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## STRATIGRAPHY AND CHRONOLOGY OF KARST FEATURES ON RODRIGUES ISLAND, SOUTHWESTERN INDIAN OCEAN

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**Abstract:** The remote Indian Ocean island of Rodrigues, while largely of volcanic origin, also contains a large body of eolian calcarenite with over thirty surveyed caves and many other karst features. Little is known, however, regarding the age and stratigraphy of the clastic deposits in the caves and the associated fossils of the highly endemic, now mostly extinct, fauna. On the Plaine Caverne and Plaine Corail of the southwestern part of the island, we obtained sediment cores up to 10 m in length and excavated bones of the extinct fauna from caves in the vicinity. Stratigraphic description and radiocarbon dating revealed that sediments in Canyon Tiyel, a collapsed-cave feature, primarily accumulated during the early and middle Holocene. Sedimentation in the canyon and adjacent caves has slowed in recent millennia, with the result that many bones of fauna that went extinct after human arrival in recent centuries are on or near the surface. The chemistry of the sediments and the alternate wet and dry regime of the cave and canyon surfaces are often not conducive to preservation of bone collagen and plant microfossils. Grotte Fougère, with an apparently unique anchialine pond inside a collapsing cave, however, contains over one meter of highly organic sediment with excellent preservation of plant and animal remains.

## INTRODUCTION

Rodrigues Island is the smallest and most isolated of the three Mascarene Islands. It was one of the last habitable places on earth to be discovered and colonized by humans. Due to its remote location about 600 km east of Mauritius in the southwestern Indian Ocean (Fig. 1) and its lack of a good natural harbor, being instead surrounded by a vast reef that posed a great hazard to curious early navigators, it was not until 1691 that the first small band of men, led by French Huguenot François Leguat, temporarily occupied the island (North-Coombes, 1971). Although the tiny colony was abandoned two years later, other visitors spent many months there at intervals of several decades, and a few French families and their slaves settled there in the late eighteenth century. At roughly thirty-year intervals beginning with Leguat, a succession of literate naturalists provided detailed accounts documenting the conversion of the island within one century from a natural paradise teeming with giant tortoises, the solitaire (*Pezophaps solitaria*), which was a giant pigeon related to the Dodo of neighboring Mauritius, and a host of other endemic birds, reptiles, invertebrates, and plants, to a deforested land lacking most of its native species (Cheke and Hume, 2008). Today this relatively small island supports a population of nearly forty thousand people, many of Creole descent.

With an area of only 108 km<sup>2</sup>, it is perhaps surprising that this old volcanic island has a relatively large area of eolian calcarenite on its southwestern side, with over thirty surveyed caves, including a stream cave over a kilometer in

length, and numerous surface karst features. Braithwaite (1994) attributes this large formation to the presence of a reef platform and shallow lagoon around the island that is more than twice the island's area. Although this karst area has yielded virtually all the fossils of the extinct and endangered endemic fauna found to date, almost nothing is known of the age and stratigraphic context of the cave sediments that have yielded these bones.

The goal of this project was to make a preliminary investigation of the island's stratigraphic contexts, with particular emphasis on the karst areas, with samples from other coastal sites for comparison. Since no natural lakes or inland marshes are known in this ancient eroded landscape, caves and related karst features offer the best hope for recovering information regarding the late Quaternary dynamics of this interesting and little-known island.

## METHODS

We have attempted to locate all the potential sites on the island and its offshore islets that might contain a stratigraphic record of the Holocene. Using sediment-coring and

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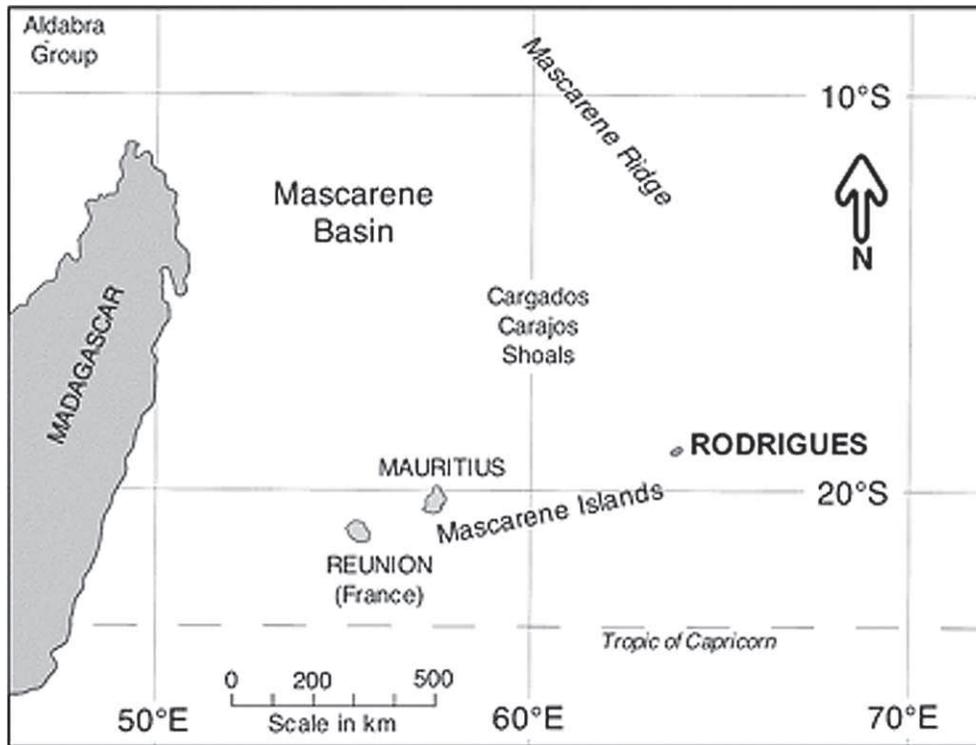


Figure 1. Location of Rodrigues Island in the southwestern part of the Indian Ocean, after Middleton and Burney (2013).

excavating equipment, we sampled sites throughout the most promising area, the caves and karst of the Plaine Corail and Plaine Caverne on the southwest corner of the island. We also sampled deposits of various types throughout the island and on Ile Gombrani, an offshore islet (Table 1, Fig. 2). Site locations were determined via GPS, and elevations were measured when possible within about 5 m using a high-resolution barometric altimeter calibrated to adjacent sea-level sites. All sediments were screened, wet or dry depending on substrate, to 1.5 mm, and all recovered fossils were dried, labeled, and placed in the accessions of the museum collections at the François Leguat Giant Tortoise and Cave Reserve (FLGTCR) near Anse Quitor.

Excavated materials and museum specimens excavated previously were submitted for AMS radiocarbon dating (Table 2). However, with few exceptions, bones selected for potential dating yielded little or no collagen, so that they could not be securely dated. The organic fraction of three key levels in the longest core, a 10 m section from Canyon Tiyel, a karst blind valley in the FLGTCR, yielded suitable material for dating after acid pretreatment to remove carbonates. Sediment samples were examined microscopically for fossil pollen contents and charcoal particles.

## RESULTS

### CANYON TIYEL CORES

Canyon Tiyel is a karst blind valley (Fig. 3) surrounded by subterranean chambers. The floor contains many

boulders likely to be the result of roof and wall collapse. Three cores were collected via bucket auger from the clay floor of the canyon, one from near the center, one from the edge nearby, and one from the lower end of the canyon. The 10.1-m core from the central area, RCT-1, is briefly described in Table 3. The early date at 740 cm in this core probably reflects some reworking of older sediments, a phenomenon that is also apparent at the surface in Canyon Tiyel and the adjacent caves. The sandy and gravelly nature of the sediments around this level suggest higher-energy conditions at this time than in the lower part of the core dated at 9540 to 9460 cal yr BP (Table 2). The latter date is from finer and more organic sediments lacking the gravel in the 740-cm date, and it is therefore likely to be more reliable.

Other cores from Canyon Tiyel, although much shorter, confirmed the stratigraphic trends of the upper unit. In particular, RCT-3, from the slightly lower south end of the site, contained a few bone fragments, including some from the extinct giant tortoise *Cylindraspis* sp. at 70–80 cm, suggesting that sediments near the surface predate the late eighteenth century, when the tortoises were known from historical records to have been driven to extinction by overharvesting (Cheke and Hume, 2008). Of course we cannot rule out the possibility of redeposition in the case of such fragmentary material.

Pollen preservation was generally disappointing, probably owing to the destructive wetting and drying cycle that affects the canyon sediments. Sediments were also examined

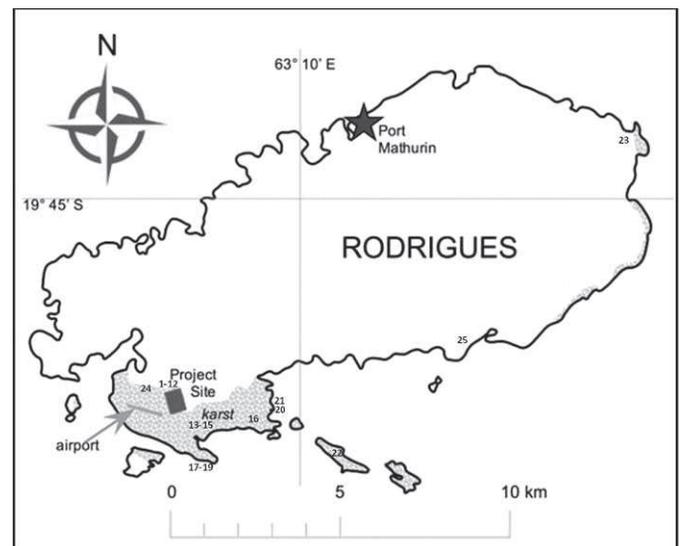
**Table 1. Sites investigated on Rodrigues Island.**

Site in Figure 2	Site Name	Type	Location		Elevation (m ASL)	Samples
			Latitude	Longitude		
1	Canyon Tiyel	Blind Valley	S19°45.357'	E63°22.205'	24	Cores: RCT-1, 1A, 2, 3
2	Grande Caverne	Cave	S19°45.190'	E63°22.232'	52	Cores: RGC-1,2,3
3	Caverne Bambara I	Cave	S19°45.274'	E63°22.186'	37	Excavation: RBA-1
4	Caverne de la Vierge	Cave	S19°45.470'	E63°22.203'	...	Excavation: RCV-1
5	Caverne L’Affouche	Cave	S19°45.428'	E63°22.117'	...	Excavation (previous)
6	Caverne Mapou	Cave	S19°45.277'	E63°22.177'	47	Excavations: RMP-1,2
7	Caverne L’Etrave	Cave	S19°45.254'	E63°22.016'	27	Excavation: RET-1
8	Caverne Solitaire	Cave	S19°45.278'	E63°22.181'	34	Surface collection
9	Caverne Dora	Cave	S19°45.428'	E63°22.217'	...	Surface collection
10	Electricity Pole Cave	Cave	S19°45.681'	E63°22.289'	26	Excavation: REP-1
11	Caverne Papaye	Cave	S19°45.635'	E63°22.314'	22	Surface collection
12	Caverne Poule Rouge	Cave	S19°45.325'	E63°22.189'	...	Excavation (previous)
13	Caverne Monseigneur	Cave	S19°45.559'	E63°22.916'	23	Excavation: RMS-1 Core: RMS-1
14	Caverne d’Ami de Monseigneur	Cave	S19°45.528'	E63°22.910'	23	Surface collection
15	Caverne Mario	Cave	S19°45.669'	E63°23.129'	16	Surface collection
16	Caverne Patate (main entrance)	Cave	S19°45.492'	E63°23.191'	26	No collection
17	Caverne Bouteille	Cave	S19°45.903'	E63°22.443'	14	No collection
18	Grotte Fougère	Cave/Sinkhole	S19°46.090'	E63°22.586'	5	Cores: RGF-1,2 Excavations: RGF-3,4
19	Petit Lac	Pond	S19°46.048'	E63°22.544'	8	Surface collection
20	South Grande Var	Cave	S19°44.984'	E63°23.618'	3	No collection
21	North Grande Var	Cave	S19°44.975'	E63°23.613'	2	No collection
22	Ile Gombrani	Sinkhole	...	...	...	Cores: RGO-1,2
23	Cotton Bay	Estuary	S19°41.297'	E63°29.587'	2	Cores: CBE-1A,1B
24	Plaine Caverne	Quarry	S19°45.212'	E63°22.557'	73	Bulk samples, surface collection
25	Port Sud-Est	Quarry	S19°45.382'	E63°23.718'	13	Bulk samples, surface collection

for charcoal particles, and they were found to generally contain charcoal only in the surficial sediments, no doubt owing to the general absence of fires before human arrival and the low sedimentation rates at the site in recent centuries, as evidenced by the presence of bones of extinct tortoises near the surface.

#### CAVE DEPOSITS

Caves in the eolianite deposits of southwestern Rodrigues were surveyed in detail. Caves were explored and sampled throughout the Plaine Caverne and to lesser degree in the more southern karst area, known as Plaine Corail. These caves vary greatly in size, configuration, and elevation (Table 1), from small caves near sea level to huge caverns with entrances up to around 50 m ASL such as Grande Caverne and Caverne Patate. Vertical profiles were also diverse, ranging from large horizontal passages in the caves that integrate with Canyon Tiyel to more vertical caves such as Monseigneur and Bouteille. Of particular interest for paleoecological potential, were caves such as Grande Caverne and Caverne Bambara that have



**Figure 2. Map of Rodrigues Island showing approximate locations of sites investigated. See Table 1 for a key to numbered locations.**

**Table 2. AMS  $^{14}\text{C}$  dates from Rodrigues Island.**

Beta Lab No.	Material	Provenance	Radiocarbon Age (yr $\pm$ 1 $\sigma$ )	Calibrated Age Range cal yr BP (2 $\sigma$ )
<b>RCT-1 Core</b>				
309300	sediment	330 cm	6460 $\pm$ 30 BP	7430–7320
309301	sediment	740 cm	10020 $\pm$ 40 BP	11750–11740, 11720–11320
305254	sediment	990 cm	8490 $\pm$ 40 BP	9540–9460
<b>Bones of Extinct Fauna</b>				
305254	bone collagen	<i>Mascarenotus murivorus</i> , Caverne Dora RDO 60-75B	2850 $\pm$ 30	3060–2870
305257	bone collagen	<i>Pezophaps solitaria</i> , Caverne Monseigneur RMS-1: 114 cm	insufficient collagen	...
305255	bone collagen	<i>Cylindraspis</i> sp., Canyon Tiyel 70–80 cm in core RCT-3	insufficient collagen	...

significant amounts of clastic fill on their floors. Grande Caverne (Fig. 4), for instance, was cored in several places with the bucket auger, yielding profiles of clay stratigraphy up to 4.4 m thick. However, the chemistry of these sediments was conducive to preservation of neither bones, which were intact only near the surface, nor pollen grains. All cores bottomed out on the limestone floor of the cave. Grande Caverne is the island's most developed show cave (Fig. 5), with electric lighting and a raised walkway that protects the features while permitting appreciative viewing by many of the approximately twenty thousand tourists each year who visit FLGTR.

Other caves, such as Bambara I (Fig. 6), which is part of a cave in the process of collapse, with many skylights and entrances, have extensive breccia deposits on the



**Figure 3. View of the floor of Canyon Tiyel, a karst blind valley where the grass is kept short by the grazing of hundreds of introduced Aldabra tortoises. The canyon and its many associated caves are part of the François Leguat Giant Tortoise and Cave Reserve.**

floors. Excavations at this site yielded bones and shells in distinct layers, often including breakdown and clay lenses. Bones of extinct species, including the solitaire and giant tortoises, were present at the surface, indicating that the site has apparently not accumulated significant amounts of sediment in the last few centuries.

Dating of bones recovered from caves proved extremely problematic. Visual inspection of many specimens at low magnification showed that the bones were generally porous and friable, as is typical of bones subjected to alternate wetting and drying, leading to oxidation and biological diagenesis of collagenous material. It was particularly disappointing that we could not date bones from a large erosion scarp below a skylight in Caverne Monseigneur, where excavation from a face and bucket augering at the foot of the scarp yielded a combined profile of 240 cm. These sediments yielded bones of solitaire and other extinct species, but these proved undatable due to a lack of collagen. Pollen preservation was also poor in these oxidized sediments.

One specimen, sampled from the museum collection, was relatively waxy and lustrous in appearance and yielded sufficient collagen for dating. This was from the extinct Rodrigues owl, *Mascarenotus murivorus*, from Caverne Dora. Although collected from only 60 to 75 cm below surface, it was dated to 2850  $\pm$  30 yr BP (3060 to 2870 cal yr BP; Table 2). Again, as in Canyon Tiyel, this suggests very low sedimentation rates in the late Holocene. Caverne Dora is a small fissure cave (Figs. 7, 8), well above the canyon floor, and has probably been well-drained throughout its existence. The matrix consists primarily of limestone breakdown and alkaline sand, rather than the more acidic clay typical in many parts of the lower caves.

Another cave in the FLGTGR that has yielded many bones of the extinct and endangered fauna is Caverne Poule Rouge, an unusual cave with a downward-spiraling passage (Fig. 9). This cave is heavily decorated with attractive speleothems, including unusually large and

**Table 3. Core sample descriptions.**

Core Sample	Depth, cm	Color <sup>a</sup>	Notes
Core RCT-1 from Canyon Tiyel	0–50	2.5YR 3/4	Dark reddish brown clayey silt containing a few limestone fragments.
	50–350	5YR 3/4 7.5YR 3/3	Dark reddish brown silty clay, becoming darker and denser downwards. Dark brown silty clay, with fewer rocks and some land snail shell fragments (cf. <i>Tropidophora</i> ). Sediment organic fraction at 330 cm dated to 6460 ± 30 BP (7430–7320 cal yr BP)
	350–580	7.5YR 3/3	Color and texture as above, becoming sandier at 580.
	580–755	7.5YR 3/2	Dark brown sandy silty humic clay. 740 cm sediment organic fraction dated to 10,020 ± 40 yr BP (11,750–11,740, 11,720–11,320 cal yr BP).
	755–810	7.5YR 3/2	Color as above, but sediments contain gravelly component consisting of basalt pebbles, shell fragments, and calcite.
	810–960	7.5YR 3/2	As above, but lacking gravel.
	960–990	7.5YR 4/3	Becoming lighter, more organic with some pebbles. 990 cm sediment organics dated to 8490 ± 40 yr BP (9540–9460 cal yr BP).
	990–1010	2.5Y 4/4	Olive brown sandy silt with basalt pebbles, calcarenite fragments, and marbling of orange-yellow to bluish-green streaks. Stopped on solid calcarenite rock at 1010 cm.
	Core CBE-1B from Cotton Bay	0–30	10YR 3/4
30–55		10YR 3/2	Very dark brown silty clay.
55–80		10YR 4/6	Dark yellowish brown sandy silty clay.
80–115		10YR 4/6	Dark yellowish brown silty humic sand, coarsening downward. Water table stood at 100 cm.
115–160		10YR 4/6	Dark yellowish brown coarse humic sand, with marine shell fragments, seeds, plant fibers, and angular to sub-rounded basalt fragments. Stopped by collapsing loose sand.
Core RGO-1 from Ile Gombrani	0–25	5YR 6/4	Light brown humic clayey sand with calcareous nodules.
	25–50	5YR 6/4	As above, changing gradually to marbled brown clay and yellow sand at ca. 40 cm
	50–60	2.5Y 6/4	Yellow sand, stopped on rocks.
Core RGF-2 from Grotte Fougère	0–20	N 2/0	Black unconsolidated muck, no coarse particles except introduced snails.
	20–40	2.5Y 3/3	Gradual change to 2.5Y 3/3 dark olive brown silty muck.
	40–70	2.5Y 4/4	Olive brown silty muck, including seeds, snails, and bones of endemics.
	70–102	2.5Y 4/4	Olive brown silty sandy muck, with increasing molluscan gravel near bottom.

<sup>a</sup> Munsell color notation, the order is hue, value, and chroma. For example, a designation of 2.5YR 3/4 has hue = 2.5YR, value = 3, and chroma = 4.

grotesque helictites (Fig. 10). Excavations through a pinkish-gray stony silt that is 85 cm thick have yielded many good fossil finds. On the surface of the floor of a distant passage is a unique virtually complete skeleton of an adult solitaire, mantled in flowstone (Fig. 11).

Table 4 is a provisional list of vertebrate taxa identified from bones collected in the caves in and near the FLGTCR (Table 1, sites 2–12). This includes many of the extinct taxa of Rodrigues, notably an associated female solitaire from Caverne L’Affouche, associated Rodrigues night heron

(*Nycticorax megacephalus*) and Rodrigues rail (*Erythromachus leguati*) from Caverne Poule Rouge, and even keratinous scutes from the carapace of the extinct tortoise *Cylindraspis peltastes*. These remains, as well as land snail shells and fossil seeds, were labeled and added to the accessions of the museum at FLGTCR for future studies.

#### OTHER DEPOSITS

Sites containing Quaternary stratigraphy were sought throughout the island. Although most of the island is

# GRANDE CAVERNE PCV1-2 PLAINE CAVERNE CAVE AREA RODRIGUES ISLAND MAURITIUS

SSS Map No. 2198

Total Length: 490 meters

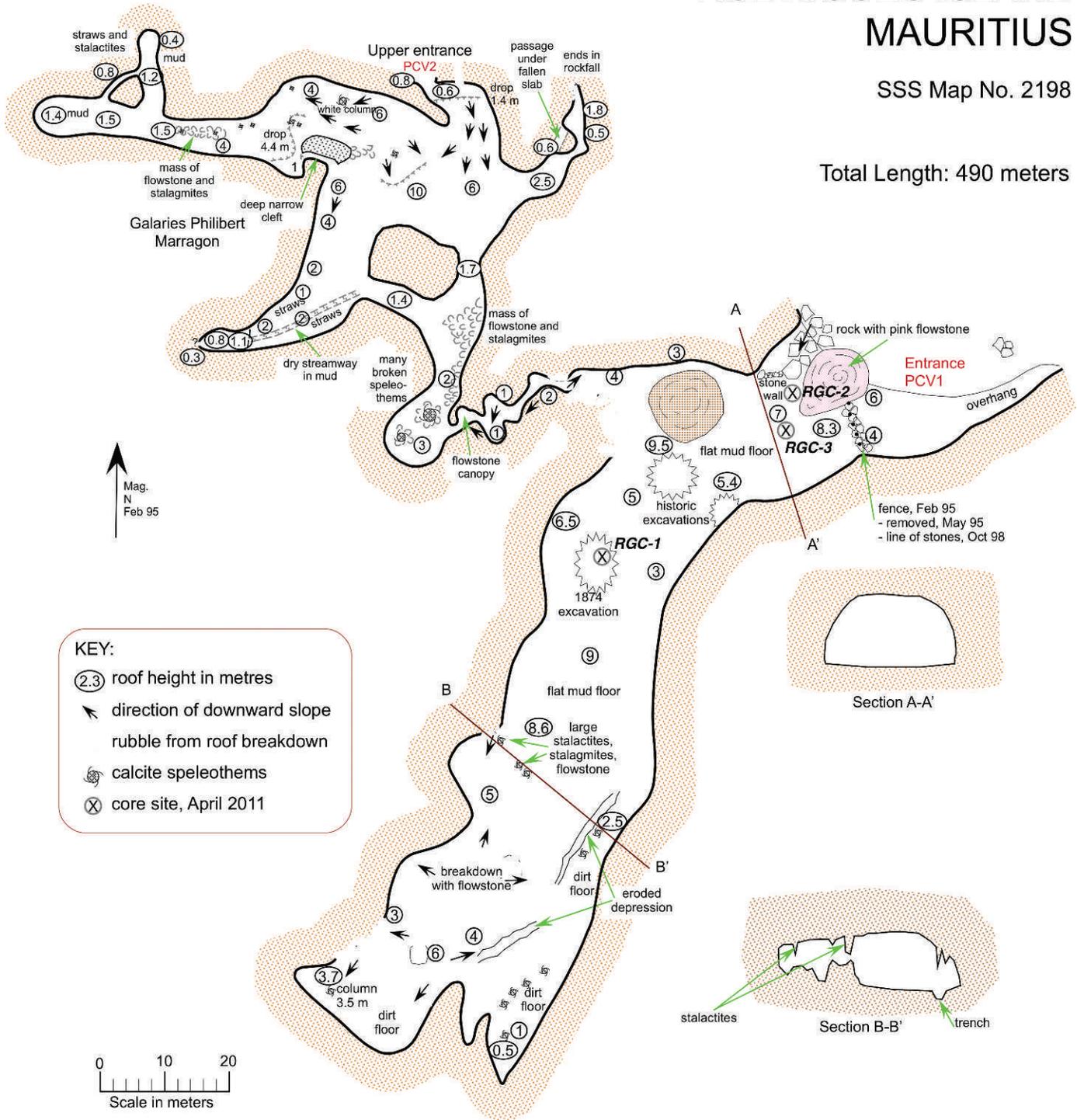


Figure 4. Map of Grande Caverne in the François Leguat Giant Tortoise and Cave Reserve. The sites of sample cores RGC1, 2, and 3 are indicated.



Figure 5. Grande Caverne is Rodrigues’s most-developed show cave, with electric lights and raised walkways designed to minimize tourist impacts while affording a good view of the spectacular speleothems.

ancient eroded volcanic rocks with no potential for our research purposes, one distinct possibility is that the inshore parts of the small estuaries formed by the short streams that drain the interior might contain intact stratigraphy. As might be expected, however, the estuarine and stream-bed sediments show evidence for high-energy deposition, with cobbles and gravel mixed into sandy, silty, or clayey deposits. Likewise, organic lenses were generally thin and superficial. The frequent occurrence of storm surges and hard downpours associated with the violent cyclones that occur periodically in the southwestern Indian Ocean at this latitude probably quickly re-mix any stratified deposits in any context that is near sea level or adjacent to the headwalls that are characteristic of the inland side of these small estuaries. Cotton Bay, number 23 in Figure 2 and Table 1, one of the largest and flattest areas inshore from the coast, was judged to be the most promising, and bucket auger cores from this site yielded some distinctive stratigraphy. The description of core CBE-1B is summarized in Table 3.

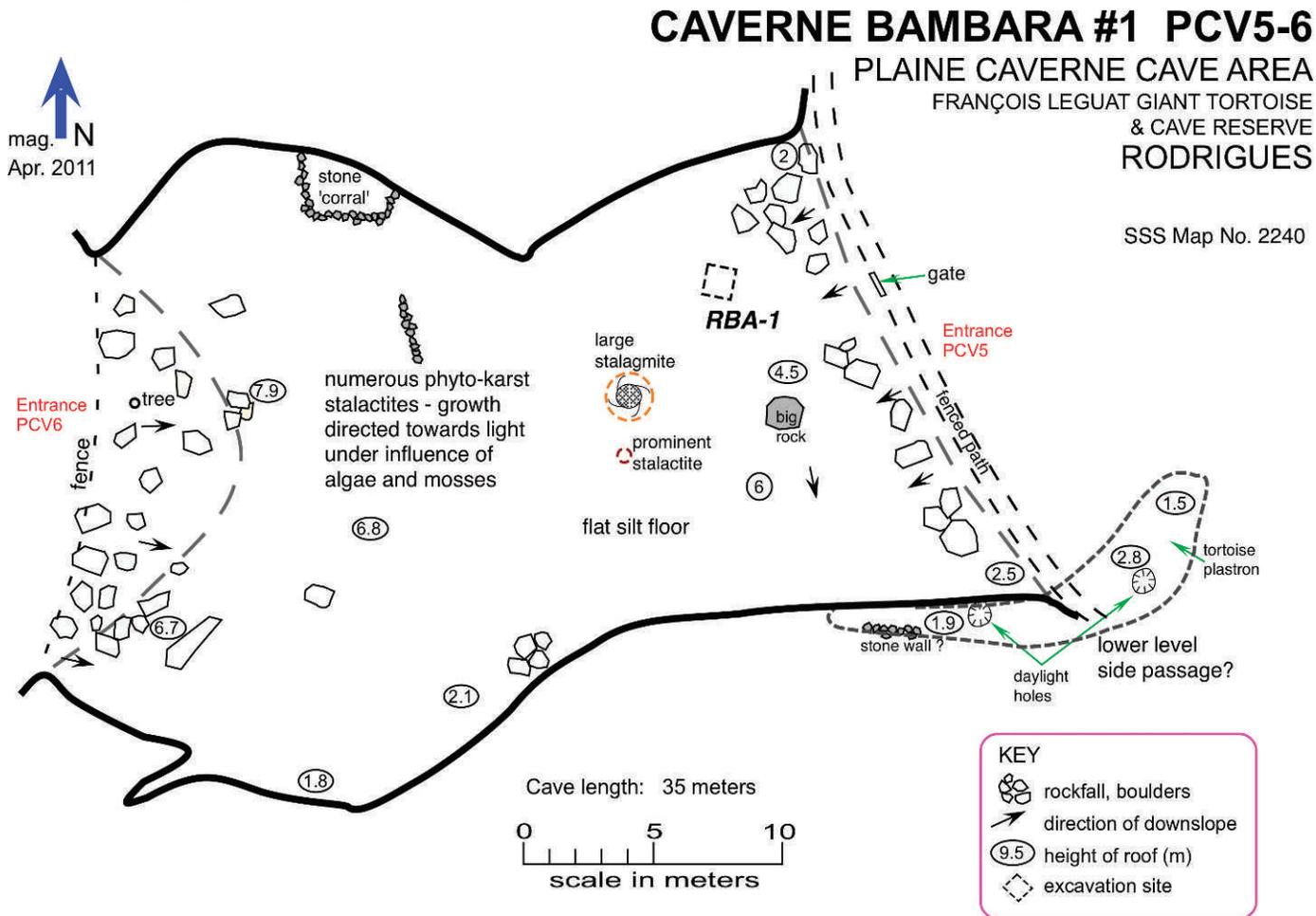
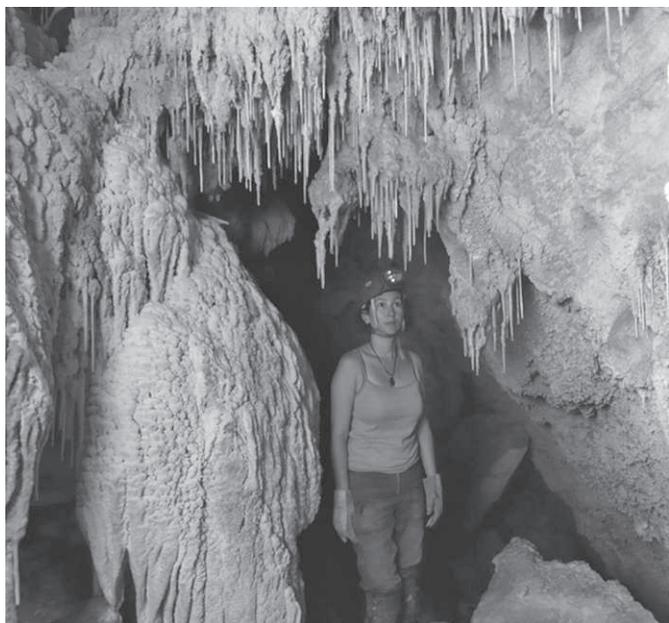


Figure 6. Map of Caverne Bambara I showing location of excavation site RBA-1. This is one of four mapped cave sections in the collapsing Bambara system, characterized by many skylights and entrances and a complex floor stratigraphy including breccias, clay lenses, and breakdown.



**Figure 7.** In Caverne Dora, one of the fissure caves in the walls of Canyon Tiyel, delicate speleothem growth even near the floor confirms that the higher caves in the system receive little if any water flow during rainy seasons, resulting in better bone preservation.

Another possibility explored was that the small eolian calcarenite limestone quarries that have been excavated on the southwest and southeast sides of the island for building stone might contain late Quaternary fossils. Indeed, the two quarries investigated contained interesting cross-bedded calcarenites, with some associated shells of land snails that appeared to be surficial and fissure-fill deposits. However, these sites were heavily oxidized and subject to water erosion, and were not found to contain organic materials of interest.

Yet another area of investigation was a search for permanent water bodies in the karst that might serve as coring sites. One subterranean pond was previously known: Caverne Bouteille is a small opening on the Plaine Corail that gives access to a water-filled chamber that serves as a water source for local people. A previous descent by author GM confirmed that the small amount of sediment in the bottom was likely to have been disturbed by manual water extraction.

Two other small bodies of water were found in surficial limestones near Pointe Corail, on the extreme southwest corner of the island. One of these was a small pond, which we named Petit Lac, in a natural depression in the surficial calcarenite. This pond contained no significant sediment accumulation, probably owing to deflation at times when the shallow water in this rain-fed pond dried out. The other is a small, partially collapsed cave feature (Fig. 12), which we named Grotte Fougère (Fern Grotto) that contained a small pond (Figs. 13, 14) beneath the cave overhang with measured water-surface elevation within a meter of sea

level. This pond is probably hydrologically stable, as its low surface elevation would suggest that it is a hydrographic window, i.e., a groundwater-fed body, and it is isolated from direct marine action by higher land surfaces on all sides. The pond is also under slight tidal influence, a true anchialine pond, as it showed variation over 30 cm during the tidal cycle, but lagging as much as 2 hr behind the much greater tidal variation of 1 m on the day of observation on the adjacent estuary of the Anse Quitor River, which is visible from the rim of the sinkhole.

Fine organic sediment has accumulated inside the small cave. Two 5-cm diameter piston cores were obtained from the area of the pool that probing showed to have the thickest sediment package, about 1.2 m to the rock bottom. The sediments are a fine dark muck containing well-preserved bones, terrestrial and freshwater gastropod shells, and microfossils that include pollen, spores, and algal skeletons. Core RGF-2 is summarized in Table 3.

Three bucket auger cores were collected next to the continuous gravity cores and wet-screened on site in 30-cm increments. Among the findings was a radius of an adult female solitaire that had a healed break mid-shaft. A 1.2 by 0.4 m test pit, RGF-4, was excavated about 15 m north-northwest of the coring site, along the western wall of the cave, to a depth of 50 cm. It yielded, at the surface, a tibial epiphysis of the extinct giant saddle-backed tortoise *Cylindraspis vosmaeri*.

An effort was made to visit as many offshore islets as possible, as we have noted previously that small islets may sometimes harbor depressions fed by fresh or brackish groundwater, and sedimentation rates may be quite low, owing to the lack of human activities and terrestrial sediment sources on these uninhabited islands. We were able to procure a small boat and visit the following islets: Chat (Pierrot), Gombrani, Hermitage, and Crabe. Only Gombrani, site 22 in Figure 2, showed any promise. On this islet, near the center, were some very small solution features in calcarenite, tiny depressions with brackish water at depth and some soft sediment. A sounding with the bucket auger revealed 60 cm of soft sediment down to rock (Table 3).

## DISCUSSION

As is often the case with small islands, it has been difficult to find suitable sites for our paleoecological investigations. However, we have made significant progress on several fronts. First, we now have, thanks to a thorough review of the historical literature for Rodrigues (see Cheke and Hume, 2008), a good understanding of the transformation there in the wake of human arrival. Second, our intensive survey of the island's paleoecological potential has shown what will and will not work in terms of future research efforts. Caves there hold great promise for further elucidating the past faunal diversity of the island, which clearly has one of the highest percentages of endemism

# CAVERNE DORA PCV23

## PLAINE CAVERNE CAVE AREA

### RODRIGUES, MAURITIUS

Cave length: 85 m (min. surveyed)

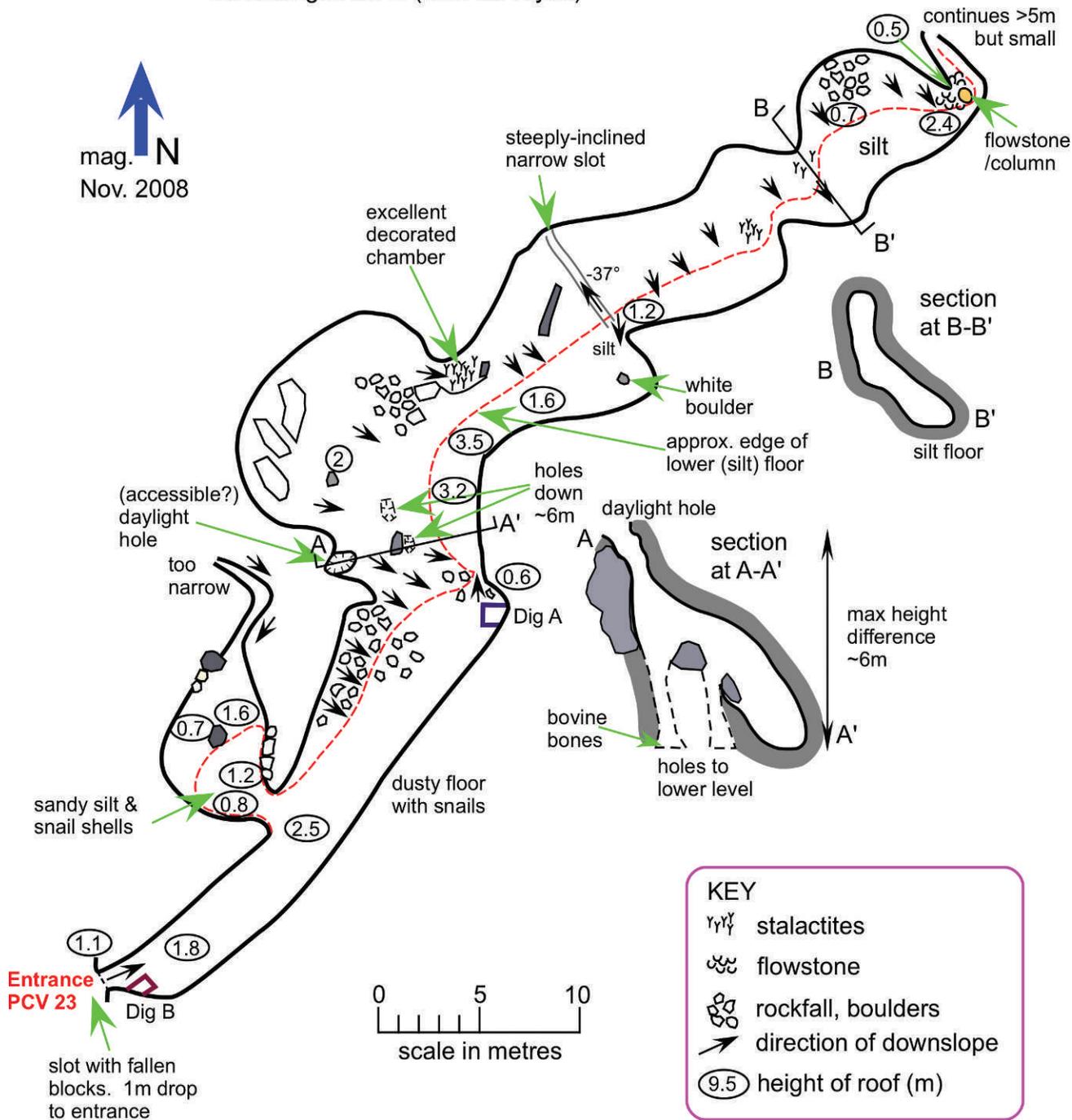


Figure 8. Map of Caverne Dora, showing the locations of the two excavations, Dig A and Dig B, conducted by authors JH and LS and others in past field seasons.

# CAVERNE POULE ROUGE PCV20

## PLAINE CAVERNE CAVE AREA

### RODRIGUES, MAURITIUS

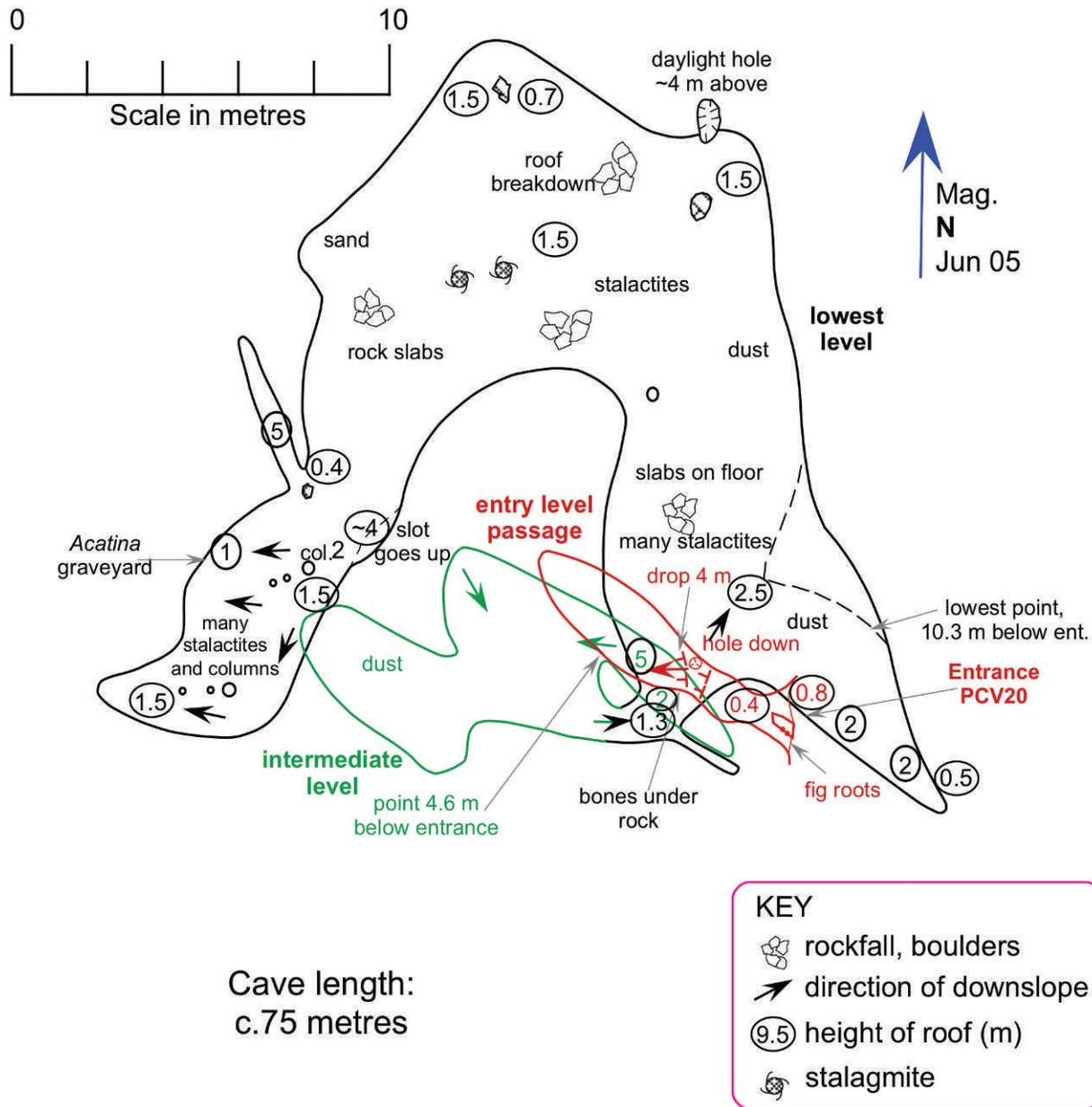
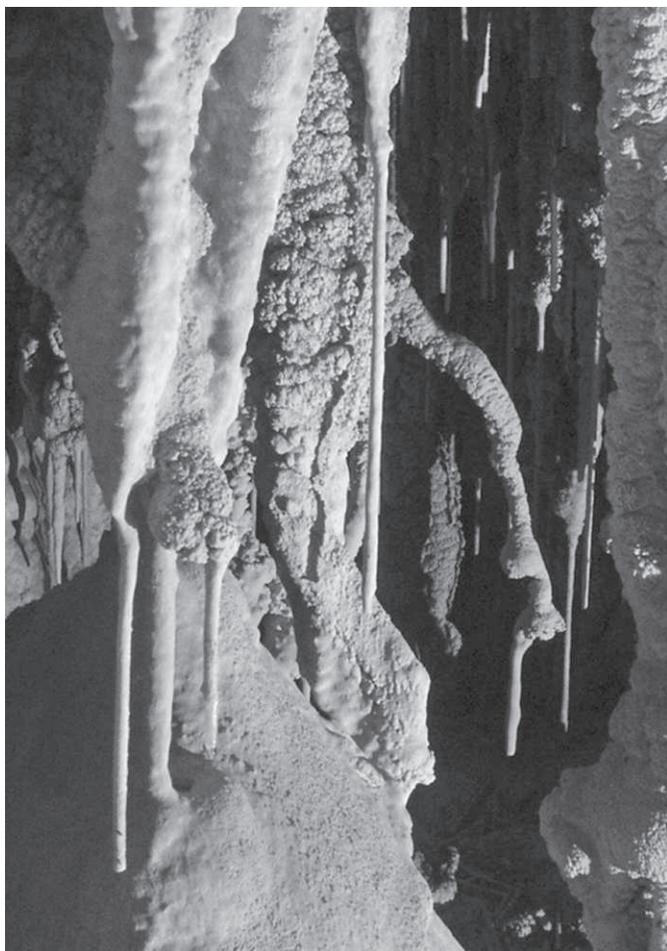


Figure 9. Map of Caverne Poule Rouge on the upland adjacent to Canyon Tiyel. It strives to show the vertical complexity of the passages, which spiral downward through three distinct levels.

found anywhere (Cheke and Hume, 2008). But the chemistry of these caves appears to be largely unsuitable for preservation of bone collagen, which limits their suitability for addressing chronological issues. Collagen

preservation was poor in nearly all materials examined, both in our excavations and in museum specimens accumulated from previous investigations. Neither the calcareous breccias, with very high pH, nor the relatively



**Figure 10. Delicate and grotesquely twisted helictites adorn the cave ceiling in some chambers in Caverne Poule Rouge on the upland adjacent to Canyon Tiyel.**

acidic clays accumulated on the floors of some caves were conducive to protein preservation, although the former often preserved the bone morphology reasonably well, allowing positive identification. Likewise, the absence of natural lakes and extensive marshlands on the island poses a challenge for recovery of microfossil evidence.

We now know many things about the island's past environment, however, that we didn't know before embarking on this project. The caves of the Plaine Caverne and Plaine Corail are in a body of eolianite not previously surveyed in detail. Now that we realize the considerable height above sea level of some of the largest and probably oldest caves and the thickness of the calcarenite deposit, which has only weak stratification other than cross-bedding and an absence of thick intercalated clay layers, the case is strong that they represent the product of a single, drawn-out depositional event. Since the relatively uniform deposits extend from the highest calcarenite quarry at 73 m to sea level and perhaps lower, possibly without major hiatus, this would imply the formation of large dunes at some time in the middle to late Pleistocene,

possibly during a period that includes an extreme high-stand of the sea. Although no literature has been found that dates these deposits on Rodrigues or analyzes them in detail, similar deposits exist in the Hawaiian Islands, the Bahamas, and Bermuda (Blay and Siemers, 1998; Hearty and Kindler, 1995). Although these islands are in both the Pacific and Atlantic Oceans, eustatic sea-level change is of course a worldwide phenomenon, and the effects of interglacial sea-level rise would be expected to be similar on any tropical island not subject to rapid isostatic rebound or tectonic subsidence.

For instance, this type of thick deposit on Kaua'i has been indirectly datable, owing to the convenient presence of a basaltic lava flow that caps the deposit. This basalt has been dated to about 350,000 yr BP with K-Ar radiometric methods, leading to the tentative conclusion that the highest-elevation eolian calcarenite deposits are from Oxygen Isotope Stage 11, about 400,000 years ago, when sea level reached its highest extent, perhaps 20 m or more above present sea level, in the late Pleistocene (Hearty *et al.*, 2000; Blay and Longman, 2001; but see Rohling *et al.*, 2010). Of course, it is possible that, as in the Hawaiian Islands, some lower-elevation deposits are from subsequent high-stands of the sea during later interglacials. The apparent absence of extensive intercalated clay or lithified red soil layers within the calcarenite beds on Rodrigues, unlike those documented for Kaua'i (Hearty *et al.* 2000) and Madagascar (Burney *et al.* 2008), for instance, would suggest that the eolianite bodies were deposited during one interglacial, since these contrasting glacial-age deposits appear to be absent. However, remarkably little is known about the Pleistocene geology of Rodrigues, and the case may not be exactly parallel.

In any case, our dating of Canyon Tiyel clastic sediments suggests that the present landforms of the Rodrigues karst were largely shaped prior to the Holocene, with subsequent subaerial formation and deposition of clays since that time. It appears that much of this deposition occurred early in the present interglacial, with the land surface inside the canyon reaching its present configuration in recent millennia. Dating of the owl bone from near the surface in adjacent Caverne Dora likewise confirms that relatively little sedimentation has occurred there in the last two millennia.

Although interesting, and useful to know, this finding also explains why our search for high-resolution deposits in the past millennium and recent centuries has proved nearly fruitless. This hampers our goal of finding paleoecological deposits coeval with the transition from the prehuman endemic biota to the current anthropogenic, biologically depauperate landscapes, which historical evidence suggests began in the late seventeenth century, later than perhaps any other habitable landscape on earth. Instead, we typically have found, on or very near the surface in cave deposits, a mixture of extinct forms, recently introduced species, and industrial materials such as glass and even plastic. If there has been human-caused erosion during the



**Figure 11. An essentially complete skeleton of the giant extinct flightless pigeon of Rodrigues, the solitaire (*Pezophaps solitaria*) is mantled by flowstone on the floor of a distant passage in Caverne Poule Rouge.**

last two centuries, this material has for the most part not been deposited in the investigated calcarenite caves of Rodrigues, or if it has, it has been hopelessly mixed with redeposited material from earlier times, perhaps by large

introduced land snails and endemic land crabs. It is more likely that the long horizontal passages in caves near the level of the floor of Canyon Tiyel, such as Grand Caverne and Caverne Bambara, were formed during earlier

**Table 4. Endemic and native vertebrate taxa identified from bones collected.**

Reptiles		Birds		Mammals	
Scientific Name	Common Name	Scientific Name	Common Name	Scientific Name	Common Name
<i>Cylindraspis vosmaeri</i>	Tortoise	<i>Acrocephalus rodericana</i>	Rodrigues Warbler	<i>Pteropus rodricensis</i>	Rodrigues Fruit Bat
<i>Cylindraspis peltastes</i>	Tortoise	<i>Alectroenas payandeei</i>	Rodrigues Blue Pigeon		
<i>Phelsuma gigas</i>	Rodrigues Night Gecko	<i>Eurythromachus leguati</i>	Rodrigues Rail		
<i>Phelsuma edwardnewtoni</i>	Rodrigues Day Gecko	<i>Foudia flavicans</i>	Rodrigues Warbler		
<i>Phelsumal/Nactus</i>	small geckos ×4 sp.	<i>Hypsipetes sp.</i>	Bulbul		
		<i>Necropsar rodericanus</i>	Rodrigues Starling		
		<i>Necropsittacus rodericanus</i>	Rodrigues Parrot		
		<i>Nycticorax megacephalus</i>	Rodrigues Night Heron		
		<i>Nesoenas rodericana</i>	Rodrigues Turtle Dove		
		<i>Mascarenotus murivorus</i>	Rodrigues Owl		
		Passerines	Undescribed ×2		
		<i>Pezophaps solitaria</i>	Solitaire		
		<i>Phaethon lepturus</i>	White-tailed Tropicbird		
		<i>Psittacula exsul</i>	Rodrigues Parakeet		
		<i>Pterodroma sp.</i>	Petrel		



**Figure 12. Grotte Fougère (Fern Grotto) near Pointe Corail is a collapse feature with an anchialine pond inside that is under some tidal influence.**

interglacials, when sea level may have been higher; and therefore, the wedge of fresh water forming the phreatic zone near the coast was at the approximate level of these cave passages and actively cutting the calcarenite deposits. In the Holocene, sea level has risen only to a much lower level, so that surface drainage is out of the adjacent Anse Quito River, which forms the present estuary. This

reconstruction, while hypothetical, is consistent with the presence of very large speleothems in these caves. During the Holocene, including the present, water only accumulates in the caverns adjacent to Canyon Tiyel during severe rainstorms, depositing the Holocene clays studied and ensuring that bone preservation is poor on the cave floors. By contrast, the higher fissure caves on the walls of Canyon Tiyel, such as Dora and Poule Rouge, show no signs of water-borne clay deposition, have only thin (<1 m) mantles of clastics derived from breakdown and infiltration from cracks in the ceiling, and contain some bones in a better state of preservation.

Of the many caves investigated, only Grotte Fougère near Pointe Corail shows any promise for future efforts at reconstructing late Holocene paleoenvironments from microfossils, seeds, and datable bones and land snail shells from an exceptional cave site, as was done at Makauwahi Cave, Kaua'i (Burney et al., 2001). Work underway on cores and excavated materials from Grotte Fougère on Rodrigues will be used in studies aimed at reconstructing paleoenvironments of the centuries just prior to the human transformation of the island. It is also conceivable that, by comparing stratigraphic records of human-caused change here to known historical events, Rodrigues could be realized as a potential Rosetta Stone for deciphering paleoecological records for other sites around the world, where the human transformation was an entirely prehistoric phenomenon known only from paleoecological inference. In this sense, Rodrigues may be highly relevant to interpreting late-prehistoric events in lands as disparate as Australia, the Americas, and large and small islands colonized by preliterate peoples, from Madagascar to Hawai'i (Burney and Flannery, 2005). Whatever the case, the many interesting caves and other karst features on this tiny remote island certainly merit further attention from the speleological community.



**Figure 13. Panoramic view of the subterranean pond in Grotte Fougère. Coring sites were on the far left of the view.**

# GROTTE FOUGÈRE PCL4

Plaine Corail, Rodrigues  
Mauritius

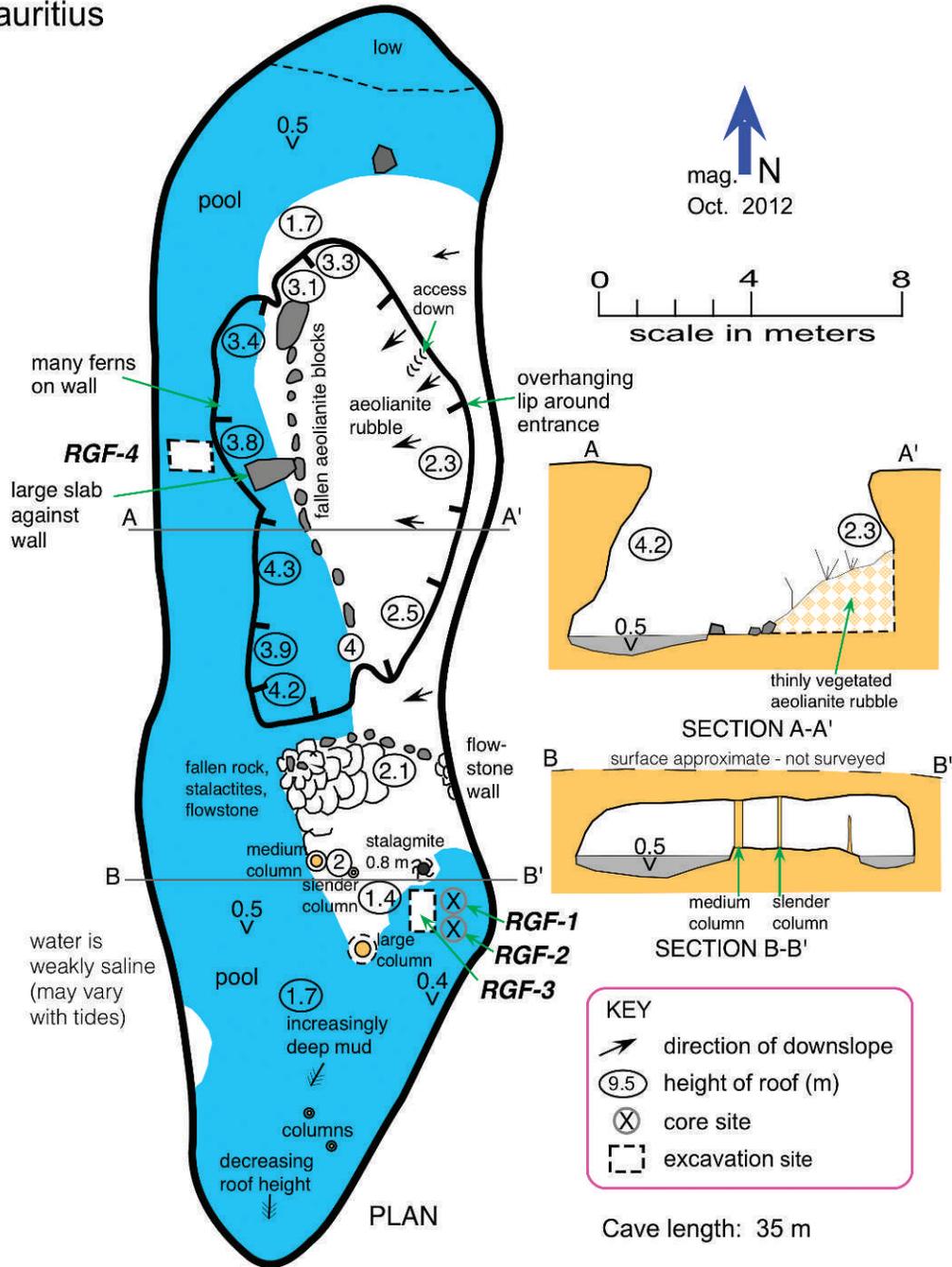


Figure 14. Map showing the location of piston coring sites RGF-1 and 2 and excavation sites RGF-3 and 4 in Grotte Fougère.

## CONCLUSIONS

The thick calcarenite deposits of southwestern Rodrigues Island contain a rich variety of cave and karst features. Coring and excavations in sediments of a range of site types reveal that cave and canyon floors in the calcarenite contain thick clay-based deposits of Holocene age. The chemistry and hydrology of many of the lower caves is not conducive to fossil preservation, although higher, well-drained caves, and one small cave pool, show more promise. This body of brackish water inside Grotte Fougère contains sediments with well-preserved bones, shells, plant macrofossils, and microfossils. Although suitable sites for paleoecological research are now known to be scarce on Rodrigues, the potential exists for using recovered stratigraphy in comparisons with other islands. Rodrigues and the rest of the Mascarenes hold considerable potential as a Rosetta Stone for comparison to landmasses colonized prehistorically by humans. On Rodrigues, to a greater extent than almost any other place on the planet, virtually the entire history of human colonization and subsequent transformation was recorded contemporaneously by literate eyewitnesses.

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