Cave Science

The Transactions of the British Cave Research Association

BCRA

Volume 13 Number 1 April 1986

Cave Science

The Transactions of the British Cave Research covers all aspects of speleological science, including geology, geomorphology, hydrology, chemistry, physics, archaeology and biology in their application to caves. It also publishes articles on technical matters such as exploration, equipment, diving, surveying, photography and documentation, as well as expedition reports and historical or biographical studies. Papers may be read at meetings held in various parts of Britain, but they may be submitted for publication without being read. Manuscripts should be sent to the Editor, Dr T. D. Ford, at the Geology Department, University of Leicester, Leicester LE1 7RH. Intending authors are welcome to contact either the Editor or the Production Editor who will be pleased to advise in any cases of doubt concerning the preparation of manuscripts.

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Cave Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 13 Number 1 April 1986

Contents

Cover: The 100 metre high arch of Yogoluk, in the highlands of Irian Jaya, visited by the Indonesia Expedition. By Andy Eavis

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Cave Science will in the future be published in three parts per volume, at the rate of one volume per year. This scheme starts with Volume 13 in 1986. The three parts will be issued in the spring, summer and winter of each year.

The number of pages will be increased in each issue. There will therefore be roughly the same length of material in future volumes as in past volumes; there will however be savings in production and distribution costs.

Indexes will be prepared to cover blocks of five volumes. The first will cover volumes 12 to 16 for 1985-1989 and will be issued with number 1 of volume 17 early in 1990. Annual indexes will no longer be prepared as they are rendered obsolete by the systematic keying of titles on the front cover of Cave Science.

CAVE SCIENCE Vol. 13, No. 1, April 1986
Transactions of the British Cave Research Association

The Blue Holes of South Andros, Bahamas

Robert J PALMER

Abstract: Twenty inland and ocean Blue Hole sites were examined on the 1985 Bahamas Operation Raleigh. The sites are described together with details on structure, hydrology and biology. A short appendix gives information on tidal variations between inland and oceanic Blue Hole sites.

The Blue Holes explored on the 1985 Operation Raleigh Expedition all lie on a major north-south slump fracture zone paralleing the deep oceanic trench (the "Tongue of the Ocean") that lies off the eastern shore of the island. Of the three main groupings visited, two lie offshore and one inland, the latter being less than a kilometre from the coast (Fig 1). Other sites are known from the area, but were not visited on this occasion (Benjamin 1984, Palmer 1984), The major sites visited in 1985 are described below, in their three groupings, from north to south.

THE INLAND HOLES

These lie in an approximately north-south line behind the community of Bluff and the Commissioner's Complex at Kemps Bay. Of the numerous water surfaces visible from the air on the fracture line, several provide access to caves beneath. Others appear to be shallow ponds, although they may be infilled or choked blue holes. Those described below are considered to have been adequately explored below the water surface. Others in the area bear fuller examination with SCUBA gear.

ELVENHOME. NGR: TB 401691. The central and smallest of three holes behind and to the south of the school at the Bluff. The entrance is a long cleft approx 30 metres by 10 metres, with 5 m high vertical cliffs to water level. The N-S orientation of the cleft follows the line of the major slump fracture. The surface freshwater is cloudy (visibility of one to two metres) with a high organic content. The H_2S layer is evident by taste at -9 m, becoming most strong at -11 m. The primary halocline is between -16 and -22 m. At -22 m the H_2S layer ends and is accompanied by an immediate increase in visibility to over 20 m and a sharp change in wall colouration from grey to light brown.

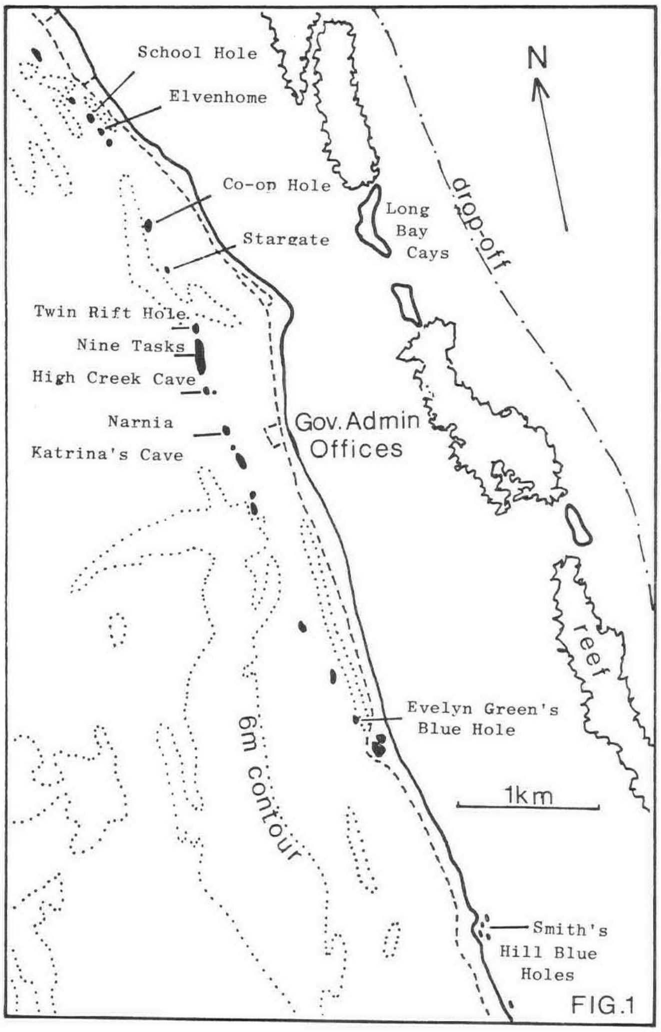

FIG.1

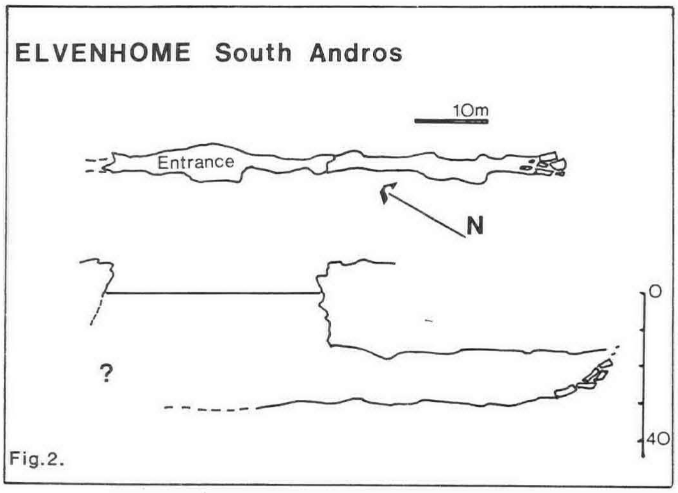

Fig.2.

To the north, a large passage, at least 6 m wide, opens up. Following this at -30 m, a massive choke is reached after 28 m, where the debris contains plastic bags, and presumably lies below the lake immediately behind the school. Speleothems in the passage are slightly discoloured, possibly due to very high H_2S concentration in the water. The halocline is visible in the roof of the passage throughout, with a zone of bacterial growth accompanying it. The cave contains a cave-adapted fauna. The continuation of the passage to the south (towards a blue hole a few hundred metres away) was not explored.

CO-OP HOLE. NGR: TB403684. An 18 m deep cenote-type feature on the fracture line, surrounded by 6 m high cliffs with incut hollows 2-4 metres above the water surface (evidence of a high sea-stance). Surface waters were fresh and fairly clear (visibility 10 m), with large shoals

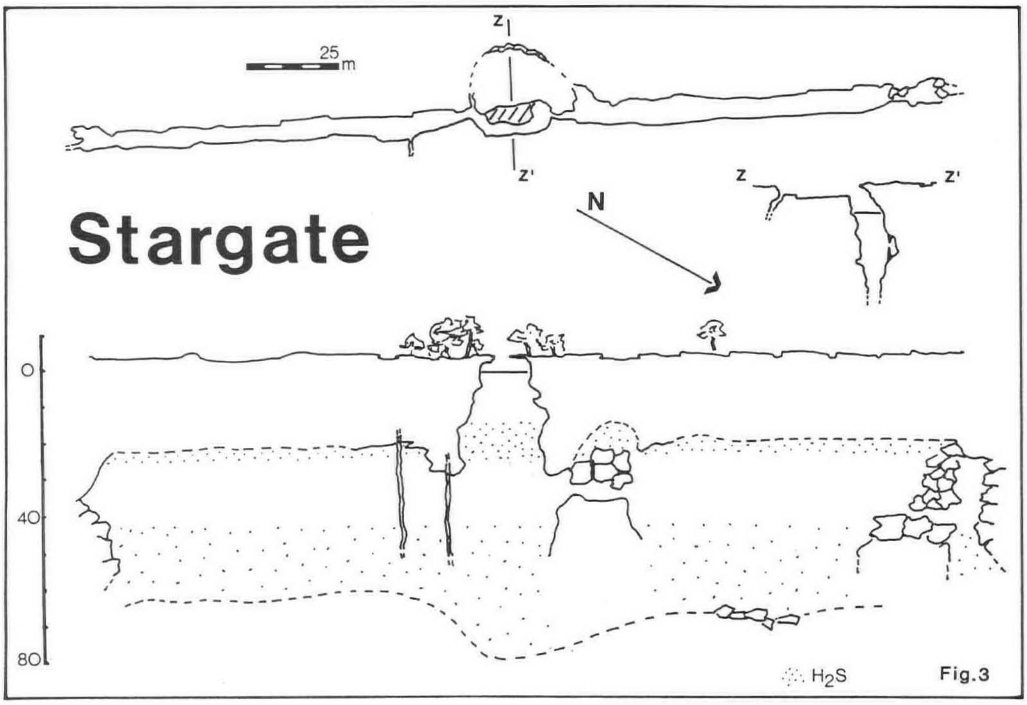

Fig.3

of Gambusia (mosquito fish). The main H_2S layer was at -17 m and the halocline from -16 m to -22 m, the lower depth being reached in cave passages to the north, on the main fracture line. These were at two levels, with a narrow, loose rift at -15 m and a larger, choked passage at -18 m. A descent can be made through boulders to -23 m, ending at a constriction beyond which the cave can be seen to open up. At -22 m, the walls change from grey to brown as the H_2S layers ends. Gray strands in the water may be some form of bacterial growth, and cave-adapted crustacea were present in the sub-halocline area. Smaller passages exist on the south side of the Hole, but these were not thoroughly explored.

STARGATE. (Joe's Hole). NGR: TB 403681. Formed on the N-S fracture line, the entrance to this major cave lies beneath a cavern overhang, with a drop to water level. The overhanging rock permits little organic input to the water, and visibility is thus excellent throughout the vertical water column. The entrance has been plumbed to -80 m on the north side, with the fresh/brackish halocline lying between -16 m and -22 m. Below this, the water takes on an exceptional clarity.

To the north, a 10 m wide passage, with the roof at -20 m, runs for 107 m to a choke. To the south, a similar passage is entered through a constriction on the right side of a massive boulder pile at the entrance, above which lies a collapse chamber in the halocline area. The south passage runs for 100 m to a further choke, passable on the right-hand side at -37 m to reach an extremely loose boulder chamber, choking again after a further 30 m. There may be a possible way on below -50 m. Approximately halfway along the south passage, a descent was made to -65 m, where a floor of massive boulders jammed across the rift was met. At -43 m, a secondary halocline was encountered, where the water again becomes sulphurous. This is accompanied by a change in wall colouration from light brown to gray. At -60 m, there was a further visual mixing zone. Speleothems on the wall are evident at all depths. The boulders were covered in fine gray/brown sediment.

A profuse cave-fauna inhabits the brackish zone between -22 and -43 m, ceasing abruptly above and below these depths.

NARNIA. NGR: TB 405668. A major, 2 m deep, collapse depression along the main fracture zone just inland and north of the Commissioner's Complex at Kemps Bay. A chain of water surfaces line the east and west sides of this depression, most of which are impenetrable to divers. On the west side of the depression, the second opening from the south ("Wardrobe Pool") was explored for 20 m to the south, to a choke below a small grotto. To the north, a larger passage leads to an entrance further along the depression (Lantern Pool). Dimensions were indistinct, and much bacterial growth was evident on the walls. There was a distinct south to north current flow, and the floor appeared cleaner-washed than in other caves. Tide in the 4 m deep lake at the north end of the Narnia depression (Aslan's Lake) was rising, and the flow was below the main sulphur layer at -16 m. Maximum depth in the passage was -22 m. There are few speleothems and the rock is extremely fretted. Visibility was strangely irregular, varying from 2 to 10 m without apparent reason.

KATRINA'S CAVE. NGR: TB 405667. A double entrance, immediately behind the Commissioner's Complex at Kemps Bay, situated between the Narnia depression to the north and a large lake to the south, all lying on the main fracture line. The two pools lie immediately below a small 3 m high cliff, the northernmost one providing access to a short passage 8 m in diameter leading south. The halocline is at -16 m, and the base of the passage is at -22 m. Speleothems on the walls are heavily corroded, and there is much bacterial growth. A current flow was evident during exploration, from south to north. The passage ended 35 m from the entrance in a rock/sand inflow. To the north of the entrance, a steeply-descending shaft falls almost vertically to a sediment-floored chamber with a maximum depth of 45 m. Beyond this, a slope rises steeply to a stalactite grotto at -30 m. There was no evident continuation.

There was no life present in the cave below the halocline, but local information was that the cave had been regularly used as a washing pool in the past, and may well have been chlorinated. There were distinct fossil beds exposed in the walls, including a bed of conch shells at -30 m, with bivalves above these.

NINE TASKS LAKE: NGR TB 404.675. A large, elongated hole between Kemps Bay Complex and Bluff, Nine Tasks lies on the fracture zone between Narnia and Stargate. It is still in regular use as a washing hole by local villagers, and so contains little freshwater life.

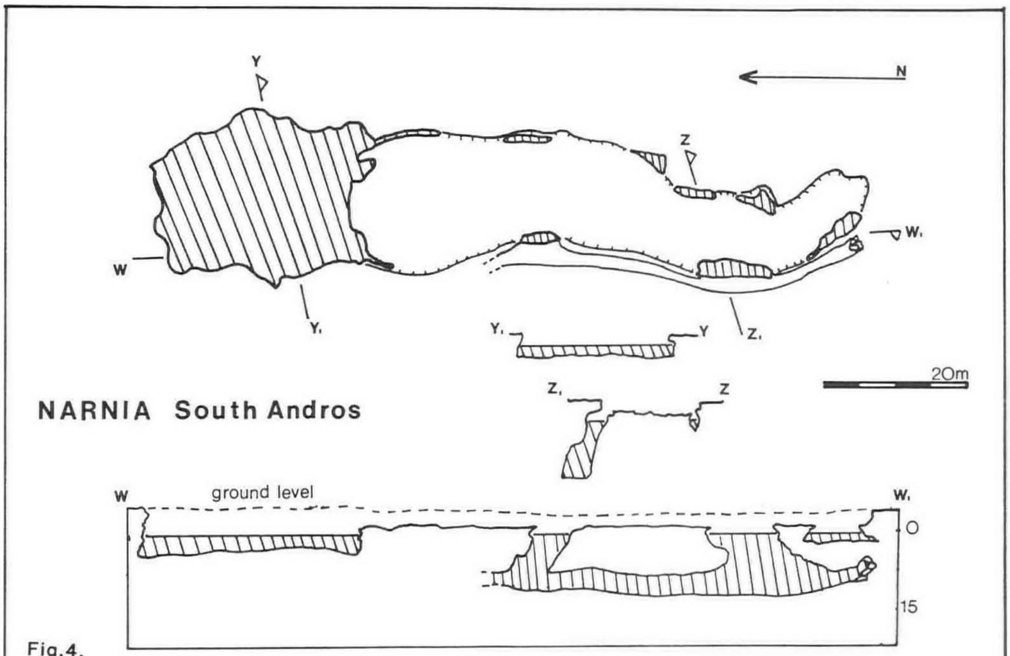

Fig.4.

The hole was not dived, but appeared to be no more than 6 m deep. Both north and south ends were screened by mangroves and the site appeared very silty. Its position at the end of a fossil marine creek from a higher sea-stance makes it worthy of further investigation.

HIGH CREEK CAVE: NGR: TB 404.672. A small blue hole at the end of a fossil tidal creek, north of the Kemps Bay Complex and immediately south of Nine Tasks. A small channel in the creek bed ends at this cave, and makes it one of the most potentionally significant sites in the area.

The south end of the pool is shallow, but there is much freshwater life present. At the northern end, there appears to be a cave passage below an overhang, sloping steeply down over a silt floor. This was descended to 14 m, before technical problems aborted the dive, but appears to continue. There was a noticeable current at this site.

EVELYN GREEN'S BLUE HOLE: NGR: TB 410.648. An apparently deep blue hole surrounded by 6 m cliffs, with no easy way down to the water. The north end looks most promising in cave terms, but the blue hole remains unexplored.

TWIN RIFT CAVE: NGR: TB 404.677. A few hundred metres north of Nine Tasks, a large entrance with a 10 m climb down to water level leads to a short dry passage on the north side, with water-filled rifts along the terminal left and right walls. Both of these appear to close down amongst boulders after a few metres.

HERON WATER: NGR: TB 401.689. A small blue hole in the northern corner of a complex collapse area just south of Elvenhome. Water level can be reached with some difficulty through the dense surrounding scrub, and the fracture zone appears to be more complex in this immediate area. There seems to be a cave passage below the water level on the north, heading towards Elvenhome.

THE OCEAN HOLES

At NGR. TB 415.633, approximately one kilometre north of Smith's Bay, the main fracture zone leaves the land and runs out to sea, to parallel the drop-off into the Tongue of the Ocean. Blue Holes to the south of this point are all marine, most being designated as "doughnut" holes, which are typified by an encircling ring of coral reef growth.

SMITH'S HILL BLUE HOLES: NGR. TB 416.632. A group of five small entrances which lie just south of the point where the fault zone crosses the coast.
No.1 A small entrance 300 m south of the others. Undived.
No.2 (Octopus Rift). Largest of the entrances, and closest inshore, only 20 m from the rock beach. The entrance rift was -15 m deep, and opened out into narrow rift passages below this, to north and south. North, the cave ran for approximately 30 m to a sand bank and narrowing of the cave. To the south, a 2 m wide passage lead for 30 m to a spiral descent in a small chamber, with a parallel rift continuing down beyond. A depth of -45 m was reached.
No.3 (Barracuda Hole). A rift entrance, with unexplored but narrow cave passage appearing to continue below -6 m.
No.4 (Eel Hole). A small rift entrance with no apparent cave large enough to explore.
No.5 This cave is the most northerly of the group and lies further offshore on a parallel fracture. The entrance slopes down to the south, to a depth of -20 m, and still appearing to descend beyond. The continuation was unexplored.

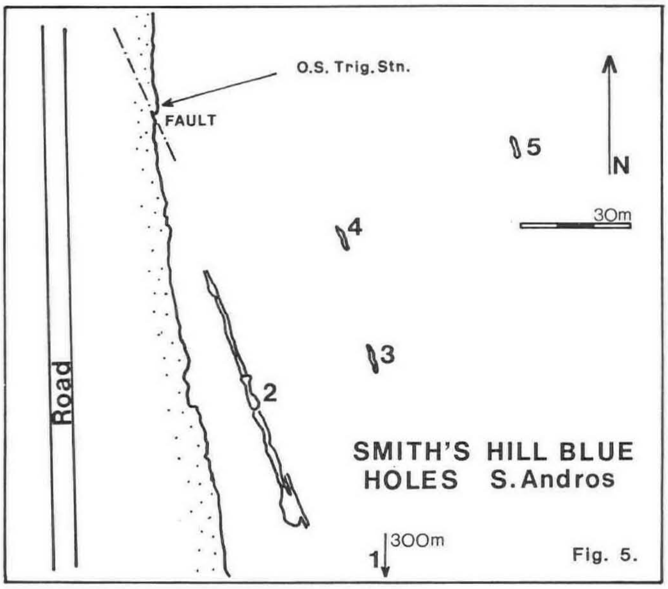

Fig. 5.

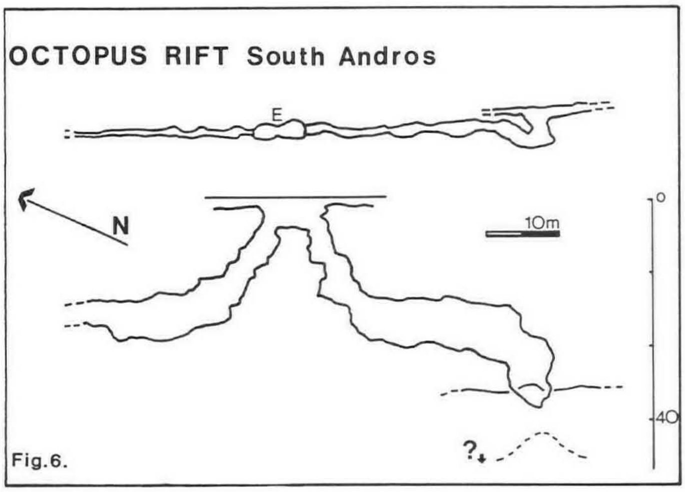

Fig.6.

DEEP CREEK BLUE HOLES:

No.1 NGR: TB 448.556 : The entrance lies near AUTEC marker no. 4. The cave has a deep entrance passage, and its bottom was not reached. It lies in 3 m of water and was descended for -17 m, no floor being seen. Cave passages extend both north and south but were unexplored. Currents at this site were weak.

No.2 Coral Hole. NGR. TB 431.537. Examined on the 1982 British Expedition, when a passage to the north was explored for 30 m, at a depth of -32 m. The entrance is a narrow rift, 3 m wide by 12 m long, and 25 m deep. The entrance is surrounded by a well-developed coral reef.

No.3 (Rubbish Pit). NGR: TB 429.547. This cave lies close inshore, well off the main fracture line. Used as a rubbish tip by locals, this is probably responsible for the dearth of marine life observed.

No.4 (Giant Doughnut). NGR: TB 451.528. Examined by the 1982 British Expedition, this is one of the largest doughnut hole entrances in the area, with a collapse entrance some 30 m in diameter, and an encircling reef approximately 80m in diameter. The floor of the entrance pit is coral sand and rubble, and slopes down to a small cave opening in the south-west wall. This is at present partially blocked by a fall of coral, but passages were entered in 1982 to a depth of -40 m.

No.5 (Shark Hole). NGR: TB 468.464. The most southerly hole examined in February 85, and one of the most spectacular, due to the prolific marine fauna and flora present. An open shaft descends vertically for 30 m to a ledge, then slopes off in a northerly direction to depths of over -40 m, in passage 10 m high by 1.5 m wide. Small passages at -16 m and -24 m emitted water on the outflow that was warmer by 2° to 3°C than the main cave water.

Mars Bay Blue Hole: NGR. TB 439.417. A deep cenote-type blue hole on the shoreline at Mars Bay, explored in 1982 by the British Expedition to a depth of 60 m, where the tip of a sand cone was met. The cave continued to descend beyond.

ACKNOWLEDGEMENTS

The author is indebted to the following for their help and assistance in the study and exploration of these caves: Katrina Abbott, Robert Trott, Robert Proctor, Mark Vinall, Richard Cook, Mary Stafford Smith, Gordon Wallace, Nigel Kennett, Peter Hatt, Gary Hardington, Bob Hartlebury, Jason Le Carteret, Godfrey Priest, Jennifer Shaw, Ross Clifford, Davis Beaulieu, Kester Keighley. Stan Clarke of Deep Creek, South Andros was of especial help, with both accommodation and sea transport in the Deep Creek area, and the Kemps Bay District Commission, who provided accommodation and workspace in their complex at the Bluff.

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APPENDIX: OBSERVATIONS ON TIDAL CHANGES IN BLUE HOLES

Tidal changes were logged in four marine Blue Holes and one inland Blue Hole on South Andros between 3rd and 22nd February 1985. The marine recording sites were in two distinct groups, one near Smith's Hill and the other south of Deep Creek. The inland hole was Co-op Hole near Bluff Settlement. High and low tide times were taken as those predicted for Fresh Creek in Central Andros.

Low tide at Co-op Hole on 03 February 1985 was recorded as being at 11.58 hrs. This is 40/45 minutes later than predicted high tide at Fresh Creek. Co-op Hole can be assumed to have a tidal lag of 40-45 minutes, due to the obstructive effect of the fractures through which the current flows, and to the distance of the Blue Hole from the sea (Smart 1984).

Records were made on 10/11th February of slack water between inflow and outflow at the ocean holes north of Smith's Hill. High tide at Fresh Creek on the 10th was at 11.24 hrs, and slack water in the Blue Holes was at approximately 14.55 hrs. On the 11th, high tide was at 12.00 hrs and slack water was at 15.30 hrs. The reversal of inflow to outflow therefore is presumed to take place in the Smith's Hill Blue Holes approximately 3½ hours after local high tide. (This reversal period is the safest time for explorations to be made.)

At Coral Hole and Shark Hole 1.5 and 9 km respectively south of Deep Creek, the inflow-outflow slack water came at approximately 15.30 hrs on 15 February. This was 4½ hours after predicted high water at Fresh Creek (10.50). It is possible either that the Deep Creek Blue Holes reverse approximately one hour later than those at Smith's Hill, or that tidal differences between Fresh Creek and Deep Creek render the figures inaccurate. Given that Shark Hole is almost as far south of Deep Creek (9 km) as Smith's Bay Blue Holes are north (8 km), and that Coral Hole lies almost halfway between the two, the 1 hour difference between Coral Hole and Smith's Bay (the same as Shark Hole) seems a little anomalous if a gradual change in either tide times or lag effect were to exist. It may be that some unknown underground effect is responsible, if the figures are accurate. The position of Smith's Hill Blue Holes at the southern end of the island section of a massive slump fracture and the observed current flow along cave passages that exist along the inland line of the fracture, may have some relevance in this matter.

In 1982, studies made on North Andros of current flow in Conch Sound Blue Hole (Warner and Moore, 1984) suggested that the reversal time in that cave, at the far north-eastern end of the island, was between 2-3 hours after high tide at Fresh Creek, the precise time being dependant on daily variations in weather that affected the surface tide times. It is likely that the times recorded for South Andros Blue Holes will have this same fluctuation in response to changing environmental conditions.

The difference in predicted reversal time between Conch Sound BH in North Andros (high tide + 2-3 hrs) and Shark Hole in South Andros (high tide + 4½ hrs) is peculiar, and cannot simply be accounted for by variations in mean tide times from north to south along the eastern coast of Andros. Smart (1984) proposed a net west to east flow of saline waters below Andros, due to tidal lag across the western shallow banks building up a slight head of water on that side of the island. This would account for the aureole of brackish water that exists off the eastern coast of Andros, with the subterranean flow encouraging west-east drainage of the freshwater lenses, but it is unlikely to offer much of a solution to the north-south difference in Blue Hole reversal times. The greater distance offshore of Shark Hole and Coral Hole (2.3 km) is probably more relevant. Further studies should allow a more precise understanding of the cause and effect of the north-south variation, and of current movement within the phreatic zones of the Bahama Banks.

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Hydrology and Speleogenesis beneath Andros Island

Robert J PALMER

Abstract: Several factors influence cave development beneath South Andros. The most important factor of these are the position of the bases of modern or ancient freshwater lenses and the presence of massive fractures running parallel to the Tongue of the Ocean. The position of underwater caves (Blue Holes) and their relationship to physical and hydrological features is examined, with special reference to "Stargate Blue Hole", a major cave, whose development has been influenced by both fracture control and hydrology of the freshwater lens base. The modern morphology, hydrological structure and biological content of Stargate is Blue Hole is examined in some detail.

Andros is the largest of the Bahama Islands, lying at 25°30' to 23°50'N, and 77°30'W. It forms an exposed section of the Great Bahama Bank, an extensive limestone plateau, the origins of which date back to the early Cretaceous, and the upper 120 m of which has been exposed during several periods of glacio-eustatic activity within the Pleistocene ice epoch. The sediments forming the islands of the Bank and the nearby Little Bahama Bank are the remains of coral reef formations and soft oolitic calcarenites. These accumulated sediments are at least 8 km thick, and represent one of the most tectonically stable limestone provinces on the planet, as well as being one of the largest at 1,500,000 km (Dietz et al. 1970).

The sea to the west of Andros averages 5-10 m in depth, extending for over 80 km to the edge of the Great Bahama Bank at the deep Florida Straits. These shallows are composed largely of pelletoidal lime muds, fringed on the margin of the Bank by oolitic and skeletal sands. The eastern coast of the island drops more steeply offshore over an extensive barrier reef for 2 km, to 50/60 m depth, where it falls abruptly into the Tongue of the Ocean, a marine trench up to 2000 m deep. This trench runs north, to meet with the NE and NW Providence Channels and, ultimately, the Atlantic Ocean.

Andros itself is more accurately a group of islands, with three main land areas, North Andros, Mangrove Cay, and South Andros, separated respectively by the North, Middle and South Bights, tidal creeks which divide the island from east to west (Fig 1). Consolidated calcarenite dunes of Pleistocene age run parallel to the east coast, rising to an average height of 10-15 metres. Behind these, to the east, the ground falls quickly to an average 2-3 m above sea level and the island breaks up into a maze of tiny cays and winding, shallow creeks.

The native vegetation is tropical pine forest, though extensive lumbering operations mean that most of the present woodland is tertiary re-growth. The eastern dune area is one of scrub woodland, and is sporadically cultivated by slash and burn methods. In the low-lying creek area to the west, the dominant flora is mangrove.

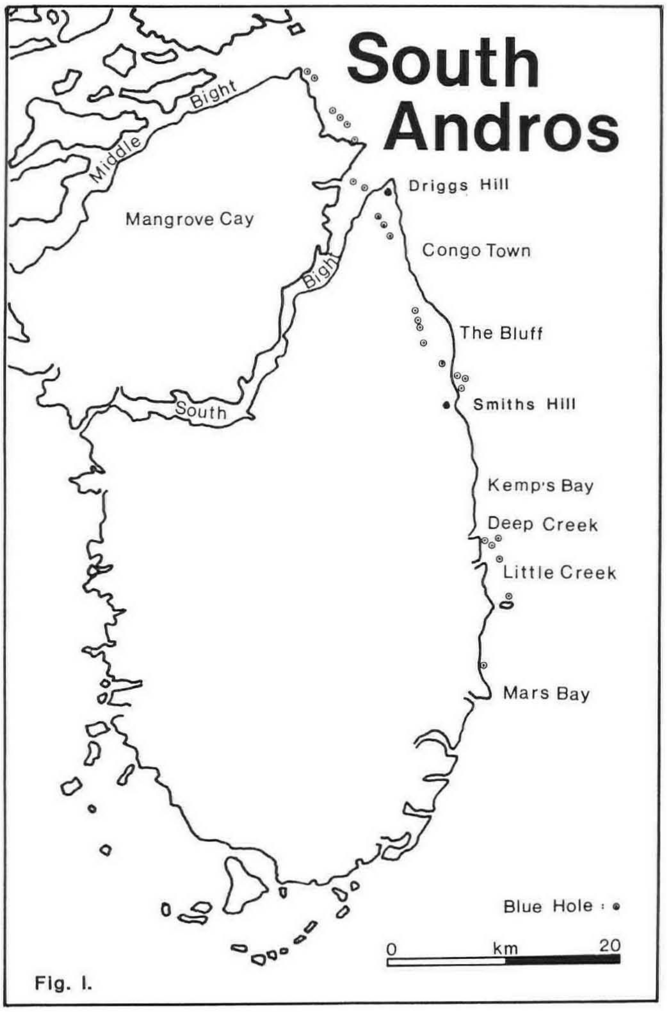

Fig. I.

CAVE DEVELOPMENT

The island supports a series of freshwater lenses, in accordance with the Ghyburn-Hertzberg principle. These are separated by tidal creeks and/or exceptionally low-lying swamp areas. Direct access to the interiors of these lenses is possible by entering Blue Holes, flooded caves which descend into the freshwater zone, often penetrating the saline zone beneath. There are at least 200 Blue Holes on Andros, including entrances which now lie offshore, and several of these are over 100 m deep (Benjamin 1984 Palmer et al. 1984).

The formation of these caves has been discussed elsewhere (Palmer and Williams 1984.), but they can be broadly classified into three types: i) lens base ii) cenote, and iii) fault controlled.

Lens base caves

The majority of the Bahamian caves owe much of their basic morphology to the position of the freshwater/saline interface (the halocline - a zone of brackish water of varying thickness and enhanced solutional aggressivity). Long and often extremely complex cave systems can be formed horizontally along the line of the interface. The structure of these cave systems can be modified vertically by roof-collapse or solutional enlargement of vertical joints during glacio-eustatic changes. Such eustatic changes can also affect the vertical position of the

Stargate: roof of North Passage at 26 m, the zone of current break down.

freshwater lens beneath the island, and thus the position of such layers of horizontal solutional cave development.

Cenotes

These typically circular, deep shafts, which can descend vertically for over 100 m into the bedrock (though 50-80 m is a more common average) are caused by successive collapse ("aston" development...Jimenez 1967) of horizontally-bedded limestones into a pre-existing solutional void. This void may be part of a lens base cave system, or a discrete solutional cavity at the halocline level, or a phreatic enlargement of a joint or fault. In rare cases, cave passages can be entered at depth in these cenote caverns. Such passages are generally associated with vertical joint enlargement, though horizontal passages have been entered as at Ocean Hole, N.Andros. (Farr and Palmer, 1984).

Fault or controlled caves

Where Bahama Banks fall vertically to the deep oceanic margins, glacio-eustatic changes and gravitational stresses have encouraged slump faulting along the edge of the limestone Banks. Such fractures are often visible from the air and on the island surface and may extend for several tens of kilometres along the edge of the Banks.

Cave development occurs along these where they are intersected by the halocline encouraging horizontal enlargement of the fracture at a particular level, or where lateral displacement of the rock opens an associated void.

Tidal currents in Blue Holes which are open to the sea are caused by differences in tidal levels on either side of the Bank (Williams 1979) and can enlarge or maintain such void entrances through marine abrasion and corrosion, and by removal and dispersal of sediments which might otherwise infill the caves.

Such fault development near the coast should encourage conduit flow along the line of the fracture, thus encouraging the intermixture of saline tidal waters with the outflow from the island's freshwater lenses.

Such a classification is not quite so simply organised; the cave types overlap to a certain degree, and any categorisation into types must be generalised.

Stargate: The deep vertical rift of the North Passage, formed by the collapse of wall and roof material induced through solution at the halocline.

POSITIONS OF CAVES ON SOUTH ANDROS

Studies on North Andros (Palmer et al., 1984) revealed Blue Holes of each of the formational categories outlines above, with an apparent dominance of cenote and fossil lens-base caves. There are distinct developmental levels at -15 m, -25 m and -48 m (all +3 m), which presumably relate to Pleistocene eustatic still-sands, all below current sea-levels. New studies (February 1985) on South Andros show that the dominant control over Blue Hole formation on the eastern coast is a massive series of slump faults running parallel to the Tongue of the Ocean from Mangrove Cay in the north to beyond the end of the island in the south.

The first fracture zone runs offshore of Mangrove Cay, where Blue Holes explored by George Benjamin and his team (Benjamin 1984) from 1958 to 1973, and the British Cave Diving Group in 1982 (Palmer et al. 1984) descend to depths in excess of -70 m. This fracture crosses the SE corner of Mangrove Cay at Bastion Point. A parallel fracture a few hundred metres to the west is evident near here, and both faults cross the South Bight. The western fault encompasses some of the deepest and most extensive Blue Holes on the island, the South Bight series Nos 1-10 explored by Benjamin. Shafts in the floor of SB No 4 descend for over 100 m below the Bight, and have not been explored to any downward conclusion. The main horizontal passages in this system run NNW to SSE at approximately 150°-160°, and are formed along the vertical plane of the fault between 35 and 60 m depth. Over 2 km of passages have been explored in this system.

From Driggs Hill, this westernmost fracture becomes dominant, paralleling the coast several hundred metres west of the main N-S road. Over 20 inland Blue Holes lie on it, in two main groupings. The first of these lies 1200 m SW of the Las Palmas Hotel, stretching almost to Congo Town. The second grouping lies a few hundred metres west of the Bluff, stretching south behind the Kemp's Bay Commissioner's Complex. The first group was not visited, but of the second, several appear to be infilled, whilst others (Stargate, Katrina's Cave, Elvenhome) reach depths of over 40 m. The floor of Stargate, at -65 to -80 m the deepest of the inland holes explored, is a mass of fallen blocks, and the cave may well continue below. These depths and passage dimensions are similar to those in SB no. 4 below the South Bight.

One kilometre north of Smith's Hill, the fault crosses the coastline. A small group of marine Blue Holes a few hundred metres south of this point, and 20-30 m offshore, were discovered to emit brackish water, of 1.6% salinity, at the height of the tidal overflow, suggesting that these caves play an active role in draining the freshwater lens. Slight tidally-related current flows were observed in several of the inland holes behind the Commissioner's Complex, on the same fracture zone.

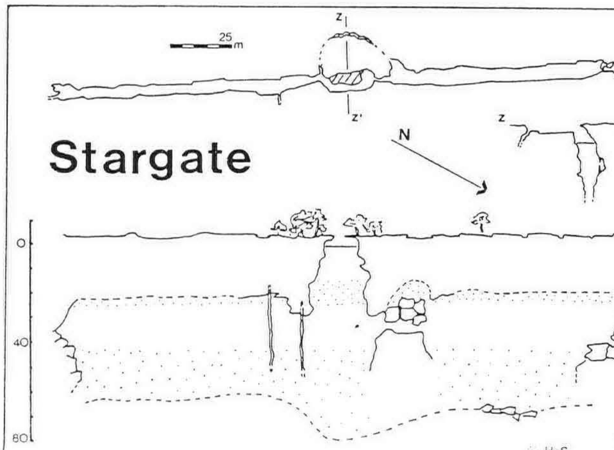

Fig.2.

Further south, the fault parallels the edge of the drop-off, about 1-2 km offshore. A series of marine Blue Holes can be traced south along it, typified by encircling rings of coral growth. These descend to depths in excess of 40 m. Other similar marine Blue Holes are found on smaller, parallel fractures closer inshore. The main fault zone appears to continue south-west of the island, following the trend of the drop-off as it curves away to the south-west.

In the interior of the island, several cenote-type Blue Holes are known to exist. These have not been explored, and are generally very remote. Nothing is known about their relationship to the physical structure of the surrounding area.

CAVE DEVELOPMENT ON THE FAULT ZONE

Eustatic movement has undoubtedly had a role in the shaping of the fault caves. Their lateral enlargement appears to relate to lens position. In Stargate, the most accessible of the inland Holes, the current zone of breakdown and corrosional activity is within the chemolimnion, from -16 to 40 m, and especially in the halocline area from -16 to -22 m. The walls in this region are clean and fretted, exhibiting a high degree of corrosion, as opposed to an apparent concretional covering in the areas above and below the chemolimnion.

Given that sea levels within the most of the Pleistocene have been lower than those of today, and both freshwater lens and interface being thus correspondingly deeper, it would be expected that the cave passage has developed at a greater depth than the modern interface region. This is in fact the case, the passage below the halocline being of regular dimensions to at least -65 m (the deepest point physically explored, and well below the current mixing zone). Speleothems present on the walls to this depth suggest that the passage was in existence prior to the last major eustatic fall, between 115,000 and 15,000 years ago, when such features might have formed.

Although several Blue Holes on the fracture line reach depths in excess of 30 m, with common horizontal development below -22 m level, Stargate is by far the finest example of its type, and is thus worth examining in closer detail.

STARGATE BLUE HOLE

The 10 m x 15 m surface opening is overhung on the west side, fortunately shielding the entrance pool from infalling organic debris that might otherwise break down to hang in suspension at the halocline, reducing visibility and light levels considerably. In Stargate, available light is adequate for exploration within the vertical entrance shaft to a depth of -40 m, and the void below this has been plumbed to -80 m (Fig 2.).

Structure

The vertical profile of the cave wall provides a direct opportunity to examine rock strata lain down over the last 2,000,000+ years subsidence and accumulation of the Bahama Banks as having been approximately 1 cm every 250 years). The top 5 m appear to be terrestial dune deposits, but below that are marine sediments, with a well-defined fossil coral bed at -8 m. Fine marine sediments extend to -17 m, from where the beds are largely massive and fossiliferous to below - 30 m. At -35 m, a thick layer of fossil conch shells was observed a short distance into the cave passage on the north side of the entrance

The entrance shaft bisects a large cave passage that trends approximately 150° for 100 m in both north and south directions. The cave passage can be entered at -30 m, and extends to a depth of -65 m in either direction. Both passages end in breakdown chokes, and dimensions are consistent, averaging 10 m wide by 35-40 m high. The floor of the cave is composed of irregular breakdown blocks which appear to have fallen from the roof and walls, suggesting that the cave is being enlarged by solutionally-induced collapse as well as direct corrosion. Speleothems - stalactites and flowstone - are evident to -65 m (the deepest point physically explored), and it is thought that the passage continues vertically below the breakdown floor at -65 m. Speleothems on breakdown blocks, at angles to their original position of growth, suggest that the collapse is continuing, as suggested by fragile nature of the roof in several places.

At the start of the South Passage, on its western side, there is a high-level breakdown chamber, associated with the structural weakness of the entrance area. On the north side of the entrance, at the beginning of the North Passage, a large fracture crosses the cave at right angles, also exhibiting solutional enlargement, and with a noticeable displacement of approximately 10 m (see Fig 2.) between east and west walls. This suggests that there has been at least a local displacement of such a distance along the main slump fault zone.

The present top of the cave passage lies between -30 and -25 m, with a further narrow upward enlargement on the main fracture to -20 and above. This upward enlargement takes the cave into the halocline, the zone at which the cave development is presumed to be most active. Rock at this level is extremely friable and corroded, though speleothems are still evident. There is a rich growth of sulphur-reducing bacteria (Sphaerotilus sp?) above -22 m, encouraged by organic debris held in suspension at this level by the increased density of the more saline waters below.

Hydrology

Stargate is effectively a meromictic lake, with the added qualification of cave passages extending off to either side of the entrance. The vertical chemical profile is further complicated by an apparent current flow in the upper part of the cave passage.

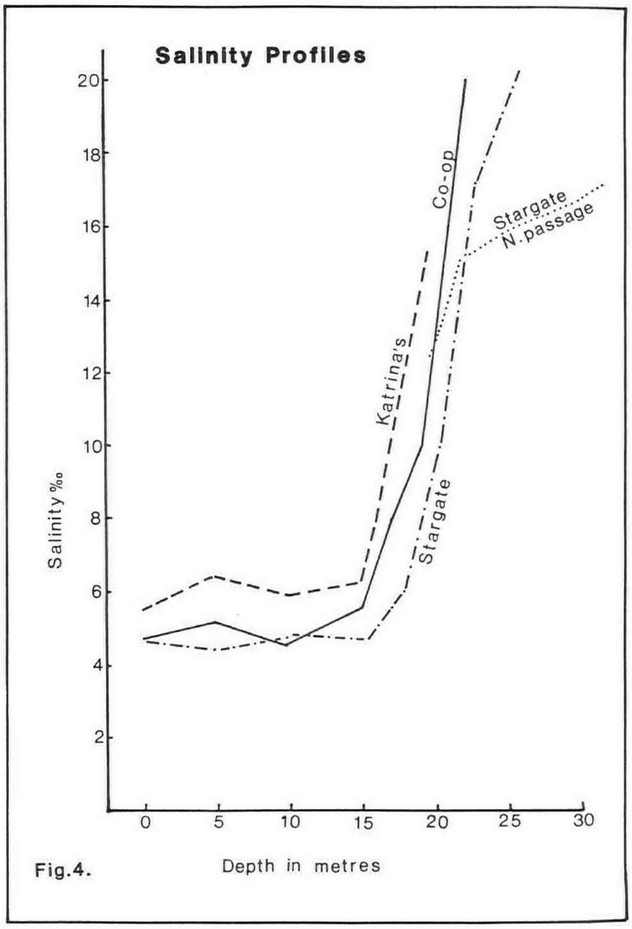

Fig.4.

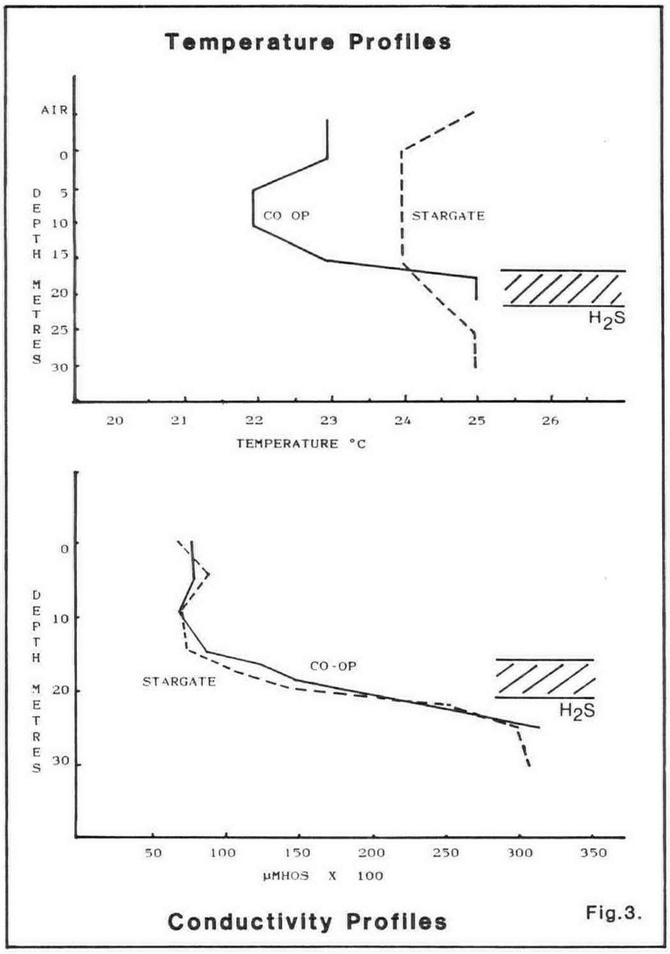

Fig.3.

The stratification profile appears to be as in Figures 3 and 4. From the surface to a depth of -5 m is the epilimnion, responding closely to changes in surface temperature and to what little effect wind-induced mixing and evaporation might have within the sheltered entrance. A slight rise in salinity and temperature at the 5 m level (more evident in other, larger surface openings nearby - e.g. Co-Op Hole and Katrina's Cave) and correspondingly fall and stabilisation at -10 m, would suggest that the zone between -5 and -10 m is the metalimnion. Salinity, temperature and conductivity are stable from -10 to 16 m, and this zone can be regarded as the hypolimnion.

From -16 to -22 m, salinity, conductivity and temperature increase suddenly from 24° to 25°C. This narrow band of rapid increase is the halocline, the boundary between the freshwater lens and the brackish/saline water below. It can be regarded in this instance as the upper boundary of the chemolimnion, the brackish interface between the mixolimnion and the deep saline monimolimnion. The halocline has a slight H_2S content and reduced visibility (partially due to the physical intermixture of the two water densities). Although sampling in February 1985 ceased at -30 m, the chemolimnion may be assumed to extend to -43 m, where a further alteration in chemistry occurs. There is a distinct change at this level, accompanied by a slight H_2S content in the lower zone, and the water below - 43 m is presumed to be static, saline monimolimnion.

There is a slight flow, probably tidally-related, within the -22 m to -43 m chemolimnion, and this zone is further distinguished by the presence of a rich and varied cave fauna, which is not present in the zones immediately above and below. This tidal flow may well encourage vertical mixing within the mixolimnion, and this zone ought to be regarded as ending at -43 m, rather than at the halocline. This flow within the chemolimnion is an unusual phenomenon and is deserving of further study.

Stargate: Stratified sand deposits cemented to the wall of the North Passage near the entrance at -30 m, possible evidence for infill during a higher sea-stand

The halocline is evident in the upper regions of the cave passages, at 22 m, associated with an area of dense bacterial plate. Salinity in the North Passage at -30 m was 1.8% as opposed to over 2% at the same depth in the entrance shaft. The higher salinities in the entrance may be due to enhanced vertical mixing in this area due to temperature and evaporational effects, though contamination due to increased diver traffic during the sampling period cannot be ruled out. This diver traffic did not appear substantially to affect the shallow stratification over a two-week period, although there was a noticeable reduction in visibility in the freshwater zone during this time.

Biology

The freshwater lens was only accessible within the vertical entrance shaft, and had a relatively restricted fauna, with Gambusia manni (mosquito fish) and the goby Eliotis pisonis. Some closely-grazed algae were observed on the west wall to -10 m, though considerably less than at other sites. The gobies inhabited both fresh and brackish layers, and were occasionally found up to 30 m into the cave passages. They stayed near walls, and were docile until disturbed.

The brackish zone between -22 m and -43 m was, within the dark zone of the cave, the most densely populated, with a fauna typical of other Bahamian anchialine caves. This fauna was primarily micro-crustacean, with copepods, amphipods, thermosbanaceans, Cirolanid isopods, shrimps and remipedes represented. Several are species new to science, or are new records for the island. A list of species so far identified is given below. As in other Bahamian anchialine caves, the food chain would appear to be detritus-based, with organic debris floating on the denser, saline waters below the halocline being broken down by bacterial decomposition to form one of the primary food-sources for the cave fauna. Some of the cave crustaceans are detritivores (ostracods, copepods, thermosbanaceans) feeding on this debris, and on the bacterial plate associated with the halocline, whilst others are predators (amphipods, remipedes). Top of the food chain appears to be the blind cave brotulid Lucifuga, common in anchialine caves throughout the Bahamas.

Of particular interest was the discovery of a polynoid polychaete, Pelagomacellicephala iliffei, recently described (Pettibone 1985) from a brackish pool in Conch Bar Cave in the Turks and Caicos group. The four specimens collected from Stargate Blue Hole were found within the deep cave fauna, in the dark zone. Three were bright red in colouration (one was white), and contained large eggs. This may account for the red colouration, and may give some indication of a breeding season (A.Muir, pers comm.) These polychaetes are distinctive in appearance, with long dorsal cirri on the parapodia of approximately every second segment. These and, the long head antennae, extend in an upward and outward curve away from the body in life, when at rest in the water. On disturbance, the animal moves with extreme rapidity in short bursts, with the cirri and antennae curving backwards along the body, before halting with equal suddeness to resume a rigid and motionless posture in the water. These polychaetes are extremely fragile, and proved difficult to collect without damage (which can be caused by their own frantic efforts to escape from an enclosing jar). One preserved specimen showed diffuse patches of golden granules on the head, which may be degenerate eyes?

Though such crustacea are found elsewhere in salinities higher than 18-20% of the brackish faunal zone in Stargate, the increased H_2S content of the water below -43 m level appears to deter the cave fauna from straying into the deepest region of the cave. The cave water below -43 m appears totally devoid of life.

SPECIES COLLECTED

Polynoid polychæte:	Pelagomacellicephala iliffei (Pettibone)
Calanoid copepod:	Enantiosis sp. (new species)
Cirolanid isopod:	Dodecalana yageræ (Carpenter)
Remipede:	Speleonectes sp. (description in progress)
Thermosbanacean:	(description in progress: Yager)
Amphipod:	Bahadzia setimana (Stock)
Brotulid:	Lucifuga sp.
Goby:	Eliotis pisonis (Gmelin)

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APPENDIX: SURFACE EXPOSURE OF THE SLUMP FAULT BETWEEN CO-OP HOLE AND STARGATE BLUE HOLE. Jennifer Shaw.

The major fault line was located easily at Co-op Hole and was traced south to Stargate Blue Hole. The only point at which the fault was not entirely visible on the surface (due to rubble and soils deposited on top) it reappeared 2 metres away.

The Co-op Blue Hole has formed on the line of the fault, and has cave entrances at depth at either end. The Blue Hole is surrounded by cliffs 4-6 m high, with occasional undercutting at 3-4 m. The cliffs are 5-6 m high on the west side of the fault, but only 4 m on the east side.

A minor fracture on a bearing of 290° does not appear to be associated with any physical features, though it can clearly be traced down the cliff face. This fracture is almost at right angles to the main fault, which runs on a general bearing of 150-180°, with local variations outside this range.

Limestone dune bedding is particularly clear on the upper portion of the north-west wall. The surrounding surface is typical rundkarren, with broken pavement and shallow solution pits up to 3 m deep, and supports a dens coppice growth.

Between Co-op and Stargate Blue Holes, three separate fractures were observed. These were, from east to west:
1) A minor rubble-choked fissure, bearing 166°.
2) Minor fissure approximately 1 m west of 1, bearing 177°.
3) A major rift 2-3 m deep in places. As it extends further from the Blue Hole, it is 1.5 m deep, bearing 230°.

Fractures 2 and 3 converge a few metres from the Hole. The general local trend is 165°. The united fracture continues in a straight line, crossing the access road on approximately the same bearing. A few metres beyond the road, the fault zone runs through an area of field clearance, where it is easily observed. In places, the fault is filled with rubble, soils and dead vegetation, but is still distinct, reaching a depth of 5 m in places.

Approximately 50 m south of Co-op Hole and 20 m south of the road, the fault opens into a series of large, shallow solution holes and alters a bearing of 160°. A few hundred metres on, a fourth fracture joins the main fault, with some apparent displacement (less than 1 m), the highest side being to the west. Approximately 15 m later, the fault opens up as the entrance to Stargate.

The two Blue Holes are therefore on the same fracture line, which represents a complex fracture zone running in a general N-NW to S-SE direction as an interconnected series of distinct fissures with a slight downthrow to the east.

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The Biota in the Marine Blue Holes of Andros Island

R J TROTT & G F WARNER

Abstract: The biota of nine marine blue holes on South Andros Island, Bahamas was surveyed during the 1985 Bahamas phase of Operation Raleigh. The marine holes fell into two groups, one with entrances close inshore and surrounded by seagrass and algal beds, while the other lay further offshore in an environment of sand flats and coral patch reefs. Significant differences were found between the biotas of each type.

Blue Holes are entrances to intricate cave systems that lie beneath the islands of the Bahamas. Solutional in origin, they were periodically exposed to sub-aerial conditions during the low sea-levels of the Pleistocene glaciations, and re-inundated as the seas rose at the end of these phases. The Blue Hole entrance and associated cave passages can be defined as follows. The Arena is the area surrounding the cave entrance on which the biotic community of the cave and the hydrological effect of water movements associated with the cave have a direct and distinct effect. The Vestibule is the underwater part of the cave mouth between the Arena and the limit of daylight within the cave (characterised by decreasing light levels and light-dwelling biota). The Transition zone is the zone extending from Vestibule to the fourth deep cave zone, and is characterised by the influence of outside factors, such as current-borne food, together with a fauna that can be regarded as troglophilic. The Deep Cave is characterised by low or little current movement, clear waters and a cave-adapted fauna. It can be described as the area of a marine cave in which the environmental conditions are such that only a specialised cave-adapted fauna can maintain a population. The energetics of the deep cave are dependant upon surface input. All of the four above mentioned definitions overlap, often to a considerable degree.

Tidal currents flush these marine Blue Holes. Inflowing current carry more planktonic organisms and fresh algal detritus, and a higher concentration of organic particulate matter than outflowing currents, which contain more faecal matter and sand (Warner and Moore 1984). Previous studies on the biology of marine caves include Vasseur (1974), MacIntyre et al (1982), and Warner and Moore (1984).

The purpose of the work reported here was to locate marine Blue Holes in the vicinity of Smith's Hill and Deep Creek, South Andros, to survey the Arena, Vestibule and Transition zones, and to compare species diversity and abundance of epibiota and mobile biota found at inshore and offshore Blue Holes. The work was carried out with the help of a team of venturers from Operation Raleigh.

METHODS

Water Currents

Divers recorded whether outward (blow phase) and inward (suck phase) currents exist within the Blue Holes. Times of slack water between blow and suck phases were recorded.

Temperature/Depth Profile

Water temperature at 5 m intervals from the sea surface to the transition zone was measured using a hand-held thermometer.

The Arena environment

The substrate type and sessile organisms of the Arena were determined by the use of four line-transects in north, south, east and west directions. Each 10 m transect line was marked at 10 cm intervals. At each mark, the substrate type or organism present was recorded. Each result gave an estimate of percentage cover.

Epibiota on Vestibule and Transition walls

Where possible, vertical surfaces were chosen at approximately 5 m depth intervals from the Arena down to the Transition zone. When possible,

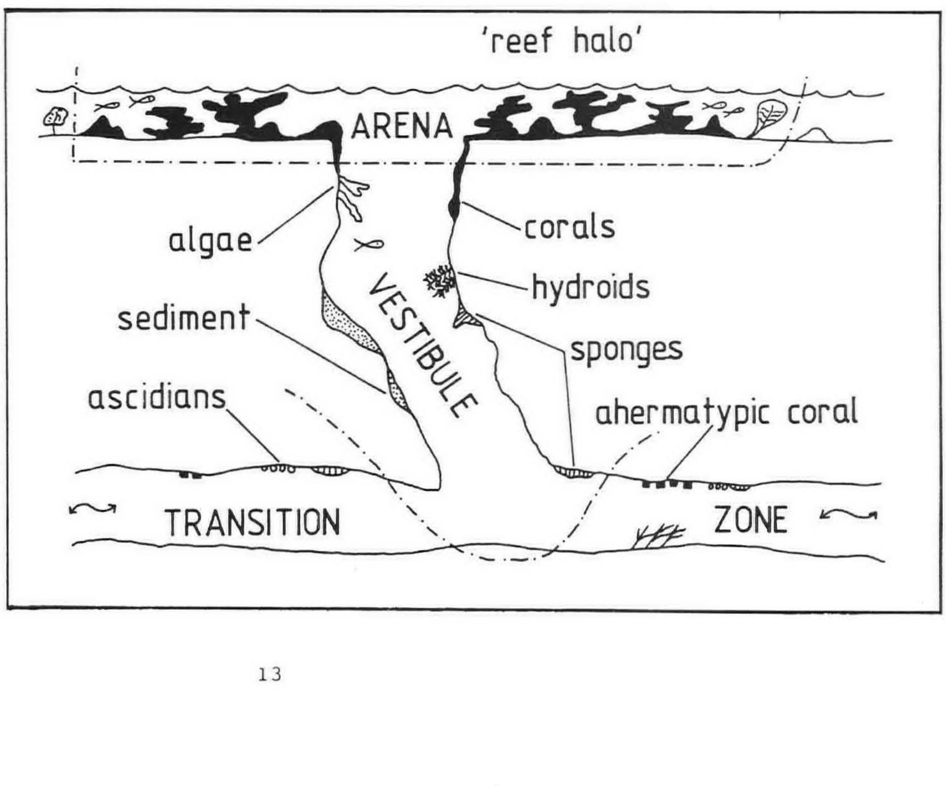


Figure 1. The Blue Hole Zones

TABLE 1: Temperature/depth profile for Blue Holes of South Andros, Bahamas. (0 m represents the surface; temperatures are represented in the body of the table, units are °C. S: suck phase; B: blow phase.)

Blue Hole		Depth measurements (metres)							
		0	2	5	7	10	15	20	22
SHBH2	S	22		22		22		22	22
SHBH3	S	22	22		24				
DCBH1	S	22		22		22	22		
DCBH2	B	26		25.5		25	25	25	
DCBH3	S	22		22		22	22		
DCBH4	B	25		25		25	24		
DCBH5	B	25		25		25	28*	25	

(* : measurement made from side passage)

five 16-point quadrat sample recordings were made at each depth. The quadrat consisted of a half-metre square, galvanised steel frame with a grid attached. The steel struts of the grid were spaced 10 cm apart. The intersection between the two struts gave a sampling point. Results have been converted into percentage cover.

Fish Species

One 30-minute dive was used to estimate the species diversity and abundance of fish found within a Blue Hole. Each diver undertaking this survey had previous experience of fish identification. Fish identification cards were used underwater as a further aid. The numbers of fish were classified as abundant (over 21), common (6-20), infrequent (2-5) and singleton (1).

Photography

A photographic collection of common, typical epifaunal communities was made using Nikonos cameras with close-up and macro attachments, and electronic flash.

Collection of material

Common epibiota was collected, labelled, and preserved in 4% formalin for transport back to the U K for identification.

TABLE 2: Times of slack water between suck and blow phases, and surface low tide times. (S/B: suck/blow changeover; B/S: blow/suck changeover)

Blue Hole		Slack Water	Low Tide
SHBH2	S/B	11.20-11.50	14.23
SHBH3	S/B	14.55-15.25	17.27
SHBH5	S/B	06.30-07.00	03.17
DCBH2	B/S	15.20-15.50	10.50
DCBH5	B/S	15.30-16.00	10.50

Other observations

Notes were made of the presence of Crustacea and their locations, particularly lobsters and crabs, and of the presence of fan-shaped organisms, particularly Hydroidea, Stylasterina, Gorgonacea and Scleractinia.

Tide Tables

No tide recordings were made. However, information on tide times was obtained from the "Yachtsman's Guide to the Bahamas 1985" for Deep Creek, South Andros.

PHYSICAL FEATURES

At Smith's Hill, four Blue Holes were surveyed, 30-100 m offshore. The Blue Holes lie in 2-4 m of water, depending on the state of the tide. At Deep Creek, five Blue Holes were surveyed. DCBH 1,2,4 and 5 lie 1-2 km offshore. They are classified as doughnut holes, due to the corals and associated flora and fauna encircling the Blue Hole entrance. DCBH 3 was found only 10 m offshore. The "doughnut holes" and DCBH 3 lie in 2-4 m and 1-2 m of water respectively, dependant on the state of tide. For temperature/depth profiles and water current results, refer to tables 1 and 2 respectively. For topographical features and map references, see Palmer (this volume).

THE SUBSTRATE/ORGANISM COMPOSITION OF THE ARENA

Smith's Hill Blue Holes (SHBH)

Blue Holes 1,2,3, and 4 were surveyed. The mean percentage cover for substrate/organism type surrounding these Blue Holes is presented in Fig 2A. The species present are recorded in Table 3.

The Arena of the SHBH are composed mainly of sand, and algae growing on sand, in all surrounding directions. For each Blue Hole, the mean percentage cover of sand (50%) was greater than that for algae (35%). Seagrass growing on sand (seagrass/sand) and live coral were also recorded at all these Holes, and in all four directions. Their mean percentage cover was low, approximately 0-5%. A low mean percentage cover of algae growing on rock (algae/rock) occurred at SHBH 3 and 4, in east south and west directions, and an even lower percentage of hydroid (3%) was recorded at SHBH 4 in north and south directions. The only other sessile organism noted, but not recorded by the transect method, was the anemone *Condylactis gigantea*.

Excluding the fish species (which will be presented in a separate section), few mobile

Typical epibenthic assemblage in Shark Hole.

Table 3. Species list. OS = offshore blue holes (i.e. DCBH one, two, four and five), IS = inshore blue holes (i.e. SBBH one to five and DCBH three).

ALGAE

- CHLOROPHYCEAE
  - *Halimeda copiosa* Goreau & Graham IS, OS
  - *Penicillus capitatus* Lamarck IS
  - *Udotea spinulosa* Howe IS, OS
- PHAEOPHYTA
  - *Turbinaria turbinata* (Linnaeus) IS, OS
  - *Sargassum* sp IS, OS
- RHODOPHYCEAE
  - Unidentified spl IS, OS
  - Unidentified sp2 IS, OS
- FORAMINIFERA
  - Unidentified spl IS, OS

PORIFERA

- DEMOSPONGIA
  - *Chondrosia* sp IS, OS
  - *Cliona* sp IS
  - *Amphimedon viridis* Duchassaing & Michelotti IS
  - *Ulosa* sp IS
  - Unidentified spl IS, OS
  - Unidentified sp2 IS, OS
  - Unidentified sp3 IS, OS
  - Unidentified sp4 IS, OS
- CALCAREA
  - *Clathrina* sp

COELENTERATA

- HYDROZOA
  - *Lytocarpus phillippinus* (Kirchenpauer) OS
  - *Sertularella speciosa* Congdon OS
  - *Thyroscyphus ramosus* Allmam IS, OS
  - *Cryptolaria* sp OS
  - *Millepora* sp OS
  - *Stylaster roseus* (Pallas) OS
- ANTHOZOA
  - *Crassimargientella* sp OS
  - *Discosoma sancitomae* Duchassaing & Michelotti OS
  - *Condylactis gigantea* (Weinland) IS
  - Zooanthid sp OS
  - Cerianthid sp OS

ECHINODERMATA

- *Echinometra lucunter* (Linnaeus) IS
- *Nemaster rubiginosa* (Pourtales) OS
- *Eucidaris tribuloides* (Lamarck) OS
- Unidentified spl IS
- Unidentified sp2 IS
- Unidentified sp3 IS

ANNELIDA

- POLYCHAETA
  - *Hermodice carunculata* (Pallas) IS, OS
  - Unidentified spl
  - Unidentified sp2
  - Unidentified sp3
  - Unidentified sp4

MOLLUSCA

- GASTROPODA
  - *Prunum guttatum* Dillwyn OS
  - *Astraea phoebia* Roding OS
  - *Olivia fusiformis* (Lamarck) OS
  - *Cyprea zebra* (Linne) IS
  - *Cymatium muricinium* (Roding)
  - *Pisania pusio* (Linne) OS
  - *Polystria albida* (Perry) IS
- BIVALVIA
  - *Chama macerophylla* (Gmelin) OS
  - *Brachiodontes citrinus* (Roding) IS, OS
  - *Pinctada radiata* (Leach) OS
  - *Lithophaga nigra* (Orbigny) IS, OS
  - *Pteria colymbus* (Roding) IS, OS
  - *Barbatia tenera* (Adams) OS
  - *Barbatia cancellaria* (Lamarck) OS

CRUSTACEA

- DECAPODA
  - *Periclimenes yucatanicus* (Ives) IS, OS
  - *Dromidia antillensis* (Stimpson) IS
  - *Carpilius corallinus* (Herbst) OS
  - *Panulirus argus* (Latreille) IS, OS
  - *Stenopus hispidus* (Oliver) IS, OS
  - *Stenorhynchus seticornis* (Herbst) IS
  - Unidentified spl
  - *Sphyraena barracuda* (Walbaum) IS
  - *Coryphopterus glaucofracnum* Gill IS
  - *Scorpaeiua inernus* Cuvier IS
  - *Acanthurus conileus* Bloch & Schneider IS, OS
  - *Acanthurus bahiamis* Castelnau OS
  - *Acanthurus chirurgus* (Bloch) OS
  - *Canthigaster rostrata* (Bloch) OS

ASCIDIA

- *Distapli* sp OS
- Unidentified spl IS

BRYOZOA

- *Bowerbankig* sp
- Unidentified sp2
- Unidentified sp3

PISCES

- *Gingilmostoma cirratum* (Bonnaterre) OS
- *Dasyatis americana* (Hildebrand & Schroeder) OS
- *Urolophus jamaicensis* (Cuvier) IS
- *Gymnothorax fuebris* (Ranzani) IS, OS
- *Aulostomus maculatus* Valenciennes OS
- *Tylosurus crocodilus* (Peron & Le Sueur) OS
- *Priacanthus cruentatus* (Lace pede) OS
- *Holocentrus rufus* (Walbaum) IS
- *Myripristus jacobus* Cuvier & Valenciennes OS
- *Epinephelus striatus* (Bloch) OS
- *Mycteroperca tigris* (Cuvier & Valenciennes) OS
- *Petrometopon cruentatum* (Lace pede) OS
- *Cephalopholis fulva* (Linnaeus) OS
- *Gramma loreta* Poey IS, OS
- *Carnax ruber* (Bloch), 1973 OS
- *Carnax latus* Agassiz OS
- *Lutjanus apodus* (Walbaum) OS
- *Lutjanus jocu* (Bloch & Schneider) IS
- *Haemulon flarolineatum* (Desmarest) OS
- *Haemulon sciurus* (Shaw) IS, OS
- *Diplodus argenteus* (Valenciennes) IS
- *Mulloidichythus martinicus* (Cuvier & Valenciennes) OS
- *Chaetodon ocellatus* Bloch, 1787 OS
- *Chaetodon striatus* Linnaeus IS, OS
- *Holacanthus ciliaris* (Linnaeus) OS
- *Microspathodon chrysurus* (Cuvier & Valenciennes) OS
- *Eupomacentrus partitus* (Poey) OS
- *Eupomacentrus lencostictus* (Muller & Troschel) OS
- *Abudefduf saxatilis* (Linnaeus) OS
- *Eupomacentrus dorsopunicans* (Poey) OS
- *Chromis multilineata* (Guichenot) OS
- *Chromis cyaneus* (Poey) OS
- *Halichoeres pictus* (Poey) OS
- *Halichoeres gamoti* (Cuvier & Valenciennes) IS, OS
- *Lachnolaimus maximus* (Walbaum) OS
- *Bodiamis rufus* (Linnaeus) OS
- *Clepticus parrae* (Bloch & Schneider) OS
- *Thalassoma bifasciatium* (Bloch) IS, OS
- *Sparisoma viride* (Bonnaterre) OS
- *Scarus croicensis* Bloch IS
- *Bartholomea annulata* (Lesueur) IS
- Parazooanthid spl OS
- Parazooanthid sp2 OS
- *Argacia fragilis* Dana IS
- *Leptoseris cucullata* (Ellis and Solander) IS
- *Phyllangia americana* (Milne-Edwards & Haine) OS
- *Astrangia solitaria* (Lesueur) IS, OS
- *Madracis decatis* (Lyman)
- *Dichocoenia stokesi* (Milne-Edwards & Haine) OS
- *Agarcia agaricites* (Linnaeus) OS
- *Eusmilia fastagiata* (Pallas) OS
- *Porites porites* (Pallas) OS
- *Porites astreoides* (Lamarck) OS
- *Scolymia* sp 1 OS
- *Mussa angulosa* (Pallas)
- *Acropora cervicornis* (Lamarck) OS
- *Acropora palmata* (Lamarck) OS
- *Manicina areolata* (Linnaeus) OS

species were recorded. The boring sea-urchin Echinometra lucunter was the most common, occurring at SHBH 2 and 3. Also recorded was the spiny lobster Panulirus argus, and a few black holothurians in the vicinity of SHBH 2.

Deep Creek Blue Holes (DCBH)

The mean percentage cover for substrate/organism type surrounding DCBH 1,2,4 and 5 is presented in Fig 2Bi, while the mean percentage cover for DCBH 3 is presented in Fig 2Bii. The species present are recorded in Table 3.

For DCBH 4, the encircling coral and associated fauna and flora was not surveyed, since low water above the coral heads made diving unsafe. However, it was established that the "doughnut" extended for 24 m to the north, 21.5 m to the east, 38.5 m to the south and 31 m to the west. For DCBH 1,2,3 and 5, quantitative surveys were carried out. For DCBH 2, only data for the north transect was recorded, due to shallow water above the coral heads. Coral surrounding the doughnut holes was more abundant than for DCBH 3 and the SHBH. For DCBH 1 and 2, coral was the dominant primary space coloniser. For DCBH 2, approximately 30%, and for DCBH 4 approximately 10%, of the mean percentage cover was dead and had been subsequently colonised by an algal mat. At DCBH 5, five large stands of coral existed but bare rock and an encrusting Alcyonarian Crassimarginatella sp. occupied 75% of the seabed, the bare rock having a higher percentage cover than the Alcyonarian. The Alcyonarian overgrew both coral and rock, though due to the time available, the amount of overgrown coral and rock could not be determined. The Alcyonarian was not found at any of the othe Blue Holes. Algae/rock existed at DCBH 2,4 and 5. Sand was recorded at DCBH 1 only.

The other sessile species observed but not recorded by the line transect method were Millepora at DCBH 4 and 5, gorgonians at DCBH 1,2, 4 and 5, and a zooanthid at DCBH 2. Apart from fish, no mobile species were recorded around the Arenas of the "doughnut" holes. Finally, the Arena of DCBH 3 was colonised predominantly by seagrass/sand, algae/sand and coral. Coral dominated the cover in the south, but approximately 60% of the coral was dead and overgrown by an algal mat. A seagrass/sand and algae/sand assemblage was common in the north, while seagrass/sand was dominant in the east and west. Bare sand and a very small covering of sponge were recorded. No other sessile or mobile species (excluding fish) were observed.

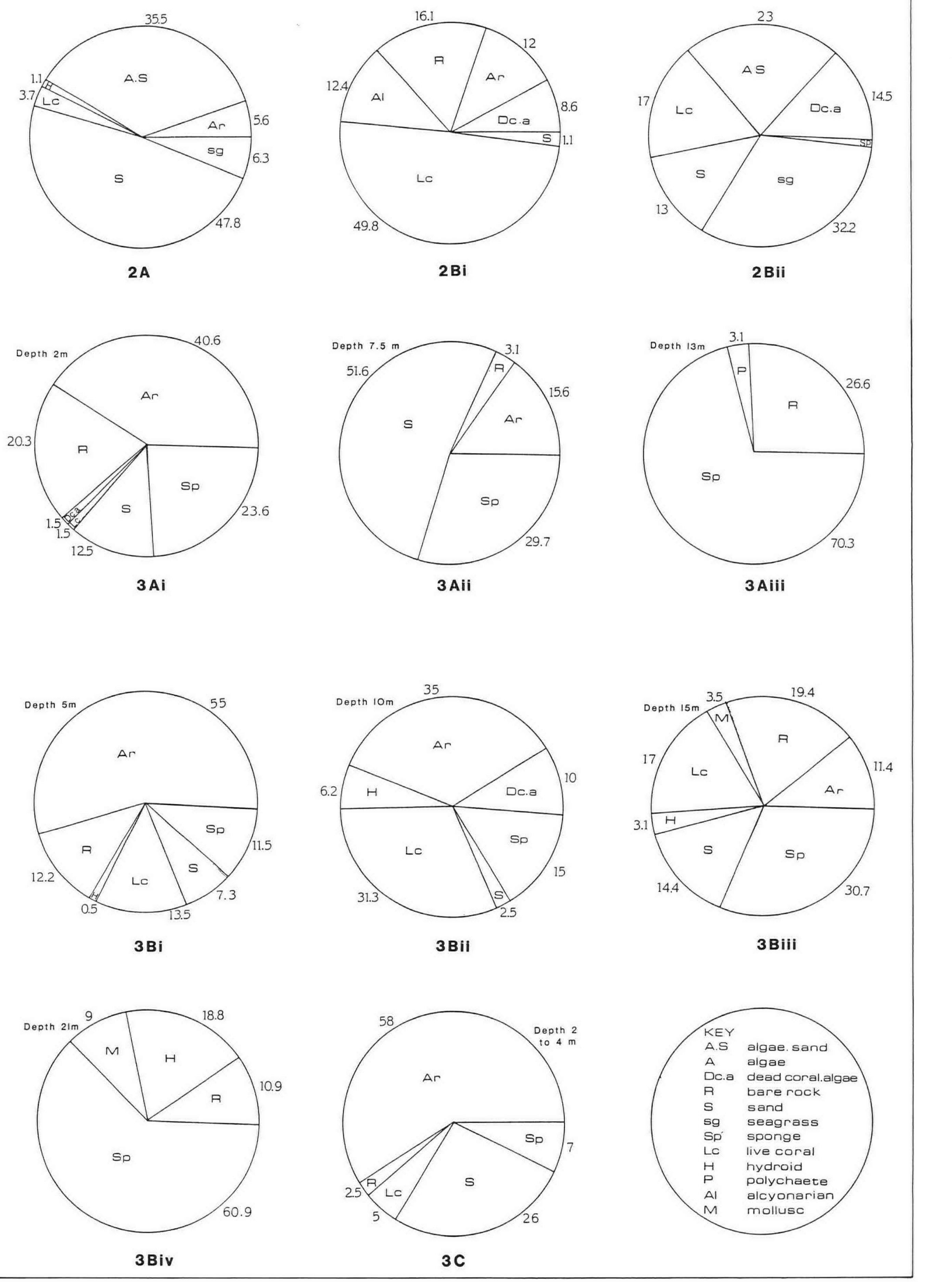
COMPOSITION OF THE VESTIBULE AND TRANSITION ZONES

Smith's Hill Blue Holes

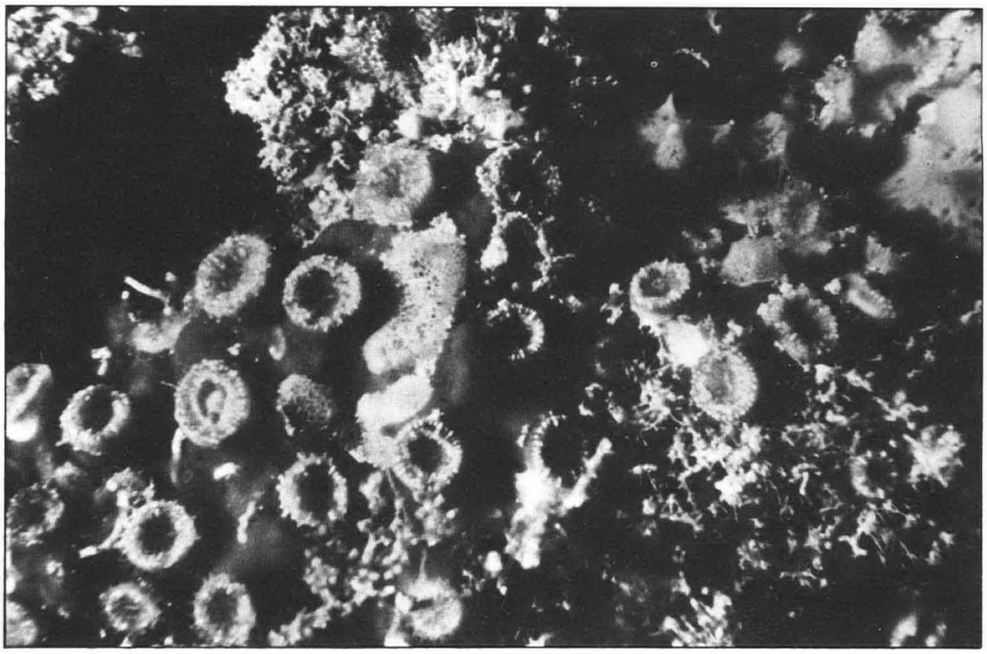
SHBH 2,3 and 4 were quantitatively surveyed. The mean percentage covers for substrate/organism type within SHBH 2,3 and 4 at depths of 2 m, 7.5 m and 13 m are presented in Fig 3Ai to 3Aiii respectively. In addition, information was gained from diver observations for SHBH 2,3,4 and 5.

The mean percentage cover of bare rock on vertical walls decreased with depth for SHBH 2,3 and 4. The only exception is for SHBH 2, where the bare rock cover was 25% at 5 m, while at 13 m bare rock covered 0% outside the cave passage, but 25% within the cave passage. The mean percentage cover of algae/rock on vertical walls decreased with depth for SHBH 2 and 4. It was also noted that the algal fronds became shorter with depth. For SHBH 3, algal cover decreased from 40% at 2 m to 19% at 6 m, but increased to 29% at 8 m. At shallow depths (0-10 m) algae were the dominant

Cover Composition within the Blue Holes Zones



Ahermatypic coral growing amongst orange sponges, Shark Hole.



space colonisers.

The mean percentage cover of sponge on vertical walls increased with depth. At depths in excess of 10 m, sponge was the dominant space coloniser on vertical walls within the Transition zone compared to vertical walls of the Vestibule zone at the same depth. The highest percentage cover of sponge was found upon the cave roof in the Transition zone. No sponge, only silt and sand, was found on the cave floor. No direct sunlight or silt penetrates the underside of horizontal surfaces, and here the primary space coloniser was sponge. On upper horizontal surfaces with heavy silt deposition, no flora or fauna was present. Apart from bare rock, algae and sponge, the only other dominant space colonisers occurring on the vertical walls were algae/dead coral (40% at 6 m: SHBH 3) and sand (20% at 10 m: SHBH 4). All other substrate/organism types covered 6% or less of primary space. This included sand, hydroids, algae/dead coral, fanworms and bivalve molluscs.

Diver observations revealed additional information to that recorded by the quadrat survey. Firstly, it was noted that the species and growth form of a sponge would change from one location to another. For example, at SHBH 2, yellow, orange and brown encrusting sponges were present at 5 m while between 7 to 11 m the common sponges were white and grey mound forms. Sponges also appeared in some way to facilitate survival of hydroid colonies; these were often found growing amongst sponge, but were rare elsewhere. All additional sessile species to those recorded by the quadrat survey came from SHBH 2, except two species of plating coral (Agaricia fragilis and Agaricia lamarcki) which were found at SHBH 3 also. Extensive bryzoan colonies were found near the Transition zone, while within the Transition zone two species of ahermatypic coral (Phyllangia americana and Astrangia solitaria), astren shells, and a few transparent anemones (probably Fagesia lineata) were present.

Apart from fish, a number of mobile species were found at SHBH 2. At 3-5 m, a few sponge crabs were found, and near the Transition zone, three unidentified crabs and two spiny lobsters (Panulirus argus) were found. Within the Transition zone, two unidentified brittle stars were common, and very well-protected, within crevices running along the vertical walls. At a penetration of 50 metres into the Transition zone, another unidentified crab was observed. No mobile species were recorded at SHBH 3 and 4. Finally, SHBH 5, several hundred metres further south, was surveyed by diver observations. Here, epiflora and epifauna occurring on vertical or near-vertical walls from the Vestibule to the Transition zone were recorded to a depth of 7 m. A sponge/hydroid/fanworm community was dominant. Between 7 and 10 m, the west wall was dominated by the two ahermatypic corals recorded at SHBH 2. Unlike SHBH 2, these corals were growing amongst vivid orange sponges. Also found in this area were hydroids and solitary ascidians. In contrast, the east wall had a high sponge cover, with no ahermatypic corals present. Btween 10-20 m, sponges were by far the dominant coloniser. Apart from fish, no mobile species were seen.

Nemaster crinoid in crevice at Coral Hole entrance.

Deep Creek Blue Holes

DCBH 1,2,3,4 and 5 were quantitatively surveyed. The mean percentage cover for substrate/organism types within DCBH 1,2,4 and 5 at depths of 5,10,15,20 and 21 m are presented in Figs. 3Bi-3Biv repectively, while for DCBH 3 at a depth of 2-4 m, the mean percentage cover for substrate/organism type is presented in Fig. 3C.

The mean percentage cover of bare rock decreased with depth for DCBH 2,3,4 and 5. For DCBH 4, bare rock cover decreased from 8% at 5 m to 0% at 10 m, then increased to 3% at 15 m.

Sand was recorded at DCBH 1,3 and 4. No pattern of sand cover with depth occurred.

The mean percentage cover of algae decreased with depth for DCBH 1,2,4 and 5. However, for DCBH 3, the algae cover increased from 36% at 2 m to 91% at 4 m. Possibly the low percentage cover at 2 m is caused by a heavy sand deposition at this depth.

The mean percentage cover of sponges increased with depth for all DCBH except DCBH 1, where the cover dropped by 5% between 10 and 15 m. Again, this could possibly be due to a higher sand cover at 15 m.

Hyroid colonies were only recorded at DCBH 1,2 and 3. At DCBH 4, the coral cover increased from 26% at 5 m to 42.5% at 10 m, then decreased to 37% at 15 m. At DCBH 5, coral cover was equal or less than 3% to a depth of 10 m, increasing to 28% at 15 m. Bivalve molluscs were recorded at DCBH 2; they occupied no more than 9% of cover on vertical walls.

Additional species recorded by diver observations came from DCBH 2 only. They include the hydrozoan Stylaster roseus and Lytocarpus phillipinus, both of which had their concave face orientated towards the Blue Hole entrance.

As for mobile species (excluding fish), none were observed at DCBH 1,2 and 3, while at DCBH 4, the red-banded coral shrimp Stenopus hispidus, a green epistobranch and a spiny lobster were noted. At DCBH 5, two spiny lobsters were recorded.

FISH SURVEY

A fish survey was carried out at SHBH 2, and DCBH 1 to 5. 51 species from 26 families were recorded in total (Table 3). 36 species were found at one Blue Hole only. Eight species were found at two Blue Holes, 5 species at three Blue Holes, 2 species at four Blue Holes. No single species was found to inhabit all six Blue Holes surveyed. 15 species were recorded at SHBH 2, 7 species at DCBH 1, 17 species at DCBH 2, 8 species at DCBH 3, 15 species at DCBH 4, and 15 species at DCBH 5.

The two Blue Holes with the least abundance of fish (ie DCBH 1 and DCBH 3) offered little refuge for fish, as they were characterised by wide entrances with an obstructed cave entrance. In contrast, the other Blue Holes had relatively narrow entrances with cave passages offering many refuges.

All but two families of fish were recorded within the Arena and Vestibule zones. The two exceptions are the squirrelfish (f. Holocentridae) and the cardinal fish (f. Apogonidae), which were recorded in the unlit Transition zone.

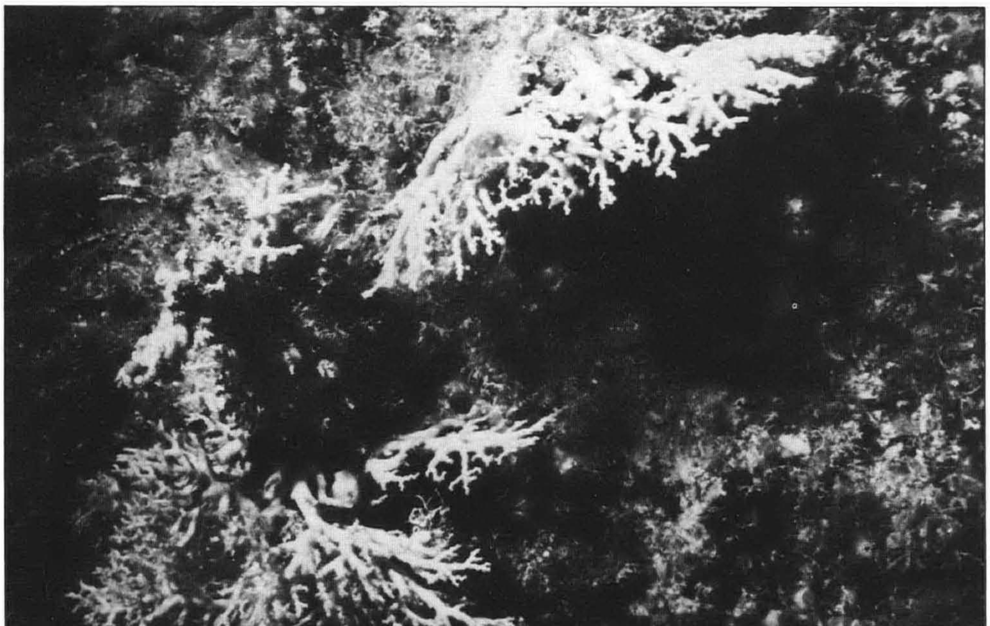
CONCLUSIONS

The Blue Holes surveyed can be categorised into either inshore Blue Holes lying 0-100 m from the mainland, or offshore Blue Holes lying 1-2 km from the mainland. Apart from the above definition, inshore and offshore holes differ in a number of other ways. The most conspicuous of these is the ring of hermatypic corals surrounding the offshore holes, which is absent from those inshore. The most obvious explanation for this would be greater coral recruitment to offshore Blue Holes due to their close proximity to the barrier reef. Other possible contributory factors are water temperatures, which are generally less variable, and silt levels, which are lower in offshore holes compared with those inshore. Coral recruitment from the reef to inshore Blue Holes may be hindered by the presence of the sand barrier between reef and shore.

The epibiota surrounding inshore and offshore Blue Holes was notably different in that for inshore blue holes, algae, seagrass and Dichocoenia stokesi were typical, with algae colonising the greatest percentage cover of primary space. For offshore Blue Holes, a number of hermatypic coral species and algae were characteristic, with corals colonising the greatest percentage cover of primary space.

The epibiota within inshore and offshore holes had similar animal and plant groups. A typical epibiotic pattern with depth persisted for both inshore and offshore sites. The percentage cover of algae and hermatypic coral decreased with depth in accordance with decreasing light levels. However, heavy siltation appeared to be the cause of algal or coral absence. The percentage cover of sponges generally increased with depth, and was usually most abundant in the Transition zone. As for the other groups present, such as hydroids, anemones, ahermatypic corals, polychaetes, bryzoans and bivalve molluscs, their spatial dominance varied from one Blue Hole to another, and showed no pattern in relation to inshore and offshore Blue Holes. However, species recorded by the photographic method were more species diverse within offshore Blue Holes ($5\text{-}6/0.03\ m^2$) than inshore Blue Holes ($2\text{-}3/0.03\ m^2$).

With mobile species, Crustaceans - in particular crabs (with the exception of Dromidea antillensis) and lobsters - were invariably



Stylaster roseus orientated to current 30 m inside Coral Hole.

located in crevices, but no distribution pattern in relation to inshore/offshore sites or depth was evident.

For fish, however, approximately twice as many species accurred in and around offshore holes compared to inland sites. Nine species, Gymnothorax fuebris, Gramma loreto, Chaetodon striatus, Abudefduf saxatilis, Halichoeres garnoti, Halichoeres pictus, Thalassoma bifasciatum unidentified species 1, and Acanthurus coruleus occurred at both inshore and offshore Blue Holes. Five species, Gramma loreto, Chaetodon striatus, Halichoeres garnoti, Thalassoma bifasciatum and Haemulon scirus were recorded as abundant at in shore holes, all being also recorded at offshore sites. For offshore Blue Holes, nine species, Carnax ruber, Abudefduf saxatilis, Chromis multilineatus, Chromis cyaneus, unidentified species Nos 1 and 2, Haemulon flavolineatum, Acanthurus coruleus and Autostomus maculatus were recorded as abundant, but only Acanthurus coruleus was also recorded at inshore sites.

Finally, the time difference between local low water at surface and slack water in the Blue Holes between suck/blow phases was approximately 3 hours for inshore Blue Holes and 4.5 hours for offshore Blue Holes. The sea surface temperature was 22°C for inshore Blue Holes and DCBH 4 (inflow/February), while the recorded outflow temperature at the remaining offshore holes was 25-26°C. Water temperatures above local winter sea surface temperatures were found within the Blue Holes of SHBH 3 and DCBH 5.

The survey was profitable in terms of the number and type of Blue Holes located and surveyed, and from the informationand experience gained from them. However, to further understand the ecology of the Blue Holes, comparative work involving extensive quantitative surveys of a selected few inshore and offshore Blue Holes is needed. In particular, colonisation would be an important aspect to examine, especially: (i) colonisation rates and subsequent development of bare substrates at various depths in inshore and offshore sites, and (ii) colonisation rates and subsequent development of bare substrates surrounding Blue Holes. In conjunction with a colonisation analysis, a plankton sampling programme of the effect of mobile species, particularly crustaceans, echinoderms and fish upon the survival and growth of an epibenthic community. Lastly, it was noted that a diverse boring fauna existed within the limestone walls of the Blue Holes. Time prevented a survey of this community. However, it would make an interesting ecological contribution to the work already carried out.

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Influence of Visitors on Carbon Dioxide Concentrations in Altamira Cave

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Abstract: A simple mathematical model has been developed from which it is possible to predict temporary variations in the CO_2 concentration in the air of the Hall of Paintings in Altamira Cave due to the influence of the presence of visitors inside the cave. The model also makes it possible to discover the recovery time necessary for the CO_2 concentration to return to its level prior to such visit. The experimental results obtained using different test groups of six vistiors to the cave over a one-year period confirm, within an acceptable degree of approximation, the validity of the proposed model.

INTRODUCTION

Conservation over the years of the cave paintings to be found in the famous Hall of Paintings of the Altamira Cave (Santander, Spain) has been made possible due to existence of a series of favourable environmental conditions. These conditions have led to the creation of a very stable microclimate which is hardly affected by variations in the outside atmosphere, and physicochemical processes which might lead to the deterioration of the paintings are not present to any significant degree. Nevertheless, the presence of visitors within this ecosystem, in very large numbers over the years, has altered its microclimate and produced deterioration in the paintings over and above the inexorable damage caused by natural agents.

One of the most important factors conditioning the conservation of the polychrome figures found within a limestone cave such as Altamira is the level of CO_2 in the air. The partial pressure of this gas in air determines its content in the water which impregnates the polychrome surface and, therefore, the aggressive or depositional properties of this water, with the consequent risk of the dissolution of the limestone beneath the paintings or the precipitation of calcium carbonate on top of them.

Since the CO_2 content of the atmosphere of the ecosystem will vary with the presence of visitors to the chamber as the result of their respiration, it is essential, if the conservation of the polychrome figures is to be assured, to study the type of variation in CO_2 levels shown in the presence of visitors over variable periods of time. It would also be useful to discover how long visitors may safely remain inside the cave and thus how the system recovers its initial condition and so to avoid any accumulation of carbon dioxide in the air of the cave.

In the specific case of Altamira Cave, the contribution of CO_2 to the atmosphere of the Hall of Paintings attributable to the presence of visitors leads to an increase in the level of carbon dioxide in solution in the waters, which possess slight depositional properties (Villar et al., 1985), that impregnate the polychrome ceiling. This increase in dissolved CO_2 may eventually confer aggressive properties on these waters which thereafter maintain the equilibrium of the CO_2-H_2O-$CaCO_3$ system by dissolving the limestone beneath the paintings (Dreybrodt, 1981). Furthermore, this problem of alterations to the surface of the polychrome ceiling of the Altamira Cave becomes aggravated if one takes into account the weak ventilation found under natural conditions within the cave (Villar et al., 1984a), since this will result in an excessively slow recovery of the initial conditions of the ecosystem after each visit.

In the light of all these factors and further to the earlier studies of the influence of human beings on the distribution of temperatures in the air and rock surfaces of the Hall of Paintings (Villar et al., 1984 b), the purpose of this paper is centred around theoretical prediction and subsequent experimental checking of variations in CO_2 concentrations produced by the presence of visitors in the air of the Hall of Paintings in Altamira Cave.

THEORETICAL PREDICTIONS

The level of carbon dioxide in the air of the Hall of Paintings during the periods visitors remain inside is determined by the balance between, on the one hand, the contributions of this gas supplied by the seepage waters that flow through the polychrome ceiling and by the presence of humans and, on the other hand, carbon dioxide losses as a result of air interchanges between the interior of the cave and the outside atmosphere (Brunet et al., 1980).

Ignoring any possible disturbances produced by the movements of visitors themselves in the natural ventilation regime of the Hall of Paintings, the equation that describes the evolution in time of the CO_2 content of the air of the chamber during visiting periods is as follows:

$$\frac{dC_t}{dt} = \Psi_W + \Psi_h - \frac{Q}{V}\cdot(C_t - C_{ext}) \qquad (1)$$

where, with concentration being expressed in ppm (by volume), V is the volume of the Hall of Paintings (approx. 326 m³), C is the concentration of CO_2 in the Hall of Paintings t hours after the commencement of the visit, C_{ext} is the concentration of CO_2 in the atmosphere outside the cave, with which an interchange with the air in the Hall of Paintings is assumed to take place, with a constant value of approximately 300 ppm (by volume), Q is the natural ventilation rate, in m/h, of the Hall of Paintings, which represents the magnitude of the existing air interchanges, under natural conditions, between this chamber and the outside atmosphere, Ψ_W is the carbon dioxide contributions, in ppm (by volume) per time unit, attributable to the seepage waters that flow through the polychrome ceiling, Ψ_h is the carbon dioxide contribution, in ppm (by volume) per time unit attributable to visitors in the Hall of Paintings which may be expressed as follows:

$$\Psi_h = \frac{17.10^3.N}{V} \text{ ppm (by volume)} \qquad (2)$$

where N is the number of persons remaining within the Hall of Paintings, each of whom exhales an average of some 17 l/h of CO_2 (Marion, 1979).

The calculation of the term ΨW, which represents the contribution of CO to the air that can be attributed to seepage waters, presents the greatest problem, since the mechanisms that govern the transfer of this gas between a liquid mass and the atmosphere surrounding the latter are extraordinarily complex and little understood (Bogli, 1980). Nevertheless, one can safely assume that in the immediate neighbourhood of the free surface of waters flowing into the chamber, the transfer of CO_2 between these waters and the air is essentially governed by a molecular diffusion process, especially if one takes into account that the air in the chamber is practically stationary (Bolin, 1960), due to weak ventilation. In these conditions, if it is assumed that the maximum concentration of CO_2 (C_{max}) experimentally measured in the Hall of Paintings throughout the year corresponds to a no ventilation situation ($Q = 0$), in which a balance has been reached between the content of CO_2 dissolved in the water and the partial pressure of this gas in the air of the Hall of Paintings, it may be suggested that

$$\Psi_W = \beta.(C_{max} - C_t) \qquad (3)$$

where C_t represents the existing CO_2 concentration in the Hall of Paintings at the time in question, and the scale factor, β, will depend essentially on the ventilation of this chamber, given that the flow of seepage water remains practically constant throughout the year.

Under natural conditions, in the absence of visitors, the level of CO_2 in the air and the ventilation of the Hall of Paintings remain practically constant over relatively long periods of time, of the order of one month (Villar et al., 1982), so that it is possible to state that $DC/dt = 0$ and that both variables are characterised, within each month, by respective constant values that are equal to their corresponding average monthly values, C_0 and Q_0, respectively.

Under nautral conditions, $h = 0$, and equation (1), may be reduced to

$$\beta.(C_{max} - C_0) = \frac{Q_0}{V}.(C_0 - C_{ext}) \qquad (4)$$

Therefore

$$\Psi_W = \frac{Q_0}{V}.\frac{(C_0 - C_{ext})}{(C_{max} - C_0)}.(C_{max} - C_t) \qquad (5)$$

Thus, equation (1) may be rewritten as follows

$$\frac{dC_t}{dt} = \frac{17.10^3.N}{V} + \frac{Q_0}{V}.\frac{(C_0 - C_t).(C_{max} - C_{ext})}{(C_{max} - C_0)} \qquad (6)$$

which, after integration, yields the following

$$C_t = C_0 + \frac{17.10^3.N}{a.V}.(1 - \exp(-a.t)) \qquad (7)$$

where

$$a = \frac{Q_0}{V}.\frac{(C_{max} - C_{ext})}{(C_{max} - C_0)} \qquad (8)$$

Once visits to the cave come to an end, the excess CO_2 supplied to the atmosphere of the Hall of Paintings by visitors is eliminated through the natural ventilation of this chamber, in accordance with the previsions of equation (6) in which, if the term $\Psi h = 0$, the following expression is obtained

$$dt = -\frac{V}{Q_0}.\frac{(C_{max} - C_0)}{(C_{max} - C_{ext})}.\frac{dC_t}{(C_t - C_0)} \qquad (9)$$

If this equation is integrated, the recovery time for the carbon dioxide level, ζC, can be determined directly. This recovery time has been determined, taking into account the fact that the average accuracy of the analyzer used in experimental measurement of the CO_2 level is 1%, as the time that has to pass between the conclusion of a visit and the moment in which the carbon dioxide concentration once more reaches a value of C, so that $(C_i - C_0)/C_0 = 0.02$, where C_0 is the existing CO_2 concentration before the visit began.

Thus, this recovery time is obtained as follows

$$\zeta_C = \frac{V}{Q_0}.\frac{(C_{max} - C_0)}{(C_{max} - C_{ext})}.\ln(\frac{50.(C_e - C_0)}{C_0}) \qquad (10)$$

where C_e is the CO_2 concentration in the air of the Hall of Paintings at the precise moment a visit comes to an end.

Once the values are known for the concentrations C_{max}, C_0 and C_e and for the natural ventilation of the chamber Q_0, equations (7) and (10) make it possible to describe the evolution in time of CO_2 concentrations in the Hall of Paintings during the course of visits, based on the number of persons remaining in the Cave N, and also to discover the recovery time taken by this concentration to return to its initial value once the visit has concluded.

On the other hand, if one takes into account the weak natural ventilation of the Hall of Paintings ($Q_0/V<<1$ in any case), equation (7) predicts, and it was possible to prove this experimentally, that for short-period stays by visitors inside the cave the temporary variation in CO_2 concentration in the Hall of Paintings turns out to be independent of the ventilation and other initial conditions of the system. In fact, the series development of the exponential factor which appears in equation (7) for small values of t (t < 1h) gives:

$$C_t = C_0 + \frac{17.10^3.N.t}{V} \qquad (11)$$

as a result of which the evolution of carbon dioxide concentration during visits will only depend on the number of visitors remaining inside the chamber.

MONTH	CO_2 CONCENTRATION (ppm (by volume))	VENTILATION ($m^3.h^{-1}$)	PERIOD OF STAY (min.)
January	3,300 ± 600	9 ± 3	22 ± 4
February	2,800 ± 500	10 ± 3	19 ± 3
March	2,700 ± 500	9 ± 3	17 ± 3
April	4,200 ± 700	6.9 ± 2.4	26 ± 4
May	5,700 ± 800	1.1 ± 0.3	25 ± 2
June	4,800 ± 800	13 ± 3	56 ± 12
July	3,500 ± 700	20 ± 4	46 ± 11
August	2,100 ± 400	17 ± 4	18 ± 3
September	1,600 ± 400	18 ± 4	14 ± 2
October	2,100 ± 500	16 ± 4	17 ± 3
November	4,700 ± 900	5.1 ± 1.4	27 ± 3
December	5,600 ± 900	5.7 ± 1.7	39 ± 6

Table 1. Average monthly CO_2 concentrations, natural ventilation rates and theoretical monthly values for periods of stay by six persons within the Hall of Paintings.

EXPERIMENTAL RESULTS

In order to test the theoretical predictions of the model used, daily experiments were carried out throughout 1983 using groups of six persons (five visitors and one guide). The time which they spent in the Hall of Paintings was used to predict the theoretical recovery time, using equations (7) and (10). A maximum recovery time of 12 hours was established, thus making it possible to ensure recovery of the carbon dioxide concentration and thereby avoid the accumulation of this gas in the atmosphere of the chamber.

Table 1 shows the theoretical monthly values for periods of stay by six persons within the Hall of Paintings together with the corresponding average monthly values of CO_2 concentrations, C_0, and the ventilation rate, Q_0, that were obtained experimentally.

Figure 1 shows, for each month of the year, the experimental results and theoretical values for the maximum variation $\Delta C_e = (C_e - C_0)$ of the CO_2 concentration in the Hall of Paintings during visit periods. From this it can be seen that, although the error intervals associated with both types of values overlap in all cases, the variations in the theoretically predicted CO_2 concentrations are always lower than those obtained experimentally. This is, no doubt, due to the fact that visitors are not distributed uniformly within the Hall of Paintings during the course of visits but rather tend to remain in groups concentrated around those areas closest to the most colourful paintings. As the probe used in the experimental CO_2 measurements is located precisely in just one of these areas (just below the painting of the Hind), this would explain the over-estimation of the experimentally measured concentrations with respect to the theoretical values predicted.

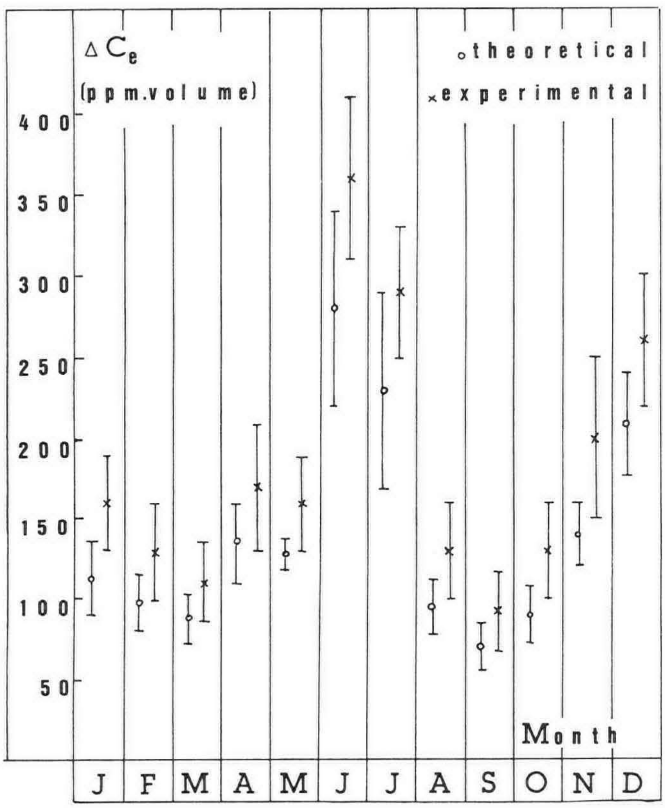

Figure 1. Experimental and theoretical monthly values for the maximum variation ΔC_e of the CO_2 concentration in the Hall of Paintings during visit periods.

CONCLUSIONS

The presence of visitors inside the Hall of Paintings of Altamira Cave represents the principal factor responsible for the alterations in the microclimate of the system and, for this reason, the regime established for visits to the cave will control the chromatic stability and the conservation of the polychrome figures there.

In particular, the influence of human beings on carbon dioxide concentration in the air of the system is of paramount importance inasmuch as the carbon dioxide contribution due to the visitors may then come to modify the slight depositional properties of the waters which impregnate the polychrome ceiling and lead to the latter becoming aggressive, with a tendency to dissolve the limestone beneath the paintings.

To study this influence of visitors on carbon dioxide concentration in the Hall of Paintings, a simple model has been developed which allows predictions to be made, for each month of the year, not only of the variation of the concentration of this gas during visit periods, based on the number of persons present wihtin the chamber, but also of the recovery time that is required for this concentration to return, after the conclusion of a visit, to the value it possessed prior to that visit. In general terms, it may be stated that the model makes it possible to explain and reproduce, with a reasonable degree of approximation, the variations in carbon dioxide concentrations that were found experimentally in the course of tests carried out daily throughout a period of one year, using different groups of six persons and differing times spent in the cave.

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The 1985 Indonesia Expedition

Tony WHITE, Editor

Abstract: During early summer 1985, seven British speleologists visited two contrasting areas of Indonesia previously unvisited by cavers. The Baliem Valley of Irian Jaya, is in a high relief area ranging from tropical montane forest to high alpine karst with complicated structural geology. In just over two weeks the area revealed about 5 km of cave, one of the largest high-level river sinks in the world, many large entrances and the potential for many exciting systems. On the island of Sumba, low relief terrain is partially inhabited but little visited by outsiders. More than 13km of passage were surveyed in over 30 caves in five different areas spread over the island, but in four weeks no indication of world-class systems was perceived. The landscape and the caves are described for both areas, with a brief look at the history, access and the people and their customs.

INTRODUCTION

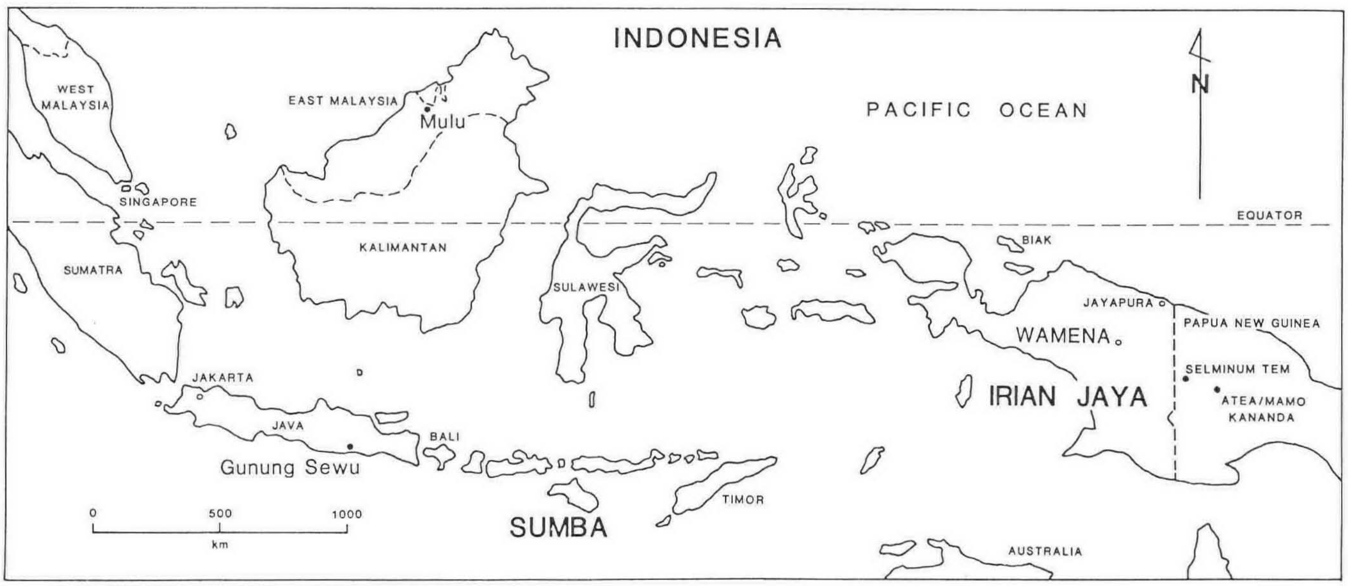
In 1975, one of the largest speleological expeditions there has ever been visited Papua New Guinea on the British New Guinea '75 Expedition. Large and extensive caves were discovered but the team felt that even better possibilities for cave exploration lay further to the west across the border with Irian Jaya.

The politics of Irian Jaya have been difficult since the original Dutch colony, moving slowly towards independence, was taken over by Indonesia in 1963. It is now ruled by fairly rigid ideals from Jakarta. Foreigners are discouraged with the exception of wealthy tourists. With the development of ties between British and Indonesian cavers, particularly with Dr Robbie Ko, Colin Boothroyd and Andy Eavis decided to visit Jakarta at the end of the Sarawak 1984 expedition to try and obtain tourist visas to enter Irian Jaya. The politics proved not to be the major hurdle. Andy was taken ill, first with leptospyrosis and, having recovered, went down with malaria on the way to Irian Jaya. Consequently he spent much of the ten days hospitalised in Biak. With Colin as nurse maid and Andy as dying patient politics seemed insignificant. Colin, however, did get in some caving on the island of Biak, and the two, after Andy's partial recovery, travelled to Nabire on the New Guinea mainland and chartered a missionary airplane to fly over the highlands. The flight was spectacular with close hand views of the snow-capped mountains and limestone plateaux. In the many hundreds of square kilometres of alpine karst covered they saw no spectacular cave features.

The two then returned to Jakarta and succeeded in getting a look at a set of aerial photographs of the whole of the Irian Jaya highlands. A number of interesting sites were spotted much further to the east around the town of Wamena and discussions with missionary pilots suggested that this area and also eastwards towards the border were the most promising speleological prospects. Colin and Andy returned to Britain very frustrated at not being able to have accomplished more but determined to follow up as soon as possible.

Consequently, late in 1984 the planning was started for the Indonesia '85 expedition. It was initially planned as a four man team to Irian Jaya with an alternative prospect as a backup in case political problems prevented entry to Irian Jaya. Robbie Ko had always been keen on Sumba, an island of modest relief but almost totally limestone and unvisited by cavers, so this was the obvious choice for a reserve area.

Funding Indonesia '85 was a difficult problem. Both Sumba and Irian could only be entered as tourists, so a low profile had to be kept on the whole project. Consequently many of the normal sources of finance were inadvisable. In the event, Irian was to prove very expensive, and being mainly funded by its members (Ghar Parau and the Sports Council being the only sources of



outside money), Colin had to swap onto the Sumba team. Andy, with Tony White and Tim Fogg, went to Irian Jaya, and Colin, with Dave Checkley, Shiela Hurd and Roo Walters, went to Sumba.

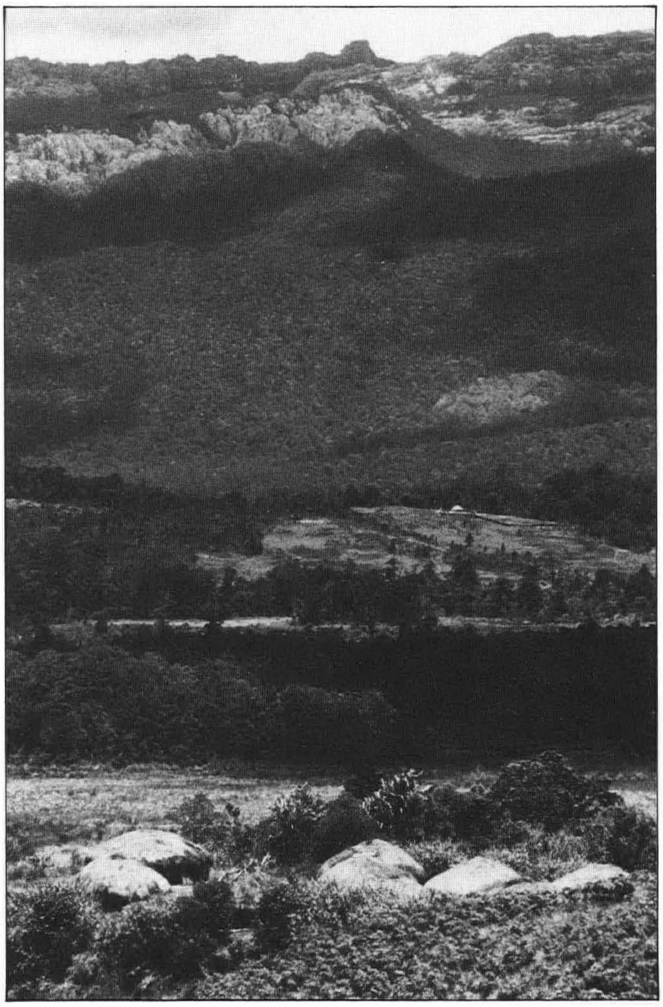
IRIAN JAYA

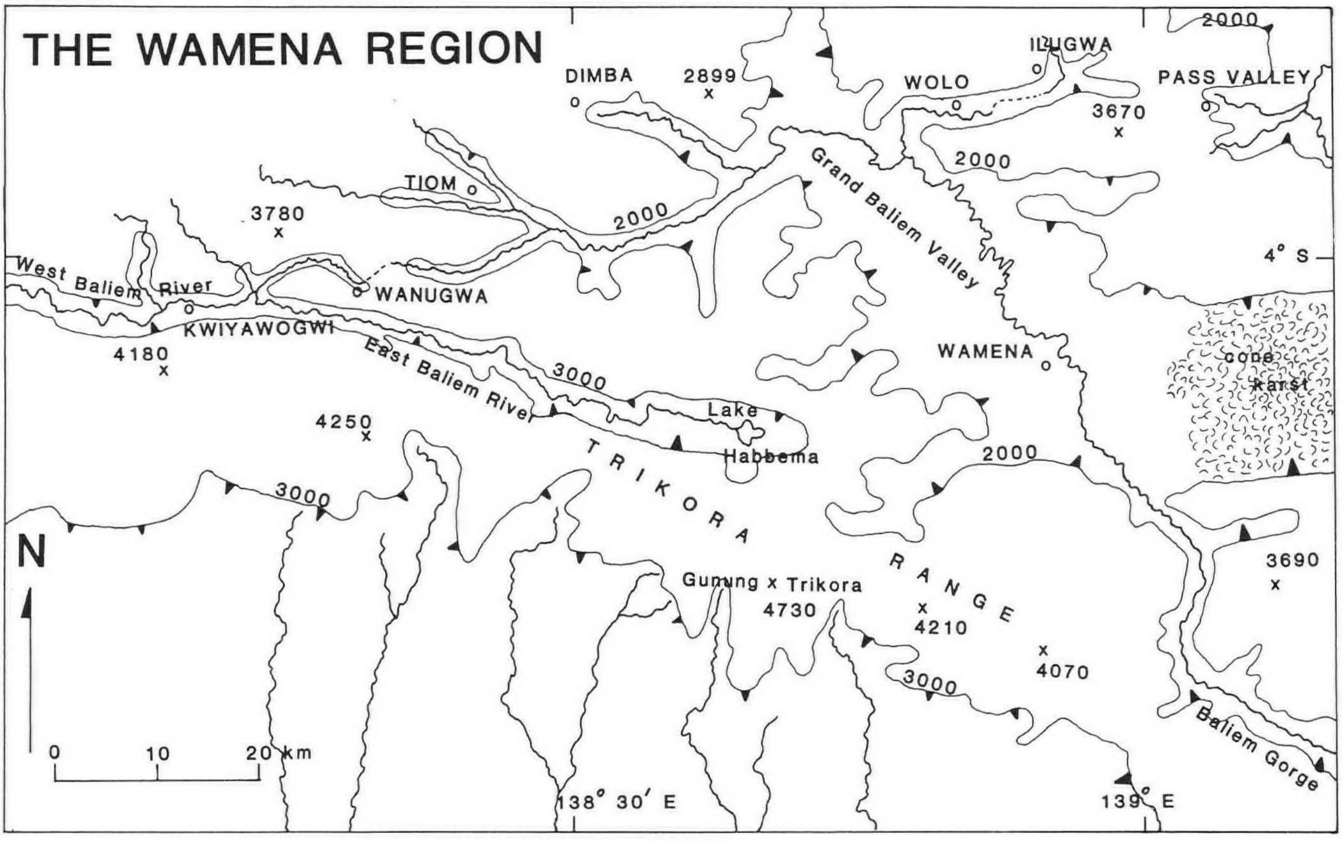
Irian Jaya contains some of the highest altitude cavernous limestone in the world. Glaciated, snow-capped mountains up to over 5000m are predominantly limestone with many caves known to exist. The area of limestone at high altitude is also very impressive with hundreds of square kilometres above 3000m elevation, with deeply dissecting gorges and spectacular escarpments giving world depth record potential.

Speleologically the entire country was unknown, reports from climbers, pilots, mining companies and missionaries being the only sources of information. One clear indication was that the general speleological structure of Papua New Guinea continues across the border into Irian Jaya, but the mountains are higher and more extensive with larger blocks of limestone than those in Papua New Guinea which have yielded some very impressive cave systems.

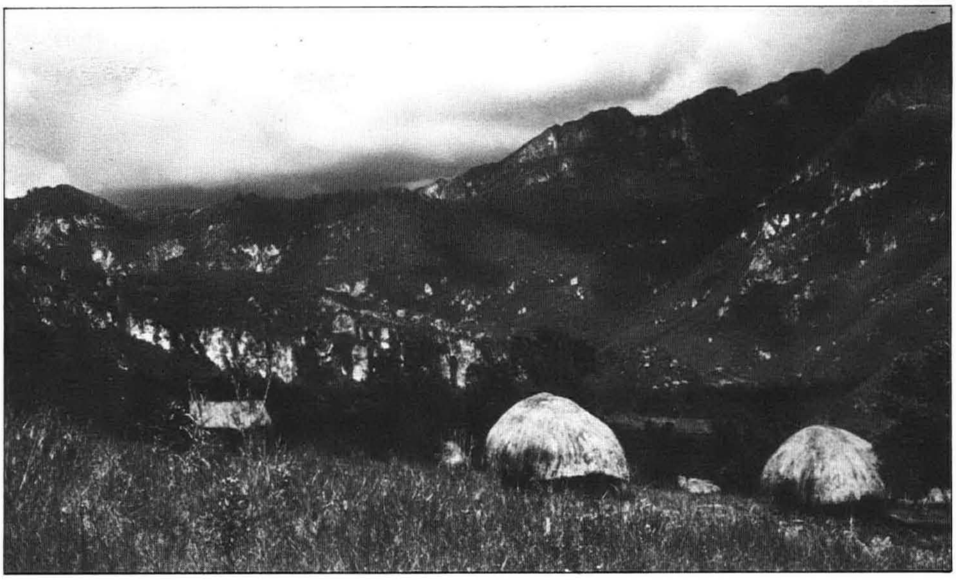
LANDSCAPE

As a result of Tertiary uplift the island of New Guinea has a great east-west chain of mountains along its centre, composed largely of limestone with interbedded sandstones and shale. In the Wamena region peaks rise to over 4700m and tend to have a very steep southerly aspect dropping in the space of 30km to the southern lowlands with typically north to south drainage. To the north side of the peaks, a system of east-west ridges deflects river drainage parallel to the range with eventual escape north to the Rouffaer and Idenburg flood plains. The major exception to this is the Baliem River which breaches the main range. In less than 50km this river descends 1500m from the Grand Baliem Valley through the spectacular Baliem Gorge and flows south to the Arafura Sea.


The Upper Baliem Valley (T. White)



Limestone scars above the Ilu Valley (A. Eavis)



The broad flat Grand Valley is at 1600m above sea level and is surrounded by limestone hills which rise up to Gunung Trikora (4730m) 30km to the south-west. The range continues west in a set of jagged bare limestone peaks and for 100km all the northern drainage is to either the West or East Baliem Rivers which meet and flow into the northern end of the Grand Valley. The eastern side of the Valley is a 30km wide belt of limestone peaking at 3670m in the north with a large egg-carton expanse of cone-karst in the south at around 2000m. Just south of this the main limestone ridges continue eastwards along the spine of New Guinea.

With a relief of over 3000m, the terrain varies considerably. The vegetation has been modified by landuse such that valleys and the lower hills may have extensive grassland or scrub with good connecting paths between villages. The higher valleys such as the East and West Baliem at over 2700m are sparsely populated and have surrounding grassland. On the slopes of the main range dense forest continues upto about 3300m where it gives way again to scrub and grassland, exposed pavements, dissected with grikes and finally bare mainrange peaks.

THE RECONNAISSANCE

The group flew from Sentani, the international airport near Jayapura, into Wamena where papers are checked by the police on arrival. One brief excursion was made to the obvious doline across the river to the south-east while permission was sought to wander in the hills. An MAF charter took them and a Dani interpreter to Kwiyawogwi where guides and carriers were hired to take them onto the higher ground to the south. Returning they walked to Wanugwa to examine the Baliem River sink where two persons worked while the third walked to Tiom and on to Dimba to investigate reported resurgences. Rejoining at Tiom an aerial reconnaissance was made over the Trikora range and returned landing the whole group at Wolo. Again two persons stayed there while the third crossed over to Pass Valley and returned to Wamena via the next valley to the south. There he again chartered a plane to take a second look over the high ground picking up the Wolo pair en route. Fourteen days were spent out of Wamena.

The High Peaks

The first attempt at flying over the range west of Trikora was cancelled because of low cloud, so the first reconnaissance was done on foot. An overnight excursion led up through moss forest and above the treeline south-west of Kwiyawogwi. A large shallow depression just on top of the scarp edge carried a stream of about 200 l/s, which flows off sandstone into a blocked sink. Several shakeholes were seen to the west of there. Descending back to the West Baliem a shallow basin containing two choked shafts about 15 m deep were the only enterable caves seen. Our guides told us of others including one five men high, but the time and variability of distance and description meant they were not visited.

Later an early morning flight was made over the high ground to the west of Wamena. Frost covered grasslands at about 3500 m had several sinking streams into what appeared open entrances. The potential is uncertain. To the south the land drops dramatically to 1000 m or so but indications are that this would be against the grain of the country, and caves are more likely to go north or east. To the east, towards the Baliem Gorge, resurgences could be at an elevation of less than 1500 m. The elevation potential to the north would not be as great.

The Baliem River Cave

What does a river in one of the wettest places on Earth with a catchment of 1600 square kilometres do when it sinks underground? This was the question which taunted us when planning the expedition. To add further attraction the site has been referred to as "the Hole in the Wall" (Temple, 1964). It seemed logical that out of the areas we could visit, this should be a major priority.

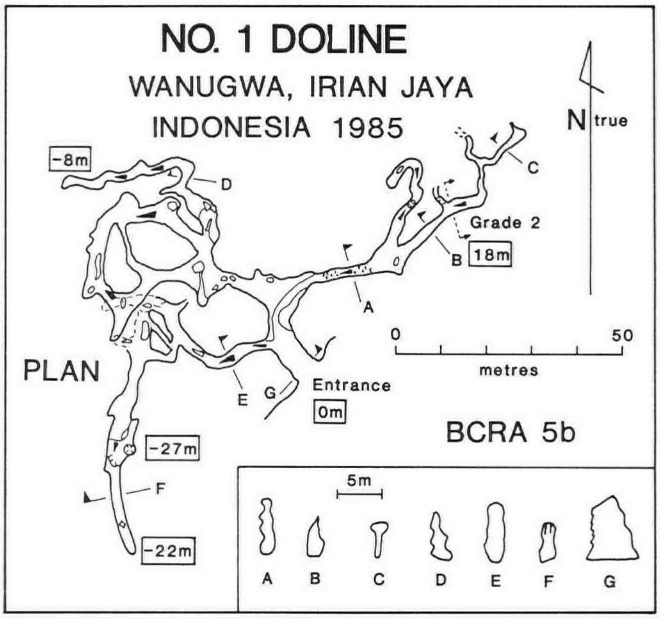
Dani people at the Baliem Sink (A. Eavis)

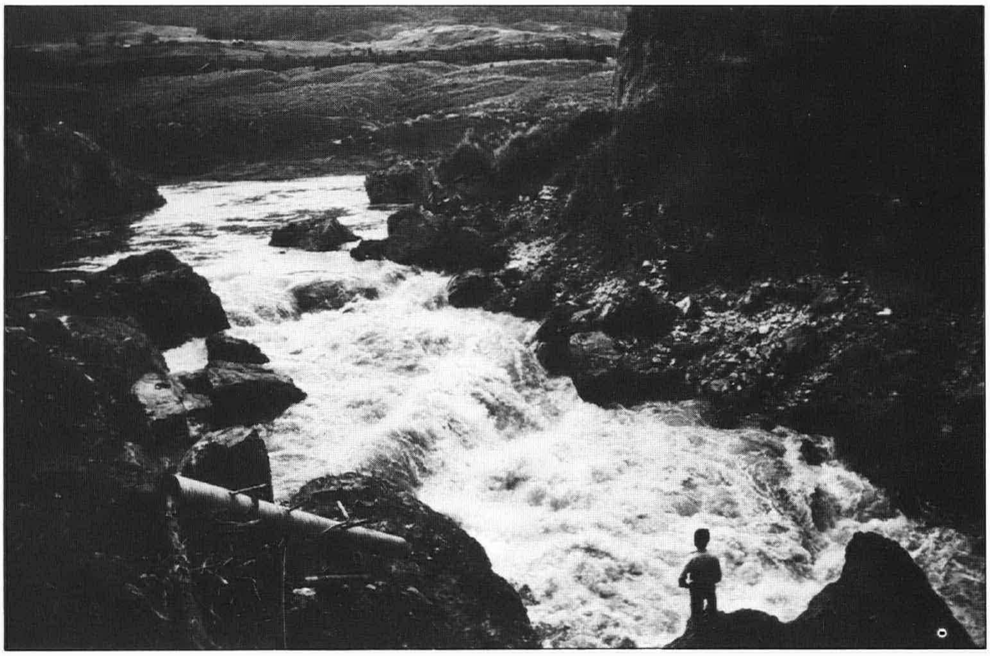
Vegetation marks the backing up level at the Baliem River sink (T. White)

There were several ways of approaching the sink. The nearest airstrip is at Kwiyawogwi, three to four hours walk away. The path down the broad valley of the West Baliem is far from the river. It crosses the East Baliem over a thirty metre long rattan suspension bridge and, rather than follow the course of the river, rises over a hill from where the view west stretches to the distant twin peaks of the Carstenz mountains. To the east it drops rapidly through forest into the blind valley where the Baliem disappears.

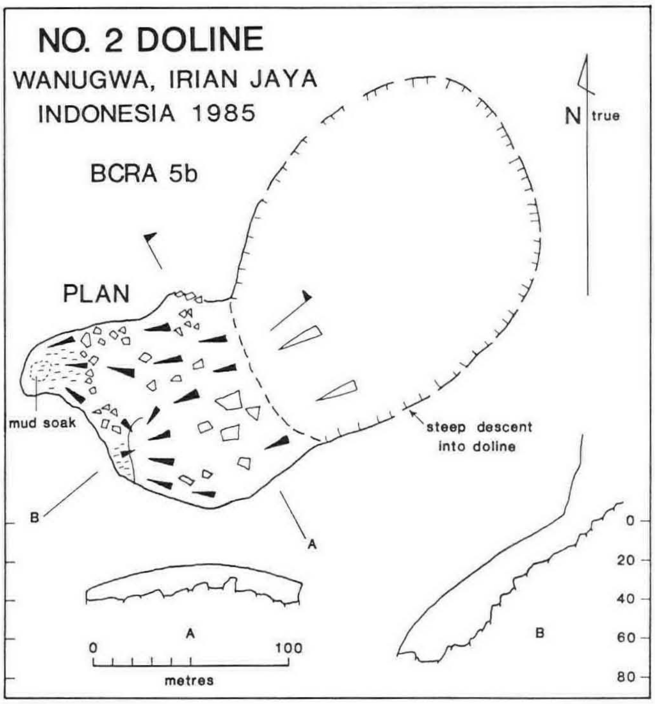
The forest ends at a distinct line well above the river indicating severe backing up, and to the south agricultural clearing has caused the forest to recede further. A few corrugated-roofed houses and many Dani huts and compounds overlook the sink. They form the village of Wanugwa.

The river was very fast flowing and a very rough estimate of its flow at 100 cumecs was made that day. It roared down into a huge swirling pool, then dropped a few metres more, crashing, foaming, spuming into a vertical cliff where it was sucked in completely. No place for the kids to play! Light rain that night caused the final rapids to back up into one huge lake. If a negotiable entrance exists it would have to be in the flood sinks, and we wandered around those like ants in a match factory.





Part of the Baliem Sink (T. White)



At the very end of the valley an obvious white scar in the forest marks a more ancient sink which was looked at quickly, revealed nothing, but might merit a more exhaustive examination.

To the east and north, between sink and resurgence, the forested high ground contains several large dolines and many smaller features. Two of the larger dolines were descended. Both had collapsed caverns in the bottom which descended to mud soaks. Part way down the first doline a more complex, phreatic developed cave led off. It carried no draught and seemed unpromising.

The resurgence was as disappointing and awe-inspiring as the sink. The river emerged from beneath a bouldery tree-covered hillside and built up gradually to a ferocious torrent. The forest could have concealed a fossil rising but there was no time available to search.

It is worth putting more effort into entering the Baliem River Cave. The river is underground for about 4 kilometres and descends perhaps 300 metres at a rough guess. Unless extensive collapse has caused the river to back up inside the cave, it could be one of the world's most exciting river caves.

Dimba

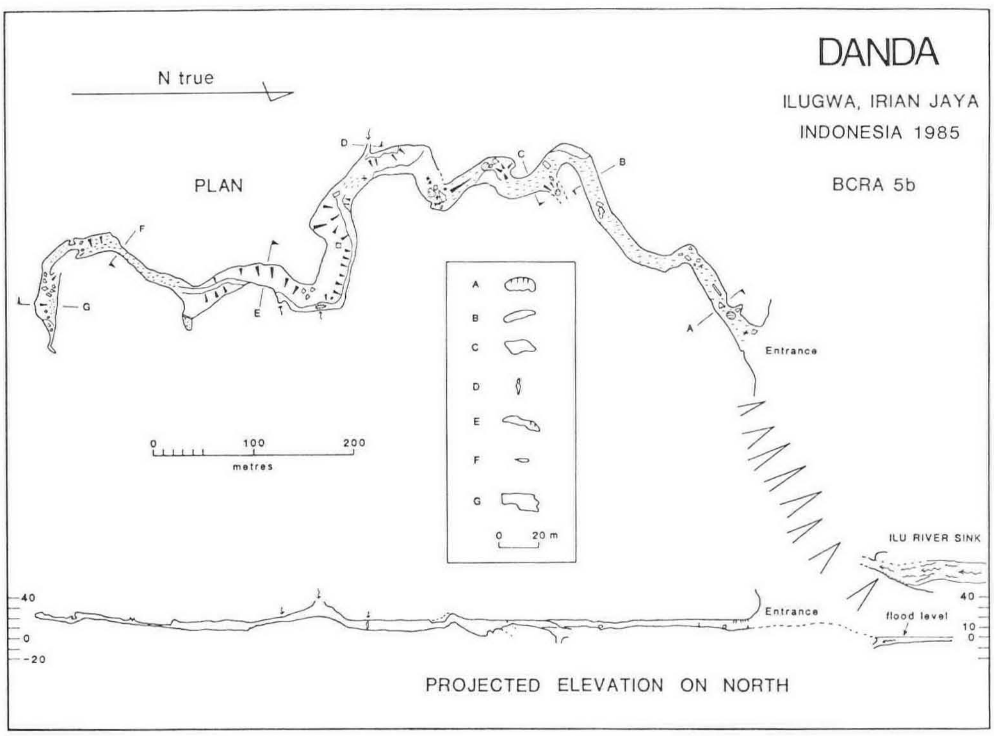
This was to the north extremity of the limestone massif and the area where local missionaries had reported underground rivers and caves. In the event, little was found, although some small caves were looked at and certainly there were sinking and resurfacing rivers, but nothing was large enough to enter. The area lacked large outcrops of limestone and shale and sandstone was evident from the surface features. The walk over from the south however took in some spectacular countryside and two of the world's finest glacial erratics, being chunks of sandstone the size of blocks of flats, sitting on shale or limestone basements.

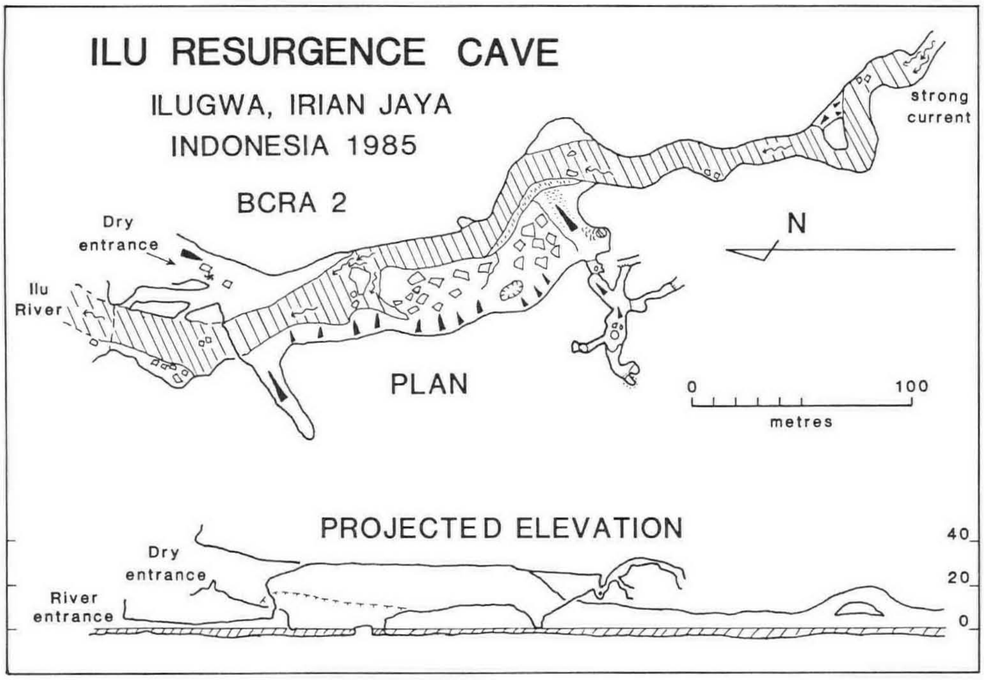
The Ilu Valley

This valley, 30 km north of Wamena, contains two airstrips at the villages of Ilugwa and Wolo which are a mere two to three hours apart. The river flows west off the mountains and sinks in the entrance to a wide limestone gorge below the Ilugwa airstrip. When first visited at dusk, the river of roughly 5 cumecs cascaded down into a 4 m wide by 2.5 m high cave but was not explored because of encroaching darkness. It was never explored, since the next day the river had risen backing up to a depth of 10 m at the entrance. It is unlikely that the exploration will be very rewarding, although for afficionadoes of mud and rotting vegetation it could be exquisite.

Just a few hundred metres into the gorge an alcove, partly concealed behind trees, contains the entrance to Danda, a cave well known in the area. Large knarled stalagmites and stalactites in the entrance give the cave an ancient feel. The dark muddy walls and floor add gloom. 350 m inside, a passage on the left descends from quagmire to worse, then to an undescended drop with the sound of a river at the bottom. When the sink was flooded this underground river obviously rose and the cave was filled with a hush.

Along the main passage lay steep slippery slopes and pools best described as "quickmud".

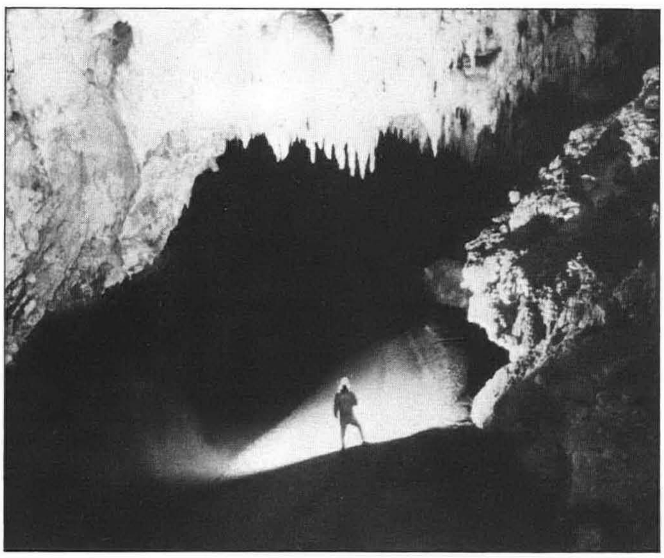




Footprints and burnt sticks proved that these had all been negotiated by intrepid locals using firebrand torches. They had turned back at a hands and knees crawl 700m from the entrance, and there probably not by the cave but by the smoke from their torches. The silence was disturbed by water falling from the roof in three places and the cave finally choked about 1100m from the entrance. A few side leads were not explored, because our surface guides would be waiting anxiously at the entrance. In fact this was not true. They had organised a rescue party and, as the smoke indicated, were already well into the cave.

Continuing from Danda along the gorge some entrances are passed which are of little interest. However one of the tracks from Ilugwa down into the gorge passes beside two 10 m deep pots with a stream flowing at the bottom. The water can be followed upstream to a sump and downstream for 400m along a wet sporting passage with two skylights to a 3m climb down followed by an exit into the gorge. This resurgence is known as the Kali Wini. To the north of there the Ilugwa to Wolo road crosses a stream, the Ilak, flowing on mudstone, which hits the limestone 100m below the bridge and sinks into a 10m deep pot. This may be the source of the Wini.

The dry gorge upstream of Yogoluk (A. Eavis)

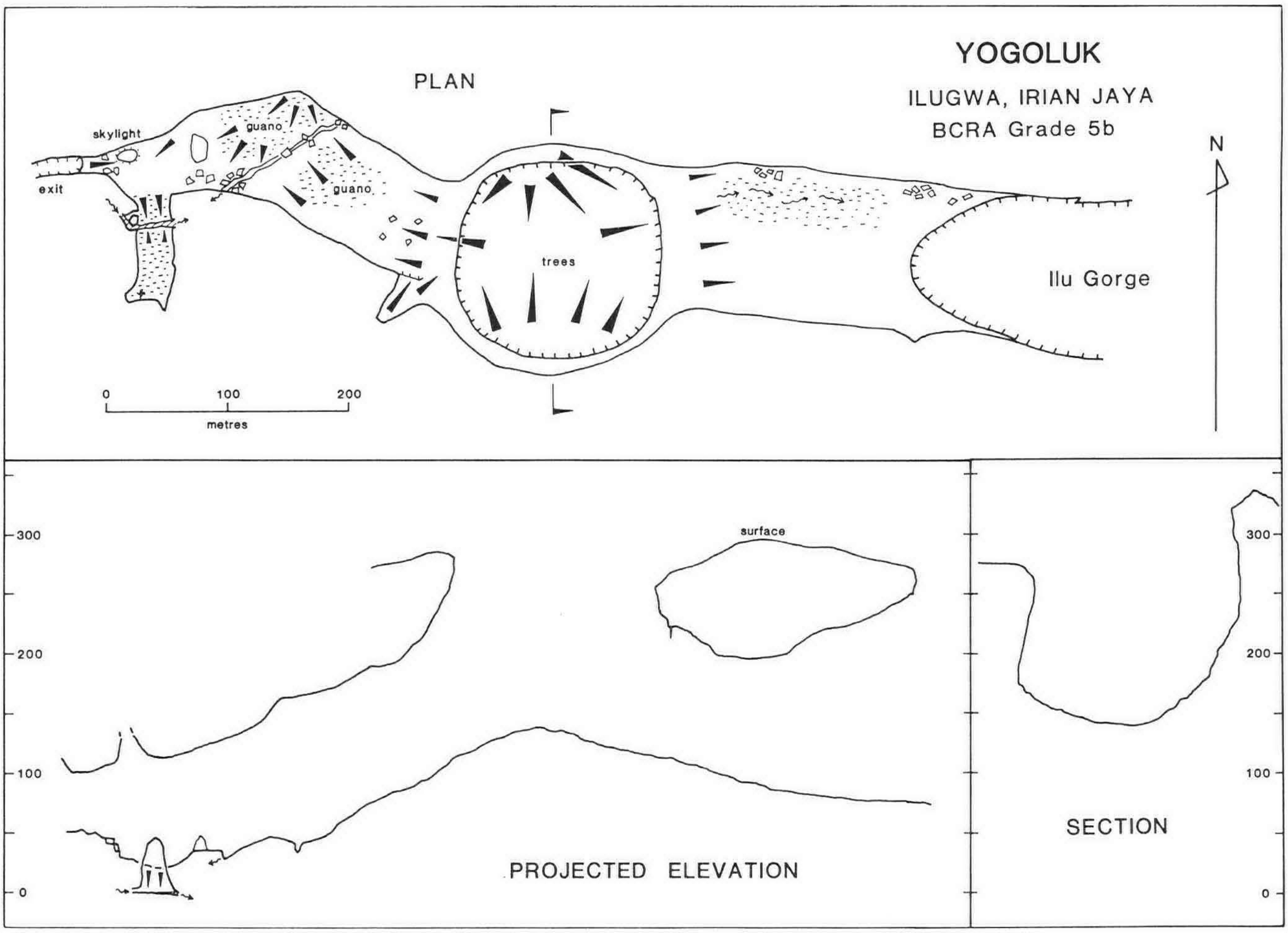


The Ilu resurgence cave (T. White)

Following the gorge for a kilometre further you enter the amazing arch of Yogoluk. The roof of a huge cave passage has collapsed to leave an enormous archway on one side and the continuation of the cave on the other. The cave is short. It descends steeply into a large cavern decorated with multicoloured walls and mounds of guano with a stream crossing the chamber at the bottom. An exit leads out into the valley to the west and a mud slope goes down into the only dark region of the cave where a second stream crosses the passage and clearly backs up in wet weather.

To the west of Yogoluk the ground falls steeply into a dry valley. It curves down to the Ilu river which enters the valley from a resurgence on the south side. Near a village just further down valley is a small rising, the Komenga, under the north hillside. The water may come from the Gua Kwalinga, a deep surface sink near the Ilugwa to Wolo road. This open pothole and two nearby shafts were not descended through lack of time. One of the dry shafts was said to contain the bodies of two Dani who had been murdered and thrown down.

The Ilu resurgence can be entered either by the river entrance, preferably by boat, or by a dry entrance which opens out over the river at

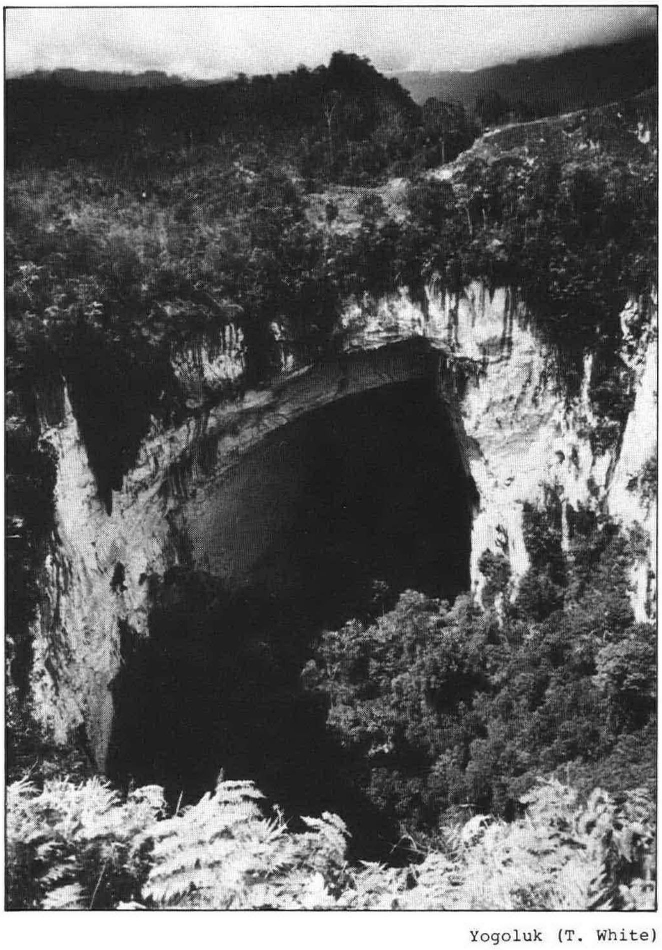


three places. At the main balcony it is possible (as demonstrated by the locals) to climb across to the other side and so completely avoid the water. This is far easier with a light! The high and wide boulder filled passage eventually stops, leaving two alternatives. One is a small switchback passage up on the right which led to a drop (not descended). The other is the main river tube which has fast flowing water from wall to wall. Progress by dragging oneself along the brittle walls seemed the best approach, with a frantic paddle across to the other side wherever the current on one side proved too powerful. After about 200m of this, just beyond a section where stalactites stuck up in the water ready to sink any passing boats, the river itself proved too much. It rushed out of a passage about 6m wide and the current was far too strong to paddle against.

It can be seen from the area map that the Ilu river near Danda must head south and west a long way to emerge from the Ilu resurgence. The connection is only assumed and the estimated flow at the resurgence was twice that of the sink. It seems likely that additional drainage is provided from the high ground to the south of the valley. If so then there is potential for a fairly deep system. However no surface drainage was seen in that area and the terrain appeared to be difficult to move around in, so discoveries might be hard won.

Pass Valley

The flight from Jayapura to Wamena usually goes through the lowest gap in the mountains into the Baliem Valley. From the plane a number of big holes can be seen and the whole of the area is undoubtedly limestone. Two of the big holes were checked out; both were about 50m deep, 2nd could be free-climbed but had no passages at the bottom. There was very little surface drainage, although in places a river could be heard. It appears from



Yogoluk (T. White)

aerial photographs and talking to locals that there is a stream that sinks and resurges a number of times going towards the south-west, eventually resurging into the Baliem River. At its lower end it is enterable and local people have been inside for some distance.

East of Wamena

Immediately to the east of the Baliem Valley is a vast area of classical cone karst. It can be seen rising from the valley and in low sunlight looks quite impressive. It is riddled with small caves, large dolines and sinking and resurging streams. The obvious doline seen from Wamena is 50m across with a 40m free descent to dense vegetation. A slope continues down for a further 40m to a choke which is typical of this sort of feature.

THE PEOPLE

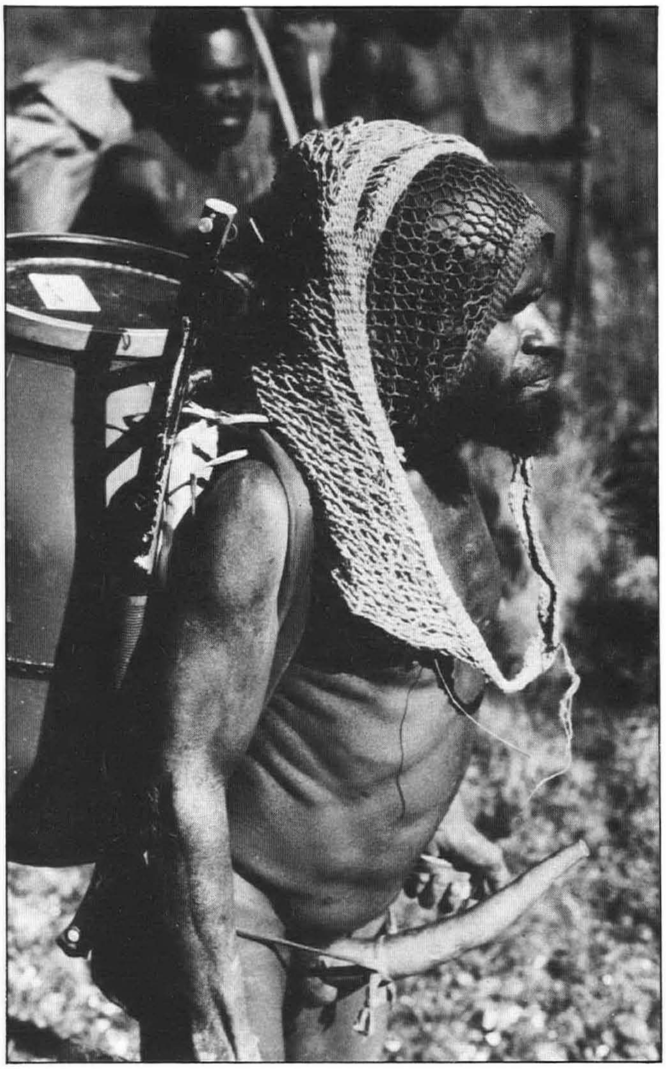
Despite more than a century of Dutch occupation and contacts by a few climbing expeditions to Trikora (then Mt Wilhelmina) the Grand Valley was virtually unknown to the outside world and was not entered until 1938 when the Archbold expedition landed a plane on the Baliem River. Despite the publicity it received Christian missions did not settle there until 1954, but in the six years following spread to many outlying villages. Since 1963 however Irian Jaya has been administered from Jakarta and an extensive township has developed at Wamena with Javanese very much in evidence in the form of police, military, traders and various administrative bodies.

The entire Baliem catchment area down to the Baliem Gorge is inhabited by a language group called the Dani. This is split up into the Grand Valley Dani and the Western Dani who speak different dialects. The people across the watershed to the east including Pass Valley and to the south of the Gorge speak a different language again called Yali. Many of the locals have learnt to speak Indonesian and this would seem to be the most useful language for visitors to know.

The Dani continue to live in hamlets divided into several compounds with mens' house, family houses and cook house within a fence. Western style and individual family houses did not catch on - they were too drafty and cold - unlike "real" houses. Where built they tend to be used for storage, miscellaneous functions and for visitors, when they become the most popular houses in the village.

Western influence in other respects has been dramatic. Steel implements have improved the efficiency in clearing the land, cutting timber and agriculture. With extensive irrigation systems and the introduction of exotic vegetables has come the ability to produce cash crops. The influx of outsiders has created, a diverse community with a cash economy and the desire for western goods. Organised markets now exist. Livestock farming extends beyond pigs which are reared more for their social significance. However the dietary change on the Dani has so far been small compared with the present variety of foods, peanuts constituting the most fundamental addition.

The result for the visitor to Wamena is that he is well supplied with a market for meat and vegetables and many stores for virtually all tinned and prepacked foodstuffs. Outside Wamena some large villages have a trade store but with very limited choice. Out of the Grand Valley and especially up high farming is for subsistence. Therefore supply may be restricted or else people may sell food and go hungry themselves. Cabbage and potatoes were usually available and sometimes eggs, chicken, sweet-potato, taro and bananas. In the high ground the Dani hunt at night and may return with possum, tree kangaro, echidna or even cassowary.



Well dressed Dani porter (T. White)

Manpower is plentiful but the Dani treat work and the procuring of wealth like many other things: for its social prestige and the good of the community. They are happier and more willing to work as a group than as individuals and only so long as it fits in with the community. The visitor can therefore be frustrated by an inexplicable lack of labour, or buried under a persuasive surplus.

Access

Visitors to Wamena must be in possession of a Surat Jalan issued by the police at Jayapura, but passage beyond Wamena is still at police discretion. Practical access to the area is by air only. There are charter flights from Sentani into Wamena and daily scheduled flights in small aircraft. In the mountains many large villages have grass strips and 4 to 6 seater planes can be chartered. Some planes are fitted with an anchor on the tail to dig into the ground should the runway prove a little short. Vehicular roads exist in the Grand Valley and very locally in some of the larger villages. Elsewhere you are on foot, but good footpaths connect all villages. There are many hunting tracks giving access to the high ground but travelling across the limestone can often be exceedingly slow and difficult.

SUMBA

We were told of Sumba by Dr R Ko of FINSPAC Indonesia, who believed it held considerable potential for cave development. He was correct and we were not disappointed.

We flew in to Waingapu, the capital of the eastern half of the island and travelled via Waikabubak to Bondokodi in the far west, looking for caves. We were not able to cover the whole of this western part of the island in detail but the areas we visited are marked on the map below. We did not plan to visit the east of the island.

LANDSCAPE

Waingapu is the major port for the island and is placed on the coastal plain. This is a wide flat strip of land between two and twelve kilometres wide, encircling the majority of the island. This strip consists of rolling grassland with deeply incised tree-lined river gorges cutting through it. A complex dendritic pattern of shallow dry valleys breaks the upper terraces. Many of these valleys carry streams only in the wet season, although resurgences supply some of them. Resurgences are found from sea level upwards.

Climbing up from the lower terraces the level of the large flat plains (400-500m above sea level) and their surrounding low hills, is reached. In the east this is largely grassland, but further west where the rainfall increases, more woodland is encountered.

There are three main flat basin areas. The most easterly is around Lewa and is bounded on the east, north and south by low hills. On the west the Kadassa river gorge forms the boundary between this and the next basin area. A climb over low wooded hills and steep descent leads to Anakalang, situated at the centre of the second plain. Here the most extensive grassland and paddy area is to the south and ends with the low hills of the South Coast Mountains. To the north, rolling hills, wooded in part and cultivated in the hollows, extend for about 10 km before descending to the more open grassland of the dendritic dry valleys, nearer the coast.

Waikabubak is the capital of the west of the island and it lies at the eastern end of the third plain. Only a small hilly area divides this region from the flat lands of Anakalang. The most extensive flat region is to the west of Waikabubak and is extensively cultivated as paddy. To the north, on the road to Memboro, after an initial climb there is further flat land. Much of this area is heavily wooded and further west the road to Bondokodi passes through endless small hills littered with lush vegetation and dolines. To the south of Waikobubak, more arid grassland and low hills are followed by a steep descent to the coast. This is an unspoilt, varied and beautiful island, inhabited by a happy people.

GEOLOGY AND GEOMORPHOLOGY

The oldest pre-Tertiary rocks are in the South Coast Mountains. These slates and basalts were subject to pre-Tertiary folding and intrusion. During the early Tertiary there was a period of marine deposition of limestone, followed by slight folding and tilting, then erosion. Volcanic activity in the Jawila Mountain region followed, and subsequently marine deposition, associated with the Quaternary North Coast Terraces.

Western Sumba may be considered as eight geological units:-

1 The North Coast Terraces

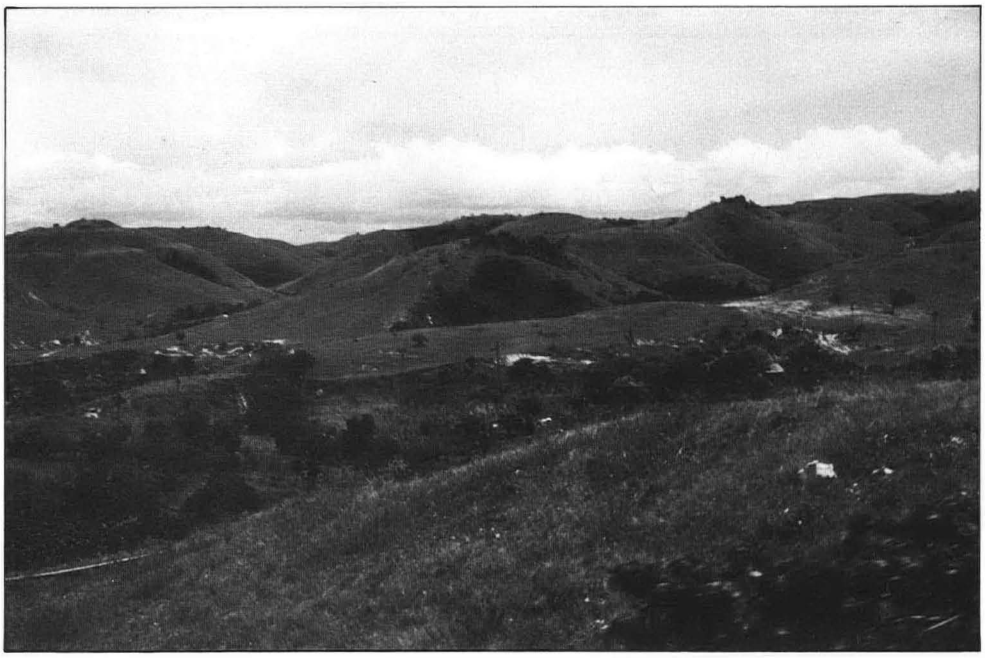
These terraces are typically in steps of 100 metres, 100 to 300 metres, and 500 metres, above sea level. Geologically the most recent formations, these Pliocene coral limestones extend well inland, particularly in the far western Kodi and Rara regions. The upper terraces are not so distinct in the far west and they are generally heavily eroded. Massive limestone beds typically up to 5 m thick are interspersed by beds of limestone and conglomerate.

2 The Lewapaku Plateau

This is the most extensive of the three large flat limestone land masses in Western Sumba. At approximately 500 metres above sea level it is a flat cultivated region of Pliocene limestone, lime marls and tuff marls, surrounded by rounded limestone hills up to 100 m high. This region has a large polje and also contains cone karst. The limestone is up to 500 m thick, and lies unconformably on dipping Miocene beds.

3 The Tandaro Mountains

These are the highest mountains in the region reaching a height of 913 metres above sea level. They form a 15 km long ridge of granodiorite which is bordered by slates, quartzites and silicified eruptives in the south and east. To the north the Waingapu series, and to the west the older Miocene limestone overlay the granodiorites.



The coastal plain of Sumba
(D. Checkley)

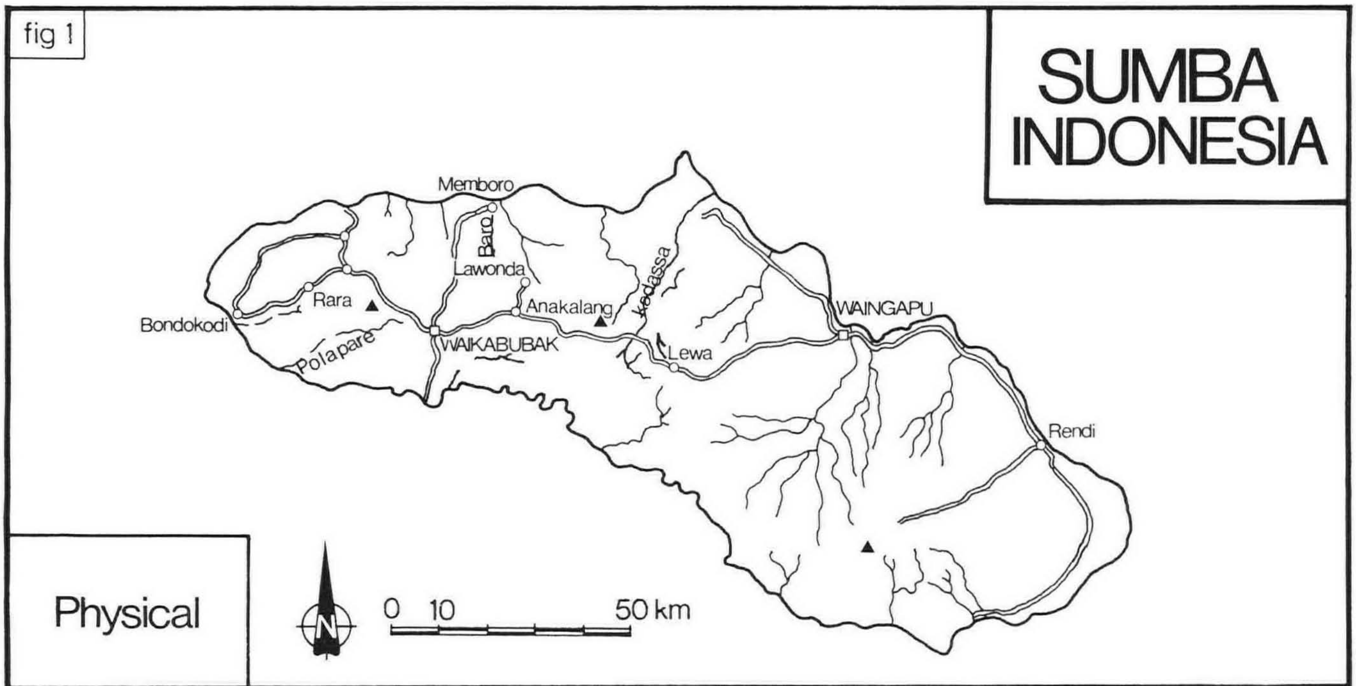


fig 1
SUMBA
INDONESIA
Memboro
Baro
Lawonda
Kadassa
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Anakalang
WAINGAPU
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Polapare
WAIKABUBAK
Lewa
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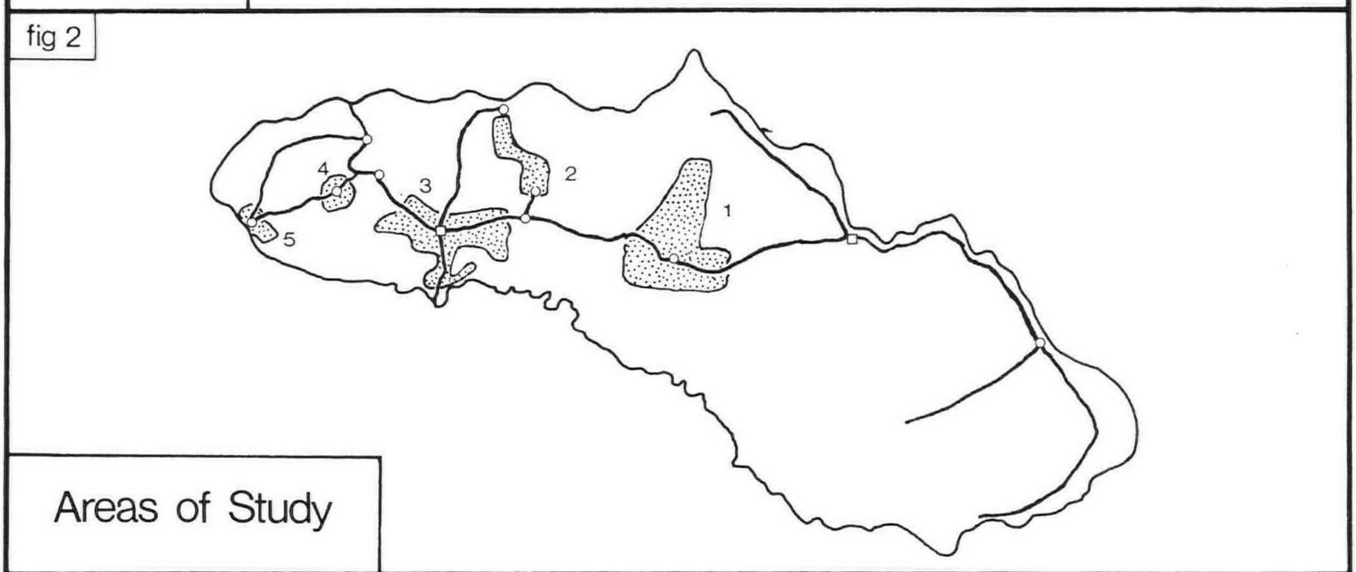
fig 2
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Areas of Study

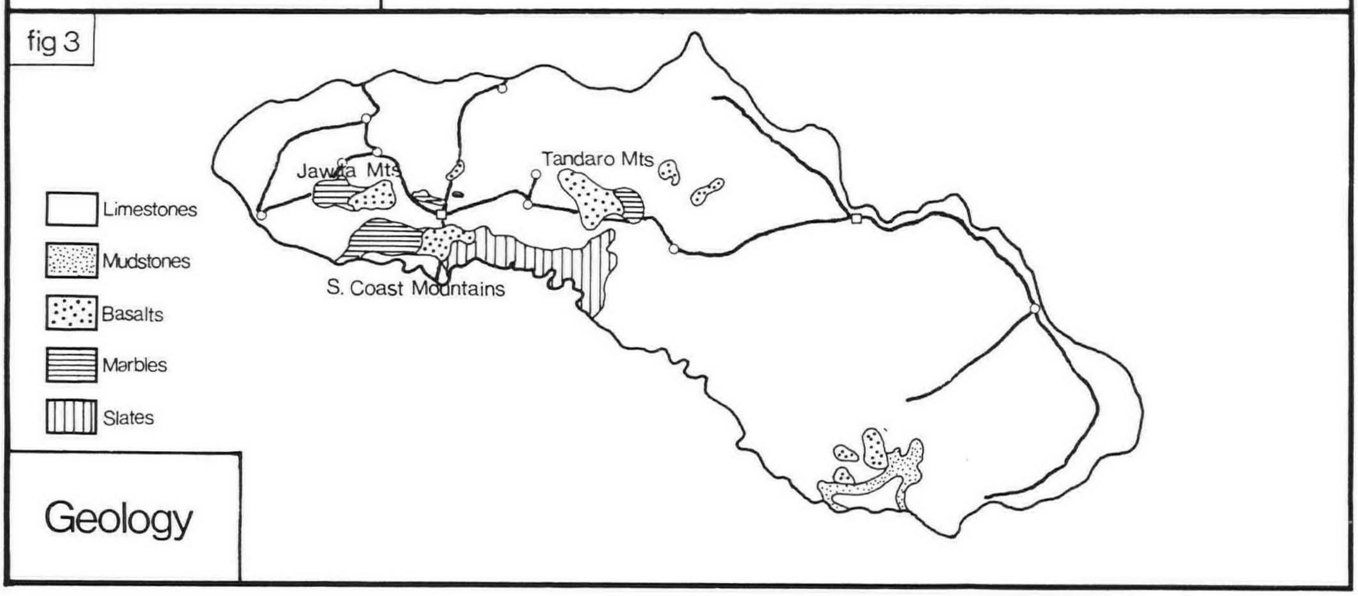


fig 3
Tandaro Mts
Limestones
Mudstones
Basalts
Marbles
Slates
S. Coast Mountains
Geology

4 The Anakalang Plateau

This plateau, on the Waingapu limestone series, slopes gently south to the coastal mountains. It also contains a large polje.

5 The Maderi Region

This area of low, wooded or grassy hills north of the Anakalang Plateau is in the older more massive Miocene limestones. The extent of this region is approximately 14km by 9km.

6 The South Coast Mountains

The eastern part of these 60km long mountains consists of intensely folded slates with some gabbro and dolerite intrusions. These beds may be up to 1000 m thick and also include quartzites and sandstones. The slopes of these low mountains (generally 500-600 m) contain deeply incised, steep-sided valleys. The slates are overlain to the north and south by the Waingapu limestone series. The western South Coast Mountains consist of younger basalts and Miocene tuffs.

7 The Waikabubak Plateau

This is the third large polje on the Waingapu limestones incised to the west by the Polapare River valley.

8 The Jawila Mountains

This 15km long mountain range consists of Miocene basalts and tuffs, which reach a height of 888m. These beds dip beneath the Pliocene limestones which surround them.

HYDROLOGY

The low hills to the east of the Lewapaku polje drain via caves into the plateau, however the principal drainage from the plateau is to the north. The large Palawundut river sinks into a deep flooded shaft in the floor of the plateau 4km north of Lewa. It is assumed to drain northwards. In the low hills on the northern edge of the plateau a number of rivers drain to the sea. Only one of these is known to have an associated cave feature, Gua Patamawai. The other rivers run through gorges on their steep descents to the coastal plain. The most significant gorge contains the Kadassa River. This drains much of the south-western part of the Lewapaku plateau and the eastern South Coast Mountains. It was followed for one day south of where the road crosses it, but no resurgences were noted in its banks. Nearer to Lewapaku, Kadassa tributaries are carried in the caves of Kanabu Wulang and Lai Yadi.

The Anakalang polje drains southwest and the resultant river eventually sinks in a large cave, which was not explored. A spectacular resurgence for the plateau appears at the unconformity with the shales, half way up a cliff north of Wanokaka. This was impenetrable due to the force of the water. The Maderi region and north of the Tandaro Mountains drain north to the sea by the Kalada and Baru rivers. The Maderi region contains many small sinks and caves. The Baru runs over limestone, at times in spectacular gorges, all the way to the sea. There were no significant cave features in the gorge.

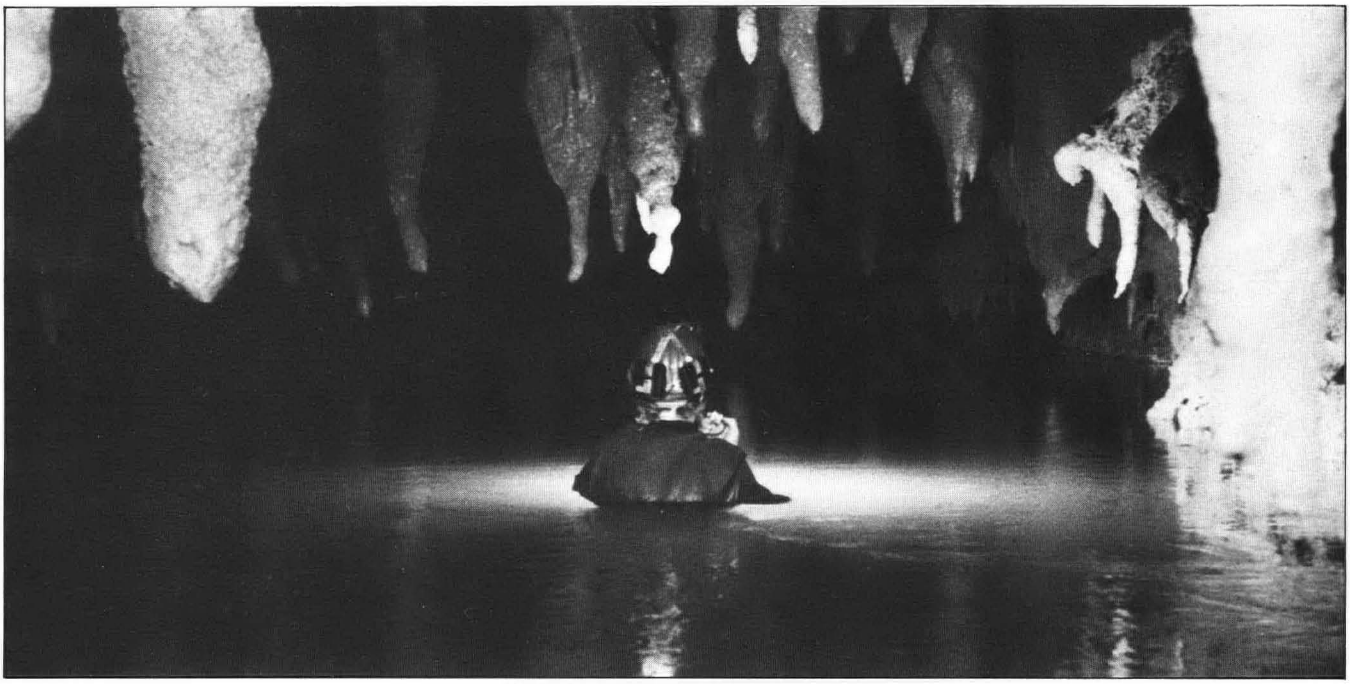
The principal drainage of the Waikabubak region is west to form the Polapare River. This river runs underground for 600 m in the magnificent Gua Kamedeta Paunnu, on its way to the sea. A major tributary for the Polapare comes from Gua Waikelo Sewah. This resurgence cave must drain much of the hilly area north of Waikabubak and a large river cave is known to exist in this area. This wooded area contains many small sinks and dolines.

The southern Jawila Mountains drain to the Polapare river in part by many small sinks and cave systems such as those at Mare de la Collada. However to the north, the Bondokodi river takes the water west to Kodi and the sea. Several active sink caves are associated with the tributaries to this river in the Rara area.

Water shortage is generally a problem on the island in the dry season. It is particularly a problem in the east where the rainfall is less than in the west. We visited the island at the start of the dry season and even then the north coastal terraces were very dry. However in the three poljes, which form the centres of population, away from the coast, water was available from wells. These wells were often shallow (6 m) and provided good water throughout the year. In the plateaux, water was generally close to the surface and any caves were normally completely flooded. At the edges of the plateaux, water was markedly deeper, up to 60 m beneath the surface.

CAVE EXPLORATION

The majority of the cave systems explored on the island were active river caves. They frequently ended in sumps and rarely contained high level abandoned passage. The resurgences Waikelo Sewah and Kanabu Wulang were the only



Gua Lai Yadi (D. Checkley)

caves to significantly show this latter pattern. We therefore consider the majority of the caves to be relatively immature. This conclusion may however partly reflect our approach to exploration. River caves, as important sources of water for the local people, were often well known. Cave exploration for birds nests was common in the west, but infrequent in the east, where some caves once served as burial sites. People knew virtually nothing about regions more than one day on foot away from their houses and in remote areas, well away from the tracks and roads, no local information was available. Given our limited time on the island we adopted two basic approaches for our reconnaissance. We visited sink and river features found on our maps and we asked the local people. The latter approach was the most profitable and teachers, followed by bird's nesters were our best contacts.

Bird's nesters had been into the majority of the caves we surveyed. They often climbed down deep shafts or high into the roofs in daring escapades on bamboo poles or lianas. Safety was not their strong point as evidenced by the two bodies we found. We hope that we taught some of them new and safer techniques. Bird's nesters took us to a number of large old, truncated phreatic caves as well as the active systems. These were apparently common in the low hills in the east, surrounding the Lewapaku plateau. They were truncated by collapse or down-cutting of the now flat-floored valleys and must be considerably older than the active systems.

In the woody hills of Maderi and in the drier hilly grasslands east of Lewapaku, small sink caves were common at the bottom of dolines. These often only contained streams when it rained and frequently became too tight. Occasionally a few sinks joined together to form a more sizeable cave system of an epiphreatic nature (Gua Watu Karamba Kondameha). These caves often had small shafts in their entrances. Blind shafts were also common. A number of deeper shafts led into large chambers with very little associated cave passage.

In the Rara region a number of large abandoned phreatic systems were found. These were not truncated and continued for long distances, but they did not have associated lower active levels. This area seems to be one of the most promising we came across. Unfortunately it was visited for only a few days at the end of the expedition and may otherwise have provided longer systems.

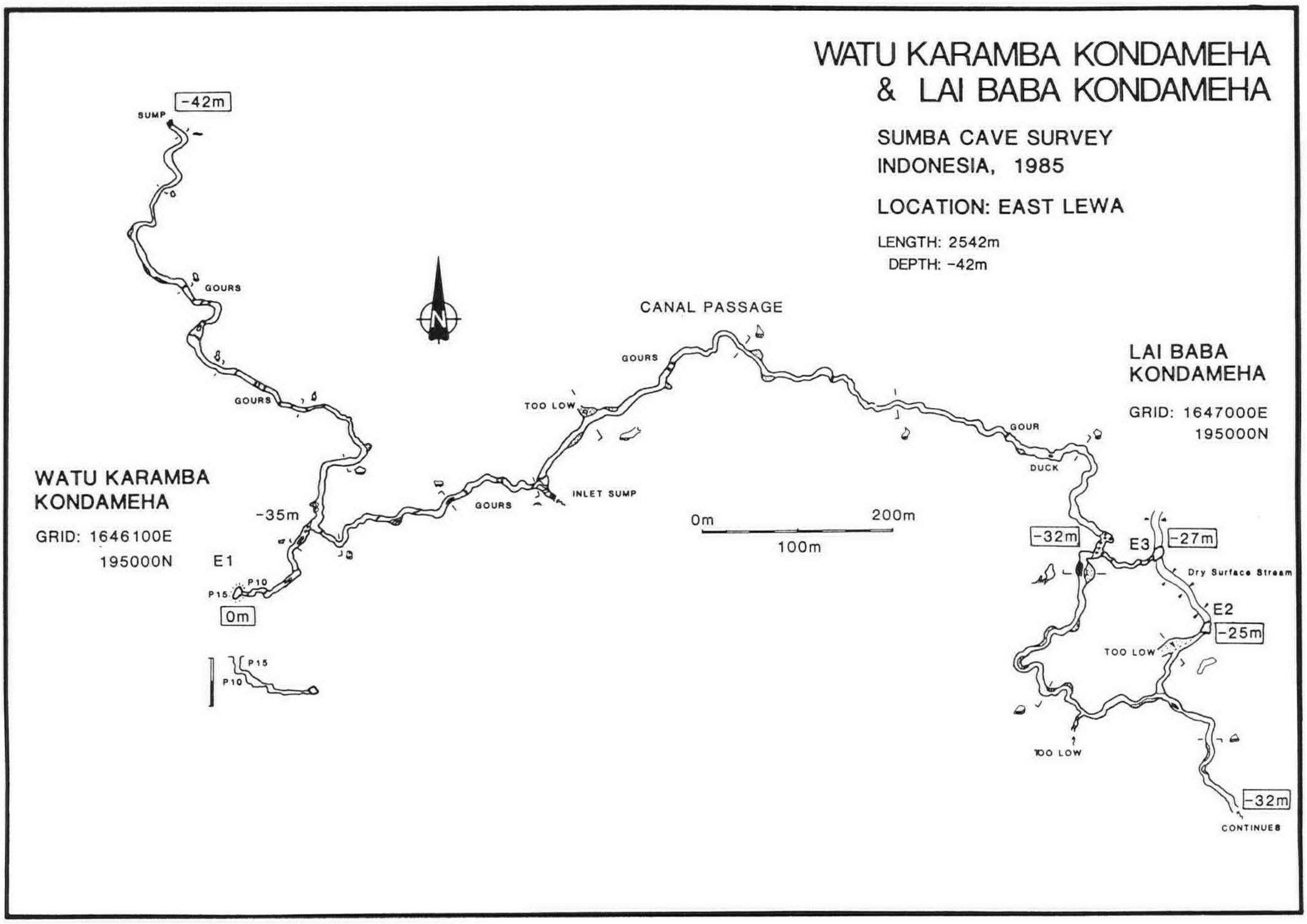
The caves were technically not very demanding, although some of the big rivers were not without interest. The rock was sometimes so soft that bolts could not be used, but natural belays were usually available. It is possible that we missed a number of the more promising areas and two come immediately to mind - around the north and west flanks of the Tandoro Mountains, and on the northern flank of the South Coast Mountains. We did in fact cover a very small proportion of the island in our four weeks there. It seems likely that if four of us can survey so much cave in such a short period of time, there must be many more caves to be found on Sumba.

AREA 1 THE CAVES OF LEWA

WATU KARAMBA KONDAMEHA & LAI BABA KONDAMEHA

Take the Waingapu road east out of the town of Lewa. After some 8km start rising out of the Lewa plateau region, and arrive at a milestone known locally as 'Kilometre 49'. The cave runs beneath the spur with entrances in both valleys, Lai Baba to the northeast and Karamba to the southwest.

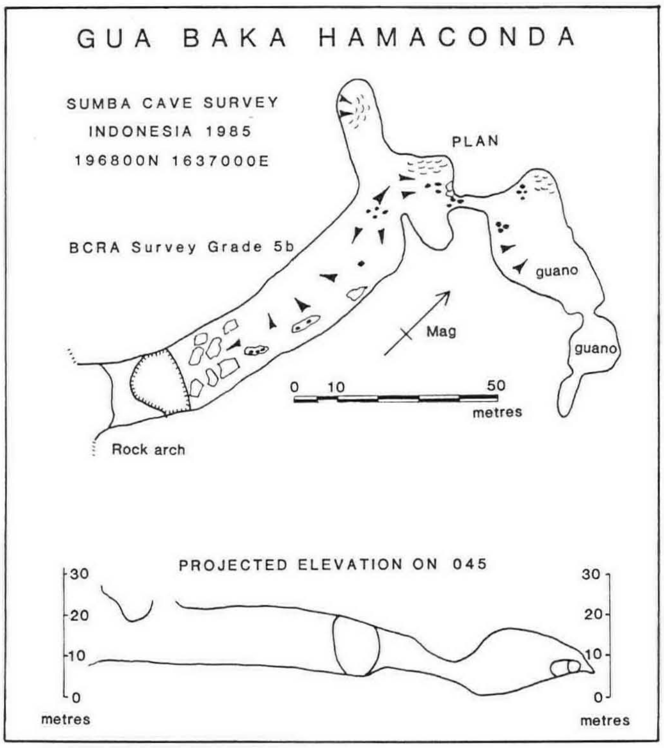
The top entrance E2 is found in a small crop of trees, obvious from the road above. The dry river bed must only take water in the main wet season. A low entrance drops down into a chamber. To the right a clean pebble-paved tube leads to



the river after about 50m. Upstream the river gets low. Downstream the river soon deepens. An inlet on the left goes for about 40m, past two sumps to a third which is longer. Traces of birds' nesters are still found 300m into the main river, with poles erected into the roof. The roof lowers to a duck by-passable to the right. Immediately after this the river sinks to the left, and a passage to the right leads to the second entrances of Lai Baba. Downstream the river is met again after a short crawl. A duck and swimming passage continues over gour dams, to a long canal. The third entrance route is met and the sporting final section leads to the sump.

GUA BAKA HAMACONDA

One kilometre along the road east of Lewa a wide paddy field is encountered. The wooded southern flank of the low hills on the western margin of the paddy contain this obscure entrance. A guide is required. An impressive arch lies in front of the entrance. A large guano-filled passage continues to a choke, and the cave is 192m long.

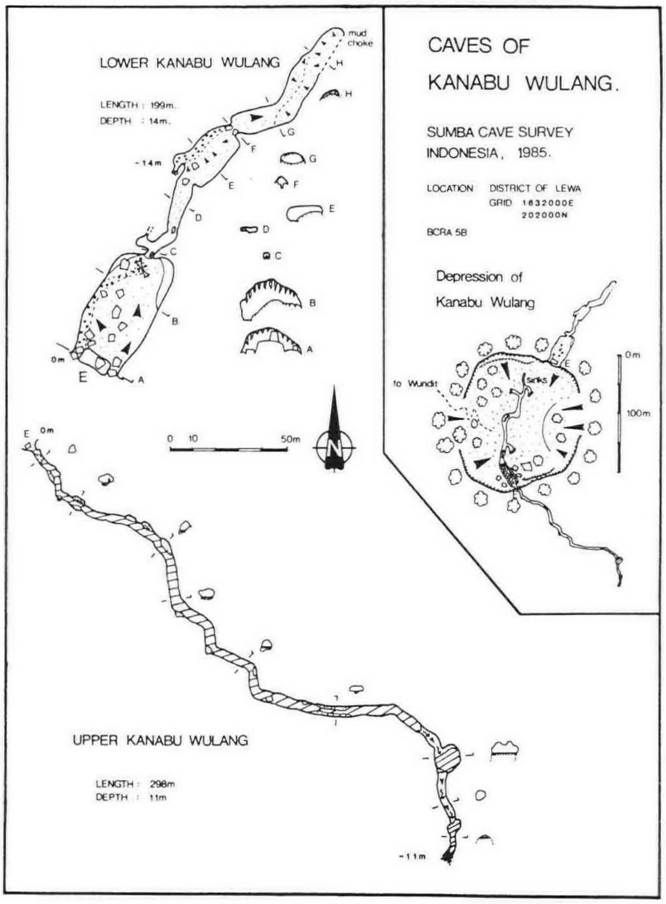


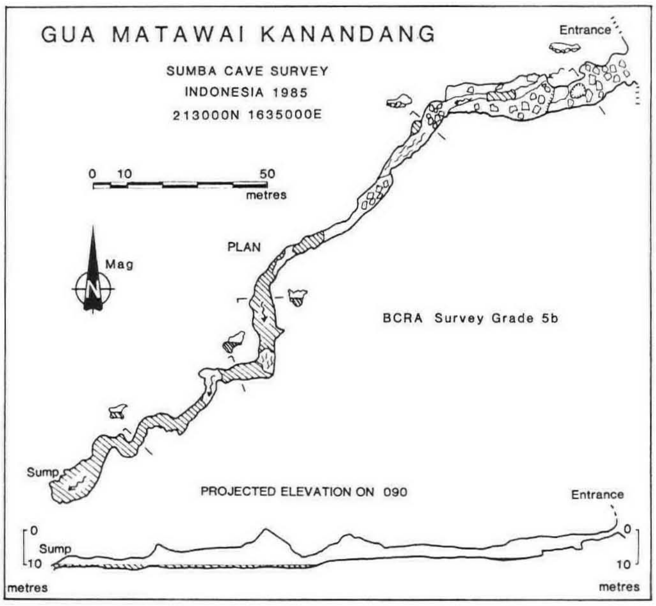
GUA KANABU WULANG (Fallen Moon Caves)

The large depression of Kanabu Wulang is 1km north-east of the village of Wundut near Lewa. Take the main road from Lewa to Anakalang, and about 500m past the track wundat, the road leaves the forest and swings west. Take a big track east from here, but after 300m head down between the tree to an obvious depression, the full size of which is not appreciated until the bottom is reached. A large river rises in the south corner from a choke and sinks in the lower northern end. There are two caves, one above the sink, and one above the resurgence.

Upper Kanabu Wulang enters above the rising and is a 230m long lake held by a gour dam. A ramp leads steeply to a large deep round pool, and then down a second ramp to a second deep pool. A duck leads to a small chamber above very deep water, and a second small duck leads to an airbell with no way on.

Lower Kanabu Wulang lies above the sink at the northern end of the depression. A large chamber full of flood debris and fruit bats leads to some low passages with one larger tunnel choking in revolting mud.



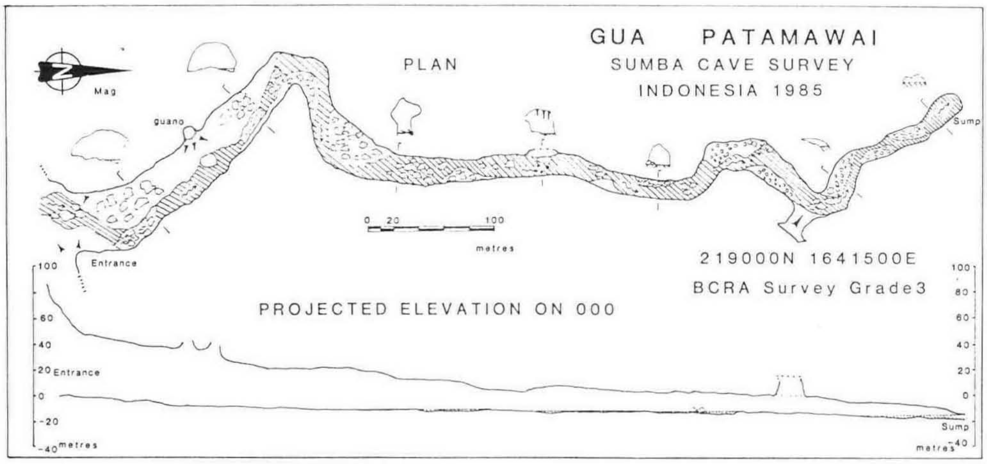


GUA MATAWAI KANANDANG (Cave of the Good Stream)

One day's walk north from Lewa is the village of Rakawatoe. The cave entrance is close to the village amongst the many dolines at the northern edge of the Lewa plateau and is obscure. A small stream is encountered just inside the entrance. Easy walking leads to a canal and final sump, after 231m.

GUA PATAMAWAI

This large river sink is obvious on maps of Sumba. The river drains the northern edge of the Lewa Plateau and is reached by walking for one day north from Lewa.



Follow the river downstream from the village of Pareharambua to the impressive sink. An alternative route is to walk east from the village of Rakawatu and abseil down the gorge side. The river of 450 l/s, sinks at the base of the cliff and flows into a 50m by 30m phreatic tunnel. There is a large, high aven with numerous birds' nests just inside the entrance. The cave gives 900m of easy walking, and the passage gradually decreases in size, until mud banks lead into the terminal sump. The resurgence was not visited.

GUA LAI YADI

Going west along the road from Lewa a path leads off on the left 500m past the 6km mark. This path leads down to the valley bottom and eventually arrives at the big river. Ten minutes along the bank is a house and clearing and 500m further a smaller one cumec tributary. This can be followed up to the entrance. This region is called Wundut.

The large entrance lies at the base of an impressive cliff, hidden by a boulder pile. Deep wading and swimming for several hundred metres, often in fast water leads to a choke. Climbing through the boulders the impressive second entrance, Liang Ajara, is reached. The way on leads via ducks to a sump. The cave is 614m long and 35m deep.

GUA LAMORECONDAMAHA

1 km east of Lewa is a small capped resurgence cave, 60m to a sump. The water is used for irrigation.

GUA DAPACONDAMAHA

Near Bakahamaconda there are two 60m long caves and several smaller ones.

GUA OCTAPANBAPANG

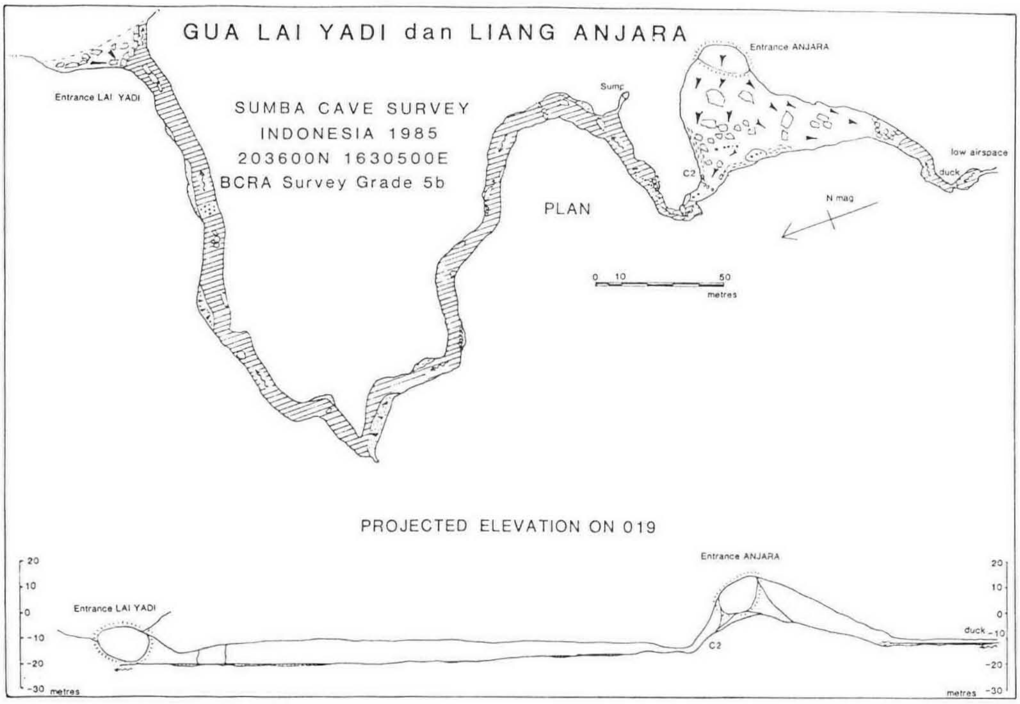
A large flooded cave 1km north of Lewa, possibly accessible in the dry season.

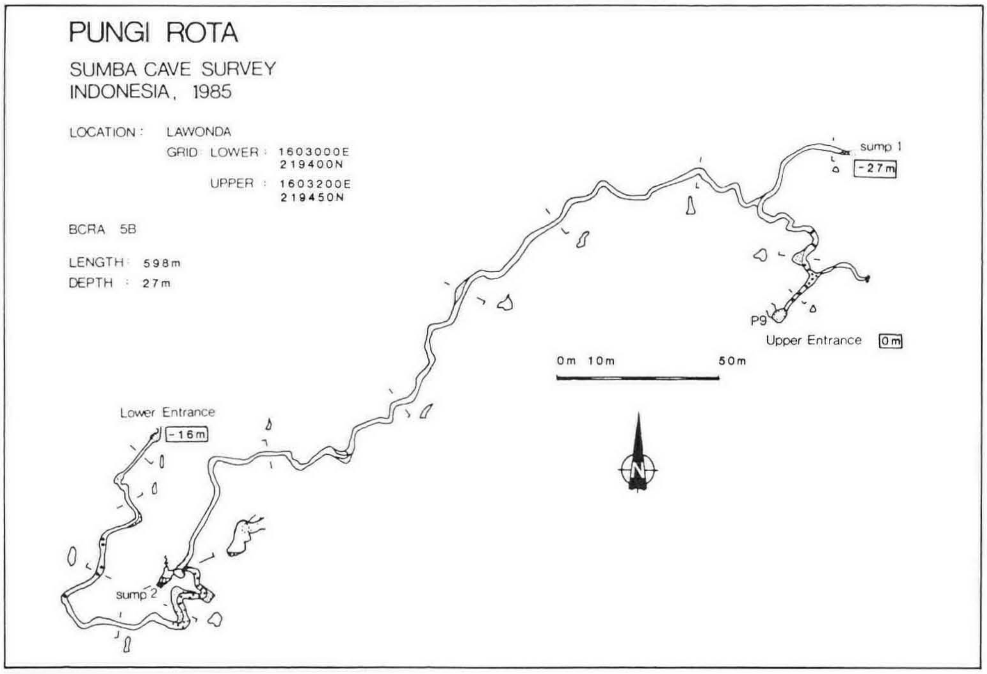
AREA 2 THE CAVES OF LAWONDA AND MADERI

PUNGI ROTA

Close to the village of Lawonda approaching from the Anakalang road, the caves are on the right about 150m from the road in a small group of houses.

A 9m pitch leads to a narrow vadose passage and a junction. Right chokes, but left winds down in old shattered vadose canyon passages. After 3 climbs down, a large junction is met. To the right sumps after another 30m, but left continues in larger passage to a pitch. Down the pitch sumps, but the roomy inlet passage leads to the lower entrance.





GUA PIDUWACU

Follow the track from Maderi north to Pondok for 3km. The shaft is well-known and is 200m from the second school on the route.

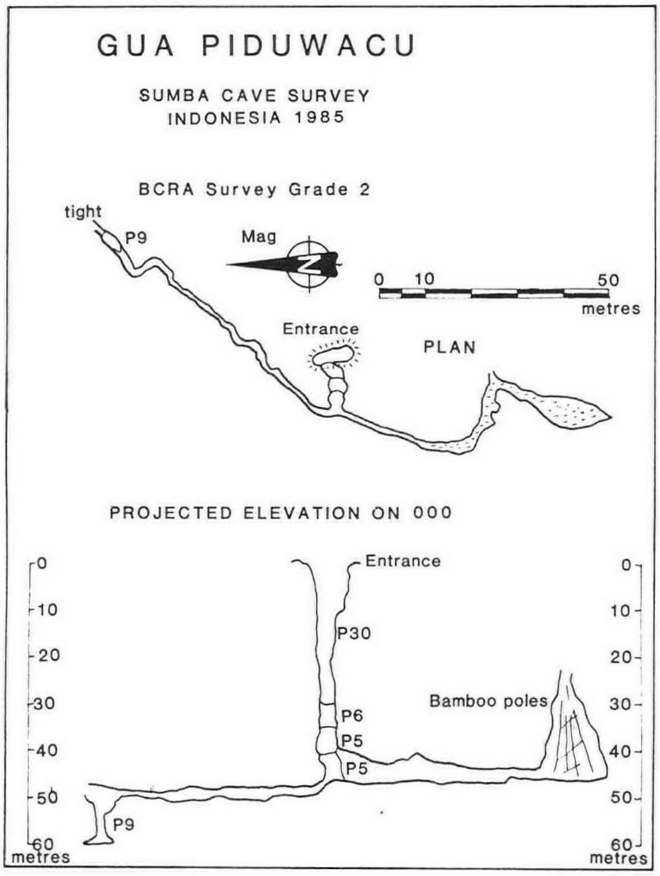
This pleasant open shaft is descended in stages for 46m to an abandoned vadose canyon. Upstream leads to a high aven with birds' nesters bamboo poles in place. Downstream becomes too tight below a 9m pitch, The cave is 173m long and 60m deep.

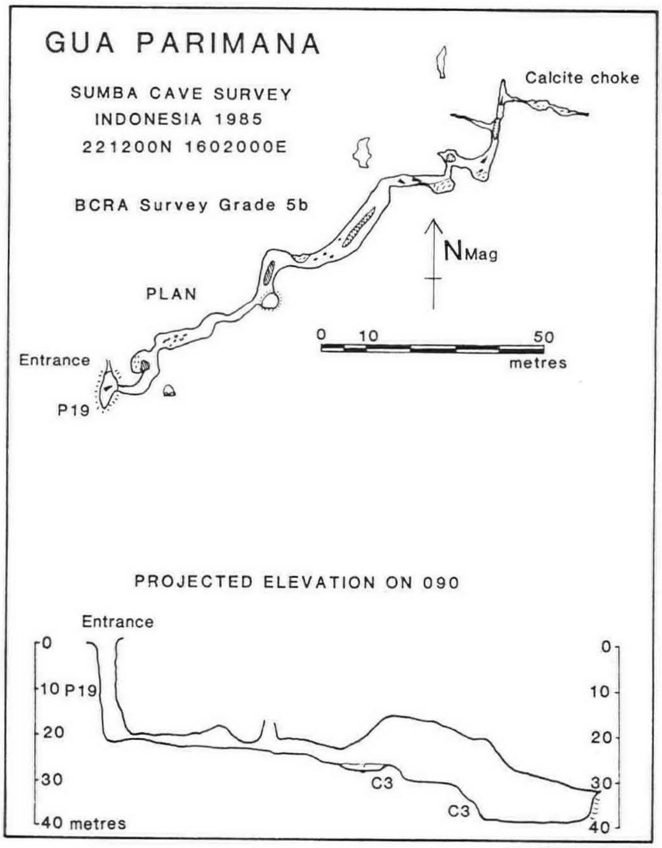
GUA PARIMANA

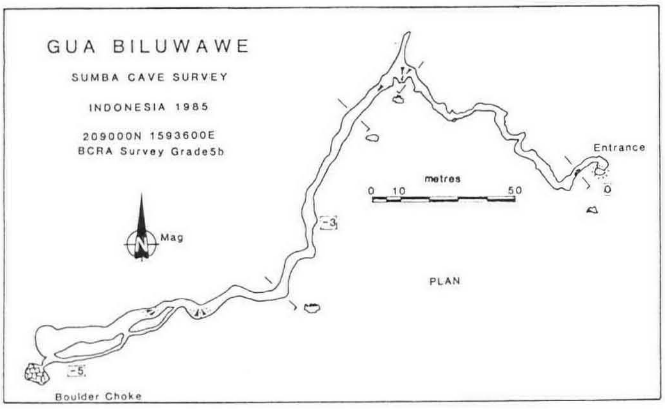
One kilometre along the track from Maderi going north to Pondok a series of dolines are reached. On the right in the bottom of a doline there is a small shaft. A pleasant 18m descent leads to walking passage, a squeeze and a final mud and calcite choke. The cave is 150m long and 40m deep.

GUA MADERI

Taking the main Pondok track north out of Lawonda, the village of Maderi is passed after about 3km. In the junctions of all the valleys beyond this there are sinks. The second junction contains the cave Gua Maderi. A small entrance leads to a very large chamber. The clean white pebble floor leads to a second large chamber with a large slope of flood debris and mud on the left. Behind this the passage drops into a very muddy sump chamber.







BONDOK

300m south of the village there is a sink into a cave containing a 100m swim to a sump.

AREA 3 THE CAVES OF WAIKABUBAK AND ANAKALANG

GUA BILUWAWE

Biluwawe is a small village 13km east of Waikabubak on the Anakalang road. A clear path on the right side of the road leads to a small hill with the village on top. At the base of this hill, leave the path and skirt around to the left. The entrance is down a short climb at the base of a small cliff.

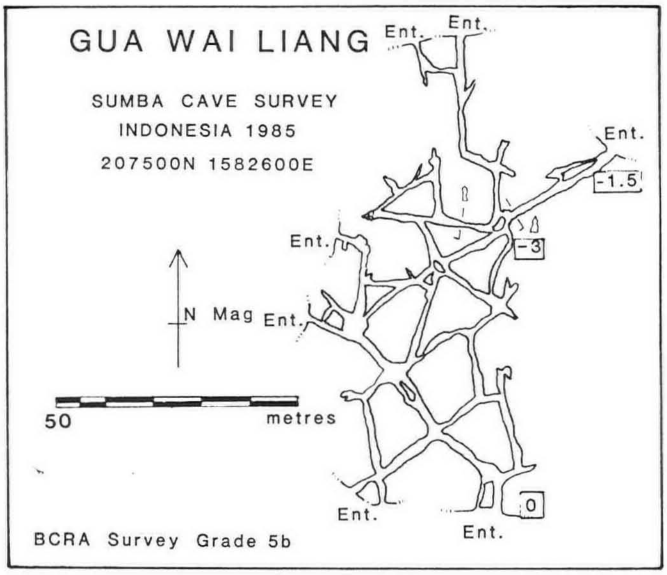
A crawl through boulders is followed by a low wet section. This opens out, and becomes muddy. Wide mud banks leads to a tight squeeze into a boulder-filled chamber with no way on. The cave is 253m long.

GUA WAI LIANG

This cave is in the centre of Waikabubak with two entrances on the main street. There is a maze of easy walking passages 335m long, and large amounts of rubbish.

GUA PAL TIGA KAMPUNG SUBU

Take the Tambulaka road northwest out of Waikabubak, to a group of houses locally known as Pal Tiga. A river of about 200 l/s passes under the road, resurging from the cave about 50m from the road on the northeast side. The entrance is well-known, and is used for freshwater and bathing. A group of local lads knew the cave well, and had certainly explored as far as the sump.

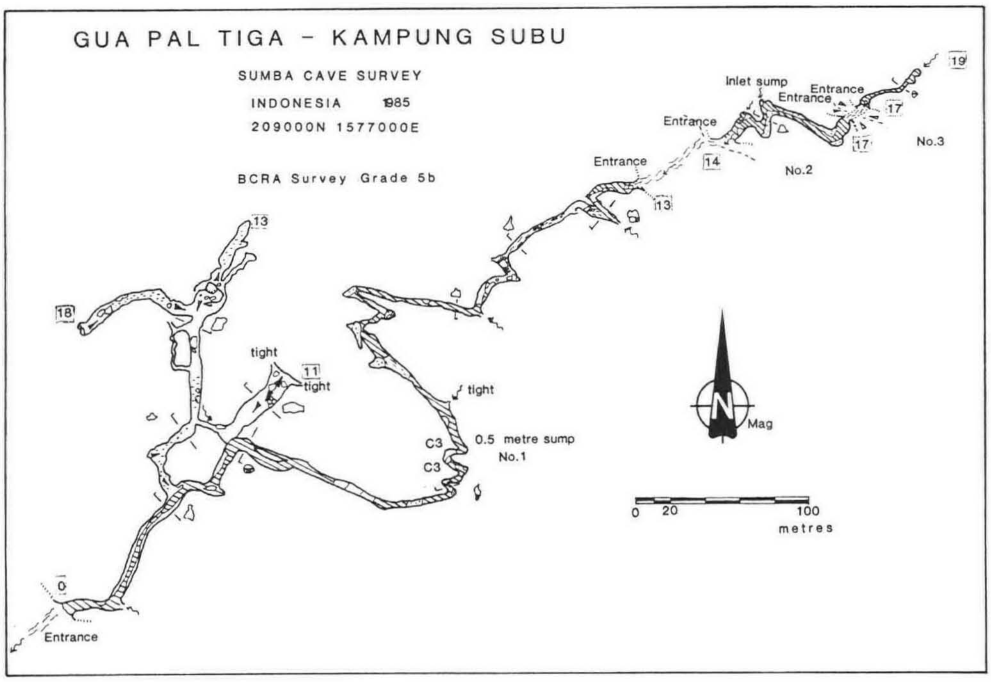


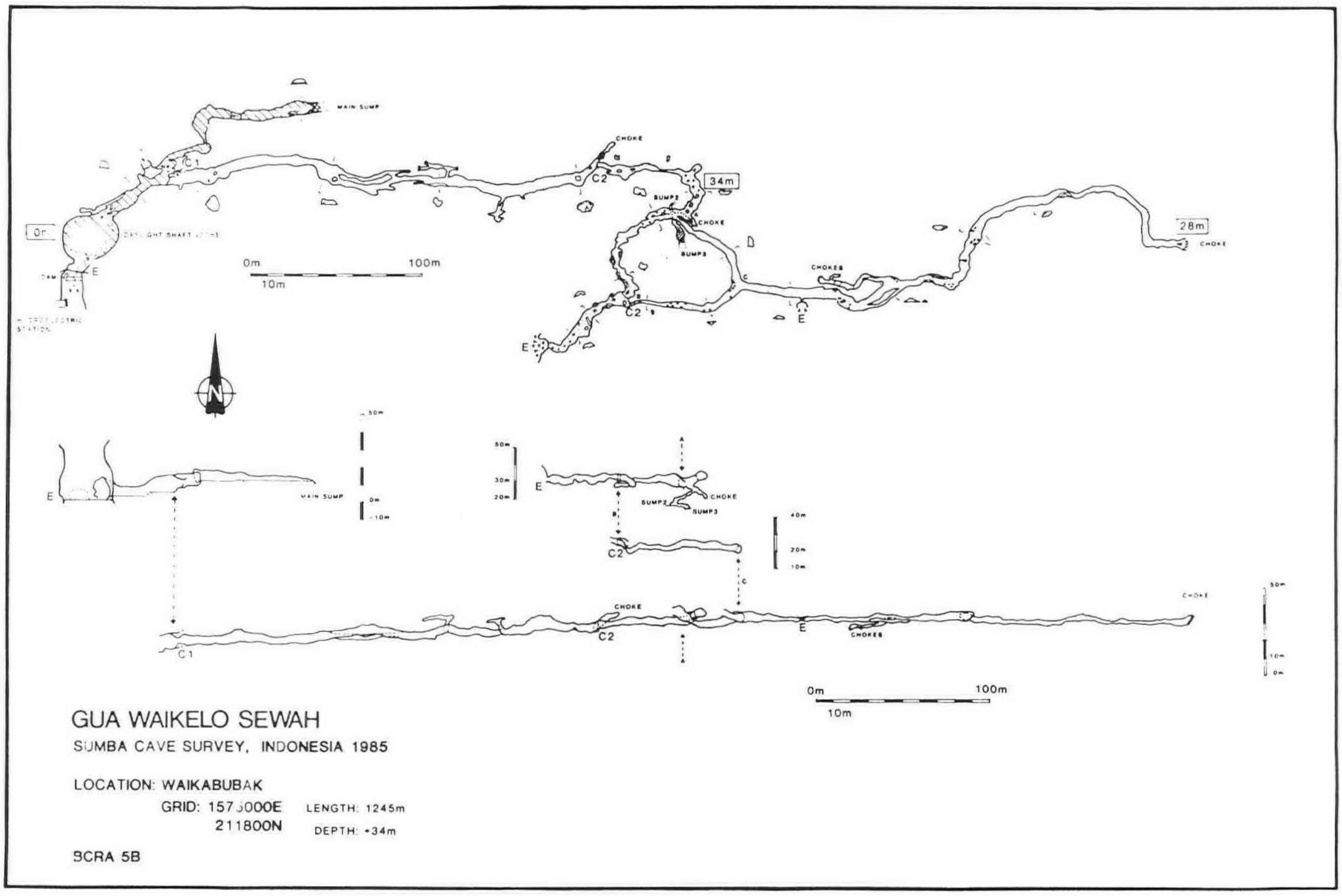
A 4m by 3m entrance leads to similarly sized vadose passage. After wading for 100m the first of two climbs up to the large high level passages is encountered. These end in boulder or sand chokes. Back in the river, stooping passage followed by deep water and calcite chokes leads to the sink entrance. Sixty metres upstream the second cave is entered by crawling. The cave increases in height but soon surfaces. The third section leads rapidly to a steeply descending sump. The main cave is 1037m long, over a vertical range of 18m.

GUA WAIKELO SEWAH

Take the Tambulaka road north-west out of Waikabubak to a junction known locally as Kilo Sembilan (9km). 1200m from this junction the resurgence is met. A dam has been built across the entrance and the water is used for irrigating paddy fields, and also for a limited hydroelectric scheme. The dam has raised the water level in the cave about 5m.

Walk up onto the left side of the dam, and climb into the water on this side. Swim along the left-hand wall into the cave - a whirlpool on the right needs care. The entrance leads to a large daylight shaft about 30m high and 25m in diameter.





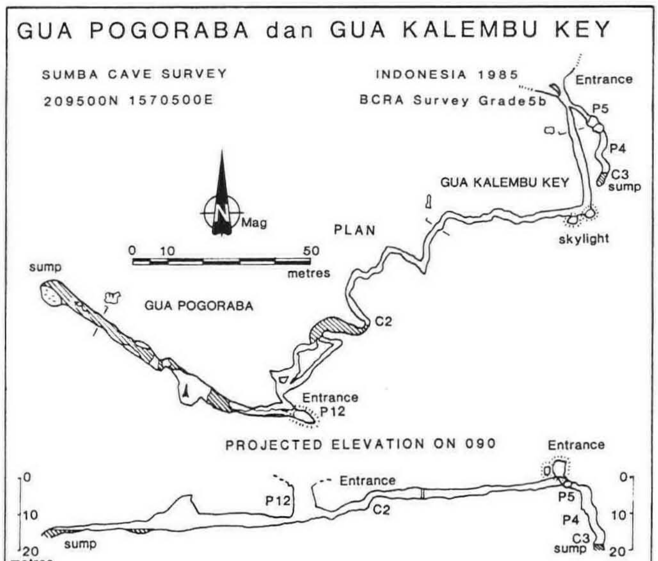
Most of the 10 cumecs of water resurges into this pool from below, and over 3 cumecs pours into the chamber from a large passage opposite the entrance. Climb into this on the left to avoid the waterfall. A swim of about 60m reaches a ledge from which the river can be crossed. Continuing up the river reaches a large sump after 110m, but a way on is up a small climb into a large passage. This provides a home for fruit bats and the stench of guano is high, but large walking passage can be followed for a kilometre. A small lower streamway is accessible from a chamber but it sumps. Two high level entrances were found.

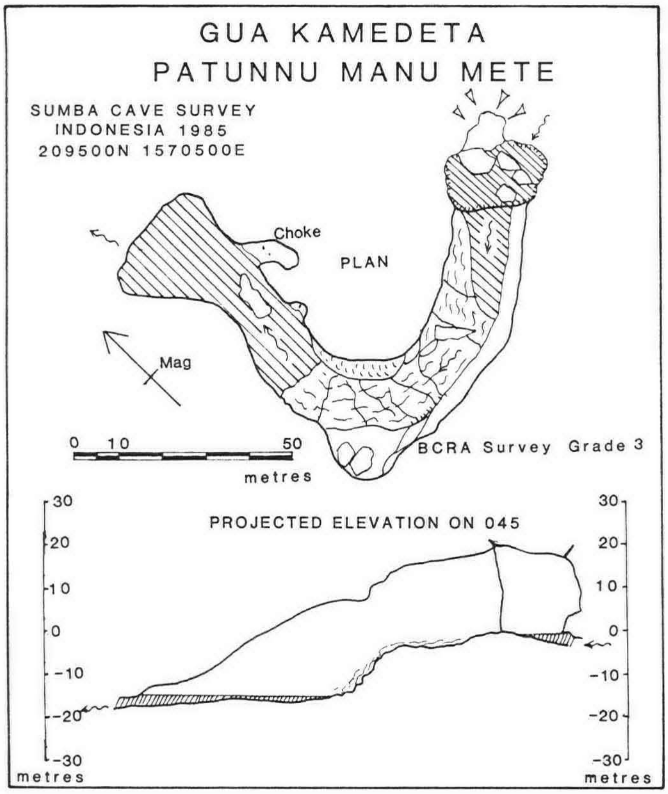
GUA POGORABA and GUA KALEMBU KEY (Cave of the Roots)

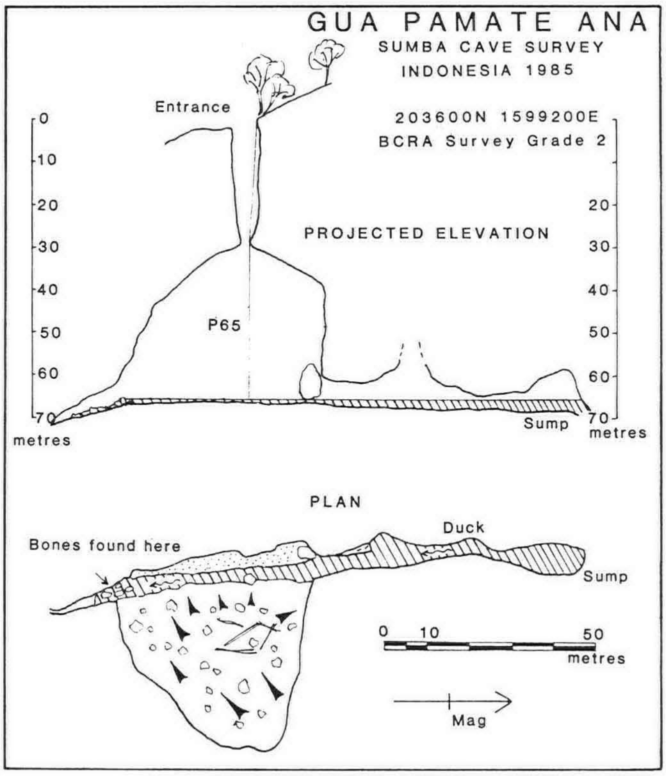
Twelve kilometres west of Waikabubak a road leads off to the left, to the village of Mari de Kalada. South of the village is a large valley and these caves are on the slopes below the village.

Gua Kalemba Key has two small pitches and leads to a sump. A narrow passage continues to loose debris which blocks the way to Gua Pogoraba. A 12m pitch leads to easy walking passage in Gua Pogoraba and a sump.

Gua Waikelo Sewah (D. Checkley)







GUA KAMEDETA PATUNNU MANU METE

In the valley bottom one kilometre south of Mari de Kalada a 5 cumec river sinks in an imposing cave. Augustinus Ola Sanga is a helpful local contact. The flow of water makes exploration very exciting. The entrance cascades are spectacular but a sump is reached in 150m. The resurgence is impenetrable.

GUA KAMAR TIGA

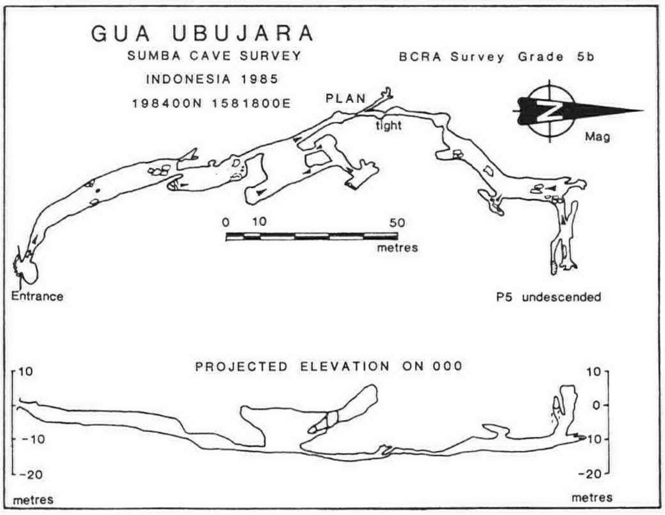
One and a half kilometres southwest of Waikabubak just beside the school at Waekerau. Climb down the tree roots into easy walking passage which is used for washing. A sump is reached, after 378m, and the far side is accessible from a short resurgence cave.

GUA PAMATE ANA KERBAU (Cave of the Dead Buffalo)

A track leads south from the centre of Anakalang across the plain for 10km. A small village is passed and eventually the river Lota is reached in the Dameka region. Cross the river and walk southeast to the obscure entrance among the limestone hillocks. Yoseph Lelaona or Hengky Mahenu of the Mona Lisa in Waikabubak are invaluable guides for this and other caves of the area. An 8m wide shaft narrows to a slot at 20m and then drops out into the centre of a large chamber with a river passage that sumps at either end. The cave is 160m long and 70m deep. The remains of two birds' nest collectors, who had fallen to their deaths down the shaft, where brought out for burial. The river Lota sinks into a large cave, but this was never visited.

GUA UBUJARA (Cave of the Large Horse)

This cave is situated close to Mamodu, a small village near the road 10km south of Waikabubak. A helpful English-speaking contact is Jack Weru in nearby Wanukaka. The small obscure



entrance lies half way up a hill. Stooping passage leads to a chamber and walking continuation to a further bat-infested room, low crawls and a loose undescended pitch after 220m.

GUA PACADIA

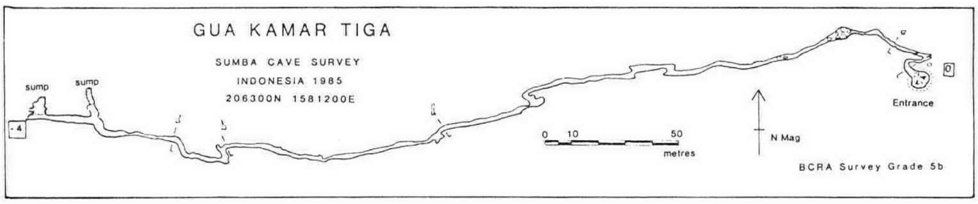
Below Praikatiti 2km east of Waikabubak - 25m long old resurgence.

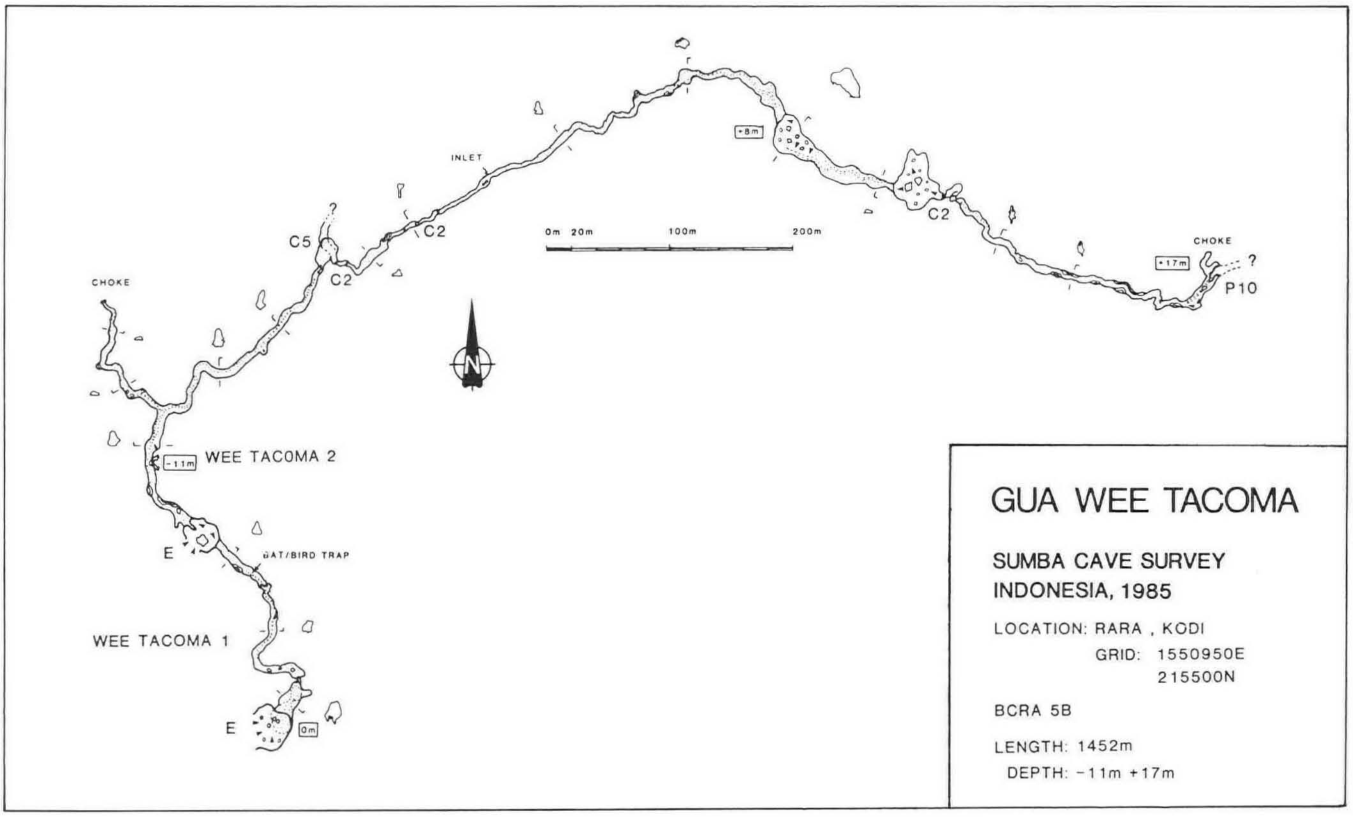
GUA PRENEGE

Near Bilawawe, a 10m shaft to 30m of passage and a choke.

GUA KALIMBUKATE

Near the village of Maredakalada a short sink cave, followed for 112m to a tight section.





GUA LAPALA
30m long fissure 3km south west of Waikabubak

AREA 4 THE CAVES OF RARA

GUA WEE TACOMA

Half way between the villages of Waimangura and Bondokodi, on the mountain road is the village of Rara. Behind the school and pastor's house is a depression containing the large entrance to Wee Tacoma 1.

An entrance 12m high and 10m wide enters a chamber well supplied with stalagmites and bat guano. A climb up over stalagmites to the left leads to a flat mud/guano floor and fine high vadose passage. Walking in 4-6m wide passage passes two choked holes and a way on under a large fence used by locals for catching bats leads to an exit in a small wooded depression. Wee Tacoma 2 starts immediately the other side in similar fashion. It was partially explored past a 5m overhanging climb to an undescended pitch.

GUA KATODA

Walking west from Rara on the Waimangura-Bondokodi road, past the central school area to the south, the road drops steeply down and swings to the right. Take a track to the north, through the trees, to the northern part of the village. To the west is a huge depression with entrance shaft of Gua Katoda in the bottom.

A large elliptical shaft of 55m depth drops into a muddy passage about 15m wide and 10m high running E/W. East leads up in the same style to a mud choke after 60m. West leads to a river after 50m issuing from a sump on the right. This river flows down the passage under an aven and into a ponded section after 70m. The ponded section arises from a sump only 90m further on in the same sort of big muddy passage. No resurgence for the water is known, and the cave is 330m long and 73m deep.

GUA PANDELUROKA

West of Rara, take a track to the south where the road steepens and turns north. This leads along a ridge between two sweet-potato fields. To the southeast a depression contains the huge shaft of Gua Pandeluroka.

This shaft (10m by 5m) descends 65m into the middle of a single chamber. It is 200m long and 70m wide, with a stream arising from boulders in the middle and sinking in a muddy sump at the north and deeper end. Huge boulders and mud cover virtually the entire floor.

GUA WEE PALIRA

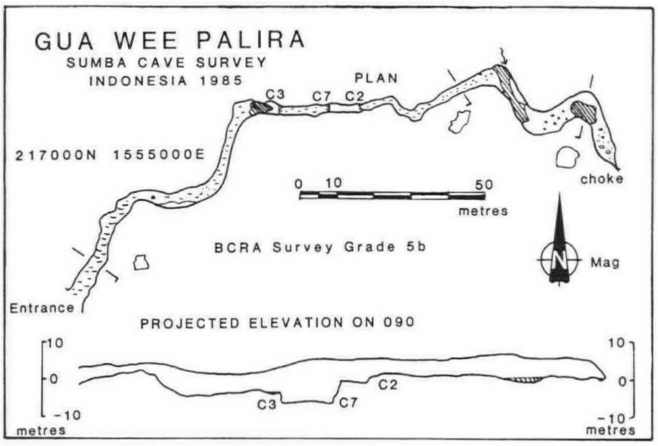
Located on the opposite side of the track leading to Gua Paneluroka, this cave is in a wooded section on the north of the sweet-potato fields. The entrance is well-known by the villager who think that a stalagmite, just inside the entrance is an image of the Virgin Mary. Scrambling over mud and forest debris leads into the entrance but beyond it is surprisingly pretty with coloured calcite surrounding deep green pools. It chokes with calcite after 180m.

GUA KURUKARA

Two parallel shafts descend in steps to a depth of 25m to a choke.

GUA PALEDUWORA

Two pitches of 15m and 9m connect.



AREA 5 THE CAVES OF KODI

GUA LEKO

Walk 2km east from Bondokodi to the point where the large river sinks below a waterfall. The river flows at speed into the 5m high by 3m wide passage. Traversing out of the water past a tree blockage leads to the sump after 224m. In drier weather a through cave may be possible.

GUA BATAMA

Situated close to the river sink 2km upstream for Gua Leko. The sink itself is choked, but a 10m high by 2m wide entrance leads to a steeply ascending rift. This breaks out into a 30m high phreatic tube which quickly chokes with stalagmite in one direction. In the other, a second entrance is reached. The cave has fruit bats and a 4m python within its 120m length.

PEOPLE AND CUSTOMS

The people of Sumba have little contact with the outside world and this has lead to a suspicion of foreigners and their motives, and even a fear of white men as cannibals. Generally we encountered frightened curiosity, and only occasionally hostility. Once the initial fears had subsided we found the local people very friendly and extremely hospitable.

The island is divided into two politically distinct parts. The east of the island, Sumba Timor, is governed for Timor, and the west, Sumba Barat is governed from Java. Apart from a rough unsurfaced road (the main road) connecting the two, there seems to be little contact between them. The islanders themselves seem to split into three ethnic groups. The first are the original Sumbanese dwellers; the second are the immigrants from the nearby island of Flores, who are generally a much darker race and who, in western Sumba, seem to hold most of the key government, police and military posts. The third group are of Chinese origin and they tend to live in the two towns and organise the shops and businesses.

Outside the two towns, people live in small villages or isolated houses, many built in the traditional style. These houses are sturdy thatched bamboo structures built on stilts, with an open fire in the middle. This fire is used for cooking and the smoke rises up into the roof, a tall thatched spire that can reach 12 metres in height. The traditional belief is that the gods live high in the roof, together with the family's prize possessions. Beneath that the people live, and below the house itself live the black pigs, dogs and chickens. The idea of English cavers exploring even lower than the pigs caused much amusement.

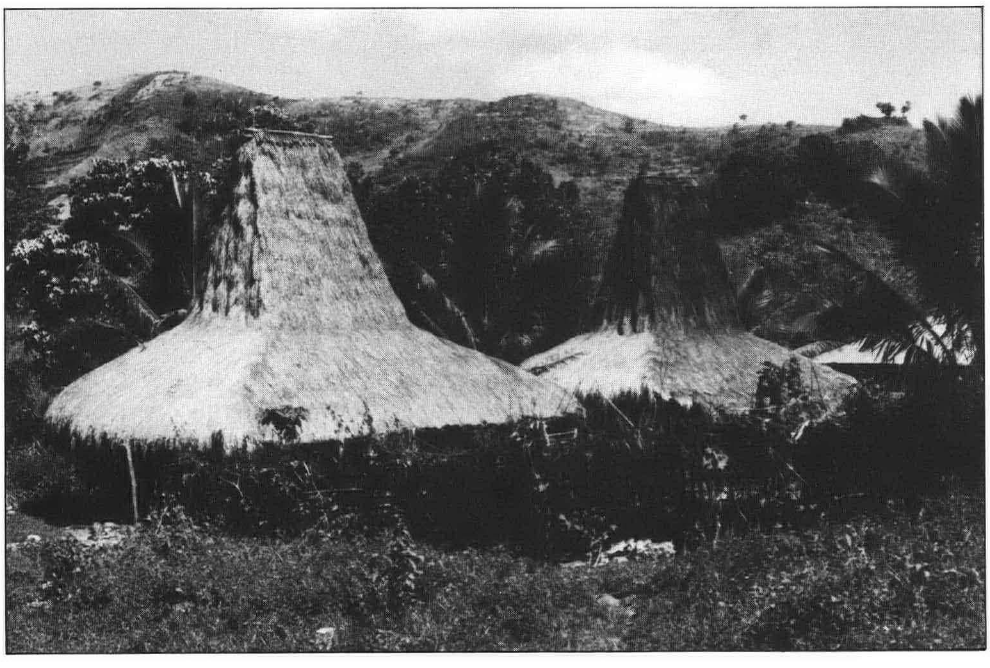
Agriculture is the prime occupation of the island with many smallholders, some of whom are organised in co-operatives for distribution. Wet rice fields abound, sometimes with fairly complex irrigation systems. Other crops are maize, coconuts, sweet potatoes, mung beans and fruit. Although large herds of cattle are kept, virtually all these are exported to Java and the local people eat pigs, chickens and dogs. Wild pig is hunted and fish are caught in the numerous rivers.

Markets provide the opportunity to trade goods and are also quite a social occasion. Some areas have a market only once a month, and on this occasion several trucks will leave the town, collecting people, their wares and animals en route, until - punctures permitting - they arrive laden and groaning at the market site. Many people come with just a couple of coconuts and a papaya, taking the one opportunity to sell their excess crop.

These markets are colourful affairs, with women dressed in their handwoven sarongs. Each piece of cloth takes weeks of work and it is not unusual for a man to have one wife whose sole task is to weave the families clothing, and the richly coloured horse blankets for which Sumba is renowned. Quite frequently a man will have several wives and consequently numerous children. The women share all the manual work, and should a woman's husband die she will either be taken as a wife by his brother or married off by him. The married women on Sumba seem to chew betel nut and lime continuously, which apart from producing rather alarming red teeth and saliva seems to induce an almost permanent state of 'contentment'.

Education on the island, is well developed and particularly in the town, crowds of immaculately uniformed children flock to the schools. Teachers are highly regarded in Sumban society and proved to be our best allies. We encountered several who spoke some English and were invaluable as mentors and friends. They were able to smooth our way both with the local officials and villagers.

The main thing that Sumba is renowned for in Indonesia is the annual 'pasola', a mock battle. This battle is part of a ritualistic ceremony to ensure a good harvest, and to satisfy ancestral spirits. The 'pasola' consists of about 300 horsemen mounted on their sturdy Sumban horses who fight a mock battle, that was, till recently both bloody and fatal for many of the participants. In modern times the event has been toned down and it



Thatched houses at Maderi

(R. Walters)

is hoped to attract more tourists in the future.

Ancestral spirits still play a large part in the lives of the Sumban people, despite the inroads of Christian and Muslim influences. Funerals involve ritualistic animal slaughter - sometimes including the horse of the deceased - and the burial of goods with the corpse to help on the journey to join his ancestors. Tombs are built with ornate stone-carved walls and a large flat stone on top. These graves tend to be built in the centre of a group of houses, and double as communal work surfaces for drying beans, coffee or clothes.

ADVICE FOR THE WOULD-BE VISITOR TO SUMBA

Flights

Flights from Bali to Sumba were approximately £200 return. They were not very reliable to either Waingapu or Waikabubak, and there was no more than one flight a day, if that.

Tourism

This is not a tourist island and the few tourists that there are go to either Waingapu or Waikabubak. People in other parts will often be frightened of white people. It is not a good idea to plan to go walking without a local guide as this may result in hostile reactions from the people. Outside the two towns there are no tourist facilities. Even food (rice) may not be locally available and it is advisable to take some with you. English is only spoken by a few teachers.

Transport

In the two towns 'bemos' (mini-buses) are cheap for local travel. There are a few buses, but most people travel by truck (£1.00 from Wangapu to Waikabubak). These sometimes go to the remote areas once or twice a month for markets - you need to be patient. We hired a motorbike for £3 a day but this is not generally possible except through local contacts. Roads are very rough and not extensive. It may be possible to hire horses, but they are small and not practical for tall people.

Permission

This may be difficult to obtain without the help of an Indonesian speaker. We entered on tourist visas and always sought permission from the police and local leader, the 'kepala desa'. We were fortunate in Waikabubak in making contact with the Bupati, the Secretary of State. His letter of recommendation was invaluable when it came to local permission problems. The more documents obtained for permission the better and starting at the top can save days. East and West Sumba have different governments and the two towns are where their offices are. It is not possible to rush these matters and patience and understanding are needed. You must explain what you want to do and why. Illustrative material with cave surveys, photos or expedition reports are invaluable. Photographs of our homes and England aroused great interest and often broke the ice. A polaroid camera is a great way of saying thank you. Never go anywhere without a few packets of cigarettes and a lighter.

Guides

Having made contact with the 'kepala desa' and the police and explained our objectives we generally found no problem in obtaining guides. Sometimes these people wanted payment but this was very little and was not usual. People were generally very helpful once they understood our interests.

Accommodation

We stayed in police accommodation, 'kepala desa' houses. the houses of other local officials, agricultural commune buildings, people's own homes and occasionally slept out. We tried to repay the people for their generosity, with polaroid photos and colour prints sent back from England.

Medicine

There are doctors and clinics on the island in the towns. We took limited medical supplies with us and found antibiotics and antiseptic dressing useful for cuts and bites. We took malaria prophylactics and had no serious health problems. The people of Sumba are generally fit and healthy.

CAVES WE NEVER VISITED BUT WOULD LIKE TO

Kaonda Mara

A large spring 12km north of Rakawatu near Numara on the district border.

Wahang

Two caves are to be found 1km from Wahang, one with a large river. A truck leaves Waingapu three times a month for Wahang.

Gua Leanang

On the boundary of East and West Sumba 100m from the coast, a large river cave.

Sink Cave

The large river 10km south of Anakalang sinks into a large cave.

Waikabuni

We spent so long looking for this sink that although it doesn't exist we felt it worth a mention. The cartographer must have run out of ink when he drew the river on the map!

CONCLUSIONS AND FUTURE WORK

The island of Sumba, as expected, yielded a fair amount of interesting cave passage and is riddled with speleological features. Although a return visit would almost certainly produce many more kilometres of cave, there are no more plans by this group to return.

Irian Jaya, however, was very much a preliminary reconnaissance which uncovered very impressive features. The massive limestone, high rainfall and high relief are factors in favour of cave formation. Active tectonics and political instability are obvious deterrents to cave formation and exploration. The British group, however, plan to return soon with a slightly larger team for a longer period in the same Wamena area, where high altitude sinks will be looked at with a small lightweight party, back-packing through the alpine grasslands. Another small team will work around the Baliem Valley and look to the east, through the cockpit country and up into the highlands beyond. This more extensive reconnaissance should open the way (politicians permitting) to large scale cave exploration in the Irian Jaya highlands, other areas of Irian Jaya, and to other states of Indonesia which together must contain some of the best caving prospects in the world.

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- Iluga: Jim & Val Riley, Banas.
- Pass Valley: Kees & Wijnie Janse.
- Bokondini: Dave Marfleet.

If you wish to cave in Indonesia you should contact Dr R. Ko, PO Bos 55, Bogor, Indonesia.

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