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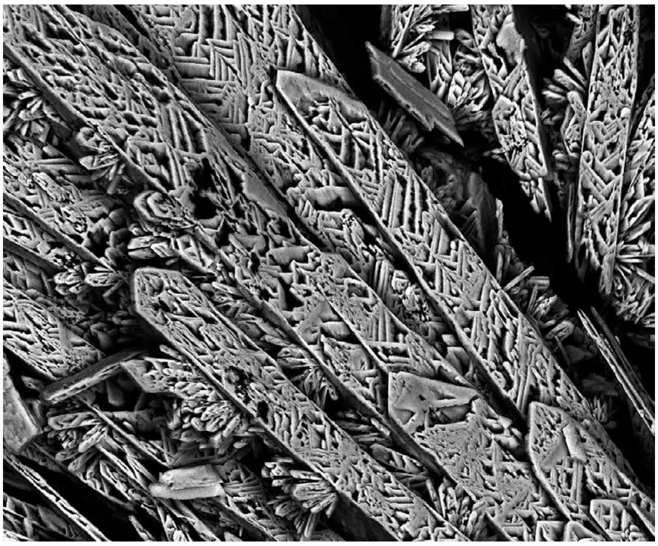
VOLUME 3



Edited by

Michal Filippi
Pavel Bosák

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BRNO 2013
CZECH REPUBLIC
WHERE HISTORY MEETS FUTURE

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Cover photos (some photos were adjusted/cropped)
Top left – Specific carbonate speleothem decorations in the Ghost Chamber, Sima de la Higuera Cave. Photo by V. Ferrer. For details see the paper by F. Gázquez and J.-M. Calaforra.
Top right – A challenging exploration in the Cueva de los Cristales. Mexico. Photo by La Venta Exploring Team and Speleoresearch & Films. For details see the paper by F. Gázquez et al.
Bottom left – An example of a microcrystalline grained halite speleothem, the Octopus formation in the 3N Cave, Qeshm Island, Iran. Photo by NAMAK team. For details see the paper by Filippi et al.
Bottom right – Internal skeleton structure of cryogenic gypsum crystals caused by the presence of partitions oriented parallel to the faces. For details see the paper by Kadebskaya and Tchaikovsky.

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Contents

AN INTRODUCTION TO SRI LANKAN GNEISS AND GRANITE CAVES

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Commencing in 2008 with a focus on caves in metamorphic terrains, the project Cave Science Sri Lanka has investigated forty-eight caves. Thirty-seven caves have been mapped by the Sri Lankan members of the project, twenty-five have been investigated in more detail and samples have been collected from twelve caves for analysis. In addition to rockshelters, boulder caves, tectonic caves and carbonate karst caves developed in marble and dolomite four distinct types of caves, Tunnel Caves, Block Breakdown Caves, Arch Caves and Network Caves have been recognised in Proterozoic gneiss and Cambrian granite in Sri Lanka. While previous workers have suggested that these caves have either formed in what was called gneiss but was really carbonate rock, or are the spaces left behind in the granitic rock after bodies of carbonate rock were removed, field evidence suggests that phreatic solution of granitic rock and/or formation and removal of phantomized granitic rock play a significant role in speleogenesis.

1. Introduction

Sri Lanka is a continental island located off the southern tip of the Indian subcontinent. Geologically it is a Gondwana fragment with most of the bedrock composed of deformed Proterozoic metamorphic rocks (Fig. 1).

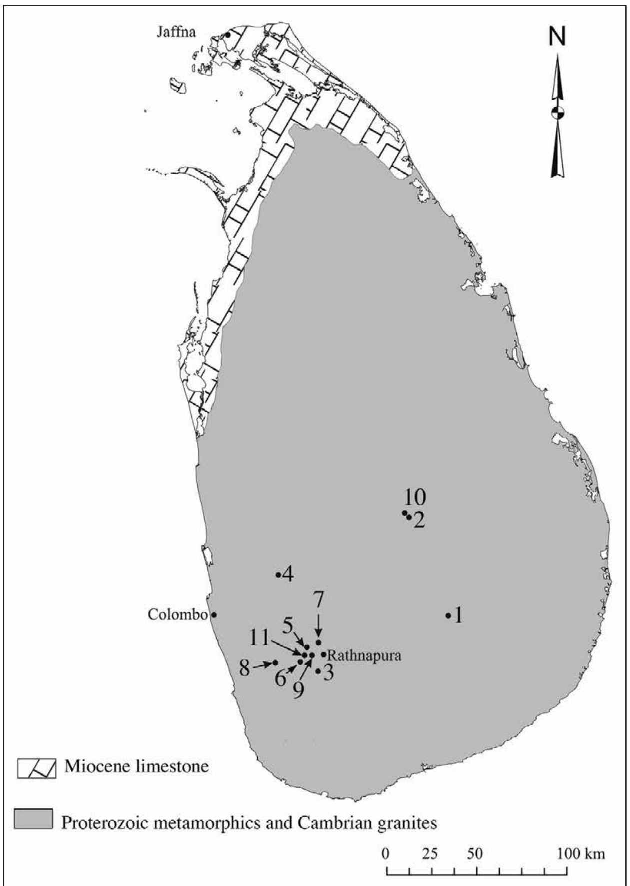

Figure 1. Sri Lanka: 1 = Ravana Ella Cave; 2 = Lunugala Lena Nitre Cave; 3 = Kukuluwa Kanda Rajamaha Viharaya; 4 = Alavala Tunnel Cave; 5 = Batathota Cave & Sthreepura Cave; 6 = Kosgala Vavul Cave; 7 = Batadomba Cave; 8 = Fa-Hien Cave; 9 = Pelpola Cave; 10 = Oil Lamp Cave, Ravana Cave & Twin Cave; 11 = Karannagoda Rajamaha Viharaya.

Sri Lankan caves occur in Proterozoic gneiss, marble and dolomite, Miocene limestone, tufa mounds, and Cambrian granite. There has been little study of Sri Lankan caves except as archaeological sites. A few caves were described by colonial naturalists, Davey (1821) and visiting Europeans: Peet (1945, 1946), Kukla (1958), Siffre (1975) and Brooks (1995a, 1995b), while Gebauer et al. (1996) and Gebauer (2010) provided a cave inventory based on literature research including 310 entries for caves and "cave-like objects" in Sri Lanka. Major Sri Lankan contributions have been by Leiter (1948) who described Nitre Cave and Deraniyagala (1965) who pleaded for international assistance in documenting the caves of Sri Lanka but received no response.

The project Cave Science Sri Lanka, which began in 2008 through the efforts of Dr Wasantha Weliange, is a Sri Lanka–Australia collaboration with the aim of establishing cave science in Sri Lanka by developing local skills in cave exploration and documentation and in scientific research and training. The project is based at the Postgraduate Institute for Archaeological Research, Colombo. The initial focus of the project has been on caves in gneiss and granite as these are significant as archaeological, cultural and religious sites. This research has identified four types of large caves in gneiss; Tunnel Caves, Block Breakdown Caves, Arch Caves and Network Caves.

2. Tunnel Caves

Tunnel caves are a common form of gneiss cave. They are tubes with an elliptical cross-section, which may be horizontal, vertical or sloping depending on the structural setting. Principal axes range in size from 1 to 12 m. Tunnel caves resemble phreatic tubes in karst caves. Large tunnel caves include Ravana Ella Cave (1 in Fig. 1) and Lunugala Lena Nitre Cave (2 in Fig. 1). Some large tunnel caves such as those at Kukuluwa Kanda Rajamaha Viharaya (3 in Fig. 1) are used as temples, one with a large Buddha reclining lengthwise in the cave.

Small tunnel caves form completely in bedrock, but guiding joints that are apparent in the cliff face near their entrance are often not visible inside the cave. It is unclear if tunnel caves begin as true solution tubes or by some other process such as the removal of phantom rock. Spalling from the cave wall is active and appears to be the main mechanism for lateral expansion of these caves.

Alavala Tunnel Cave (4 in Fig. 1) is good example of this type of cave. It is a tunnel 12.6 m long with an elliptical profile (long axis 1 m; Figs. 2A, B) guided by a westerly dipping joint. After about 5 m the cave steps up to the east. The cave floor is composed of bedrock with a hard, black manganiferous coating. Small elliptical pockets are developed in the western wall of the cave. The only sediments in the cave are two small piles of sub-rounded bedrock fragments, one close to the termination of the lower passage ("i" in Fig. 2A) and the other at the far (northern) end of the cave ("iii" in Fig. 2A). There are signs of active spalling in the cave ceiling, but no spall fragments occur on the cave floor. Small remnant deposits of yellow material that may be phantom rock occur on the eastern wall ("ii" in Fig. 2A) and at the northern end of the cave ("iii" in Figs. 2A, 2C).

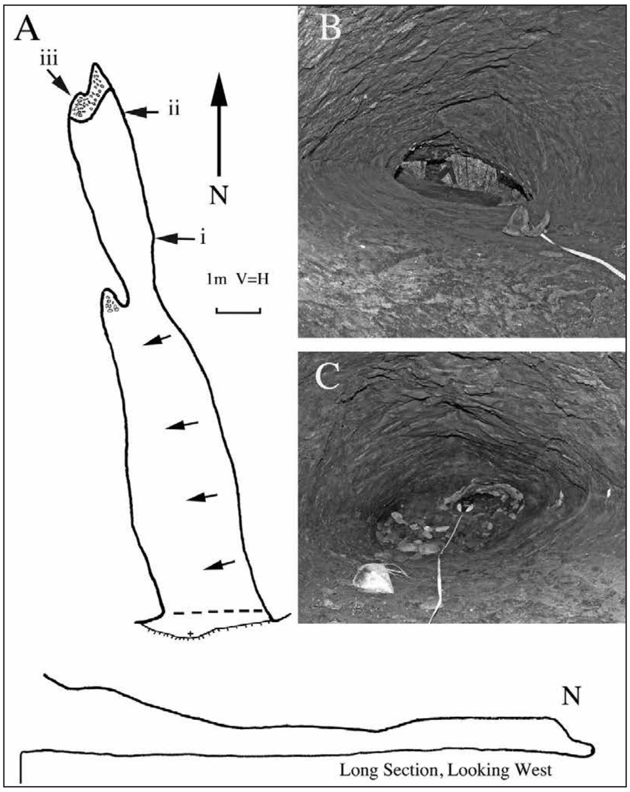

Figure 2. A: Plan and section of Alavala Tunnel Cave. B: Looking south out of Alavala Tunnel Cave note elliptical profile. C: Looking north to end of Alavala Tunnel Cave, note bedrock cobbles and remnant phantom rock (white in B & W image).

3. Block Breakdown Caves

Block breakdown caves are among the larger caves so far investigated in Sri Lanka. They consist of chambers produced by the structurally guided breakdown of gneiss. They are strikingly similar to breakdown chambers in limestone caves. Two block breakdown caves have been investigated in the Rathnapura district, Sthreepura Cave (5 in Fig. 1) a system of breakdown chambers and Kosgala Vavul Cave (6 in Fig. 1) a large single-chamber breakdown cave.

Sthreepura Cave is approximately 80 m long and consists of a series of breakdown chambers formed by failure along pairs of conjugate joints most striking NNW–SSE, but in the Guano Chamber breakdown is guided by NE–SW striking joints (Fig. 3A.) This has resulted in the development of "A-type" ceilings (Fig. 3B).

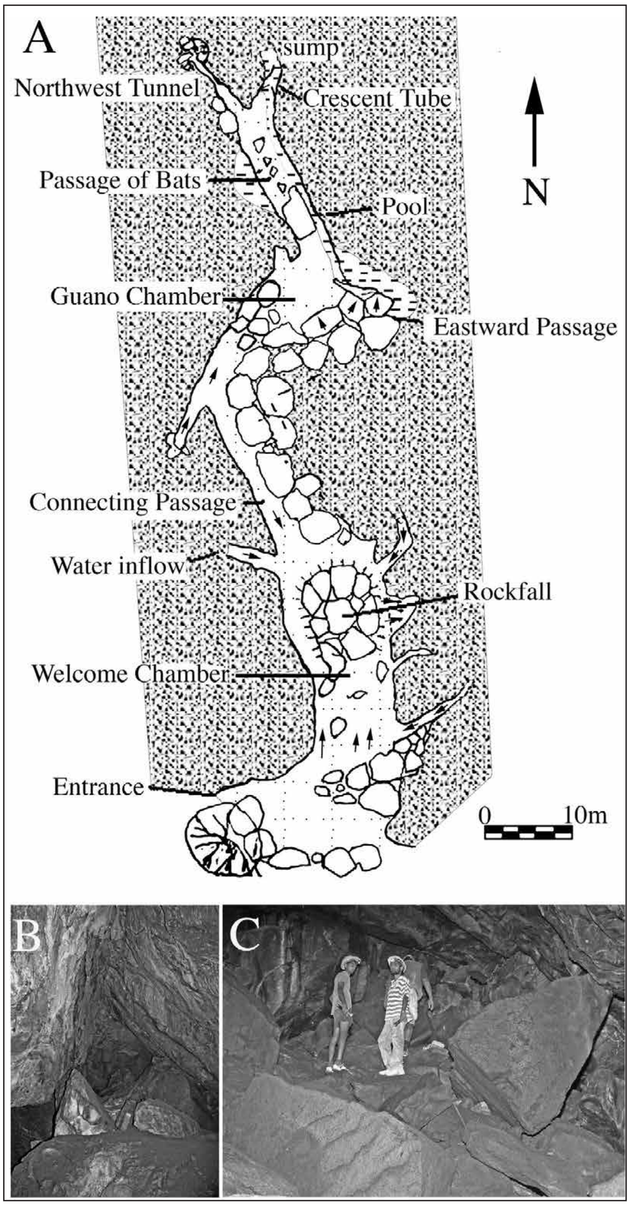

Figure 3. A: Plan of Sthreepura Cave, B: An "A" type ceiling on NNW-SSE joint, connecting passage, Sthreepura Cave. C: Large breakdown blocks Kosgala Vavul Cave.

A remnant half tube is preserved in the ceiling along the axis of the Passage of Bats suggesting that some phreatic-like process proceeded breakdown. A small phreatic tube, the Crescent Tube, extends from the NE corner of the Passage of Bats. Most of the walls, the ceiling and all of the fallen blocks in Sthreepura Cave are composed of gneiss. A small section of the wall and floor in the NW side of Guano Chamber is composed of dolomite. Much of the floor of the cave is covered by dry loose sediment composed of organic silt derived from bat guano and mica flakes derived from the bedrock.

Kosgala Vavul Cave contains breakdown on a much larger scale (Fig. 3C) and like Sthreepura Cave shows remnants of an old small-scale phreatic network with small phreatic tubes exposed as half tubes in joint faces.

4. Arch Caves

Arch caves are large chambers with a triangular-shaped plan and cross-section, their shape and volume makes them ideal for use as temples and as habitation sites. Many such as Batathota Cave (5 in Fig. 1) have been converted into temples and some such as Batadomba Cave (7 in Fig. 1) and Fa-Hien Cave (8 in Fig. 1) are both temples and archaeological sites.

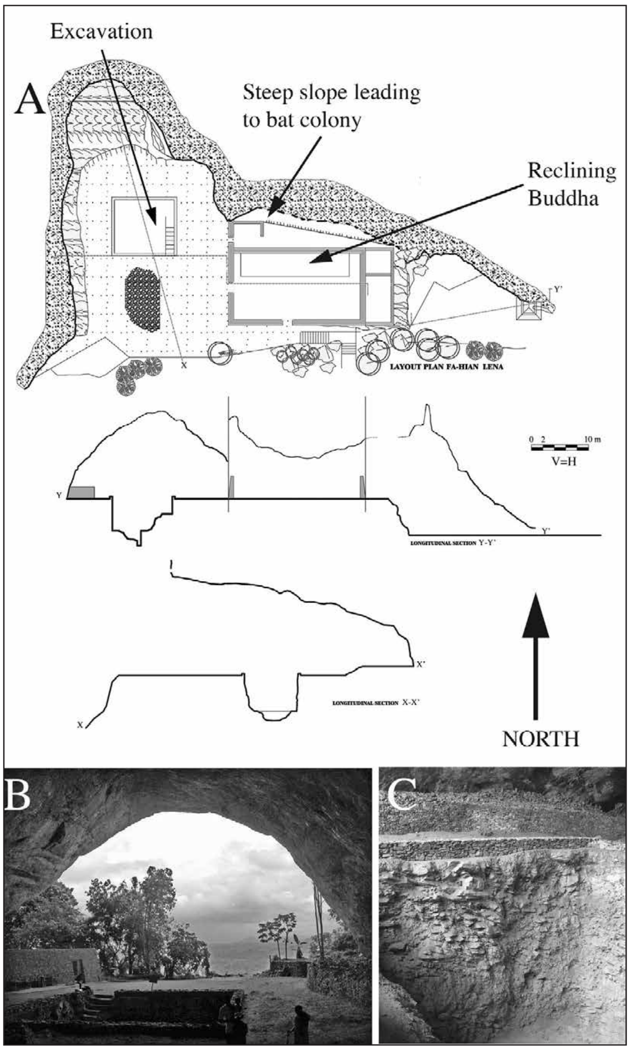

Figure 4. A: Plan and sections of Fa-Hien Cave. B: Looking out through main arch of Fa-Hien Cave, note shape of arch, excavation in foreground. C: Western side of excavation showing relict foliation dipping north.

Fa-Hien Cave is the largest arch cave so far investigated. Its arch chamber is approximately 30 m wide and 14 m high at the entrance and extends 50 m into the rock mass (Fig. 4A). Like other arch caves, Fa-Hien Cave has an arch-like cross section (Fig. 4B).

While the floor of the arch chamber appears to be made of sediment, the exposure in the 6.3 m-deep archaeological excavation shows relict foliation dipping to the north (Fig. 4C). This indicates that the cave floor is not made of fallen matter from the ceiling, as apparently assumed by the archaeologists, but of intensively weathered (? phantomized) bedrock. The base of the excavation reveals a network of small tubes developed in the weathered rock. This has yet to be explored.

Sheet spalling/exfoliation is continuing from the cave walls and masses of spall rubble have been removed from the cave floor and packed around the side of the cave.

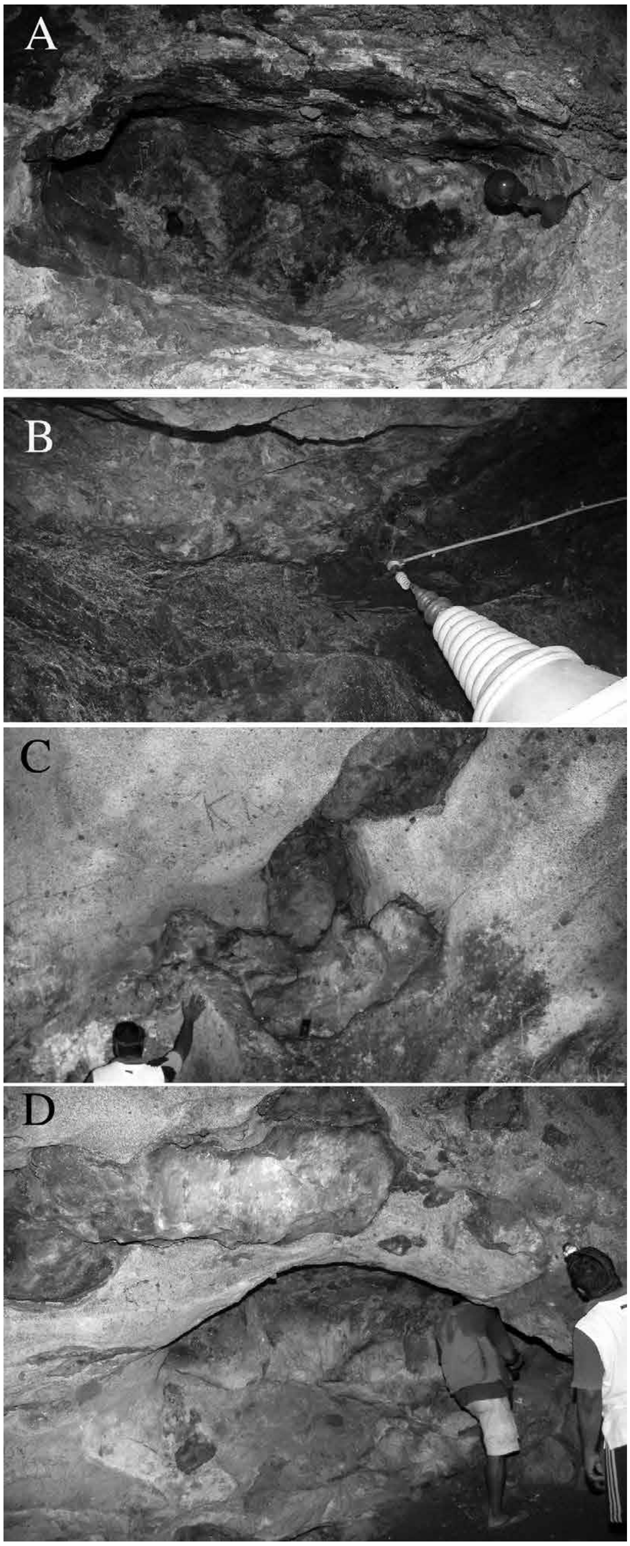

Figure 5. A: Wall pocket, Batathota Cave. B: Ceiling half-tube, Batathota Cave. C: End pocket, Batadomba Cave; lighter rock is gneiss and darker rock is dolomite. D: Ceiling pocket, Batadomba Cave; lighter rock is gneiss, darker rock is dolomite.

The walls and ceilings of arch caves can be quite complex with cupola-like features, wall pockets and ceiling half-tubes developed in Batathota (Figs. 5A, 5B) and Batadomba Cave. The pockets in Batadomba Cave are quite instructive concerning the relationship between speleogens and bedrock. The pocket at the end of Batadomba Cave (Fig. 5C) cuts across both gneiss and dolomite bedrock with minimal effect on its morphology. A similar situation can be seen in Figure 5D where the morphological features below "D" in the image continue with minimal disruption across irregular lithological boundaries.

The origin of these caves remains unclear, while spalling is the main process currently acting to expand the caves, the lack of spall material in the archaeological dig in Fa-Hien Cave suggests that this is probably not the main process involved in cave development over time.

5. Network Caves

Our research so far has focussed on large cavities near the surface and serious attempts at digging in caves have yet to be undertaken, partly because such activities may be interpreted by archaeologists as illegal digs and also because it may lead us to be identified as treasure hunters.

The presence of relict half tubes in block breakdown caves and arch caves and of tubes in the base of the excavation in Fa-Hien Cave, suggests that complex network caves may exist further into the rock mass.

One complex cave with potential for extension by digging is Pelpola Cave (9 in Fig. 1). The entrance to Pelpola Cave is a small collapse doline, much like that seen in limestone karst. At the base of the entrance rubble pile there is a triangular-shaped entrance chamber (Fig. 6A). A passage in bedrock from which mud has been artificially excavated extends downwards from the SE corner of the entrance chamber (1 in Fig. 6A). Figure 6B shows the view looking SE down the passage from "1" in Figure 6A. A profile of the passage is visible in the background showing a triangular upper part and inward-sloping walls in the lower part. After about 10 m an artificial side passage extends to the NE and leads into Treasure Hunters Chamber (2 in Fig. 6A). This chamber has a relatively horizontal bedrock ceiling and a sediment floor, level at the NE end of the chamber that then slopes steeply to the SW. Figure 6C is taken looking east from "2" in Figure 6A. The ceiling above the cavers' heads is composed of siliceous gneiss. The edge of a zone of very large crystals is seen in the upper right corner of the image. The cavers are sitting on a rock shelf composed of dolomite covered by a white mineral paste. There is a large amount of a loose mixture of clay and gravel on the floor of Treasure Hunters Chamber that appears to have been moved from further inside the cave and piled up artificially along the southern edge of the chamber near "3" in Figure 6A. While it was not possible to enter without digging there appears to be a void to the south of "3" and there are indications that the clay/gravel mixture may be retained by timber supports (Fig. 6D). The passage from the Entrance Chamber continues as a trench along the SW wall of Treasure Hunters Chamber and ends in a sediment plug (Fig. 6E). It seems likely that gem miners excavated Pelpola Cave, targeting the clay/gravel mixture as a possible source of gemstones. The clay/gravel mixture appears to be a weathering or alteration product derived from the gneiss bedrock, excavated from further inside the cave.

6. Speleogenesis

While little has been written about Sri Lankan gneiss caves, two explanations for the origin of the caves have emerged in the literature.

The first explanation arises from the idea that if there are caves then they must be in limestone. This idea has been reinforced by Gebauer (2010) locating all caves not in Miocene limestone in "calcareous granulite" or "metamorphosed, crystalline and dolomitic limestone /marble" and by other workers placing caves on dolomite outcrops on low-resolution geological maps.

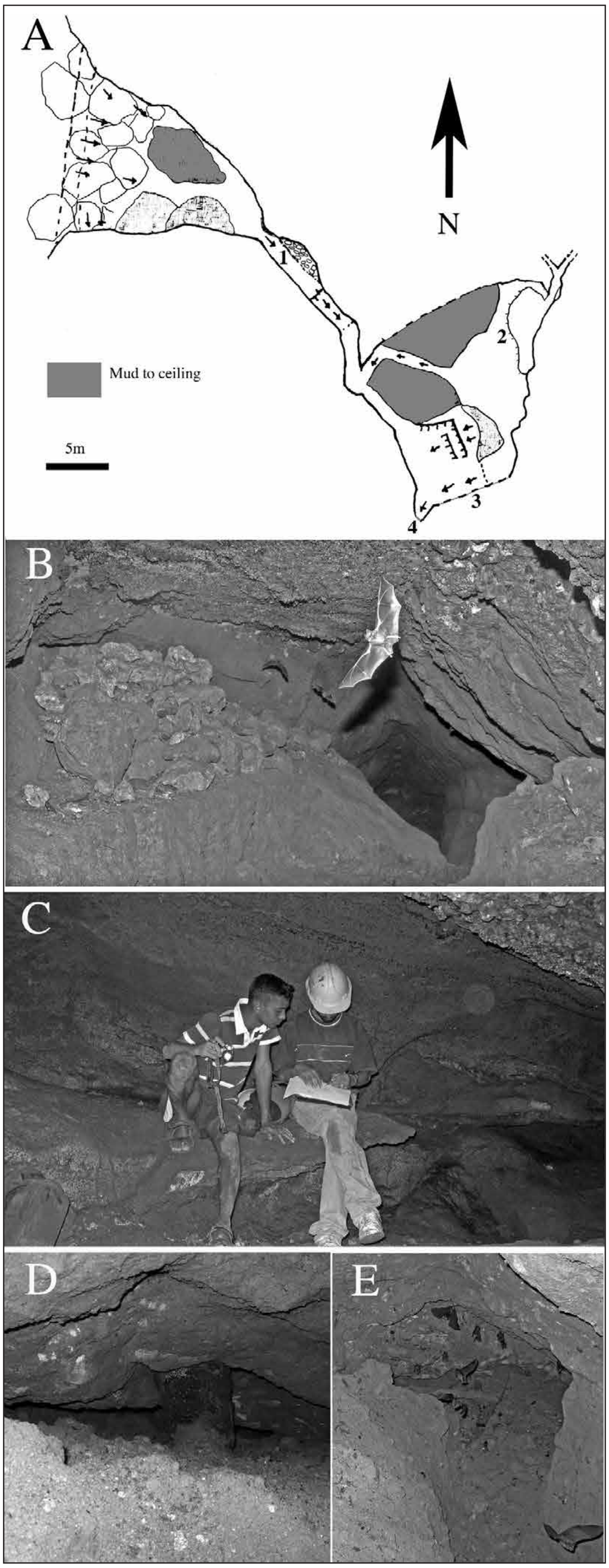

Figure 6. A: Plan of Pelpola Cave. B: View looking SE down passage from "1". C: Looking east from "2". D: Looking south at "3". E: Termination of passage at "4".

Another reason for this idea is that gneiss caves frequently intersect small bodies of marble. This has led to confusion as to what the principal bedrock is. The occurrence of carbonate rock in some gneiss caves lead Davey (1821) to consider that if the gneiss contained caves, then it was so carbonate rich that it should be considered marble. Our observations so far have shown that while many gneiss caves morphologically resemble caves in carbonate rock, most gneiss caves are principally developed in siliceous metamorphic rocks.

The second idea was proposed by Leiter (1948), who considered gneiss caves to be the spaces left behind in the gneiss following the removal of masses of carbonate rock by solution. Since both irregular masses and whole folia of carbonate rock are exposed in many, but not all gneiss caves, this is not an unreasonable suggestion.

We have found a small cave that probably did form this way, Oil Lamp Cave (10 in Fig. 1). Oil Lamp Cave is a small joint-guided passage with a triangular profile and walls composed of gneiss (Fig. 7A). After a few metres the cave comes to a sudden end in a flat surface of solid rock (Fig. 7B). This rock is not siliceous gneiss, but dolomite, with rusting ferromagnesian minerals. The shape of the boundary between the gneiss and the dolomite, indicated by the torch in Figure 7B, matches the profile of the adjacent wall, suggesting that the cave has formed by removal of the carbonate rock from the enclosing gneiss.

While removal of underling folia of carbonate rock is a plausible explanation for the development of block breakdown caves and might explain the initial formation of arch caves, there is too much evidence in Sri Lankan gneiss caves of solution-like speleogens on siliceous gneiss for this mechanism to be universally viable.

Evidence for another mechanism arose on our very first field visit to Kukuluwa Kanda Rajamaha Viharaya (3 in Fig. 1) in 2009. The feature seen in Figure 8A was encountered up hill from the tunnel caves used as temples. This is a structurally-guided, cave shaped depression in the face of a small cliff-like outcrop of gneiss marked by a sign in Singhalese. The cave shape is filled with yellow material. On close inspection the filling appeared not to be sediment but altered/weathered gneiss, the yellow colour resulting from secondary ferruginous cement. The outcrop suggests that natural weathering/erosion has preferentially removed about 1 m of the yellow material. If this were to continue, the result would be a cave with an elliptical profile much like Alavala Tunnel Cave, making this a nascent phantom rock cave. When asked about the sign (right foreground Fig. 8A) the resident monk explained that this was the site of a future meditation hall, he intended to construct by digging out the yellow material to make a new cave. On a return visit in 2012 no progress had been made with the excavation, probably due to the strength of the ferruginous cement.

Further evidence for phantom rock processes in gneiss cave formation is found at Karannagoda Rajamaha Viharaya (11 in Fig. 1) where, in addition to tunnel caves and sections through phantom rock filled tubes, an extensive overhang cave is developed by the partial removal of a horizontal body (folium) of phantomized rock. This cave is approximately 21 m wide by 17 m deep with a ceiling height ranging from 2.1–0.8 m (Fig. 8B).

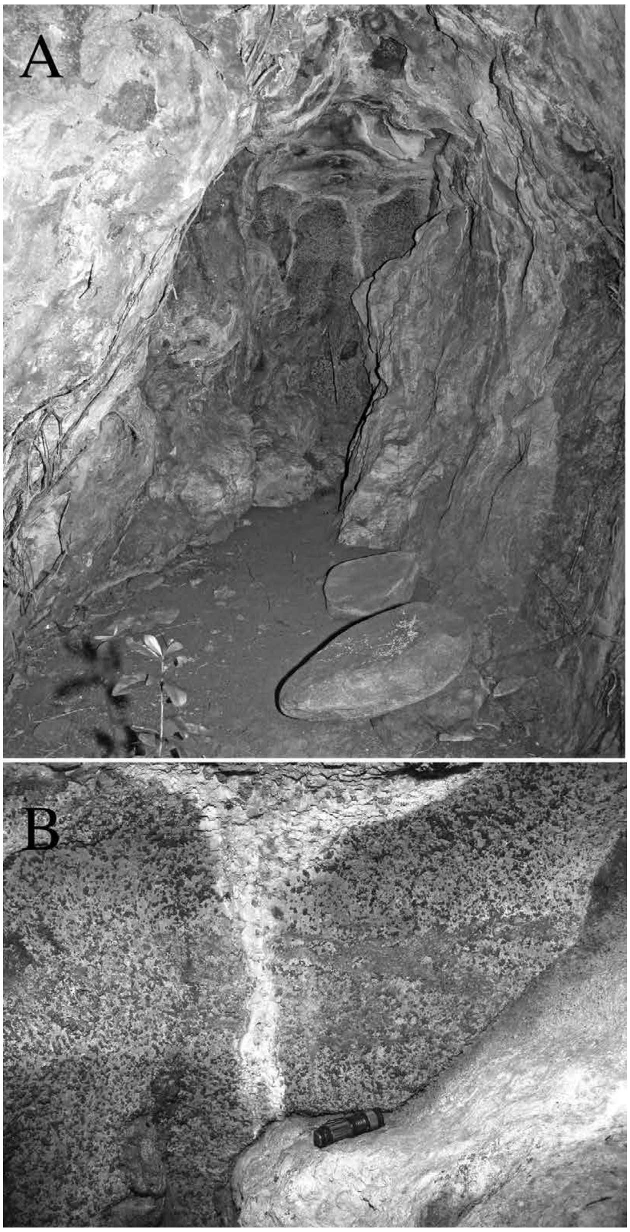

Figure 7. A: Looking into Oil Lamp Cave. B: Bedrock termination of Oil Lamp Cave. Speckled rock is dolomite; white rock below and to the right of black torch is siliceous gneiss. Torch is 95 mm long.

The ceiling slopes to the northeast with the foliation in the bedrock, suggesting that a segment of a whole phantomized folium has ben removed to form the cave. Pillars of phantom rock remain in the cave, separated by curved gaps that resemble the profiles of phreatic tubes suggesting that before mass removal of the phantomized rock there may have been a network of tubes, similar to that in the excavation at Fa-Hien Cave.

The remnant phantom rock in Alavala Tunnel Cave, the deep zone of "weathered" rock in Fa-Hien Cave, the clay/gravel mixture in Pelpola Cave and the observations at Kukuluwa Kanda Rajamaha Viharaya and Karannagoda Rajamaha Viharaya all suggest that formation of phantom rock, followed by its natural, and in places artificial removal is likely to be a major agent for speleogenesis of gneiss caves in Sri Lanka.

Since Vergari and Quinif (1997) have shown that many phreatic-like solutional forms can result from phantom rock processes, it is possible that the range of phreatic-like cavities

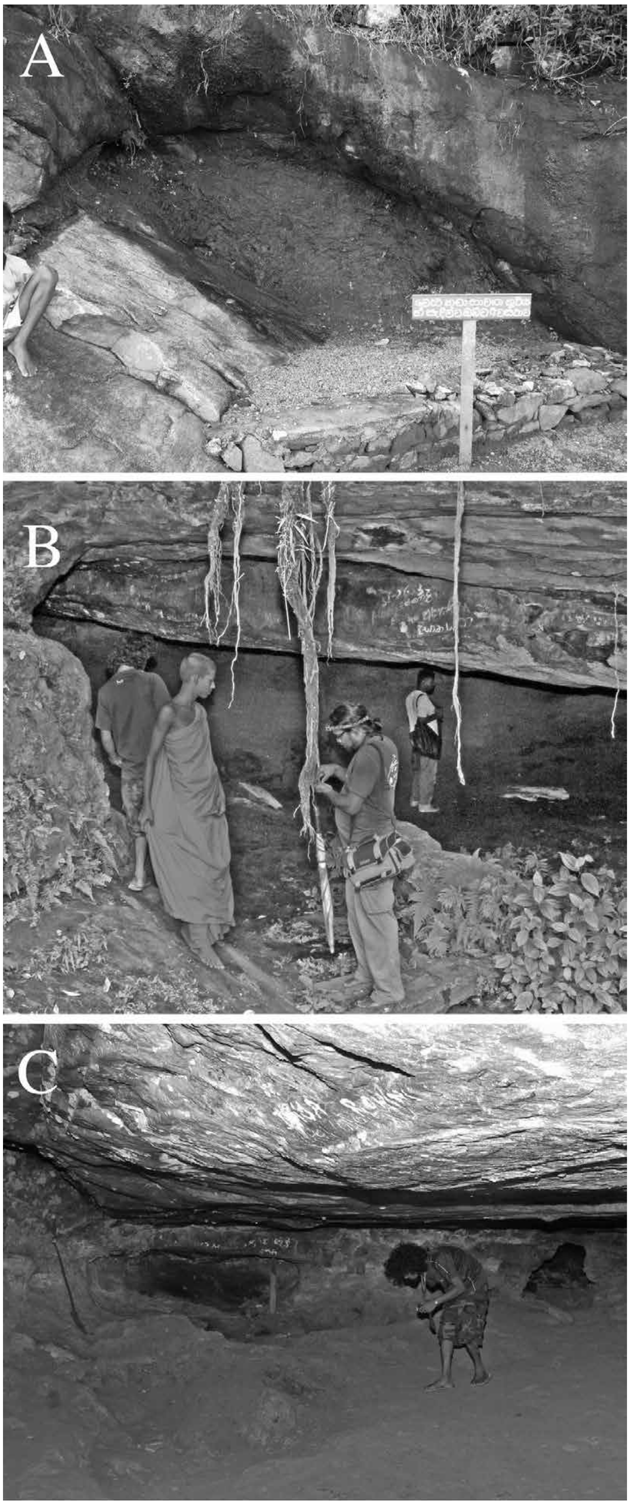

Figure 8. A: Nascent phantom rock cave and meditation hall, Kukuluwa Kanda Rajamaha Viharaya. B: Looking into cave in folium at Karannagoda Rajamaha Viharaya. C: Remnant pillars of phantom rock in cave in folium at Karannagoda Rajamaha Viharaya.

and speleogens found in Sri Lankan gneiss caves are not the product of direct solution of the silicate rock but of its phantomization.

7. On-going Research

In addition to cave morphology and speleogenesis we have also investigated cave sediments and surface karst-like features on gneiss and granite. Minerals and speleothems are being investigated in collaboration with Ross Pogson and David Colchester of the Australian Museum, Sydney. An initial paper (Osborne et al., in prep.) has been submitted to *Acta Carsologica*. Current research is focussed on a 200 m-long network cave, largely developed in phantom rock.

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