REPLY: "POST-SPELEOGENETIC EROSION AND ITS EFFECT ON CAVES IN THE GUADALUPE MOUNTAINS, NEW MEXICO AND TEXAS"

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In his discussion of our paper on erosion, Davis (2001) presents thought-provoking comments on erosion and speleogenesis in the Guadalupe Mountains (DuChene & Martinez 2000). We respond to Davis' comments on the impact of erosion on caves, and address his remarks on speleogenetic history. We point out, however, that speleogenesis is beyond the scope of our original paper.

We agree that erosion is not the sole control on cave distribution; tectonic events, climatic changes, dynamics of the groundwater system, and exhumation of the Capitan Reef Complex are other important factors.

Davis observes that the three segments we selected for our study of erosion can be subdivided based on the distribution of caves. This is true, but is not a valid approach for a study of erosion. We divided the mountains into three segments based on topographic slope, which is a reflection of the structural geology. Our west and east segments slope east at 1.2° and 1.1°, respectively, and are developed on an east-dipping regional homocline. This homocline is interrupted by the north-northwest trending Huapache Monocline, which crosses the Guadalupes between Double and Rattlesnake Canyons. This segment has a 2.2° eastward slope reflecting the steeper dip of the monocline. Our divisions are, therefore, based on topographic slope and structural dip, which *contribute* to erosion, rather than caves, which are a *product* of erosion.

In his discussion of our western segment, Davis states, "…I have seen little demonstrable correlation between passage locations and surface geography in the Guadalupe Mountains. Surface canyons do not routinely align with cave passages."

An examination of joint patterns in the Guadalupes shows two prominent trends: one parallel to the Capitan Shelf Margin and the other approximately perpendicular to it (King 1948; Jagnow 1979). Many of the largest and most extensive passages in Carlsbad Cavern and Lechuguilla Cave parallel the Shelf margin. We assume that many cave passages in the western segment were similar in orientation to Carlsbad and Lechuguilla. Jagnow's map of the Guadalupes (Jagnow 1979: Fig. 14) shows that most cave passages in our western segment are perpendicular to the shelf margin, which is exactly what we would expect in this highly dissected area. Few remaining passages parallel the canyons because they have been removed by erosion, but remnants persist as surface deposits of cave travertine (*e.g.* Horberg 1949).

We agree with Davis that speleogenesis in the Guadalupes has been episodic and that intensity has varied with time, but do not agree with some of his reasons. Davis wrote, "The watershed has also enlarged with uplift. It follows that the intensity of speleogenesis has varied from east to west as uplift proceeded." There is evidence that most, if not all, of the uplift of the Guadalupes occurred *prior* to speleogenesis, and that the size of the watershed and recharge area has *decreased* since the onset of hypogenic dissolution (Cunningham *et al.* in prep.). A review of Cenozoic history as it relates to hydrologic conditions in the Guadalupe region illustrates these points.

The Guadalupes are one of many fault block mountain ranges within the Cenozoic Rio Grande rift. The predecessor to the rift, a continental-scale arch extending from Colorado to northern Mexico called the Alvarado Ridge (Eaton 1987), began to rise in Early Tertiary time reaching a maximum elevation of 1500 - 3000 m in southern Colorado. As it rose, material was eroded from highland areas and transported to the flanks, forming a regional erosion surface of Late Eocene age (Epis & Chapin 1975). In the Guadalupes, this erosion surface is preserved in flat upland surfaces distributed throughout the western part of the mountains (Horberg 1949). Renewed uplift in Oligocene and Miocene time tilted the Eocene erosion surface eastward (Horberg 1949) and dissected it by faulting during the opening of the Rio Grande Rift (Eaton 1987). The mountain ranges along the axis of the rift were significantly higher than the tallest peaks of the Guadalupes. For example, Sierra Blanca Peak in the nearby Sacramento Mountains, with an elevation of 3693 m, is about 1000 m higher than Guadalupe Peak.

The water table in the Guadalupes today is approximately at the level of the Pecos River at the town of Carlsbad, New Mexico. In the past, the water table had to be higher, or we would not have large cave systems. Lindsey (1998) concluded that oil fields in southeastern New Mexico and west Texas were water-washed by eastward hydrodynamic flow prior to the opening of the Rio Grande Rift, which required a large, unfaulted upland watershed and stronger hydrodynamic system than exists today.

Hypogenic caves are believed to form by mixing of sulfidic and oxygenated water along steeply curving flow paths within the Capitan Reef Complex (Davis 1980). Palmer and Palmer (2000) indicate that some cave entrances may have been flowing springs at the time of speleogenesis. Virgin Cave, located in Big Canyon ~5 km from the western escarpment of the Guadalupes, is a hypogenic cave with an entrance elevation of ~2,030 m, ~615 m above the floor of the Salt Basin. To the west, the aquifer had to extend beyond the modern faulted escarpment of the mountains to support upward flow of meteoric water at Virgin Cave. This means that the Salt Basin graben and Border fault zone could not have existed at the time Virgin Cave was formed (DuChene *et al.* 2000; Cunningham *et al.* in prep.).

Major tectonic spasms related to the opening of the Rio Grande rift occurred approximately 17 Ma and 7 - 4 Ma (Eaton 1987). Polyak *et al.* (1998) reported that hypogenic cave-forming events occurred 12.3 - 11.3 Ma, and from 6 - 3.9 Ma. Could it be that the apparent episodic nature of hypogenic speleogenesis is related to quiet periods between tectonic events? The coincidence of the most recent hypogenic cave development (3.9 Ma) and the end of the last tectonic pulse (~4.0 Ma) suggests that downfaulting and erosion were associated with lowering of the water table and may have terminated the most recent phase of hypogenic cave development in the Guadalupes.

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