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CAVES AND SPELEOGENESIS OF MANGAIA, COOK ISLANDS

BY

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ABSTRACT

Ten caves in the makatea limestone of Mangaia, Cook Islands were explored and mapped, totalling over 3.7 km of passage. Of these, there was an apparent grouping by elevation that corresponds with previously described sea-level terraces in the makatea. Four caves have major level sections 10-20 m above sea-level, corresponding with a 14.5 m Pleistocene terrace. The high dimensions of these caves indicate downcutting during slow uplift, or multiple reoccupations by highstands of Pleistocene sea-levels. One major cave has level passage 20-30 m above sea-level, corresponding with a 26-27.5 m terrace. Three caves have level passage 40 m above sea-level, corresponding with a 34-39 m terrace. Active conduit caves are developed at the present sea-level, but are closed with heavy clay deposits from recent soil erosion.

INTRODUCTION

Mangaia is the second largest and most southerly of the Cook Islands (21°54'S, 157°58'W), with a land area of 52 km^2 (Fig. 1). The island is divided into two concentric geological zones. The inner zone is a subdued basaltic volcanic cone rising to 168 m, flattened at the summit possibly by marine erosion prior to its uplift (Wood, 1967), dating between 17-19 m yr BP (before present) (Dalrymple et al., 1975). The outer zone is a complete raised limestone rim or makatea, 0.7 to 2 km wide, up to 70 m in height, with erosional topography of steep terraces on the outer edge, and cliffs on the inner edge (Stoddart et al., 1985).

Yonekura et al. (1988) showed from the identification of planktonic foraminifera in makatea limestone that these are up to 17 m years old, indicating that coral reefs developed shortly after the volcanic island formed. While the major part of the limestone is Tertiary, Pleistocene deposits occur on the seaward margins to an elevation of 14.5 m (Stoddart et al., 1985). Emergence occurred in late Tertiary to Quaternary times, during which there were two periods of stability in relative sea-level to cut marine terraces at 26-27.5 m and 18-20 m (Stoddart et al., 1985).

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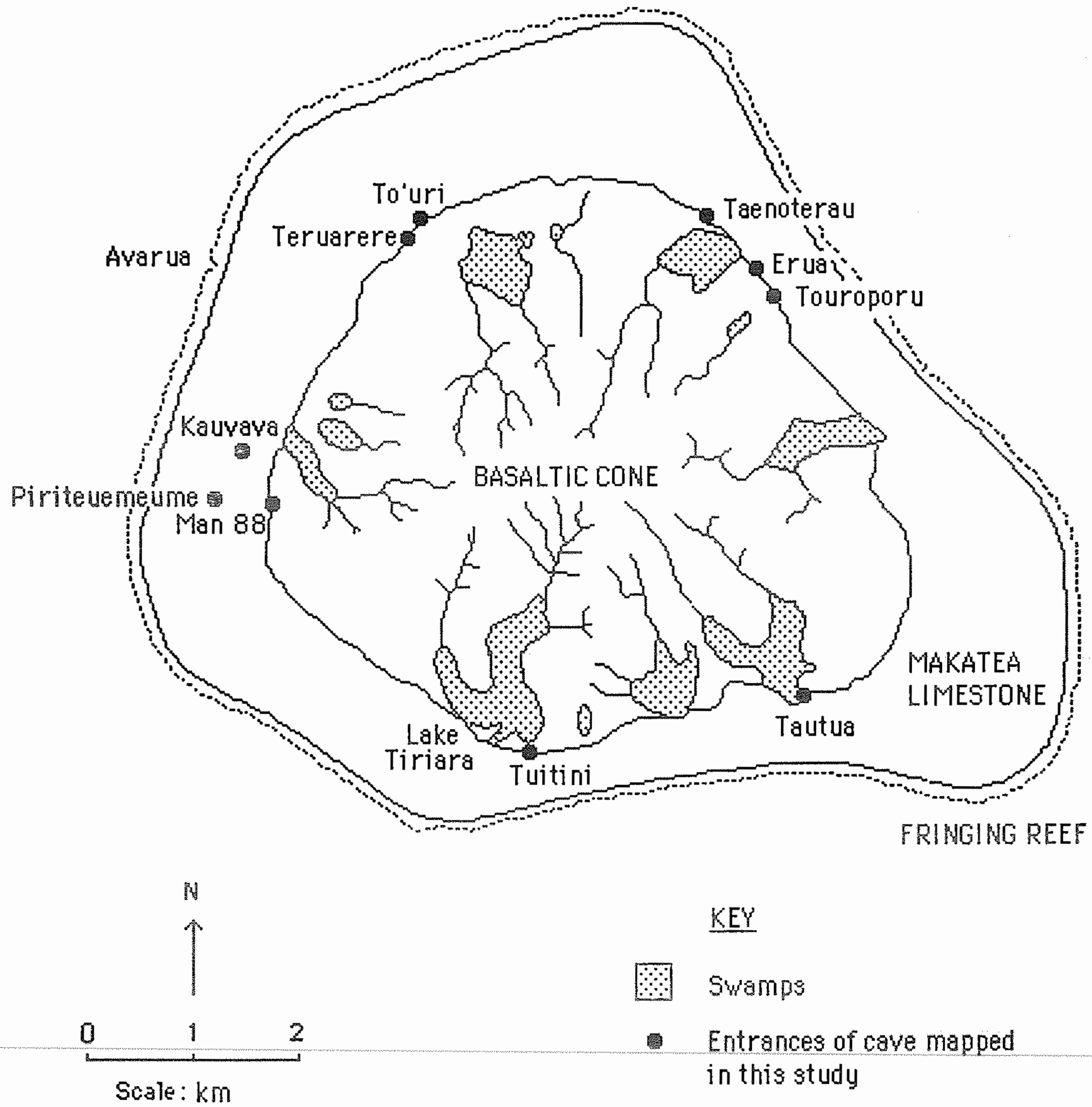


Figure 1. Map of Mangaia, showing geology and locations of entrances to caves in this study

Mangaia receives a mean annual rainfall of 1967 mm, with range in the period 1914-1984 of 1024 to 2983 mm (Thompson, 1986). There is a pronounced wet season from November to April, and dry season from May to October. Drainage is radial, with deeply incised first and second order streams off the central cone feeding lowland taro swamps collected against the inner makatea cliff. Water from the swamps sinks beneath the makatea limestone in radially draining cave systems. Stoddart et al. (1985) showed that stream water entering the makatea limestone is aggressive, supporting the interpretation that the cliffs of the inner makatea are erosional remnants from a former complete cover of limestone to equivalent elevations on the volcanic slopes (Stoddart and Spencer, 1987, Figure 4).

The purpose of this study is to investigate how these events are expressed in the speleogenesis of Mangaia. Many cave entrances can be seen in the makatea cliffs, and the topographic map of Mangaia shows 65 sink holes on the top of the makatea, which considering that the map was made from air photographs of a heavily forested area must under-estimate total numbers. The sinkholes are strongly clustered to indicate traces of cave systems. A few are used for burials or settlement and hence are of archaeological interest. As commented by Gill (1894), "the numerous and extensive caves that honeycomb the makatea were formerly used as habitations, cemeteries, places of refuge, and stores. Scores of them are filled with dessicated human bodies".

While very little work has been done on the cave systems of makatea islands, but the following principles on cave evolution are suggested from the surface geomorphological work.

1. As cave development is most active at the water table, those that are presently under active development can be found at the vadose conduits where streams enter the makatea. These decline slightly along their course, similar to a stream.

2. Caves above these levels are fossil conduits, with a positive relationship between elevation and age, resultant from uplift of Mangaia and general decline in sea-levels from the Tertiary to the Quaternary (Haq et al., 1987).

3. Fossil conduit caves should decline slightly from the influent entrance at the inner edge of the makatea to the coast, at an elevation that is slightly above the sea-level position at the time of development. On low limestone islands, such caves can be used as an indicator of former sea-level (Mylroie and Carew, 1988).

4. Higher elevation caves should therefore show features of older caves, with collapse, flowstone infill and large speleothem formations. Lower elevation caves should show features of younger caves, with more even walls and floor, and smaller formations.

5. A conduit cave could cut into its floor during uplift of the makatea, developing a deeply rifted cave. Such caves could indicate a period of slow uplift, while rapid uplift would result in abandonment of the former conduit and development of a new cave at a lower level.

METHODS

In July 1991 ten caves were explored and surveyed, to the British Cave Research Association Grade 5b standard, using a Suunto compass and clinometer, and 50 m fibreglass tape. This standard requires a station- to-station survey, with passage details recorded at the time (Ellis, 1976). Cave maps produced are shown in plan view, so it must be remembered that passages are not shown at their actual length unless they are horizontal. A profile view is also shown of the cave passage. No vertical techniques were possible in this study, and climbing risks not taken owing to lack of back-up support.

Where possible, surface survey was continued to a known elevation to give the altitude of the cave as indicated on the maps, otherwise it was estimated from contours on the topographic map.

DESCRIPTIONS OF THE CAVES

Tuitini cave, Veitatei (Figure 2)

Tuitini is the largest cave explored in this study, with two entrances about 100 m to the east of Lake Tiriara. It would have been the conduit cave for the Veitatei drainage basin, which is the largest on Mangaia, when relative sea-level was 20 m higher. Survey was continued to the water level of the lake to establish the altitude. The main passage is large, with few formations, while the upper passages to the south and east are well decorated with formations. There are four burials in the cave, permission to explore should be sought from the chief in Kaumata village (Oneroa).

The main passage indicates downcutting, with heights of 20 to 25 m, while the upper passages have low ceilings of 10 m or less. There are sections in the main passage with collapse, it is necessary to climb around or over large boulders. At the end of the surveyed section the main passage continues at the base of a 7 m pitch, at which point the cave is around 30 m high.

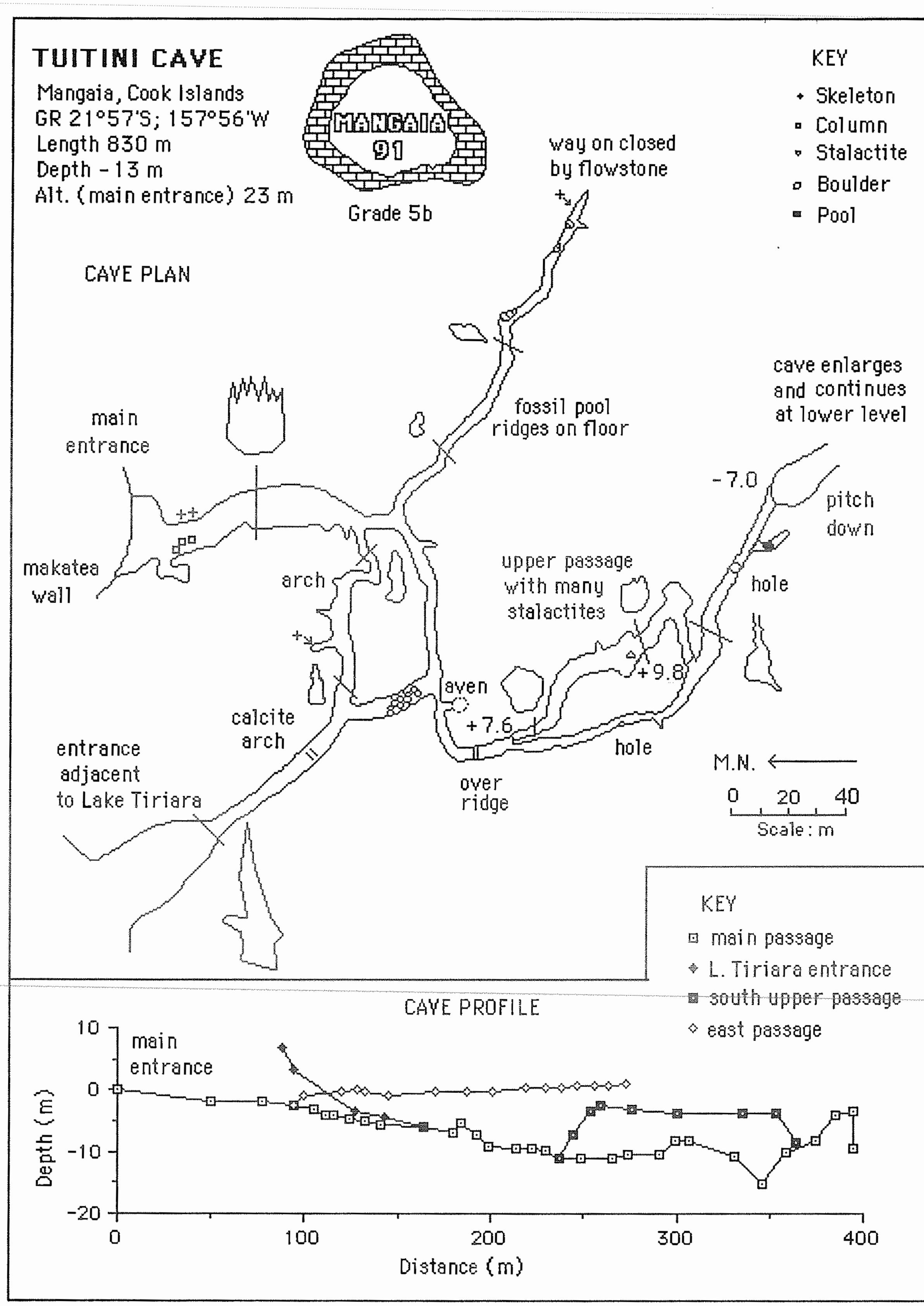

TUITINI CAVE
Mangaia, Cook Islands
GR 21°57'S; 157°56'W
Length 830 m
Depth -13 m
Alt. (main entrance) 23 m
MANGAIA 91
Grade 5b
KEY
Skeleton
Column
Stalactite
Boulder
Pool
CAVE PLAN
way on closed
by flowstone
fossil pool
ridges on floor
cave enlarges
and continues
at lower level
main
entrance
makatea
wall
arch
-7.0
pitch
down
upper passage
with many
stalactites
hole
+9.8
aven
+7.6
calcite
arch
entrance
adjacent
to Lake Tiriara
over
ridge
hole
M.N.
0 20 40
Scale: m
KEY
main passage
L. Tiriara entrance
south upper passage
east passage
CAVE PROFILE
main
entrance
Depth (m)
10
0
-10
-20
0
100
200
300
400
Distance (m)

Figure 2.

To'uri cave, Tava'enga (Figure 3)

The entrance to To'uri is where the depression to the west of Tava'enga swamp meets the makatea wall. A stream leads to the cave entrance, which is approached by a steep climb down over boulders and ferns into a large overhang. The cave is partially an active streamway, with heavy wet red clay deposits throughout. A bank of red clay at the entrance has been incised by headward erosion of the stream to create a 2 to 3 m profile.

The small stream follows the left hand side of the cave for 60 m, then sinks into a hole. In the stream water are small black fish.

To'uri cave indicates recent stream flow that has downcut through older clay deposits, leaving exposed mud sections along sections of the passage wall. The cave is large in passage dimensions relative to others in Mangaia, the roof a wide vertical fissure visible to 20-30 m, the passage 3-10 m wide. There are occasional rocks fallen down, and occasional large stalagmite or flowstone formations. Stalactites are the more common.

After 490 m of passage there is a clay bank 2.5 m down to flowing water, which heads out through a tight passage to the north. The water tasted salty and waves could be heard. Opposite, up a clay climb, the cave continues to the west. This was not explored.

Elevations for Tou'ri and Teruarere caves are based on the salt water being at sea-level.

Teruarere cave, Tava'enga (Figure 4)

This is the second largest cave explored in this study, located 40 m above the entrance to To'uri Cave, along the makatea wall to the SW.

The cave is accessed from the top of the makatea. The entrance rift trends east- west, and there is a 10 m climb down to the cave entrance 50 m back from the makatea edge, assisted by roots. A large *Hernandia moerehroutiana* tree grows out of entrance. Where the rift reaches the makatea edge one can look down on entrance to To'uri cave, some 100 m to the left. Strong winds come through the cleft. The cave entrance leads away from makatea edge, under the entrance climb.

Cave is simple fossil streamway, 10-30 m high, 1-10 m wide, dry. It contains at least 7 skeletons lying on the floor near the cave wall, surrounded by stones. This is a burial cave, in the charge of Tuara George of Oneroa village, from whom permission to explore the cave should be obtained.

Cave has been studied by the ornothilogist D. Steadman, showing from fossil bird bones that early Polynesian settlement caused extinction of many species (Steadman, 1985, 1986).

The rift opens above to four daylight avens in the first 200 m of the cave. Formations are mainly calcite cascades, curtains and flowstones, with vandalism of whatever possible. The floor is hard red mud, with occasional patches of rubble. Lower in the cave, calcite flows cover the floor, and there are places where ridges on the floor indicate fossil pools. Towards the end of the main passage of the cave, there are a couple of climbs down, then a

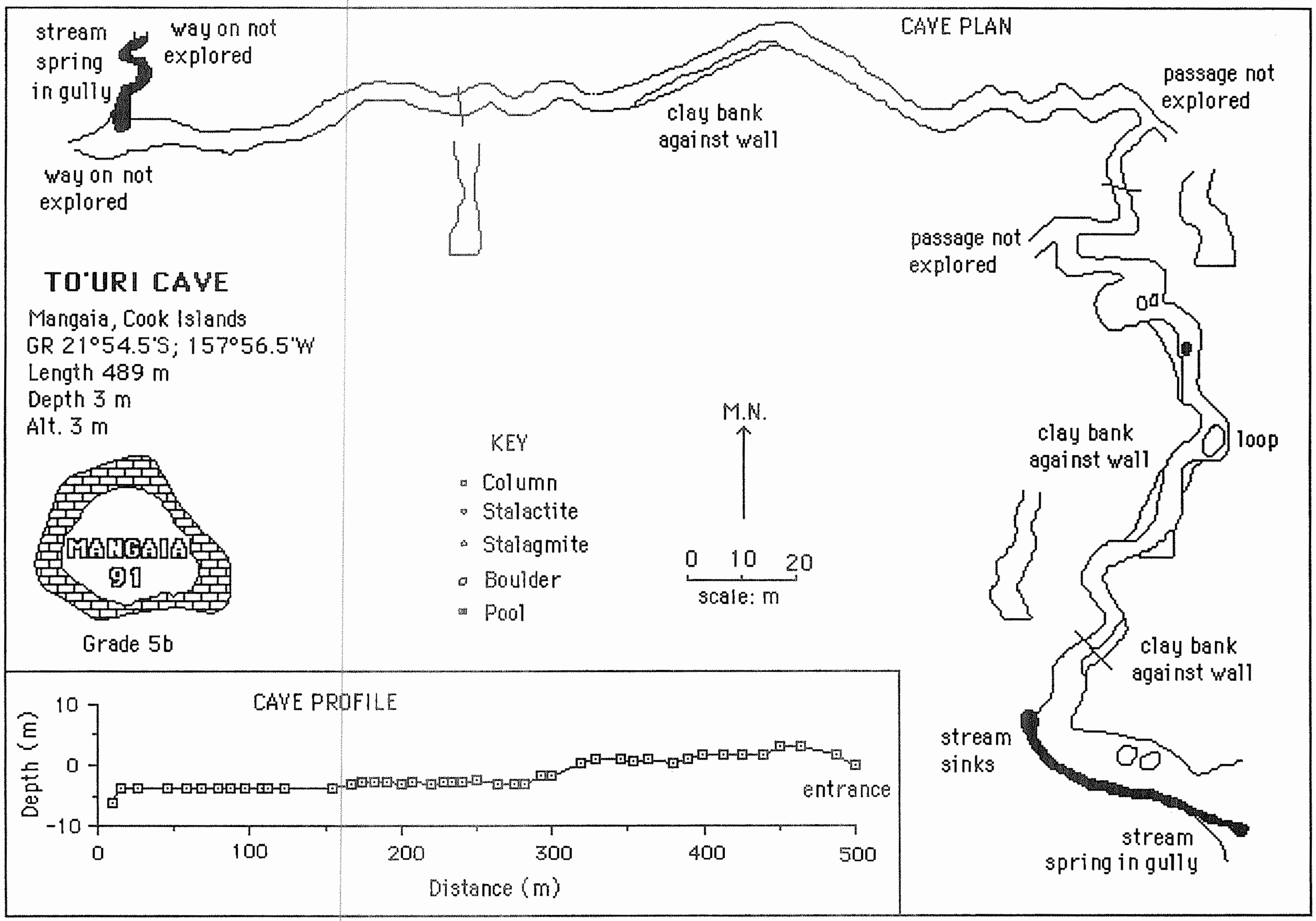
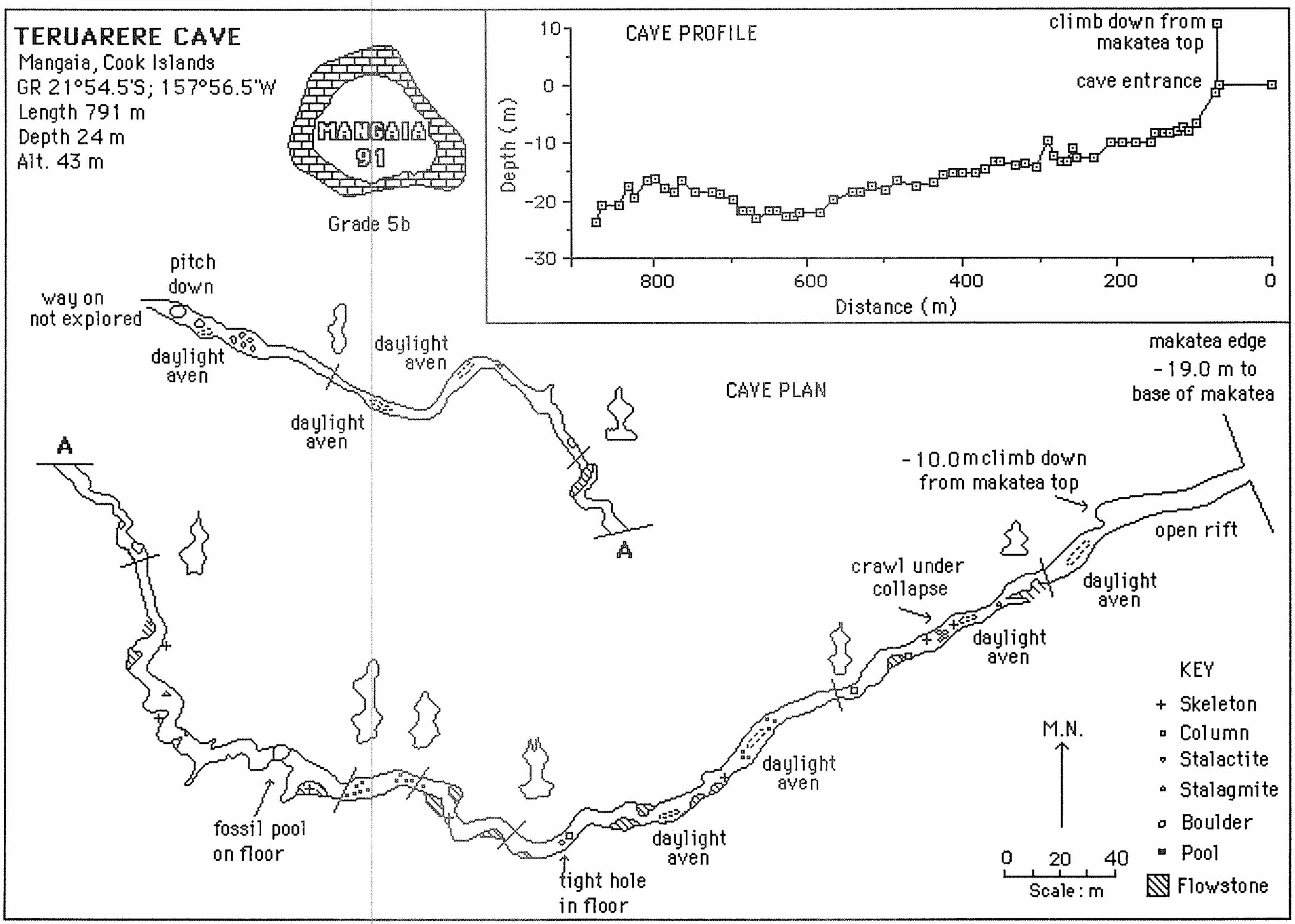

CAVE PLAN
stream spring in gully
way on not explored
way on not explored
clay bank against wall
passage not explored
passage not explored
od
loop
clay bank against wall
clay bank against wall
stream sinks
stream spring in gully
TO'URI CAVE
Mangaia, Cook Islands
GR 21°54.5'S; 157°56.5'W
Length 489 m
Depth 3 m
Alt. 3 m
MANGAIA 91
Grade 5b
KEY
Column
Stalactite
Stalagmite
Boulder
Pool
M.N.
0 10 20
scale: m
CAVE PROFILE
Depth (m)
10
0
-10
0
100
200
300
400
500
Distance (m)
entrance

Figure 3.



TERUARERE CAVE
Mangaia, Cook Islands
GR 21°54.5'S; 157°56.5'W
Length 791 m
Depth 24 m
Alt. 43 m
MANGAIA 91
Grade 5b
CAVE PROFILE
climb down from makatea top
cave entrance
Depth (m)
10
0
-10
-20
-30
800
600
400
200
0
Distance (m)
CAVE PLAN
makatea edge
-19.0 m to base of makatea
open rift
-10.0 m climb down from makatea top
daylight aven
crawl under collapse
tight hole in floor
fossil pool on floor
pitch down
way on not explored
A
A
KEY
+ Skeleton
Column
Stalactite
Stalagmite
Boulder
Pool
Flowstone
M.N.
0
20
40
Scale : m

Figure 4.

pitch down that was not explored. Some daylight comes through high above the pitch. The upper passage continues, but is a tricky climb past the pitch, this was not explored.

Touropuru cave, Ivirua (Figure 5)

This is the third largest cave explored in this study. The entrance is 10 m up the makatea wall adjacent to the small Kirikiri swamp, between the larger Karanga and Ivirua taro swamps. Adjacent to the entrance to the south was a large cave shelter used for habitation, which has unfortunately recently collapsed.

This cave is the burial cave of the Totongaiti tribe, with 22 skeletons in the main cave and 9 in a small cave above the lower entrance. Permission to explore this cave must be obtained from a member of the tribe in Ivirua village, such as Ma'ara Ora, Director of Forestry. Just inside the entrance is a side passage to the right, 39 m long to a window 10 m up the makatea wall. The passage is narrow and lined by 19 skeletons in open coffins, mostly of planks (post-contact), but some canoes (pre-contact).

The main passage is a fossil vadose stream passage, generally 1-2 m wide and 3 m high, but sections which widen to some 6 m, and sections where the rift above is visible to some 15 m. After 350 m the passage forks, the left passage closing up with flowstone after 150 m, the right fork leading to the base of a doline entrance in Ivirua village, that has a 22.5 m pitch that can be climbed (GR 21° 54' 45" S, 157° 54' 15" W). The main passage has been closed in by flowstone deposits and some collapse, causing the route to go up and down, but from the entrance to the fork over a distance of 350 m there is no elevation change. There are three more skeletons at the start of the main passage, then no more. Formations are mainly curtains and flowstones, though there are some large stalagmites and columns and more smaller stalactites. There is less vandalism of formations in the final left branch. After the fork, both passages climb some 4 m. There are some small passages off the main route, some of which may have unexplored sections.

Erua Cave, Karanga (Figure 6)

The cave entrance is located some 200 m to the south of the Karanga swamp conduit entrance, just north of where the path from Karanga village descends the makatea to the Karanga swamp. The cave entrance is conspicuous, 14 m above the base of the makatea, a rift 20 m tall, and a strong through breeze can be felt. The passage of this cave is wide and high, with few formations and a mud floor with frequent cobble-sized angular rocks. It was used as a refuge during prehistoric wars, and several human structures and midden deposits can be seen, but no burials. Like Tautua cave, which was also used as a war refuge, Erua has light inside the cave, from an aven. There is a debris slope from material which has fallen through the aven, including some animal skeletons. The few formations are large

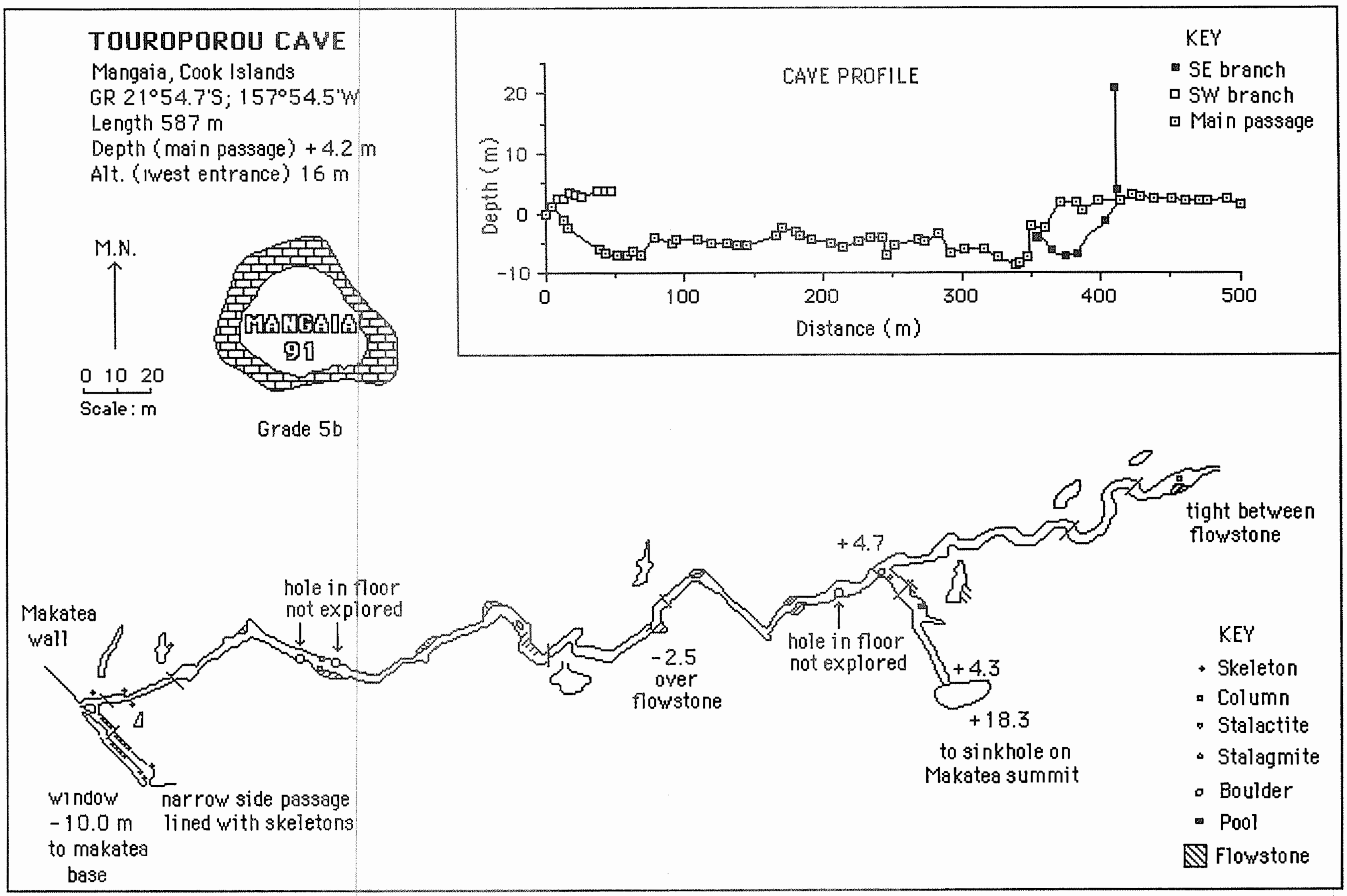

TOUROPOROU CAVE
Mangaia, Cook Islands
GR 21°54.7'S; 157°54.5'W
Length 587 m
Depth (main passage) +4.2 m
Alt. (west entrance) 16 m
M.N.
0 10 20
Scale: m
MANGAIA
91
Grade 5b
CAVE PROFILE
Depth (m)
Distance (m)
KEY
SE branch
SW branch
Main passage
Makatea wall
hole in floor not explored
window -10.0 m to makatea base
narrow side passage lined with skeletons
-2.5 over flowstone
+4.7
hole in floor not explored
+4.3
+18.3
to sinkhole on Makatea summit
tight between flowstone
KEY
Skeleton
Column
Stalactite
Stalagmite
Boulder
Pool
Flowstone

Figure 5.

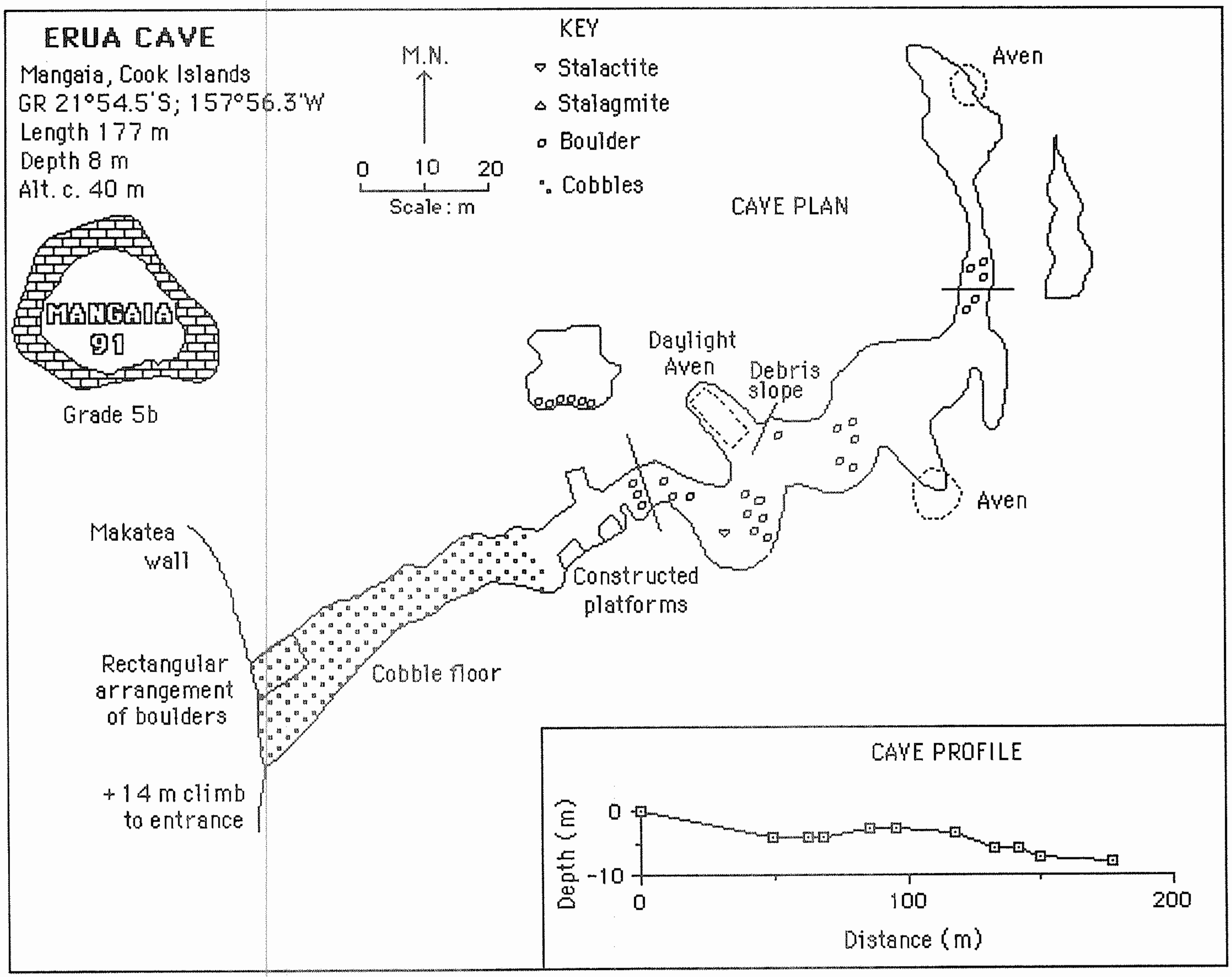

ERUA CAVE
Mangaia, Cook Islands
GR 21°54.5'S; 157°56.3'W
Length 177 m
Depth 8 m
Alt. c. 40 m
MANGAIA
91
Grade 5b
M.N.
0
10
20
Scale : m
KEY
Stalactite
Stalagmite
Boulder
Cobbles
CAVE PLAN
Aven
Aven
Daylight
Aven
Debris
slope
Constructed
platforms
Makatea
wall
Rectangular
arrangement
of boulders
Cobble floor
+14 m climb
to entrance
CAVE PROFILE
Depth (m)
0
-10
0
100
200
Distance (m)

Figure 6.

stalactites and stalagmites, and there are two avens which could extend the cave.

Taenoterau Cave, Karanga (Figure 7)

The cave entrance is located to the north of the Karanga swamp conduit entrance, 20 m above the level of the swamp. Behind the large rock at the entrance are trenches where a Japanese archaeological group dug in 1990. The lighted entrance is some 25 m tall, but falls to 5-10 m as the cave begins. Flowstone formations have blocked the passage twice in the first 20 m, so one has to climb over. The formations are all large, stalactites, stalagmites and dripstones, and crystalline flowstone walls.

Tautua cave, Tamarua (Figure 8)

At the makatea wall where the East Tamarua swamp collects there is a large cavern, over 30 m high and 100 m across (Plate 1). The floor is covered by large boulders from collapse, and there are old, vertical stalactites on the ceiling, indicating that the cavern has been exposed by makatea retreat. The stream from the swamp enters the cavern and through a conduit cave that is 15 to 20 m wide, mostly 1 to 2 m high, with extensive wet clay deposits.

Above the conduit is the entrance to Tautua cave, up an 11 m climb. At the entrance the cave is 15 to 20 m high, and this height continues along the right branch just inside the entrance. This does not extend far, and has two connections with the lower streamway.

On the left branch are habitation sites clustered around a window out of the makatea wall. The cave is well known from oral traditions as the primary refuge of the Tonga'iti tribe in times of war (Gill 1894, Buck 1934). Permission to explore the cave should be obtained from a member of that tribe, such as Noka Tumarama of Tamarua village. There are stone faced platforms, a *marae* (worship place), a tupe disk pitch (for playing a bowling-type game), and midden deposits. The site was analysed by P. Kirch and other archaeologists from University of California at Berkeley in 1989, and mapped by theodolite in 1991.

The site was a retreat in times of war as it is easily defended. The lower entrance is a vertical climb, and defenders could bombard invaders with rocks. Past the archaeological site is a T junction, where the left branch leads up to a high makatea entrance, used as an escape route or otherwise blocked with stones. The right branch leads down to the main part of the cave, which was mapped here until a pitch down was reached.

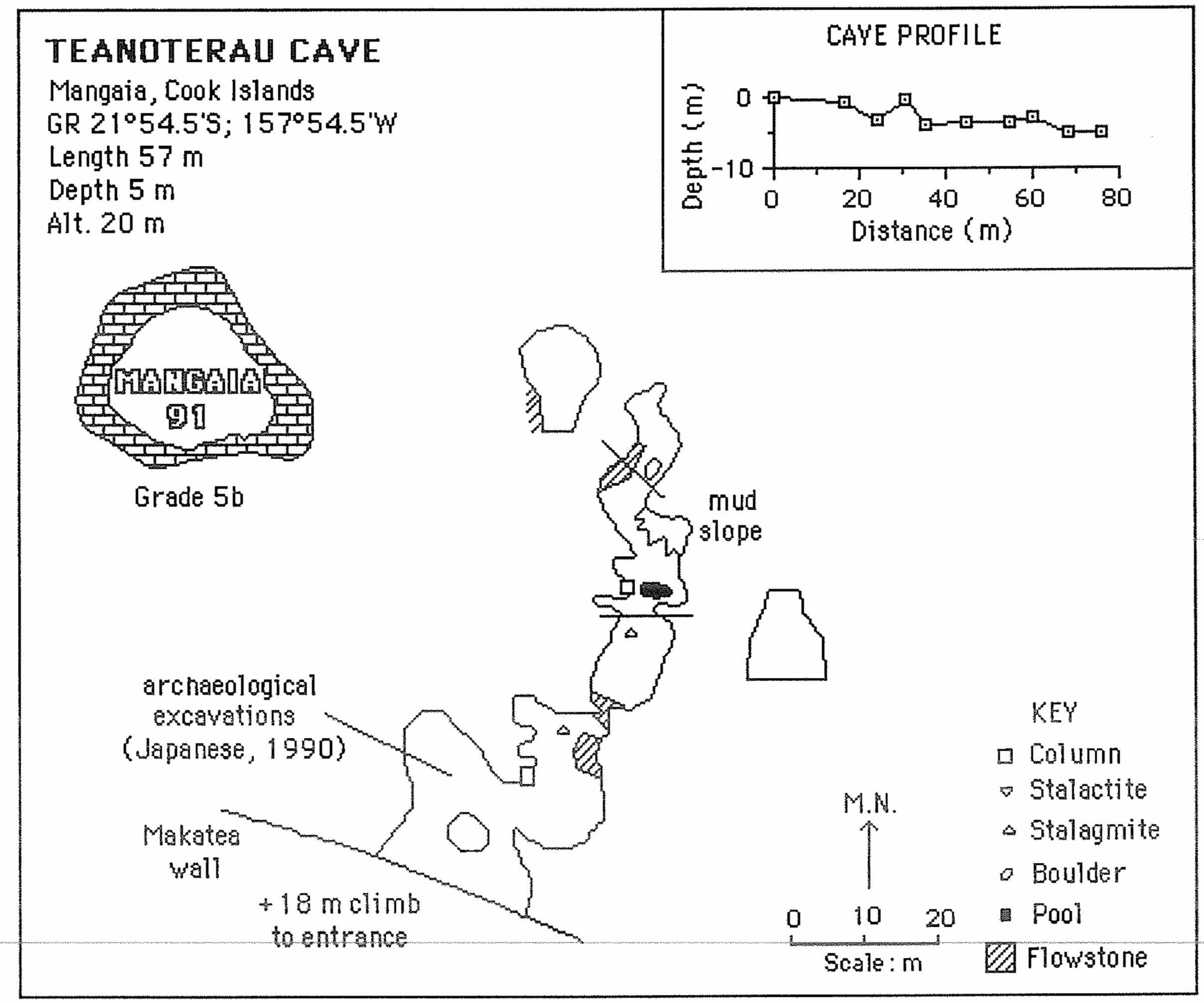

TEANOTERAU CAVE
Mangaia, Cook Islands
GR 21°54.5'S; 157°54.5'W
Length 57 m
Depth 5 m
Alt. 20 m
MANGAIA
91
Grade 5b
CAVE PROFILE
Depth (m)
0
-10
0
20
40
60
80
Distance (m)
mud
slope
archaeological
excavations
(Japanese, 1990)
Makatea
wall
+18 m climb
to entrance
M.N.
0
10
20
Scale : m
KEY
Column
Stalactite
Stalagmite
Boulder
Pool
Flowstone

Figure 7.

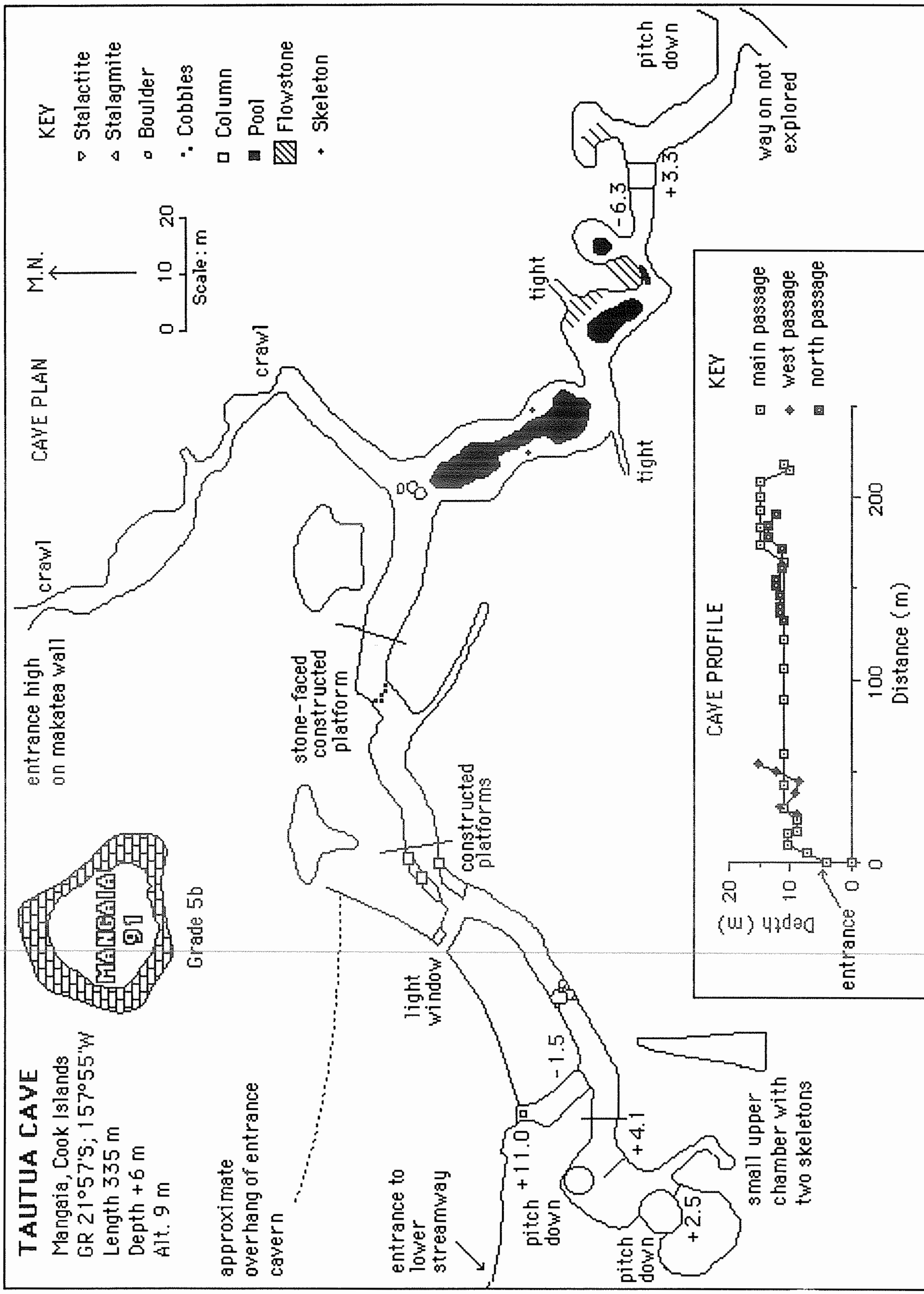

TAUTUA CAVE
Mangaia, Cook Islands
GR 21°57'S; 157°55'W
Length 335 m
Depth +6 m
Alt. 9 m
MANGAIA 91
Grade 5b
CAVE PLAN
M.N.
0 10 20
Scale: m
KEY
Stalactite
Stalagmite
Boulder
Cobbles
Column
Pool
Flowstone
Skeleton
entrance high on makatea wall
crawl
crawl
tight
tight
pitch down
way on not explored
-6.3
+3.3
stone-faced constructed platform
constructed platforms
approximate overhang of entrance cavern
light window
-1.5
+11.0
+4.1
+2.5
entrance to lower streamway
pitch down
pitch down
small upper chamber with two skeletons
CAVE PROFILE
Depth (m)
20
10
0
entrance
0
100
200
Distance (m)
KEY
main passage
west passage
north passage

Figure 8.

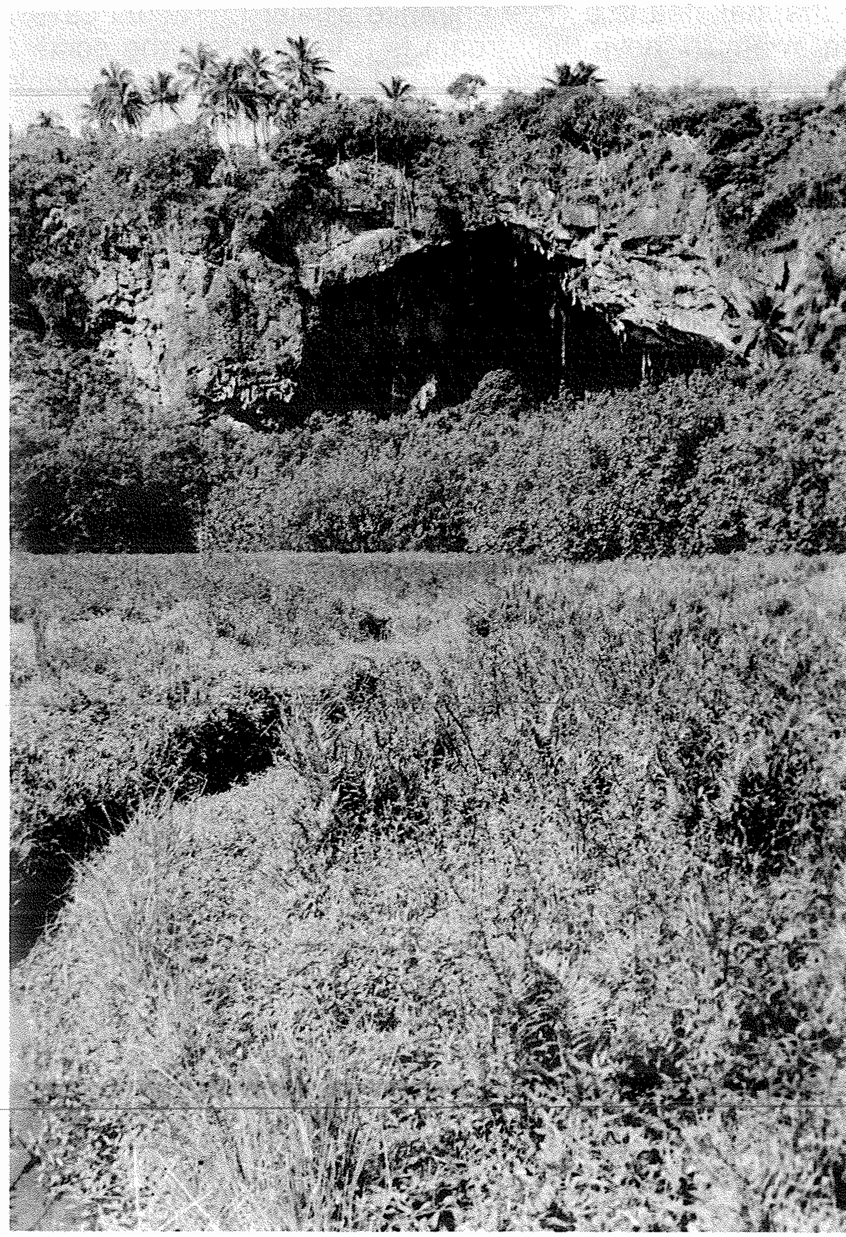


Plate 1. Entrance cavern by Tautua cave, East Tamarua swamp

Other Active Conduit Caves

Ivirua Conduit Cave

GR 21° 55' 30" S, 157° 54' 00" W. Where the Ivirua swamp drains through the makatea is a cave entrance similar to Tautua cave in the East Tamarua swamp. Above the stream is a large overhang some 25 m high, with old stalactites. The stream has red clay banks, and in pools there are many freshwater prawns (*Macrobranchium lar*). The conduit cave is wide and low, with few and small formations, and heavy red clay deposits, similar to East Tamarua. Neither of these active streamway caves were explored far because of problems of sinking in the wet clay. A small raft is recommended, as this could be dangerous.

To the north of the streamway, there is a cave entrance up a 10 m climb, resembling the position of Tautua cave in Tamarua. The cave was not explored.

Lake Tiriara Conduit

GR 21° 57' 00" S, 157° 56' 15" W. Lake Tiriara in Veitatei, adjacent to Tuitini cave, drains through a large cave entrance (Plate 2). These dimensions continue for some 50 m, with 2 m depth of water, then the cave narrows and the roof meets the water level. Figure 2 shows that the main passage of Tuitini cave trends towards the Lake Tiriara conduit, and it is possible that they connect in the lower unexplored section of Tuitini cave.

On the makatea summit directly above where the Lake Tiriara conduit enters the cliff, c. 10 m back from the cliff face, there is an arch some 15 m high, and a pitch cave entrance in the south wall of the arch. The topographic map shows a number of clustered cave entrances on the makatea summit above the Tuitini and Lake Tiriara conduit cave systems.

Kauvava cave, Temakatea (Figure 9)

Kauvava and Piriteumeume caves both have doline entrances, rather than makatea wall former streamway entrances. As they are of the highest elevation of caves explored, they could have been formed before erosion developed the makatea wall.

The southern entrance to this cave is the large doline to the N of Temakatea village. Permission to explore the cave should be requested from Papa Tua, who lives to the east of the cave entrance. At the base of the doline is a 6 m climb down at the entrance, which is filled with boulders and other debris. The entrance passage has rounded walls, indicating meandering stream activity, but is presently dry. The cave is mostly a tall rift, visible to 20 m. Some 60 m into the cave the passage descends and narrows, indicating a sink which is now infilled by deposits of clay. This is the lowest part of the cave between the two avens.

Towards the northern aven flowstone has closed the passage, but there is a tight climb up the rift over this. The aven is 23 m high, the opening is behind the Mormon church in Temakatea village. Below the aven the cave

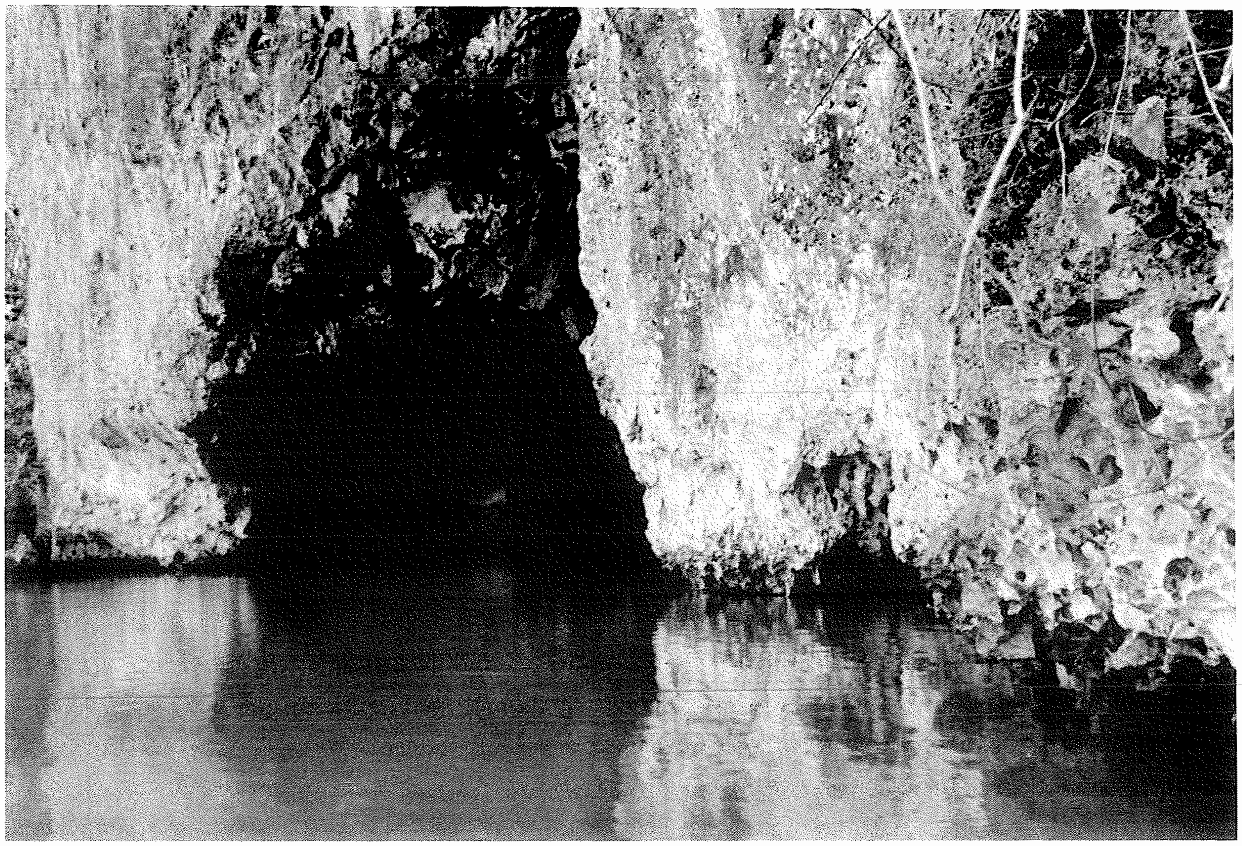


Plate 2. Conduit cave entrance in Lake Tiriara, Veitatei.

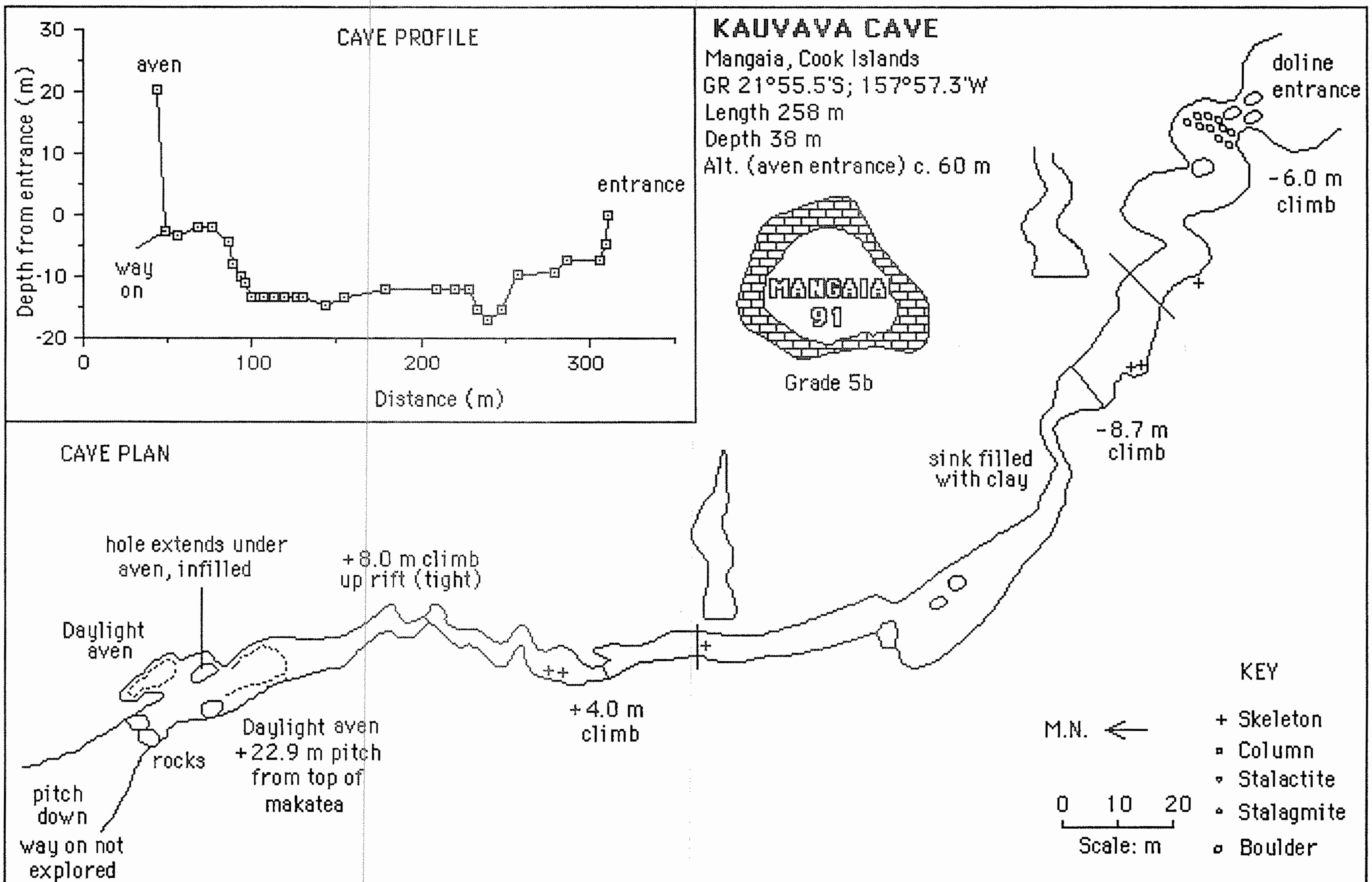

KAUVAVA CAVE
Mangaia, Cook Islands
GR 21°55.5'S; 157°57.3'W
Length 258 m
Depth 38 m
Alt. (aven entrance) c. 60 m
MANGAIA 91
Grade 5b
CAVE PROFILE
Depth from entrance (m)
30
20
10
0
-10
-20
0
100
200
300
Distance (m)
aven
way on
entrance
CAVE PLAN
doline entrance
-6.0 m climb
-8.7 m climb
sink filled with clay
+4.0 m climb
+8.0 m climb up rift (tight)
hole extends under aven, infilled
Daylight aven
Daylight aven +22.9 m pitch from top of makatea
rocks
pitch down
way on not explored
M.N.
0 10 20
Scale: m
KEY
+ Skeleton
Column
Stalactite
Stalagmite
Boulder

Figure 9.

continues to the north, but this is down a pitch so could not be explored in this study.

Pirituemeume cave, Temakatea (Figure 10)

The makatea summit is characterised by deep (5-10 m) dissection, with "karst streets" that follow the joints (Stoddart, et al., 1985). The entrance to Piriteumeume cave is a small doline in a karst corridor to the south of the inland road from Temakatea village, opposite the quarry. There are old (dry) flowstone walls at the entrance, and a strong draft.

The cave is relatively old, indicated by its elevation, collapse features and large formations. It links three dolines, and has a low daylight aven towards the northern end. The height varies from 4 to 15 m, and the floor is irregular and filled with collapsed boulders. The flowstone walls are dry and rough, indicating that they are no longer under formation. The southern section of the cave has a cavern with large stalactites and dripstones, while the northern section has several large columns.

Man 88 cave, Keia (Figure 11)

No name could be found for this cave, so it is described by the archaeological site number of P. Kirch, who excavated both in the cave and below its entrance in 1991. The entrance is 8 m from the makatea base, a large lighted cavern adjacent to a pool of water further inside the cave, with signs of occupation. The cave does not extend far, and seems to have been closed by calcite deposits.

SPELEOGENESIS

The ten caves described include the major caves of Mangaia, but many more remain to be explored. However, there is an apparent grouping of these caves according to elevation of major sections, as shown in Table 1.

The lowest caves are the present conduits, such as To'uri cave, and the East Tamarua conduit below Tautua cave, as well as the Lake Tiriara and Ivirua conduit caves described. These contain an active streamway, few formations, and heavy clay deposits resulting from soil erosion off the volcanic cone. The elevations are close to sea-level, and they resurge at the coast as seen at Avarua landing, or on the reef flat as at Tamarua.

Tuitini, Touropouru, Tautua and Taenoterau caves all have major level sections between 10 and 20 m above sea-level. This suggests that they were conduit drainage caves corresponding with the 14.5 m elevation of Pleistocene

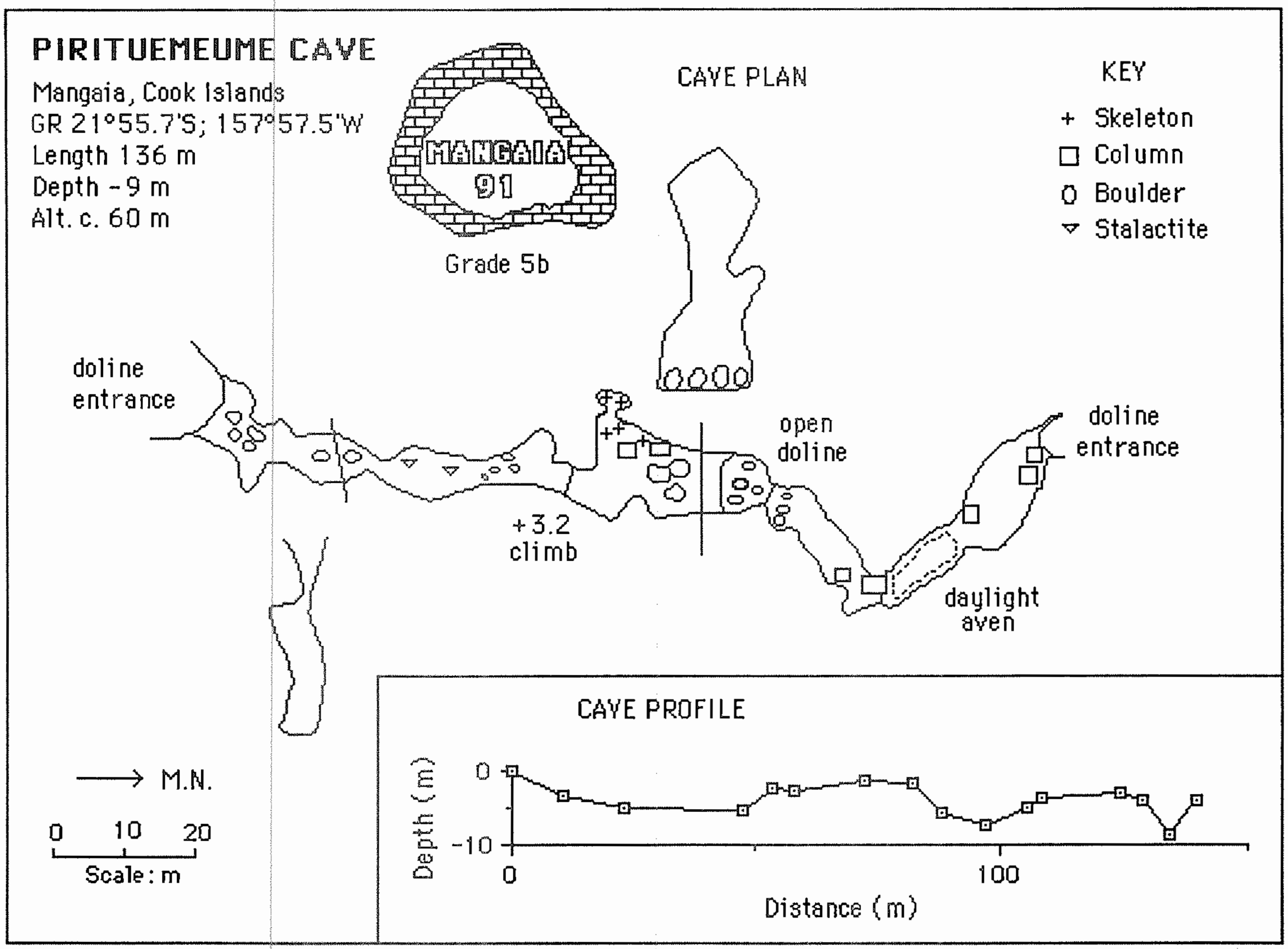
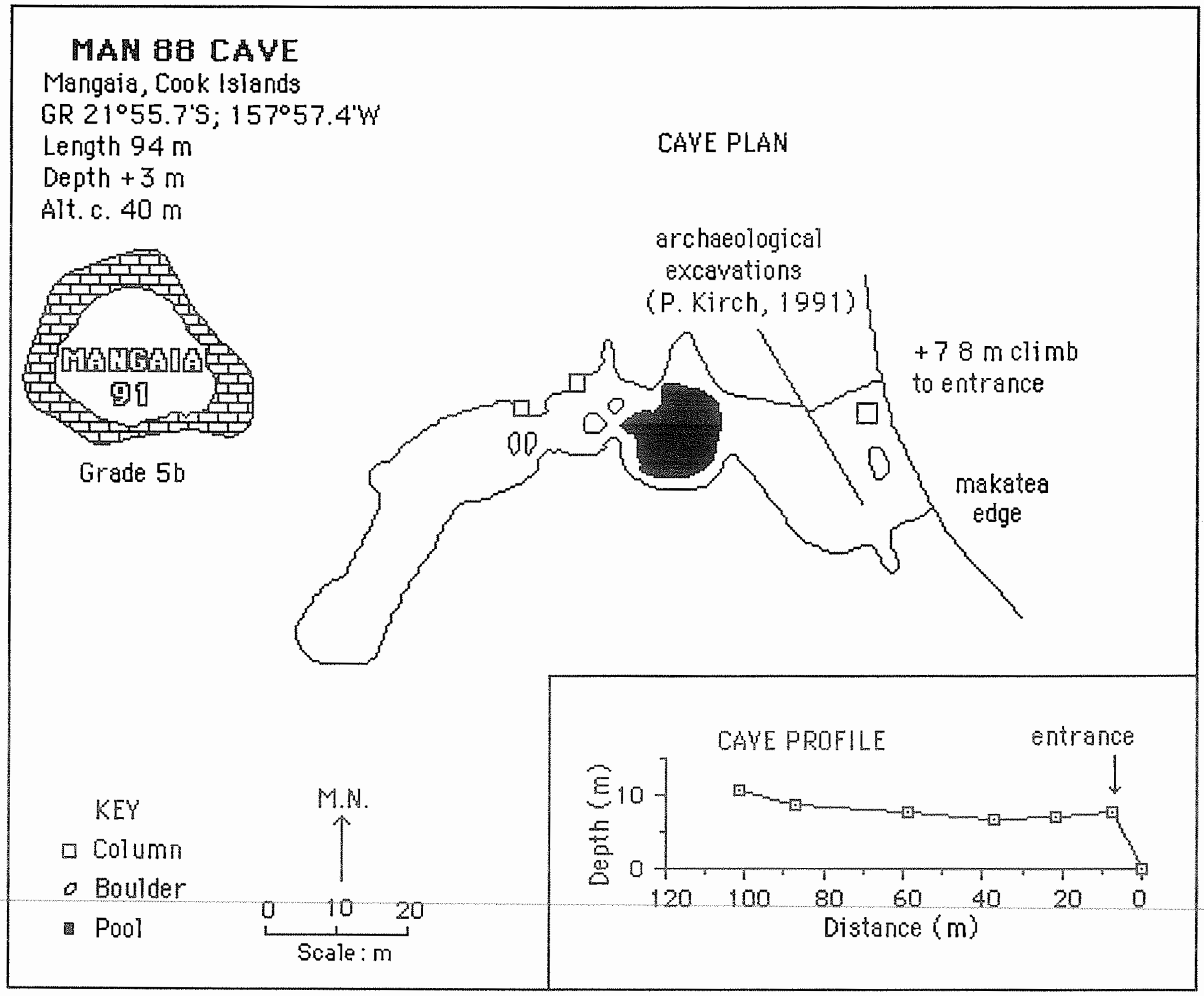

PIRITUEMEUME CAVE
Mangaia, Cook Islands
GR 21°55.7'S; 157°57.5'W
Length 136 m
Depth -9 m
Alt. c. 60 m
MANGAIA
91
Grade 5b
CAVE PLAN
KEY
+ Skeleton
Column
Boulder
Stalactite
doline
entrance
+3.2
climb
open
doline
daylight
aven
doline
entrance
M.N.
0
10
20
Scale: m
CAVE PROFILE
Depth (m)
0
-10
0
100
Distance (m)

Figure 10.



MAN 88 CAVE
Mangaia, Cook Islands
GR 21°55.7'S; 157°57.4'W
Length 94 m
Depth +3 m
Alt. c. 40 m
MANGAIA 91
Grade 5b
CAVE PLAN
archaeological excavations (P. Kirch, 1991)
+7 8 m climb to entrance
makatea edge
KEY
Column
Boulder
Pool
M.N.
0 10 20
Scale: m
CAVE PROFILE
entrance
Depth (m)
10
0
120 100 80 60 40 20 0
Distance (m)

Figure 11.

Table 1. Dimensions and elevations of Mangaia caves (m)

Cave	Length explored	Altitude of entrance	Depth	Elevation of level sections	Height of rift
To'uri	489	3	-3	1	20-30
Tuitini	830	23	-13	10 & 20	20-25
Touropouru	587	16	+4	10 & 18	15
Tautua	335	9	+6	15 & 19	10-20
Taenoterau	57	20	-5	17	5-10
Teruarere	791	43	-24	20 & 30	10-30
Erua	177	c. 40	-8	c. 40	20
Kauvava	358	c. 60	-38	c. 40	20+
Man 88	94	c. 40	+3	c. 40	10-15
Piriteumeume	136	c. 60	-9	c. 55	4-15

limestones, probably formed at the same time as a relative sea-level 20 m higher than present (Woodroffe et al., 1991). Reef groove-and-spurs formed at this time are now 2 to 11 m above sea-level (Stoddart et. al, 1985). Thus it is indicated from three corresponding features that sea-level was in this position for considerable time.

Teruarere cave is a major feature of Mangaia, a minimum of 791 m of continuous level passage ranks with the spectacular find of Ana Maui by the Tonga '87 caving expedition on 'Eua (the cave named after the Tongan demi-god) (Lowe, 1988). It declines from 30 to 20 m above sea-level, a simple fossil streamway, corresponding with the 26-27.5 terrace described by Stoddart et al. (1985). The terrace is deeply dissected, and was believed to represent a very old sea-level feature. Similarly, Teruarere cave has a number of high daylight avens, indicating long-term dissolution and collapse. The pitch at the end of the surveyed section indicates that one of these cut down to a deeper level after uplift of the main passage.

Erua, Kauvava and Man 88 caves all occur at about 40 m above sea-level, and could correspond with the 34-39 m terrace identified by Schofield (1967), Wood and Hay (1970), and Ward et al., (1971), and shown by several profiles of Stoddart et al., (1985). However, this feature is so old that they must have eroded dowm from their formative elevation. While Erua and Man 88 caves are closed by calcite deposits, the pitch beneath the 23 m aven at the northern end of Kauvava cave indicates that flow through here allowed the cave to cut down to a deeper level after uplift.

The highest elevation cave in this study is Piriteumeume, which has all the features of an old cave, with large formations, collapse and irregularity, and dryness. During development of the cave the dolines would have drained a higher surface, and the karst corridors leading to the entrance would also have been caves. The makatea surface has many such small relic caves to be found in the karst corridors, though the caver will probably get lost finding them!

CONCLUSIONS

Cave systems are a relatively neglected aspect of study of raised limestone islands, possibly owing to the specialised techniques of survey, and potential dangers. This study shows that they can make a contribution to the knowledge of limestone geomorphology and changes in relative sea-level .

Features of the caves explored indicate the validity of the principles of makatea cave development outlined in the introduction.

It is apparent that caves of lower elevation are of larger dimensions than those higher. This could be because parts of the higher caves have been lost with time, but as well as length the lower caves have higher rifts or vadose slots. This could result from slower rates of island uplift that allowed the streams to downcut their caves, or it could indicate the sea-level changes of the Pleistocene that have caused multiple reoccupations of these caves.

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