*in* BOUCHET P., LE GUYADER H. & PASCAL O. (Eds), *The Natural History of Santo*. MNHN, Paris; IRD, Marseille; PNI, Paris. 572 p. (Patrimoines naturels; 70).

# Karst and Caves

Bernard Lips, Franck Bréhier, Denis Wirrmann, Nadir Lasson, Stefan Eberhard, Josiane Lips & Louis Deharveng

## THE KARST OF SANTO: GEOLOGICAL SETTING

Limestone facies account for almost half of the surface of Santo Island. The Papatai limestone is the most extensive areally, covering *c.* 90% of the karst area east of a line drawn south from the mouth of the Jourdan River (see Fig. 325B in "Caves as Archives" by Wirrmann and coauthors). It overlies the Tawoli calcarenite-calcilutite formations (ranging from middle Miocene to Pliocene), and forms widespread plateaus in eastern Santo as well as isolated plateau remnants in the western part of the island (for example the coastal plateau in Cape Cumberland). The Papatai formation consists of massive Pleistocene coralline limestone, very porous, and made up entirely of high-magnesium calcite: it is an uplifted complex of coral terraces and flat, coralline islands. The coral terraces related to glacio-eustatic sea-level changes during late Pleistocene and Holocene time are constantly uplifted above modern sea-level (see "The late Quaternary reefs" by Cabioch & Taylor). The pure Quaternary reef limestones comprise the East Santo Plateau, its highest elevation being at 348 m in the Butmas Plateau.

The oldest Quaternary limestones, older than the last interglacial, present a pronounced residual karst morphology with well developed conical hills. They formed at former reef crests and along interfluvial ridges on tilted limestone plateaus and terraces in the eastern central part of the island at Butmas Plateau, Mt Tanakar and Mt Tiouri. The conical hills have developed along the reef crests as the result of fluvial erosion perpendicular to the crests rather than through pure dissolution effect. Only in a few locations, more particularly at the northwestern end of Butmas Plateau, are conical hills associated with typical over-deepening of solution dolines. The hills are most pronounced near the local base level of the Sarakata River, suggesting a fluviokarst morphology mainly related to erosional processes. Karst is totally absent in Tertiary calcarenites, where fluvial erosional forms dominate the relief, due to their high content of volcaniclastic impurities which induces better mechanical strength.

The last interglacial terraces (130-115 ka BP, Eemian Stage [1 ka = 1000 years; years BP: before 1950]) form a broad compound terrace surface, termed the Luganville Surface. This formation exhibits a variety of solutional topography: small solutional and shallow depressions (dolines) and residual hills, without large scale dissection into residual conical hills. This topography has been interpreted as the initial stage of a cone and cockpit karst landscape related to over-deepening of preexisting depressions on the former lagoon floor. Numerous collapse features, many of them with maximum depths extending to more than 150 m below the Luganville surface, are associated with the dolines. They are always associated with absence of roofing limestones over underground streams. On topographical arguments, the related subterranean river courses have been considered as very young features, younger than 60 ka BP. Collapse features are most pronounced in the areas where streams from the volcanic basement enter the limestones. Along the tectonic lineaments the allogenic rivers were provided with paths of easier and faster penetration and solution so that extensive underground channels could develop. On the isolated plateaus of the Luganville Surface west of Hog Harbour, north of Port Olry and around the Walroul Plateau, collapse features are generally absent, while surficial solution features are well developed, however.


Figure 317: Karst (yellow area) and caves (red dots) of Santo.

The karst forms on the uplifted Holocene coral reefs correspond to circular or elongated collapse dolines of 4 to 6 m deep, sometimes extensive like at Hog Harbor and further north along the east coast and south of Mt Tomebou (See Fig. 325B in "Caves as Archives" by Wirrmann and coauthors). Most of them occur within a kilometre-wide strip parallel to the coastline. Their development has been related to areas where subterranean water reaches the piezometric surface near the present coast. Nevertheless, more especially between Mt Tomebou and Wambu River, other depressions, which are not related to collapse over underground streams, are also observed on this Holocene surface. Their origin probably reflects "premature" emergence of incomplete reef development, rather than a unique solution processes like that of the Luganville surface. Rapid tectonic uplift and a rising Holocene sea-level must have resulted in mainly vertical growth, which has overtopped a former and older submerged reef, explaining how the extensive Holocene reef surface could have formed in such a short time.

This brief overview based on published works shows that, in combination with a perhumid tropical climate, the karst relief on the Quaternary limestones of Santo is the result of facies-controlled lithology and purity of parent material (lack of karst feature on the Tertiary calcarenite formation), tectonic conditions (the linear topographical features defining preferential paths for vertical and lateral solution), influence of soil and plant cover (the deeper the soil, the stronger the dissolutional process) and Quaternary sea-level changes.

## THE CAVER PERSPECTIVE

For cavers, the Santo karst is first a huge and compact block of limestone, 60 km long by 25 km wide (Fig. 317), i.e. one of the largest karst blocks in the Pacific. The few outlying islands and small outcrops in the North and the West of the main island have much less speleological potential. Elevation is moderate (784 m at the highest point, Mt Tanakar) and undulating terrain is the dominant landscape, with few large dolines and rare cliffs except along the coast. The archetypical features of tropical karsts, pinnacles or steep karst towers, are absent in Santo. Nevertheless, the karst is amazingly rich in other karst features, including caves, deep dolines and large coastal springs, enough to be very attractive for cavers.

Finding caves in Vanuatu can only be done in tight connection with local people. Not only the lush vegetation (Fig. 318) and absence of prominent landscape features would make direct prospection long and uncertain, but also permission is mandatory for underground access, from the owner of the cave entrance and the tribal chief of the area where it is located. Local guides also are necessary to reach the entrances, and young (and less young) villagers often enthusiastically accompany the cavers into the darkness. At least, in many cases, sleeping in the villages is the best way to optimize the time spent underground — and is an unforgettable experience.

## HISTORY OF EXPLORATION

The first cave explorations on Santo were done by Australian divers in search of sumps to dive (1996-2000). They surveyed the large system Mt Hope-Sarakata resurgence (with a total horizontal development of about 3 400 m), and made the first trip to the Patunar giant doline. These pioneer explorations were published in diving journals, and remain little known among cavers.

In August 2005, Josiane and Bernard Lips and Rufino Pineda, undertook a preliminary trip to Santo, searching for biologically significant caves in the island in order to evaluate how much emphasis should be placed on subterranean biology for the 2006 expedition. The results were beyond expectation, with 54 karstic features located (mostly caves) and 5 886 m of underground passages mapped. The most obvious biological features observed were the omnipresence of bats, often in large colonies, and the frequent occurrence of swiftlets, in association with large guano piles supporting abundant animal communities in numerous caves.

A second preliminary reconnaissance targeting subterranean water habitats was made from 17 October to 13 November 2005 by Franck Bréhier, with three objectives: diving some inland caves to detect their richness in subterranean species; exploring karstic areas not seen by the preliminary reconnaissance, specially the northern cape of the island; searching for anchialine habitats and fauna. In total, Franck explored 30 karstic features, of which 10 potential anchialine habitats, 2 000 m cave passages were recognized, and five caves were dived. Aquatic fauna was present in most caves, and in several sites pottery as well as human bones were observed.

Based on these promising results, we set up a strong team of skilled cavers and divers to continue the exploration and mapping of the cave systems of the island, and to assist the biologists in the field.


Figure 318: Cave and shaft entrances.
**A**: Lavav Aven near Port Olry. **B**: Avorani shaft on Malo. **C**: Bottom of Patunar doline. **D**: Patunar resurgence. **E**: Fapon Cave.


Figure 319: Passing a "voûte mouillante" in Fioha Aven.

## MAIN RESULTS

The 2006 expedition allowed us to push exploration and mapping of the caves recognized in 2005, but also to discover 28 additional caves or karstic features. In one month, 13 961 m of subterranean passages were explored, of which 7 961 m were mapped. Eighty-six subterranean karstic features are recognized today on Santo: 10 blue holes, 41 caves less than 50 m length, 15 caves from 50 to 100 m, 21 more than 100 m, 12 more than 500 m and five more than 1 km long. With more than 19 km of explored underground passages in total, Santo is the richest of the Pacific islands in number of caves and length of explored passages — outside New Guinea.

In lowlands, most caves were dry entrances and did not give access to underground streams, with the noticeable exception of the anchialine Loren Cave (see "Focus on Loren cave"). Even the spectacular blue holes did not open onto significant underground passages.

The most interesting cave systems of the island were discovered in two upland areas: the Funafus area, which gave access to the largest caves of Santo, and the Butmas region, the most promising area, which was the most intensively studied biologically.

### • • • The Funafus system (Fig. 320)

The largest subterranean system of Santo explored so far is located near the village of Funafus, between 100 and 250 m of altitude, in the southern part of the Santo karst. Six caves, awaiting interconnection, belong to this complex:

- Amont Cave (length: 259 m northwestern part of the system, not represented on the map);
- Kafae Aven (length: 3 702 m);
- Streamsink and Tarius Caves (length: 2 139 m mapped + 380 m not mapped);
- Riorua Cave (length: 400 m);
- Tchawak Cave (length: 58 m);
- Patunar resurgence and doline (length: 742 m).

The total known passages of the Funafus system reach 7 662 m, i.e. more than 1/3 of the total length of subterranean passages currently known from the island. The Patunar doline is probably the most impressive karst surface feature of Santo: it is a large depression with subvertical cliffs on three sides, 100 m deep and 100-150 m in diameter. In

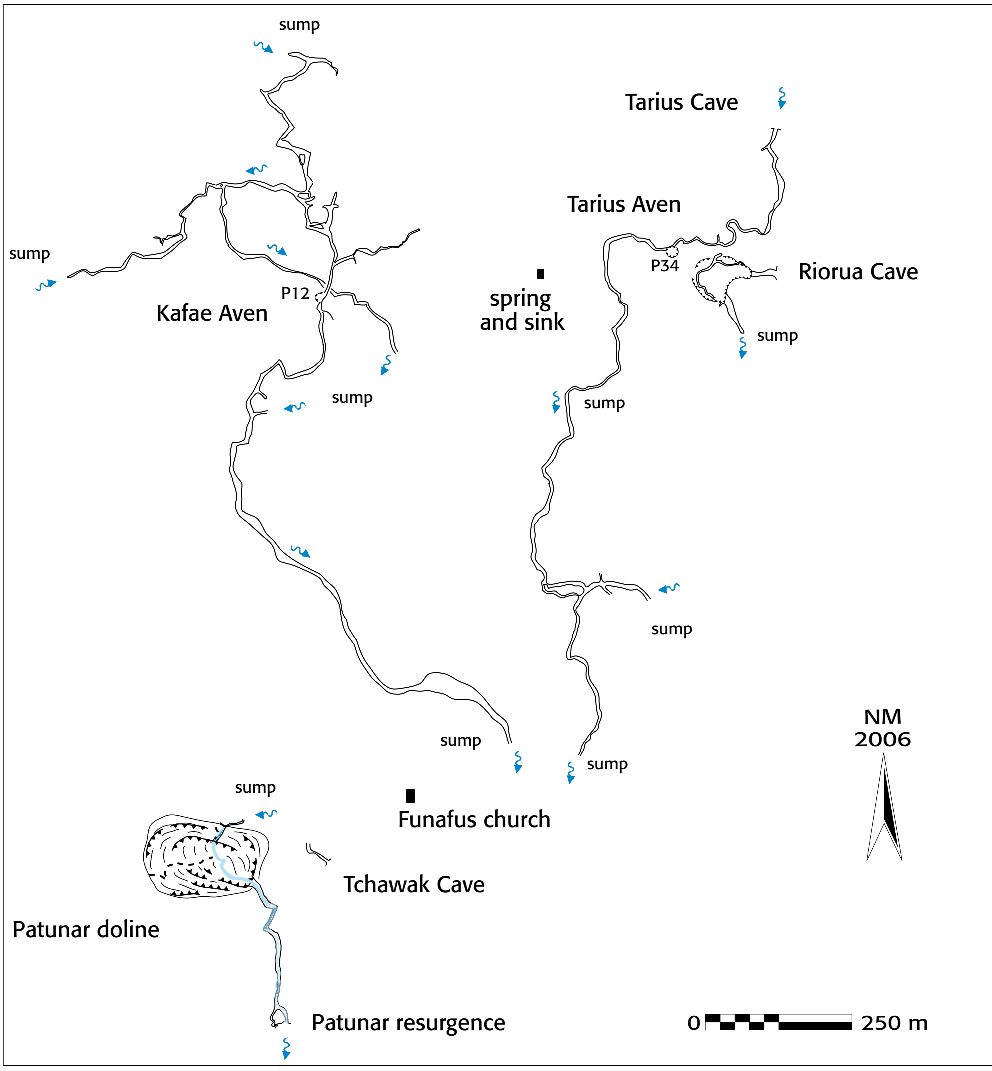


Figure 320: The Funafus system (Funafus-Santo-Vanuatu, Santo 2006 expedition).


Figure 321: Underground exploration.
**A, B**: Underground river in large passages of the Kafae Aven. **C**: Descent in Kafae Aven. **D**: Amarur Cave. **E**: Fapon Cave.

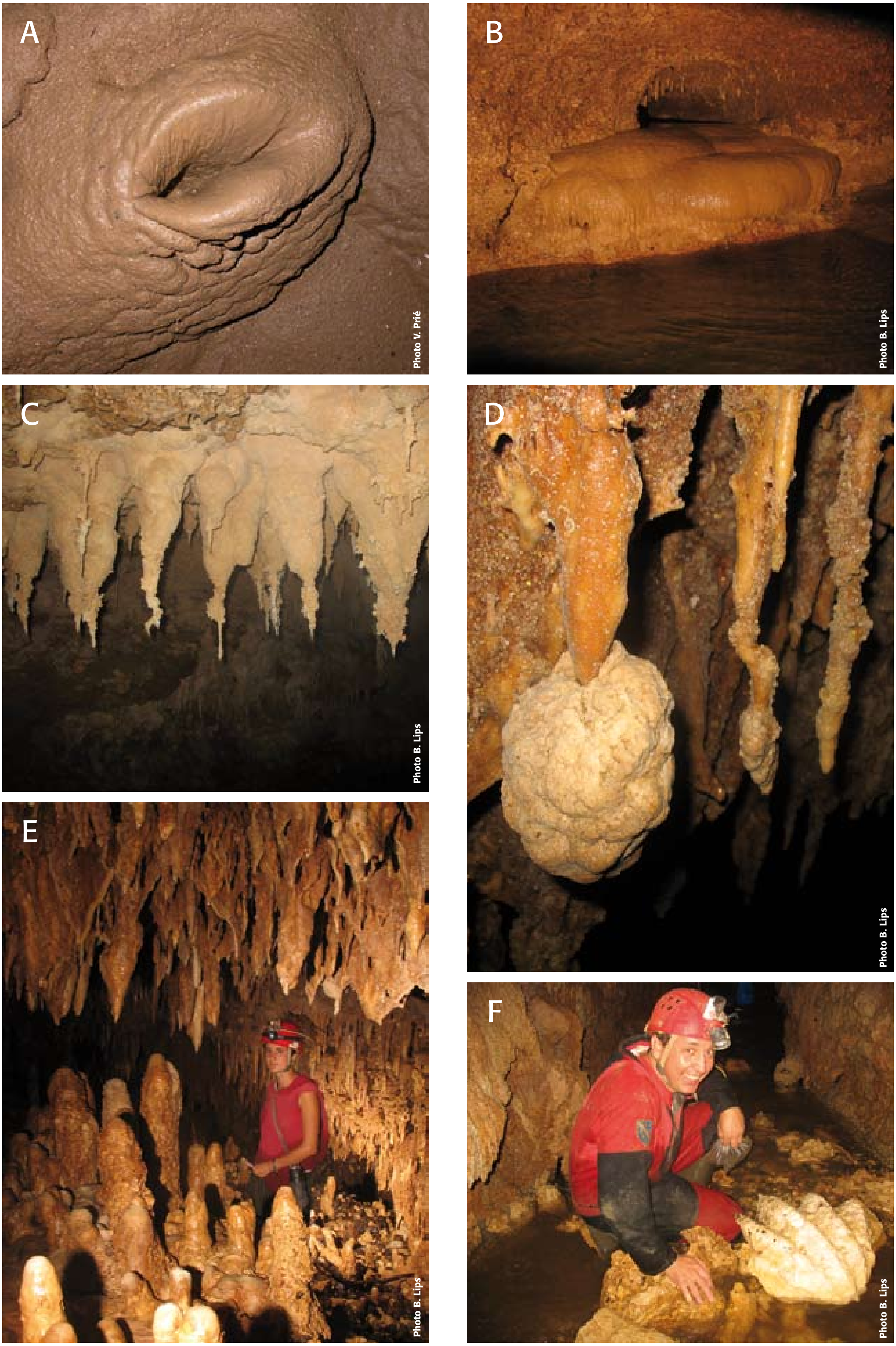


Figure 322: Underground exploration.
**A**: Kafae Aven, clay formation. **B**: Calcite formation deposited by a little inlet in Kafae Aven. **C** & **D**: Stalactites in Fapon Cave. **E**: Stalactites and stalagmites in Fapon Cave. **F**: Amarur Cave, large fossil clam (*Tridacna* spp.).

Table 30: Longest (more than 300 m) and deepest (more than 25 m) caves of Santo and Malo Islands.

| Name of the caves | length in m | depth in m | explored by |
|---|---|---|---|
| Kafae Aven (Funafus) (Figs 321A-C & 322A-B) | 3 702 | -77 | Santo 2006 |
| Tarius Aven (Funafus) | 2 139 | -90 | Santo 2006 |
| Fapon Cave (Butmas) (Figs 318E, 321E & 322C-E) | 1 400 | -44 | Santo 2006 |
| Sarakata resurgence (Fanafo) | 1 200 | -30 | Australians (Harris 2006) |
| Loren Cave (Lotoror) | 1 013 | -40 | Santo 2006 |
| Mt Hope System: Fifty Four, Champagne Hole, Pump Sink, Three Way Sink, Three sisters, Tourist Blue Hole (Fanafo) | 900 | -54 | Australians (Harris 2006) |
| Amarur Cave (Nambel) (Figs 321D & 322F) | 874 | -21 | Santo 2006 |
| Mt Hope System: Drinking Hole, Clam Shell (Fanafo) | 800 | -67 | Australians (Harris 2006) |
| Patunar resurgence and Doline (Funafus) (Figs 318C-D) | 791 | -106 | Santo 2006 |
| Fioha Cave (Belmol) (Fig. 319) | 550 | -29 | Santo 2006 |
| Wanror (Butmas) | 525 | -40 | Santo 2006 |
| Mt. Hope System: Bush Rope Hole (Fanafo) | 500 | -36 | Australians (Harris 2006) |
| Millenium Cave (Nambel) | 432 | -41 | Santo 2006 |
| Riorua Cave (Funafus) | 400 | -25 | Santo 2006 |
| Mba Aven (Butmas) | 387 | -59 | Santo 2006 |
| Vobananadi shaft (Malo: Avorani) (Fig. 318B) | 209 | -87 | Santo 2006 |
| Lavav Aven (Loran) (Fig. 318A) | 60 | -31 | Santo 2006 |
| Tchawak Cave (Funafus) | 58 | -31 | Santo 2006 |

the Kafae and Tarius shafts, the longest caves of Santo recognized at this time, passages may reach up to 15 m wide by 15 m high with huge underground streams. In several leads, exploration stopped simply by lack of time, or on big sumps (there were about ten, all of them easily divable). The different parts of the system are likely interconnected by underwater passages, so future exploration is now in the hands of divers, and probably would encompass more than 10 km of passages given the number of galleries running in parallel.

### Butmas: Fapon Cave and Mba Aven (Figs 323 & 324)

The village of Butmas is set in the middle of Santo in the jungle near the western border of the karst and at the foot of Mt Tanakar. This area is overgrown with dense secondary forest and tangled vegetation, and is the wettest of Santo. Several biological surveys were made in the largest cave of the area (Fapon Cave), which turned out to host a rich and original fauna in its dark passages as well as in its deep dolines which open on the course of the subterranean stream.

The upstream entrance of Fapon Cave is a narrow passage, where a small stream sinks among blocks. The subsequent galleries are moderate in size, some well decorated, and connect three successive deep dolines. Several passages are aquatic: the last one, downstream of the third doline gives onto a shallow sump 42 m-long. It was dived during the last field trip of the diving team and gave access to a much larger and very different passage, with a big river running northward, perpendicular to the first part of the cave, i.e. towards the Jourdain valley. Interestingly there were bats flying in this post-sump gallery indicating that another direct access exists to this part of the cave. Alone for this diving, Nadir Lasson had to turn back by lack of time after 400 m of easy walk, after observing huge continuations upstream and downstream.

The same day, in the Mba Aven, another team of cavers got access to another large river where exploration stopped upstream on a waterfall, and downstream on a winding, low ceiling passage.

These last-day discoveries of major underground collectors highlighted the Butmas area as the most promising site for future explorations in the Santo karst. Indeed, finding such big underground streams suggests that a huge network of hydrological passages are developed in the three or four hundred meters thick limestone terrain above Butmas. The potential is even higher downstream, with suspected water resurgences at the coastal blue holes, several kilometers away and more than 300 m below).

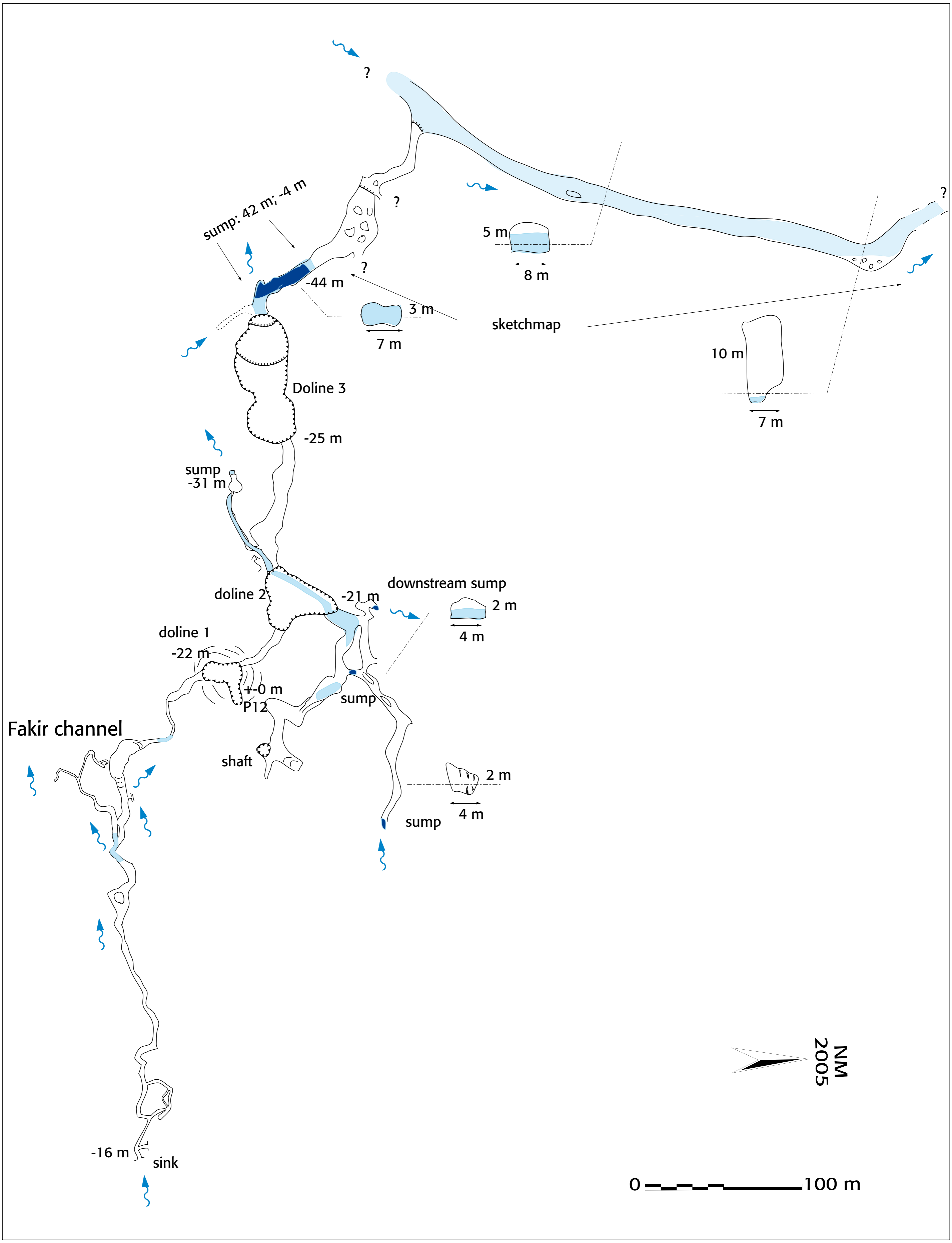


Figure 323: Fapon Cave (Butmas-Santo-Vanuatu, Santo 2006 expedition).

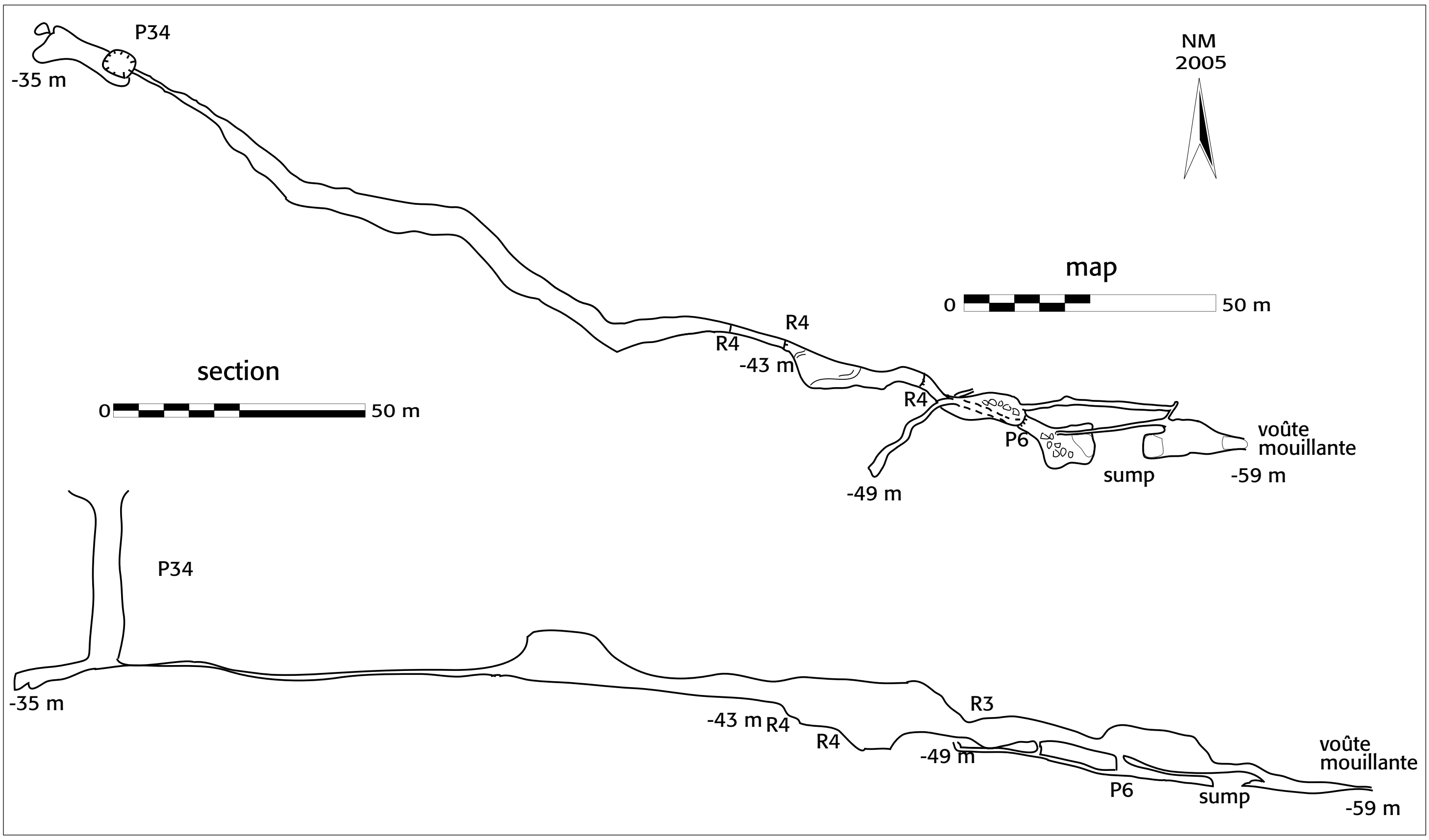


Figure 324: Mba Aven (Butmas-Santo-Vanuatu, Santo 2006 expedition).

## THE FUTURE OF CAVE EXPLORATION IN SANTO

One of the important and unexpected finding of Santo 2006 has been the existence of a well organized underground drainage, with very large underground passages in spite of the relative recentness of the karstification (younger than the Upper Miocene). Kilometers of beautiful galleries have already been recognized, but they clearly represent only a small part of what exists in the heart of the limestone, both in terms of length and depth of the karstic features. Furthermore, we have no idea of the hydrological course of the largest subterranean rivers discovered in Butmas: these questions are the exciting challenge that Santo 2006 has raised for future expeditions.