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Bruce C. Panuska
Mississippi State University

John M. Mylroie
Mississippi State University

Darrell Armentrout
Mississippi State University

Donald A. McFarlane
Claremont McKenna College; Pitzer College; Scripps College

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MAGNETOSTRATIGRAPHY OF CUEVA DEL ALEMAN, ISLA DE MONA, PUERTO RICO AND THE SPECIES DURATION OF AUDUBON'S SHEARWATER

BRUCE C. PANUSKA, JOHN M. MYLROIE, DARRELL ARMENTROUT
Department of Geosciences, Mississippi State University, Mississippi State, MS 39762 USA
DONALD MCFARLANE
W.M. Keck Science Center, The Claremont Colleges, 925 North Mills Ave., Claremont, CA 91711 USA

*Magnetostratigraphic analysis of deposits exposed in Cueva del Aleman shows two reversed and two normal chronozones. The lower normal polarity event is observed in a clastic dike and probably predates initial cave formation. Sediments deposited inside the cave proper show a R-N-R sequence and probably date to at least 1.8 Ma. A fossiliferous clastic dike contains normal polarity with an overlying reversed magnetozone. Audubon's Shearwater (bird) bones occur in the dike, which is tentatively correlated with the lower N polarity zone predating cave formation. If this correlation is correct, the Audubon's Shearwater (*Puffinus lherminieri*) range can be extended back to at least 1.8 Ma, the Olduvai subchron.*

The caves of Isla de Mona, Puerto Rico, contain evidence of a rather protracted and complicated history. (See Frank *et al.* 1998, for a description of Isla de Mona.) Many of the caves contain dissolved speleothems, which have been interpreted to indicate at least two separate phreatic events (Mylroie *et al.* 1995). This, in turn, implies considerable age for the cave systems. In an attempt to determine some semi-quantitative constraints on the age of various deposits, a magnetostratigraphic study was undertaken in Cueva del Aleman, a cave displaying unusually well-constrained stratigraphic relationships. Additionally, vertebrate fossils, including the bird, Audubon's Shearwater, have been recovered from well-lithified sediments in the cave.

Audubon's Shearwater, *Puffinus lherminieri*, is a pelagic circumtropical species which breeds in burrows, crevices and caves. The species is known from the West Indian late Quaternary cave deposits on Cayman Brac (Morgan 1994), Barbuda (Brodkorb 1963), Barbados (Brodkorb 1964), Crooked Island, Bahamas (Wetmore 1938) and Mona Island (Kaye 1959). The oldest of these deposits that has been securely dated is from Pattons Fissure, Cayman Brac, with an age of 11,180 ± 105 yrs BP (Morgan 1994). Evidence presented here extends the minimum age for this species by 2 orders of magnitude.

CAVE STRATIGRAPHY

Cueva del Aleman (see issue reference map) has been mapped and described by Mylroie *et al.* (1995) and preliminary magnetostratigraphic age inferences were proposed (Panuska *et al.* 1995; Armentrout & Panuska 1995; Mylroie *et al.* 1995). The critical stratigraphic relationships are exposed in the Pasunka Room of Cueva del Aleman, (locality A, Fig. 1; Fig. 2).

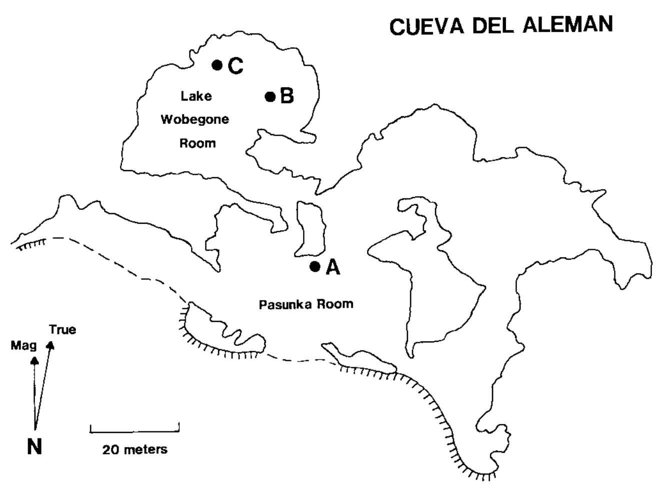

Figure 1. Map of central portion, upper level, of Cueva del Aleman. Letters indicate locations referred to in text. Hachures indicate cliff face; dashed lines indicate cave entrances.

The oldest deposit in Cueva del Aleman is a clastic dike (filled dissolutional fissure) containing red soil derived from the surface. A second red soil wash-in deposit overlies the clastic dike. The very sharp contact between these units is interpreted to be the result of the phreatic event that dissolved the initial cave chamber. Overlying the red cave floor deposit is a dripstone column (here termed Keillors Pillar) of complex origin.

The uppermost portion of the Keillors Pillar consists of vertically laminated flowstone, which can be traced for several meters in the cave ceiling. These laminations appear to be coating the walls of a former fissure in the cave ceiling. Below the vertical laminations is a set of apex-down chevron shaped

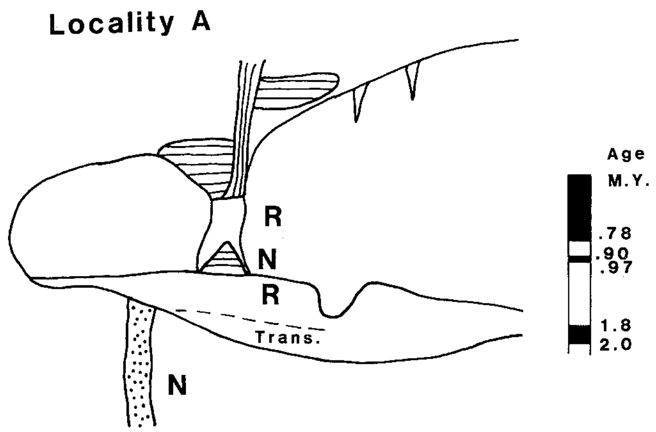

Figure 2. Locality A in Pasunka Room of Cueva del Aleman. N and R indicates normal and reversed magnetic polarity; Trans indicates a paleomagnetic direction transitional between normal and reversed polarity. Black portion of reference time scale is normal polarity; white portion is reversed polarity. See text for a discussion of cave deposits.

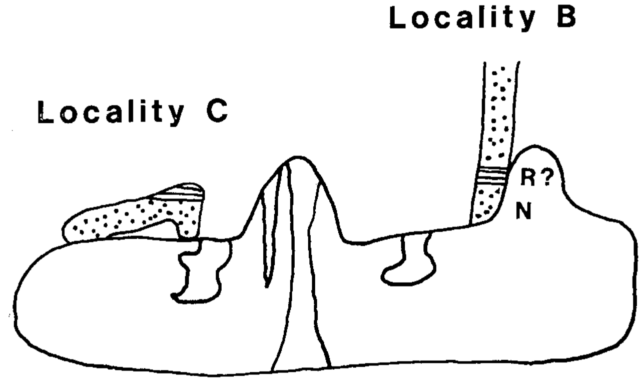

Figure 3. Cross section view of deposits in Lake Wobegon Room. Stipple pattern is red soil redeposited in clastic dikes and dissolution pockets. Parallel lines are laminated flowstone. Irregular roof pendants are phreatically dissolved speleothems. N and R indicates normal and reversed polarity respectively.

laminations, with a thin vertical tube occurring near the center. The chevron laminations are interpreted to be a former stalactite, with the tube forming a soda straw precursor. Chevron laminations give way to crudely laminated to massive carbonate, interpreted to be a dripstone column. The base of the column contains a triangular pocket of horizontally laminated flowstone. These horizontal laminations curve near their margins and become parallel to the side of the pocket. This triangular set of laminations is considered to be a poolstone deposit formed by water dripping from a stalactite overhead. Massive flowstone bounding the poolstone would, thus, be rimstone confining the pool. Cores extracted from beneath the column show red cave floor sediment and red sediment with white flowstone below the poolstone pocket. Thus, the column stratigraphically overlies the cave floor sediment.

The preferred scenario for Pasunka Room speleogenesis begins with soil washing into fissures in the limestone, forming a clastic dike. Phreatic dissolution cross cuts the clastic dike during the opening of the initial cave chamber. Red soil was subsequently washed in during vadose conditions, producing the cave floor sediment. Vadose deposition is favored as the upper portion of the floor sediment consists of interbedded red sediment and white flowstone and since the floor sediment is thicker at the deeper sections of the cave floor, rather than blanketing the floor evenly. Following soil wash-in, a stalactite-poolstone pair formed above the cave floor sediment. Continued dripstone deposition joined the stalactite and poolstone with a column. Although the stalactite and poolstone are penecontemporaneous, a stratigraphic sequence of column-poolstone-cave floor sediment-clastic dike can be established. Following this early phase of speleothem deposition, the cave was flooded, partially dissolving dripstone formations, and subsequently drained, giving rise to a second stage of vadose dripstone deposition.

A second room, adjoining the Pasunka Room, is depicted in cross section D-D', figure 12A of Mylroie *et al.* (1995). This room, here termed the Lake Wobegon Room (Fig. 1), is important as it contains fossiliferous clastic dikes. The Lake Wobegon Room shows two stages of speleothem deposition, with the older phase being partly dissolved (Fig. 3). Clastic dikes can be seen in the ceiling and walls of this chamber. Cross cutting relationships show at least two stages of dike emplacement; the younger of these dikes is depicted as locality B in figure 3.

The correlation of deposits between the Lake Wobegon and Pasunka Rooms is problematic; however, the clastic dike at locality B can be tentatively correlated with the dike in the floor of the Pasunka Room. Portions of walls confining the clastic dikes have been phreatically dissolved. Moreover, the dikes are associated with phreatically dissolved speleothems. This implies a depositional history where cave chambers were dissolved across pre-existing clastic dikes, vadose conditions then allowed for dripstone deposition, followed by a second phreatic dissolutional event and, finally, cave draining and a second stage of vadose dripstone formation.

VERTEBRATE FOSSILS

Bird bones are present, although sparsely distributed, in the Lake Wobegon Room clastic dikes. Two recovered long bone fragments are indistinguishable from *Puffinus lherminieri*, a species whose fossil and subfossil remains are superabundant in and on younger, unconsolidated cave deposits in Cueva

Aleman and many other Isla de Mona caves.

P. lherminieri apparently made extensive use of the Mona caves as breeding sites, but is now extirpated from the island. The species has also been extirpated from Cayman Brac (Morgan 1994). The surficial nature of the bone deposits in Cueva Negra, Isla de Mona, and their loose association with anthropogenic charcoal deposits led Kaye (1959) to propose that the species had been a major prey for Taino Indians. However, the absence of any burning of the bones themselves, the absence of other taxa known to have been consumed by the Taino, and the absence of any evidence of Taino use in other Isla Mona caves containing *P. lherminieri* deposits argues against a catastrophic human predatory impact on the species.

Holdaway & Worthy (1994) have studied the extirpation and extinction of *Puffinus* species in the New Zealand archipelago. These authors have noted the susceptibility of *Puffinus sp*. to predation by *Rattus exulans*. Holdaway (1997) has further noted a correlation between *Puffinus* egg size and *Rattus* body mass. It seems likely that *P. lherminieri* on Isla Mona, and on the other West Indian islands from which it has been extirpated, is a casualty of nest predation by introduced *Rattus rattus*.

PALEOMAGNETIC DATA

Approximately 50 samples were collected from red sediment and speleothems. (All sample holes were filled with similar color material and restored to original contour. One year after initial backfill techniques were employed, cave researchers had to be shown the extraction points before they could recognize that samples had been collected.) Standard paleomagnetic specimens (2.5 cm diameter, 2 cm high) were measured on a Schonstedt SSM-1a spinner magnetometer. Some of the more weakly magnetized specimens (flowstones, less than 10^{-7} emu/cm^3) were measured on cryogenic magnetometers at the University of Alaska, Louisiana State University and the University of Pittsburgh. Specimens were cleaned using standard alternating field (AF) techniques.

Normal secondary components could be especially pronounced in the reversely magnetized specimens (Fig. 4), being stronger than the characteristic component. However, most secondary components were no more than about 10% of the signal. In nearly all cases, AF was sufficient to remove secondary components of magnetization allowing the characteristic components to be isolated. Full details of the paleomagnetics will be given in Armentrout (in prep.).

At locality A, 5 samples in the lower clastic dike are normally magnetized. The upper portion of the cave floor sediment is reversely magnetized (10 samples), whereas the lower portion shows a variety of directions (15) with VGPs (virtual geomagnetic poles) located in eastern China to the Indian Ocean. These anomalous directions are interpreted to be a record of a transitional geomagnetic field. It is not possible to tell whether this is a N→R transition or a R→R excursion of the field. Two specimens from the poolstone above the floor sediment record normal polarity and two specimens from the column above the poolstone are reversely magnetized.

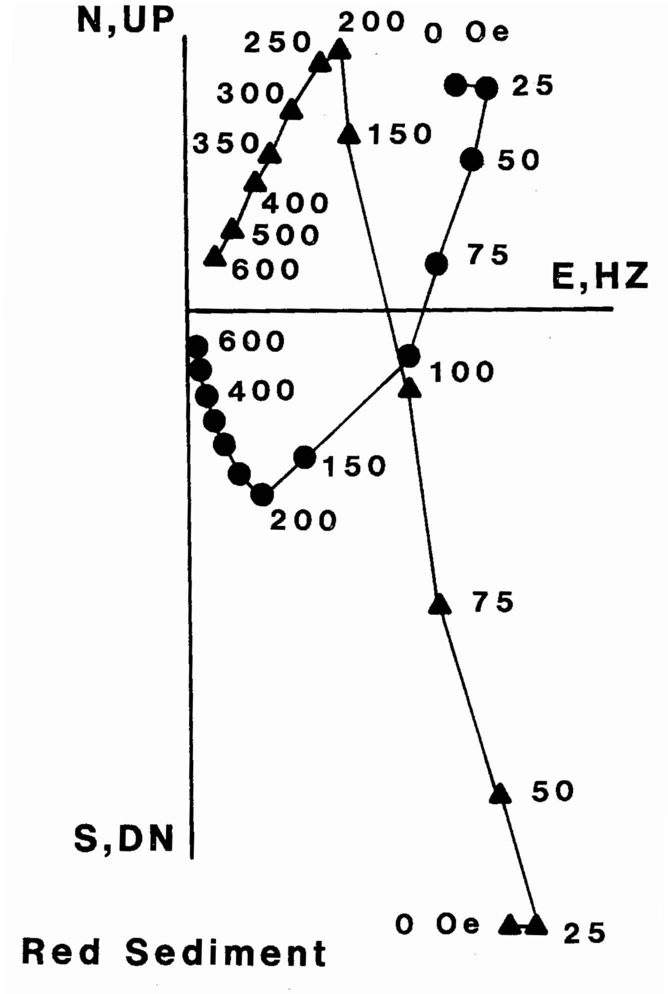

Figure 4. Demagnetization diagram showing primary and secondary components of magnetization. Dots indicate magnetic declination plotted in N, E, S (north, east, south) coordinates. Triangles represent magnetic inclination plotted in UP, DN, HZ (up, down, horizontal) coordinates. Numbers show alternating field demagnetization intensity in Oersteds (Oe). Note that the normal secondary component is removed by 200 Oe demagnetization step.

To infer age, the magnetozones are assigned to the youngest reasonable chronozones. The reversed dripstone column is assigned to the uppermost portion of the Matuyama reversed zone older than 783 Ka (Baksi *et al.* 1992), the normal poolstone is correlated to the 70 Ky long Jaramillo event and the normally magnetized clastic dike would be the Olduvai event (1.8-2.0 Ma) (Baksi 1994). The initial cave passage was formed after the lower clastic dike, in post-Olduvai time. If the transitional zone in the cave floor sediment is inferred to be a N→R record, the age of the cave is 1.8 Ma. The N→R correlation is considered to be more likely than a R→R Matuyama excursion.

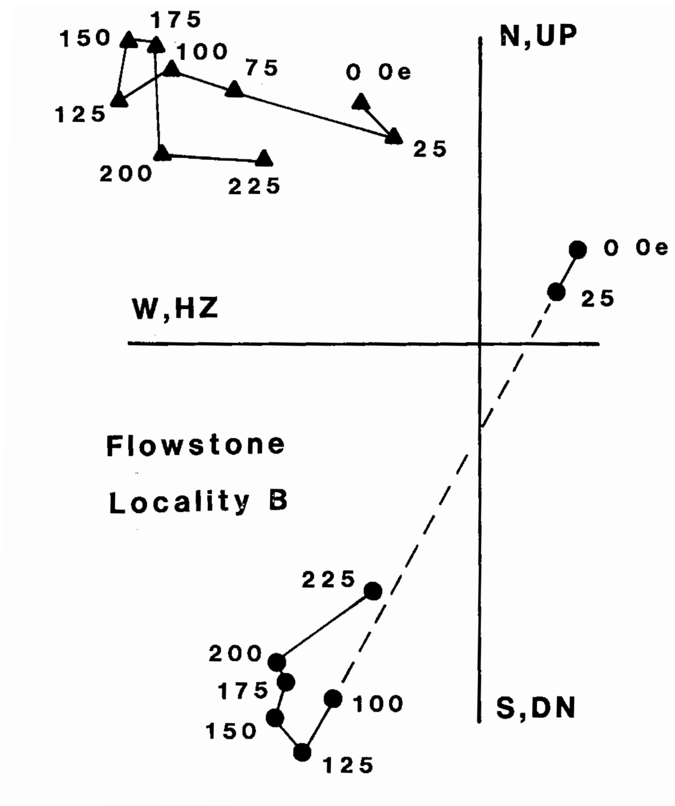

Figure 5. Demagnetization diagram of flowstone sample from locality B. See figure 4 caption for plotting conventions. Secondary components appear to be removed by 125 Oe demagnetization. While the characteristic direction is not well-defined, all measurements between 200 and 350 Oe shows a southwest (S, W) and negative (UP) direction, a reversed magnetization.

At locality B, the clastic dike has a lower normally magnetized section, with a probable reversed flowstone overlying the clastic dike wash-in sediment. The magnetization of the flowstone is problematic as only one sample was strong enough to be measured. While this sample does not display a well-defined characteristic direction (Fig. 5), the 200-350 Oe demagnetization steps show directions which are southwest and negative, a reversed direction. Even without acceptance of the reversed flowstone, the dike at locality B can be correlated with the clastic dike in the floor of locality B, as both cave chambers show evidence of two phreatic events, with the dikes predating initial cave dissolution. Thus, the age of the Audubon's Shearwater fossils may be taken as 1.8 - 2.0 Ma. It must be emphasized that these ages should be considered minimum ages, in the absence of independent age constraints.

CONCLUSIONS

A magnetostratigraphic study was undertaken in Cueva del Aleman. Pre-cave clastic dikes show a normal polarity. Sediment and speleothems deposited inside the cave show a R-N-R sequence. Conservative assignment of the reversals to standard chronozones suggests that the cave formed during the Matuyama epoch, a minimum of 1.1-1.8 Ma. Pre-cave clastic dikes date at least to the Olduvai normal event. Audubon's Shearwater bones recovered from some of these dikes would then be 1.8-2.0 Ma. The establishment of a two million year tenure of this species on Isla de Mona and the probable correlation of its extirpation with the introduction of *Rattus rattus* further illustrates the extreme fragility of small island ecosystems.

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