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BASE-LEVEL CHANGES INFERRED FROM CAVE PALEOFLOW ANALYSIS IN THE LAGOA SANTA KARST, BRAZIL

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The interpretation of flow marks in relict cave passages in two drainage basins in the tropical karst of Lagoa Santa, East Central Brazil was used to characterize past flow routes. Comparison with present groundwater flow deduced from dye tracing was performed in order to assess the evolutionary history of the karst drainage basins. Samambaia Basin's dry caves show that paleoflow in this basin was directed towards other local base levels, suggesting that some fluviokarst features in the basin were generated in a later stage. Paleoflow analysis in the Palmeiras-Mocambo Basin shows that flow direction has not changed significantly since the genesis of today's dry caves. Relict caves can provide useful clues on the paleohydrology of karst areas.

The Lagoa Santa karst area contains two major drainage basins, both possessing underground and subaerial components. Samambaia and Palmeiras-Mocambo basins drain distinct plateaus containing well-developed karst landforms. Although located a few kilometers apart, the basins show distinct paleoflow patterns, suggesting dissimilar histories of drainage basin evolution. A comparative developmental history can be inferred from the analysis of dissolution features in relict caves located inside each basin's boundaries. Local variations in paleoflow direction at the downstream part of Samambaia Basin contrast with the more straightforward evolution of Palmeiras-Mocambo Basin. The data suggest base-level changes during the development of Samambaia Drainage Basin.

The study area is located at Minas Gerais state, East-Central Brazil, about 40 km north from Belo Horizonte, the state capital (Fig. 1). The area lies inside the limits of the municipalities of Lagoa Santa, Matozinhos and Pedro Leopoldo. Several villages occur throughout the area. Limestone quarrying together with agriculture and cattle farming are the main economic activities in the region.

The local geology comprises sequences of Upper Proterozoic limestone of the Sete Lagoas Formation, Bambuí Group, laid over gneiss and migmatite. The karst develops mostly over calcitic limestone with subhorizontal lamination. The limestone is about 200 m thick in the karst plateaus. Cave development is controlled mostly by N75º-85ºE and N-S joints (Beato et al.,1992). Soil cover occurs over most of the karst area. Phyllite and gneiss mark the western limit of the area.

Two major karst plateaus concentrate most of the karst landforms. These elevated areas are separated by a large valley known as Mocambeiro Depression, containing several water-table lakes and a distinct drainage basin. Samambaia Creek and its tributaries drain the southeasternmost karst plateau, whereas Palmeiras-Mocambo Creek drains the karst plateau to the northwest (Fig. 2). The area has a tropical climate with nearly 90% of the yearly rainfall concentrated between October and March. The mean annual rainfall reaches 128 cm at Pedro Leopoldo meteorological station. The mean annual temperature and humidity are 23°C and 68% respectively.

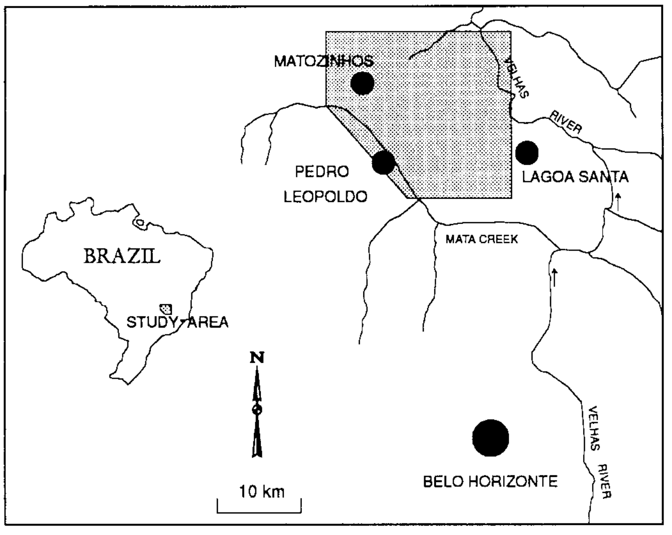

Figure 1. Location map of the study area.

KARST HYDROLOGY

Auler (1994) has made a hydrogeological characterization of the area. Most of the karst water is autogenic, originating as rainfall infiltrating into the limestone. Small allogenic contributions come from the areas of phyllite. Total runoff in the

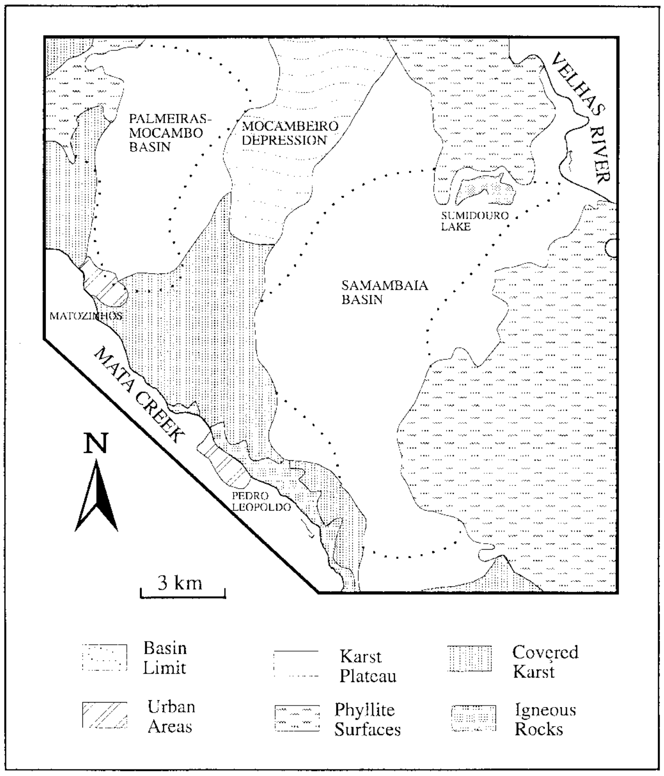

Figure 2. Main physiographical features in the Logoa Santa Karst.

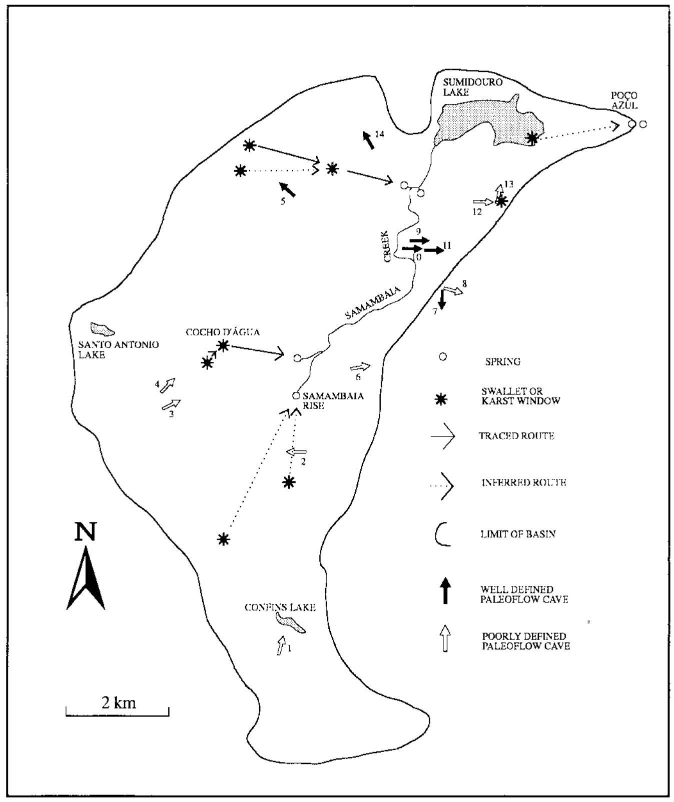

Figure 3. Dye tracing and cave paleoflow results at Samambaia Basin. Caves analyzed are: 1. Galinheiro, 2. Entrada Alta, 3. Borges, 4. Encanação, 5. Baú, 6. Mãe Rosa, 7. Monjolo I, 8. Monjolo II, 9. Lapinha I, 10. Lapinha II, 11. Lapinha III, 12. Corredor de Pedra, 13. Labirinto Fechado, 14. Buraco do Frederico.

karst as measured in springs varies between 1.8 m^3/s for the dry season to about 3.15 m^3/s during the wet months. Velhas River to the northeast is the major base level, draining about 88% of the karst water. The remaining 12% drains towards Mata Creek in the southwest. Dye tracing and discharge measurements have determined that Samambaia and Palmeiras-Mocambo are the largest karst drainage basins in both surface area and discharge. Groundwater flow occurs mainly along joints and lamination bedding, in accordance with the hydraulic gradient.

Samambaia Basin

The Samambaia catchment area comprises around 60 km^2 (Fig. 3). The basin's upper section probably includes a large underground catchment area that eventually drains into Samambaia Creek rise. Much of the incoming flow concentrates in four springs along the creek's margin. Samambaia creek has a subaerial run of ~8 km, flowing through a shallow valley limited by gentle soil-covered slopes with some limestone outcrops. The creek discharges into Sumidouro Lake, which is subject to intense evaporation. Sumidouro Lake has a short underground course probably heading toward Poço Azul Spring, located a few meters from the Velhas River channel. Total discharge of the springs that feed Samambaia Creek range from 0.3 m^3/s during the dry season to 0.7 m^3/s during the wet season.

Palmeiras-Mocambo Basin

The catchment area for this basin is about 30 km^2. The recharge area includes part of the town of Matozinhos as well as some highly karstified surfaces to the north. The watershed receives water from three different sources (Fig. 4): some small convergent sinks that feeds Bom Jardim Lake, the sink of Palmeiras Creek and the creek at Zé Irene Sinkhole. Except for a small contribution from phyllite surfaces at the source of Palmeiras Creek, all the water comes from diffuse infiltration into the limestone. These three branches have both subaerial and underground sections, discharging at Mocambo Spring. From here, the Mocambo Creek flows through fluviokarst valleys into Velhas River.

The Palmeiras-Mocambo Basin shows a highly segmented drainage route with numerous karst-windows along its course. Subaerial sections occur along the bottom of large collapse sinkholes (karst windows). The discharge at Mocambo Spring varies between 0.4 and 1.0 m^3/s for dry and wet seasons, respectively.

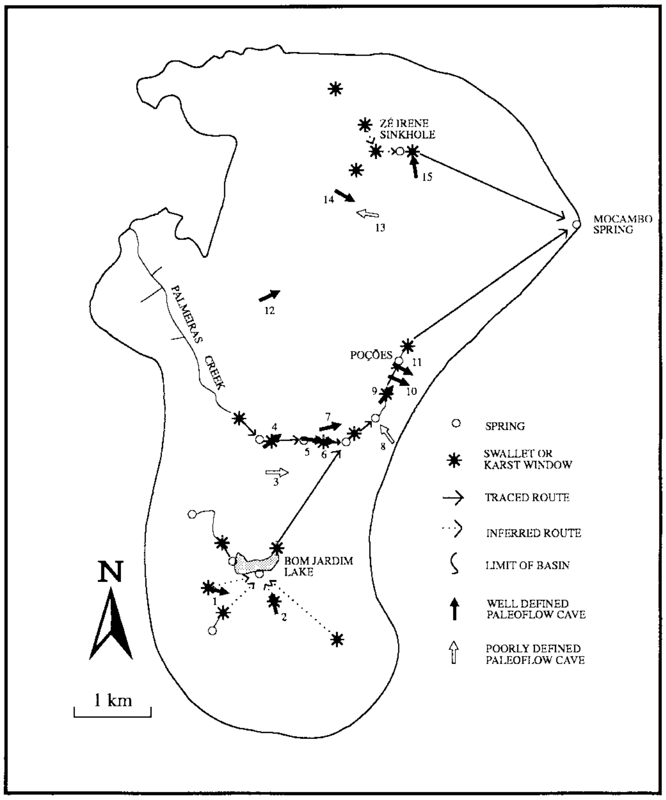

Figure 4. Dye tracing and cave paleoflow results at Palmeiras-Mocambo Basin. Caves analyzed are: 1. Faustina, 2. Boca, 3. Itapucú, 4. Milagres, 5. Periperi I, 6. Periperi II, 7. Pallet, 8. Chapéu, 9. Poções, 10. Poções Cliff I, 11. Poções Cliff II, 12. Escadas, 13. Caieiras, 14. Cacimbas, 15. Esquecida.

PALEOFLOW ANALYSIS

Over 300 caves have been identified in the Matozinhos-Pedro Leopoldo Karst. Lakes play a significant role in the speleogenesis in the area (Auler, 1995). According to Piló (1986), 55% of the caves in the area are dry, aborted from the regional hydrology. Observed hydrological processes inside some of these caves are restricted to dripping from percolation water or invasion runoff during severe storms. The dry caves usually have entrances associated with cliff walls, located above valleys and sinkhole floors. The caves are fragments of larger systems, dissected by surface lowering or by clastic and chemical sediment chokes. They show a complex history of paragenetic development followed by sediment removal.

Solutional forms in the relict caves can provide useful information on the paleohydrology and evolution of an area (Kastning, 1983; Lauritzen, 1982). Scallops have long been recognized as indicators of paleoflow direction in caves (Coleman, 1949). Studies of paleohydrology based on analyses of scallops have been performed in some settings, especially in the Mammoth Cave area, Kentucky, USA (Drake & Borden, 1981 and White & Deike, 1989). Theoretical equations and the hydraulic mechanics of the development of scallops are given by Curl (1974) and Gabriel (1986). Moreover, scallops can potentially be used to estimate drainage-basin area (Lauritzen, 1989).

Observations made in 47 caves inside both drainage basins allowed the determination of the general flow directions of the past. It also provided an insight on the relative evolution of the two karst drainage systems. The studied caves did not experience a synchronous evolution, having become dry at different periods. Absolute ages for cave development have not yet been determined.

In this study, analysis of several sections of cave walls were performed in the sampled caves. The longest possible section of cave passage was always considered in the determination of flow direction, in order to avoid non-representative data from segmented meanders. In some caves, the walls are smooth and scallops are not well defined. Dissolution by water vapor or under a covering of sediment may have played a role in masking scallop morphology.

Preservation of scallops in the dry caves is highly variable. In some caves scallops are not visible at all, whereas in others, the direction of paleoflow varies, suggesting backflooding or changing directions. Some caves show non-prominent scallops where flow direction was determined with some uncertainty. The remaining caves have a well defined paleoflow direction, due to well preserved scallops.

Flow directions were plotted on the maps of the drainage basins as distinct single vectors for either well defined paleoflow caves or poorly defined paleoflow caves, together with the cave reference number. Non-defined paleoflow caves were not taken into account. Due to the segmented nature of many caves, paleoflow vectors were assumed to be acceptable representations of ancient flow directions. Present groundwater flow routes were also represented as approximations, based on inputs and outputs of dye traces. Dye tracing was performed using fluorescein and is described in detail in Auler (1994).

SAMAMBAIA BASIN RESULTS

Figure 3 shows the paleoflow directions in Samambaia Basin. In the upstream section, the paleoflow of the caves studied (1,2,3 & 4) match well with the present underground hydrology. However, the downstream section shows some anomalies, with the paleoflow not pointing towards Samambaia Creek, the present local base level. Flow in some caves, such as caves 6, and 8 to 12 point toward the present regional base level, Velhas River, whereas others (caves 5 & 14) are directed toward the Mocambeiro Depression to the west. Caves 7 and 8 are located just outside of the presumed boundary of the existing drainage basin.

PALMERIRAS-MOCAMBO BASIN RESULTS

Paleoflow in this basin is represented in Figure 4. The great majority of the paleoflow indicators are directed in accordance with the present active hydrogeological routes. In the upstream section, the flow in all analyzed dry caves agree with the existing flow directions. The sole exception occurs in the downstream section of the basin for cave 13 (a cave with poorly defined scallops). Some caves located in the eastern side of this basin (caves 10 & 11) show paleoflow pointing toward the Mocambeiro Depression.

DISCUSSION

Paleoflow data for the downstream part of Samambaia Basin (Fig. 3) shows that there is little concordance between the present-day hydrology and past flow routes. Some caves (5 & 14) point toward the Mocambeiro Depression, showing that the positions of the water divides between the Samambaia Basin and the Mocambeiro Depression basin were perhaps located to the east in the past. Other caves (6,9,10,11 & 12) near Samambaia Creek have paleoflow toward the present location of Velhas River. It seems likely that the Samambaia Creek did not represent a significant base level at the time of genesis of these caves. The groundwater paleoflow does not correlate with the present position of the creek, but is directed instead towards other basins (Mocambeiro) or straight to Velhas River. Figure 5 represents the observed major paleoflow trends at Samambaia Basin. The data suggest that some features of this basin, especially in the downstream section, may be more recent in age.

The dry caves at the Palmeiras-Mocambo Basin (Fig. 4) show a concordant paleoflow direction when compared to the present routes. The general drainage flow pattern has not changed much within the area of the basin. There is convergent paleoflow in the upstream part of the basin and more uniform flow directions with some tributaries (cave 8 for example) in the downstream section. The data show no evidence of a major allogenic paleostream entering this basin as had been suggested by Kohler (1989). The data from active and dry caves point toward multiple autogenic input points that formed the basin in both past and recent times.

CONCLUSIONS

Although located near to each other and having been subject to the same lithologic and climatic controls, the Samambaia and Palmeiras-Mocambo basins have a rather distinct developmental history. Palmeiras-Mocambo Basin seems to be a more mature drainage basin, in the sense that its flow pattern at the time of genesis of today's dry caves closely resembles the present flow pattern. In contrast, the morphology of Samambaia Basin is probably more recent owing to the fact that several dry caves are related to either another distinct local base level (such as the Mocambeiro Depression drainage basin) or to the regional base-level (Velhas River).

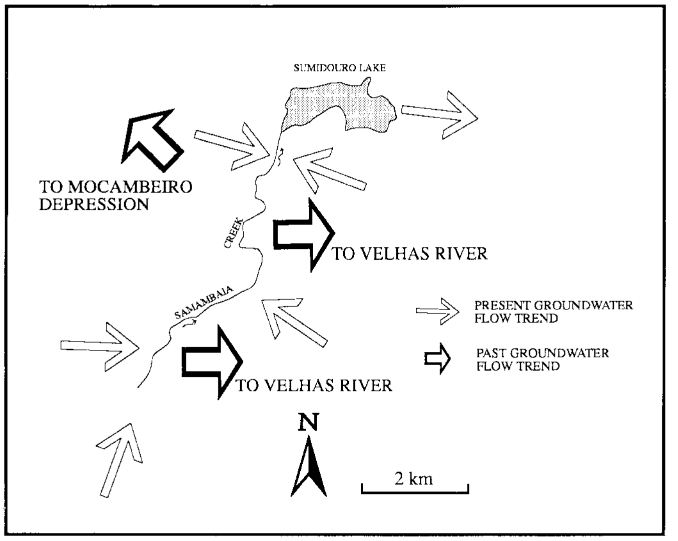

Figure 5. Trends of present and past groundwater flow at Samambaia Basin.

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