Karst in granitic rocks, South Cameroon: cave genesis and silica and taranakite speleothems

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ABSTRACT

A cave in granitic rocks was studied in Mezesse, South Cameroon. Coralloid speleothems, draperies and dissolution traces on the cave walls attest to its truly karstic nature. The speleothems consist of microlayers of opal and taranakite $(K,NH_4)Al_3(PO_4)_3(OH).9H_2O$. They indicate a significant mobilization of silica, Al and K from granite during the formation of the cave. Identification of silicified bacteria in the speleothems layers suggests a possible role of these micro-organisms in silica deposition. The presence of taranakite and of silicified organic remains within the speleothems lead to a better understanding of the genesis of the cave.

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Introduction

Karstic morphologies in noncarbonate rocks have been described around the world (Renault, 1953; White *et al.*, 1966; Conrad *et al.*, 1967; Marescaux, 1973; Busche and Erbe, 1987; Willems *et al.*, 1996), but their genesis is only partially understood. Few caves have been observed in granitic rocks (Ollier, 1965; Urbani and Szczerban, 1975; Bunnel and Richards, 1977; Kastning, 1977; Shaw, 1980; Finlayson, 1982; Rodriguez, 1992). Different hypotheses have been proposed for their formation: regolith erosion between residual boulders (Ollier, 1965); mechanical desegregation of the granite as a result of preferential chemical weathering along altered fracture zone (Kastning, 1977) or along easily dissolved siderite veins under warm climates; coalescence of tafonis (Anderson, 1930) or simple widening of fractures under cold climates (Sjöberg, 1969). The occurrence of speleothems in these granite caves is quite rare (Webb and Finlayson, 1984).

The cave at Mezesse, South Cameroon, is developed within a calc-alkaline granite massif. It contains siliceous speleothems as well as draperies and significant chemical dissolution traces on the walls (honeycombs). Detailed geomorphological and mineralogical analyses of the cave and its siliceous deposits were carried out in order to determine the processes involved in the development of this true granitic karst.

In this paper, the term 'karst' is used to mean 'one or several morphologies characteristic of the traditional karstic series: cave, clints (karren), pits… in the genesis of which dissolution plays an essential role' (Willems, 2000).

The Mezesse cave

The Mezesse cave is located about 30 km south of Yaoundé, on the northern margin of the Congo craton where several calc-alkaline granites of Archean age outcrop (formed 2.6 Ga) (Toteu *et al.*, 1994; Tchameni *et al.*, 2000). The landscape is a 600–800-m-high plateau strewn with domed hills covered with degraded equatorial forest. The Mezesse hill is one of them. Its top and its southern slope exhibit metre-scaled depressions (solution pans, kamenitza), some being developed along fractures. Clints (lapiaz) can be seen on the steeper sides of the hill.

In that area, the rock is cross-cut by a network of subvertical and subhorizontal curved fractures, corresponding, respectively, to strike-slip faults and to decompression joints of the granitic massif. The cave is on the northern edge of the hill where subrounded blocks of up to 10 m are dismembered by the fractures (Fig. 1C).

The north-western and south-eastern parts of the cave (Fig. 2) show morphologies related to the widening of decompression joint-planes (Fig. 3-A,C). The vertical walls of the fractures and parts of the ground display 'honeycomb' alteration (Fig. 1E). In places, draperies are developed (D, Fig. 3C; Fig. 1F). Collapsed blocks from the roof cover the floor of the cave and are covered by mosses and bat excrement. Traces of water seepage are observed on the ground in several places.

In the central part, the cave widens and the roof consists of dm-scale monoliths (Figs 1A and 3B) whose internal faces show blade morphology (L, Fig. 3B; Fig. 1B). The floor comprises angular collapsed rocks that partially cover the lower part of the cave. Under this collapse is a conduit, a few metres in length and ≈ 50 cm in diameter, which follows the strongest slope of the cave (C, Fig. 3B). Its walls are fluted overhanging to the main channel and are covered with coralloid speleothems (Fig. 1D) described in this paper. This is probably an old pressure flow tube.

Methods

Thin sections of the coralloid speleothems were studied under polarized light microscope.

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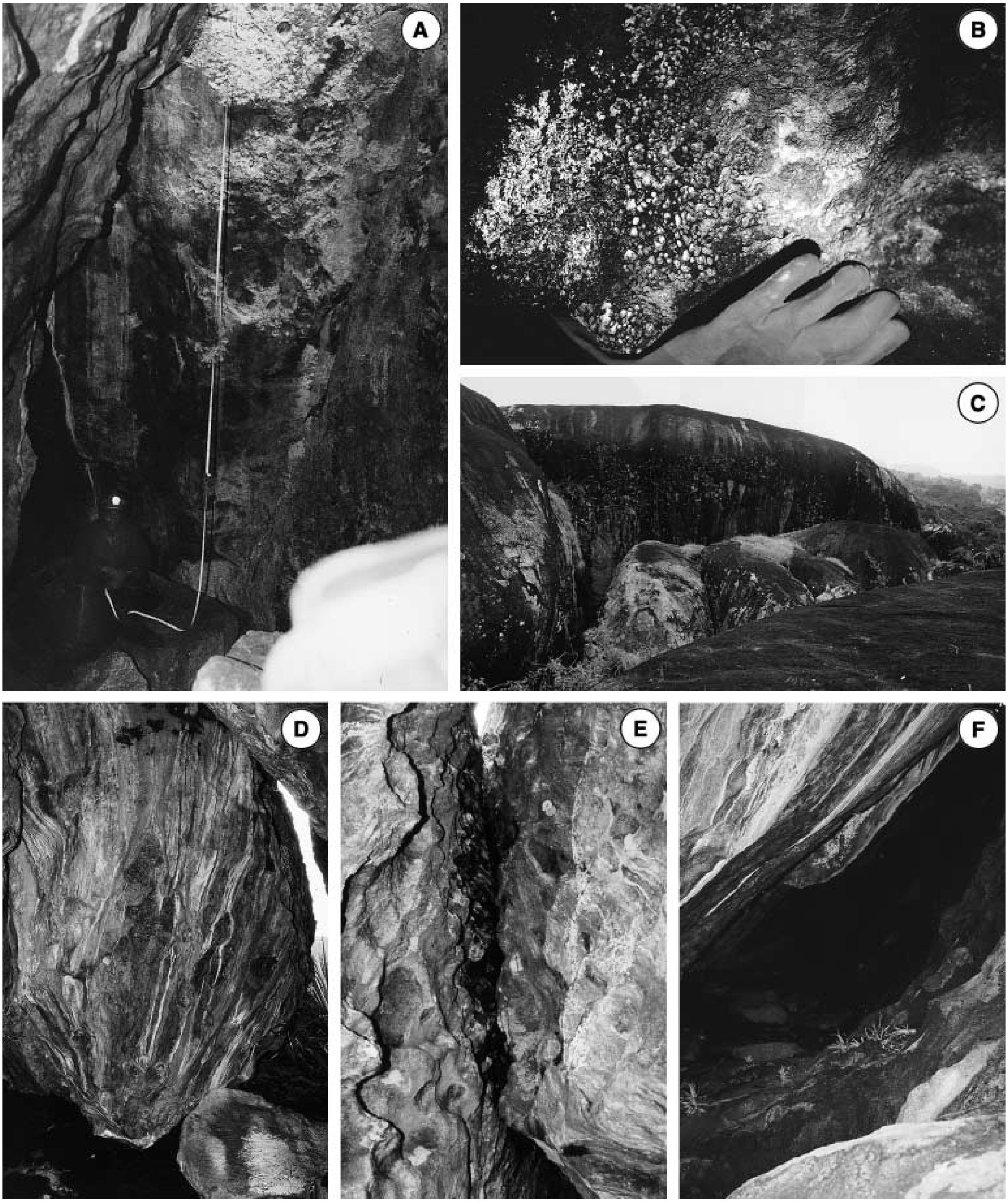

Fig. 1 Views of Mezesse cave. (A) Central part of the cave with the main shaft (Fig. 2A). (B) Coralloid speleothem analysed in this paper. (C) Upper blocks of the Mezesse hill, forming the roof of the Mezesse cave. (D) Central block (as in B) with razor sharp edge morphology viewed from the central part of the cave. (E) Honeycomb morphology in a vertical fissure. (F) Drapery in the east part of the cave.

Selected polished sections, as well as hand-broken raw samples, were examined after Au/Pd coating with a scanning electron microscope (SEM) (JEOL JSM-840 A) under 20 kV accelerating voltage. The chemical composition of the speleothems was determined by Energy Dispersive X-ray Spectrometry (EDS). The

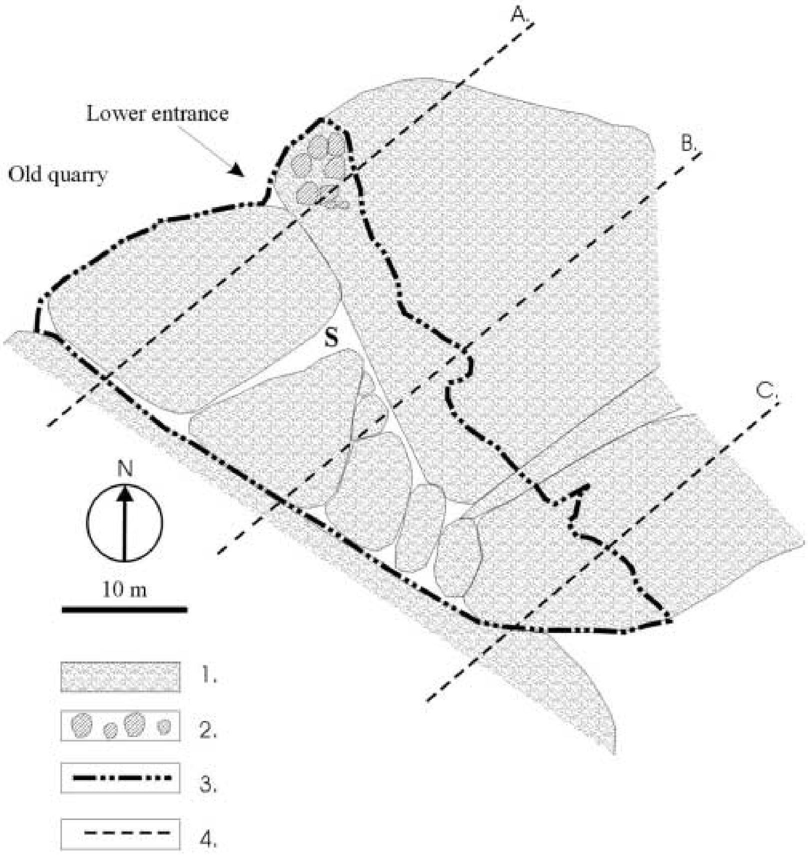

Fig. 2 Map view of the Mezesse cave. South Cameroon (from Willems, 2000). 1, surface rocks; 2, collapsed blocks inside the cave; 3, limits of the cave; S, main shaft; A,B,C, cross-section lines of the Mezesse cave (see Fig. 3).

minerals were identified by X-ray powder diffraction. The X-ray powder diffraction pattern of taranakite was recorded on a diffractometer equipped with a graphite monochromator and using FeKα radiation ($\lambda = 1.9373$ Å). The unit-cell parameters were calculated with the least-squares refinement program LCLSQ v.8.4 (Burnham, 1991), with the d-spacings corrected with an internal standard of $Pb(NO_3)_2$. The unit-cell parameters of this trigonal phosphate mineral were calculated from 27 reflections: $a = 8.686(7)$ and $c = 95.98(9)$ Å.

Results

Speleothems were sampled on the conduit walls in the central part of the cave (C, Fig. 3B; Fig. 1B). They are of coralloid type, very friable and only a few millimetres thick. Investigation of polished thin sections in light microscopy shows that the speleothems are made up of concentric layers averaging 10 µm in thickness. Two successive stages of deposition are visible (Fig. 4). The first, in contact with the granitic rock, shows light brown laminae alternating with darker and thinner laminae of rather uniform thickness. The second stage is composed of a succession of yellowish to brown laminae with a similar morphology to those observed in the first stage of the speleothem, but the layers are more irregular.

Contact between the rock and the inner laminae is very sharp. The wall rock does not show any traces of alteration. The deposit penetrates rock fractures for 1–2 mm. Some

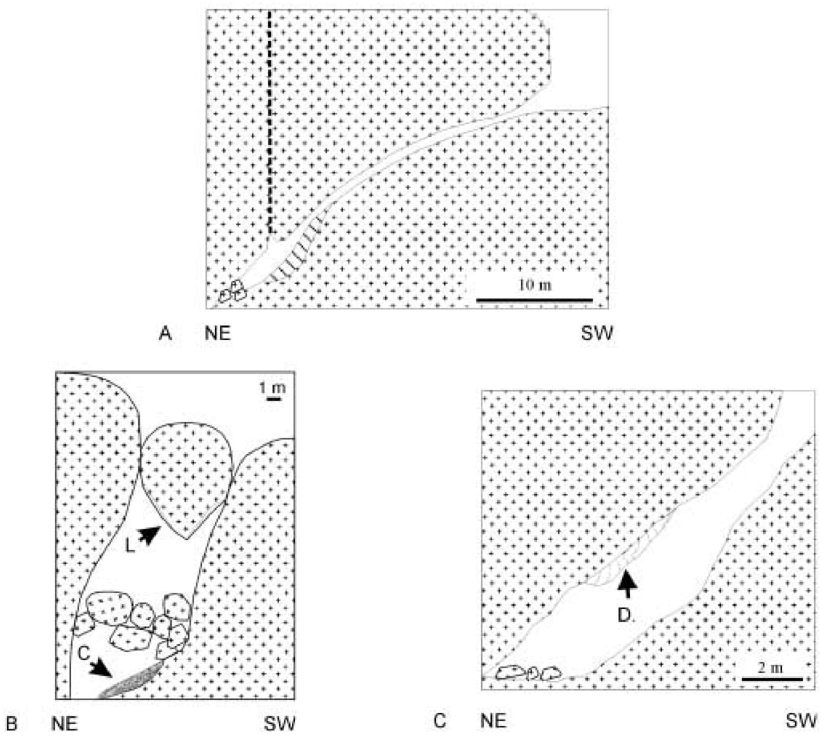

Fig. 3 Vertical section of the central part of the Mezesse cave at three different positions (A,B,C), shown in Fig. 2. L, plurimetric monoliths whose internal face shows a razor sharp edge morphology; C, conduit and coralloid speleothems; D, drapery.

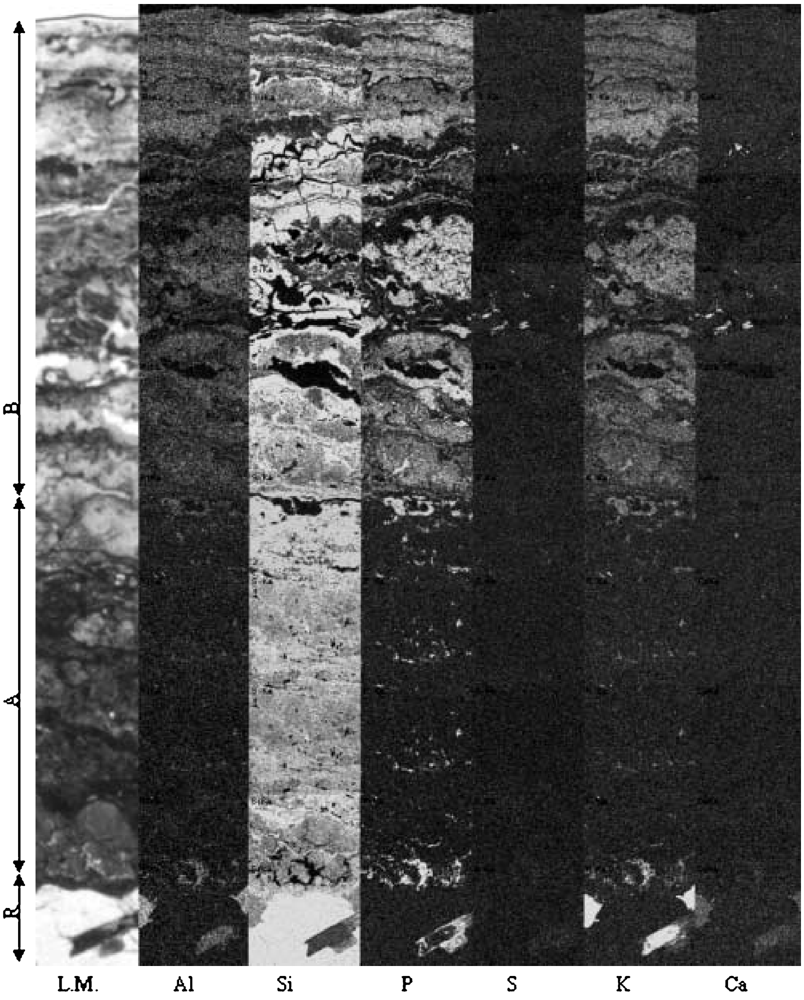

Fig. 4 Light microscopic view and SEM elemental maps of a speleothem. L.M., optical view; R, rock wall; A, first stage of deposit; B, second stage of deposit (scale bar = 100 μm).

layers, mainly in the peripheral layers, include detrital particles and fresh biotite crystals. Stromatolitic-like structures with a millimetric relief and a lamination thickened towards the centre are developed mainly within layers of the second speleothem stage (Fig. 5A). A higher magnification reveals that these stromatolitic laminations include non-dichotomic filaments 4–8 mm in diameter, attributable to microbes (Fig. 5B).

SEM observations show that the external surface of the speleothems is composed of unstructured detrital material. This material often covers a network of shrinkage cracks that affect the peripheral layers of the speleothems. Microalveoli are found between or in the laminae and are generally more abundant in the second speleothem stage. These microalveoli are covered with microcrystals. Filaments found in the speleothem periphery are also present. Organic remains such as spores, pollens and leaf are observed in some layers (Fig. 6).

Energy-dispersive X-ray microanalyses (Fig. 4) show that silicon is the main element in the inner layers of the speleothems (Fig. 4A). The amorphous material observed in the silica-rich layers is constituted by opal-A, with a broad and diffuse peak at about 3.9 Å on its X-ray powder diffractogram. The isotropy of these layers confirms the amorphous nature of this material. The outer layers are (Fig. 4B) characterized by an alternation of Si layers and layers both containing Si, Al, P and K. Zones rich in Ca and S are noticeable and correspond to the anhydrite or gypsum crystals coating the microalveoli. Organic remains, observed by SEM, are silicified. X-ray diffraction shows that the layers containing Si, Al, P and K consist of taranakite $(K,NH_4)Al_3(PO_4)_3(OH).9H_2O$. Because Si is in all layers, the precipitation of silica must have been continuous and independent of that of taranakite.

Discussion

Formation of speleothems

The 'honeycomb' walls and the morphology of the floors and of the conduits in the cave attest to the undeniable role of dissolution in the genesis of the cave. Coralloid speleothem analyses provide information on the conditions of the cave formation. Coralloid speleothems found in limestone caves are usually associated with two types of environments: subaerial or more or less subaqueous (Hill and Forti, 1997). The pressure flow tube morphology of the conduit, in the Mezesse cave supports a vadose genesis for the speleothems.

The formation of siliceous speleothems must have occurred under conditions of a fluctuating water level. Presumably, the water was fairly stagnant and renewed at each rain season. This genesis is similar to that observed for certain pedogenic silicifications at the base of voids, where solution circulation is slow or stagnant (Paquet and Clauer, 1997).

The relatively regular alternation of taranakite layers and of amorphous silica in the second speleothem stage suggests a certain periodicity in the genesis of the speleothems. Taranakite, also found in limestone caves, usually results from the interaction between phosphate-rich solutions derived from bat guano and clay minerals in the permanently wet substrate (Fiore and Laviano, 1991). In the Mezesse cave, each layer of this mineral indicates an annual leaching of guano in the upper part of the cave during the rainy season. This is in accordance with the recent discovery by Genty (1992) that the laminated structure of carbonated stalagmites frequently reflects seasonal alterna-

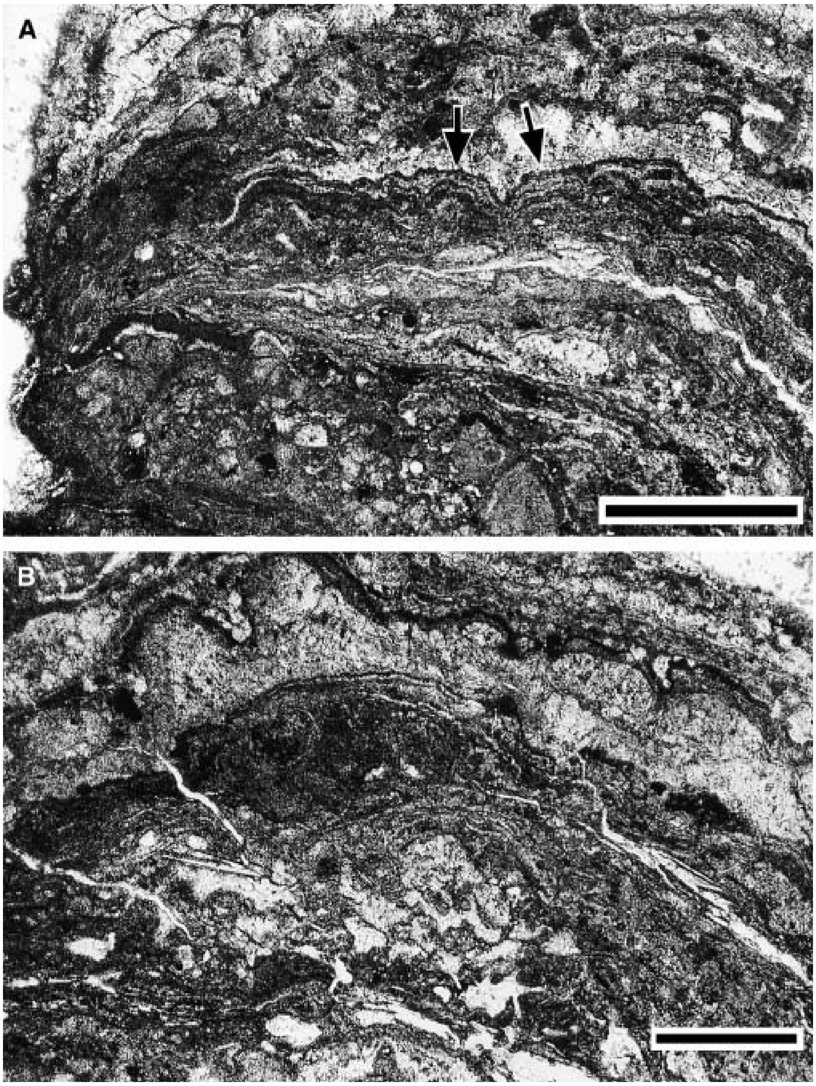

Fig. 5 (A) General view of speleothem showing the domes and the organic lamination (thin section, polarized light, scale bar = 500 μm). (B) Close-up of domical and lamination (scale bar = 250 μm).

tions. During the dry season, silica continues to precipitate. A decreased flow prevents any further formation of taranakite because phosphate and clay from the upper part of the karst system can no longer reach the conduit.

Taranakite, which precipitates only at a pH below 3.5 (Haseman *et al.*, 1950, 1951; Filipov, 1978; Fiore and Laviano, 1991; Hill and Forti, 1997), attests to the acidity of solutions passing through the Mezesse system. Thus, rainwater arriving in the upper part of the karst network of Mezesse must have been permanently acid, as it is today (average pH 4.9) (Sigha-Nkamdjou *et al.*, 1998). This acidity is strengthened by percolation through the guano. Physicochemical mechanisms usually invoked to explain the solubilization and precipitation of silica in an acid environment – namely evaporation and decrease in temperature (Finlayson and Webb, 1985) – do not appear sufficient to explain the significant precipitation of silica in the Mezesse speleothems.

Microbial activity is also known to play a role in silica precipitation. The role of such micro-organisms can be fundamental in the concentration and precipitation of silica. Their capacity to produce chemically active polymers or their metabolic activities can lead to localized precipitation by modification of pH or redox conditions (e.g. Chafetz and Buczinski, 1992; Fortin and Beveridge, 1997; Léveillé *et al.*, 2000).

Both the size and morphology of filaments incorporated in the speleothems suggest that they are of bacterial origin. The question is whether they played an active or a passive role. The morphology of the speleothems – the stromatolitic and finely foliated structure, probably the consequence of a mat of filaments – is similar to the spongiostromate structure described by Pia (1927). Sedimentological studies by Walter (1976) have shown that this structure is related to the development, degradation and diagenesis of microbial mats built by bacteria, cyanobacteria or algae. These small speleothems also recall the 'microstromatolithes' observed in cavities from Frasnian reefs, partially built by ferro-oxidizing bacteria (Boulvain *et al.*, 2001). Thus, bacteria probably play an active role in the construction of speleothems and might also control saturation levels of the silica solutions.

Deposition rate of speleothems

The freshness of both feldspar and biotite minerals within both the rock wall and the speleothems is an indicator of the formation rate of speleothems. Biotite and feldspar are highly sensitive to chemical weathering, and usually alter very quickly. This suggests an external origin of those solutions responsible for speleothem formation, and also indicates rapid deposition of the speleothems. Corroborating observations include the sharp contact between the rock wall and the first speleothem layer (cf. Fig. 4), the presence of many vacuoles between or inside the layers, and the presence of organic remains that normally would quickly degrade. The friability of the speleothem material also suggests their relatively recent origin. Subject to erosion, they should be quickly destroyed.

Genesis of the Mezesse cave

Based on the present investigations, the following model is proposed for the genesis of the Mezesse cave. The granitic hill is crosscut by a fracture network related to the shearing and

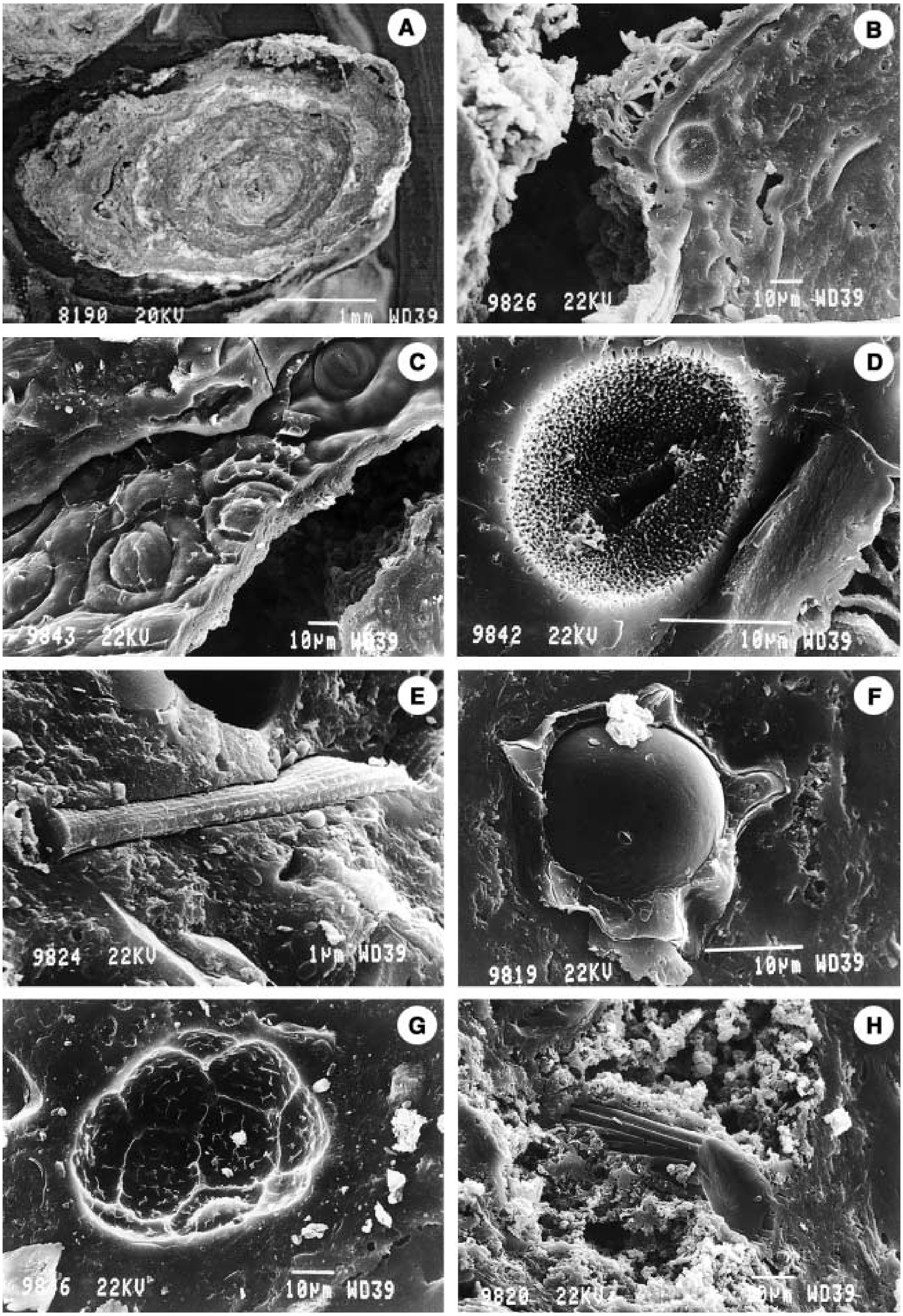

Fig. 6 SEM views of a speleothem: (A) cross-section of a speleothem with concentric layers; (B–H) organic remains or prints of organic remains. The silicified organic materials or their prints incorporated in the speleothem are not yet identified with certainty. Images (D), (F) and (G) show pollens or spores of alga or fungi. Image (C) is a piece of leaf characterized by visible stomata.

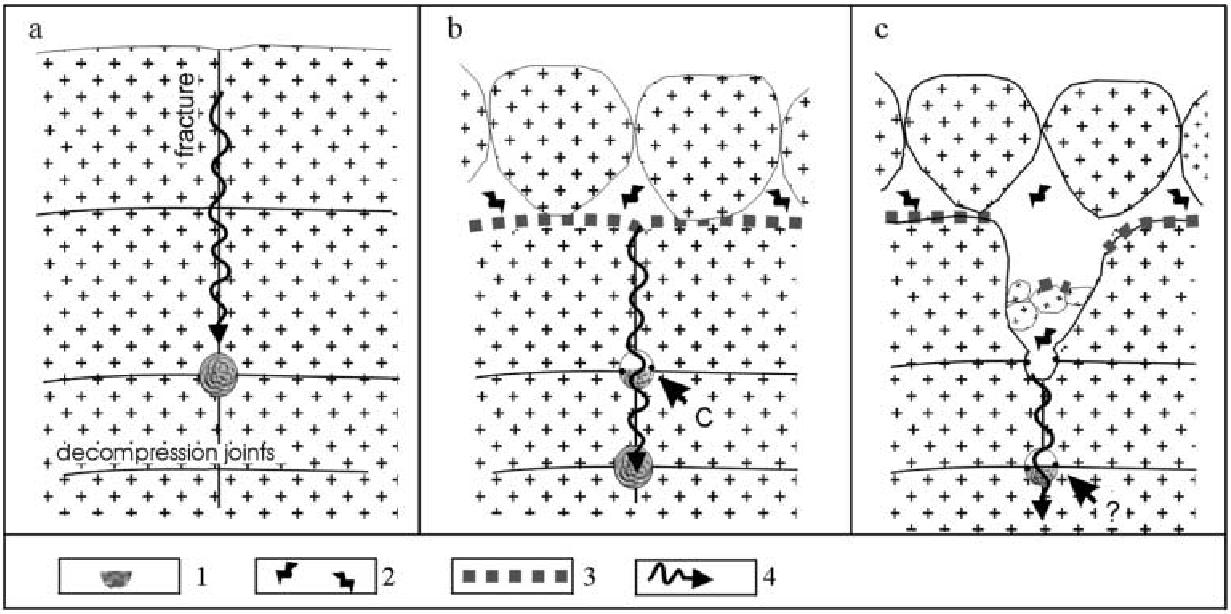

Fig. 7 Stages in the genesis of Mezesse Cave. (a) Initial stage; (b) intermediary stage; (c) current stage. 1, wet conduit; 2, bats; 3, guano deposits; 4, percolation; C, speleothems; '?', hypothetical actual evolution deeper inside the karst system.

the decompression plane of the rock (Fig. 7a). Cross fractures, some tens of metres below the surface, become drainage conduits and pressure flow tubes. The system is relatively closed, without bats and with poor communication to the surface. Seasonal fluctuations in water level occur. The water that arrives in the conduit contains no organic material. Coralloid speleothems, consisting only of amorphous silica, are formed. The silica precipitation could be due to bacteria found in the speleothems.

As weathering continues, the system gradually opens in the upper part of the hill (Fig. 7b). Acid rainwater widens the fractures and isolates certain blocks, which become suspended. The voids created provide suitable habitats for cave-dwellers, notably bats, which deposit guano on the ground. The deeper water conduits are always subject to refill during rainy seasons. However, the solutions arriving there have percolated through the guano. Their acidity increases and causes the periodical precipitation of taranakite, possibly in relation to rainy seasons. In parallel with wider upper channels, the arrival of the solutions is faster and is marked by a more irregular deposition of the various speleothem layers. The system opens more and more (Fig. 7c) and locally collapses. Some conduits are destroyed. The upper part of the network drains and water streams all the way to the bottom of the current cave.

Speleothems, now entirely exposed, cease growing. Their surfaces thus only react periodically during fluctuating moisture in the cave atmosphere. Air movements, produced by bats, suspend dust, which adheres to the speleothem surfaces. The speleothems are partially desiccated, giving rise to desiccation cracks on their surface. Anhydrite or gypsum crystallizes in the microalveoli and on the external surfaces of the speleothems. Deeper conduits are currently developing below the bottom of the current cave. Their evolution is similar to that of the now opened and accessible conduits.

Conclusions

Observations in the Mezesse cave developed in granitic rocks confirm its karstic nature. Water circulation, chemical weathering, mechanical erosion and speleothem formation are similar features to those encountered in many limestone karsts. Analyses of siliceous speleothems suggest their rapid formation with a significant mobilization of silica from granite during the opening of a karst system. Taranakite and silica speleothems indicate that periodical precipitation tracks alternation of dry and wet seasons. The occurrence of bacterial filaments within the speleothems and the stromatolitic structure of some speleothem layers suggest that these microorganisms may have played a role in the silica and taranakite deposition. Many thanks to professor James Boles for his suggestins for improvement.

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