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CAVERNA DOS ECOS (CENTRAL BRAZIL): GENESIS AND GEOMORPHOLOGIC CONTEXT OF A CAVE DEVELOPED IN SCHIST, QUARTZITE, AND MARBLE

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Caverna dos Ecos (Echoes Cave) occurs in low-grade metamorphic rocks of the Mesoproterozoic Canastra Group, 60 km west of Brasília, and exhibits a total linear development of 1600 m and a depth of 140 m, with halls up to 100 m across and 35 m high, a gallery 350 m long and 70 m wide, and at its lowest point, a lake 280 m long and 10 m deep. What makes this cave so unusual is that ~70% of its large volume is presently developed within schist and quartzite. Detailed structural study, together with speleomorphologic analysis, revealed two phases of speleogenesis: the first, typical of carbonate rocks, created phreatic tubes along the intersections of fractures and bedding planes, whereas the second involved breakdown processes that opened up large vadose cavities in the overlying schist and quartzite but without producing any indication of karstic relief in the overlying topography.

Caverna dos Ecos (Echoes Cave; Sociedade Brasileira de Espeleologia register number GO-18) occurs at 15º40´S, 48º15´W, and 1050 m altitude in the Municipality of Cocalzinho, State of Goiás (GO), about 60 km west of Brasília, central Brazil (Fig. 1). Contrary to typical regions of carbonate caves, there is no evidence whatsoever of karstic relief, either at the local scale or on aerial photographs, that might suggest the presence of this or any other cave in this area. This paper describes the morphology and geology of the cave and proposes a model for its formation based on a detailed study of geologic structures in the cave. Exploration and mapping of Caverna dos Ecos was first carried out by the Espeleo Grupo de Brasília in the 1970s. Remapping by the Grupo de Espeleologia da Geologia of the University of Brasília between 1990 and 1996 increased its known dimensions.

Despite its relatively small proportion of carbonate rocks and isolated nature, Caverna dos Ecos is a remarkable subterranean karstic feature held in special esteem by Brazilian speleologists as no other Brazilian cave of comparable size is known from similar lithologies (mica schist, quartzite, and marble), with ~70% of its volume developed within schists and quartzite. The cave also represents a potential geotechnical hazard, as a road, albeit a secondary dirt track, passes directly over the unsuspected and surficially undetectable, voluminous 35-m high Hall of Clouds.

REGIONAL CONTEXT OF THE CAVE

The cave is on the Central Goiano Plateau in the highest part of central Brazil that divides the Paraná and Amazon River Basins. It lies specifically within the Verde River Basin, a

Figure 1. Location of Caverna dos Ecos in central Brazil. GO, Goias; DF, Distrito Federal; MG, Minas Gerais.

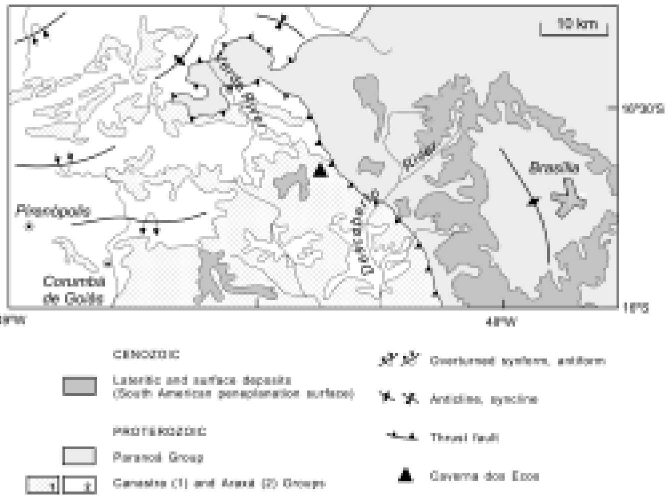

Figure 2. Geologic setting of Caverna dos Ecos.

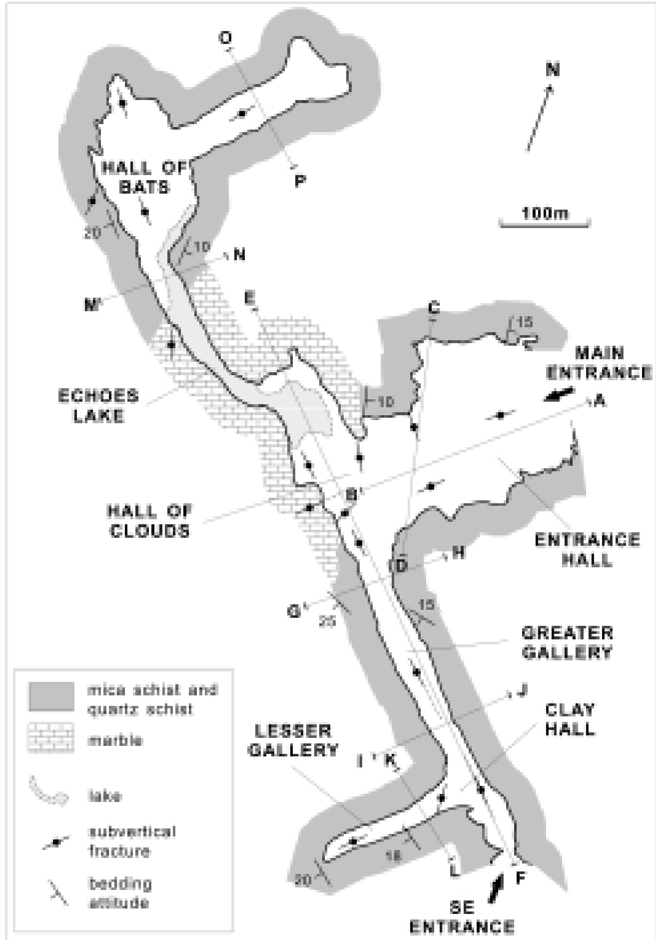

Figure 3. Geospeleologic map of Caverna dos Ecos.

southern tributary of the Maranhão River, which itself comprises part of the headwaters of the Tocantins River (Fig. 1). The region is hilly, between 450 and 1200 m in altitude, with very broad, flat divides and symmetrical valleys predominantly with convex slopes.

A geomorphologic feature typical of the region (and of great importance for understanding the timing of speleogenesis) is the lateritic crust that developed during the Sul-Americano erosional cycle (King 1956; Braun 1971) and gave rise to vast planar surfaces, dissected and incised by Holocene and earlier erosional processes to produce tabular relief.

The Caverna dos Ecos lies within the Cerrado Morphoclimatic Dominion (Saber 1977), typified by open scrub and savanna with two distinct seasons, one cool and dry from May to September, and the other warmer with irregular rain between October and April. Annual rainfall is ~1500 mm and mean annual temperatures are between 19º-22ºC.

The cave developed within metasediments of the Mesoproterozoic Canastra Group (Fig. 2), regionally made up of muscovite schist, muscovite-chlorite schist, calcschist, quartz schist, and garnet-biotite schist, with subordinate lenses of calcitic and dolomitic marble (Schobbenhaus *et al*. 1975; Marini *et al.* 1984). Dardenne (2000) estimates the age of sedimentation between 1200 and 900 Ma and regional metamorphism between 800 and 630 Ma for the Araxá and Canastra Groups in this region.

The schistosity of the metasediments in the area is associated with low-angle reverse faults, as well as with recumbent folds whose axial planes dip SW from 20º-30º with NE-directed tectonic transport. Farther to the east, the Canastra and Araxá Groups override the slate, metasiltstone, and metalimestone of the Paranoá Group (Fig. 2).

CAVE MORPHOLOGY

Caverna dos Ecos exhibits a total linear length of 1600 m and a depth of 140 m. There are two entrances, the main one to the NE and the other to the SE (Fig. 3 & 4). In plan view the cave exhibits an orthogonal rectilinear pattern of conduits following two main directions. In cross section the ceilings are domed, typical of breakdown profiles (Fig. 4). Except in the area of the lake and in some parts of the large conduits, the primary morphology of solutional enlargement has been completely modified by collapse processes.

The cave floor is dominated by 1-m or even 10-m blocks of mica schist and quartz schist that have fallen from the ceiling. Lower in the cave, close to the lake, great fallen blocks of carbonate occur. Fine-grained detritus, partly external in origin, partially covers blocks and the lateral portions of the lowest parts of the galleries and halls. Such sediments totally cover blocks in Clay Hall.

The roof and floor of the cave are generally parallel. Lengthwise in the Entrance Hall and in the southeast entrance to the cave, the roof roughly follows the slope of the pile of fallen blocks. In the Greater and Lesser Galleries, roof and floor are approximately horizontal, as can be seen in the map

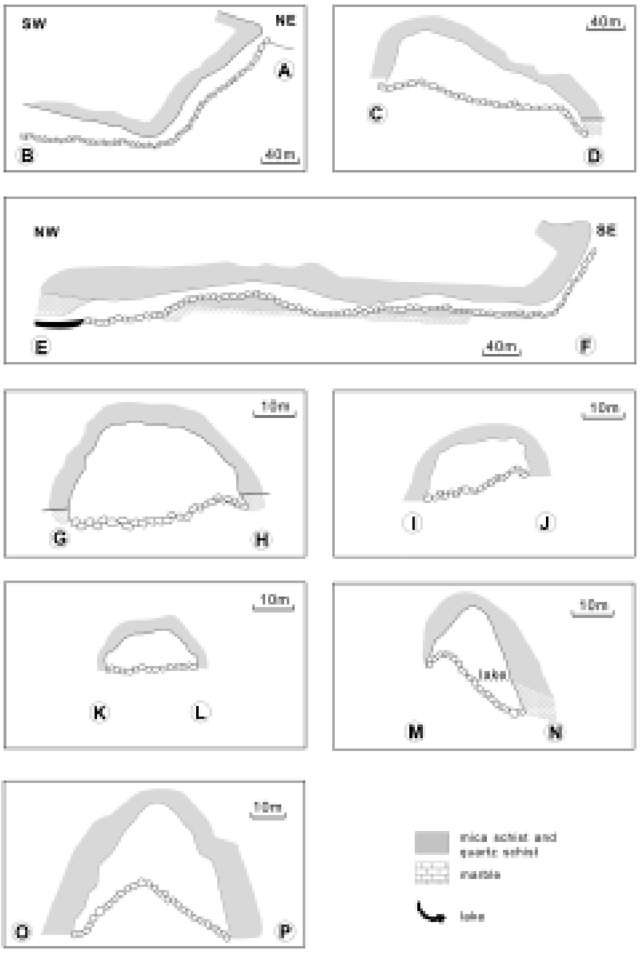

Figure 4. Cross-sections of the cave. See figure 3 for location of sections.

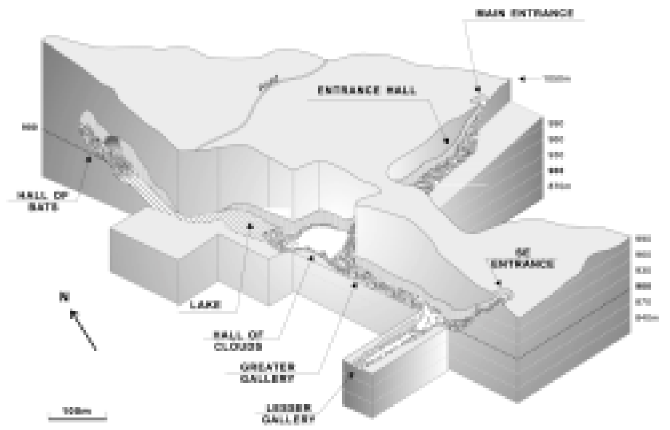

Figure 5. Block diagram of Caverna dos Ecos. Altitude in meters indicated along right side of diagram. Vertical lines represent walls of the cave.

and cross sections in figures 3 and 4.

A subterranean lake, 280 m long, 2-50 m wide, and 10 m deep in July 1980, stretches between the Hall of Clouds and Hall of Bats (Fig. 5). Water depth varies, as the lake is known not only to have dried up but also to have completely filled its gallery, cutting off access to the northwest portion of the cave. An annual variation of 2 m has been observed. The bottom of the lake consists of limestone blocks covered by fine, white calcite and quartz sand. The water is crystal clear, and currents are not evident.

Geology of the Caverna Dos Ecos

Lithology and Structure

The geologic section in figure 6 schematically shows the lithologies observed along the walls of the galleries and halls of the cave. Two distinct units are apparent: upper metapelites and metapsammites and lower metacarbonates. Chlorite schist, predominant in the upper unit, is made up of chlorite, muscovite, biotite, and quartz, with such accessory minerals as tourmaline, epidote, pyrite, albite, and calcite. Intercalated subordinate quartz-chlorite schist and muscovite quartzite within the predominantly pelitic succession provide evidence of original bedding. Contacts between these strata are gradational. The quartz-chlorite schist contains rotated porphyroblasts of chlorite with quartz at their centers, representing garnets altered by retrograde metamorphism. Quartz-bearing marble and muscovite-bearing marble comprising the lower unit are made up of carbonate (calcite and dolomite), muscovite, and quartz. Two distinct beds of fine-grained black marble rich in organic matter and tiny pyrite crystals stand out in this part of the section.

Schistosity is concordant with bedding in both the schists and the marbles with the principal foliation (bedding and schistosity) striking approximately N60º-70ºW and dipping 15º-20ºSW. In the marbles, foliation is expressed by the flattening and recrystallization of carbonate grains. Common tight to isoclinal folds have axial planes parallel to bedding, attesting to a phase of transposition and shearing during generation of the schistosity. Fold axes associated with transposition have horizontal attitudes near N80ºE. Later deformation produced crenulation cleavage expressed locally as undulations on the principal foliation surface.

Fracture Systems

Various sets of fractures (Fig. 7 & 8) are recognizable along the walls of the cave. A set with steep NW and SE dipping beds that strike N30º-50ºE, almost perpendicular to the principal axis of the cave, is prominent in both the metapelites and the carbonates. Fractures of this set are closely spaced (from 0.1m to several meters apart), commonly filled by quartz, and evident for lengths of 1-10 m in the marbles, principally near the lake (Fig. 3 & 8).

Sets oriented N30º-40ºW and N70º-80ºW are represented by unfilled subvertical fractures that are few in number but rather extensive within the cave. These sets are continuously evident for the entire extent of the roof of the Greater Gallery

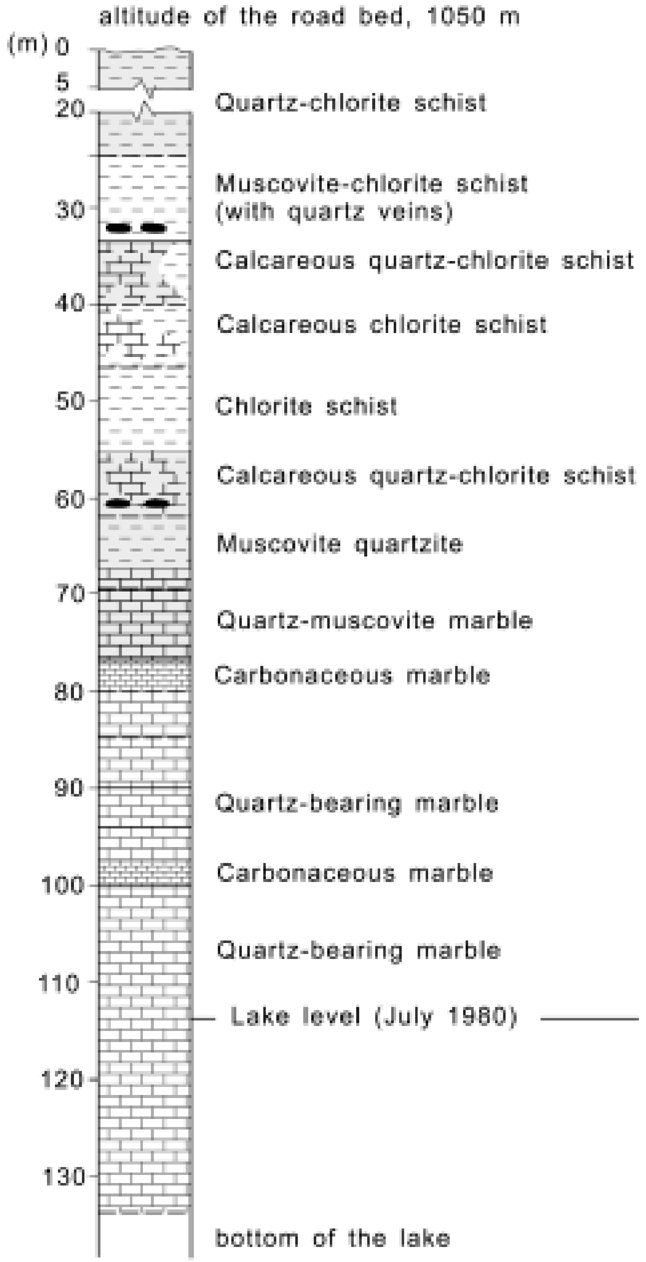

Figure 6. Lithologic columnar section for the cave.

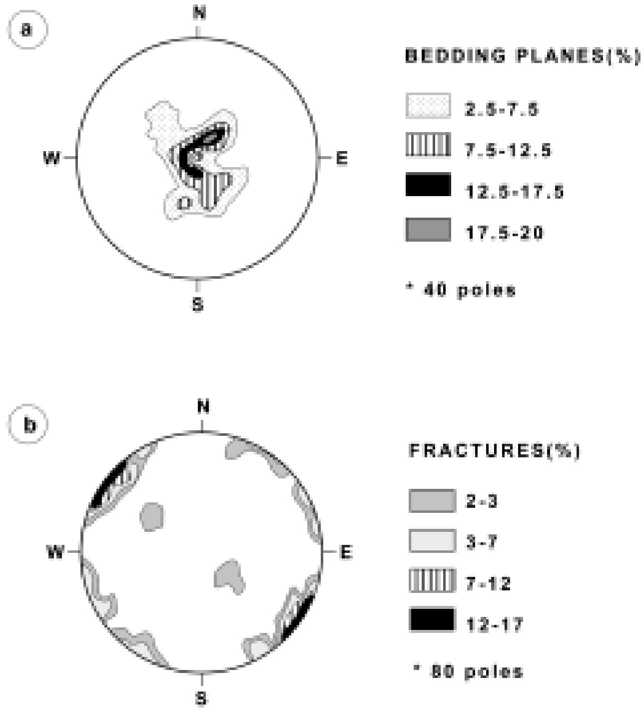

Figure 7. Wulff net stereographic projections for: (a) bedding planes and foliation and (b) fractures in as measured within the cave.

(Fig. 3). Quartz-filled fractures of the N70º-80ºW set, oblique to the cave walls, stand out in relief due to carbonate dissolution, whereas fractures of the N30º-40ºW set, paralleling the principal direction of cave development, although visible on the roof, cannot be observed along the walls. Despite the greater abundance of structural data for the N30º-50ºE fractures oblique to the main direction of cave development (Fig. 8), aerial photographs of the area of the cave at a scale of 1:60,000 reveal the regional importance of linear topographic features (Fig. 9; interpreted as disruptive subvertical planar structures) exactly paralleling the primary direction of development (N30º-40ºW), with a secondary direction oriented N40º-50ºE, parallel to the secondary direction of development.

SPELEOGENESIS

The genesis of Caverna dos Ecos can be differentiated into two principal phases according to the traditional model (Bögli 1969). The first phase (phreatic initiation and development) took place under phreatic conditions and resulted in the opening of conduits along discontinuities in the carbonates. In the second phase (vadose development), collapse occurred under vadose conditions while phreatic dissolution processes continued deeper within the carbonates. The change from one phase to the other was related to regional epeirogenic uplift.

The first phase is evidenced by phreatic dissolution features, such as tubular "wall pocket" cavities (Bretz 1942), observed principally along the walls of the Greater Gallery and along the margins of the lake, where phreatic dissolution is still active. There, "boxwork" structures (Bretz 1942) appear as the carbonate dissolves away, revealing intersecting platy, microcrystalline quartz-filled fractures in relief.

Given that phreatic dissolution of carbonate occurs along the paths of greatest groundwater flux (Bögli 1978; Ford & Ewers 1978), the opening of phreatic conduits in Caverna dos Ecos most likely began along the lines of intersection between bedding planes (and foliation) in the marble and the two principal sets of fractures described above. Their intersection produces N35ºW lineations plunging gently SE and N40ºE lin-

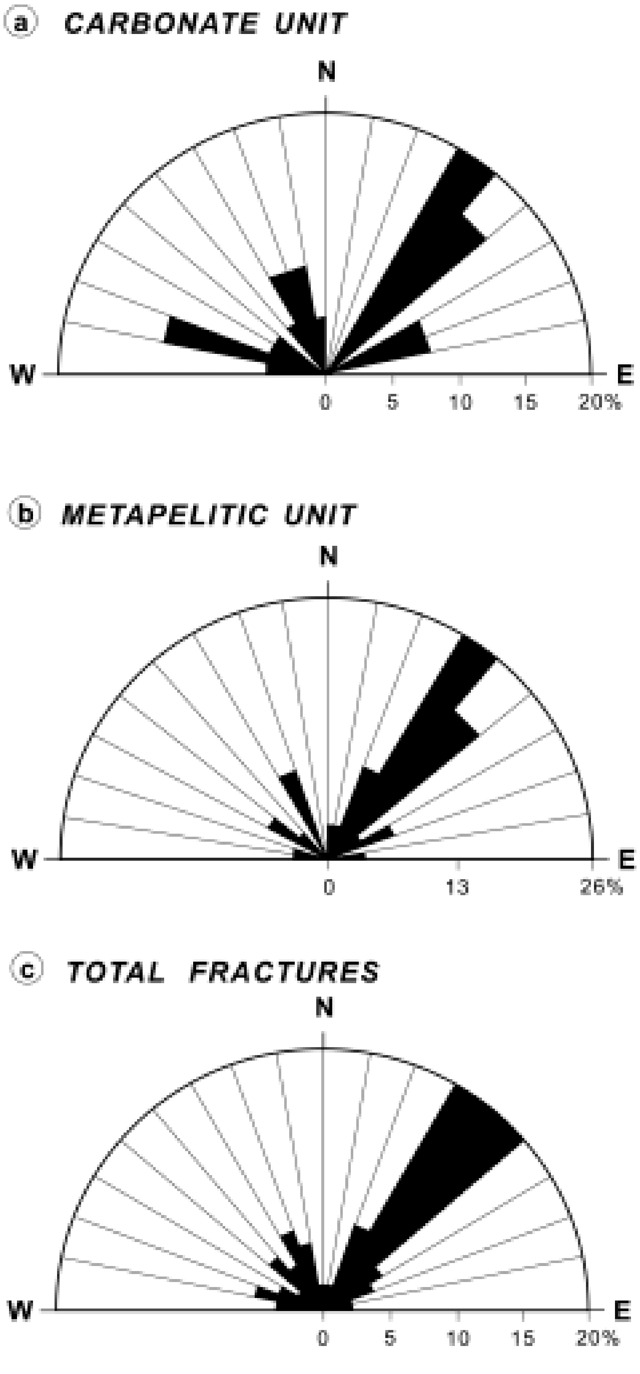

Figure 8. Rose diagram of vertical to subvertical fractures observed in Caverna dos Ecos.

eations plunging S10º-20ºW (Fig. 10), that are exactly collinear with the major and minor axes of cave development, respectively. This is strong evidence that the opening of proto-caves began along these lines of intersection. As these conduits enlarged by dissolution, and water flux gradually increased, the principal fracture and bedding planes in the carbonate layers themselves began to open up, thereby giving rise to ever larger phreatic conduits.

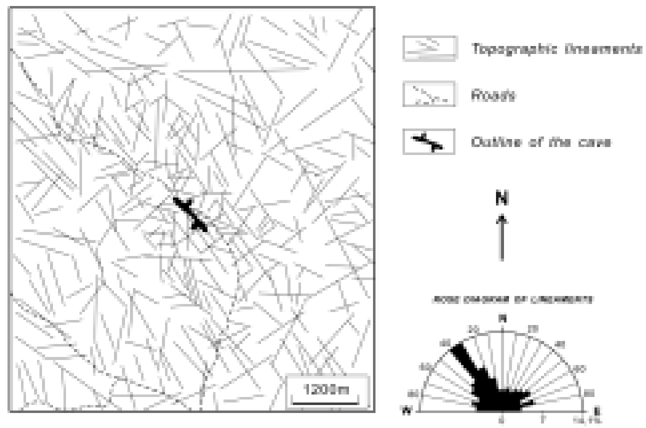

Figure 9. Topographic lineaments traced from aerial photographs of the study area (1:60,000 scale, USAF 1964).

The second phase began when the original phreatic cavities started to drain, withdrawing considerable support (potentially up to 42% according to Warwick 1976) from the roof. This led to physical accommodation through the process of breakdown, in which roof blocks delimited by the fracture system and bedding planes collapsed to the floor. Phreatic cavities began to drain when local valleys deepened due to regional epeirogenic uplift and surficial erosional processes intercepted the phreatic level of the cave. As local base level changed, phreatic dissolution continued ever deeper within the carbonates below the water table. These processes correspond to typical covered-karst speleogenesis.

GEOMORPHOLOGIC CONTEXT OF CAVE DEVELOPMENT

The geomorphologic history of central Brazil during the final part of the Mesozoic and the Cenozoic was one of slow uplift of the South American Platform, as deduced from the relatively low elevations of this region and partially quantified by recent fission-track analysis in apatite (Amaral *et al*. 1997). Superimposed upon this general tendency for uplift were two periods of peneplanation, first recognized by King (1956) on the basis of comparison and correlation of the topographic relief of southern Africa and eastern Brazil.

The older period was responsible for the development of the most extensive and most nearly horizontal planation surface in Brazil, known as the Sul-Americano Surface. The duration of Sul-Americano erosion is not well defined. Nevertheless, by identifying sedimentary deposits correlative with erosion and on the basis of correlation with southern Africa, Braun (1971) attributed the peneplanation phase of the Sul-Americano cycle to sometime between the Eocene and Pliocene, ending with deposition of the extensive Barreiras Group along the coast in the Tertiary (Neogene).

Peneplanation and aggradation of the Sul-Americano Surface were interrupted by an uplift event resulting in the Velhas cycle of King (1956), evidenced by the dissection of

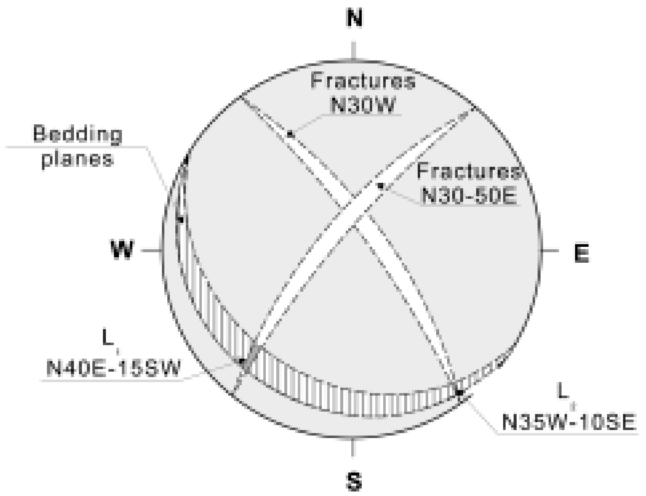

Figure 10. Wulff net stereographic representation of the intersection between main fracture sets and bedding planes showing the collinear relationship between the lines of intersection (L1 and L2) and the main axes of cave development.

both the Barreiras sediments along the coast and the detrital-lateritic cover in central Brazil. This cycle gave rise to the main drainage pattern presently observed in central Brazil and continues to this day. Based on geochronology of the Barreiras Group along the coast (Braun 1971), but without equivalent data available for the interior of Brazil, the beginning of this cycle is placed somewhere within the Pliocene or Pleistocene. There are suggestions that this cycle may have begun first along the coast, perhaps in the Miocene (Valadão & Dominguez 1999), subsequently extending further into the country.

In previous studies, Karmann (1994) has shown that large phreatic volumes in other caves in the state of Goiás are related to slow cratonic uplift in the same manner as the Sul-Americano surface. We interpret the large phreatic volumes of Caverna dos Ecos in a similar manner. Thus, we correlate initiation and development of phreatic cavities, the first phase of speleogenesis of Caverna dos Ecos, with peneplanation and aggradation of the Sul-Americano Surface, sometime between the Eocene and Pliocene, following King's (1956) suggestion for the initiation of calcareous caves of the State of Minas Gerais. Later generalized uplift associated with the Velhas cycle (beginning in the Pliocene or Pleistocene) led to the installation of the present-day drainage pattern, gradually lowering the water table and draining the phreatic conduits within the carbonates, subjecting them to vadose conditions. This initiated the second phase of speleogenesis, marked by the instability of the open spaces and modification of the conduits by breakdown. Upward propagation of open spaces through a series of roof collapses eventually breached the surface, allowing access to the present-day Caverna dos Ecos.

CONCLUSION

Caverna dos Ecos represents an isolated feature of covered karst that developed within mica schist, micaceous quartzite, and marble of the Proterozoic Canastra Group. An initial phreatic phase of cave formation opened up conduits along the intersection of bedding planes with two sets of subvertical fracture planes, one oriented N30º-40ºW and the other N40º-50ºE. A second phase greatly enlarged cavities under vadose conditions as a result of the collapse of phreatic conduits due to the mechanical instability of the rock mass as a result of the lowering of the water table. The first phase may be correlated with the formation of the Sul-Americano Surface sometime between the Eocene and Pliocene, the second phase began with the Velhas cycle in the Pliocene or Pleistocene and continues to the present.

Besides being one of the largest Brazilian caves developed in areas without karst topography, the Caverna dos Ecos is also important as a reminder of the potential problems and danger of carrying out large construction projects above undetected caves in non-karstic terrains. Hence, thorough investigation of the subsoil is necessary in order to detect large subterranean cavities prior to initiating major civil engineering projects in terrains occupied by the extensive Canastra Group in central Brazil. It is, thus, significant that other smaller caves have been reported in the same geological context from areas under consideration for power plant construction in this region (Augusto Auler, pers. comm., December 2000).

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