, the absence of these Paleocene and early Eocene beds has previously been taken as evidence that the area was elevated during that time interval (Lehman, 1986; Corry and others, 1990). Deposition of Black Peaks and Hannold Hill Formations (the informal Star Creek allogroup; Stevens and Stevens, 1990, p. 86–90, their Figs. 2 and 9) in the area now occupied by the Terlingua uplift-Solitario dome complex, however, may still be open to question. Recent work that bears directly on this situation is that of Lehman (1985a, 1985b) and Runkel (1988, 1990), who are not referenced by Erdlac.

In the area covered by Erdlac's study, we know of no outcrops older than Santa Elena Limestone (late Albian), and he does not substantiate his stratigraphic interpretation with subsurface information such as the recent study of Sandidge-Bodoh (1989). Lithostratigraphic and lithologic descriptions of the Lower Cretaceous rocks in Erdlac's paper appear to be based on exposures in the Sierra Del Carmen, 80 km or more distant from the Terlingua uplift on the southeastern boundary of Big Bend National Park. Thicknesses for the probable subsurface units might thus have more appropriately come from DeCamp (1981), Yates and Thompson (1959), Maxwell and Dietrich (1965, Fig. 41, p. 133), or Corry and others (1990).

Much older rocks do crop out in the Solitario (Corry and others, 1990), but we have not located Maxon Sandstone there despite excellent exposures, and Erdlac does not reference that study. The Maxon Sandstone, whose distribution and stratigraphy were summarized by McBride (1987), and listed by Erdlac in his Figure 2, does not crop out in the Sierra Del Carmen, at least in the United States, and it is not suspected anywhere in or near the Terlingua area. Maxwell and others (1967), working in a large area much closer to the Marathon uplift, included the Maxon Sandstone in stratigraphic columns explicitly for the sake of regional completeness. DeCamp (1981, 1985) provided more recent and useful lithologic descriptions of the Lower Cretaceous rocks from Santa Elena Canyon, at most about 15 km south of Erdlac's study area and much less severely deformed than areas of best exposure in the Terlingua uplift (Stevens, 1988), but Decamp is not cited on this subject.

STRUCTURAL PROBLEMS

The inconsistencies in Erdlac's stratigraphy may help to explain why Yates and Thompson (1959) found 980 m of structural relief, but Erdlac finds only a maximum of 457 m. On the northwest end, where the Terlingua uplift merges with the Solitario dome, Corry and others (1990) found ~500 m of structural relief. Erdlac, however, found only 244 m (p. 1067) at the Fresno Mine thrust fault and less to the north toward the Solitario. Thus, he described only about one-half of the structural relief found by other workers, but he did not attempt to explain why or how he obtained these low values.

Erdlac stated that two models have been proposed for the origin of the Terlingua uplift, but he summarily dismissed the laccolith model. In fact, modern workers, to whom he makes no reference (Corry and others, 1990; Sandidge-Bodoh, 1989; Mosconi, 1984; Stout, 1979) with regard to the origin, have universally regarded the structure as seen today as a laccolithic intrusion. Conversely, Maxwell and others (1967, p. 283), while working mainly in Big Bend National Park to the southeast, recognized that the Terlingua-Solitario area was first elevated during the Laramide orogeny, as noted earlier by Baker (1934). About the most that can be said about Maxwell's "model" is that Maxwell (in Maxwell and others, 1967) did refer to the Terlingua Uplift as a Laramide structure, and that, as an inference from other parts of their publication, contraction would be involved in the formation of Laramide structures. Maxwell probably had a model in mind for the Laramide orogeny as a very general concept, but he certainly did not describe the model. In point of fact, Maxwell said almost nothing at all about the Terlingua uplift, and not much about the Laramide orogeny.

Biddle and Christie-Blick (1985, p. 380–381) defined *push-up* as "a block elevated by crustal shortening at a restraining bend or restraining overstep along a strike-slip fault zone." As we were unfamiliar with the term, it would have been useful for Erdlac to have included that definition.

Erdlac clearly divided the tectonics of the area into pre-Solitario (>38 Ma) and post-Solitario. In his pre-Solitario model, he extended the Fresno monocline through the site of the future Solitario. There is no evidence that the radially symmetric Solitario had any pre-existing structure along its western, or any other, flank. It seems unlikely that a radially symmetric laccolith the size of the Solitario had any sizeable structures nearby at the time it was formed (Corry and others, 1990). Any significant pre-existing crustal break (deep, or comparatively shallow), through, or even close to the Solitario would have caused significant departure from the near-perfect symmetry of the Solitario. Without convincing evidence for such pre-Solitario structure, it is difficult to envision how the Terlingua-Solitario uplift fits the definition of a push-up block. Thus, there is little to suggest that the present Terlingua-Solitario uplift originated during the Laramide orogeny, and a good deal of evidence that it is much younger.

The formation of the Terlingua uplift as a broad, gentle (dips of 10° or less) fold during the Laramide, as postulated by Baker (1934) (probably toward the end of Bridgerian [lower Eocene] time), is accepted. The difference we have with Erdlac is that the evidence we have seen and collected strongly suggests that the steep, topographically youthful structure seen today is younger than Laramide, probably early Oligocene (34 to 36 Ma).

Consider the following arguments.

His Figures 3 and 7 both clearly show what he claims is a Laramide age (>50 Ma by his definition) feature on top of the Terlingua uplift, the Lowes Valley graben, cutting the Black Mesa laccolith that is 34.5 Ma (p. 1073). The crosscutting is clearly evident on the ground, and we agree with his field mapping but wonder how the crosscutting graben can be interpreted as older than the feature it cuts?

Yates and Thompson (1959, p. 34) stated that the Lowes Valley graben must have formed at the same time or later than the Black

Mesa dome, which directly contradicts Erdlac's thesis. Erdlac does provide some weak, and partially based on hearsay, evidence (p. 1073) that Black Mesa may have vented a tuff to the northwest into the graben; however, he presents no evidence that the tuff and the dome are the same age. Younger, intrusive rhyolite and montmorillonized, tuffaceous, laharic sediments cut or rest on an older megabreccia (Stevens and Stevens, 1990). The younger rocks may be related to the formation of the dome, or more precisely, to the magmatic episode that formed both the dome and the laccocaldera, and provide the 34.5 Ma date noted by Erdlac. This age approximates the Eocene-Oligocene boundary and is not significantly different from the 34 Ma age produced by analyses of the Mule Ear Spring Tuff Member of the Chisos Formation. "Lowes Valley graben" is thus a complex of at least two generations of features (probably three). Erdlac's hypothesis would require a third (fourth) generation, but he does not give attention to the idea of even two stages of development. On the other hand, the set of intrusive-extrusive-volcaniclastic rocks in the northern and northwestern part of Black Mesa that provide the 34.5 Ma age determination he references probably are directly related to formation of the dome.

There are volcanic and volcanogenic units of two, as a minimum, ages in the laccocaldera at Black Mesa. Large blocks of older, zeolitized volcaniclastic strata lie in various attitudes (including vertical) as parts of the megabreccia created by the explosion. It seems improbable that incompetent, volcaniclastic sediments included in the megabreccia would have persisted throughout the Eocene unprotected on top of the uplift as Erdlac's hypothesis would require. Noting that the same reasoning applies to Upper Cretaceous rocks found in the megabreccia, Stevens and Stevens (1985, 1986, 1990) not only supported the conclusions of Yates and Thompson (1959) about relative ages of the dome and graben, but they also suggested that no strongly positive structural feature (uplift) existed in the area of Black Mesa until approximately the time of formation of this dome.

Erdlac's stress analysis of presumed Laramide compression is based on stylolites. Although elementary statistics tell us that correlation does not imply causation, he has relied heavily on the orientation (N60°E) of the stylolites coinciding with Laramide directions measured elsewhere to infer that the stylolites he measured are Laramide age also. He also showed, however, a trajectory change along the structure to N34°E and elsewhere to N45°W. There are tectonic stylolites that cut across the layering of the rock and could not have been load-induced in flat-lying rocks, nor load-induced in the current attitude of the rocks. It seems obvious that not all of these stylolites could be the result of Laramide contraction. How then do we sort out the age of these features? What evidence is there that the stylolites represent only Laramide shortening, rather than some other event, or combination of events before, during, or after the Laramide orogeny? Tectonic events in this structurally complex area that could easily have formed post-Laramide stylolites include laccolithic intrusion, the mercury mineralization event, and basin-and-range faulting. Erdlac said that the explanation for the rotation in orientation of the stylolites is to be published in a later paper. In our opinion, his present study should not have proceeded until these fundamental questions were answered. It is also reasonable to ask what evidence is there that the stylolites are, in fact, tectonic in origin and, if tectonic, how and why should such stylolites form in a "push-up" block?

A more conventional stress analysis might be based on the many fractures in the area. There are extensive fracture systems (Stout, 1979; Sandidge-Bodoh, 1989), both filled and unfilled (Erdlac, 1988). Sandidge-Bodoh (1989) did a fracture study near Lajitas on the Terlingua uplift, and her analysis shows an orthogonal pattern oriented north-northwest and east-northeast (her Fig. 5.3f). Orthogonal fracture patterns are not generally taken to be caused by contraction but are frequently associated with extension during uplift as, for example, on the roof of a laccolith.

Corry (1972) and Bagstad (1981) found no significant Laramide folding in the adjacent Solitario. It is difficult to reconcile the apparent absence of Laramide deformation in such a closely related structure as the Solitario with extensive, regional shortening as Erdlac claims for the Terlingua uplift. Furthermore, the boundary for the northeastern extent of Laramide deformation given by Henry and Price (1985) is drawn southwest of the Terlingua uplift. The close structural relationship between the Solitario and the Terlingua uplift is mentioned by Erdlac (title and see p. 1065 and 1067) but never examined (see field area in his Fig. 1 and statement on his p. 1067). If these spatially related structures are to be divorced in time, we believe that Erdlac should have provided a clear statement of the reasons for doing so.

Erdlac painted a picture of strike-slip with both sinistral and dextral movement at different times, oblique slip, and thrust faulting. It is generally accepted that sinistral and strike-slip displacement occurred along such faults as Chalk Draw to the north during the Laramide orogeny. Erdlac assumed but did not demonstrate the same relationship in his area. The failure to clearly demonstrate such a relationship greatly weakens his arguments for such features.

Age of the Uplift

The age of the Terlingua uplift is constrained by the following relationships. Yates and Thompson (1959, p. 54) concluded that the mercury mineralization postdates the formation of the uplift, the graben faulting, and the extrusion and intrusion of igneous rocks. Furthermore, because the mercury mineralization is primarily in rocks within 3 m above to 15 m below the Del Rio–Santa Elena contact, the Del Rio Clay must have acted as a mineral trap. Therefore, the Del Rio Clay, and a protective cover of Buda Limestone and at least Boquillas, must have been uneroded at the time of mineralization. Furthermore, because the mineralization postdates the intrusions mapped by Yates and Thompson (1959), the Del Rio and Buda could not have been eroded at the time these intrusions were emplaced. Isotopic ages for these intrusions are given by Henry and others (1986), Henry and McDowell (1986), and Henry and others (1989), and range from 34 to 43 Ma. The mineralization must then be *younger* than the youngest of these intrusions, Black Mesa, which Erdlac quotes as 34.5 Ma. Field relations (for example, see Yates and Thompson, 1959), however, clearly demonstrate that the Del Rio and Buda were deeply eroded by the end of the Chisos time (34 Ma). The field relations and isotopic ages thus require that the uplift be relatively uneroded at 35 to 34 Ma, while the mineralization was being trapped in the Del Rio Clay, and then eroded to approach the present level by 34 Ma when the uplift was largely stripped of Boquillas Formation, Buda Limestone, and Del Rio Clay, and the exposed Santa Elena Limestone was covered with Chisos Formation. Thus, the uplift is inferred to be young at 35 Ma because it is uneroded at that time, and Corry and others (1990, p. 95) concluded that, as a reasonable estimate, the Terlingua uplift is 2 to 4 m.y. younger than the Solitario. Erdlac (1990, p. 1076), however, concluded that the uplift was stripped to the top of the Santa Elena at ca. 50 Ma, which is clearly inconsistent with the age relations stated above.

Alternatively, the uplift could have occurred during the Laramide orogeny and remained uneroded for ~20 m.y. Corry and others (1990), however, present evidence that the adjoining Solitario, formed 38 Ma, was eroded to its present level within 1 m.y. If the Terlingua uplift we see today is Laramide, as Erdlac postulated, then it would have had to have stood uneroded for about 20 m.y., and then within 1 m.y. (time of emplacement of igneous intrusions till time of mineralization) eroded to its present level before being covered by Chisos Formation. Erdlac presented no evidence that would support a long history of an uneroded structure. Indeed, he claimed the opposite, that the feature was quickly eroded after uplift. That is clearly inconsistent with the igneous and mineralization relationships described above.

Based on the relationships between mineralization, igneous emplacement, and erosion (summarized here), the most reasonable age estimate for the uplift is 34 to 36 Ma, or 2 to 4 m.y. younger than the Solitario.

SUMMARY

We find no sound basis for any of Erdlac's conclusions, because the data he did present are inadequately explained or integrated with other available data; he has ignored the relevant work of others in the area; and he apparently failed to cite sources for his stratigraphic section. Additionally, the stratigraphic section he did present is not representative of his study area. The preponderance of evidence, as summarized here, suggests that the Terlingua anticline formed by emplacement of an Oligocene age (34 to 36 Ma) trap-door laccolith, and that the Solitario was clearly formed by intrusion of a late Eocene (38 Ma) laccolith. Thus, the Terlingua-Solitario structural block that Erdlac (1990) discussed is most likely the result of two, or more, closely spaced intrusions of late Eocene–early Oligocene age and largely, or totally, unrelated to the Laramide orogeny or contractile tectonics as he claimed.

REFERENCES CITED

Bagstad, D. P., 1981, Structural analysis of folding of Paleozoic sequence, Solitario uplift, Trans-Pecos Texas [M.S. thesis]: Lubbock, Texas, Texas Tech University, 42 p.

Baker, C. L., 1934, Major structural features of Trans-Pecos Texas, *in* The geology of Texas, v. II; Structural and economic geology: Austin, Texas, University of Texas Bulletin 3401, p. 137–214.

Biddle, K. T., and Christie-Blick, N., 1985, Strike-slip deformation, basin formation, and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 37, 386 p.

Corry, C. E., 1972, The origin of the Solitario, Trans-Pecos Texas [M.S. thesis]: Salt Lake City, Utah, University of Utah, 151 p.

Corry, C. E., Herrin, E., McDowell, F. W., and Phillips, K. A., 1990, Geology of the Solitario, Trans-Pecos Texas: Geological Society of America Special Paper 250, 122 p.

DeCamp, D. W., 1981, Structural geology of Mesa de Anguila, Big Bend National Park, Trans-Pecos Texas [M.A. thesis]: Austin, Texas, The University of Texas at Austin, 185 p.

DeCamp, D. W., 1985, Structural geology of Mesa de Anguila, Big Bend National Park, Texas, *in* Dickerson, P. W., and Muehlberger, W. R., eds., Structures and tectonics of Trans-Pecos Texas: West Texas Geological Society, Publication 85-81, p. 127–135.

Eifler, G. K., Jr., 1951, Geology of the Barrilla Mountains, Texas: Geological Society of America Bulletin, v. 62, p. 339–353.

Erdlac, R. J., 1988, Structural development of the Terlingua uplift, Brewster and Presidio Counties, Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 403 p.

Erdlac, R. J., 1990, A Laramide push-up block, the structures and formation of the Terlingua-Solitario structural block, Big Bend region, Texas: Geological Society of America Bulletin, v. 102, p. 1065–1076.

Henry, C. D., and McDowell, F. W., 1986, Geochronology of magmatism in the Tertiary volcanic field, Trans-Pecos Texas, *in* Price, J. G., Henry, C. D., Parker, D. F., Jr., and Barker, D. S., eds., Igneous geology of Trans-Pecos Texas, field trip guidebook and research articles: Austin, Texas, The University of Texas, Mining and Mineral Resources Research Institute, Bureau of Economic Geology Guidebook No. 23, prepared for the 99th Annual Meeting, Geological Society of America, p. 99–122.

Henry, C. D., and Price, J. G., 1985, Summary of the tectonic development of Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Miscellaneous Map 36, with text, 8 p.

Henry, C. D., McDowell, F. W., Price, J. G., and Smyth, R. C., 1986, Compilation of potassium-argon ages of Tertiary igneous rocks, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 86-2, 34 p.

Henry, C. D., Price, J. G., and Miser, D. E., 1989, Geology and Tertiary igneous activity of the Hen Egg Mountain and Christmas Mountain quadrangles, Big Bend region, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations 183, 105 p.

Lehman, T. M., 1985a, Sedimentology, stratigraphy, and paleontology of Upper Cretaceous (Campanian-Maastrichtian) sedimentary rocks in Trans-Pecos Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 299 p.

Lehman, T. M., 1985b, Transgressive-regressive cycles and environments of coal deposition in Upper Cretaceous strata of Trans-Pecos Texas: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 431–438.

Lehman, T. M., 1986, Late Cretaceous sedimentation in Trans-Pecos Texas: West Texas Geological Society Bulletin, v. 25, no. 9, p. 4–9.

Maxwell, R. A., 1968, The Big Bend of the Rio Grande: The University of Texas at Austin, Bureau of Economic Geology, Guidebook 7, 138 p.

Maxwell, R. A., and Dietrich, J. W., 1965, Geology of the Big Bend area, Texas: West Texas Geological Society Field Trip Guidebook, Publication 65-51, 216 p.

Maxwell, R. A., and Dietrich, J. W., 1970, Correlation of Tertiary rock units, West Texas: Austin, University of Texas, Bureau of Economic Geology, Report of Investigations No. 70, 34 p.

Maxwell, R. A., and Dietrich, J. W., 1972, Geology of the Big Bend area, Texas, West Texas Geological Society Field Trip Guidebook, Publication 72-59, 248 p.

Maxwell, R. A., Lonsdale, J. T., Hazzard, R. T., and Wilson, J. A., 1967, Geology of Big Bend National Park, Brewster County, Texas: The University of Texas at Austin, Bureau of Economic Geology, Publication 6711, 320 p.

McBride, E. F., 1987, Diagenesis of the Maxon Sandstone (Early Cretaceous), Marathon region, Texas: A diagenetic quartzarenite: Journal of Sedimentary Petrology, v. 57, p. 98–107.

McCulloh, R. P., 1977, Geology of the Yellow Hill quadrangle, Brewster County, Texas [M.A. thesis]: Austin, Texas, The University of Texas at Austin, 126 p.

McKnight, J. F., 1970, Geologic map of Bofecillos Mountains area, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map 37, with text, 36 p.

Mosconi, L. S., 1984, Tectonic history of the Black Mesa–Lowes Valley area, Brewster County, Texas [M.S. thesis]: Nacogdoches, Texas, Stephen F. Austin State University, 72 p.

Price, J. G., and Henry, C. D., 1988, Dikes in Big Bend National Park; petrologic and tectonic significance, *in* Hayward, O. T., ed., Centennial field guide, Volume 4: Geological Society of America, South-Central Section, p. 435–440.

Rigsby, C. A., 1986, The Big Yellow Sandstone: A sandy braided stream, *in* Pause, P. H., and Spears, R. G., eds., Geology of the Big Bend area, and Solitario dome, Texas: West Texas Geological Society, Guidebook, Spring 1986 Field Trip, Publication 86-82, p. 111–115.

Runkel, A. W., 1988, Stratigraphy, sedimentation, and vertebrate paleontology of Eocene rocks in the Big Bend region of southwest Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 253 p.

Runkel, A. W., 1990, Stratigraphy and depositional history of Cretaceous and Paleogene rocks, Trans-Pecos Texas, *in* Dickerson, P. W., Stevens, M. S., and Stevens, J. B., eds., Geology of the Big Bend and Trans-Pecos Texas: South Texas Geological Society, Guidebook prepared for the 74th Annual Convention, American Association of Petroleum Geologists, p. 117–146.

Sandidge-Bodoh, V. L., 1989, Investigating the effects fracture systems have on seismic wave velocities at the Lajitas, Texas seismic station [M.S. thesis]: Dallas, Texas, Southern Methodist University, 161 p.

Stevens, J. B., 1969, Geology of the Castolon area, Big Bend National Park, Brewster County, Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 129 p.

Stevens, J. B., 1988, Basal Gulfian and Comanchean Section, Anguila fault zone and Santa Elena Canyon, Big Bend National Park, Trans-Pecos Texas, and Chihuahua, Mexico, *in* Geological Society of America Centennial field guide; South-Central Section, v. 4, p. 423–428.

Stevens, J. B., and Stevens, M. S., 1985, Basin and range deformation and depositional timing, Trans-Pecos Texas, *in* Dickerson, P. W., and Muehlberger, W. R., eds., Structure and tectonics of Trans-Pecos Texas: West Texas Geological Society, Field Conference Guidebook, Publication 85-81, p. 157–164.

Stevens, J. B., and Stevens, M. S., 1986, An outline of the Cenozoic geologic history of the area around Big Bend National Park, *in* Stevens, J. B., Roberts, D. C., and Stevens, M. S., Field seminar on the Big Bend, Trans-Pecos region, Texas: Houston Geological Society, Spring Field Trip Guidebook, 120 p., p. 45–73.

Stevens, J. B., and Stevens, M. S., 1990, Allostratigraphy and major structural-tectonic events along and near the Rio Grande, Trans-Pecos Texas and adjacent Chihuahua and Coahuila, Mexico, *in* Dickerson, P. W., Stevens, M. S., and Stevens, J. B., eds., Geology of the Big Bend and Trans-Pecos Texas: South Texas Geological Society, Guidebook prepared for the 74th Annual Convention, American Association of Petroleum Geologists, p. 73–116.

Stevens, J. B., Stevens, M. S., and Wilson, J. A., 1984, Devil's Graveyard Formation (new), Eocene and Oligocene age, Trans-Pecos Texas: The University of Texas at Austin, Texas Memorial Museum Bulletin 32, 21 p.

Stout, J. D., 1979, Structure and origin of Terlingua Uplift, Brewster and Presidio Counties, Texas [M.S. thesis]: Canyon, Texas, West Texas State University, 79 p.

Yates, R. G., and Thompson, G. A., 1959, Geology and quicksilver deposits of the Terlingua District, Texas: U.S. Geological Survey Professional Paper 312, 114 p.

MANUSCRIPT RECEIVED BY THE SOCIETY JUNE 15, 1993
MANUSCRIPT ACCEPTED NOVEMBER 2, 1993
WOODS HOLE OCEANOGRAPHIC INSTITUTION CONTRIBUTION NO. 8456

Reply

RICHARD J. ERDLAC, JR. *The University of Texas of the Permian Basin, 4901 E. University, Odessa, Texas 79762-0001*
CHRISTOPHER D. HENRY* *Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas 78713-7508*

Erdlac (1990) provided extensive data for the Terlingua uplift and bounding Fresno-Terlingua monoclines, demonstrating that they are Laramide structures as originally suggested by Baker (1934). Corry and others concede this Laramide origin, yet simultaneously dismiss the very geologic evidence that supports this origin and continue to argue that it is mostly a 36- to 34-m.y.-old laccolithic dome. Our discussion (Henry and others, 1994, this issue) of the Solitario (Corry and others, 1990) briefly addresses the Terlingua uplift, and we elaborate here.

STRATIGRAPHIC PROBLEMS

Corry and others take issue with the presentation and discussion of the stratigraphic section (Fig. 2) in Erdlac (1990). As more complete stratigraphic discussions can be found elsewhere, only those formations pertinent to the description of local structures were mentioned. Neither did Erdlac state this stratigraphic section to be his own work. In fact it is described as a "composite stratigraphic section" of the region. It was not possible to cite all of the references in the figure caption which included many more than cited by Corry and others.

Corry and others' objection to use of Jeff Conglomerate is really not to Erdlac (1990) but to the nearly universal use of this designation for the basal Tertiary conglomerate in Trans-Pecos Texas, including areas adjacent the Terlingua uplift (Eifler, 1951; DeFord, 1958; McKnight, 1970; Maxwell and Dietrich, 1970; Twiss, 1979). The report of Stevens and others (1984), who included the conglomerate in an overlying formation composed predominantly of tuffaceous sediments, is probably the only exception. More importantly, the Jeff Conglomerate clearly records erosion of Laramide highs largely before the onset of magmatism in Texas. What one calls it is irrelevant to its stratigraphic or tectonic significance.

Corry and others state that "Erdlac appears to view the Chisos Formation as having a stratigraphic simplicity comparable to the Buda Formation." Figure 2 of Erdlac (1990) shows all of the members, thicknesses, and age relations of the Chisos Formation that they mention and imply were inadequately treated. Erdlac's Figure 2 lacks only the informal members designated by Stevens (1969) in his dissertation, an unacceptable format for formal designation (North American Stratigraphic Code, 1983).

Corry and others stated that "the absence of these Paleocene and early Eocene beds has previously been taken as evidence that the area (that is, the Terlingua uplift) was elevated during that time interval," citing Lehman (1986) and Corry and others (1990). Structural relief of the Terlingua uplift at this time can only be a Laramide fold, not a laccolith, because the oldest Tertiary igneous activity in Trans-Pecos Texas is middle Eocene (47 Ma; Henry and McDowell, 1986) in age.

*Present address: Nevada Bureau of Mines and Geology, University of Nevada-Reno, Reno, Nevada 89557-0088.

STRUCTURE OF THE TERLINGUA UPLIFT

Corry and others apparently accept most of the data presented by Erdlac (1990) that demonstrate a Laramide origin for the Terlingua uplift and quibble over only the structural relief of the uplift, the significance of stylolites, and the age of uplift, especially relative to the Solitario. Interested readers should review Erdlac (1990) for the complete structural picture.

The geometry and structures of the Terlingua uplift are the keys to understanding it. The uplift is a structural high capped by flat-lying to gently dipping Cretaceous sedimentary rocks (Erdlac, 1988, 1990). It is bounded on the south and west by the steep (south to southwest dips up to 75°) Terlingua and Fresno monoclines. The Terlingua monocline continues eastward to the west side of Big Bend National Park, where it disappears beneath Quaternary deposits. Cretaceous rocks dip gently northeast off its northeast flank; however, there is no clear-cut northeastern margin. The uplifted area is at least 30 by 20 km. The Solitario is superposed upon the northwestern corner of the Terlingua uplift—hence the name, "Terlingua-Solitario structural block."

Structures along the Terlingua and Fresno monoclines demonstrate contraction across them. East-northeast–directed thrust faults, related to strike-slip and reverse movement on faults that core the monoclines, occur along both monoclines. The strike-slip and reverse faults, which are exposed in deep gorges that cut the Terlingua monocline, define small pull-apart structures along its crest. The Terlingua monocline consistently steps left where intersected by northeast-striking, strike-slip faults.

In discussing structural relief, Corry and others fail to distinguish relief across the entire uplift (reported by Yates and Thompson, 1959) from that across the bounding monocline (reported by Erdlac, 1990). Yates and Thompson found 580 m (measured from their cross section, although their text says 610 m), whereas Erdlac found 457 m at Reed Plateau, the only location where both reported data. These values aren't markedly different, and the newer one was determined from balanced cross sections. Relief of 500 m cited from Corry and others (1990) was measured across the Solitario, hardly the location to estimate relief of the Terlingua uplift.

The extensive field and theoretical work on the mechanisms of stylolite formation supports Erdlac's interpretation, rather than Corry and others, regarding their significance (Blake and Roy, 1949; Rigby, 1953; Arthaud and Mattauer, 1969; Fletcher and Pollard, 1981; Engelder and Geiser, 1984; Guzzetta, 1984). Corry and others' statement that tectonic stylolites on the Terlingua uplift "cut across the layering of the rock and could not have been load-induced in flat-lying rocks" contradicts widespread experience (Ramsay and Huber, 1983). As Ramsay and Huber (1983, p. 52) define transcurrent or tectonic stylolites as having formed "under tectonic stress situations and are probably initiated perpendicular to the maximum compressive tectonic stress," the tectonic stylolites across the Terlingua uplift formed under nearly horizontal load conditions immediately prior to uplift (Erdlac and Erdlac, 1992). Additionally, Corry and others suggest alter-

native events for tectonic stylolite formation (laccolithic intrusion, mercury mineralization, Basin and Range faulting) but do not describe how these events would have generated stylolites. Finally, Corry and others argue that the N60°E trend of stylolite teeth does not necessarily mean that they are Laramide in age. This orientation, however, agrees closely with other tectonic stylolite teeth trends in the Big Bend region interpreted as Laramide in age (DeCamp, 1985; Moustafa, 1988; Maler, 1990) and with the inferred Laramide stress field in the southern Cordillera (for example, Chapin and Cather, 1981).

Corry and others repeat an implied assumption of Corry and others (1990), that the east-northeast and north-northwest faults formed simultaneously during laccolithic uplift. The east-northeast faults, however, are dominantly strike-slip and formed during Laramide deformation. The north-northwest faults are Basin and Range normal faults formed no earlier than ca. 25 Ma. The north-northwest faults generally terminate against east-northeast faults, which indicates that the former are younger. Distinctive Miocene alkali basalts, widespread in Trans-Pecos and everywhere related to Basin and Range extension (Henry and Price, 1986; Henry and others, 1991), intruded along two north-northwest faults within the uplift (Erdlac, 1988; Henry and others, 1989; Fig. 1 of Henry and others, 1994). Contrary to Corry and others, who stated that Yates and Thompson (1959) concluded that mercury mineralization postdates graben faulting, Yates and Thompson recognized that mercury mineralization is concentrated along the east-northeast faults, but north-northwest faults are unmineralized. The reason is obvious; the north-northwest faults did not exist at the time of mercury mineralization; furthermore, north-northwest and east-northeast faults are spatially distinct. East-northeast faults are present throughout the uplift, whereas north-northwest faults are primarily in the eastern part.

The age of faulting bears on relations in the Lowes Valley–Black Mesa area. Erdlac (1990) was slightly remiss in showing the Laramide, east-northeast Lowes Valley faults cutting the 34.7-Ma Black Mesa laccolith (new $^{40}Ar/^{39}Ar$ data; C. D. Henry and M. J. Kunk, unpub. data). In fact, the faults cut only Santa Elena Limestone, the host for the laccolith. The laccolith body probably rose along the southernmost fault of the Lowes Valley system. Black Mesa is an example of a small (2.5-km-diameter) laccolith developed upon, but hardly creating, the uplift.

Corry and others repeat the unsubstantiated contention of Corry and others (1990) that the radial symmetry of the Solitario, a 36- to 35-Ma laccolithic dome (C. D. Henry and W. R. Muehlberger, unpub. data), indicates no "sizable structures nearby at the time it was formed." Their argument is that any existing structures would deflect the stress field so that the Solitario would not be symmetrical. Corry and others, however, provide no references or theoretical discussion to describe how such a stress field deflection would occur. Additionally, they contradict themselves by accepting the conclusion of Baker (1934) that the Terlingua uplift is a Laramide anticline. They also ignore the fact that the Solitario laccolith is hosted by highly folded and thrust-faulted rocks of the Ouachita-Marathon foldbelt. Finally, the Solitario preserves abundant evidence of pre-doming Laramide deformation (Henry and others, unpub. data). Most critically, it is steepest on its southwest flank, where tilting related to doming was superposed on Laramide folding along the Fresno monocline. East-northeast, strike-slip faults are abundant along the Fresno monocline

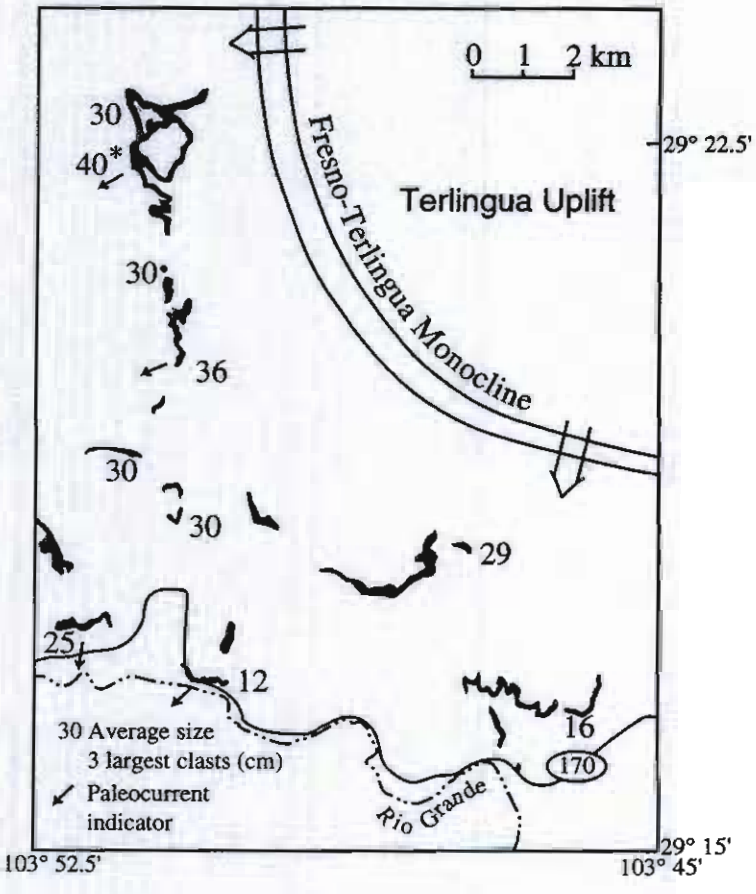

Figure 1. Outcrop, maximum clast size, and paleocurrent data for the Jeff Conglomerate southwest of the Terlingua uplift. Asterisk indicates location of clasts of Boquillas Formation. The data demonstrate that the Jeff Conglomerate in this area was derived from the Terlingua uplift.

and continue along the western flank of the Solitario (Figs. 1 and 2 of Henry and others, 1994), where they have been tilted by doming.

AGE OF THE TERLINGUA UPLIFT

Corry and others cite "steep, topographically youthful structure" as evidence for early Oligocene origin of the uplift. They do not explain, however, why a 35-m.y.-old structure should be markedly more "youthful" than a 50-m.y.-old structure. Moreover, they fail to distinguish erosion of the entire uplift from erosion along its steep, southern and western edges (Fresno-Terlingua monocline). Early erosion was concentrated along the monocline where folding created steep topography. Tertiary rocks were deposited unconformably against the monocline. The interior of the uplift, which was and is a broad plateau, was more slowly eroded. Small remnants of Upper Cretaceous rocks are preserved on top of the uplift, mostly within Basin-Range grabens, which suggests that they were extensive at least until 25 Ma. Only the Terlingua monocline is steep today, and its topographic expression for the most part reflects latest Tertiary-Quaternary exhumation related to development of the Rio Grande during that time (Gustavson, 1991). The eastern part of the monocline, which has not been affected by this late erosion, has little topographic expression.

The Jeff Conglomerate southwest of the uplift was clearly shed from the Terlingua uplift and provides the most definitive evidence for the age of the uplift (Fig. 1). The Jeff overlies progressively older rocks to the north toward the uplift and pinches out against the Fresno and Terlingua monoclines. The conglomerate becomes finer southward, away from the uplift. Clasts of soft limestone of Boquillas Formation, which would not survive long transport, are present in the Jeff only near the monocline. Channels and imbricated pebbles in a few outcrops indicate that flow was southwestward. The Jeff Conglomerate in this area underlies 47-m.y.-old Alamo Creek Basalt, the oldest Tertiary igneous rock in the Terlingua area (McKnight, 1970; Henry and McDowell, 1986). Additionally, sediments and lavas of the overlying Chisos Formation clearly filled a basin southwest of the uplift. The lower (pre ca. 35 Ma) Chisos Formation thins from nearly 170 m approximately 2 km southwest of the Fresno monocline to less than 30 m thick 1 km to the northeast, at the southwest edge of the monocline (McKnight, 1970; C. D. Henry and L. L. Davis, unpub. data). These data demonstrate a topographic high coincident with the Terlingua uplift and a basin southwest of it at the time of deposition of the lower Chisos Formation. Additionally, the data prove that the Terlingua uplift existed before 47 Ma, before all Tertiary magmatism in the area, and long before 35 Ma, the time of origin postulated by Corry and others.

Finally, some objections are totally misleading. In conceding that Baker (1934) identified the Terlingua uplift as a Laramide fold, Corry and others imply that he assigned it dips of "10° or less." In fact, Baker specified only a Laramide origin and did not give dips. Corry and others claim that Erdlac (1990) does not cite Corry and others (1990), Sandidge-Bodoh (1989), Mosconi (1984), or Stout (1979). In fact, the last two were cited, the first was not published until after Erdlac (1990) was published (and long after it had finished review), and Sandidge-Bodoh is an unpublished thesis that we still have not seen.

CONCLUSION

A Laramide origin for the Terlingua uplift is well supported by considerable field, structural, sedimentologic, and geochronologic data. We know of no evidence that a large laccolith underlies the Terlingua uplift or had anything to do with its formation.

REFERENCES CITED

Arthaud, F., and Mattauer, M., 1969, Exemples de stylolites d'orine tectonique dans le Languedec, leurs relations avec la tectonique cassante: Bulletin Société Géologique de France, v. 7, p. 738–744.

Baker, C. L., 1934, Major structural features of Trans-Pecos Texas, *in* Sellards, E. H., and Baker, C. L., eds., The geology of Texas, Volume II: Structural and economic geology: The University of Texas Bulletin 3401, p. 137–214.

Blake, D. B., and Roy, C. J., 1949, Unusual stylolites: American Journal of Science, v. 247, p. 779–790.

Chapin, C. E., and Cather, S. M., 1981, Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountains area, *in* Dickinson, W. R., and Payne, W. D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 199–213.

Corry, C. E., Herrin, Eugene, McDowell, F. W., and Phillips, K. A., 1990, Geology of the Solitario, Trans-Pecos Texas: Geological Society of America Special Paper 250, 122 p.

DeCamp, D. W., 1985, Structural geology of Mesa de Anguila, Big Bend National Park, Texas, *in* Dickerson, P. W., and Muehlberger, W. R., eds., Structure and tectonics of Trans-Pecos Texas: West Texas Geological Society Publication 85-81, p. 127–135.

DeFord, R. K., 1958, Tertiary formations of Rim Rock Country, Presidio County, Trans-Pecos Texas: University of Texas, Austin, Bureau of Economic Geology Report of Investigations No. 36, 37 p.

Eifler, G. K., Jr., 1951, Geology of the Barrilla Mountains, Texas: Geological Society of America Bulletin, v. 62, p. 339–353.

Engelder, T., and Geiser, P., 1984, Near-surface in situ stress: Residual stress in the Tully Limestone, Appalachian Plateau, New York: Journal of Geophysical Research, v. 89, p. 9365–9370.

Erdlac, R. J., Jr., 1988, Structural development of the Terlingua uplift, Brewster and Presidio Counties, Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 403 p.

Erdlac, R. J., Jr., 1990, A Laramide-age push-up block: The structures and formation of the Terlingua-Solitario structural block, Big Bend region, Texas: Geological Society of America Bulletin, v. 102, p. 1076–1091.

Erdlac, R. J., Jr., and Erdlac, R. J., 1992, A mathematical model of push-up block formation: An example from the Big Bend region, Texas: Journal of Geophysical Research, v. 97, p. 11,073–11,083.

Fletcher, R. C., and Pollard, D. D., 1981, Anticrack model for pressure solution surfaces: Geology, v. 9, p. 419–424.

Gustavson, T. C., 1991, Arid basin depositional systems and paleosols: Fort Hancock and Camp Rice Formations (Pliocene-Pleistocene), Hueco Bolson, West Texas and adjacent Mexico: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 198, 49 p.

Guzzetta, G., 1984, Stylolite formation: An insight into the pressure-solution process, *in* Moussly, M., Bathurst, R.G.C., and El-Ouri, A., eds., Stylolites and associated phenomena: Relevance to hydrocarbon reservoirs: Abu Dhabi National Reservoir Research Foundation, 304 p.

Henry, C. D., and McDowell, F. W., 1986, Geochronology of the mid-Tertiary volcanic field, Trans-Pecos Texas, *in* Price, J. G., Henry, C. D., Parker, D. F., and Barker, D. S., eds., Igneous geology of Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Guidebook 23, p. 99–122.

Henry, C. D., and Price, J. G., 1986, Early Basin and Range development in Trans-Pecos Texas and adjacent Chihuahua: Magmatism and orientation, timing, and style of extension: Journal of Geophysical Research, v. 91, p. 6213–6224.

Henry, C. D., Price, J. G., and Miser, D. E., 1989, Geology and Tertiary igneous activity of the Hen Egg and Christmas Mountains quadrangles, Big Bend Region, Trans-Pecos, Texas: The University of Texas at Austin Bureau of Economic Geology, Report of Investigation No. 183, 105 p.

Henry, C. D., Price, J. G., and James, E. W., 1991, Mid-Cenozoic stress evolution and magmatism in the southern Cordillera, Texas and Mexico: Transition from continental arc to intraplate extension: Journal of Geophysical Research, v. 96, p. 13,545–13,560.

Henry, C. D., Muehlberger, W. R., Erdlac, R. J., Jr., Price, J. G., and Dickerson, P. W., 1994, Discussion of Special Paper 250 *Geology of the Solitario, Trans-Pecos Texas*: Geological Society of America Bulletin, v. 106 (this issue).

Lehman, T. M., 1986, Late Cretaceous sedimentation in Trans-Pecos Texas: West Texas Geological Society Bulletin, v. 25, p. 4–9.

Maler, M. O., 1990, Dead Horse graben: A West Texas accommodation zone: Tectonics, v. 9, no. 6, p. 1357–1368.

Maxwell, R. A., and Dietrich, J. W., 1970, Correlation of Tertiary rock units, West Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 70, 34 p.

McKnight, J. F., 1970, Geology of Bofecillos Mountains area, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map No. 37, scale 1:48,000, text 36 p.

Mosconi, L. S., 1984, Tectonic history of the Black Mesa–Lowes Valley area, Brewster County, Texas [M.S. thesis]: Nacagdoches, Texas, Stephen F. Austin State University, 72 p.

Moustafa, A. R., 1988, Structural geology of Sierra del Carmen, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map No. 54.

North American Stratigraphic Code, 1983, American Association of Petroleum Geologists Bulletin, v. 67, p. 841–875.

Ramsay, J. G., and Huber, M. I., 1983, The techniques of modern structural geology, Volume 1: Strain analysis: New York, Academic Press, 306 p.

Rigby, J. K., 1953, Some transverse stylolites: Journal of Sedimentary Petrology, v. 23, p. 265–271.

Sandidge-Bodoh, V. L., 1989, Investigating the effects fracture systems have on seismic wave velocities at the Lajitas, Texas, seismic station [M.S. thesis]: Dallas, Texas, Southern Methodist University, 161 p.

Stevens, J. B., 1969, Geology of the Castolon area, Big Bend National Park, Brewster County, Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 129 p.

Stevens, J. B., Stevens, M. S., and Wilson, J. A., 1984, Devil's Graveyard Formation (new): Eocene and Oligocene age, Trans-Pecos Texas: The University of Texas at Austin, Memorial Museum Bulletin 32, 21 p.

Stout, J. D., 1979, Structure and origin of Terlingua Uplift, Brewster and Presidio Counties, Texas [M.S. thesis]: Canyon, Texas, West Texas State University, 79 p.

Twiss, P. C., 1979, Marfa sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale, 1:250,000.

Yates, R. G., and Thompson, G. A., 1959, Geology and quicksilver deposits of the Terlingua district, Texas: U.S. Geological Survey Professional Paper 312, 114 p.

MANUSCRIPT RECEIVED BY THE SOCIETY NOVEMBER 1, 1993
MANUSCRIPT ACCEPTED NOVEMBER 2, 1993

Printed in U.S.A.

and continue along the western flank of the Solitario (Figs. 1 and 2 of Henry and others, 1994), where they have been tilted by doming.

AGE OF THE TERLINGUA UPLIFT

Corry and others cite "steep, topographically youthful structure" as evidence for early Oligocene origin of the uplift. They do not explain, however, why a 35-m.y.-old structure should be markedly more "youthful" than a 50-m.y.-old structure. Moreover, they fail to distinguish erosion of the entire uplift from erosion along its steep, southern and western edges (Fresno-Terlingua monocline). Early erosion was concentrated along the monocline where folding created steep topography. Tertiary rocks were deposited unconformably against the monocline. The interior of the uplift, which was and is a broad plateau, was more slowly eroded. Small remnants of Upper Cretaceous rocks are preserved on top of the uplift, mostly within Basin-Range grabens, which suggests that they were extensive at least until 25 Ma. Only the Terlingua monocline is steep today, and its topographic expression for the most part reflects latest Tertiary-Quaternary exhumation related to development of the Rio Grande during that time (Gustavson, 1991). The eastern part of the monocline, which has not been affected by this late erosion, has little topographic expression.

The Jeff Conglomerate southwest of the uplift was clearly shed from the Terlingua uplift and provides the most definitive evidence for the age of the uplift (Fig. 1). The Jeff overlies progressively older rocks to the north toward the uplift and pinches out against the Fresno and Terlingua monoclines. The conglomerate becomes finer southward, away from the uplift. Clasts of soft limestone of Boquillas Formation, which would not survive long transport, are present in the Jeff only near the monocline. Channels and imbricated pebbles in a few outcrops indicate that flow was southwestward. The Jeff Conglomerate in this area underlies 47-m.y.-old Alamo Creek Basalt, the oldest Tertiary igneous rock in the Terlingua area (McKnight, 1970; Henry and McDowell, 1986). Additionally, sediments and lavas of the overlying Chisos Formation clearly filled a basin southwest of the uplift. The lower (pre ca. 35 Ma) Chisos Formation thins from nearly 170 m approximately 2 km southwest of the Fresno monocline to less than 30 m thick 1 km to the northeast, at the southwest edge of the monocline (McKnight, 1970; C. D. Henry and L. L. Davis, unpub. data). These data demonstrate a topographic high coincident with the Terlingua uplift and a basin southwest of it at the time of deposition of the lower Chisos Formation. Additionally, the data prove that the Terlingua uplift existed before 47 Ma, before all Tertiary magmatism in the area, and long before 35 Ma, the time of origin postulated by Corry and others.

Finally, some objections are totally misleading. In conceding that Baker (1934) identified the Terlingua uplift as a Laramide fold, Corry and others imply that he assigned it dips of "10° or less." In fact, Baker specified only a Laramide origin and did not give dips. Corry and others claim that Erdlac (1990) does not cite Corry and others (1990), Sandidge-Bodoh (1989), Mosconi (1984), or Stout (1979). In fact, the last two were cited, the first was not published until after Erdlac (1990) was published (and long after it had finished review), and Sandidge-Bodoh is an unpublished thesis that we still have not seen.

CONCLUSION

A Laramide origin for the Terlingua uplift is well supported by considerable field, structural, sedimentologic, and geochronologic data. We know of no evidence that a large laccolith underlies the Terlingua uplift or had anything to do with its formation.

REFERENCES CITED

Arthaud, F., and Mattauer, M., 1969, Exemples de stylolites d'orine tectonique dans le Languedec, leurs relations avec la tectonique cassante: Bulletin Société Géologique de France, v. 7, p. 738–744.

Baker, C. L., 1934, Major structural features of Trans-Pecos Texas, *in* Sellards, E. H., and Baker, C. L., eds., The geology of Texas, Volume II: Structural and economic geology: The University of Texas Bulletin 3401, p. 137–214.

Blake, D. B., and Roy, C. J., 1949, Unusual stylolites: American Journal of Science, v. 247, p. 779–790.

Chapin, C. E., and Cather, S. M., 1981, Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountains area, *in* Dickinson, W. R., and Payne, W. D., eds., Relations of tectonics to ore deposits in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 199–213.

Corry, C. E., Herrin, Eugene, McDowell, F. W., and Phillips, K. A., 1990, Geology of the Solitario, Trans-Pecos Texas: Geological Society of America Special Paper 250, 122 p.

DeCamp, D. W., 1985, Structural geology of Mesa de Anguila, Big Bend National Park, Texas, *in* Dickerson, P. W., and Muehlberger, W. R., eds., Structure and tectonics of Trans-Pecos Texas: West Texas Geological Society Publication 85-81, p. 127–135.

DeFord, R. K., 1958, Tertiary formations of Rim Rock Country, Presidio County, Trans-Pecos Texas: University of Texas, Austin, Bureau of Economic Geology Report of Investigations No. 36, 37 p.

Eifler, G. K., Jr., 1951, Geology of the Barrilla Mountains, Texas: Geological Society of America Bulletin, v. 62, p. 339–353.

Engelder, T., and Geiser, P., 1984, Near-surface in situ stress: Residual stress in the Tully Limestone, Appalachian Plateau, New York: Journal of Geophysical Research, v. 89, p. 9365–9370.

Erdlac, R. J., Jr., 1988, Structural development of the Terlingua uplift, Brewster and Presidio Counties, Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 403 p.

Erdlac, R. J., Jr., 1990, A Laramide-age push-up block: The structures and formation of the Terlingua-Solitario structural block, Big Bend region, Texas: Geological Society of America Bulletin, v. 102, p. 1076–1091.

Erdlac, R. J., Jr., and Erdlac, R. J., 1992, A mathematical model of push-up block formation: An example from the Big Bend region, Texas: Journal of Geophysical Research, v. 97, p. 11,073–11,083.

Fletcher, R. C., and Pollard, D. D., 1981, Anticrack model for pressure solution surfaces: Geology, v. 9, p. 419–424.

Gustavson, T. C., 1991, Arid basin depositional systems and paleosols: Fort Hancock and Camp Rice Formations (Pliocene-Pleistocene), Hueco Bolson, West Texas and adjacent Mexico: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 198, 49 p.

Guzzetta, G., 1984, Stylolite formation: An insight into the pressure-solution process, *in* Moussly, M., Bathurst, R.G.C., and El-Ouri, A., eds., Stylolites and associated phenomena: Relevance to hydrocarbon reservoirs: Abu Dhabi National Reservoir Research Foundation, 304 p.

Henry, C. D., and McDowell, F. W., 1986, Geochronology of the mid-Tertiary volcanic field, Trans-Pecos Texas, *in* Price, J. G., Henry, C. D., Parker, D. F., and Barker, D. S., eds., Igneous geology of Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Guidebook 23, p. 99–122.

Henry, C. D., and Price, J. G., 1986, Early Basin and Range development in Trans-Pecos Texas and adjacent Chihuahua: Magmatism and orientation, timing, and style of extension: Journal of Geophysical Research, v. 91, p. 6213–6224.

Henry, C. D., Price, J. G., and Miser, D. E., 1989, Geology and Tertiary igneous activity of the Hen Egg and Christmas Mountains quadrangles, Big Bend Region, Trans-Pecos, Texas: The University of Texas at Austin Bureau of Economic Geology, Report of Investigation No. 183, 105 p.

Henry, C. D., Price, J. G., and James, E. W., 1991, Mid-Cenozoic stress evolution and magmatism in the southern Cordillera, Texas and Mexico: Transition from continental arc to intraplate extension: Journal of Geophysical Research, v. 96, p. 13,545–13,560.

Henry, C. D., Muehlberger, W. R., Erdlac, R. J., Jr., Price, J. G., and Dickerson, P. W., 1994, Discussion of Special Paper 250 *Geology of the Solitario, Trans-Pecos Texas*: Geological Society of America Bulletin, v. 106 (this issue).

Lehman, T. M., 1986, Late Cretaceous sedimentation in Trans-Pecos Texas: West Texas Geological Society Bulletin, v. 25, p. 4–9.

Maler, M. O., 1990, Dead Horse graben: A West Texas accommodation zone: Tectonics, v. 9, no. 6, p. 1357–1368.

Maxwell, R. A., and Dietrich, J. W., 1970, Correlation of Tertiary rock units, West Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 70, 34 p.

McKnight, J. F., 1970, Geology of Bofecillos Mountains area, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map No. 37, scale 1:48,000, text 36 p.

Mosconi, L. S., 1984, Tectonic history of the Black Mesa–Lowes Valley area, Brewster County, Texas [M.S. thesis]: Nacagdoches, Texas, Stephen F. Austin State University, 72 p.

Moustafa, A. R., 1988, Structural geology of Sierra del Carmen, Trans-Pecos Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map No. 54.

North American Stratigraphic Code, 1983, American Association of Petroleum Geologists Bulletin, v. 67, p. 841–875.

Ramsay, J. G., and Huber, M. I., 1983, The techniques of modern structural geology, Volume 1: Strain analysis: New York, Academic Press, 306 p.

Rigby, J. K., 1953, Some transverse stylolites: Journal of Sedimentary Petrology, v. 23, p. 265–271.

Sandidge-Bodoh, V. L., 1989, Investigating the effects fracture systems have on seismic wave velocities at the Lajitas, Texas, seismic station [M.S. thesis]: Dallas, Texas, Southern Methodist University, 161 p.

Stevens, J. B., 1969, Geology of the Castolon area, Big Bend National Park, Brewster County, Texas [Ph.D. dissert.]: Austin, Texas, The University of Texas at Austin, 129 p.

Stevens, J. B., Stevens, M. S., and Wilson, J. A., 1984, Devil's Graveyard Formation (new): Eocene and Oligocene age, Trans-Pecos Texas: The University of Texas at Austin, Memorial Museum Bulletin 32, 21 p.

Stout, J. D., 1979, Structure and origin of Terlingua Uplift, Brewster and Presidio Counties, Texas [M.S. thesis]: Canyon, Texas, West Texas State University, 79 p.

Twiss, P. C., 1979, Marfa sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale, 1:250,000.

Yates, R. G., and Thompson, G. A., 1959, Geology and quicksilver deposits of the Terlingua district, Texas: U.S. Geological Survey Professional Paper 312, 114 p.

MANUSCRIPT RECEIVED BY THE SOCIETY NOVEMBER 1, 1993
MANUSCRIPT ACCEPTED NOVEMBER 2, 1993

Printed in U.S.A.