



**Preliminary Report on  
the Caves and Karst  
of ROTA (LUTA), CNMI**

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**WATER AND ENVIRONMENTAL RESEARCH INSTITUTE  
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UNIVERSITY OF GUAM**

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## ABSTRACT

The island of Rota, Commonwealth of the Northern Mariana Islands, contains caves developed by most of the mechanisms previously documented for similar islands. Rota has a large number of flank margin caves, developed by mixing dissolution, under diffuse flow conditions, at the edge of the fresh water lens. Rota has a few caves developed along the contact with the underlying volcanic rock. Rota also has a few caves formed primarily by the physical erosion of ocean waves. Unlike the other islands in the Mariana Arc, Rota has a large number of mixing zone fracture caves. These mixing zone fracture caves apparently developed as fresh water discharging from the fractures mixed with sea water to create zones of enhanced dissolution in each fracture. These mixing zones are thought to have migrated headward as each fracture was widened by dissolution.

The interaction between uplift, subsidence and glacio-eustasy has formed caves on Rota all elevations. Caves are documented from sea level to within a few meters of the summit of the island.

Keywords: Mariana Islands, Rota, island karst, caves

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# PRELIMINARY REPORT ON THE CAVES AND KARST OF ROTA (LUTA), CNMI

## INTRODUCTION

This report documents the interim results of the ongoing project to inventory the caves and karst features of the Island of Rota (Luta), Commonwealth of the Northern Mariana Islands (CNMI). Two intensive field seasons (May to June 2003 and December 2003 to January 2004) have resulted in the documentation of over 80 caves and related karst features. Since it is known that caves and other karst features on other small carbonate islands, such as Rota, develop as freshwater lens recharge and discharge sites, an understanding of the caves of Rota will provide a basis for a better understanding of Rota's freshwater resources and lead to better decisions regarding fresh water use. The cooperation of the people of Rota and of various government agencies has been instrumental in the success of this work.

## SETTING

### Physiographic Setting

The Marianas Islands (Figure 1), located in the western Pacific Ocean, are composed of fourteen islands that are the exposed parts of the Mariana Ridge just west of the Mariana Trench, which includes the Challenger Deep, the deepest point in the ocean. The Mariana Trench-Ridge system is a product of the subduction of the Pacific Plate under the Philippine plate. Figure 2 shows that the Mariana Islands are composed of two parallel island chains, both of which sit atop the Mariana Ridge (Karig, 1971). The eastern, paleo-volcanic chain is expressed at the surface as the islands of Guam, Rota, Aguijan, Tinian, Saipan and Medinilla. Karig (1971) reports that the eastern arc

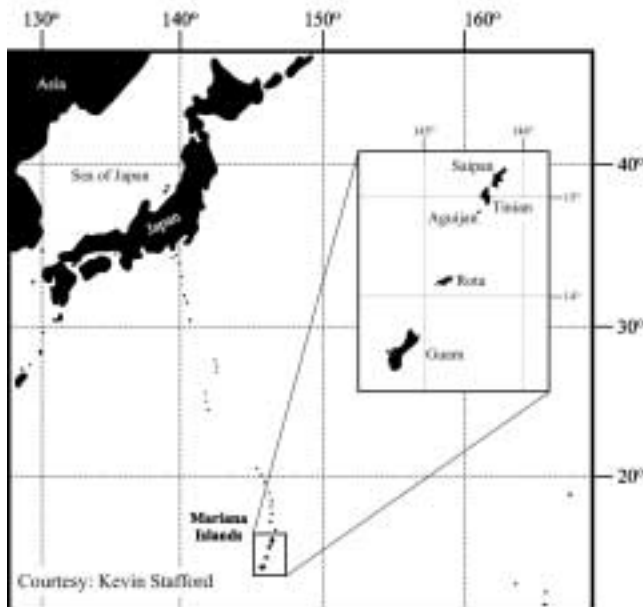


Figure 1. Location of the Mariana Islands.

continues northward from Medinilla as a series of sea mounts along the eastern edge of the Mariana Ridge to its intersection with the Bonin Arc. Dickinson (2000) states that the volcanoes that formed the basement rock of Guam, Rota, Aguijan, Tinian, Saipan and Medinilla were primarily active during the Late Eocene to Early Oligocene (45 –30 Ma) but that Guam and Saipan have volcanic deposits from as late as the mid-Miocene (15 - 12 Ma). The chain on the western edge of the Mariana Ridge is expressed at the surface as the nine, volcanically active, northern islands of the CNMI, which

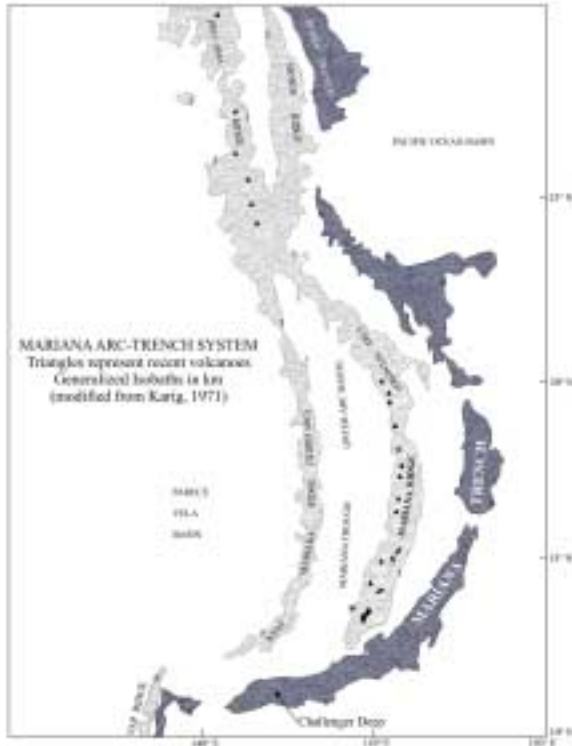


Figure 2. Mariana Arc-Trench System.

have probably been active since the Pliocene (Dickinson, 2000). Anatahan, the southernmost island on the eastern arc is known to have been active in 2003. Karig (1971) reports that the eastern arc on the Mariana Ridge continues as far south as Guam as active submarine volcanoes and states that thrusting as well as island arc volcanism was likely involved in the development of the Mariana Arc (Figure 2). To the west of the Mariana Ridge lies the Mariana Trough, which Karig (1971) described as an extensional back arc basin. To the west of the Mariana Trough is the West Mariana Ridge, a remnant volcanic arc that was part of the Mariana arc-trench system prior to the opening of the Mariana Trough during the Eocene (Reagan and Meijer, 1984). Dickinson (2000) quotes several authors whose work will be discussed in the Previous Investigation section below,

when he states that the paleo-volcanic islands of the Mariana Island Arc (Guam, Rota, Aguijan, Tinian, Saipan and Medinilla) are mantled by Miocene, Pliocene, Pleistocene and Holocene limestones.

Rota (Figure 3) is located on the Mariana Ridge about 80 km north of Guam, the southernmost island in the arc, about 100 km south of Tinian and about 3000 km east of Asia at E 145° 12', N 14° 10'. Rota (Figure 3) has a surface area of about 85 km<sup>2</sup> and a coastal perimeter of about 52 km. Sugawara (1934) described Rota as having six distinct terrace levels (see Previous Investigation section below). While Rota certainly can be described as “terraced”, focusing on the terrace levels tends to over simplify the shape of the island. Rota is oriented east-west with the elevations on the north side of the island generally lower. The western end of Rota is dominated by the *Sabana* Region. The top of the *Sabana* is an irregular plateau (400+ m) that spans 4 km east-west and 2.5 km north-south. There are two prominent peaks on the *Sabana*. One reaches 491 m and the other, Mt. Sabana, reaches 496 m, Rota’s highest elevation. To the east, north and west of the *Sabana*, the land drops in a series of irregular terraces. To the south, the *Sabana* is bounded by a steep scarp above the *Talakhaya* region. The *Talakhaya* is characterized by a large, relatively steep exposure of weathered volcanoclastic material (Stafford et al., 2002). The *Talakhaya* contains the only surface streams on Rota and has a discontinuous band of limestone at about 100 m elevation and a continuous band of limestone from sea level up to about 40 m elevation. The eastern end of the island, the *Sinapalo* region, is dominated by a relatively high plateau (100 – 200 m). Along the north side of the *Sinapalo* region, the terrain slopes gradually down to sea level. From the eastern end of the island and all along the southern side of the *Sinapalo* region, the

plateau is bounded by steep cliffs that drop to a variable width coastal terrace. The *Taipingot Peninsula* (Wedding Cake) is connected to the west end of Rota, at *Songsong*, by an isthmus about 0.5 km wide. The *Taipingot* reaches an elevation of 143 m (USGS, 1999). Rota has a wet-dry tropical climate with a distinct rainy season (July – September) and dry season (February – March). Rainfall averages 27 cm in the wet season and 10 cm in the dry season. Temperature on Rota is quite uniform and averages 27°C (USDA, 1994).

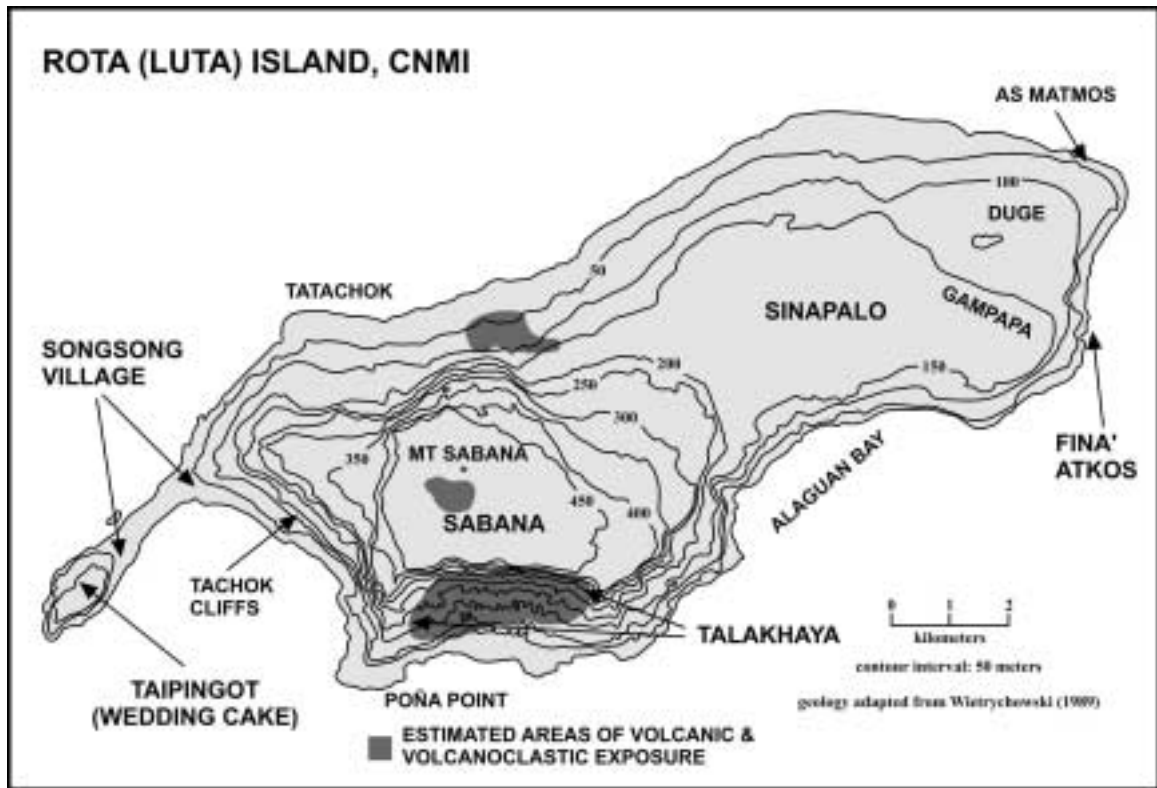


Figure 3. Rota (Luta) Island, Commonwealth of the Northern Mariana Islands

### Historical and Political Setting

Rota was settled by the Chamorro people around 1500 BCE. Ferdinand Magellan landed somewhere in the Marianas in 1521 and named them *Islas de los Ladrones*. In the early 1600's the name was changed to *Islas de las Marianas* after Maria Ana of Austria, widow of King Phillip IV of Spain and Spanish missionaries began the "reduction" of the islands in 1668 (Coomans, 1997). For almost four hundred years, the Marianas remained under Spanish control, during which a considerable number of people immigrated from the Caroline Islands. In 1898, during the Spanish–American war, the United States took control of Guam and to this day, continues to maintain ownership as a Territory. Since that time, Guam has been politically separate from the remainder of the islands in the Mariana Island Arc. In 1899, Spain sold the northern Marianas, along with Palau and the Caroline Islands, to Germany to pay off debt from the Spanish–American War. Germany maintained control of the northern Marianas until World War I, when Japan occupied the

islands in 1914. In 1920, the League of Nations granted Japan a mandate to administer the northern Marianas and it maintained possession until World War II. Under Japanese administration, large tracts of Rota were cleared for sugar cane production and a sugar mill was built in *Songsong Village*. During this time, an area near the summit of the island, on the *Sabana*, was mined for phosphate-rich soil which was transported to the coast using an aerial tramway that ended east of *Songsong Village* at *Sagua* (Rodgers, 1948). During World War II, the United States forcibly took possession of the Saipan and Tinian from Japan, but Rota was never invaded. The United States took possession of Rota after the Japanese surrender. In 1947 the United Nations created the Trust Territory of the Pacific Islands under which the United States Department of the Interior administered the northern Mariana Islands, as well as the Marshall Islands and Caroline Islands. After being approved in a plebiscite in the northern Mariana Islands, the United States ratified the *Covenant to Establish the Commonwealth of the Northern Mariana Islands in Political Union with the United State of America* in 1978. This agreement created the Commonwealth of the Northern Mariana Islands (CNMI) and established a unique relationship. The CNMI is self governing with regard to taxation, immigration, and labor laws, yet is part of the United States. Several federal agencies, including the US Postal Service, National Park Service, USGS and USDA operate in the CNMI. Permanent residents of the CNMI became citizens of the United States in 1986. Rota, the southernmost island in the CNMI, is one of its three municipalities, along with Saipan and Tinian.

## STATEMENT OF PROBLEM

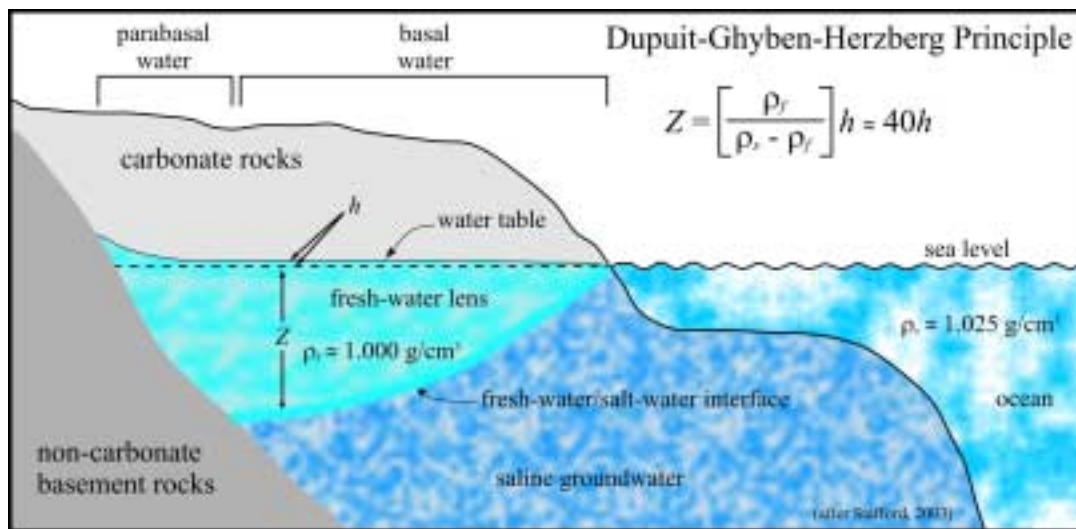
The geology of Rota has had very little systematic examination. The caves and karst of Rota have been studied even less. Sugawara (1934) mentioned caves in passing; providing a vague description of one cave. Rogers and Legge (1992) reported on their brief investigation of the caves and karst of Rota; surveying a few caves and assigning names that will be used when those caves can be identified except when common local names are found to take precedence. Stafford et. al (2002) reported on their brief reconnaissance trip, which laid the ground work for the investigation reported here. Other than these investigations, the caves and karst of Rota are essentially absent from the literature.

Rota is unique among the islands of the Mariana Arc in that it does not get municipal water from the fresh water lens. All the municipal water on Rota (Figure 3) presently comes from two contact springs on the *Talakhaya* (see Setting above), Water Cave (Matan Hanum) and *As Onan* Spring (Stafford et al., 2002). This means that the knowledge gained by investigations on Guam, Tinian and Saipan (see Previous Investigation) has limited applicability to the present fresh water supply on Rota. An inventory of the caves and karst of Rota is needed as a foundation for further investigation of Rota's hydrologic system(s) and as a start of a comprehensive study of the island's geology. The objective of this project is to add to the limited body of knowledge of Rota with a systematic representative sampling of the caves and karst developed there. Feature names in the document based on the native Chamorro language will be italicized for clarity.

## PREVIOUS INVESTIGATIONS

### Caves and karst on eogenetic carbonate islands

This summary of cave and karst development on young carbonate islands is based on the work of Mylroie and Carew (1995a; 1995b), Mylroie et. al (2001), and Mylroie and Vacher (1999). The development and morphology of a freshwater lens in a simple island composed of permeable rock is controlled by the Dupuit-Ghyben-Herzberg principle (Figure 4) which states that the depth of the freshwater lens below sea level at any point will be a function of the height of the lens above sea level at that point and the relative densities of the fresh and marine water. Given that fresh water has a density very near unity and marine salinity water is usually around  $1.025 \text{ g/cm}^3$ , the difference of one part in forty means that the depth of a fresh water lens below sea level will generally be forty times the height above sea level at a given point. This idealized diagram of the Dupuit-Ghyben-Herzberg principle is intended to depict an island consisting of a non-carbonate core mantled by relatively young limestone. Basal water is the part of the freshwater lens underlain by salt water, while parabasal water is underlain by non-carbonate rock. A fresh water lens developed according to the Dupuit-Ghyben-Herzberg principle, interacting with limestone, and the surrounding sea water creates a setting for cave and karst development on carbonate islands that is different from the setting in which most continental caves and karst are developed.



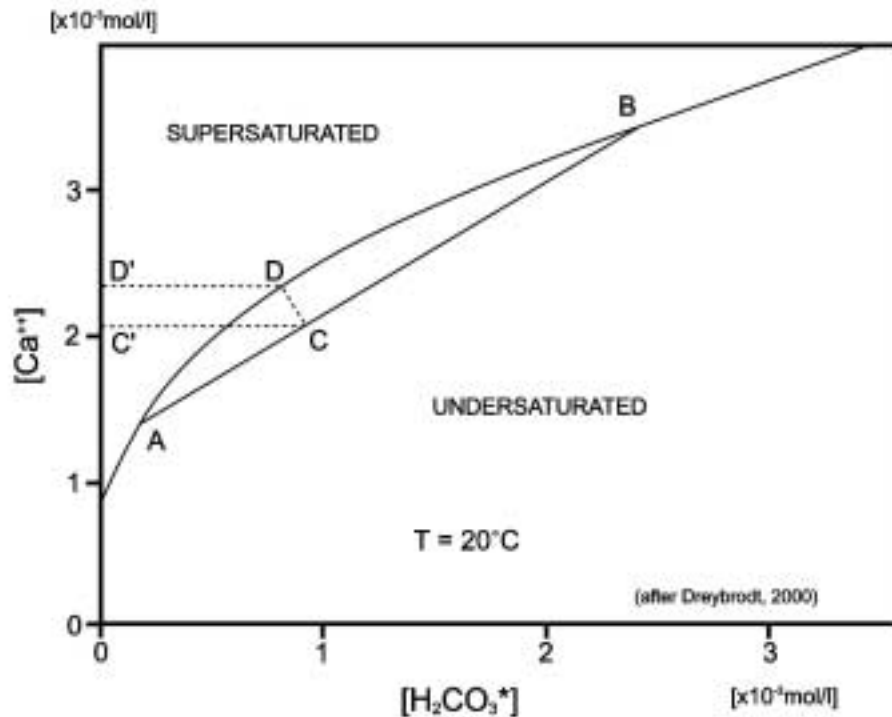
**Figure 4. Dupuit-Ghyben-Herzberg Principle**

The Carbonate Island Karst Model (CIKM) was first developed to explain the caves and karst on relatively simple carbonate islands such as those that make up the Bahamas. Further work on Guam and Saipan led to modification of the CIKM to incorporate parameters such as faulting and interfingering on carbonate and non-carbonate rock. The primary components of the CIKM are:

1. Dissolution of the carbonate rock is enhanced by mixing effects.
2. Effects of glacio-eustasy.
3. Effects of local tectonic uplift and subsidence.

4. The CIKM primarily applies to eogenetic carbonate islands.
5. Four classifications of carbonate islands are based on the relationship of the basement rock to the freshwater lens.
  - A. Simple carbonate islands
  - B. Carbonate cover islands
  - C. Composite islands
  - D. Complex islands

**Mixing Effects:** According to White (1988), “The dissolved calcite concentration varies with the cube root of the CO<sub>2</sub> partial pressure.” Figure 5, after Dreybrodt, presents Ca<sup>++</sup> concentration as a function of carbonic acid (H<sub>2</sub>CO<sub>3</sub>) concentration. Since H<sub>2</sub>CO<sub>3</sub> concentration is a function of CO<sub>2</sub> partial pressure, this figure is a graphic representation of the above statement by White (1988). The area above the curved saturation line represents supersaturated conditions while the area below the line represents saturation. For example, if water at points A and B on the saturation curve are mixed, the resulting mixture lie along the straight line between A and B. The position along the line will be a function of the proportion of A and B mixed. Since every point on line A-B is below the saturation curve, any mixture of two saturated solutions will produce unsaturated conditions, as long as the initial solutions have different initial concentrations. In the example shown on Figure 5, the mixture of A and B resulted in solution C, which is capable of dissolving calcite until it reaches D. The amount of calcite dissolved is shown by C'-D' (Dreybrodt, 2000). Plummer (1975) has shown that a similar effect occurs when marine salinity water is mixed with fresh water. Palmer et. al (1977) have shown that in Bermuda, this fresh/marine mixing effect is typically smaller than the effect caused by differences in CO<sub>2</sub> concentration (Figure 5).



**Figure 5. Calcite Solubility vs. Carbonic Acid**



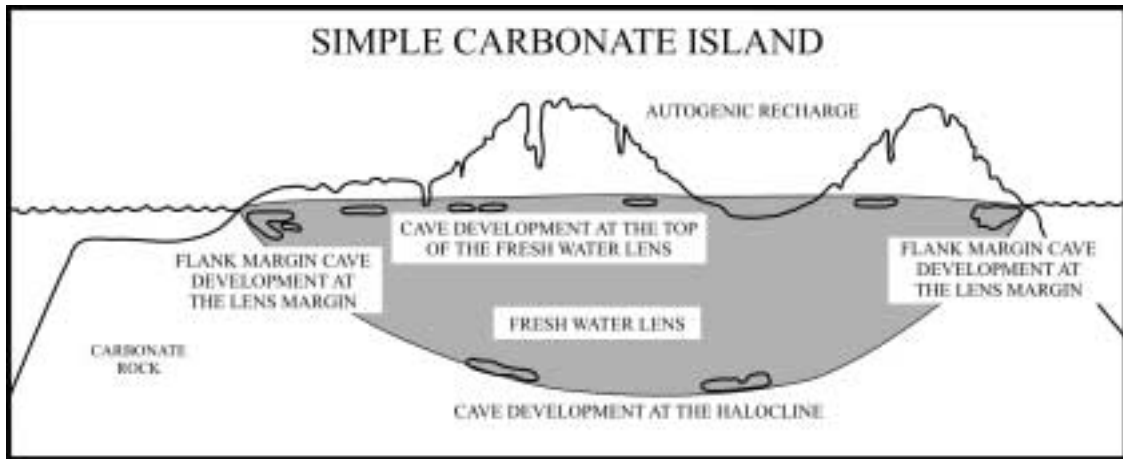
At the edge of the freshwater lens in a carbonate island, the two effects described above are additive, creating a zone of enhanced dissolution within which flank margin caves develop. Flank margin caves develop by diffuse flow from the lens and thus form without conduits (entrances) connected to the surface and are only enterable when breached by erosion. Flank margin caves typically express a morphology that can be characterized as globular interconnected chambers with chambers further inland typically being smaller (Myroie and Carew, 1995b). Harris et. al (1995) showed that voids can develop at the top of the fresh water lens due to CO<sub>2</sub> concentration mixing effects that occur as meteoric water is added to the lens. When these voids are breach by erosion they are referred to as “banana holes” in the Bahamas. That terminology will be adopted for this project. Voids would be expected to develop along the interface at the bottom of the freshwater lens due to mixing effects. Although not directly related to mixing of different solutions, the upper and lower boundaries of the freshwater lens are thought to act as density traps for organic material carried down from the surface. It has been speculated that micro-organisms fed by these organics produce CO<sub>2</sub> and potentially lead to anoxic conditions. Anoxic conditions could promote the formation of H<sub>2</sub>S, which could then be oxidized to H<sub>2</sub>SO<sub>4</sub> when conditions change. Even a small amount of H<sub>2</sub>SO<sub>4</sub> produced by this process would have a tremendous dissolution potential

**Glacio-eustasy:** Since an island fresh water lens floats on top the more dense marine salinity water, sea level determines the position of the lens. Since the beginning of the Pleistocene, 1.8 Ma, global sea level has been as much as 6 m higher and 125 m lower than today.

**Local Tectonics:** Uplift and subsidence caused by local tectonics will change relative sea level and thus the position of the freshwater lens, creating a complex interaction with glacio-eustasy in determining the elevation at which lens effects are later found. Isla de Mona, Puerto Rico exhibits tremendous development of flank margin caves elevated by tectonics to a position well beyond glacio-eustatic fluctuations; about 80 m msl.

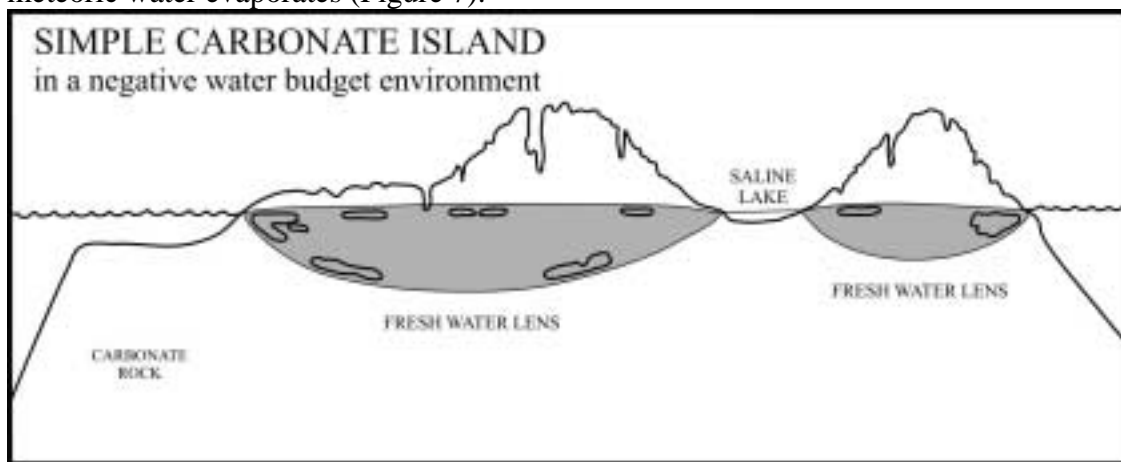
**Eogenetic Carbonate Islands:** The CIKM is primarily applicable to islands at least partly composed of eogenetic limestone. Eogenetic means that the limestone has never been buried below the range of meteoric diagenesis. Such young limestone typically has high initial matrix porosity and moderate permeability with vuggy porosity developing from meteoric diagenesis. Over time, the vertical permeability decreases while the horizontal permeability increases as a result of lateral flow in the lens. The matrix porosity decreases with secondary cementation of the pore spaces (Myroie and Vacher, 1999).

**Four Classifications of Carbonate Islands:** The first three classifications of carbonate islands (Myroie et al., 2001) are based on the relationship of the lens to any non-carbonate rock. In a Simple Carbonate Island, there is no non-carbonate rock shallow enough to interact with the fresh water lens. All recharge to the lens is autogenic and phreatic cave development occurs at the water table and the edge of the fresh water lens. (Figure 6)



**Figure 6. The Simple Carbonate Island Karst Classification.**

The islands of the Bahamas are good examples of Simple Carbonate Islands. Even on a Simple Carbonate Island such as San Salvador, Bahamas, the lens can be partitioned by saltwater lakes as a result of negative water budgets and up-coning of seawater as meteoric water evaporates (Figure 7).



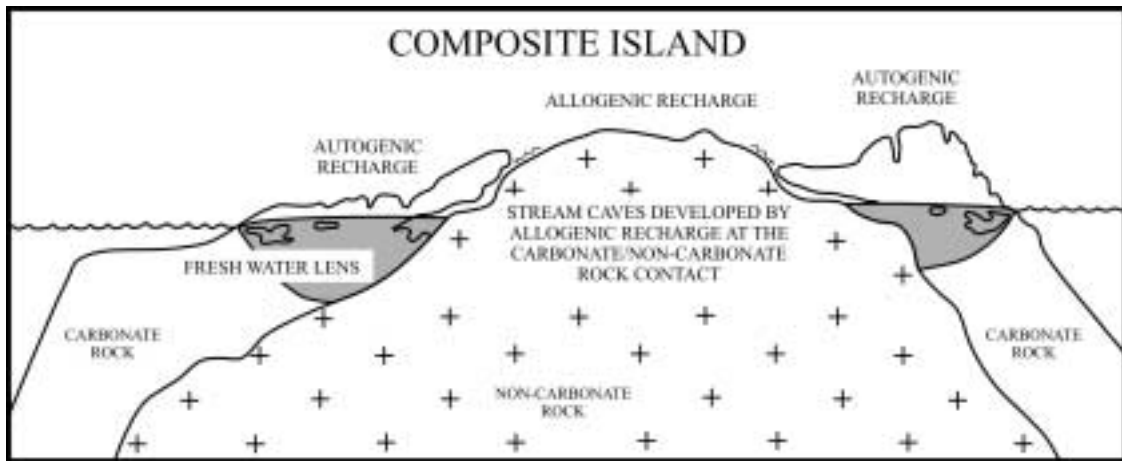
**Figure 7. Simple Carbonate Island in negative water budget environment.**

In a Carbonate Cover Island (Figure 8), non-carbonate rock is shallow enough to partition the lens but is not exposed on the surface. Recharge is autogenic and caves can form at the top, bottom and edges of the lens. Caves can also form along the contact of the non-carbonate rock and the overlying limestone. It should be noted that a drop in relative sea level can shift an island from Simple to Carbonate Cover by lowering the position of the lens so that it interacts with non-carbonate rock. Bermuda is presently a Simple Carbonate Island but has been a Carbonate Cover Island when sea level was lower.



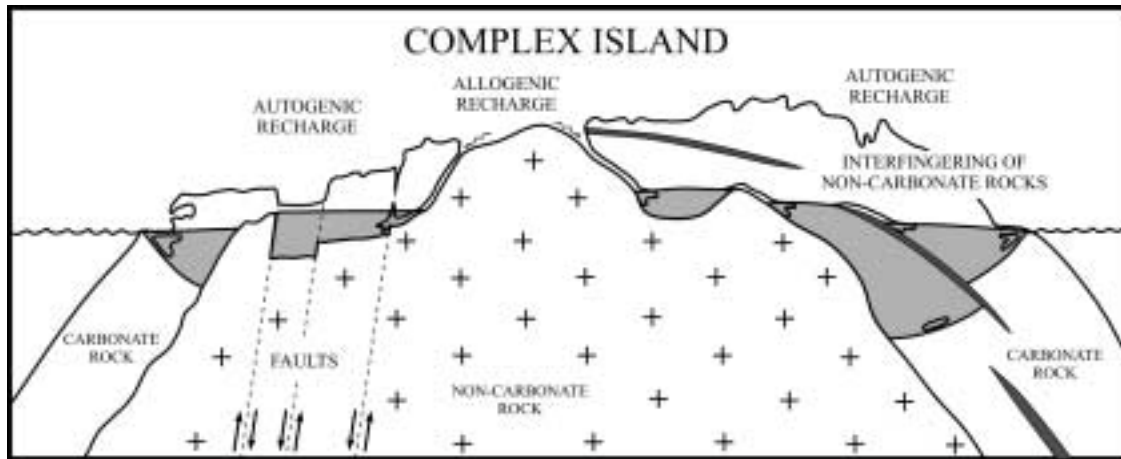
**Figure 8. The Carbonate-cover Island Karst Classification.**

Composite Islands have non-carbonate rock exposed on the surface. There can be allogenic recharge, with streams on the non-carbonate rock sinking into caves at the contact, and autogenic recharge on the limestone. Composite Islands can still develop caves at the top, bottom and edges of the lens (Figure 9).



**Figure 9. The Composite Island Karst Classification.**

The Complex Island classification combines aspects of the Carbonate Cover and/or Composite Islands with the effects of faulting and/or interfingering of non-carbonate rock. The aquifer in a Complex Island will not exist as a single lens. Faulting can partition the lens and position non-carbonate rock adjacent to limestone creating contorted flow paths. Fault planes can provide preferential flow paths, distorting the lens. Interfingering of non-carbonate rock with carbonate rock can create perched aquifers and artesian pressure surfaces. Parts of Saipan and Guam in the Mariana Arc were the archetypes for development of the Complex Island classification (Jenson et al., 2002) (Figure 10).



**Figure 10. The Complex Island Karst Classification.**

Other types of caves are known to develop on carbonate islands. Stafford et. al (2002) reported fissure caves on Tinian and such caves are expected to be found on Rota. Fissure caves develop along faults, fractures or joints by enhanced dissolution along these preferential flow paths (White, 1988). Pit caves, vertical shafts having a depth to width ratio greater than 1 (Harris et al., 1995), are also known from several carbonate islands and are expected to be found on Rota. On carbonate islands, pit caves can develop as an interconnected series of shafts and typically act as vertical fast flow routes for water (Myroie and Carew, 1995b). Stream caves are known to develop along the contact of non-carbonate basement rock and overlying carbonate, either by sinking of surface streams or by allogenic recharge feeding a stream perched on non-carbonate basement rock. Bermuda is a good example of an island with stream caves (Myroie et al., 1995). Point source recharge features are places where a concentrated stream of water can enter the subsurface through a conduit instead of flowing diffusely through the bedrock. Point source recharge features are often associated with streams flowing off non-carbonate rock. However, all point source recharge features are not associated with enterable caves. Discharge features are places where a concentrated stream of water is discharged from the aquifer. On carbonate islands, springs are point source discharge features located at sea level or at the top of an aquiclude (contact spring). Water Cave and *As Onan* Spring on Rota are contact springs (Stafford et al., 2002). Submarine fresh water vents are points where fresh water discharges from the lens below sea level (Jocson et al., 2002).

### **Geology of Rota**

The primary work on the geology of Rota was published in Japanese by Sugawara (1934) and translated into English by the United States military in 1949. No English translation of Sugawara's (1934) geologic map of Rota is available. Sugawara's (1934) approach was primarily to define the physiography of Rota based on the prominent series of terrace levels that are obvious almost all the way around the island. He also defined a series of depositional units based on his understanding of depositional facies and presented exhaustive lists for fossil fusulinids and corals found in the various units. These units essentially followed the visible terraces, which he described as constructional. The positions of the terraces is probably the product of interaction between glacio-eustasy and local tectonics. Flank margin cave development is expected

to have occurred at all of these terrace levels since they apparently represent relatively long sea level still stands and thus long periods of stability for the freshwater lens.

The work of Sugawara (1934), Stafford (2003) and Stafford et. al (2002) has been combined with inferences made from the work of Doan et. al (1960) on Tinian, Tracey et. al (1964) on Guam, Cloud et. al (1956) on Saipan and Karig (1971) on the geologic history of the Mariana Arc, to assemble the following basic history of Rota geology. During the Eocene, island arc volcanism, which had been producing submarine pyroclastic flows and pillow basalts since the early Tertiary, created a seamount that reached into the phototropic zone. Coral and calcareous algae colonized the seamount despite sporadic volcanism, creating interfingering of volcanics and volcanoclastics with the limestone that was being built from the coral and algae. Uplift and subsidence, driven by the volcanism and plate motion, produced a complex set of faults, some of which are masked by younger limestone deposits and some of which are expressed on the surface. Net uplift that probably exceeded 500 m has left Rota with a maximum elevation of 496 m and mantled with limestone to within 20-30 m of the summit on the *Sabana*. The highest part of the *Sabana* is composed of the weathered clay product of volcanics and a small amount of intact volcanic rock. Formerly intensive, and still active agriculture, combined with remarkably low relief and thick vegetation, make the contact between the limestone and the volcanics difficult to locate on the *Sabana*. The *Talakhaya* area, on the south side of Rota is a stream eroded hill slope dominated by an exposure of red clay weathered from the volcanics. The contact with the overlying limestone is at about 350 m elevation and is exposed laterally for about 4.5 km. This slope is covered by a discontinuous band of limestone at about 100 m elevation and covered with a continuous band of limestone along the coast. The steep scarp at the top of the *Talakhaya* suggests that this exposure of the core of the island was produced by mass wasting. At the western end of the *Talakhaya*, at *Pugua*, there is what appears from the air, to be the tongue of a slide about 700 m long and 300 – 400 m wide. The well-known Japanese Canon sits on this probably ancient slide. The *Talakhaya* contains the only surface streams on Rota. The rest of the island is classic island karst terrain with autogenic recharge.

The two springs that presently provide all the municipal water for Rota issue from the contact of the limestone and the underlying volcanics near the top of the *Talakhaya*. Water Cave (*Matan Hanum*) is located at 350 m elevation, about 2 km directly south of the summit of the island on the *Sabana*. Based on its morphology, Water Cave is thought to be a flank margin cave that coincidentally developed at the contact and now intercepts a large part of the underground flow along the contact from the recharge area on the *Sabana*. Most of the water collected into the municipal system at Water Cave, several thousand liters per minute, appears inside the cave from impassable holes along the east wall. Municipal water is also collected at *As Onan* Spring on the contact at about 350 m elevation, about 1.5 km east of the Water Cave (Stafford et al., 2002). The volcanic/limestone contact at the level of the Water Cave has many smaller springs that are not tapped for municipal water.

Rota is fringed for much of its perimeter by Holocene reef limestone that was exposed by tectonic uplift. Estimates of the maximum amount of uplift range from 3.1 m (Dickinson, 2000), to 3.5 m (Kayanne et al., 1993). Weathering and erosion of this recently exposed limestone has produced a jagged, rugged coast around most of the island.

Bell (1988) and Wietzychowski (1989) published MS theses documenting diagenetic change of the lower elevation limestones around the perimeter of Rota. While important to the geologic knowledge of Rota, the work of these authors is not directly applicable to the present project since neither included caves in their research.

### **Known Caves of Rota**

Sugawara (1934) almost completely ignored the caves of Rota, making passing mention of the presence of caves. Stephenson and Moore (1980), in documenting fresh water use customs on Rota, mention the Water Cave several times. Rogers and Legge (1992) documented some of the caves on Rota including: *Taga (Tonga) Cave*, a large cave adjacent to *Songsong Village*; a popular coastal spot called the Swimming Hole; and the Water Cave, which they called Water Fall Cave. Rogers and Legge (1992) report that some caves on Rota were mapped during their investigation but no cave maps were published, however, cave names that they published will be maintained except where there are compelling reasons to use more common local names. Not until a report of the reconnaissance visit by Stafford et. al (2002), do the caves and karst of Rota reappear in the literature. Stafford et. al (2002) mapped two small recharge caves on the *Sabana*, which they named *Sabana Caves #1* and *#2* (herein changed to Rota Rooter Cave and Discus Cave), mentioned visiting *Taga (Tonga) Cave* at *Songsong Village* and the prominent horizon of remnant flank margin caves on the northeast point of the island at *As Matmos*, reported on their visit to the Water Cave, reported a horizon of breached flank margin caves along the *Tachok* cliffs near *Songsong Village* and reported that the Swimming Hole resembles a caleta of the Yucatan (Back et al., 1984). This work by Stafford et. al (2002) acted as the foundation for the work reported here.

## **METHODS OF INVESTIGATION**

### **Data Collection**

Fieldwork on Rota was conducted with the support and assistance of personnel from the Water and Environmental Research Institute of the Western Pacific (WERI). The reconnaissance work of Stafford et. al (2002) and advanced study of the USGS topographical map of Rota (1999) was used to devise a preliminary plan for finding caves and karst features on Rota. Once work began on Rota, the locations of newly found caves and information from island residents were used to revise the search plan. During their reconnaissance visit, Stafford et. al (2002) established relationships with several governmental agencies on Rota, including the Office of the Mayor, the Commonwealth Utilities Corporation, the Historic Preservation Office, the Department of Lands and Natural Resources and the Department of Wildlife Conservation. These relationships provided the foundation for tremendous cooperation and assistance from these agencies (see Acknowledgements, page ix).

All significant cave and karst features located were classified as one of the following: flank margin cave, fracture cave, sea cave, contact cave. When appropriate, these features were surveyed using standard cave survey techniques as documented by Dasher (1994). A unique name was assigned to each documented feature and each feature was photographed when possible. Feature locations were determined with handheld Global Positioning System (GPS) units whenever possible. When GPS was not

available, locations were be estimated from the USGS topographical map of Rota (1999). Cave locations were recorded as UTM coordinates.

### **Data Processing**

The survey data from each cave was reduced using the WALLS Project Editor (McKenzie, 2000) computer program. The line plot of the cave produced by WALLS Project Editor (McKenzie, 2000) was imported into XaraX (2001) drawing program. The sketch of the cave made as part of the survey was scanned and converted to a digital file which was then imported to XaraX (2001). The line plot and the sketch were properly sized and oriented so that a map of the cave could drawn to the appropriate scale. The cave and the features within it were depicted using the symbols adopted by the Association of Mexican Cave Studies (Sprouse and Russell, 1980). Other symbols were incorporated as needed to properly depict the features discovered in various caves. The maps cave maps produced to date are included in appendix B of this report.

## CAVE AND KARST FEATURES OF ROTA

Descriptions of the individual named cave features on Rota are listed alphabetically in Appendix A of this report. Since the investigation of the caves and karst of Rota is ongoing, this report is preliminary. Further investigation is expected to document caves that may or may not change the tentative conclusions presented here.

As expected from the previous investigations of the caves on Saipan, Guam and Tinian (Myloie and Jenson, 2001; Myloie et al., 2001; Stafford, 2003; Stafford et al., 2002; Stafford et al., 2003; Taborosi, 2000; Taborosi and Jenson, 1999), and from the relatively brief investigations of the caves of Rota by Rogers and Legge (1992), and by Stafford et. al (2002), Rota has many flank margin caves, some obvious sea caves, some caves influenced by underlying volcanic rock and many caves developed along bedrock fractures. However, the investigations done on the other islands in the Mariana Arc did not predict the large number of fracture caves found on Rota. Forty three of the 81 documented caves on Rota are developed along bedrock fractures. Thirty three of these fracture caves are mixing zone fracture caves, discussed below. These numbers are somewhat misleading for two reasons: 1) the extensive horizon of flank margin caves at Sagua was survey as one feature, but could be counted as about 20 separate caves, 2) there are known horizons of remnant flank margin caves in the cliff face at *As Matmos*, in the cliff face below the western end of the *Chenchon* Bird Sanctuary and in the cliff face in the middle of *Alaguan Bay*, that have not been surveyed. Regardless, the significance of fracture caves on Rota is a new discovery in the Mariana Islands. Fracture caves on Rota tend to have entrances that open at or near the bases of cliffs and they tend to vary greatly in length but a maximum length of about 100 m. Most fracture caves are oriented normal to the cliff face. These caves tend to be quite linear, and the fractures along which they are developed are often prominently visible in the ceiling. The floors of these caves tend to be fairly level, with some significant exceptions. Since little structural geology on Rota has been mapped, it is difficult to definitively state the nature of the individual fracture along which any given fracture cave is developed. Some of them appear to be simple fractures with minimal displacement, while others appear to be significant faults. For the purpose of this discussion, the caves of Rota have been divided into 4 categories: Fracture caves, flank margin cave, contact caves, and sea caves.

### Fracture Caves

Stafford (in press) identified three basic types of fracture caves on Tinian and Aguijan. The first type is caves developed along fractures normal or near-normal to the coast that show evidence of having formed in the mixing zone as the fracture discharged fresh water. On Tinian and Aguijan this type of cave was found to extend as far as 30 m horizontally. In this report caves of this type that developed by from fresh water discharge along a fracture will be called "mixing zone fracture caves". The second type identified by Stafford (in press) is formed by the solutional modification of fractures formed by bank margin failure along scarps or coastal cliffs. Stafford (in press) reported that some of these caves on Tinian and Aguijan were over 40 m deep and reached the water table. This type of cave has not been documented of Rota. The third type of fracture cave found on Tinian and Aguijan is apparently formed by dissolution and



collapse along steeply dipping fault planes. A few small features on Rota are similar to these fault plane caves but the lack of geologic mapping on Rota make it difficult to determine if these features are developed along faults or along fractures with no displacement. In this report, this type of cave will be called “non-mixing zone fracture caves”.

### **Mixing Zone Fracture Caves**

As mentioned above, Rota has 33 documented caves that apparently formed from fresh water discharging from a bedrock fractures at or just below sea level. The mixture of the discharging fresh water and sea water would have an enhanced ability to dissolve limestone, even if the fresh water and sea water were saturated (see above and, Bögli, 1980; Palmer, 1991; Plummer, 1975). It is hypothesized here that development of these caves progresses as this mixing zone works its way headward in the discharging fracture, somewhat analogous to the headward erosion of a waterfall. The morphology of the mixing zone fracture caves on Rota fits this model. Most of the mixing zone fracture caves have fairly wide entrances that can be explained by the erosive and dissolutional action of waves. The main passages of these caves are generally quite linear with walls that are near parallel. The end of several of the mixing zone fracture caves on Rota have a “boneyard” (dissolutional fretwork) appearance that suggests an aggressive dissolutional environment, as would be expected where fresh water discharged from the narrow fracture into the previously formed part of the cave. Almost all the mixing zone fracture caves have ceilings that extend up into the fracture along which the cave is developed. In several places on Rota, mixing zone fracture caves have formed in clusters that are close enough to suggest that they formed during the same sea level still stand and that their genesis may be related. The largest mixing zone fracture caves on Rota are significantly larger than the largest ones documented by Stafford (in press) on Tinian or Aguijan. Several mixing zone fracture caves on Rota extend greater than 100 m from the cliff face in which they are found. Among the largest are *Liyang Matan* and *Knuckle Bone Cave* near *As Matmos*, *Liyang Botazon* at *Fina’ Atkos* and *Deer Cave*, facing *Alaguan Bay*. The drip lines of all three of these caves are set back a few tens of meters from the cliff face in which the cave is located. If the areas outside the actual caves are included, these features are by far the largest cave/karst features on Rota.

As mentioned above, some of the fracture caves on Rota appear in clusters. At the base of the cliff in the *Chenchon* Bird Sanctuary there are two clusters. The northernmost cluster consists of *Liyang Paluma* and *Liyang Lu’ao*, plus the much smaller *Letterman Cave*, which are within about 40 m of each other. Further south, *Arrowhead Cave* and *Liyang Neni* are about 30 m apart. *Liyang Siete* is in this same general area but was not closely associated with another cave feature. The problematic *Liyang Siete* is tentatively classified here as a remnant of a fracture cave, but may be a solutionally modified bank margin fracture that was never a cave.

Another cluster of four fracture caves was found at the base of the cliff, inland from *Puntan As Fani*, on the eastern end of Rota. *Liyang Apaka’*, *Honey Comb Cave*, *Forked Cave* and *Birthday Cave* are all within about 40 m of each other. While *Liyang Apaka’* is significantly larger than the other three caves, they all were apparently developed by fresh water discharging along bedrock fractures that are clearly visible in the ceiling of each cave. *Liyang Apaka’* is different from most of the fracture caves

documented on Rota in that the fracture along which the cave is developed is visible at the cave entrance and near the back of the cave but not in the middle of the cave where the ceiling drops to less than 2 m.

Another cluster of caves that are clearly developed along bedrock fractures was found along the top of the first cliff above *Puntan Haina*, on the southeast side of Rota. *Liyang Perseverance* and Second Chance Cave are located just below the cliff top while Incidental Cave is located about 15 m lower. Second Chance Cave is intriguing in that the ceiling of the cave appears to be a single, sub-meter thick layer of cemented boulders and cobbles. The section of cliff adjacent to these three caves has several unnamed features that appear to be collapsed caves that were oriented normal to the cliff face, like the three existing caves. *Liyang Perseverance* and Incidental Cave are accessible by climbing up from *Puntan Haina*, but Second Chance Cave would be very difficult to reach by this route. Second Chance Cave is accessible via the largest of several skylights that are several meters inland from the cave entrance in the cliff face.

At *Puntan Fina Atkos*, at the eastern tip of Rota are three large fracture caves that may constitute a cluster but are more widely spaced than caves in some other clusters. If the size to which a fracture caves grows is a function of the amount of water that discharges through it, along with other factors, then it might be expected that larger fracture caves would be more widely spaced. *Liyang Matan* (Cave of the Eye), Knuckle Bone Cave and Bonus Cave are each greater than 100 m long, among the longest documented fracture caves on Rota. The entrances to *Liyang Matan* and Knuckle Bone Cave are incised into the cliff face by a few tens of meters, probably by collapse of the outer part of the cave roof. This collapse was probably promoted by the existence of two parallel fractures that each of these caves are developed along. Each cave would be significantly longer if the distance from the drip line out to the cliff face was included. One of the fracture along which Knuckle Bone Cave is developed is very prominent on the cliff top above the cave, expressed for part of its length by a raised wall of more resistant limestone on one side of the fracture. The fracture along which Bonus Cave is developed did not show much surface expression. Any possible surface expression of the fractures along which *Liyang Matan* is developed is obscured by thick vegetation. Bonus Cave is oriented near-parallel to the present cliff face that contains an extensive horizon of remnant flank margin caves. This orientation is unusual for mixing zone fracture caves on Rota.

*Liyang Ganas* and *Nanong Katiyu* (Rogers and Legge, 1992), in the cliff face just east of *Liyang Tonga*, in *Songsong Village*, are near-parallel fracture caves containing historical human modifications, including a man made tunnel connecting them. From the existence of the tall, narrow entrance on the south side of *Liyang Tonga*, an argument can be made that it is the remnant of a fracture cave that was breached in the side by cliff margin failure and that these three caves constitute a cluster

Although not found in apparent clusters there are several other significant fracture caves on Rota. *Taisacan Museum Cave*, near *Esong*, is significant for its size. Pictograph Cave, at *Gampapa*, is a significant fracture cave for its size and for the canyon extending from the cave entrance that apparently represents collapsed cave passage, giving this feature a length in the range of 100 m, around the maximum length of fracture caves on Rota.

*Liyang Botazon*, at the prominent coastal notch at *Fina' Atkos* (south of *Puntan Fina Atkos*), is unique among the documented fracture caves on Rota in that it opens at the present sea level and has storm tossed boulders and plastic net floats at the back of the cave, about 100 meters from the shore line. The prominent canyon above *Liyang Botazon*, cutting steeply across several cliff lines and extending up to the wide bench below Pictograph Cave, suggests that development of this feature is along a significant fault, although do evidence of displacement is documented. The sets of linear fractures and small caves of the Banyan Complex, including Not Much Cave and Skull Cave, appear to be in alignment with the *Fina Atkos* canyon. The Banyan Complex is classified at non-mixing zone fracture caves (see below). Further inland, in a cliff face, there is a vertical notch, also in alignment with the *Botazon* canyon. Along the base of the coastal cliffs on either side of *Botazon* are what appear to be caves. However, large waves made exploration of these features unsafe during the investigation of this area during the Winter 2003-2004 field season. They should be safely accessible during the calmer seas of the summer.

*Liyang Alapin* is an isolated fracture cave located in the cliff face inland from *Poña Point*. *Liyang Alapin* stands out for its lack of linearity, appearing to have developed along two parallel cliff margin fractures and one fracture oriented sub-normal to the cliff face.

Deer Cave is a large, isolated fracture cave, developed along two parallel fractures, at the base of the cliff at *Payapai*. Near it however, are *Alaguan Feature A2* and *Alaguan Feature A3*, which are shallow cave-like features developed along bedrock fractures that possibly have a genesis related to fracture caves.

Along the inland cliff face south west of *Ginalangan* are the Four Crosses and Kaigun 223 Japanese Command Post. Features at both these locations appear from a distance to be cave entrances. However, they are shallow features developed along fractures similar the *Alaguan Feature A2* and *Alaguan Feature A3*. The man made tunnels At Kaigun 223 were surveyed as an example of such historic features on Rota.

Near *Taksunok*, *Liyang Finta* is a fracture cave that is also expressed on the cliff top above it. Many broken and re-cemented speleothems and the rubbly facies below *Liyang Finta* in which Basement Cave is developed suggest that this fracture is in fact a fault the has had movement since the development of *Liyang Finta*. No map of *Liyang Finta* has due to survey error that was discovered after the end of field work.

Canyon Cave is located about 40 m inland from the coast near Deer Cave, south of *Alaguan Bay*. The cave is formed at the head of a canyon that runs inland from the coast. The width, 4-5 m, and the shear walls of the canyon suggest that this canyon/cave arrangement is associated with a fault. Further investigation should be done to determine it the trend of this canyon coincides with Deer Cave, which is developed along a linear fracture.

### **Non-mixing Zone Fracture Caves**

The sub-category of non-mixing zone fracture caves includes solutionally modified fractures and fractures that are large enough to be considered talus caves that do not show evidence of significant solutional modification.

Flange Cave is located at the northern edge of the closed depression, on the east side of the Sabana, at the base of the prominent (fault?) scarp there. The cave is

developed along one or more fractures parallel to the scarp. Flange Cave is at the boundary on the jumbled rock along the scarp and the highly pitted, pinnacle karst of the closed depression.

Southwest of Tachok, near the Rota Zoo, Village View Cave is prominently visible from the road. While there is fracture associated with Village View Cave, it appears that the fracture is a result of the presence of the cave and not vice versa. The larger remnant flank margin chamber of Village View Cave is intersected by a displaced fracture that extends to the top of the cliff above the cave and out to the cliff face south of the cave. The relative lack of solutional modification in the fracture indicates that it is much younger than the cave. The boulder created by this fracture has dimensions of well over 10 m.

Slab Cave, located east of *Liyang Finta*, is a simple talus cave formed by a bank margin failure slab. Slab Cave has minimal solutional modification, suggesting that it is relatively young.

While each is developed along a fracture, Bitsy Cave, Bee Cave, and One Shot Cave are much too small to be helpful in gaining an increased understanding of Rota's caves.

### **Flank Margin Caves**

The most outstanding section of flank margin caves documented is the *Sagua Cave Complex*, consisting of multiple flank margin caves exposed in the cliff face at and just above sea level at *Sagua* across *Sasanhaya Bay* from *Songsong Village*. The degree to which these caves are open indicates that significant portions of most of them may have been destroyed by erosion. Many of the caves in this complex have skylights and/or multiple entrances. The *Sagua Cave Complex* is the longest semi-continuous horizon of flank margin caves documented in the Marianas to date. Just to the west of the *Sagua Complex*, *Saguita Cave* is another remnant flank margin cave similar to those in the *Sagua Complex*.

Although more dispersed than those in the *Sagua Complex*, the caves along the coastal cliff west of *Okgok* represent significant flank margin cave development. These include Christmas Cave, Dasher Cave, Dancer Cave, Prancer Cave, Vixen Cave, Comet Cave, Cupid Cave, Agrippa Cave and Arch Cave. These caves may simply be individual flank margin caves or they may be the remains of a formerly more extensive complex. Their position along the coast below the surface streams of the *Talakhaya* suggests that each of these caves may possibly be related to surface drainage. Further investigation of the relationships between this "string" of caves and the streams on the *Talakhaya* is warranted. Based on Agrippa Cave's location about 2 m above a spring apparently perched on volcanic rocks, its formation was probably affected by the volcanic rocks as well as by fresh water discharge, although no volcanic rocks are visible inside the cave.

Picnic Cave is located at the coast, adjacent to the road, near the Veterans Memorial on the north east coast. Picnic cave is more like the typical flank margin cave of the Bahamas than any other cave documented on Rota. It is less than 1 m above present sea level and located in a limestone "hill" along the coast.

In terms of culture and hydrology, the Water Cave (*Matan Hanum*), reported as Water Fall Cave by Rogers and Legge (1992), is the most significant cave on Rota since

it is the source for most of the fresh water entering the municipal system. Water Cave is apparently a flank margin cave that coincidentally developed at the contact between the volcanic basement rock and the overlying limestone that is now at an elevation of about 350 m on the *Talakhaya*. Apparently, the buried topography of the underlying volcanic rock concentrates the flow of water that sinks on the *Sabana*. This concentrated flow appears from holes along the east wall of the Water Cave. There are also several smaller springs along the contact just outside the Water Cave. A system of pipes collects water to be delivered by pipelines west to *Songsong Village* and northeast to *Sinapalo*. The elevation of Water Cave (approx. 350 m) allows the use of a gravity fed system without the need for pumps. About 30 m east of the Water Cave is *As Matan*, an apparent flank margin cave remnant located about 3 m above the volcanic/limestone contact. The limestone that this cave is developed in is very crumbly and reddish to pink, apparently resulting from a high clay content due to its proximity to the volcanics. There are several springs along the volcanic/limestone contact between the Water Cave and *As Matan* that were flowing significantly greater in January 2004 than in June 2003. Discharge at the Water Cave is known to vary seasonally.

The *Reyes Cave Complex*, located in the cliff face just north of *I Koridot*, is problematic. There are indications that these wide-open rock shelters are the remnants of flank margin caves. However, they may simply be sea cave formed primarily by erosion. Steeply dipping bedding planes are exposed in all the part of this complex. About one km north of the *Reyes Complex* is another ridge in near alignment with the *Reyes* ridge. In this northern ridge is *Liyang Ayuyu*, which penetrates into the ridge about 30 m. This cave is much more enclosed than caves of the *Reyes Complex* but also has strong expression of dipping bedding planes.

Crab Hunter Cave is a small flank margin cave along the road leading from the west end to the *Talakhaya*. Crab Hunter Cave has very strong expression of dipping depositional beds.

Hourglass Cave and Monkey Cave are flank margin caves in the east wall of the notch in which *Liyang Finta* is located. They are located at significantly different elevations indicating that they represent different sea level still stands. The larger Monkey Cave has a somewhat linear character indicating the a fracture in the bedrock may have affected its formation, yet its overall morphology indicates that it is a flank margin cave.

Bay Cave Remnant is located just south of the cliff embayment on *Alaguan Bay*. This feature appears to be a remnant of a once much larger flank margin cave.

Exception Cave is located just below the top of the cliff at *Duge*, and is accessible but not visible from above. It is the highest of several caves that are visible from the coastal bench below *Duge*. None of these other caves have been surveyed and most would be very difficult to reach due to steep slopes and very thick vegetation.

The Swimming Hole, first documented by Rogers and Legge (1992), located on the north coast of Rota, is most likely a collapsed flank margin cave. Three rock slabs in the pool appear to have once been part of the roof of the cave. Since fresh water presently discharges at the Swimming Hole, it may be analogous to the caletas of the Yucatan, Mexico (Back et al., 1984). Perhaps the Swimming Hole is the remnant of a flank margin cave that formed immediately prior to the Holocene uplift of Rota

(Dickinson, 2000; Kayanne et al., 1993). The coast east and west of the Swimming Hole should be explored for similar features.

*Alaguan Bay Cave* is located on the south side of the cliff embayment adjacent to *Alaguan Bay*. This flank margin cave is developed in what appears to be a facies composed of large limestone boulders that had been re-cemented prior to the development of the cave. Although local informants reported no other caves in this embayment, further exploration along the same elevation as *Alaguan Bay Cave* might be productive.

Some other, smaller flank margin caves include: *Alapin Two*, a small flank margin cave located a few meters away from *Liyang Alapin*; *Liyang Chenchon*, located on the bench at *I Koridot*; *Itsy Cave*, a very small flank margin remnant near *Deer Cave*; *Shoo Fly Cave*, located near the east end of the *Talakhaya* near the road; and *Husky Cave*, located a few meters west of the mouth of *Liyang Matan*, near *As Matomos*.

### Contact Caves

Although they are located at the volcanic/limestone contact on the *Talakhaya*, the *Water Cave* and *As Matan* are discussed under Flank Margin Caves above.

There are three other true contact caves on the Sabana. The largest, by far, is *Summit Cave*, located at the bottom of sinkhole (closed depression) on the Sabana, on the south side of the summit of Mt. Sabana, the highest point on Rota. *Summit Cave* appears to take in a great deal of surface water from the clay and volcanic rock exposed on the highest parts of Mt. Sabana. However, the lack of any indication of back flooding inside the cave indicates that it is able to quickly pass through the water that it does receive. *Summit Cave* is a likely choice for an input point for a dye trace of the Sabana Watershed/ *Talakhaya* contact discharge system. *Discus Cave* and *Rota Rooter Cave*, in the large closed depression north of the Sabana Peace Memorial, are both very small but probably both play a role in rapid direct recharge to the aquifer during heavy rain events. Observing all three of these features during and after heavy rainfall should be informative.

The other cave on Rota whose development was influenced by a volcanic/limestone contact is very different from the three on the Sabana. *Black Cobble Cave* is the largest cave along the coast between *Okgok* and *Poña Point* and was probably formed by the breaching and erosional modification of a flank margin cave that happened to develop along a pyroclastic flow that pinches out almost exactly at present sea level. The pyroclastic wedge is clearly visible in the west wall of the cave. A large part of the outer floor of *Black Cobble Cave* is covered with cemented carbonate sand (beach rock) that has black volcanic cobbles dispersed through it and eroded in relief. The beach rock is clearly stratigraphically younger than the limestone and volcanics that the cave is developed in and is probably younger than the cave.

*I'm Your Cistern Cave* is a flank margin remnant in the cliff face at *Tachok*, east of *Songsong Village*. The original part of *Village View Cave*, discussed above under *Fracture Caves*, is a flank margin remnant.

As mentioned above, there are extensive horizons of apparent flank margin caves in cliff faces at *As Matomos*, in the cliff face below the western end of the *Chenchon Bird*

Sanctuary and in the cliff face in the middle of *Alaguan Bay*, that have not yet been fully explored or surveyed.

### Sea Caves

Since glacio-eustasy has moved relative sea level across a great deal of the surface of Rota, it is not surprising that many of the caves appear to have been modified by waves. However, a few cave on Rota appear to have formed almost exclusively by physical erosion of the bedrock by waves.

The largest known sea cave is Double Cave at the base of the cliff, along the beach between *Puntan Malilok* and *Gaonon*. It is presently well within the reach of storm waves and contains much debris. The walls of the cave and the cliff face all along this stretch coast exhibit dramatic, large scale cross bedding that is apparently from fore reef deposition.

The other know sea caves are Paupau Sea Cave on the south side of the isthmus connecting the Wedding Cake (*Taipingot*) to the rest of Rota, and Sea Cave A1, in the wall of a coastal notch along *Alaguan Bay*.

Some of the features seen along the coast of Rota during a reconnaissance by boat in June 2003, are probably sea caves but have not been explored due to unsafe access.

### SUMMARY AND TENTATIVE CONCLUSIONS

The interaction of glacio-eustatic sea level change, local uplift and subsidence, fracturing and faulting, location of the volcanic/limestone contact, mixing dissolution, mass wasting and wave erosion have created a variety of caves at a variety of elevations on Rota. There are caves at sea level (probably some below sea level) and caves within 30 m of the summit of the island.

As expected from investigation of the caves on other islands in the Mariana Arc, Rota has a significant number of flank margin caves, a few contact caves and a few erosional sea caves. However, the large number of fracture caves, particularly mixing zone fracture caves, sets Rota apart from the other islands in the chain. The use of contact springs as a municipal water source on Rota is unique in the Mariana Islands.

Further field work and analysis is necessary to fully characterize the caves of Rota and gain a full understanding of their relationship to the geology and hydrology of the island.

## APPENDIX A

### DESCRIPTIONS OF THE CAVES OF ROTA

**Conventions:** For clarity some conventions were adopted for writing these cave descriptions. All cave names based on the local Chamorro language, and all place names taken from the USGS topographical map will be italicized. Note that some Chamorro words contain prefixes that are the same as English words, i.e. *I* and *As*. If a feature name contains Chamorro and English words, the entire name will be capitalized for consistency. All number values will be presented as numeral ( e.g. “4” not “four”), except that numbers that begin sentences will be spelled out.

#### **Agrippa Cave**

Agrippa Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. Agrippa is distinctive from the other caves in this area in that it is about 2 m directly above a spring that is discharging about 1m above sea level. The spring apparently discharges above sea level due to being perched on volcanics bedrock. Despite Agrippa Cave’s proximity to an active spring, the shape of this cave suggests flank margin type development. The cave is about 8 m long and 5 m wide. At the entrance it widens to about 8 m. The cave is about 1 m high throughout except for somewhat taller at the entrance. Near Agrippa Cave, above the active spring, is a very small hole that appears to be a paleo-spring conduit that is not enterable.

#### **Alaguan Bay Cave**

*Alaguan Bay Cave* is located on the south side of the embayment at *Alaguan Bay* at about 50 m elevation. The entrance is 4 m wide and 2 m high and extends for 3 m before the cave opens up into an irregular chamber 20 m long and 12 m wide. Off this room are a few small chambers, all higher than the main floor. The walls and floor at the rear of the main chamber are covered with flowstone and stalagmites. The ceiling and walls of this cave show strong evidence of the bouldery facies that that the cave is apparently developed in. One boulder visible at the back of the cave is about 3 m diameter. Based on the location and the shape, this is apparently a flank margin cave.

#### **Alaguan Feature A2**

*Alaguan Feature A2* is located south of the large embayment at *Alaguan Bay* and is documented as an example of the features that are visible from sea and appear to be large cave entrances but which contain no significant cave. It is a shallow rock shelter developed along a fracture in the cliff face. There is one small indentation high in the cliff face the back of which is not visible from ground level. Perhaps this feature represent a mixing zone fracture cave that never developed because fresh water that it might have discharged, was diverted to another fracture, perhaps nearby Deer Cave.

#### **Alaguan Feature A3**

*Alaguan Feature A3* is located south of the large embayment at *Alaguan Bay* and is documented as an example of the features visible from off shore and appear to be large cave entrances but which contain no significant cave. This feature is apparently developed along a fracture in the bedrock and extends back from the face of the cliff for



about 10 m. The feature is about 3 m wide and the main part is about 10 m high. There is a fissure in the ceiling that extends upward an undetermined distance. The floor is covered with boulders so that its shape of the bedrock below cannot be determined.

### **Alaguan Sea Cave A1**

This small feature was mapped as an example of a sea cave, the development of which appeared to be almost entirely controlled by physical erosion as opposed to dissolution. It is located at about 10 m elevation near *Alaguan Bay* at the base of the large embayment that dominates this stretch of coast. It consists of about 11 m of drip line and only extends back about 5 m.

### **Alapin Two Cave**

*Alapin Two Cave* is a few meters from the entrance to *Liyang Alapin*, in the cliff face inland from *Poña Point*. It is apparently a remnant of a formerly larger flank margin cave. The cave is about 8 m wide, about 2 m high across most of its span and is divided by a bedrock wall near the rear. In plan view, the cave is a truncated oval about 6 m in diameter.

### **Arch Cave**

Arch Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. The cave has two levels connected by a vertical hole. Each of the two levels has the appearance of a breached flank margin cave. Other caves in the area do not exhibit two-level development. The lower level consists of one low, wide “room” completely open on the south side. The upper level consists of an open “room” about 5 m high and about 20 m wide. It narrows to a small passage in the rear that leads to a chamber about 3 m wide and 2 m high.

### **Arrowhead Cave**

Arrowhead Cave is one of several linear caves located in the cliff base, north of the *Chenchon* Bird Sanctuary overlook. This 50 m long, linear cave is obviously developed along a bedrock fracture. The floor of the cave is nearly level and covered with loose soil, probably including old guano. The entrance to Arrowhead Cave is about 13 m wide and about 17 m high. About mid-length of the cave it is only about 4 m wide and narrows to 1-2 m before ending abruptly. The crack along which the cave is developed is prominent along the length of the cave. In one area of the cave the ceiling crack is so high that an estimate of the ceiling height was not possible.

### **As Matan Cave**

*As Matan Cave* is located at the about 350 m elevation, about 30 m east of Water Cave (*Matan Hanum*) on the *Talakhaya*. The 10 m wide by 7 m high entrance is reached by climbing up about 3 m from the base of the cliff at the limestone/volcanic contact. This climb up is set back about 4 m inside the drip line. The contact is not exposed inside the cave. The cave consists of one room the width of which varies from 10 m at the entrance, to about 8 m in the middle and narrowing to a pinch out at the back, about 25 m from the drip line. Cross sections of the cave indicate that it is developed along the fracture visible in the ceiling. On the left side of the widest part of the cave are two small passages

sloping downward through the crumbly, incompetent, argillaceous limestone that the cave is developed in. These passages are very small and unstable and only extend a few meters.

### **As Onan Spring**

*As Onan Spring*, located at about 350 m elevation on the east end of the *Talakhaya*, is used as a source for municipal water that is pipe to the *Sinapalo* region of Rota. It is a series of springs at the limestone/volcanic contact, modified with small concrete catchments and pipes to collect the water and surrounded by a chain link fence on the down slope side. The limestone overhangs the igneous rocks for about 50 m along the cliff face creating a shelter cave 3-4 m wide and a maximum of 3 m high. At the individual springs, small passages have developed along the contact that penetrate no more than 1-2 m beyond the back wall in most cases. The longest penetrates about 8 m before becoming impassable.

### **Banyan Complex**

The Banyan Complex is located on the nearly level bench, north east of Pictograph Cave. The Banyan Complex consists of several small cave features (not all of which were surveyed) developed along a series of linear fractures clearly visible in the surface. Not all the fractures in this area are parallel. Most of the cave features in the Complex are small vertical shafts about 2 m deep and about 1 m in diameter. The cave on the northern part of the mapped portion of the Complex is about as deep as the other features but also has about 4 m of passage.

### **Basement Cave**

Basement Cave is located just below *Liyang Finta*, a fracture cave at 50 m elevation and is apparently developed along the same fracture. Airflow detected in *Liyang Finta* was probably coming up from Basement Cave. Basement Cave only extends about 6 m back from the drip line. It is about 3 m high at the drip line but closes to about 2 m at the rear. The cave appears to have possibly developed by boulders and cobbles filling in a fracture, becoming cemented, some of this bouldery facies material being removed.

### **Bay Cave Remnant**

Bay Cave Remnant is located south of the embayment at *Alaguan Bay*, in the 3 m bench along the coast. It consists primarily of a 15 m by 25 m embayment in the cliff. The deepest point is about 4 m below the surrounding bench. The floor of the embayment has a series of 1 m bedrock ridges running parallel to the embayment. On the south side of the embayment is a section of cave that opens onto the embayment at both ends. The cave segment has an irregular cross section with maximum dimensions about 3 m by about 3 m. The passage is about 15 m long. Bay Cave Remnant appears to be the remnants of a flank margin cave.

### **Bee Cave**

Bee Cave is located on the northwest side of the Wedding Cake (*Taipingot*) about 150 m from Tewksbury Park and is accessible by climbing about 9 m up the cliff face. Bee Cave is a shallow overhang developed along a fracture in the limestone bedrock. There is a beehive hanging over the entrance to this small feature.

### **Birthday Cave**

Birthday Cave is the northernmost of four linear caves located adjacent to each other at about 30 m elevation, in the cliff face inland from *Puntan As Fani*, south of *Fina' Atkos*. Birthday Cave is about 13 m long and developed along an obvious fracture that is expressed in the ceiling of the cave for its full length. For most of its length, Birthday Cave is about 2-3 m wide and 7-8 m high. The floor of the cave is very flat and covered with soil and a few boulders near the entrance.

### **Bitsy Cave**

Bitsy Cave is a very small feature just above the active bio-erosion notch, at the west end of the point below *Gaonan*. It is apparently developed as dissolution and physical erosion exploited a crack in the bedrock. Although the vertical part of the cave is far too small to be passable, it does allow light in from the cliff top about 3-4 m above the cave entrance. The drip line of Bitsy Cave merges with the bio-erosion notch on the east side of the cave.

### **Black Cobble Cave**

Black Cobble Cave is located at sea level, about 400 m west of the western most stream draining the *Talakhaya*. The cave is about 25 m long, 20 m wide at the entrance and developed along an obvious pyroclastic flow which is prominently visible in the east and west walls of the cave. There is small side room on the east, just inside the entrance. At the back and over part of the front, the floor of the cave is covered with storm washed boulders and cobbles. About 1/3 of the cave floor is covered with an buff-colored (Holocene?) limestone that contains a number of black basalt cobbles that are eroded out in striking contrast to the limestone matrix. Close examination reveals that this buff-colored limestone is stratigraphically above the pyroclastic flow, meaning that it is younger than the cave as well.

### **Bonus Cave**

Bonus Cave is located at about 30 m elevation, about 1 km east of the end of the road at *As Matmos* and is the first of three large cave entrances along this stretch of cliff face. The entrance is visible as a about 20 tall cleft in the cliff face. The cave consists primarily of one large passage 10-20 m high and 6-8 m wide running at about 280 degrees for about 100 m. The passage ends with a small room and some bedrock "bone yard" at the back of the cave. The "bone yard" is believed to be similar to cave "sponge work" documented by Palmer (1991) and is thought to indicate an aggressive dissolutional environment. Bonus cave is developed along an obvious linear fracture in the bedrock. Along the lower walls in some parts of the cave are "curbs" of what appear to be bedrock sticking out about 0.25 m from the wall and running horizontally for several meters.

### **Canyon Cave**

Canyon Cave is a small feature at the head of a canyon in the first terrace inland from the coast, south of *Alaguan Bay*, at about 15 m elevation. The cave and the canyon appear to be developed along a fracture (fault?) The cave extends about 9 m from the drip line and is about 14-15 m wide. The floor of the “C” shaped chamber is mostly covered with boulders and cobbles. It does not appear that the canyon adjacent to this small feature is the collapsed remains of a larger cave.

### **Christmas Cave**

Christmas Cave is located just inland from the west end of the beach at *Okgok*, where the main stream from the *Talakhaya* enters the ocean. The entrance to the cave is about 10 m wide and about 4 m high. The drip line merges with the inactive bio-erosion notch the runs along this cliff face. The cave extends back about 8 m from the drip line with the northern end of the cave being partially enclosed. The cave is developed in bedrock exhibiting very evident dipping, depositional beds—possible fore-reef facies.

### **Coastal Fissure Example (no cave)**

The feature, on *Alaguan Bay*, was surveyed as an example of a coastal fissure that does not appear to have ever had a roof. It is about 25 m long and about 7 m deep with the walls forming a “V”. It apparently forms from dissolutional widening of fracture in the limestone by wave action.

### **Comet Cave**

Comet Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. Two distinct parts of Comet Cave are encompassed by one drip line. The western, higher part consists only of a back wall, floor and overhanging ceiling and appears to be a remnant of a flank margin cave. This part of the cave is about 1.5 m high, 5 m wide and 11 m long. The eastern, lower part of the cave is an open irregular chamber that appears to be developed along a fracture. It is about 10 m long, 3 m wide and 5 m high for most of its length. At the rear a small hole allows light to enter from above.

### **Crab Hunter Cave**

Crab Hunter Cave is located at about 210 m elevation, about 20 m east of the road on the west side of the *Sabana*, near *Sailigai Hulo*. The cave consists of a main room about 7 m long and about 4 m wide open to the cliff face on the east side. Leading from the south end of this room, a low passage leads up to an enclosed room about 4 m long and about 3 m wide. The cave is developed in a rubbly facies and clearly shows that the lithology of the fore-reef beds influenced the morphology. The entire floor of both rooms is parallel to the beds.

### **Cupid Cave**

Cupid Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. The cave is developed along a fracture and extends about 8 m back from the drip line. The cave is variably 2-3 m wide and about 4 m high at the entrance. The floor and the ceiling of the cave slope up toward the back. There are two places where light shines through the crack along which the cave is developed. Cupid Cave is at the same level as the raised bio-erosion notch.

### **Dancer Cave**

Dancer Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. The cave consists of two small, open chambers, each about 3 m across, 2-3 m high and reaching about 4 m back from the drip line. Both parts of the cave are encompassed by the same drip line. Both chambers are above the level of the adjacent, active bio-erosion notch. This cave appears to have been significantly modified by physical erosion.

### **Dasher Cave**

Dasher Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. Dasher Cave consists of two remnant flank margin chambers encompassed by the same drip line. The sloping floors of these chambers are about 3 m above sea level.

### **Deer Cave**

Deer Cave is the first large cave entrance south of the embayment at *Alaguan Bay* and is visible from the ocean. The entrance is about 20 m high and about 18 m wide. The ceiling grades down to about 10 m with about the same width for about 35 m, where the passage is nearly filled with a large breakdown block. Beyond this block, the cave narrows in height and width but continues for about 40 m before ending in an irregularly shaped room. The ceiling of the outer part of Deer Cave is highly decorated with phototropic stalactites, a few of which are forked.

### **Discus Cave**

Discus Cave was reported by Stafford and coworkers (2002) as *Sabana Cave #2*. The name is herein changed to Discus Cave. It is located near the limestone/volcanic contact, about 200 m northwest of the Peace Memorial on the *Sabana*. It consists of one shallow ovoid chamber about 3 m across, breached at the top by a 1.5 m hole. This cave probably acts as a recharge feature during heavy rainfall.

### **Double Cave**

Double Cave is located about 2 m above sea level, at the base of the cliff, near the western end of the rocky beach between *Puntan Malilok* and *Gaonon*. Double Cave consists of two large main chambers and was formed in fore-reef beds. The two large chambers are connected near the rear by a passage less than 1 m in maximum dimension. The westernmost chamber is about 20 m wide and extends about 12 m back from the drip line. The easternmost chamber is about also about 20 m wide and extends about 20 m back from the drip line. Both chambers are completely open to the outside and floored with boulders, cobbles, beach sand, flotsam, and jetsam. A low, narrow section of the cave extends from the east end of the easternmost large chamber. If Double Cave is

either a flank margin cave heavily overprinted by wave driven erosion or is simply a sea cave formed primarily by erosion.

### **Exception Cave**

Exception Cave is located less than 2 m below the cliff top at *Duge*, south of *Puntan Fina Atkos*. The cave is the remaining “half” of a wide, flat chamber that has been partially removed by cliff failure. The entrance is not visible from the cliff top but is accessible by climbing down from the top to the north end of the cave. The entrance, at about 2 m high and 25 m across, is the longest part of the cave and is clearly visible from the coast below. The height of the cave averages about 2 m with little variation. The width of the cave varies from 5 to 10 m. Exception Cave is highly decorated with speleothems, although they are somewhat weathered due to the exposed nature of the cave. In contrast to most of the other caves documented on Rota, Exception Cave shows very little to no apparent lithologic control on its morphology and development.

### **Flange Cave**

Flange Cave is located on the northwest side of the *Sabana*, beside the 30 m scarp that strikes at 55°. Flange Cave is relatively small but complicated fragment of a previously larger cave developed along a possible fault. The southern branch of the cave has man-made steps leading down to a room about 4 m long and about 3 m wide and two small passages which dead end. The northern branch leads to a second entrance on the left about 9 m in, then continues for about 15 m more, to an impassable hole that connects to another small segment of cave that is accessible from the outside.

### **Forked Cave**

Forked Cave is one of four linear caves located adjacent to each other at about 30 m elevation, in the cliff face inland from *Puntan As Fani*, south of *Fina' Atkos*. Forked Cave is the second cave from the north. Forked cave, which is developed along an obvious fracture, is boulder floored at the 10 m tall, 8 m wide entrance. The passage narrows gradually to about 3 m at about 20 m in. Then the cave widens to about 7 m before it splits into two short passages the both end at impassable fractures.

### **Four Crosses**

In the cliff face southwest of *Ginalangan*, three white crosses are visible in what appear, from a distance, to be cave entrances. A closer inspection reveals that there are actually four white crosses but no significant cave passage. About 20 m east of the crosses is an open sided chamber that may be a remnant flank margin cave. It is about 12 m wide, 7 m deep and 3 m high. The floor is built up level behind a man-made wall about 1 m high. There are steps through the wall leading up to the floor. About 20 m west of the crosses there is an open irregular chamber 10 m wide, 8 m deep and 8 m high. The crosses are located in an alcove that is developed along a fracture in the bedrock. The floor of the alcove has been highly modified by the construction of a manmade wall, which has been filled in to create a narrow floor at the lower part of the alcove. The rest of the steeply sloping floor of the alcove is covered with a series of man-made steps. Slight overhangs on each side of the alcove converge at the fracture on which the alcove is developed.

### **Honey Comb Cave**

Honey Comb Cave is one of four linear caves located adjacent to each other at about 30 m elevation, in the cliff face inland from *Puntan As Fani*, south of *Fina' Atkos*. Honey Comb Cave is the second cave from the south and was so named because of the conspicuous beehives up very high in the entrance. While the entrance to Honey Comb is 10 m tall and 10 m wide, the cave only extends back from the drip line about 8 m. Like the other caves in this group, Honey Comb is developed along an obvious fracture. The floor in the entrance is dominated by one large boulder but the rest of the floor is covered with soil plus a few cobbles.

### **Hourglass Cave**

Hourglass Cave, at about 40 m elevation, is part of a complex of caves around *Liyang Finta*, in a notch in the cliff between *I Koridot* and *Taksunok*. It is at about the same elevation as *Liyang Finta* on the east wall of the notch and is reached by a short horizontal traverse across the cliff face. The south part of Hourglass Cave is about 1 m high, 2 m wide tapering to zero and about 6 m long. This south part of Hourglass has a high density of flowstone columns that are highly weathered due to complete exposure. The north part of Hourglass is about 2 m high, 4 m wide, and extends about 5 m back from the drip line. This part of Hourglass has evidence of solution of speleothems. Hourglass is apparently a flank margin cave remnant.

### **Husky Cave**

Husky Cave is located just south of *Liyang Matan* at *Puntan Fina Atkos* near *As Matmos* at about 25 m elevation at the base of the cliff. There is about 18 m of passage in this apparent flank margin cave. It is about 8 m wide just inside the entrance but narrows to about 1.5 m before ending in a boulder wall. The floor of the outer part of the cave is covered with what appears to be beach sand.

### **I'm Your Cistern Cave**

I'm Your Cistern Cave is located in the cliff face at *Tachok*, east of *Songsong Village*. The cave is one of many visible from the main road and is reached by climbing about 4 m up the cliff face. The side of the cave open to the cliff face is about 15 m across while the cave has a maximum width of about 12 m. The floor is irregularly sloped to the edge of the opening and mostly covered with loose boulders, cobbles and sand. There are some speleothems along the back wall. I'm Your Cistern Cave is apparently a remnant of a flank margin cave.

### **Incidental Cave**

Incidental Cave is located near *Liyang Perseverance* at about 80 m elevation directly west of *Puntan Haina*. The entrance is about 20 m wide and about 10 m high. The ceiling slopes steeply down as the floor also comes up, such that at about 7 m back from the drip line the cave is about 4 m high. The ceiling and the floor continue rising at about the same slope before the cave ends at about 20 m. The floor of the cave is entirely re-cemented rubble, giving the impression that the entrance to the cave was filled from the inside. The area above the cave should be investigated for a possible collapse feature.

### **Isty Cave**

Isty Cave is located south of the embayment at *Alaguan Bay*, about 30 m down-slope from the entrance to Deer Cave. Isty Cave consists only of a curved about 1 m diameter tube about 3 m long. It is apparently a remnant of a flank margin cave.

### **Kaigun 223 Japanese Command Post**

Although this site contains no real caves, Kaigun 223 Japanese Command Post is documented here as an example of the World War II era tunnels that are common on Rota. It is located in the northeast-facing cliff at *Ginalangan* at about 240 m elevation, south of the white crosses prominently visible in the same cliff face. This site has extensive human modification including at least four pillboxes, three cisterns, a defensive wall running about 160 m, and several man-made tunnels most of which have concrete barrier walls at their openings.

### **Knuckle Bone Cave**

Knuckle Bone Cave is located at about 30 m elevation near *Puntan Fina Atkos*, about 1 km east of the end of the road at *As Matmos*. Knuckle Bone is the middle of three fissure caves along this stretch of cliff. The area just outside the entrance to Knuckle Bone is dominated by a large block of rock that may be an in place bedrock remnant or collapse boulder. The drip line of Knuckle Bone Cave runs diagonally across the entrance to the cave from southeast to northwest. The cave is composed of two passages that lead from the entrance. The shorter, southern passage extends back about 60 m from the drip line and ends in solutionally modified cracks. This southern passage is about 5 m wide tapering toward the rear and is about 10 m high at the drip line and tapers irregularly to about 4 m high near the end. The ceiling of this passage narrows into a crack for most of its length. The northern passage extends about 70 m back from the drip line, and is about 5-6 m wide back to about 45 m where it widens to the south to about 10 m. The southern wall of this part of the cave appears to be coincident with the southern passage of the cave, indicating that it is related to the fracture along which the southern passage is developed. The floor of the northern passage of Knuckle Bone Cave drops at about 10 m from the drip line, giving a ceiling height of about 12-14 m for most of its length.

### **Letterman Cave**

Letterman Cave is the smallest of several linear caves located in the cliff base, north of the Chenchon Bird Sanctuary overlook, between *Liyang Paluma* and *Liyang Lu'ao*. Letterman Cave is about 8 m long, 2-3 m wide and about 4-5 m high. The entrance to Letterman Cave is partially blocked by a boulder. The floor of the cave is mainly soil with a few cobbles.

### **Liyang Alapin**

*Alapin* Cave is located on private property at the base of the cliff directly north of the road to *Poña Point* overlook. The cave is developed sub-parallel to the cliff face and appears to be developed along the prominent fracture that strikes at 213°. The entrance to the main part of the cave is 5 m high by about 7 m wide. The drip line extends on both sides of this entrance, incorporating a high, shallow overhang to the south, which shows manmade modification, and incorporating a smaller overhang to the north with the



remains of a large stalagmite, indicating that the entire outer portion of the cave was once enclosed. The ceiling of the main room, just inside the entrance, slopes from southeast to northwest and is clearly developed along a bedding plane. The 7 m high vertical wall on the southeast is developed along a (bank-margin?) fracture. For some distance the crack extends an undetermined distance into the cave ceiling. About 25 m into the cave, the passage developed along the prominent fracture narrows to 3-4 m wide variably and ends after 10 m more. To the right, at the entrance to this narrower section, a passage 4-8 m wide extends for about 15 m. About 15 m inside the main entrance there is an overhang low on the left wall. Under this overhang there is a short dead end passage to the left. To the right leads down a short slope to a room about 4 m across and about 1.5 m high. A low crawlway leading northwest from this room leads to a room about 1.5 m across and about 1m high. An impassable hole leads northwest from this room and admits some daylight. Exploration on the surface revealed an entrance to a 15 m passage that that connects to this small hole. This section the cave is parallel to the main cave.

### **Liyang Apaka'**

*Liyang Apaka'* is the southernmost and largest of four linear caves located adjacent to each other at about 30 m elevation, in the cliff face inland from *Puntan As Fani*, south of *Fina' Atkos*. *Liyang Apaka'* is developed in a fine-grained, detrital limestone. The caves adjacent to *Apaka'* are not apparently in this facies despite their proximity. Also, few other documented caves in other parts of Rota show clear evidence of being developed in this facies. The entrance to *Apaka'* is about 13 m wide and 17 m tall. The passage continues at about this size to a dramatic ceiling drop about 18 m into the cave. For about 3-4 m the ceiling is around 1.5 m high before it suddenly increased to about 9 m then the ceiling drops irregularly toward the rear of the cave. The total length of *Apaka'* is over 60 m. It ends at a small impassable passage at floor level. *Apaka'* is developed along a fracture that is evident at the entrance and at the rear of the cave but not at the low ceiling point near the middle. The floor of *Apaka'* is covered mostly with cobbles and boulders in the outer section and with soil and guano in the middle and rear.

### **Liyang Ayuyu**

*Liyang Ayuyu* is located at the west end of the isolated cliff line about 500 m directly north of the parking area of the *Chenchon* Bird Sanctuary. *Liyang Ayuyu* is developed in limestone with a strong expression of depositional beds, probably fore-reef facies. The entrance area of *Ayuyu* is about 17 m wide and about 7 m tall. The cave extends back about 22 m back from the drip line. About 8 m back into the cave, it narrows irregularly to about 6 m. The floor of the cave is primarily cobbles on top of the stepped exposure of the depositional beds.

### **Liyang Botazon**

*Liyang Botazon* is located at the coastal notch labeled *Fina' Atkos* on the topographical map (USGS, 1999), below the steep canyon that cuts across several terraces. The floor of the cave at the entrance is at sea level and is about 50 m wide and about 15 m tall. About 10 m from the drip line, there is a large skylight that is about 15 m across and reaches across most of the width of the cave. The entrance area of *Botazon* is mostly covered with very large to large boulders with bedrock exposed in a few places. At about 20 m

from the drip line the cave narrows to about 10 m and only gradually narrow toward the back of the cave. The ceiling stays at about the same level but the boulder-covered floor gradually climbs such that the passage is about 10 m high before it pinches down at the end of the cave. *Botazon* has a few short side passages that are apparently developed along fractures. The entire cave is coincident with the surface canyon that cuts across the terraces above the cave. This entire *Fina' Atkos* notch-steep canyon-*Liyang Botazon* complex is developed along what appears to be a significant fault, although no positive evidence of displacement was identified.

### **Liyang Chenchon**

*Liyang Chenchon* is located at about 90 m elevation near *I Koridot* in the *I Chenchon* area. The entrance is two holes that drop into the north end of a low wide room that slopes away to the south. This room is about 7 m by about 5 m. At the south end this room opens into a larger room, about 10 m long by about 8 m wide, that continues to slope at about the same grade. The floor at the north and south edges of this larger room drops away but no passable leads were found.

### **Liyang Finta**

*Liyang Finta* is located at about 50 m elevation, just below the cliff top, at the head of a notch in the cliff between *Taksunok* and *I Koridot*. The fracture that *Liyang Finta* is obviously developed along is expressed in the cliff top above the cave. A map of *Liyang Finta* is not included in this report due to a serious error in the survey that will be corrected on a follow-up visit.

### **Liyang Ganas and Nanong Katiyu**

Adjacent to *Songsong Village*, about 70 m ESE of *Tonga Cave*, are *Liyang Ganas* and *Nanong Katiyu* (Rogers and Legge, 1992), which are two caves connected with a man-made tunnel. The tunnel is located about 5 m inside *Liyang Ganas*. Both caves have human modification for apparent defensive purposes. Compared the somewhat globular morphology of *Liyang Tonga*, these two caves are much more linear. The smaller, western-most *Nanong Katiyu* is about 18 m long and 4 m wide, oriented NE/SW. The entrance to the larger cave, *Liyang Ganas*, is about 15 m east of the smaller cave. It runs along the same trend, but is about 58 m long and 7 to 18 m wide. About 2/3 of the way back into the larger cave the distance between the walls widens to form a room just north of the main trend of the cave. Both caves are apparently developed along the fractures that are visible in the ceiling of each cave. The drip line of the larger cave is incised along the fracture.

### **Liyang Lu'ao**

*Liyang Lu'ao* is one of several linear caves located in the cliff base, north of the Chenchon Bird Sanctuary overlook. *Lu'ao* is located about 40 m south of *Liyang Paluma*, which is the cave immediately at the bottom of the climb down from the cliff top. *Lu'ao* has an enormous, dramatic entrance, especially when seen from the large boulder pile that has accumulated at the entrance from breakdown. No evidence of recent breakdown was seen. From the top of the breakdown pile, the entrance is about 8 m high. Just inside the drip line, off the boulder pile, the ceiling is about 12 – 15 m high for about

30 m where it drops to 10–11 m for the rest of the cave. *Lu'ao* is about 14 m wide at the drip line, gradually narrowing to about 4 m at about 35 m. Beyond about 35 m, *Lu'ao* gradually widens to about 9 m before narrowing at the rear. *Lu'ao* extends a total of about 65 m from the drip line. The floor of the cave beyond the breakdown pile at the entrance is mainly soil and guano with a few cobbles. Along the left wall, mid-way back in the cave are two pieces of a breakdown slab that are each about 8 m high, 2-3 m thick. The first is about 10 m long and the second is about 8 m long. These slabs are standing nearly vertical and appear to have fallen as one piece. Just toward the drip line from the outer slab is a sloping bedrock shelf on the south wall that leads up to a small passage that ends at about 3 m. *Liyang Lu'ao* is developed along a fracture that is prominent in the ceiling of the cave for its full length.

### **Liyang Matan**

*Liyang Matan* is the southern most of the three large cave entrances at *Puntan Fina Atkos* near *As Matmos*, at about 30 m elevation. The area just outside the entrance is dominated by massive breakdown block that has dimensions of 10+ m. The entrance is very large, about 20 m high and 30 m wide. The drip line forms a deep “V” into one of the fractures that the cave is developed along. About 1 m in from the point of the “V” is an oblong skylight that lends the cave its name: *Liyang Matan* (Cave of the Eye). The floor of the entrance room is decorated with highly weathered speleothems while the ceiling has phototropic stalactites. The cave continues as a wide, tall room for about 40 m from the “eye” where the size changes abruptly. At the left rear is a very short passage (1-2 m) that is in alignment with one of the fractures seen in the ceiling of the main room. At the right rear, a short climb down leads to a narrow canyon that can be followed for about 50 m, sometimes requiring crawling. Inaccessible higher levels can be seen from below. This narrow passage is in alignment with one of the fractures visible in the ceiling of the main room.

### **Liyang Neni**

*Liyang Neni* is one of several linear caves located in the cliff base, north of the Chenchon Bird Sanctuary overlook. *Liyang Neni* is located about 30 m southwest of the much larger Arrowhead Cave. Like the other caves in the area, *Liyang Neni* is developed along an obvious fracture, but is only about 18 m back from the drip line. The ceiling is 7-8 m for the length of the cave and tapers into the fracture. About 3 m back from the drip line there is a skylight about 1 m in dimension. *Neni* is about 8 m wide at the drip line, including alcoves on the left and right. The cave quickly narrows to about 3 m wide and gradually narrows to the back. The floor of the cave is primarily soil with a few cobbles and boulders.

### **Liyang Paluma**

*Liyang Paluma* is the northernmost of several linear caves located in the cliff base, north of the Chenchon Bird Sanctuary overlook. *Liyang Paluma* is about 37 m long, about 7 m wide at the drip line and about 3 m wide for most of its length, before narrowing significantly at the back. The floor of *Paluma* is covered with soil (possibly guano) and has some boulders and cobbles near the entrance. The entrance dominated by a 3 m high breakdown block that spans the passage. The ceiling *Paluma* clearly expresses the

fracture along which the cave is developed. In several places the actual ceiling height could not be measured from the floor because of high pockets developed along the fracture. There appears to be no safe way to reach these parts of the cave from below. None of the pockets appeared to reach the surface.

### **Liyang Perseverance**

*Liyang Perseverance* is the largest of the cave entrances visible from *Puntan Haina*, just below the cliff top at about 80 m elevation. *Perseverance* is about 23 m wide at the entrance and narrows to about 12 m for most of its length. It ends about 20 m back from the drip line. From the outside, the entrance to *Perseverance* resembles an uneven keyhole. The ceiling of the cave is roughly level but there is dramatic relief in the floor in the entrance area, giving the entrance an uneven keyhole profile when seen from a distance. The ledge that makes up this higher floor in the south side of the entrance has several large, weathered, algae-covered speleothems. Overall, the floor of the cave rises irregularly to the rear. A large part of the ceiling has collapsed creating a skylight 5+ m across. About 2 m west of the large skylight there is another much smaller skylight that can be reached by free climbing. *Perseverance* shows some evidence of having developed along a fracture, but erosion has altered the cave such that fracture control is difficult to confirm. Much of the outer part of the cave has apparently been destroyed by cliff retreat.

### **Liyang Siete**

*Liyang Siete* is the southernmost of several linear caves located in the cliff face, north of the *Chenchon* Bird Sanctuary overlook, at about 30 m elevation. *Liyang Siete* is difficult to classify due to its fragmentary, remnant nature. It may be what is left of a fissure cave that was once similar to the others in the area, although it would have been much higher than the others. It may be the result of solutional modification of a bank-margin failure block. Gaining access to this feature from the cliff top might allow observations that would help in understanding its origin.

### **Liyang Tonga (Taga)**

*Tonga Cave*, a large remnant of an apparent flank margin cave, is a prominent landmark in *Songsong Village*. It is about 65 m long and about 30 m wide, oriented north-south. *Tonga Cave* has an entrance, about 25 m wide by 8 m high, on the west side of the upper large chamber and a second, more commonly used entrance (3 m wide, 5 m high) off the southwest corner of the large chamber. To the south of the smaller entrance is a lower, much smaller chamber that is completely open on one side. It was mapped as part of *Tonga Cave* because it is contained within the same drip line. *Tonga Cave* contains significant human modifications including concrete and stone steps, concrete slabs, a small shrine, and even a barbecue grill. The cave has reportedly been used as a shelter during typhoons. The floor and ceiling are decorated with speleothems, including phototropic stalactites. Immediately east of the smaller entrance to *Tonga Cave* a shrine and several tunnel entrances. The tunnels were investigated sufficiently to determine that they are not natural features but they were not mapped.

### **Mendiola Cave**

*Mendiola Cave* is located at about 160 m elevation, above the second right hand switch back on the road leading up the Water Cave. The cave consists primarily of a large oval chamber about 30 m across. The floor of the chamber slopes irregularly downward and is covered on sand, cobbles and boulders plus some vegetation. There are two small rooms off to the left of the entrance and a deposit of reddish brown clay at the bottom of the wall on the left rear. On the right rear is a small (0.25 m) pool of water where the cave barely intersects a stream with flow on the order of 10 liters per minute in May 2003. This area does not show evidence of flooding but is probably very close to the volcanic basement rock.

### **Monkey Cave**

Monkey Cave located at about 25 m elevation, is part of a complex of caves around *Liyang Finta*, in a notch in the cliff between *I Koridot* and *Taksunok*. It is at the base of the east wall of the notch about 30 m south of Basement Cave. Monkey Cave has a combination of the morphologies seen in flank margin caves and in “fissure” caves that develop along bedrock fractures. Monkey Cave is about 13 m wide at the entrance and extends back a total of about 24 m from the drip line. The entrance area slopes irregularly down to the south into a room about 8 m wide and about 10 m long. Leading from the north side of this room is a linear passage 1-2 m wide and about 2 m high. The floor of this passage slopes to the south and the ceiling pinches into a crack. At about 5 m in, this passage widens to about 3 m where there is a small hole leading to a roughly circular room with a cobble and sand floor. On the west wall of this room is a small “port hole” into a very small chamber that has sunlight entering through an impassable linear passage from the entrance area. From the south side of this room leads a crawlway that leads back to the entrance area. The total surveyed length is about 45 m.

### **Not Much Cave**

Not Much Cave is located on the nearly level bench, north east of Pictograph Cave, near the Banyan Complex. It is developed along the same set of fracture as the Banyan Complex but was surveyed separately. Not Much Cave consists of a small vertical shaft about 2 m deep, about 3.5 m long and about 1 m wide. The long axis of the feature is oriented to the northeast. At the southeast end of the feature there is a vertical section of intact bedrock that reaches from ground level almost to the floor of the feature.

### **One Shot Cave**

One Shot Cave is located near *Liyang Alapin*, north of the *Poña Point* overlook. The cave is about 5 m long, 1-1.5 m wide and about 1-2 m high. The floor of One Shot Cave is primarily bedrock with some soil and a few secondary formations.

### **Paupau Sea Cave**

*Paupau Sea Cave* is located near *Songsong Village*, on the coast, about 250 m south of the old Rota Paupau Hotel at about 1 m elevation. The cave is about 11 m long, about 4 m wide with a simple oval cross section. The floor is mostly bedrock with a few loose boulders and cobbles.

### **Picnic Cave**

Picnic Cave is a flank margin cave located just above sea level, beside the main road, about 120 m north of the Veterans Memorial, about 1 km northwest of the Cave Museum. The cave is located inside a knob of limestone projecting higher than the general trend along this immediate section of coast. The oval main chamber of Picnic Cave is about 18 m wide and extends back about 13 m back from the drip line and has an entrance about 10 m wide. This main chamber is variably about 2 m high and floored with loose beach sand plus a few cobble, boulders and abundant flotsam and jetsam. To the east of the main entrance is a 10 m long overhang, encompassed by the same drip line, that has the appearance of a bio-erosion notch. Off the west end of the main chamber is a smaller room also floored with beach sand, etc. To the west of the main chamber there are two open cave sections encompassed by the same drip line. The easternmost of these sections has a small connection to the side room off the main chamber. Sitting just outside this part of the cave is a large (6 m long and 3 m high) limestone boulder that may be a breakdown block from above the cave or may be in-place bedrock.

### **Pictograph Cave**

Pictograph cave is well known on the island but apparently seldom visited despite a trail leading to it. It is located at about 130 m elevation, about 200 m down hill from the old Japanese railroad bed on *Gampapa* ridge. The entrance to the cave is in a “canyon” that is apparently the un-roofed outer part of the cave. At the drip line, the entrance is about 5 m wide and about 5 m high. Man-made steps lead down to the main floor level of the cave, where the ceiling is about 7 m high and the walls 4-6 m apart. The cave consists of one linear passage, about 60 m long, apparently developed along the fracture that is visible in the ceiling. About 30 m back the cave widens to about 12 m before narrowing to end in an area decorated with speleothems. The walls are decorated in several places with pictographs that were reportedly created by ancient Chamorro people. The cave shows evidence of more recent use and was reportedly used as a hospital during WW II.

### **Poña North Sea Cave**

*Poña North Sea Cave* is located at about 3 m elevation, at the bend in the cliff face on the north side of *Poña Point*. The cave shows very strong expression of fore-reef deposition beds. The *Poña North Sea Cave* is about 25 m wide at the drip line and extends back about 15 m, narrowing quickly toward the back. The floor dips steeply to the south along the fore-reef beds. The irregular overall shape of this cave strongly suggests that physical wave erosion has been the main factor in its formation.

### **Prancer Cave**

Prancer Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. Prancer Cave is about 8 m wide at the drip line and extends back about 10 m with a small 2 m extension at the back. Beyond the drip line, the cave widens to about 9 m. The cave ceiling is about 5 m at the drip line but drops steeply to about 3 m. The ceiling climbs toward the back of the cave at about the same slope as the floor. The floor of the cave mostly covered with boulders that in some places are covered with soil that comes into the cave through cracks that lead up to the surface. The deteriorated condition of Prancer Cave makes determination of its primary formation mechanism difficult.

### **Reyes Flank Margin Cave Complex**

This complex of flank margin cave remnants is located at about 120 m elevation, northwest of *Taksunok*, near *I Chenchon*. The complex consists of several mostly open flank margin cave remnants not encompassed by the same drip line. The southern most section is about 30 m long and about 4 m deep. The next section to the north is almost 40 m long and about 4 m deep. The next two sections to the north are much smaller and partially enclosed. Continuing to the north, there are three more open sections 13 m, 5 m, and 20 m long. The complex contains a large amount of human modification, primarily stone walls, built up floors and steps. The cliff face and most of the cave walls show distinctive fore-reef beds. In the middle part of the complex are two chambers that are more enclosed, supporting the idea of mixing zone cave development followed by later breaching and wave driven modification. The different sections of this complex are predominantly at the same elevation indicating that they probably all developed during the same sea level high stand. Southeast of the complex there are more flank margin remnants that are not tied in to this survey.

### **Rota Rooter Cave**

This cave was reported by Stafford and coworkers (2002) as *Sabana Cave #1*. The name is herein changed to Rota Rooter Cave. This cave is located on the *Sabana*, in a closed depression about 150 m northeast of the Peace Memorial. This feature consists of a solutionally modified crack filled with mud at the bottom. It is about 3 m deep, about 3 m long and less than 1 m wide. Based on its location in the closed depression near the contact between the limestone and pyroclastic material, the feature is believed to play an important role in aquifer recharge and should be observed during or immediately after a heavy rain event.

### **Sagua Cave Complex**

The *Sagua Cave Complex* is located at sea-level below the area marked “*Sagua*” on the USGS topographic map (1999), about 2 km southeast of *Songsong Village*. The complex consists of about 650 m of coastal cliff line that contains numerous, breached, erosionally modified, flank margin caves that required 1168 m of survey to document. Assigning a specific number to the caves in this complex is problematic because many are connected through small holes and many share the same drip line. This complex was mapped as one unit in order to show the very high density of cave development. Significant fresh water discharge was noted at sea-level in several places along this stretch of cliff line in May 2003. In January 2004 some of these locations had very large fresh water discharges; detectable by temperature difference and by schlieren mixing for tens of meters out into the ocean. The northernmost end of the complex is located in the cliff face behind the only “mushroom” shaped sea stack along the coast at *Sagua*. Here there is a small cave about 3 m long. About 4 m to the south there is a 5 m long section of cave containing an arch. The floor of this section is a compact, fine grained facies but the walls and ceiling are in a boulder/cobble conglomerate. About 10 m further south there is a large section of cave with typical flank margin cave morphology. The floor here is the same compact fine grained limestone; the walls and ceiling expose the boulder/cobble conglomerate with some boulders up to 2-3 m maximum dimension. This section of cave

has some secondary speleothems, including soda straws and some small phototrophic stalactites. Just south of this section, the cliff line extends out to the high tide line, but a partially collapsed cave section allows easy passage. There is “boneyard” development in this section. From here, there is continuous flank margin cave at the level of the elevated bio-erosion notch; about 2 m. The same contrast between the fine grained limestone on the floor and the boulder/cobble conglomerate exposed in the walls and ceilings is prominent in this section as well. This section of cave ends where a large, in-place conglomerate boulder extends out to the high tide line. Just south of this boulder, there is a small linear cave at about 2 m elevation, apparently developed along a fracture and exhibiting sculpted wall morphology suggesting that it once acted as a discharge conduit for fresh water. This cave is about 8 m long and extends vertically as a small crack for 3-4 m. Just south of this linear cave there is a breached flank margin cave that extends back about 7 m. To the south of this cave, there is a break in cave development for about 25 m of cliff line. This section of cliff has a very well developed elevated bio-erosion notch and several fractures discharging fresh water. The next cave to the south appears to be a breached flank margin cave that extends back about 5 m from the cliff face. Just south of this, there is a breached flank margin cave about 4 m across that has a large skylight formed by ceiling collapse. Sea level fractures here appear to be discharging some fresh water. For the next 16-17 m of cliff line there is no cave development, but there is a fracture discharging a significant volume fresh water at sea level. This discharge was easily detectable by schlieren mixing even with tide fairly high. About 4 m south of this spring, the cliff face turns inland behind some large (4 m) boulders. In the corner, where the cliff face turns back toward the south, there is a fragment of what appears to be flank margin cave. This area has several large masses of weathered flow stone, supporting the idea that it is a collapsed cave. The next cave appears to be a small collapsed flank margin cave. South of this there is a 6 m section of broken cliff line set back from the flat bench above the present bio-erosion notch. There is a small flank margin remnant at the south end of this section. Just a few meters to the south is the most complicated section of the *Sagua Cave Complex*. It is a flank margin cave about 7 m by 7 m, breached on the north and south, and closed on the seaward side. The complication of this section is due to the many remnant pillars of bed rock scattered though the cave. South of this section, there is a section of cliff face about 8 m high that has a small cave at about 4 m elevation that runs parallel to the cliff face and has entrances at the north and south ends. Just to the south, there is the largest notch in the cliff line along this section of coast. The opening to this notch has several large (5-6 m) boulders. The notch extend back about 20 m from the high tide line to a relatively small overhanging cave remnant in the back. The north wall of this notch has the facies change contact from the lower, finer-grained limestone to the upper, boulder/cobble conglomerate at about 7 m elevation. The south wall of the notch has the same contact at about 9 m elevation, suggesting that the notch is developed along a normal fault. It is impossible to clearly see the relationship of the north and south sides of the contact where the two cliff faces meet in the overhanging cave. The section of cliff face just south of this notch is riddled with “boneyard” cave development. The next two sections of cave to the south, extend below sea level and area receive direct wave action. The larger of the two is a partially enclosed cave and is a popular swimming hole. Beginning adjacent to this cave and extending to the south there is a level bench up to 4 m wide at sea level. At



the south end of this bench there is a manmade stone wall about 1 m high. On the cliff face above the wall there is a concrete foundation that was part of the Japanese era bucket tram for moving phosphate rich soil from the Sabana to be loaded onto ships at *Sagua* (Rodgers, 1948). The approximately 70 m of cliff line between the remains of the tram tower foundation and the rocky beach contains several small flank margin cave remnants at sea level. The *Sagua Cave Complex* is an outstanding example of flank margin cave development. There is evidence that the exact elevation of cave development may have been locally driven by the position of the contact between the lower finer-grained limestone and the upper boulder/cobble conglomerate. Also, the apparently offset in the elevation of the contact between these two facies, in the large notch in the central part of the complex, suggests that there may be a normal fault through this area.

### **Saguita Cave**

*Saguita* Cave is located at sea level, just west of *Sagua Cave Complex*, below *Takta*. It is apparently a breached, erosionally modified flank margin cave. Some parts of the cave are developed in boulder facies and in one area the cave ceiling at the drip line appears to be only one “boulder” thick.

### **Second Chance Cave**

Second Chance Cave is the second largest of the cave entrances visible from *Puntan Haina*, just below the cliff top at about 80 m elevation. Second Chance Cave is located a few m south of the larger *Liyang Perseverance*. Second Chance Cave is nearly inaccessible from below, due to the steep cliff face, but is easily accessible through a skylight entrance along the south wall near the west end of the cave. There is another, barely passable skylight entrance about 4 m back from the drip line. There are several other places where light shines through the very thin ceiling of Second Chance Cave. From inside the cave, the ceiling has the appearance of being composed of cemented cobbles and boulders. This facies is not evident in the walls of the cave. The cave extends about 30 m back from the drip line and is variably 7 m wide, tapering toward the rear. The cave is about 7 m high at the entrance and tapers gradually to the rear where there is a significant ceiling drop. The floor is primarily bedrock with some soil cover and some cobbles and boulders. Second Chance Cave is apparently developed along a fracture. The facies in the cave ceiling suggests that possibly the cave developed in a wide fracture that was filled with cemented rubble or cemented breakdown.

### **Shoo Fly Cave**

Shoo Fly cave is located on private property at *Taiapu* on the east end of the *Talakhaya*, just north of the road, at about 140 m elevation. It consists of three flank margin remnants at the base of the cliff. The easternmost section is about 17 m long, 2 m high and 3 m deep and floored with sand. The middle the west is 10 m long, 3 m deep, with a ceiling the tapers up into the cliff face and a bedrock floor. The westernmost section is 10 m long, 7 m deep and 7 m high with a floor mostly covered with sand. Fore-reef bedding planes are well expressed in all three sections.

### **Slab Cave**

Slab Cave is located at the base of the cliff north of the complex of caves around *Liyang Finta* at about 30 m elevation. Slab Cave is a talus cave produced by simple cliff margin failure and has very little solutional modification. Slab Cave is about 10 m long with a slight bend near the middle and open at both ends. The floor is composed of loose rocks and vegetation that have accumulated in the bottom of the fracture. The height of the cave is difficult to determine because the detached slab is nearly parallel to the remaining cliff face.

### **Summit Cave**

This cave is located at about 470 m elevation, about 300 m south of the summit of *Mt. Sabana (Mt. Manila)*, the highest point on Rota, at the contact between the volcanic rock exposed on the summit and the limestone. Both entrances are located in a closed depression that is not shown on the USGS topographical map (1999). Up slope from the depression is a groove in the hillside about 15 m wide and about 60 m long that leads to the depression. One entrance to the cave is located at the bottom of the depression at the west end while the other is located about 2 m higher and to the west. The lower entrance leads to a passage 0.5 m high and about 2 m wide. It initially runs south then trends west. After about 12 m it opens into a room with daylight coming in from the higher entrance. This crawlway was surveyed in May 2003 but found to be flooded in January 2004. The main room is about 15 m long and about 11 m wide, trending north-south. The floor slopes irregularly from a steep “ramp” leading up to the higher entrance at the north end, down to a depression beside the south wall. It appears that water sometimes flows across the floor of this room and drains through the bottom of the depression. The room does not show any signs of back flooding. Two meters east of the floor depression is a muddy crawlway leading up to a roughly circular room about 4 m in diameter. The flat ceiling of this room is about 5 m high and must be very near the surface.

### **The Swimming Hole**

The Swimming Hole is located along the north coast of Rota, about 2.5 km northeast of the Coconut Village Hotel and is easily accessible by the road that runs past the hotel. The Swimming Hole is a roughly oval, water filled depression within the tide zone, but is protected from the surf by raised reef rocks on the north side. The coastal (north) end of the Swimming Hole is covered in loose boulders and sand down to the water, while most of the floor of the depression is covered in sand. There are two large rock slabs adjacent to the south side of the depression and one adjacent to the north side. The north end of the depression is overhung by at least a few meters but was not fully explored. An unpublished, scaled drawing obtained from Edgar Tuazon at Dive Rota was used in conjunction with survey data to construct a map of the Swimming Hole showing the underwater connection to the ocean. The lip of the depression on the east and west sides, adjacent to the deep overhang on the north, are overhung by about 1/3 m. The large slabs near these lips appear to have once been part of a ceiling. Fresh water discharges into the coastal end of the Swimming hole and at a few places to the east. It is hypothesized that the Swimming Hole is a collapsed flank margin cave and somewhat analogous to the caletas of the Yucatan, Mexico (Back et al., 1984).

### **Taisacan (Antigo) Museum Cave**

*Taisacan (Antigo) Museum Cave* is located beside the main highway, about 1.5 km northeast of *Songsong Village*, at *Esong*. The entrance to the cave is covered by doors under a building that is built above the entrance. The first 30 m of the cave consists of a linear room variably 5 m wide and starting at 2.5 m high rising to about 10 m. Beyond 30 m the cave widens into a room 25 m by 18 m by about 12 m high, with the long axis orientated the same way as the entrance passage. At the back of the larger room, a short climb-up leads to a tall narrow room that pinches down to an impassable crack. The floor of the most of the cave is packed soil. The trend of the entire cave is along a fracture that strikes at azimuth 154°. The fracture along which the cave is developed is prominent in the ceiling for most of the length of the cave. *Taisacan Museum Cave* is developed in a striking, white, fine-grained detrital limestone. The cave is a privately owned museum and houses an extensive collection of artifacts from the Chamorro, Spanish, German, Japanese and American eras of Mariana Islands history.

### **Village View Cave**

Village View Cave is located in the cliff face near the southeast end of *Tachok*, near *Songsong Village* and is visible from the road. Village View is a complicated cave consisting of two open, solutional chambers the larger of which is intersected by a large fracture that is apparently younger than the cave. The smaller northern chamber is about 12 m long, 3 m wide and 2.5 - 3 m tall. It widens to 5-6 m near the back before ending in two pinch outs. This part of the cave is floored with mostly with loose sand a few breakdown boulders near the entrance. This northern chamber is connected to the larger part of the cave through a body-sized porthole. The larger part of the cave is about 10 m tall at the drip line and very open except for a smaller chamber at the back. The floor climbs steeply at first, then more gradually over breakdown such that the ceiling height is less than about 7 m. On the south side of this larger chamber, a passable bedrock fracture intersects the cave. About 5 m into this fracture it turn roughly 90 degrees to the south and extends out to the cliff face. This crack extends up to the surface above the cave and out to the cliff face outside the cave. The relative lack of dissolution and deposition in this crack suggests that it is significantly younger than the solutional part of the cave. A minimum estimate for the size of the block that moved to form this fracture is 12 m<sup>3</sup> cubed. Using an approximate whole rock density of 2.5 gm/cm<sup>2</sup>, the mass of this block is at least 4.3 X 10<sup>6</sup> kg (4300 tons), probably far greater. Since one or more homes are within the potential path of this rock, its stability should be investigated.

### **Vixen Cave**

Vixen Cave is one of several caves accessible along the coast between *Poña Point* and *Okgok*. The entrance to Vixen Cave is dominated by a boulder about 4 m high that contacts the drip line dividing the entrance into two parts. The cave extends back about 8 m from this boulder. The floor rises irregularly and the ceiling drops to make the rear of the cave about 1 m high. The boulder-strewn floor of the cave also slopes steeply to the south, probably reflecting the fore-reef beds in this area. Vixen Cave is about 9 m wide at the entrance and gradually narrows toward the back. The shape of Vixen cave suggests that it may have had a flank margin origin, but modification by physical erosion makes a determination difficult.

### **Water Cave (Matan Hanum)**

Water Cave, also known as *Matan Hanum*, Chamorro for “eye” and “water”, is the primary source for municipal water for Rota. The cave is located in the *Talakhaya* area at about 350 m elevation at the contact between the volcanic rocks, which make up the core of Rota, and the overlying limestone. The entrance to the cave is surrounded by a chain link fence. Inside the fence is an assortment of pipes and concrete tanks that are part of the water collection system. Some of the pipes collect water the issues from springs just outside the cave. The entrance to the cave has floor to ceiling chain link fence and a concrete dam to impound more water than would naturally pool. The main room of the cave is a roughly oval dome about 20m long (north-south) and about 18 m wide (east-west). From the surface of the water, the ceiling is 5-6 m high. The east wall of the main room is mostly covered by flowstone over which cascades several thousand liters of water per minute. There is no accessible cave passage where the water erupts from the wall. At the north end of the room, a climb of about 3 m leads to a 7 m X 5 m X 2.5 m high room that also has much water coming into it from the east wall. The estimate height of the main chamber of Water Cave only includes the space from the water level up. No attempt was made to measure the water depth. The water cave is thought to be a flank margin cave that happened to develop at the contact and later intercepted water flowing along the contact. The local geology leaves little doubt that this water comes from the *Sabana* Region on the top of Rota, but no dye trace has been done to date.

APPENDIX B

MAPS OF THE CAVES OF ROTA

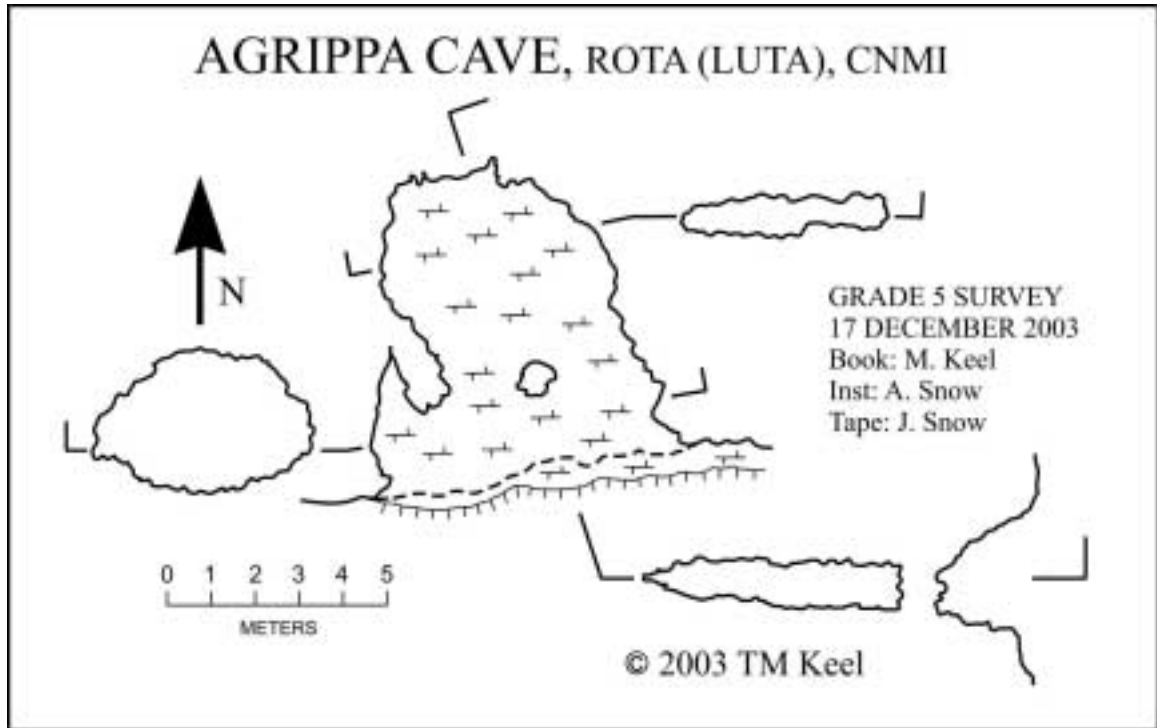


Figure 11. Map of Agrippa Cave

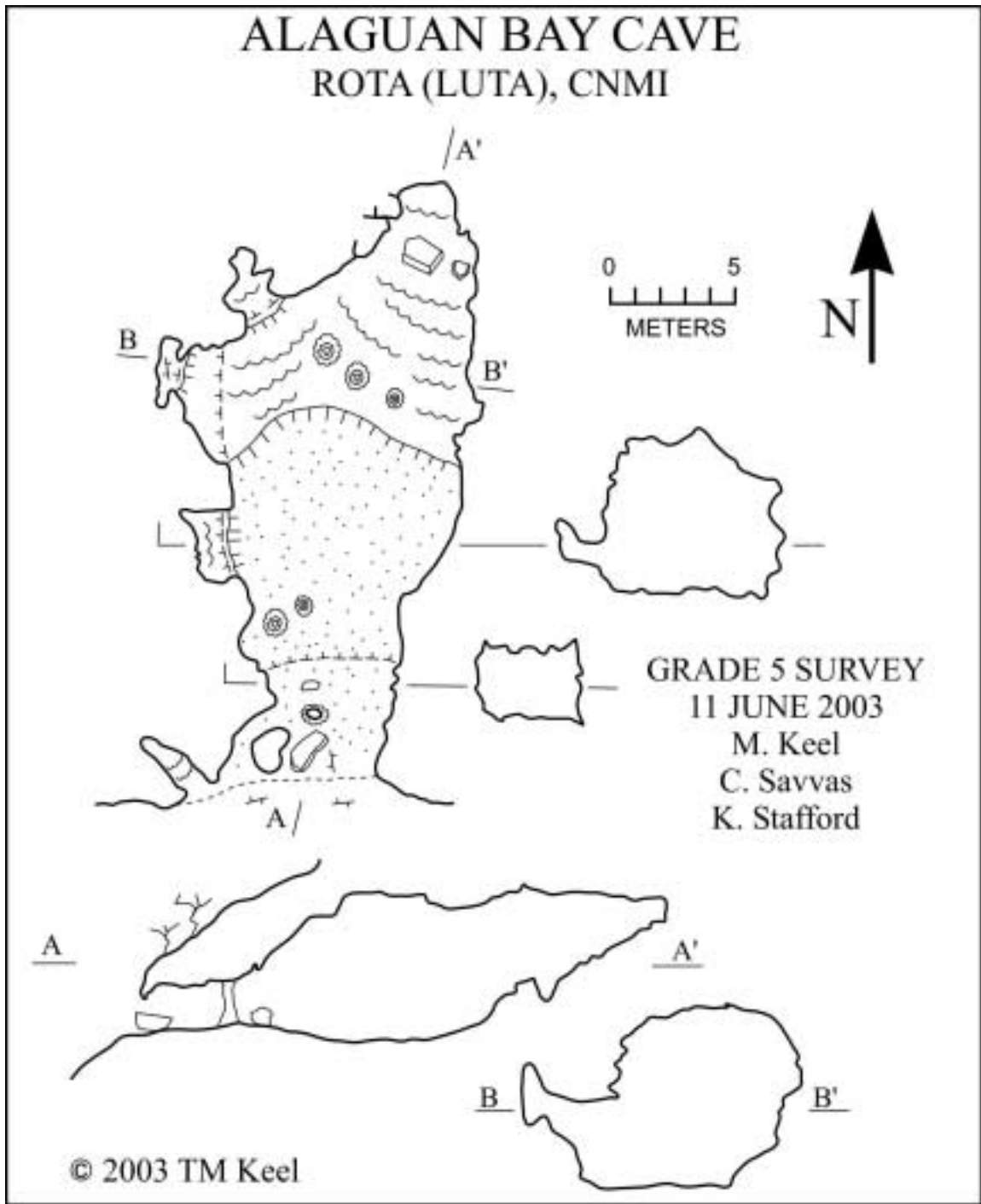
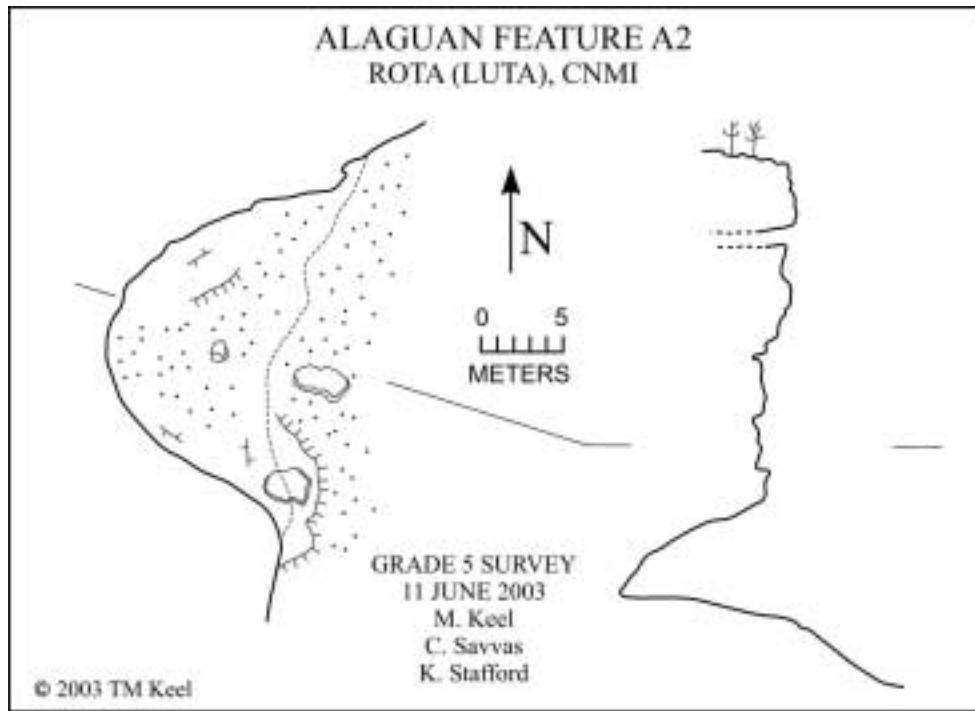
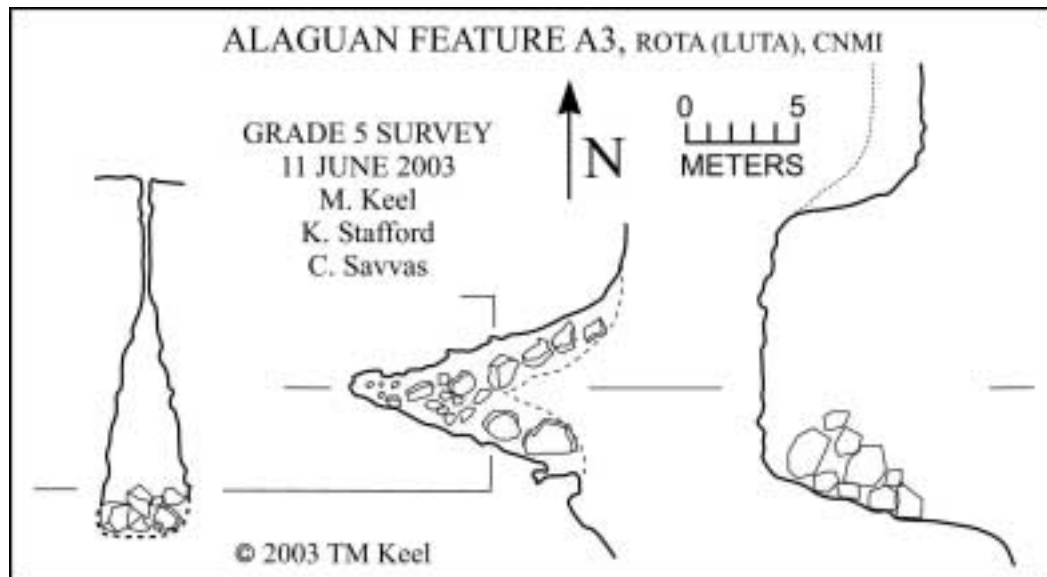


Figure 12. Map of Alaguan Bay Cave



**Figure 13. Alaguan Feature A2**



**Figure 14. Alaguan Feature A3**

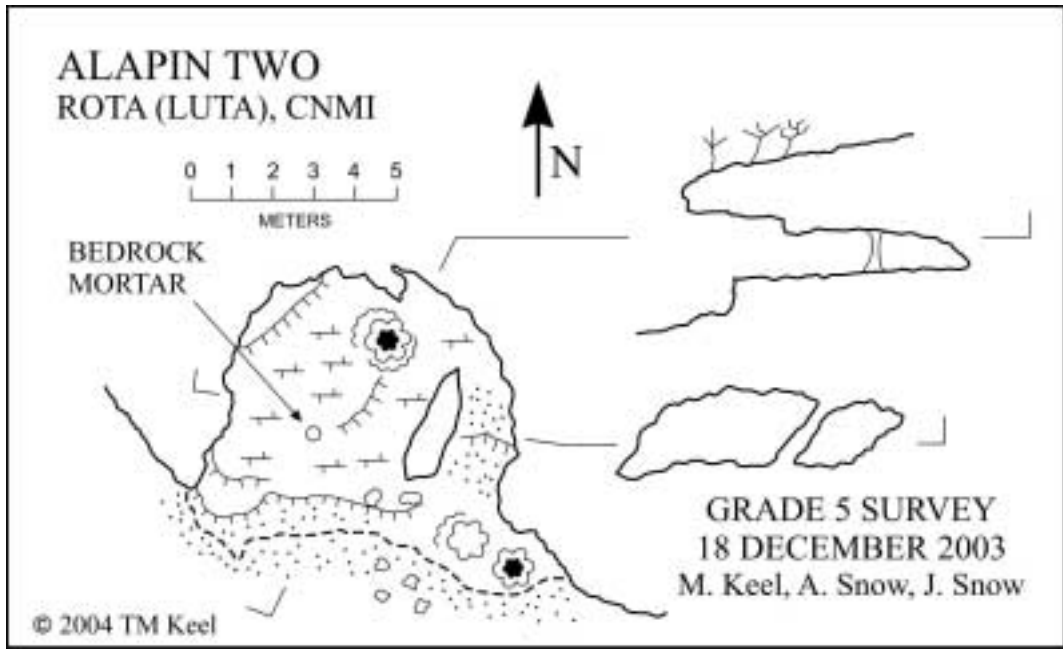


Figure 15. Map of Alapin Two

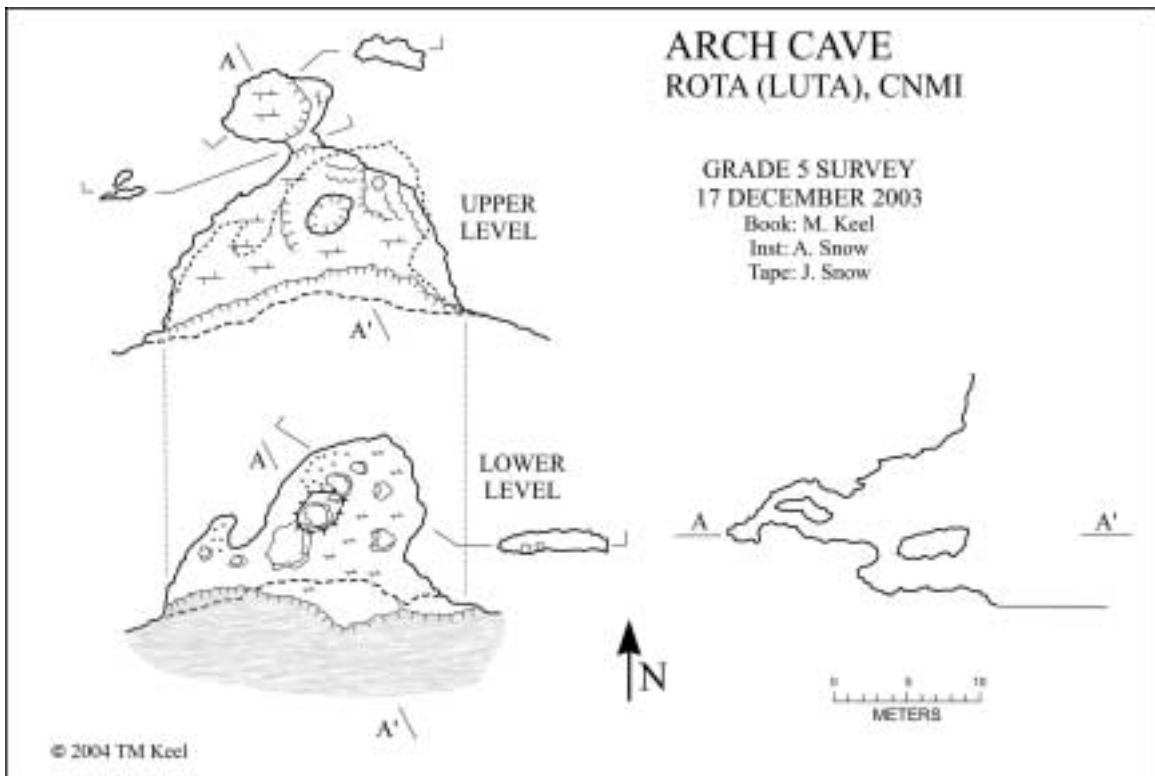


Figure 16. Map of Arch Cave



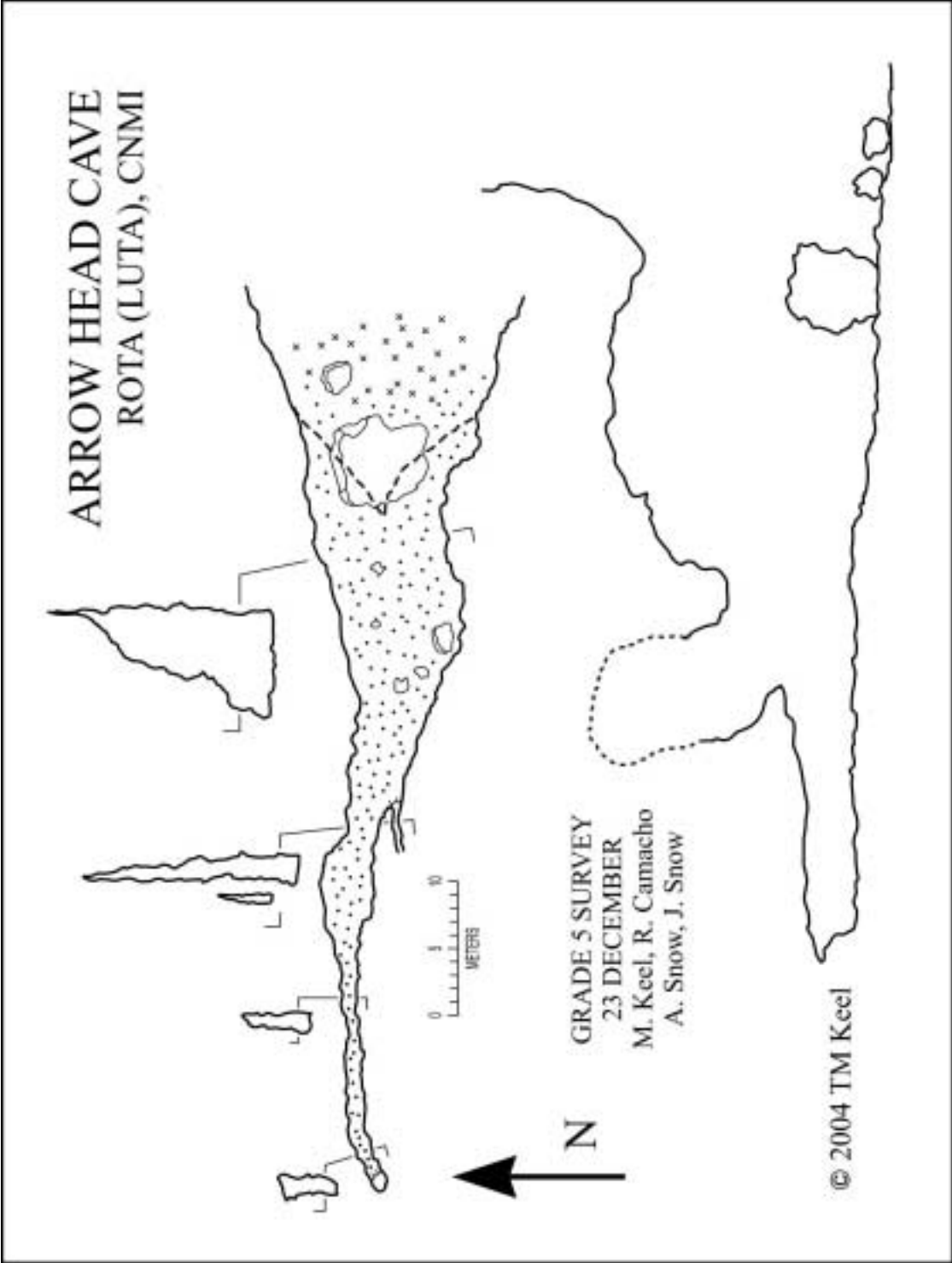


Figure 17. Map of Arrowhead Cave

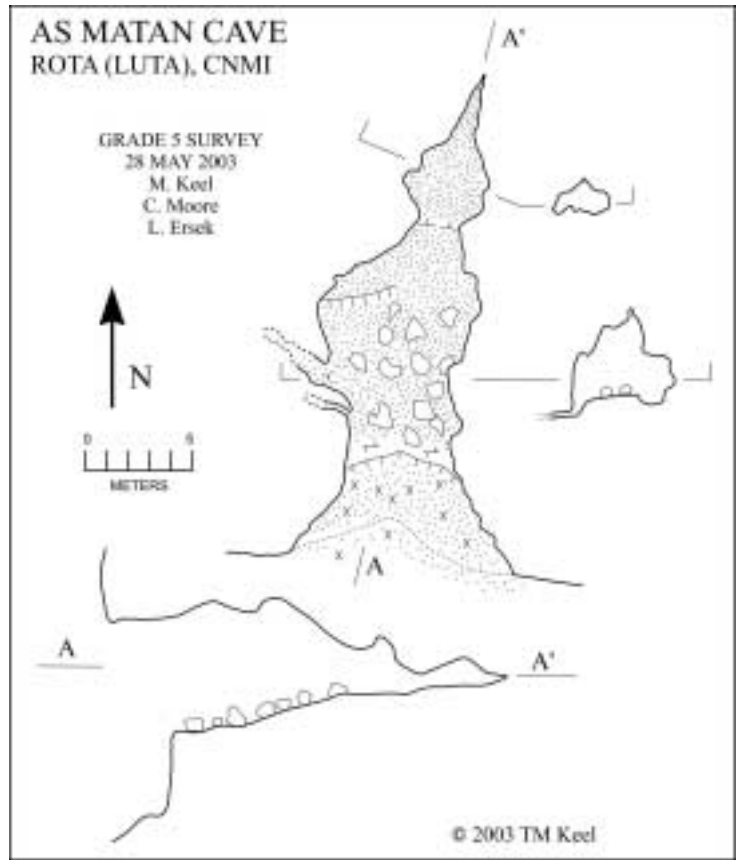


Figure 18. Map of As Matan

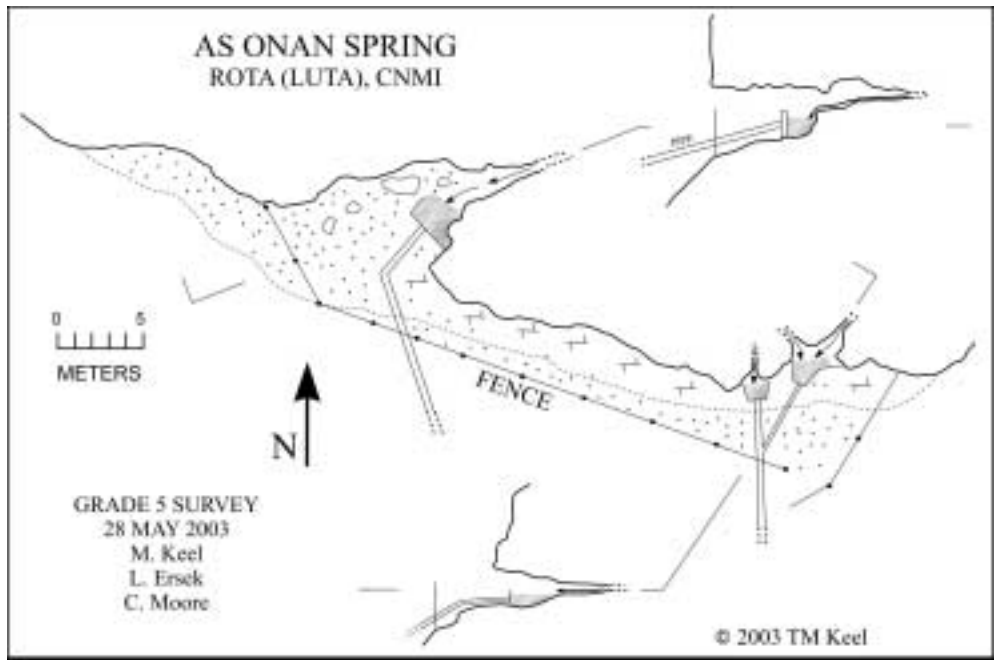
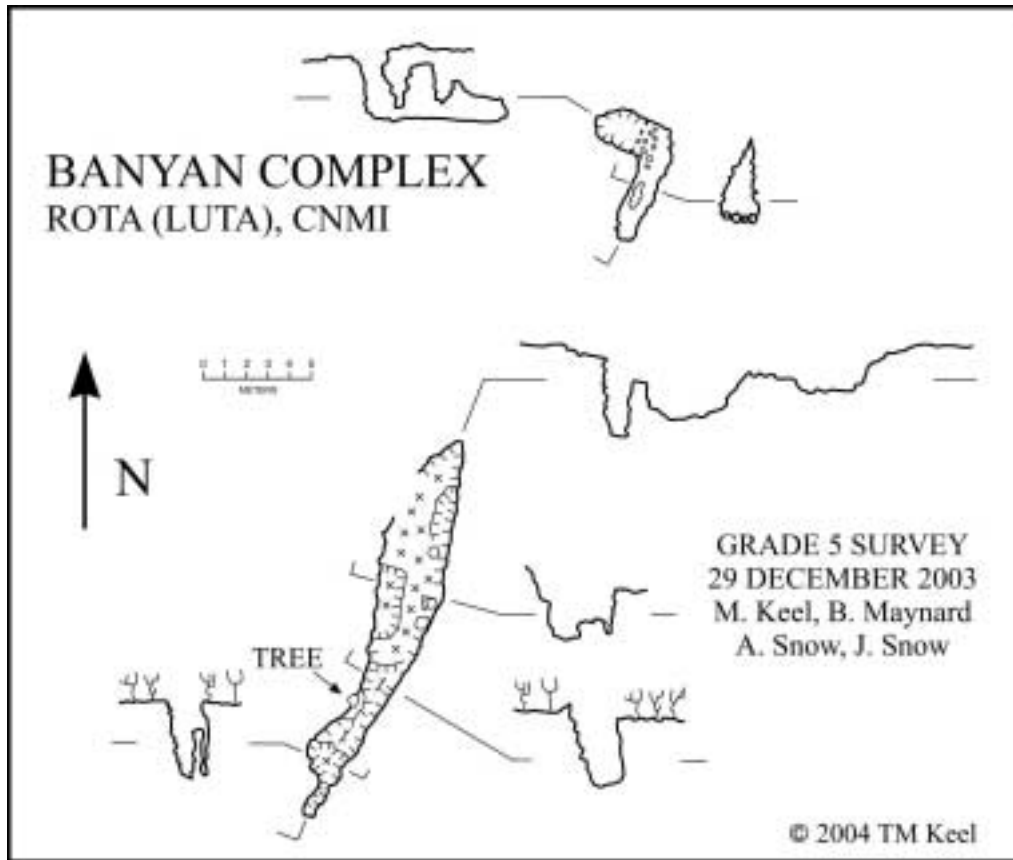
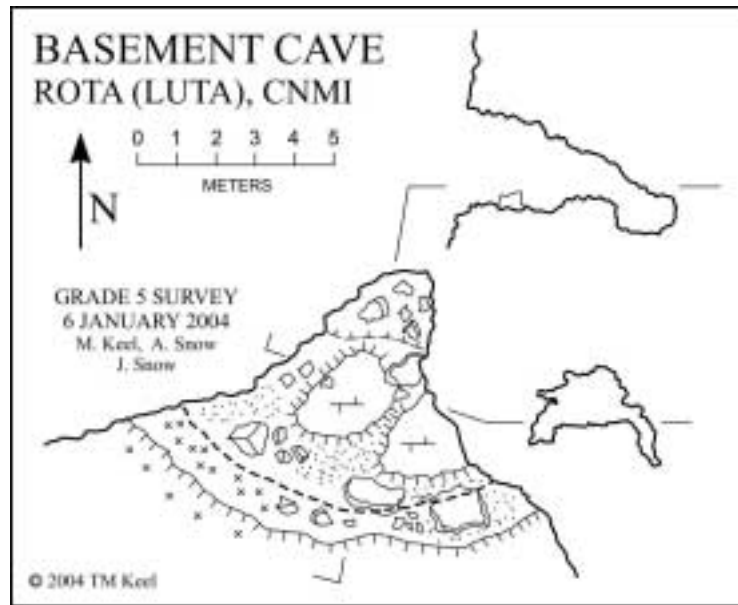


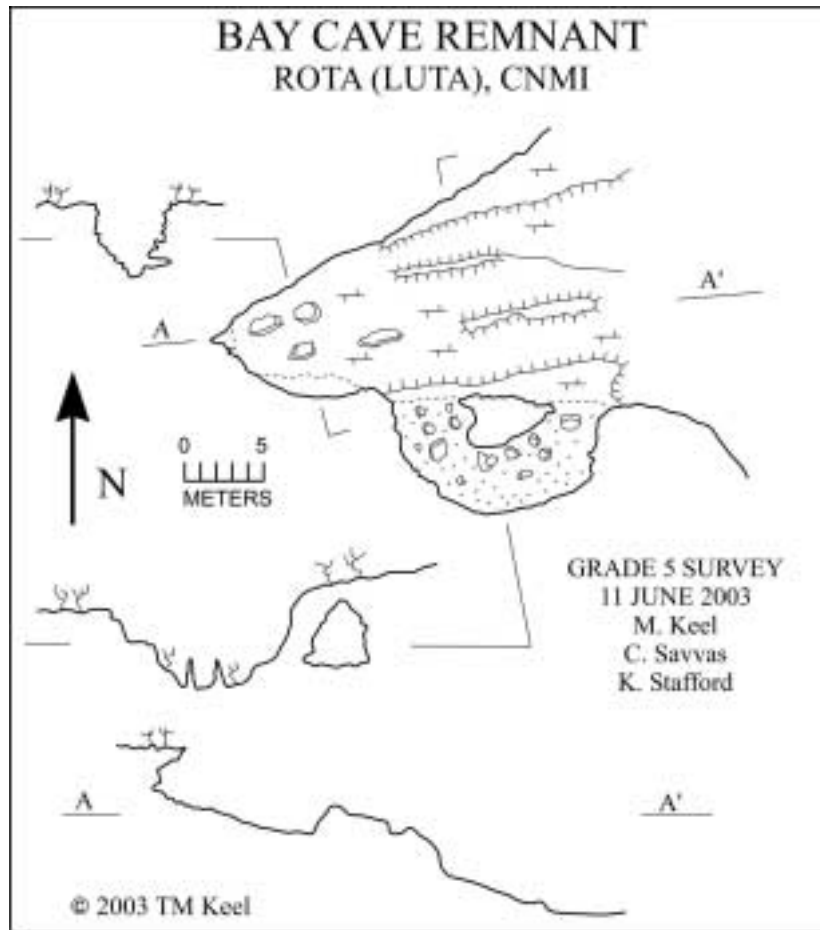
Figure 19. Map of As Onan Spring



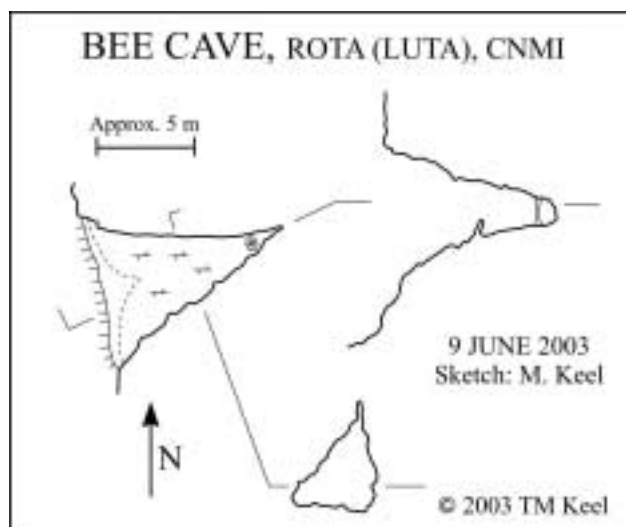
**Figure 20. Map of the Banyan Complex**



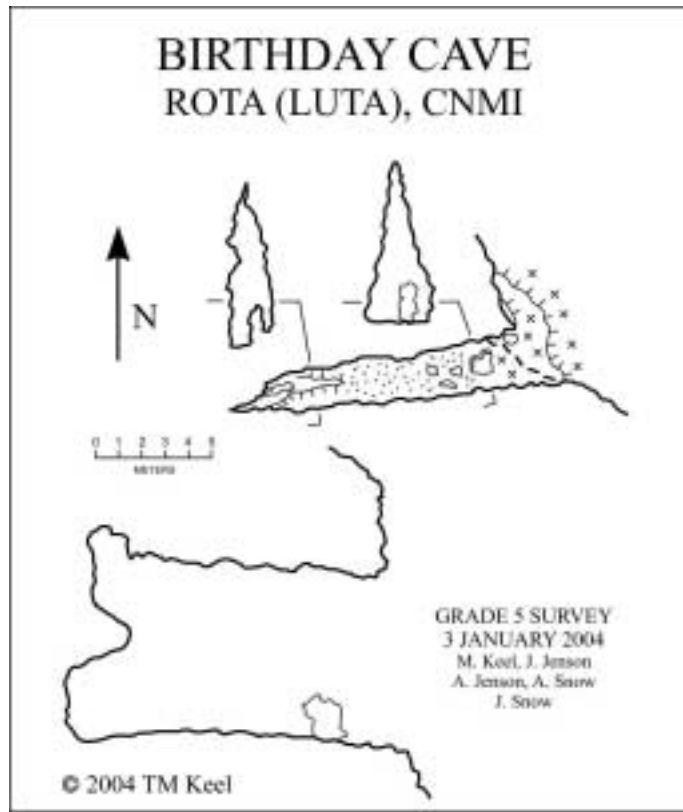
**Figure 21. Map of Basement Cave**



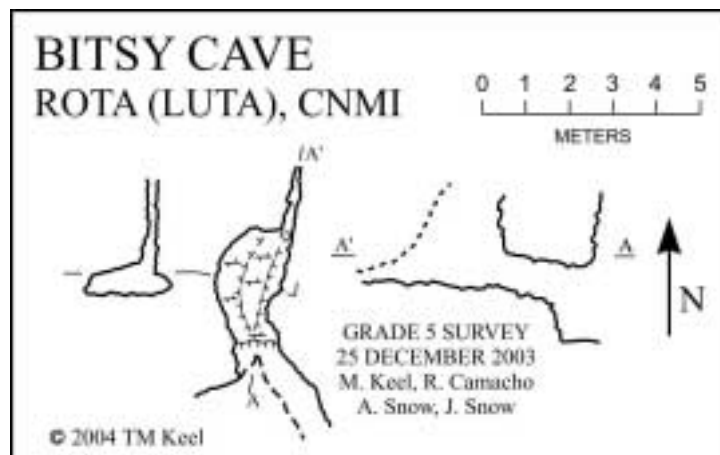
**Figure 22. Map of Bay Cave Remnant**



**Figure 23. Map of Bee Cave**



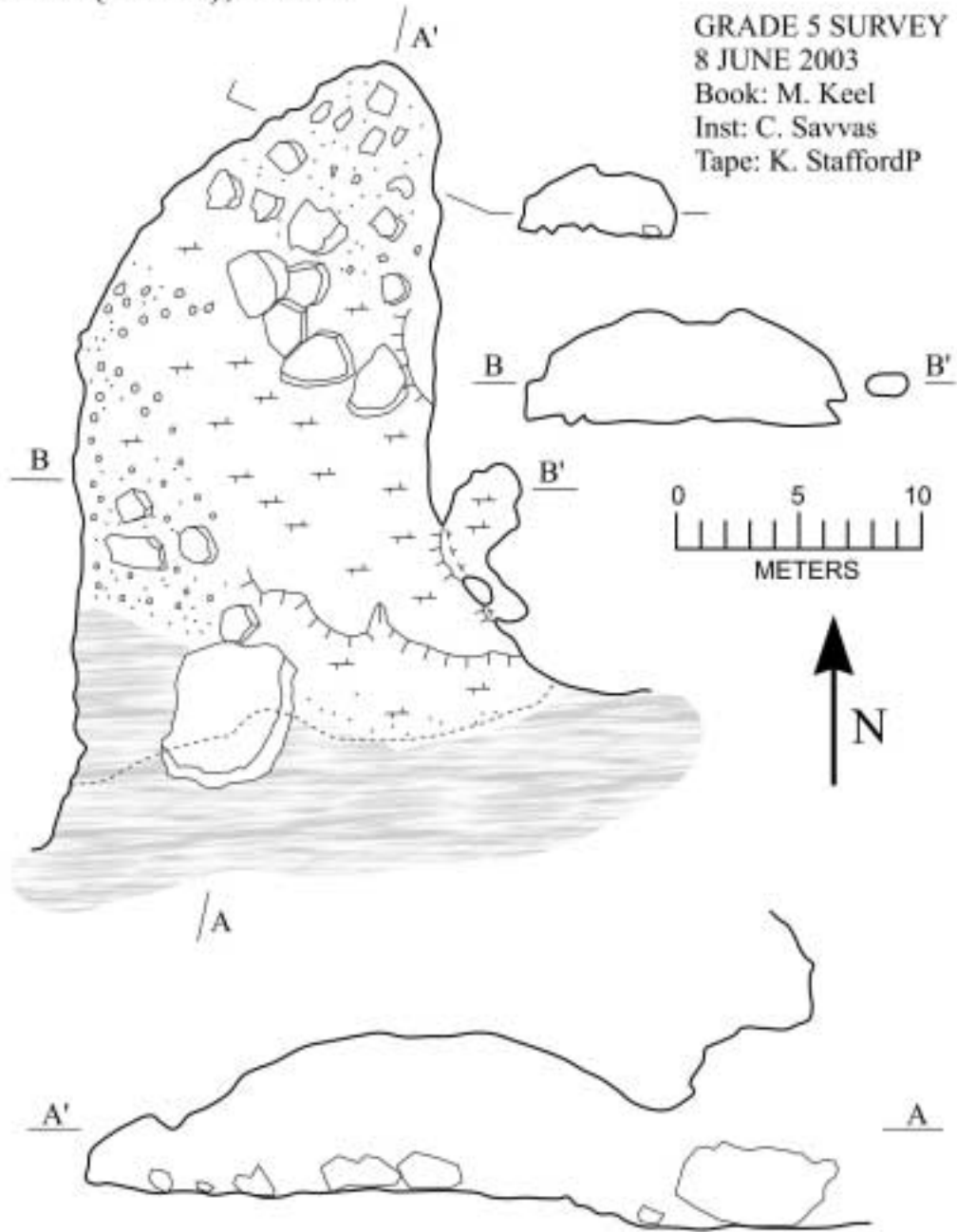
**Figure 24. Map of Birthday Cave**



**Figure 25. Map of Bitsy Cave**

**BLACK COBBLE CAVE**  
ROTA (LUTA), CNMI

GRADE 5 SURVEY  
8 JUNE 2003  
Book: M. Keel  
Inst: C. Savvas  
Tape: K. StaffordP



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**Figure 26. Map of Black Cobble Cave**

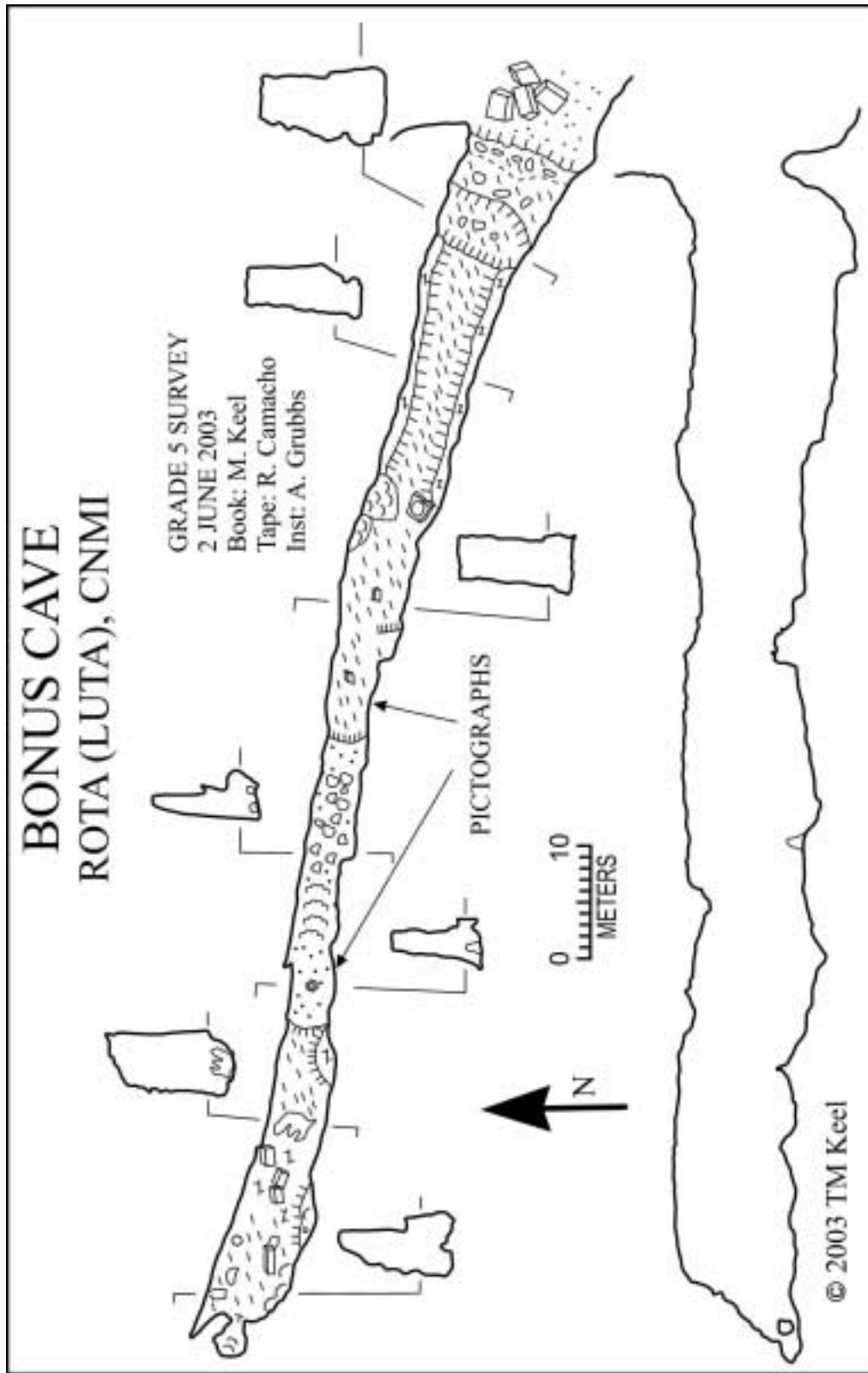


Figure 27. Map of Bonus Cave

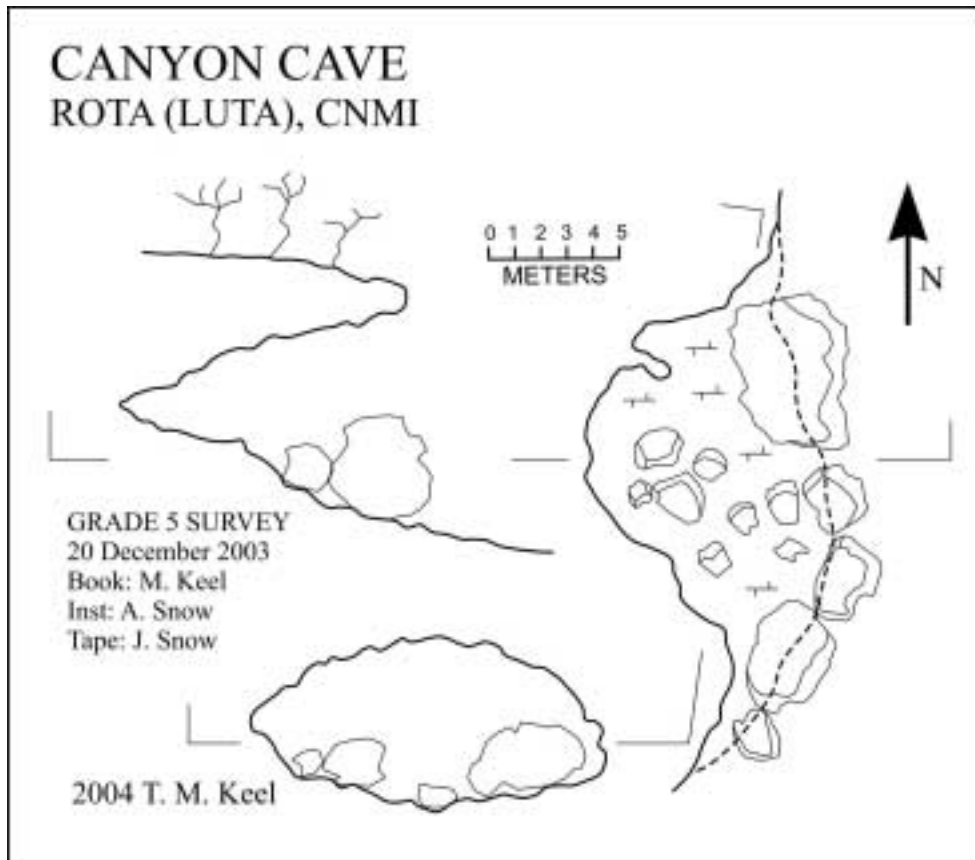
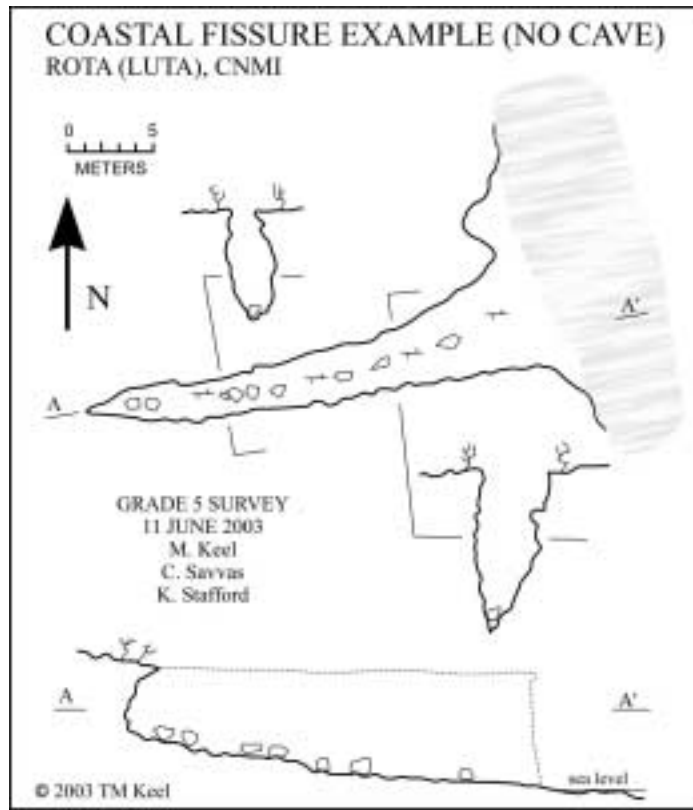


Figure 28. Canyon Cave

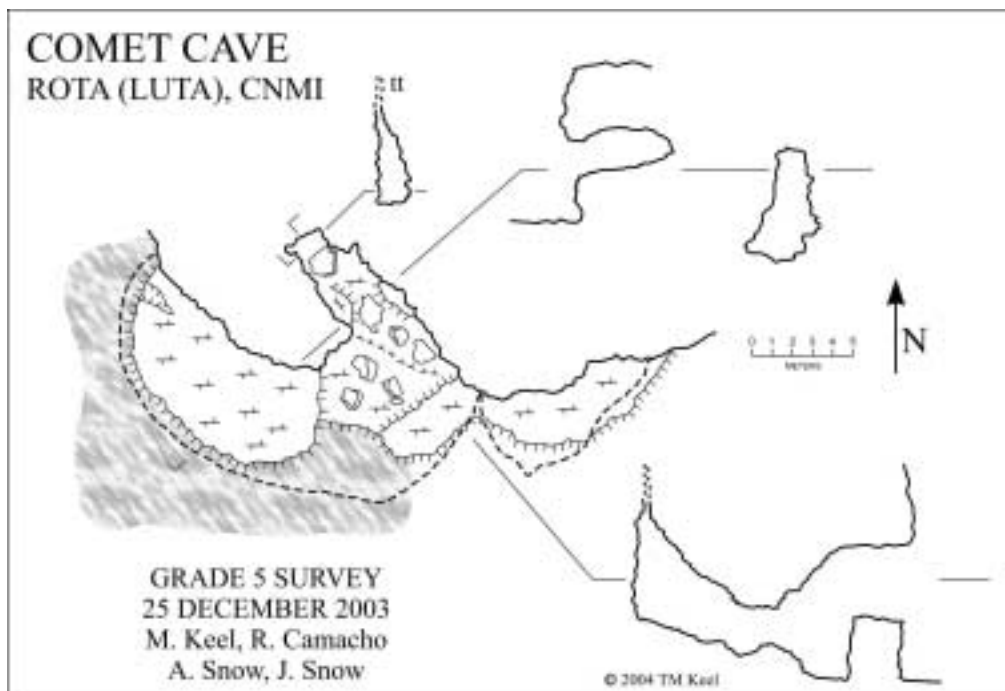


Figure 29. Christmas Cave





**Figure 30. Map of Coastal Fissure Example**



**Figure 31. Map of Comet Cave**

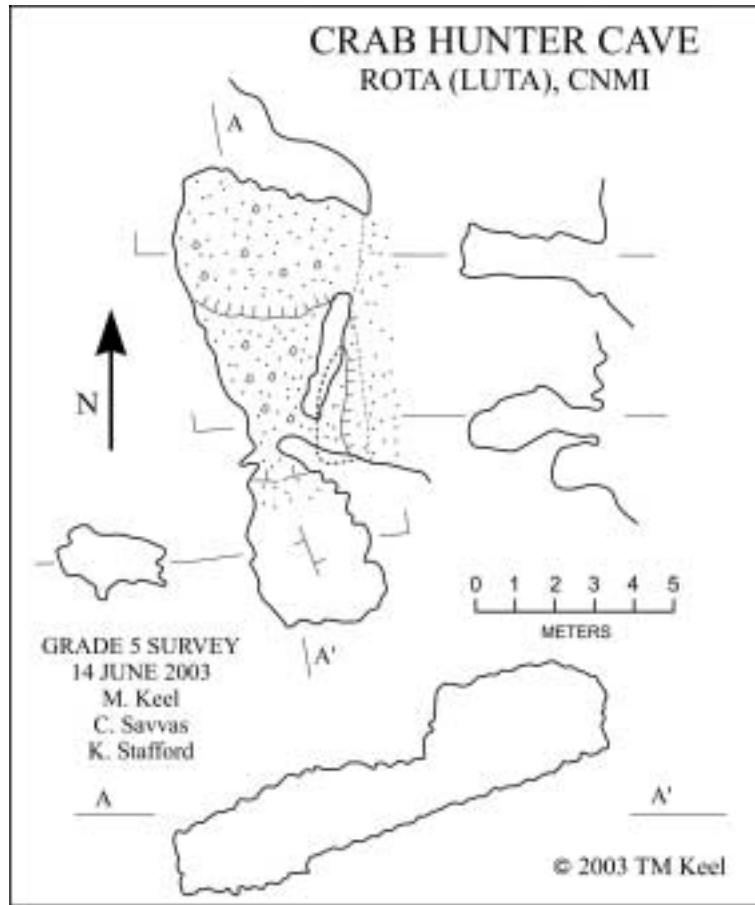


Figure 32. Map of Crab Hunter Cave

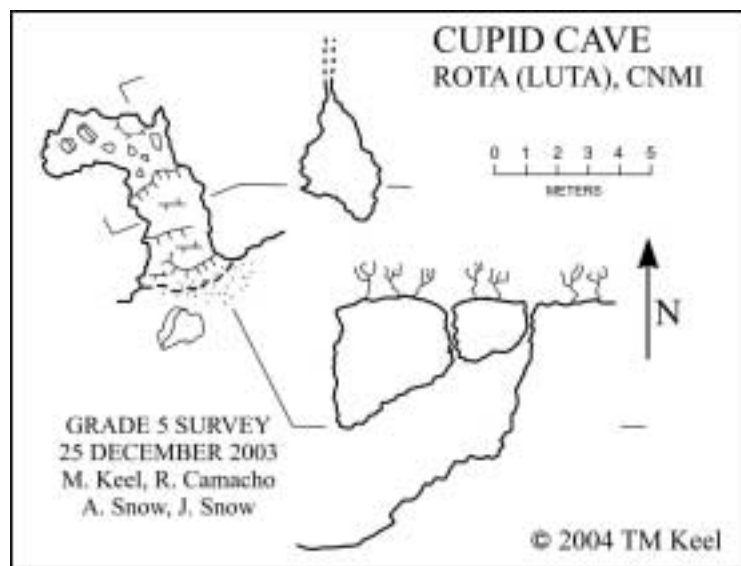


Figure 33. Map of Cupid Cave

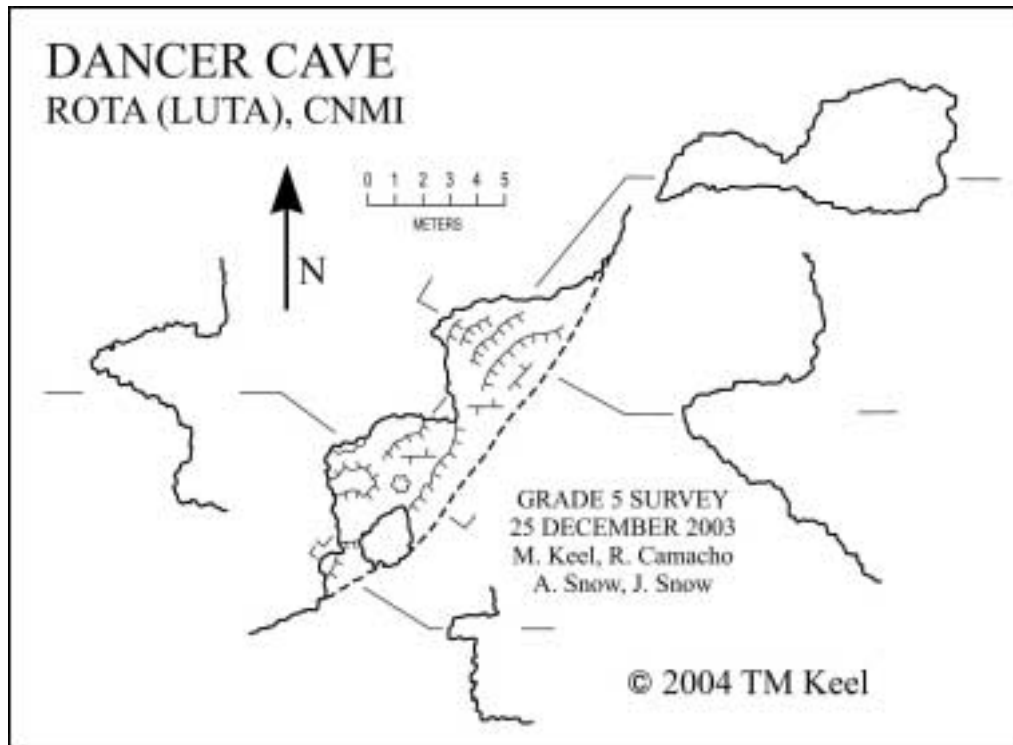


Figure 34. Map of Dancer Cave



Figure 35. Map of Dasher Cave

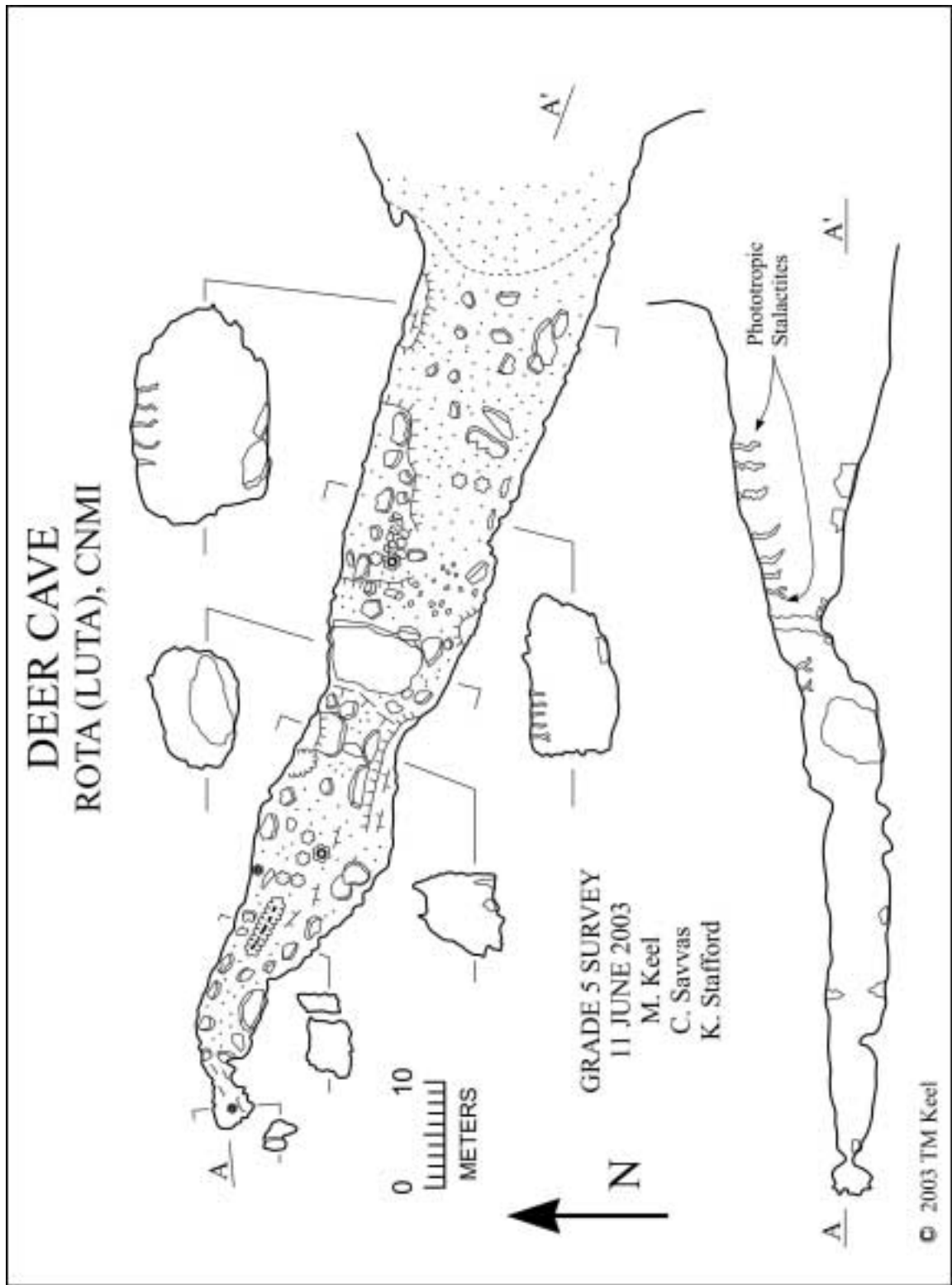


Figure 36. Map of Deer Cave

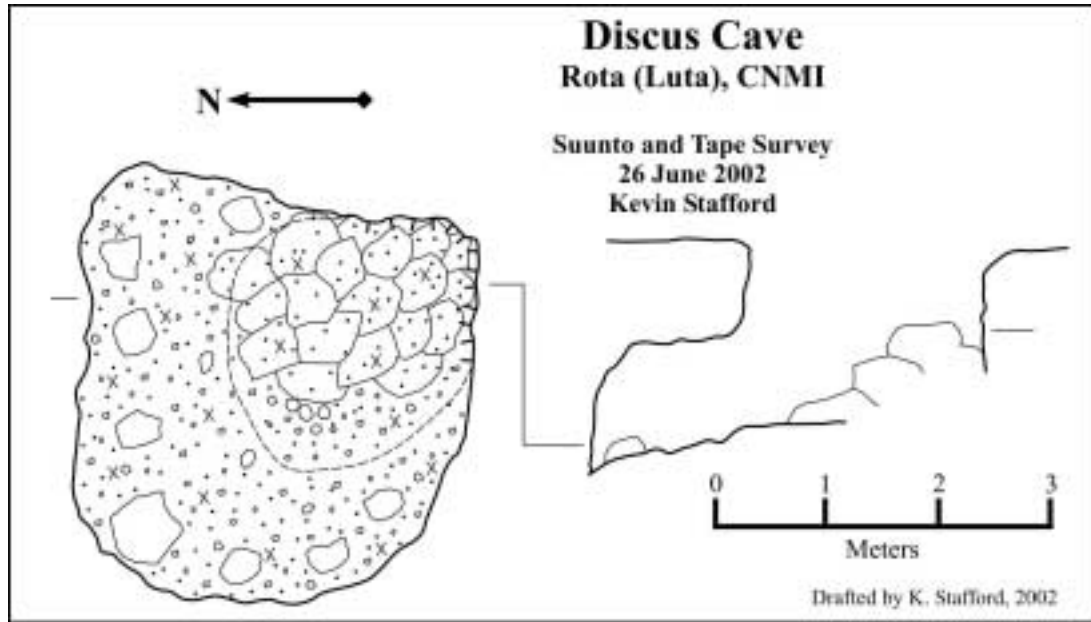


Figure 37. Map of Discus Cave (Modified from Stafford 2002)

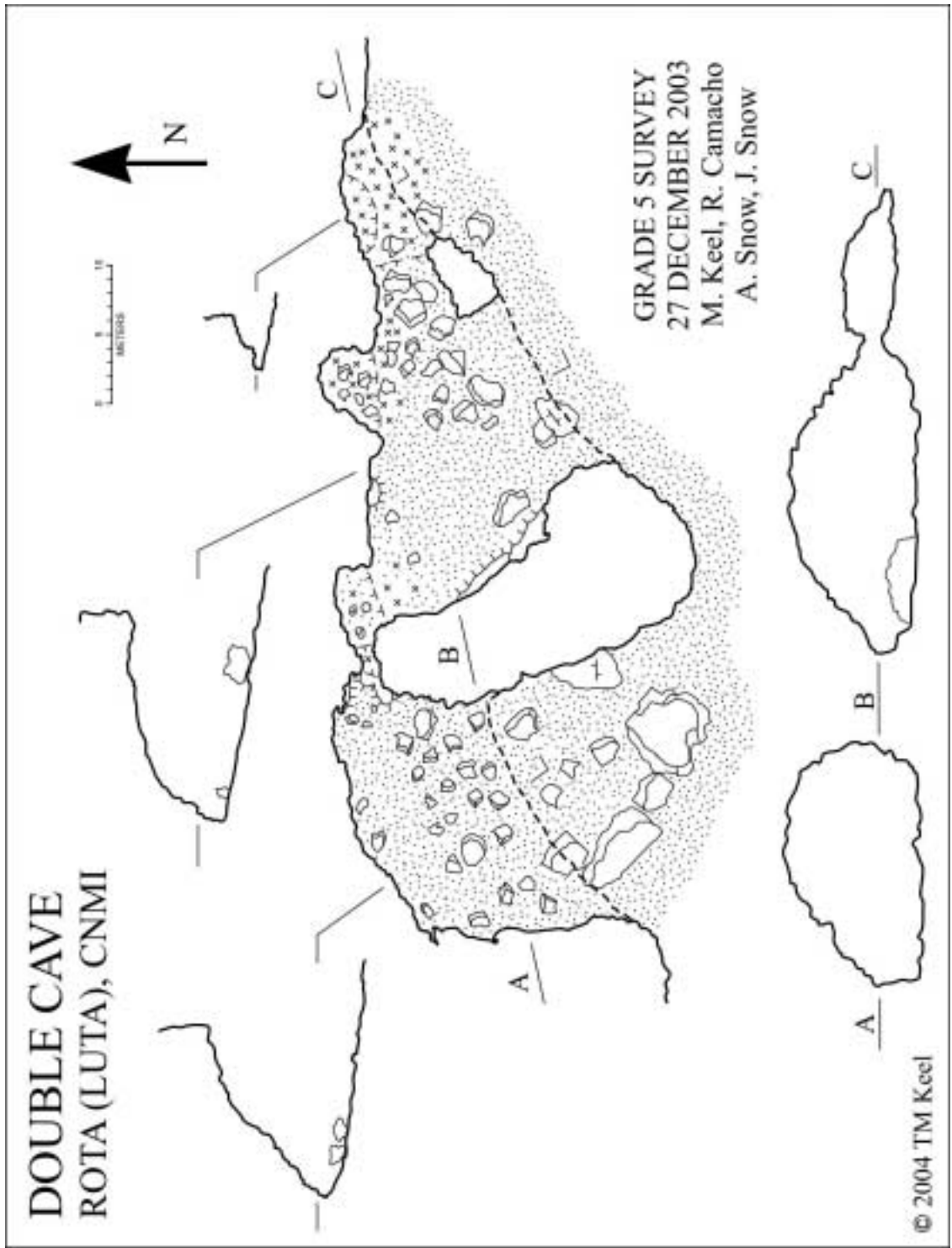


Figure 38. Map of Double Cave

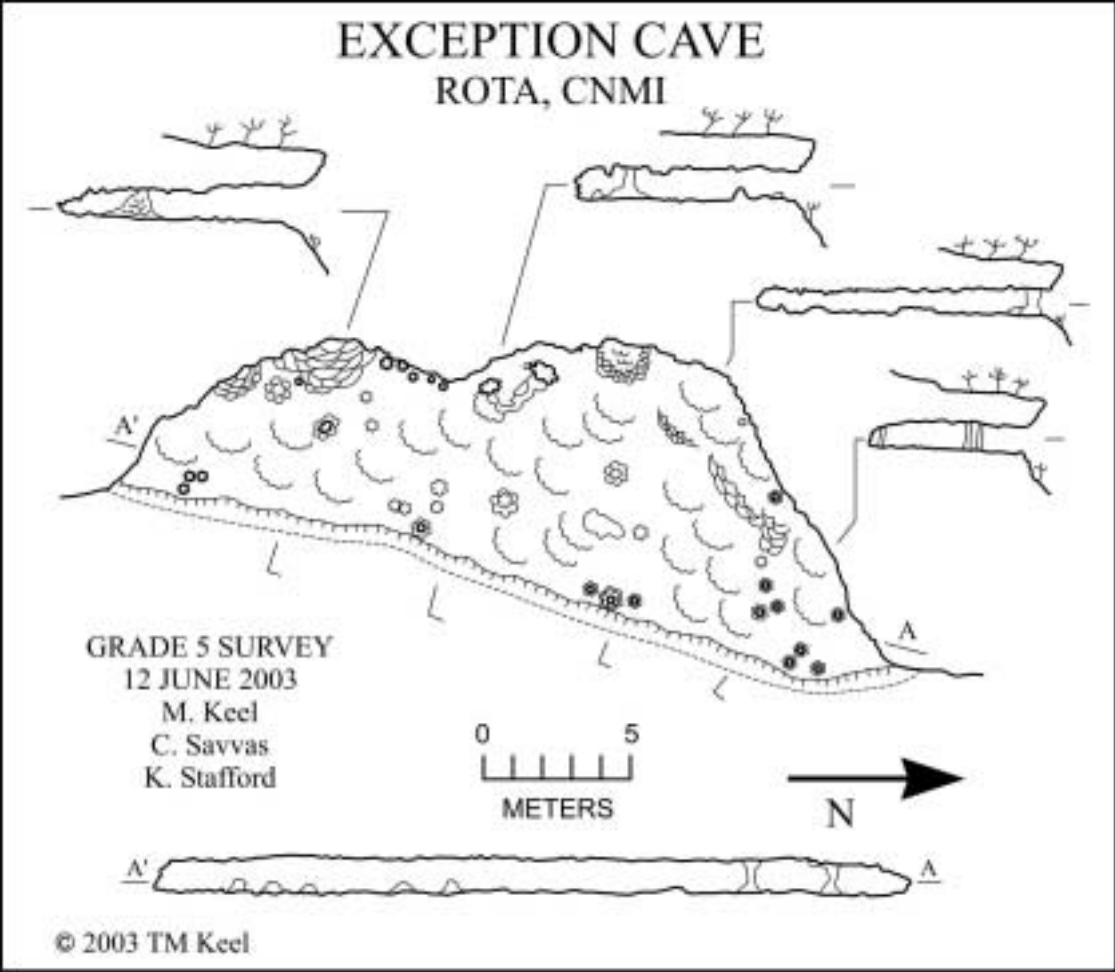
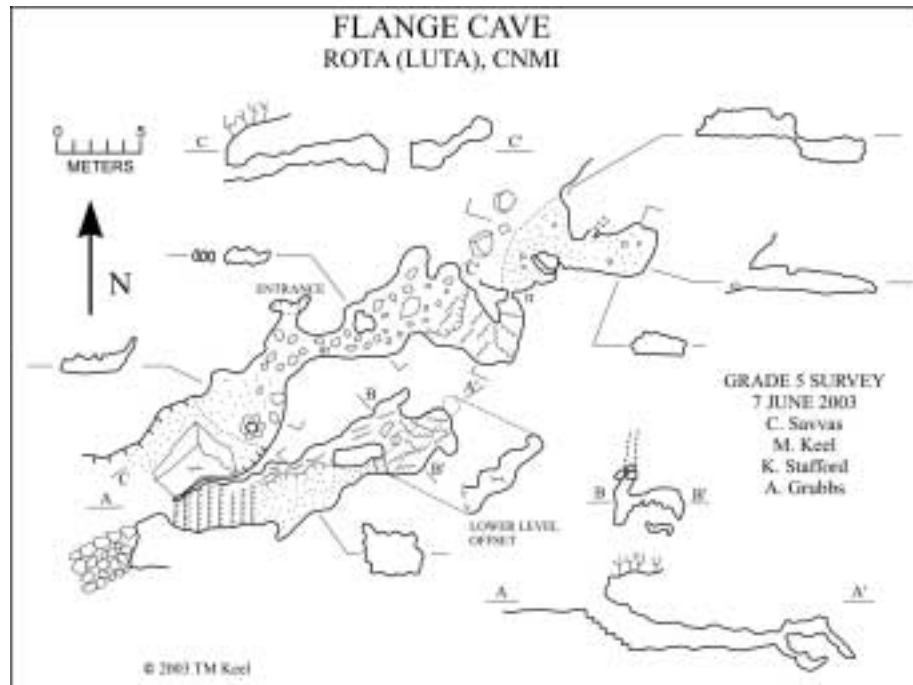
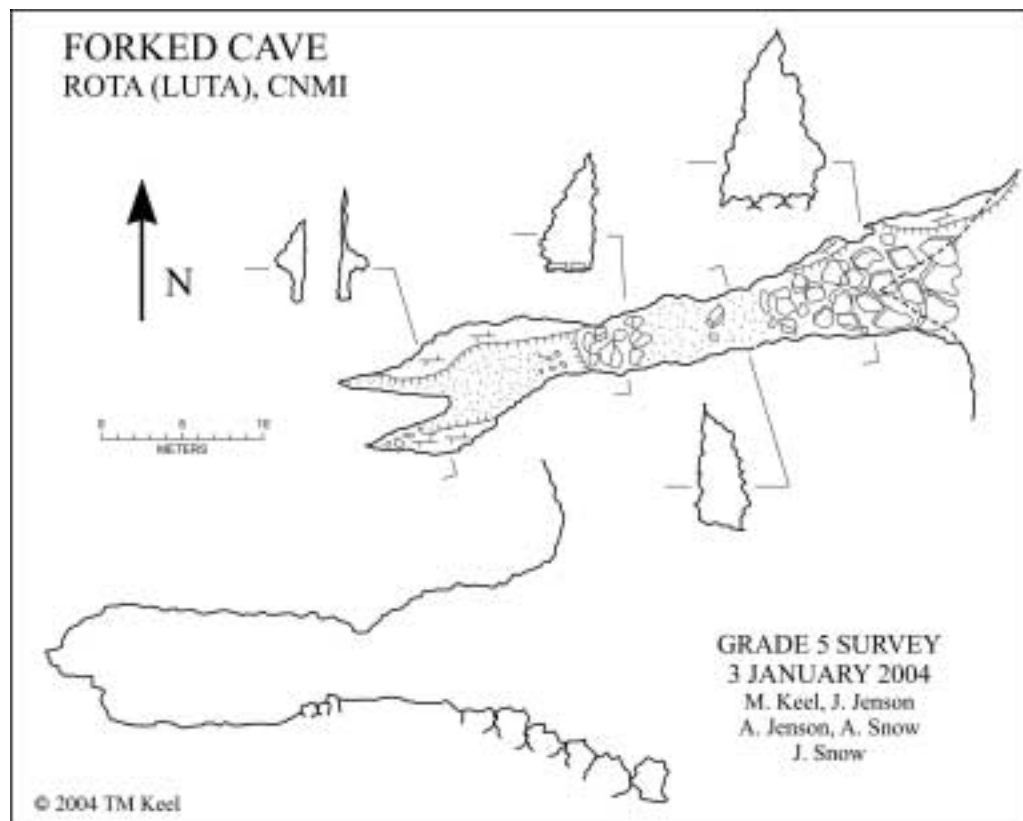


Figure 39. Map of Exception Cave

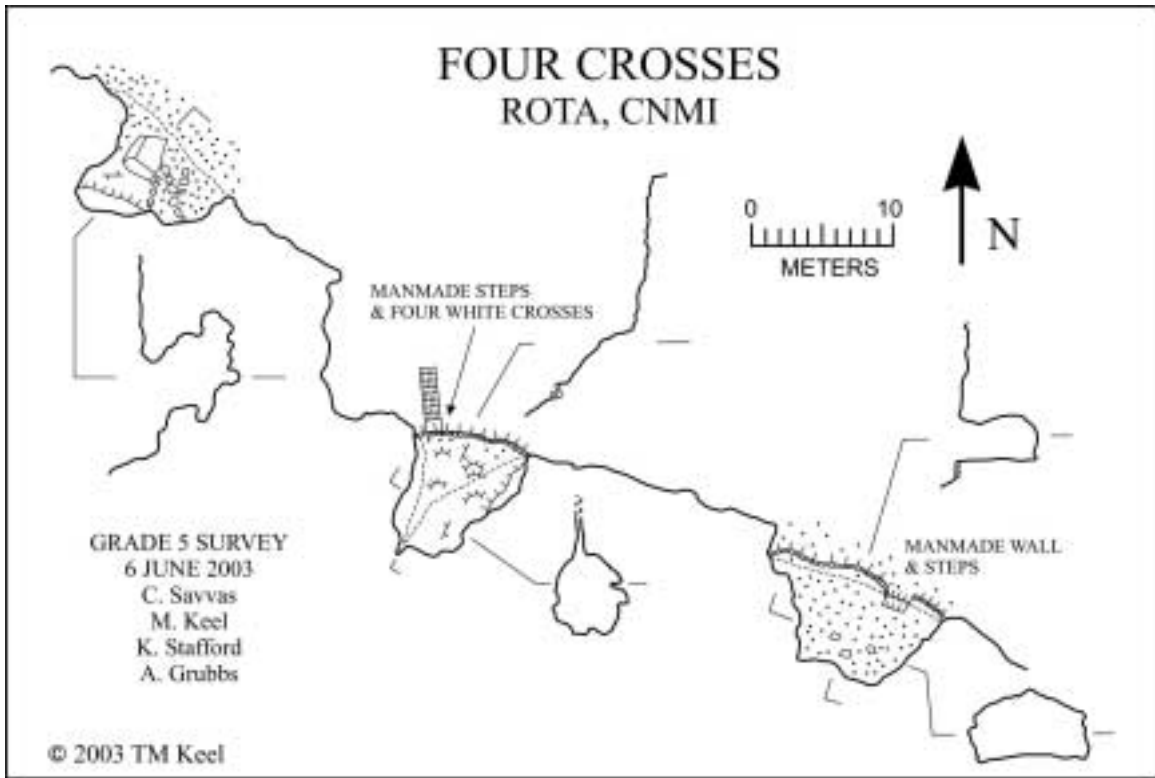


**Figure 40. Map of Flange Cave**

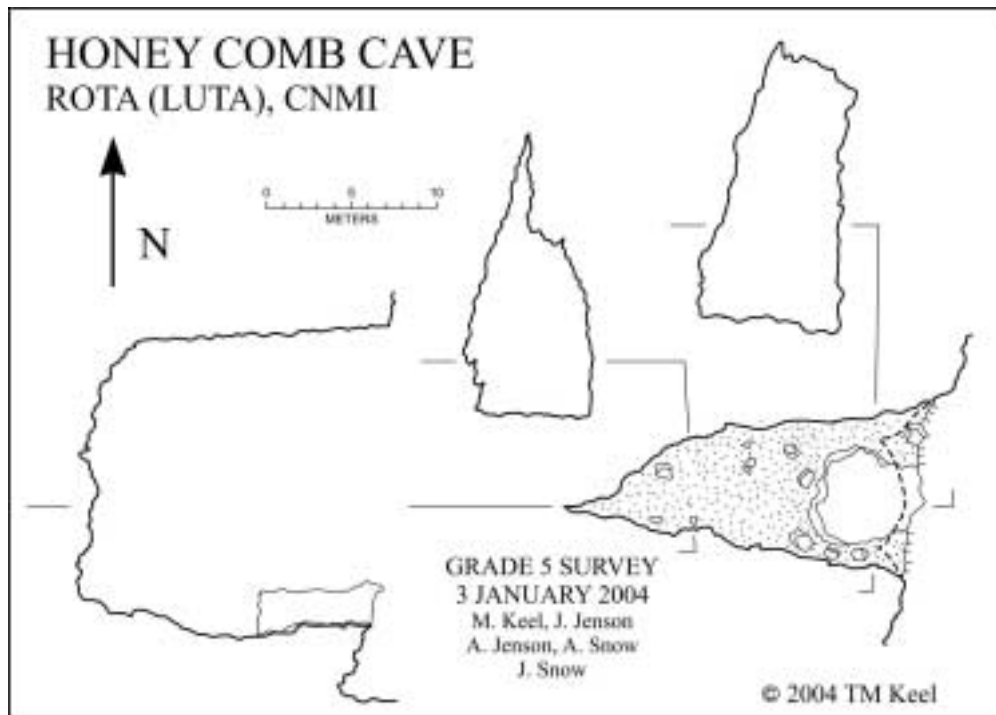


**Figure 41. Map of Forked Cave**





**Figure 41. Map of Four Crosses**



**Figure 43. Map of Honeycomb Cave**

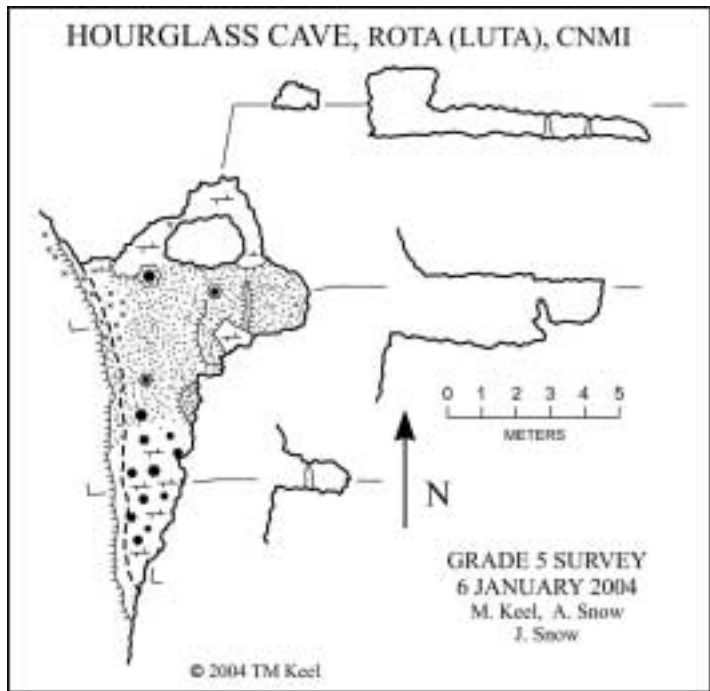


Figure 44. Map of Hourglass Cave

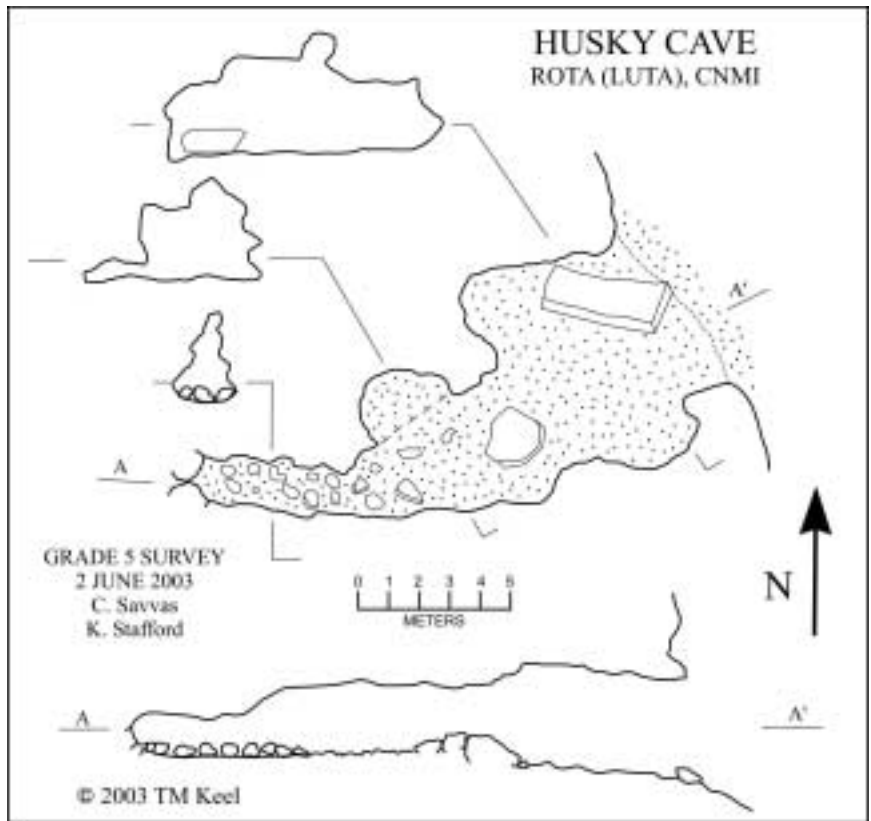


Figure 45. Map of Husky Cave

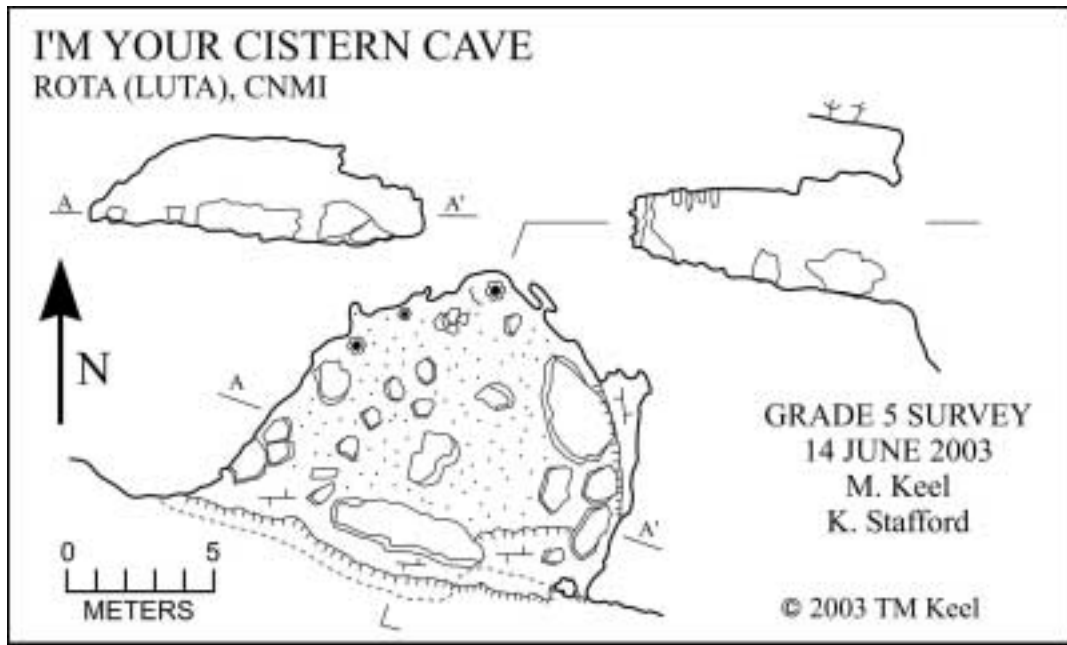


Figure 46. Map of I'm Your Cistern Cave

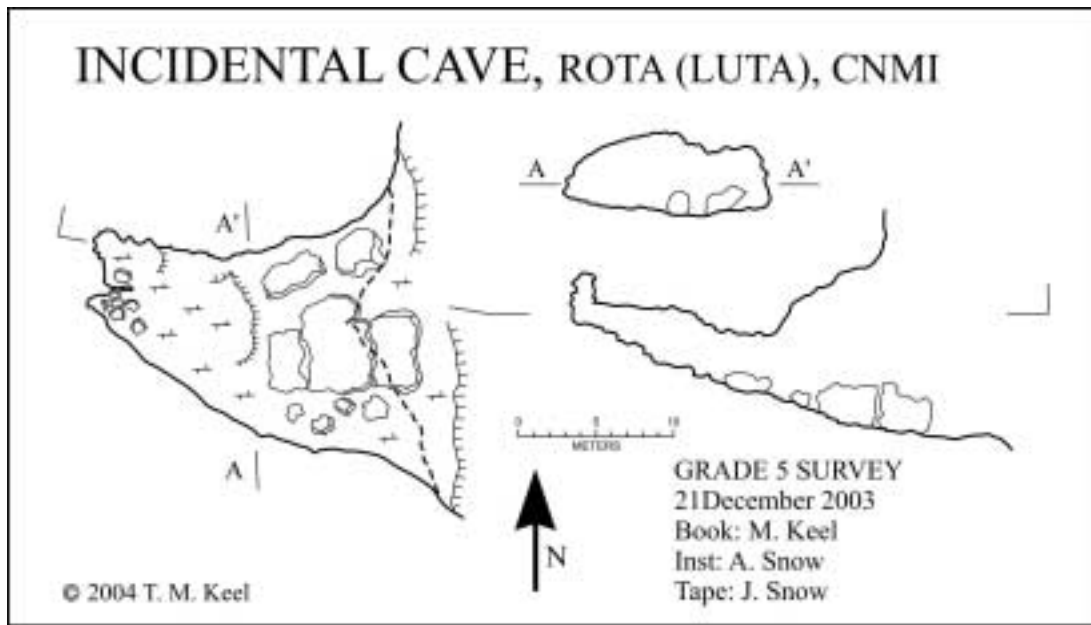


Figure 47. Map of Incidental Cave

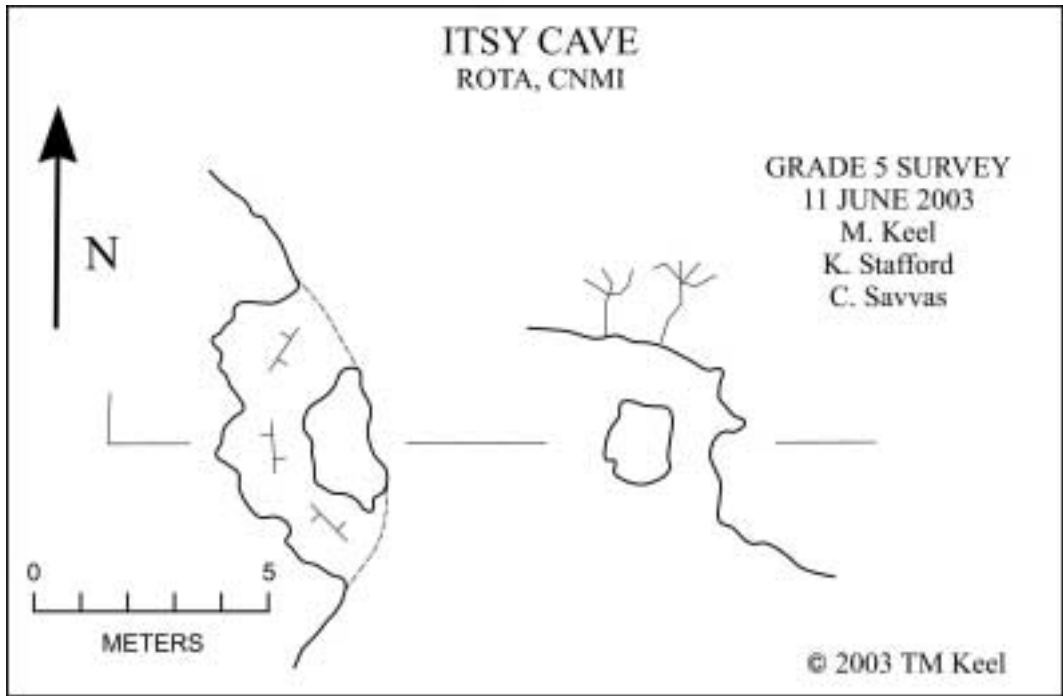
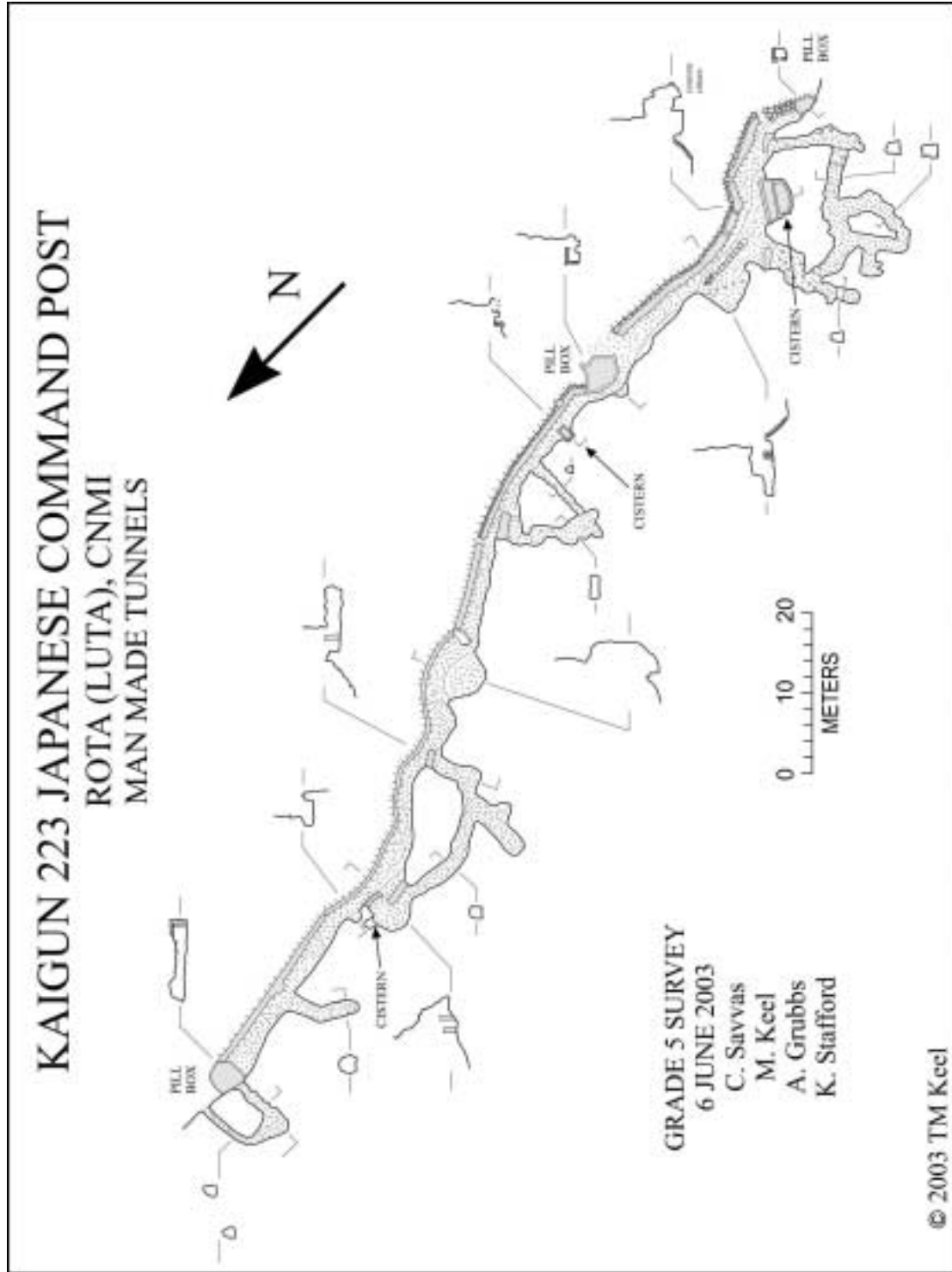


Figure 48. Itsy Cave



**Figure 49. Map of Kaigun 223 Japanese Command Post**

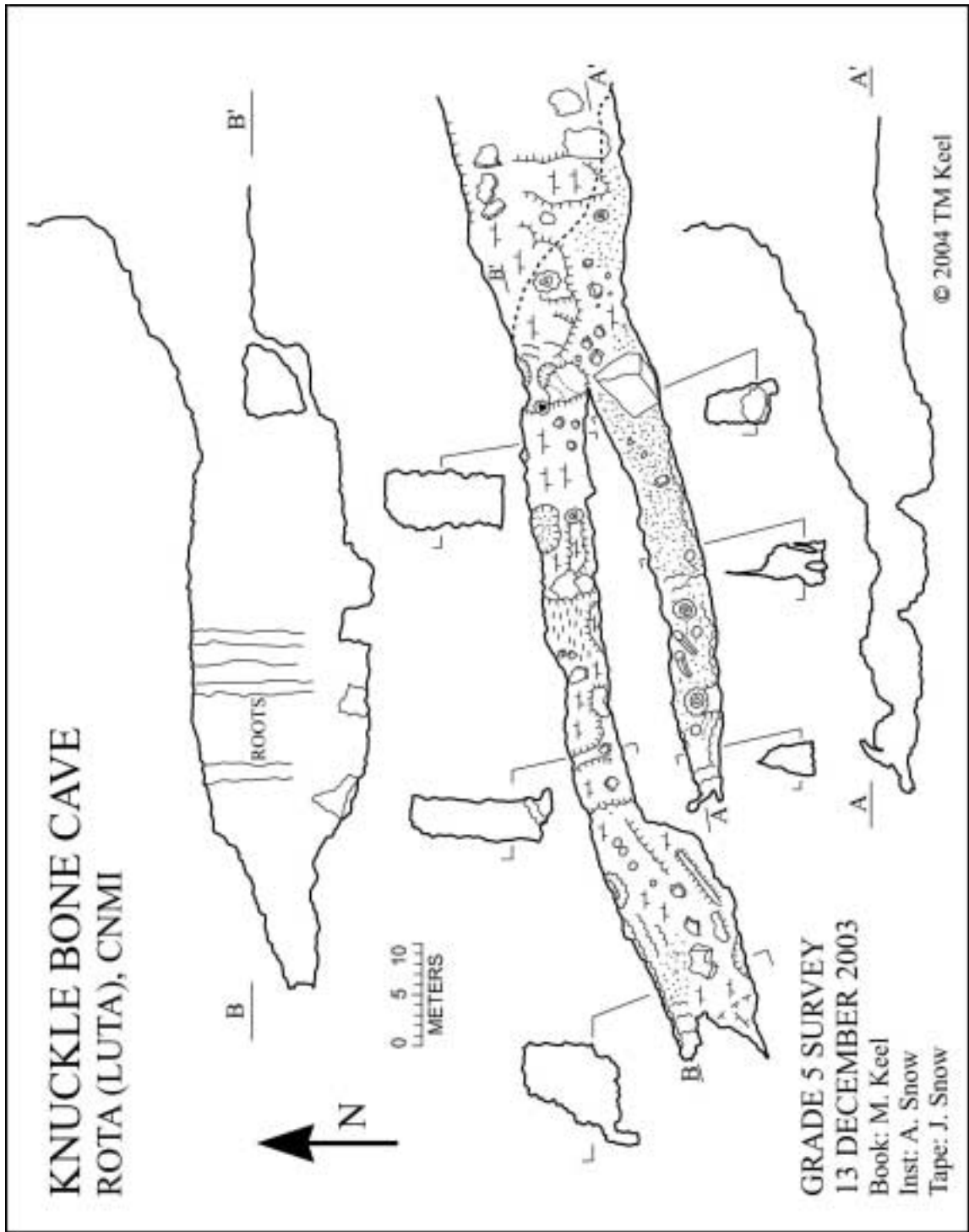
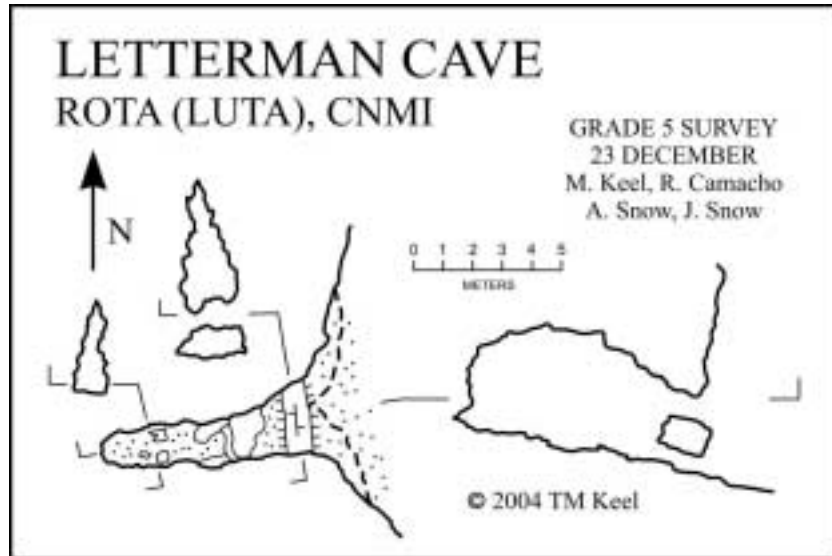


Figure 50. Map of Knuckle Bone Cave



**Figure 51. Map of Letterman Cave**

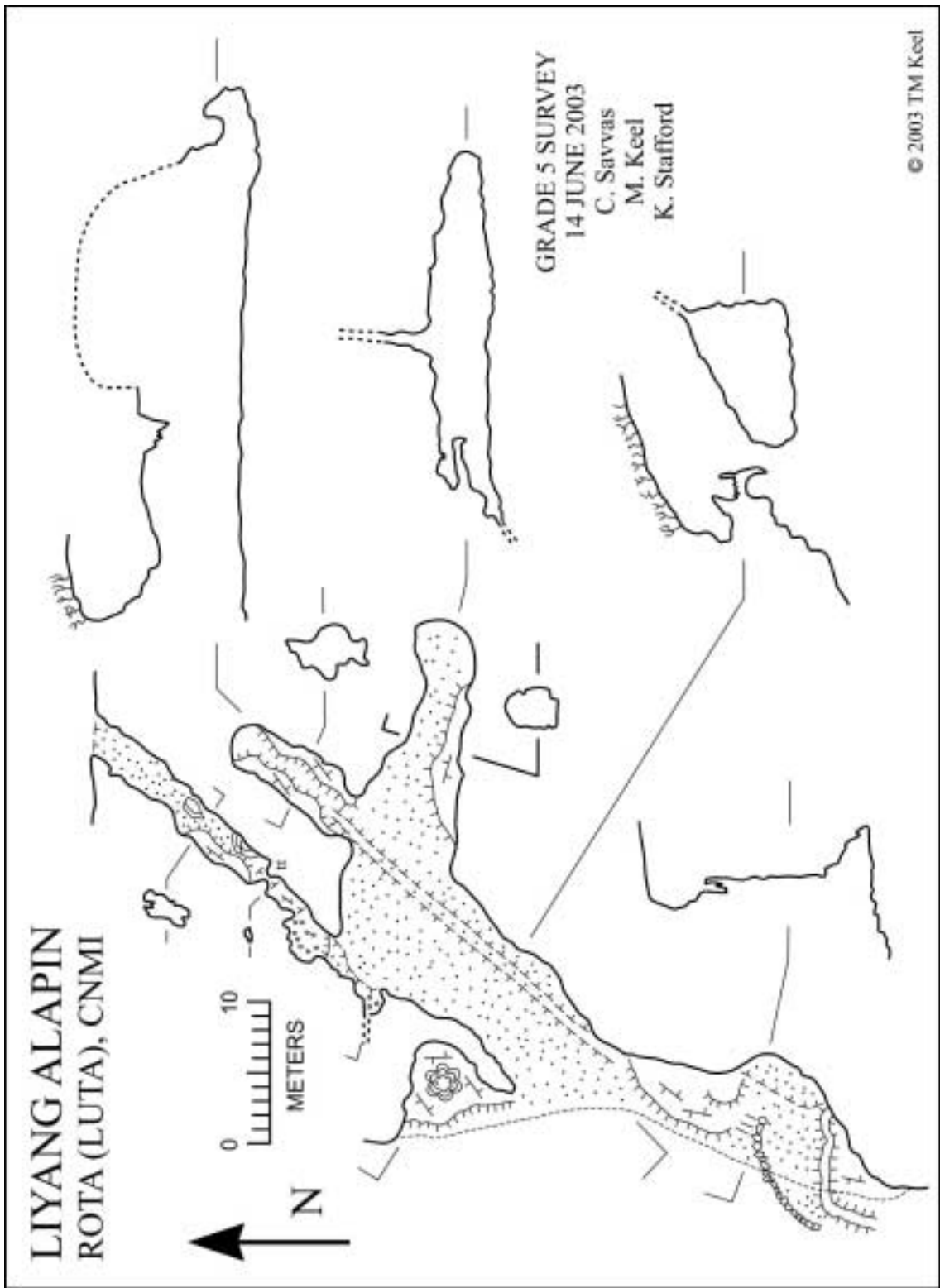


Figure 52. Map of Liyang Alapin



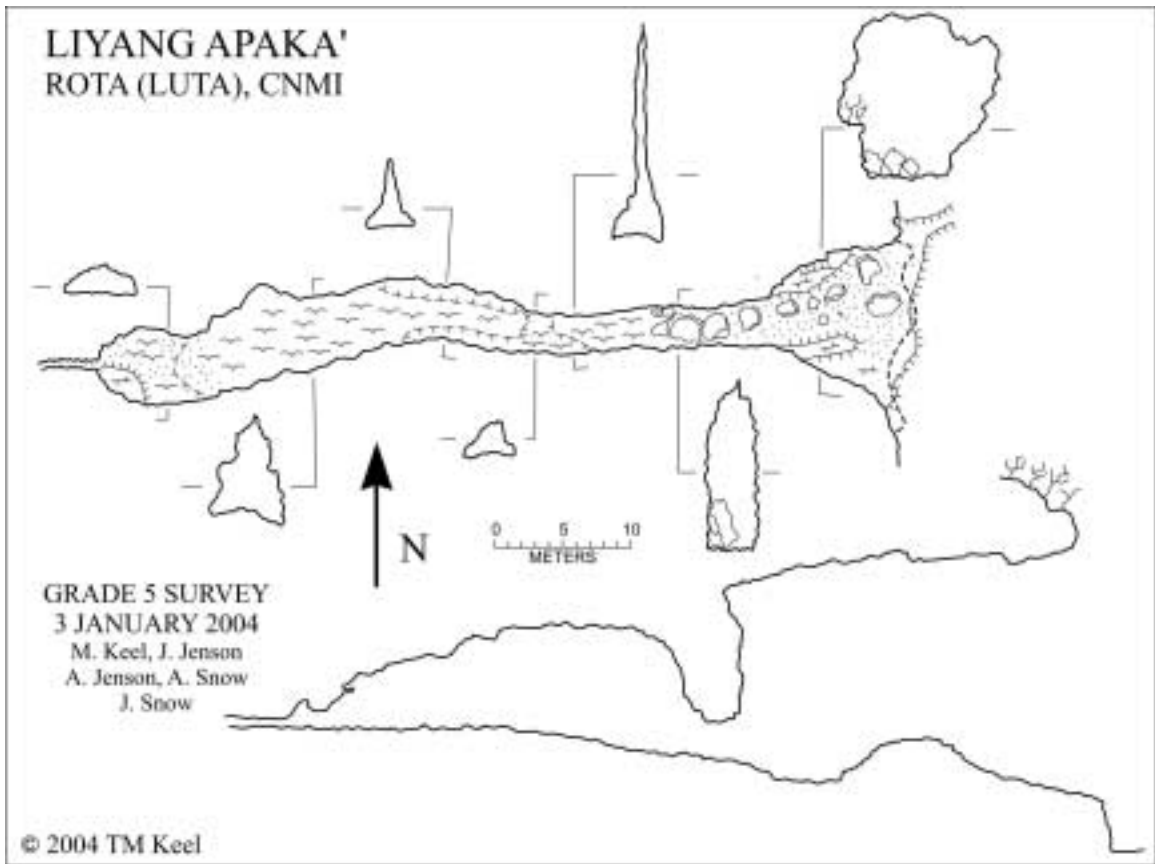


Figure 53. Map of Liyang Apaka

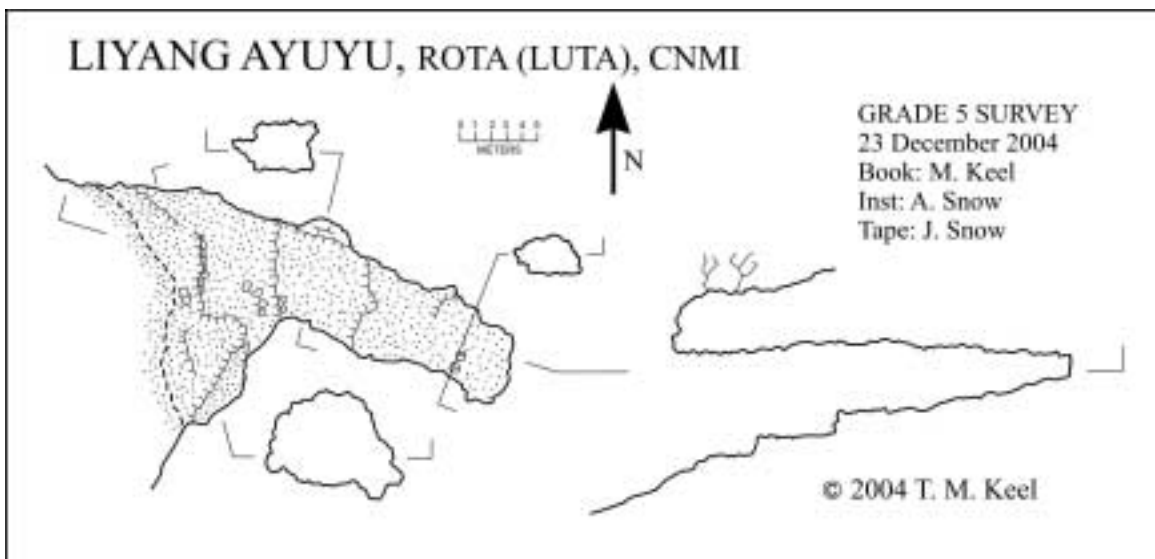


Figure 54. Map of Liyang Ayuyu

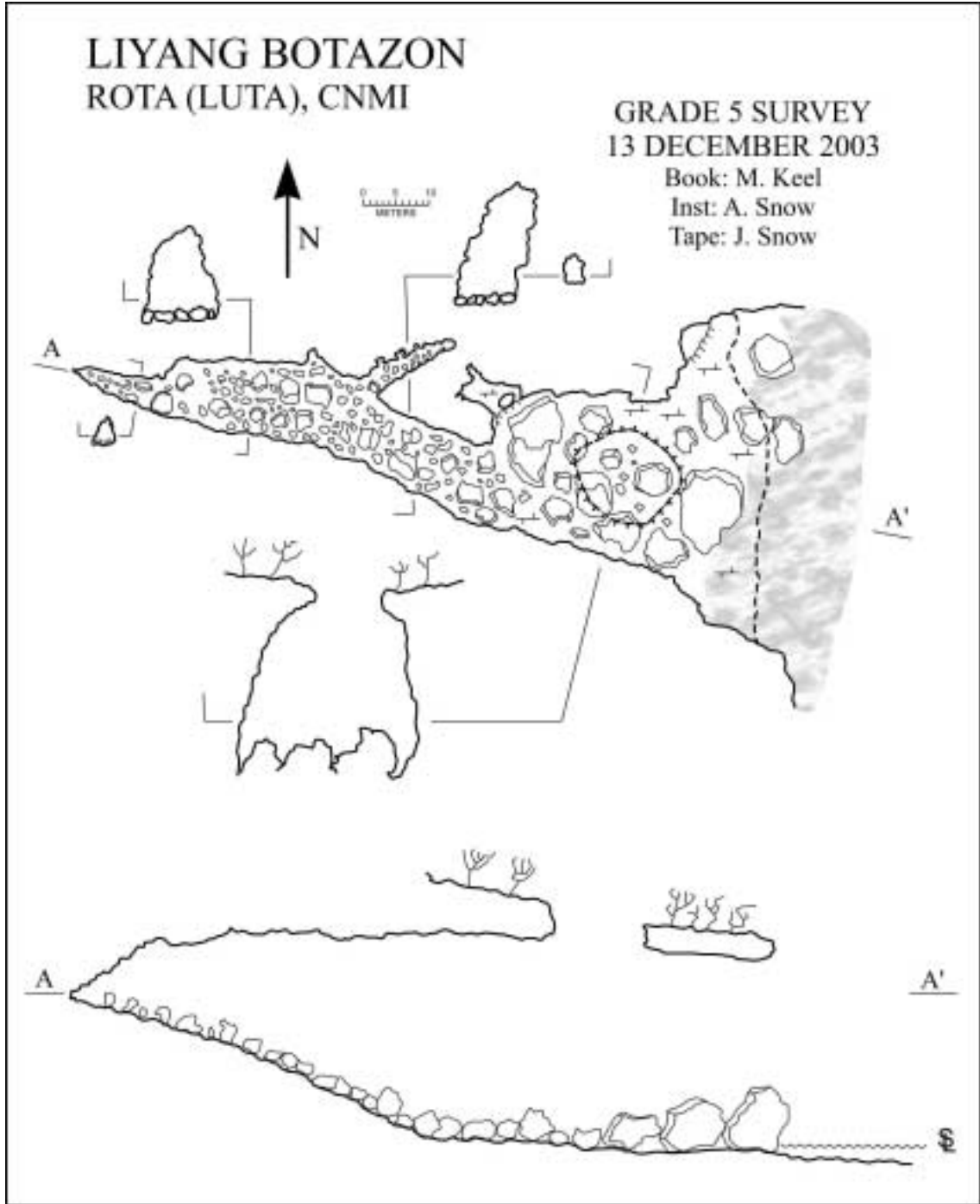
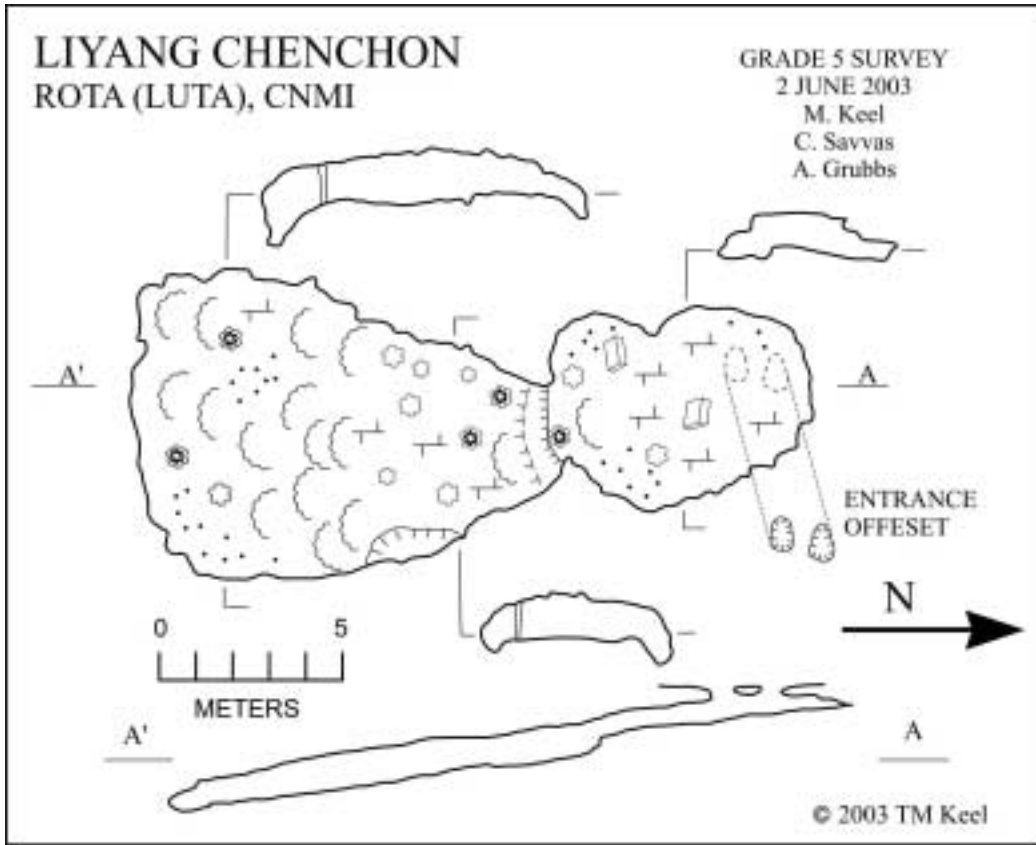


Figure 55. Map of Liyang *Botazon*



**Figure 56. Liyang Chenchon**

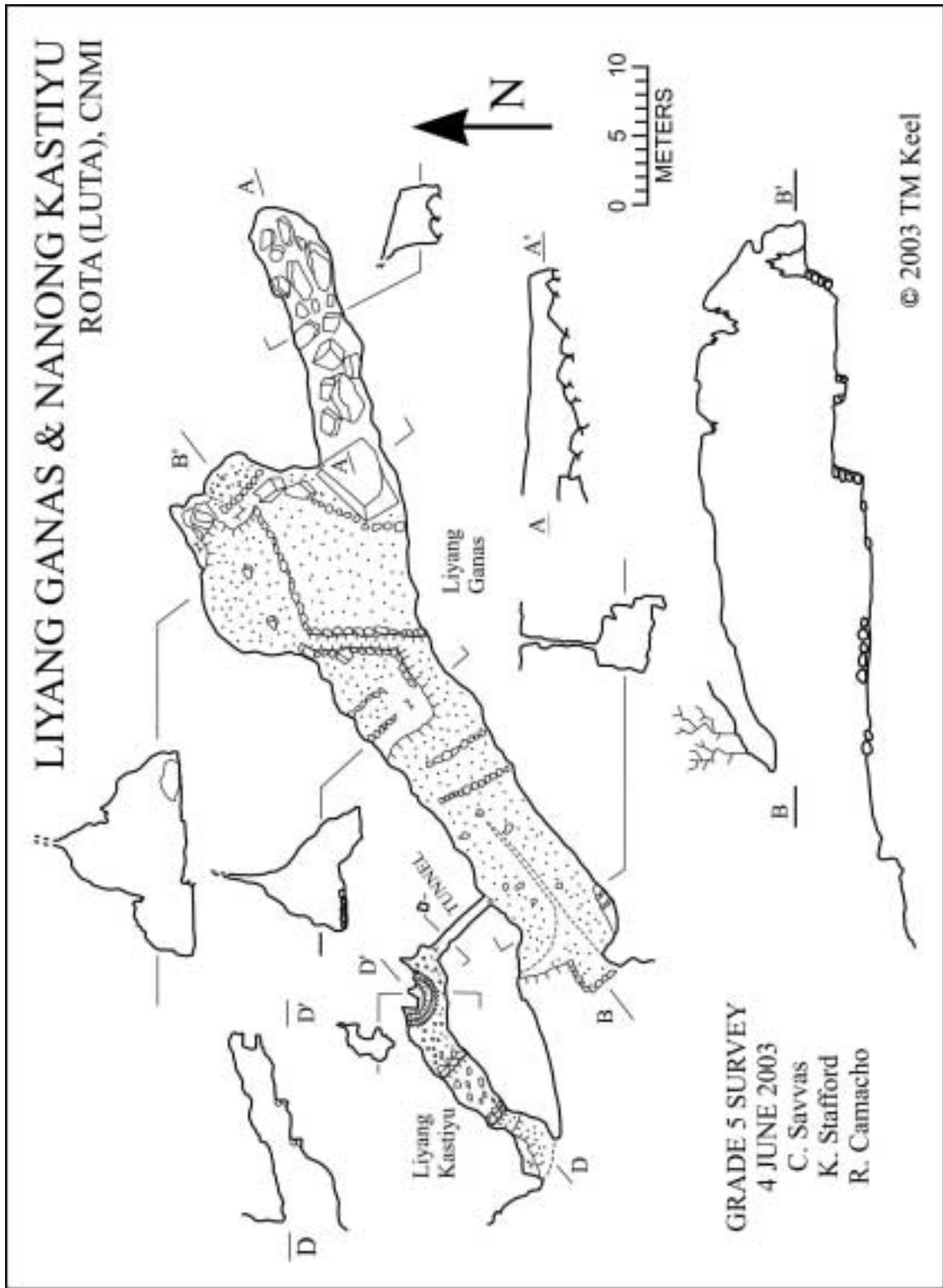


Figure 57. Liyang Ganas and Nanong Kastiyu

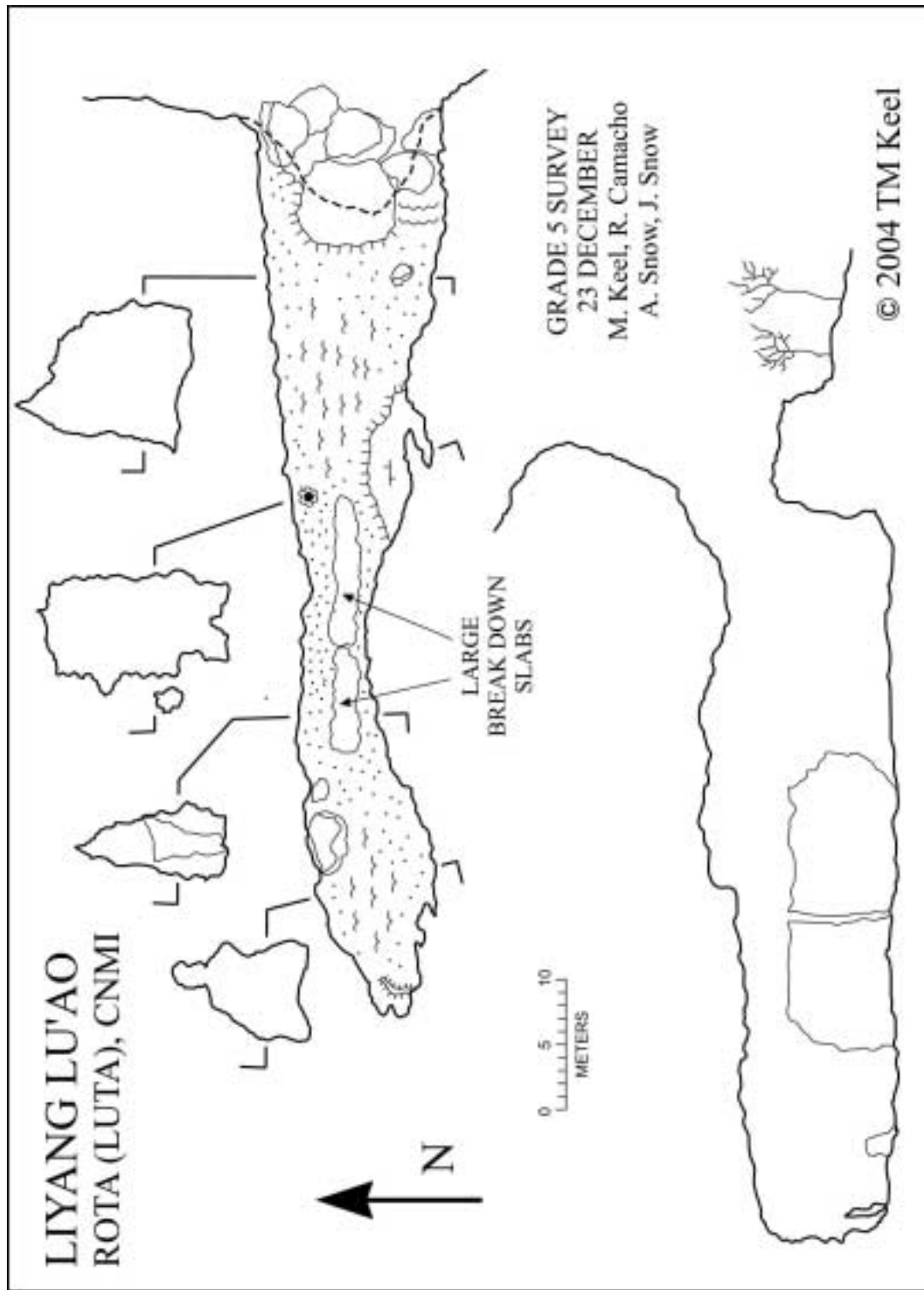


Figure 58. Map of Liyang Lu'ao

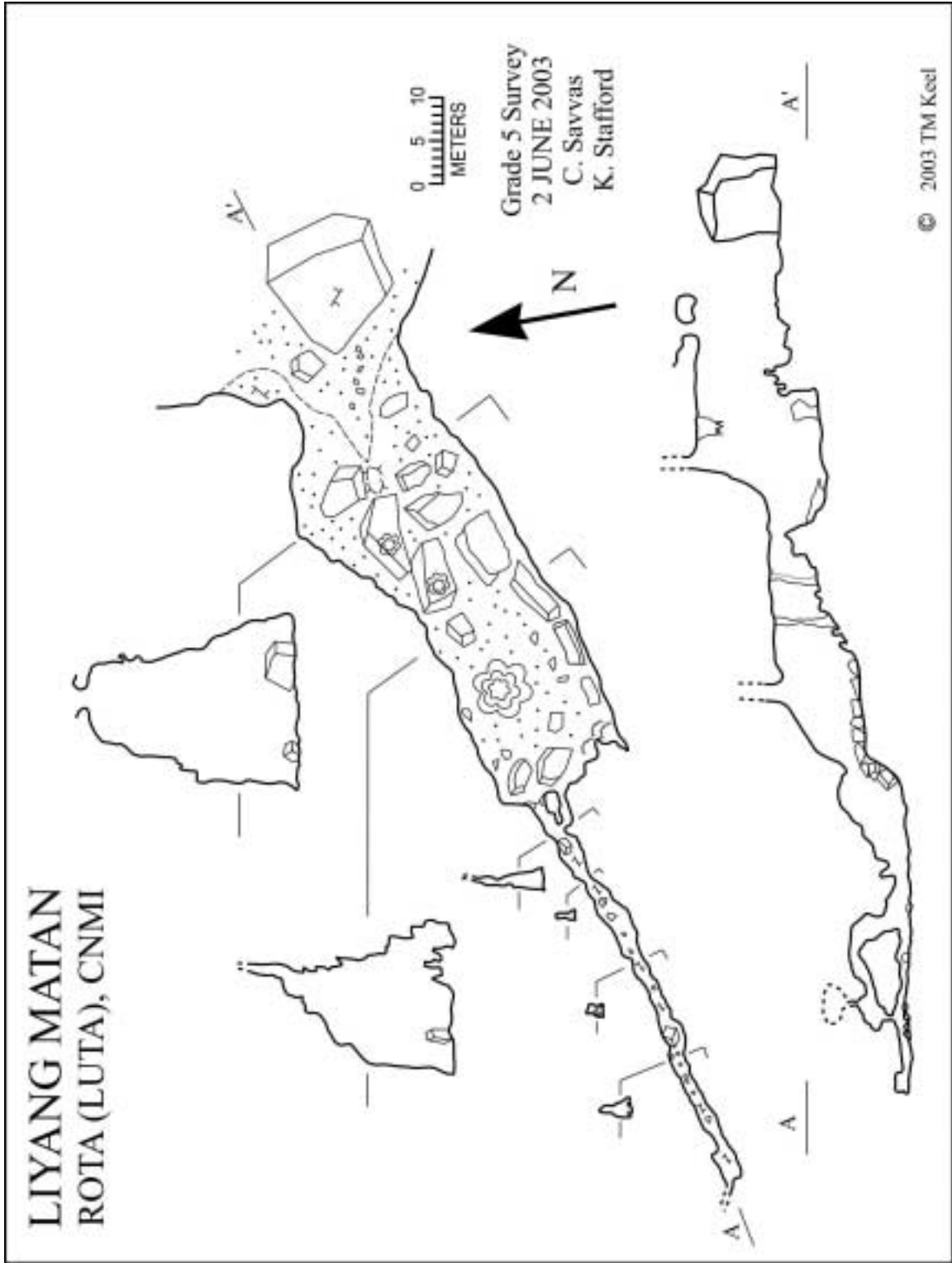


Figure 59. Map of *Liyang Matan*

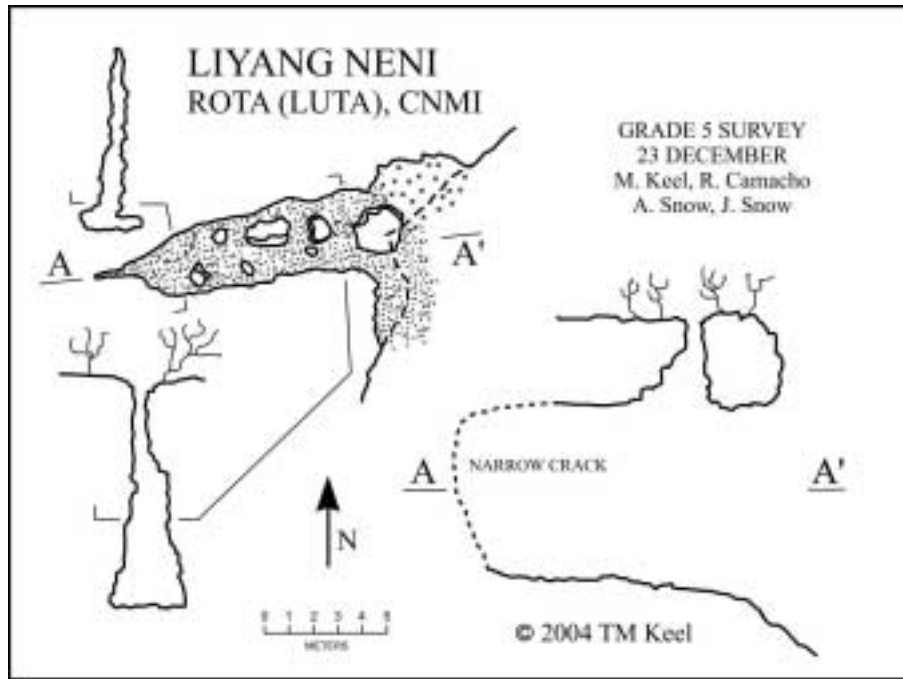


Figure 60. Map of Liyang Neni

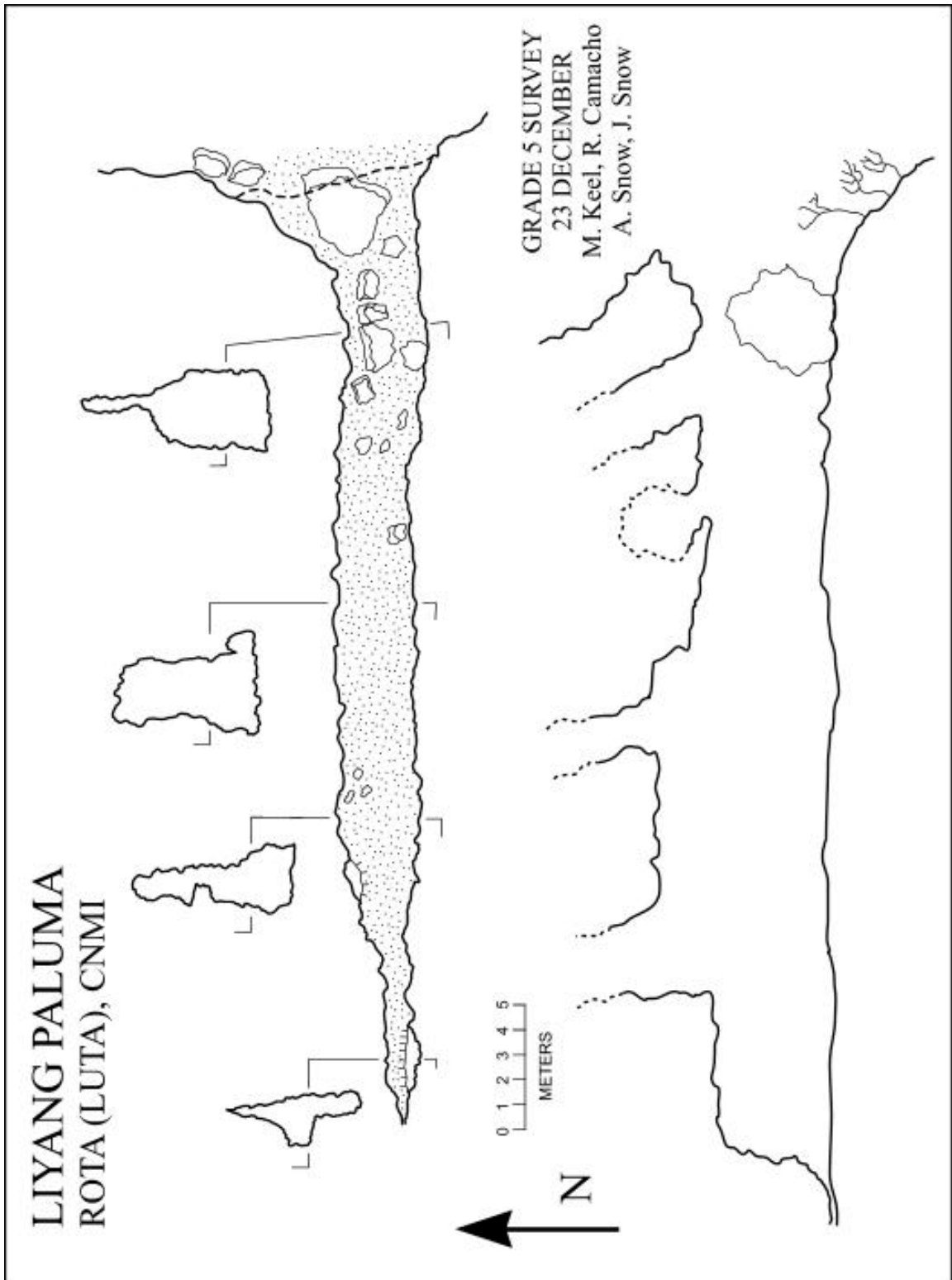


Figure 61. Map of Liyang Paluma



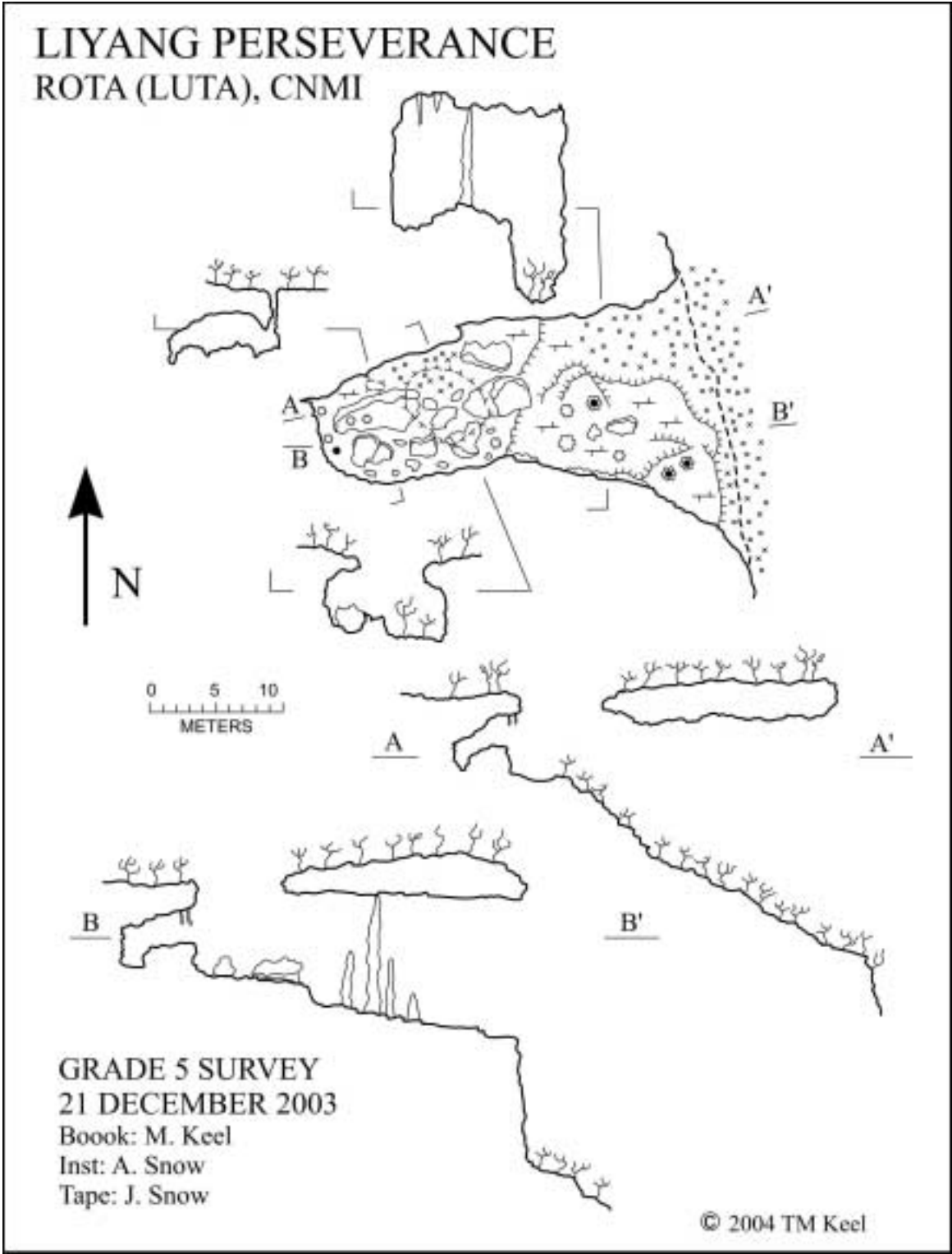


Figure 62. Map of Liyang Perseverance

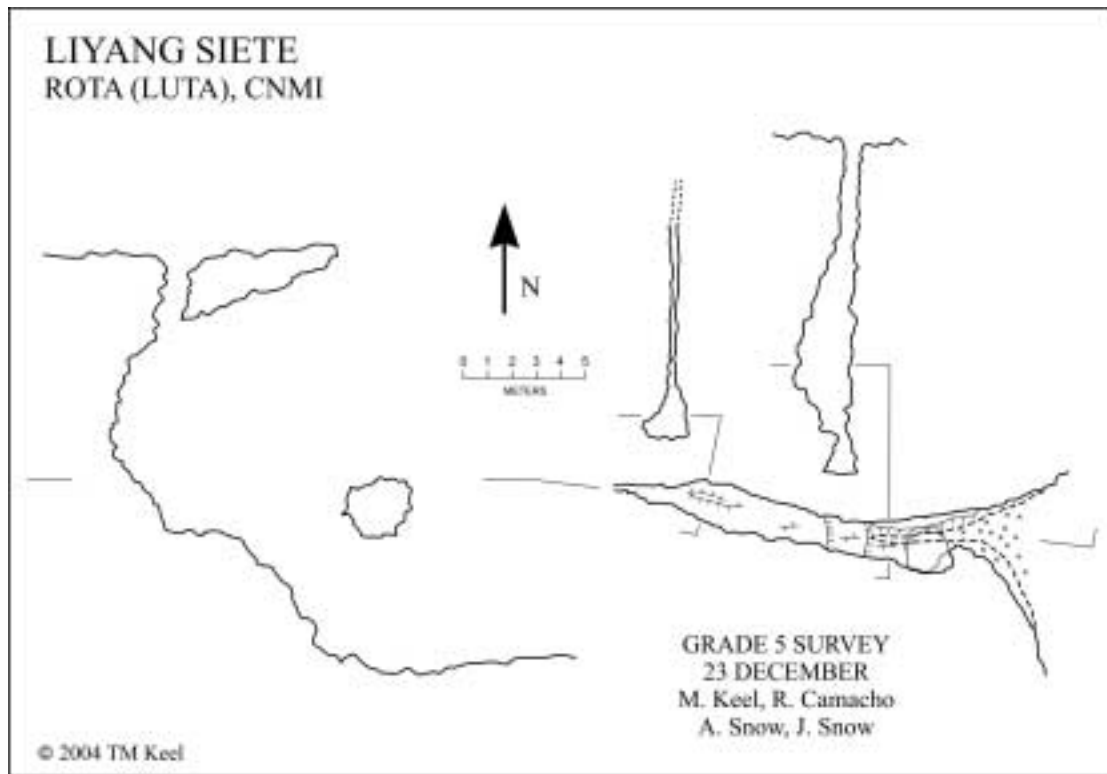


Figure 63. Map of Liyang Siete

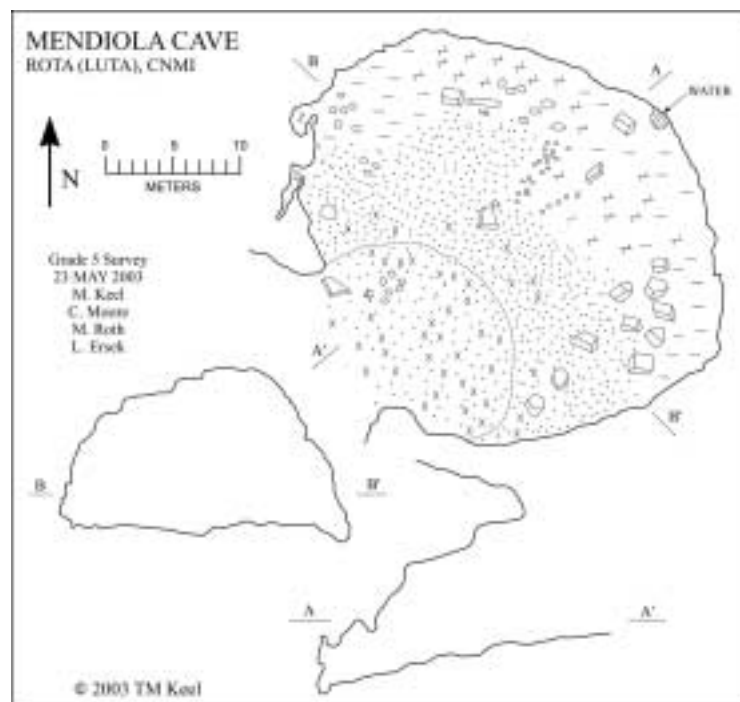


Figure 64. Map of Mendiola Cave

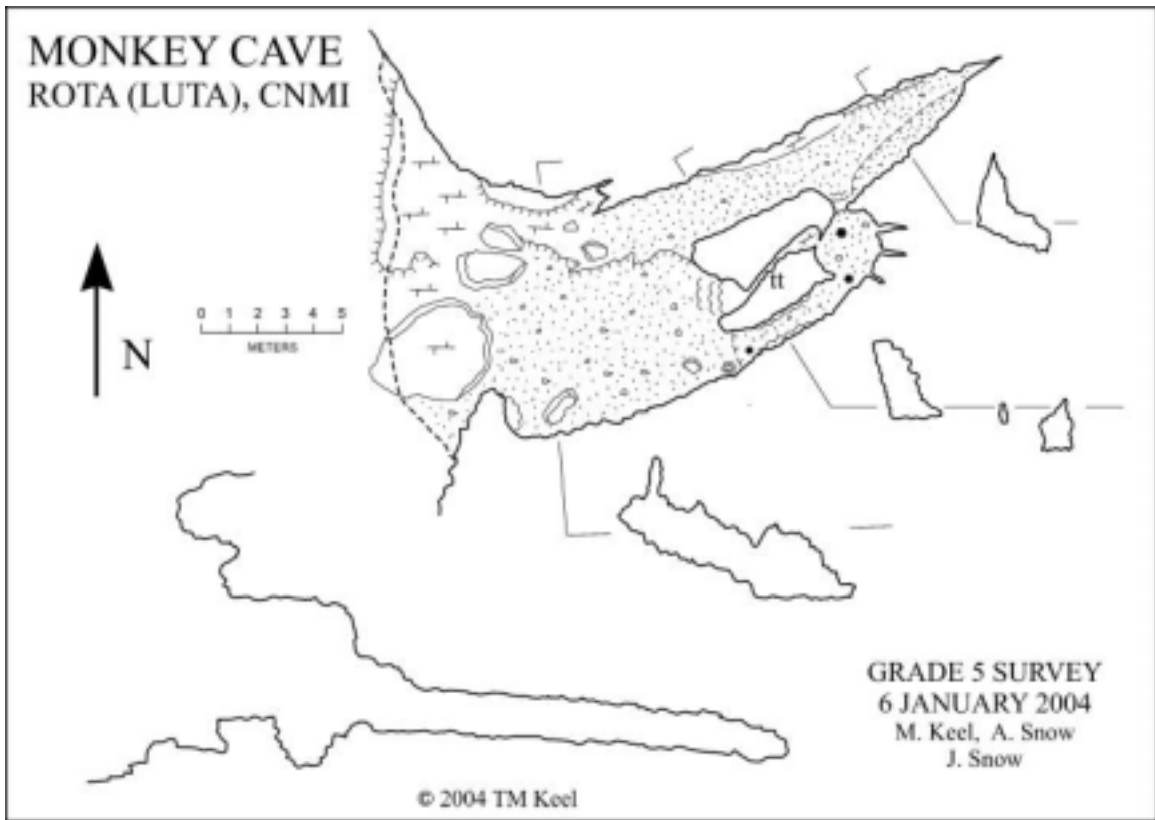


Figure 65. Map of Monkey Cave

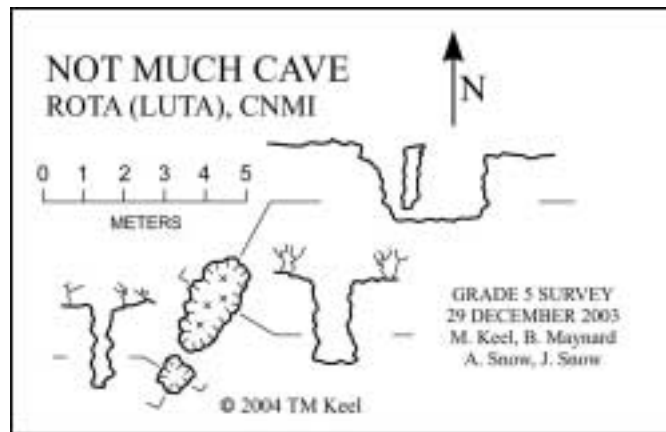


Figure 66. Map of Not Much Cave

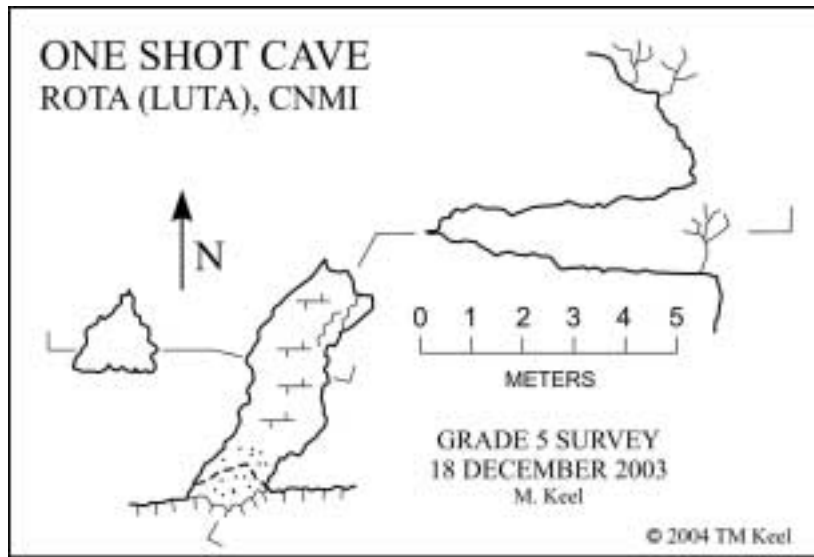


Figure 67. Map of One Shot Cave

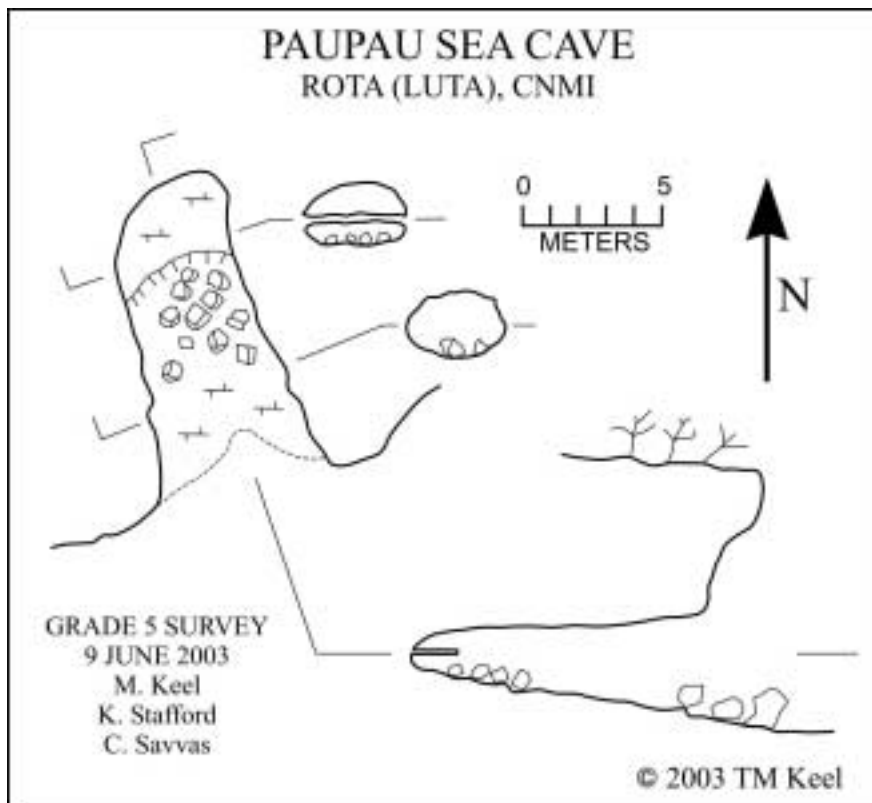


Figure 68. Paupau Sea Cave

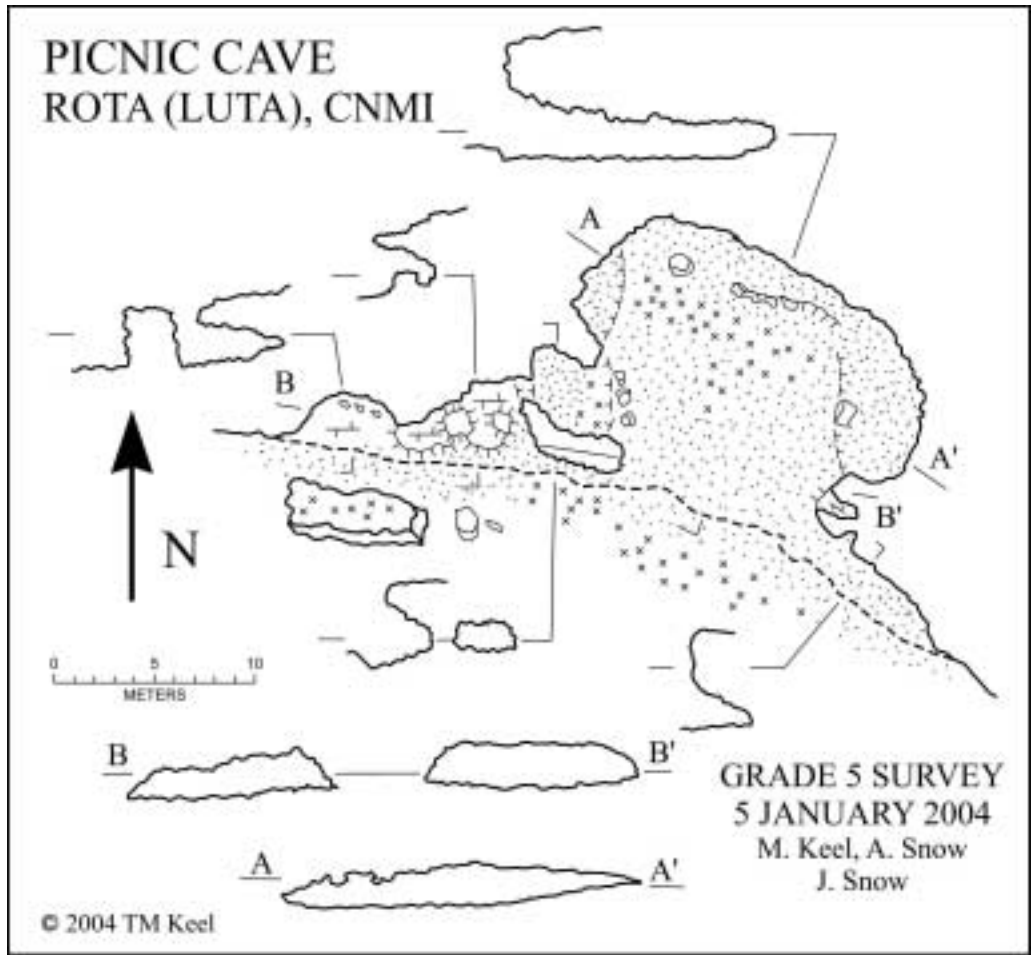


Figure 69. Map of Picnic Cave

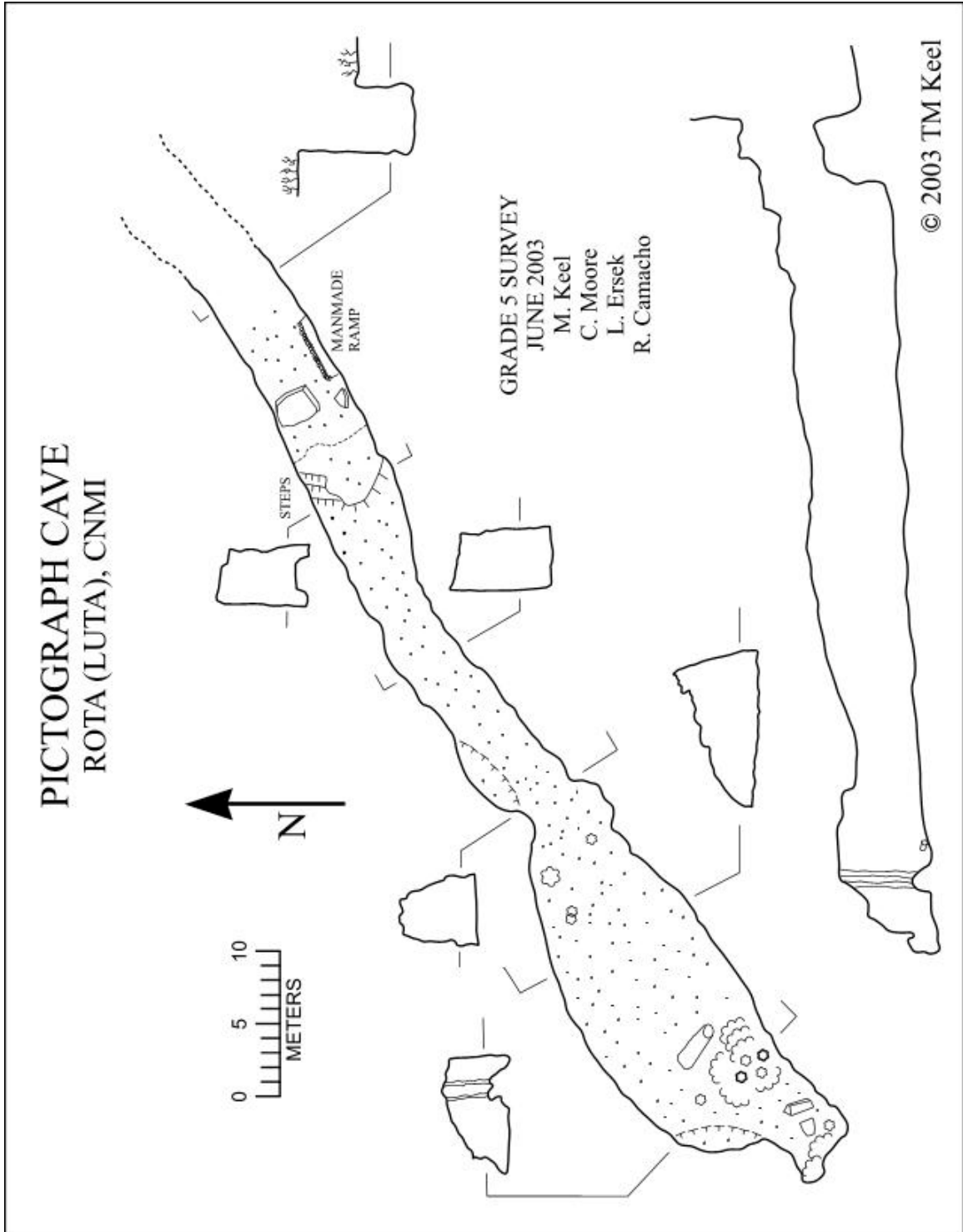
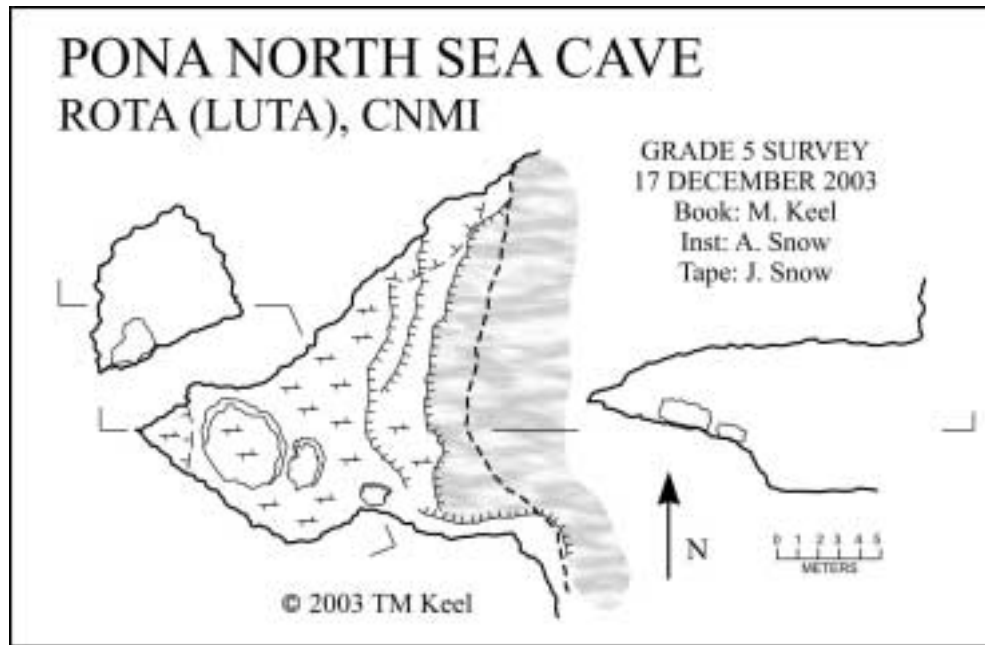
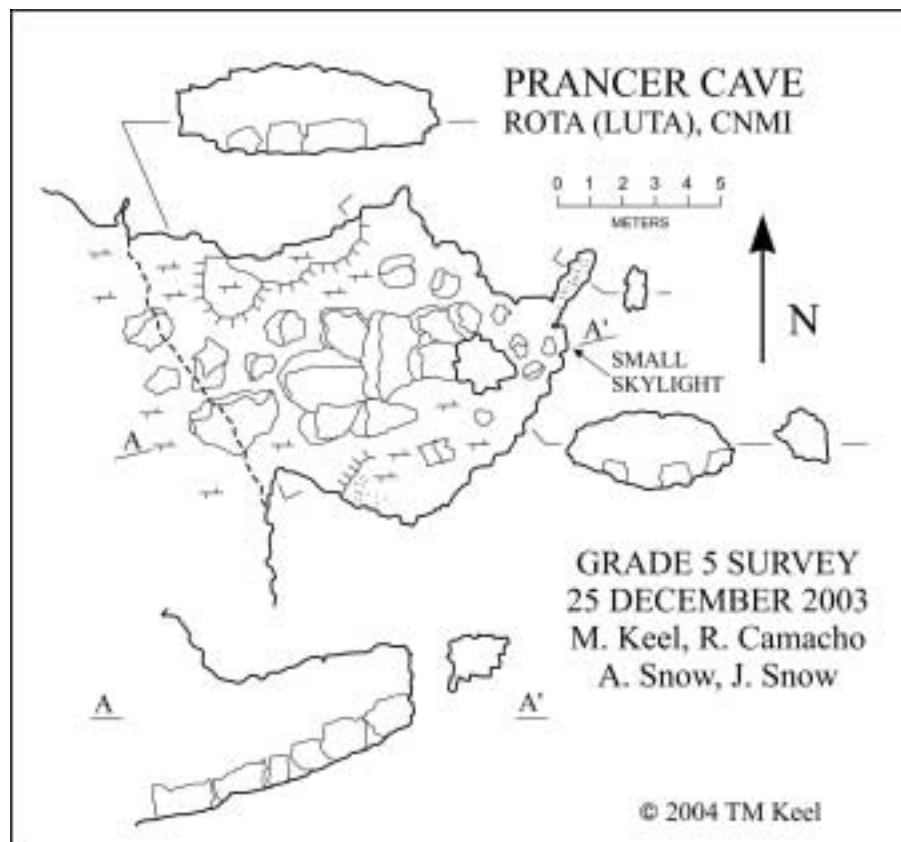


Figure 70. Map of Pictograph Cave



**Figure 71. Map of Poña North Sea Cave**



**Figure 72. Map of Prancer Cave**

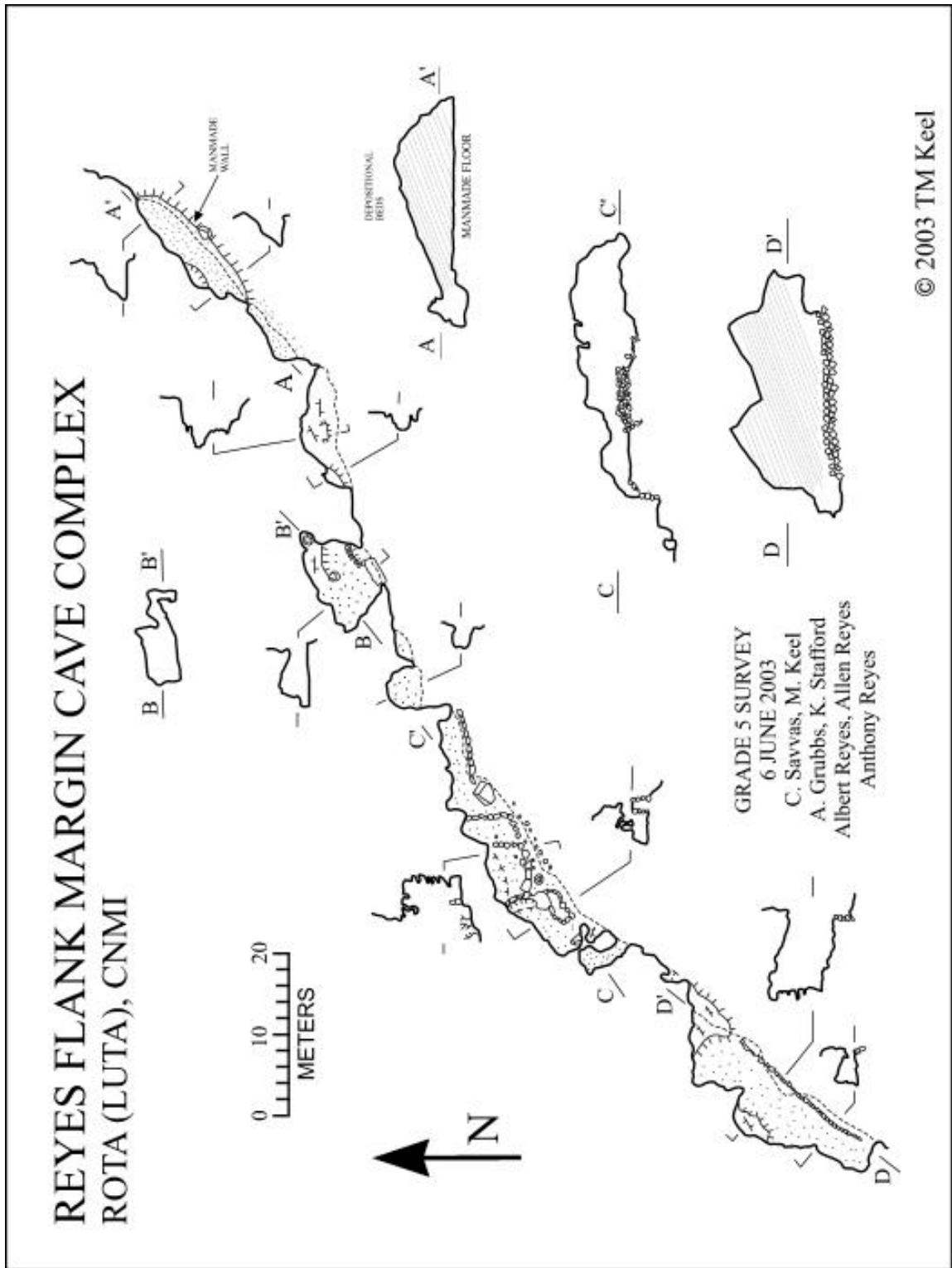
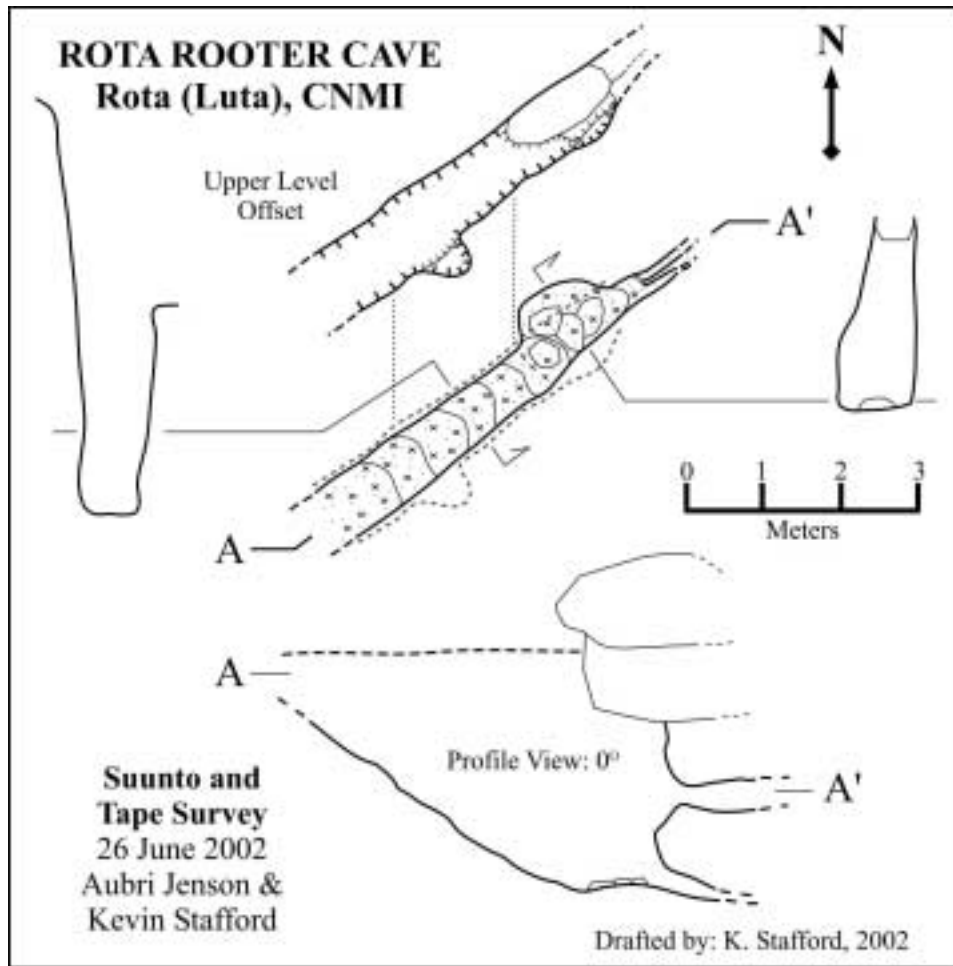
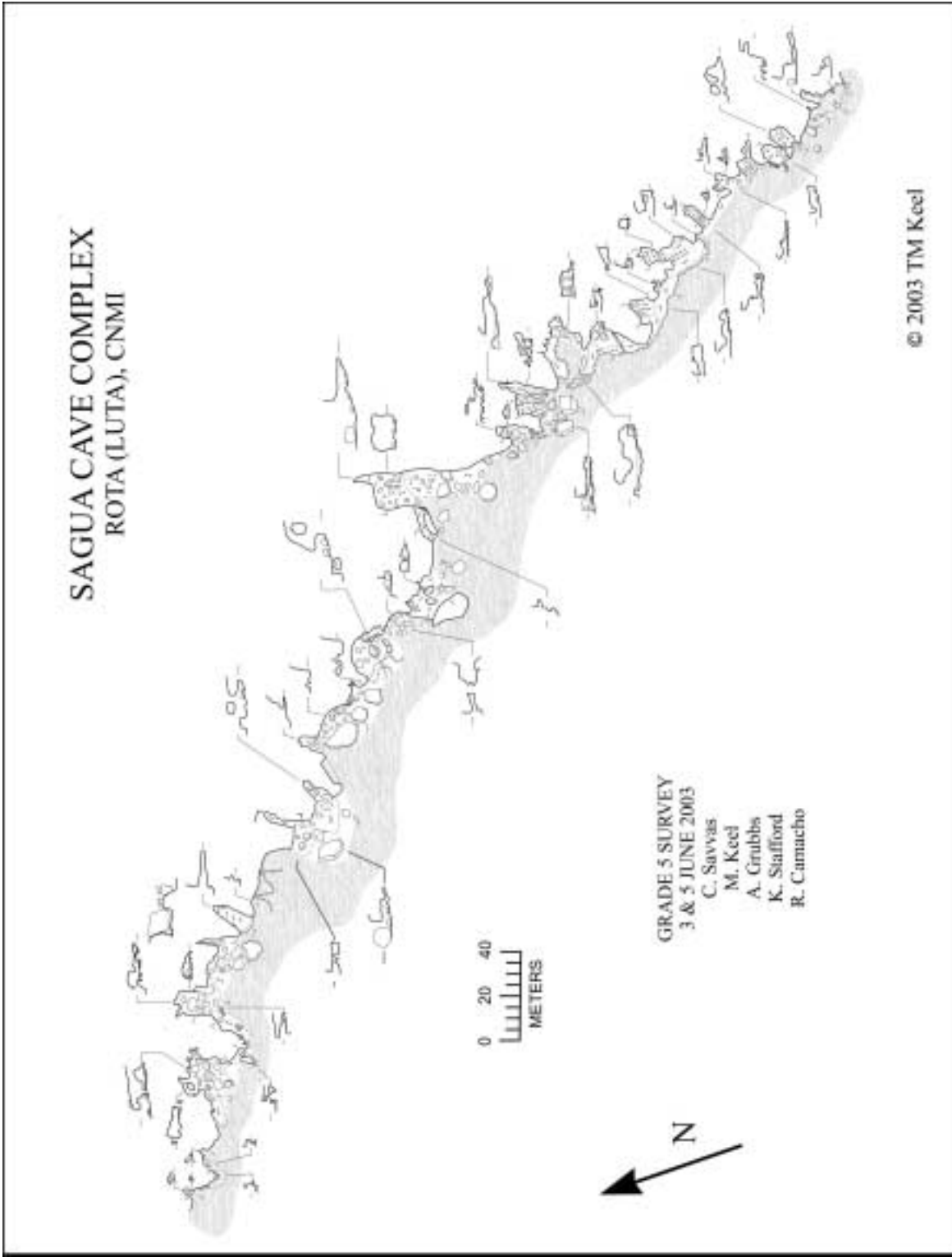


Figure 73. Reyes Complex



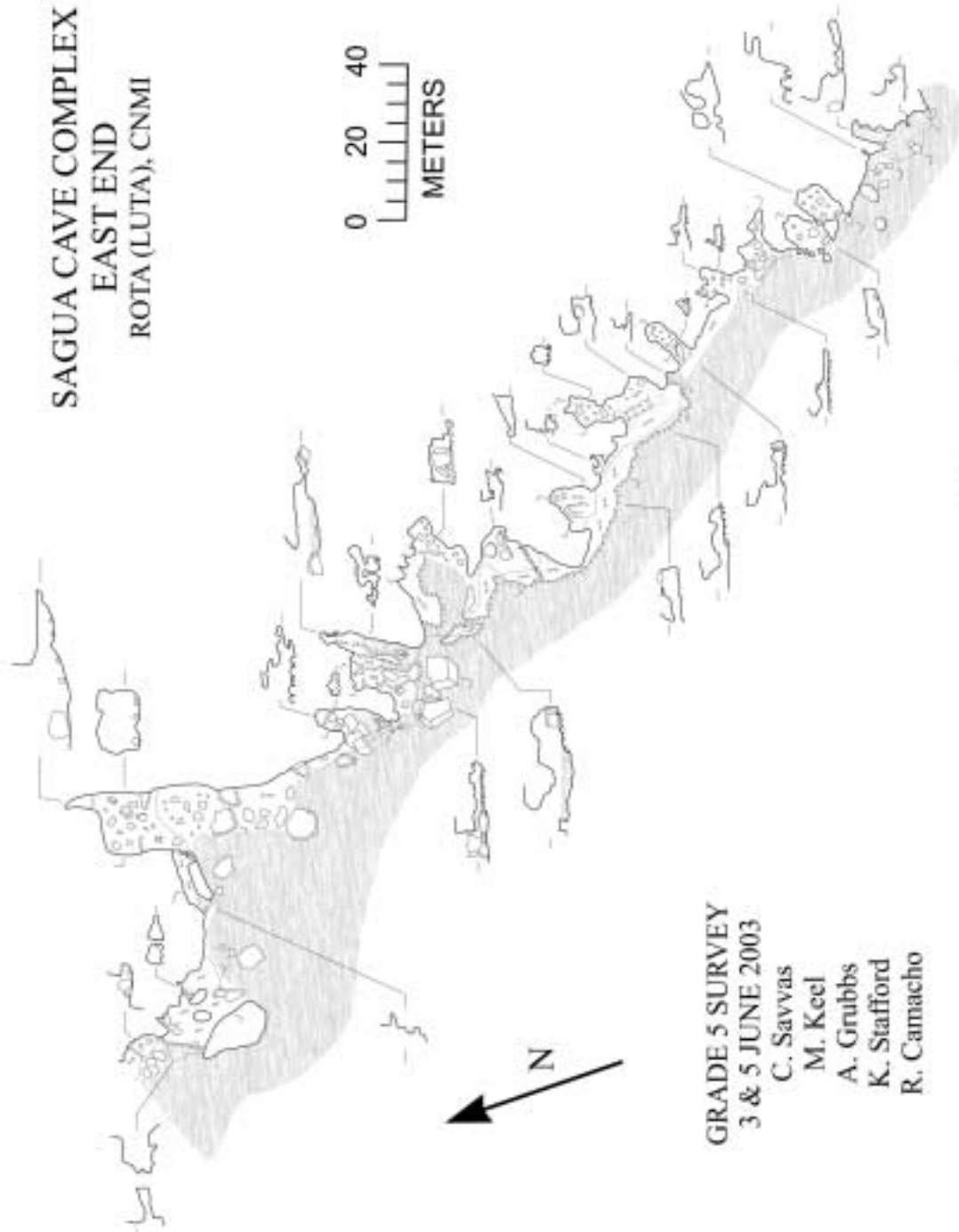


**Figure 74. Map of Rota Rooter Cave**



**Figure 75. Sagua Cave Complex**

SAGUA CAVE COMPLEX  
EAST END  
ROTA (LUTA), CNMI



GRADE 5 SURVEY  
3 & 5 JUNE 2003

- C. Savvas
- M. Keel
- A. Grubbs
- K. Stafford
- R. Camacho

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Figure 76. Map of *Sagua Cave Complex, West End*

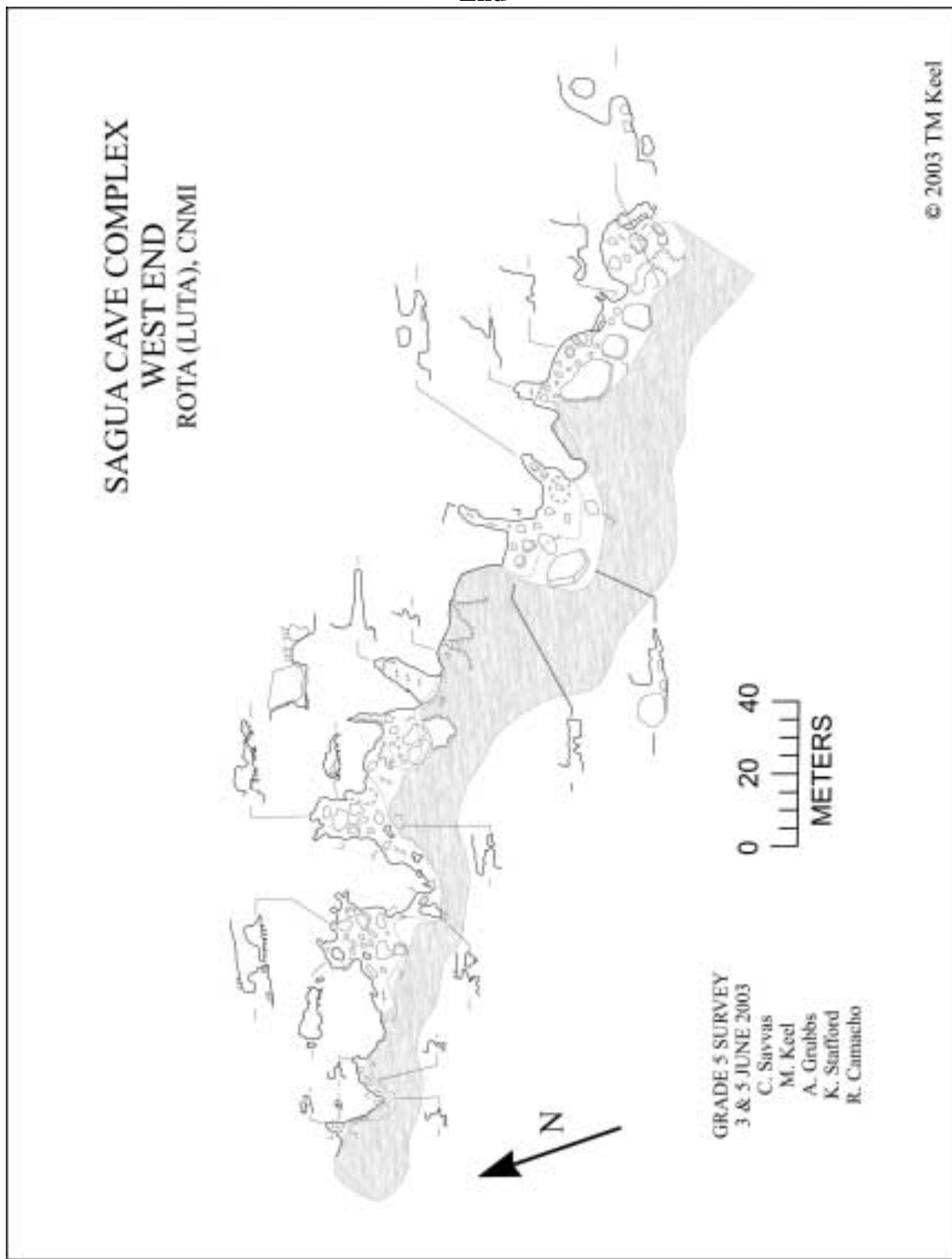
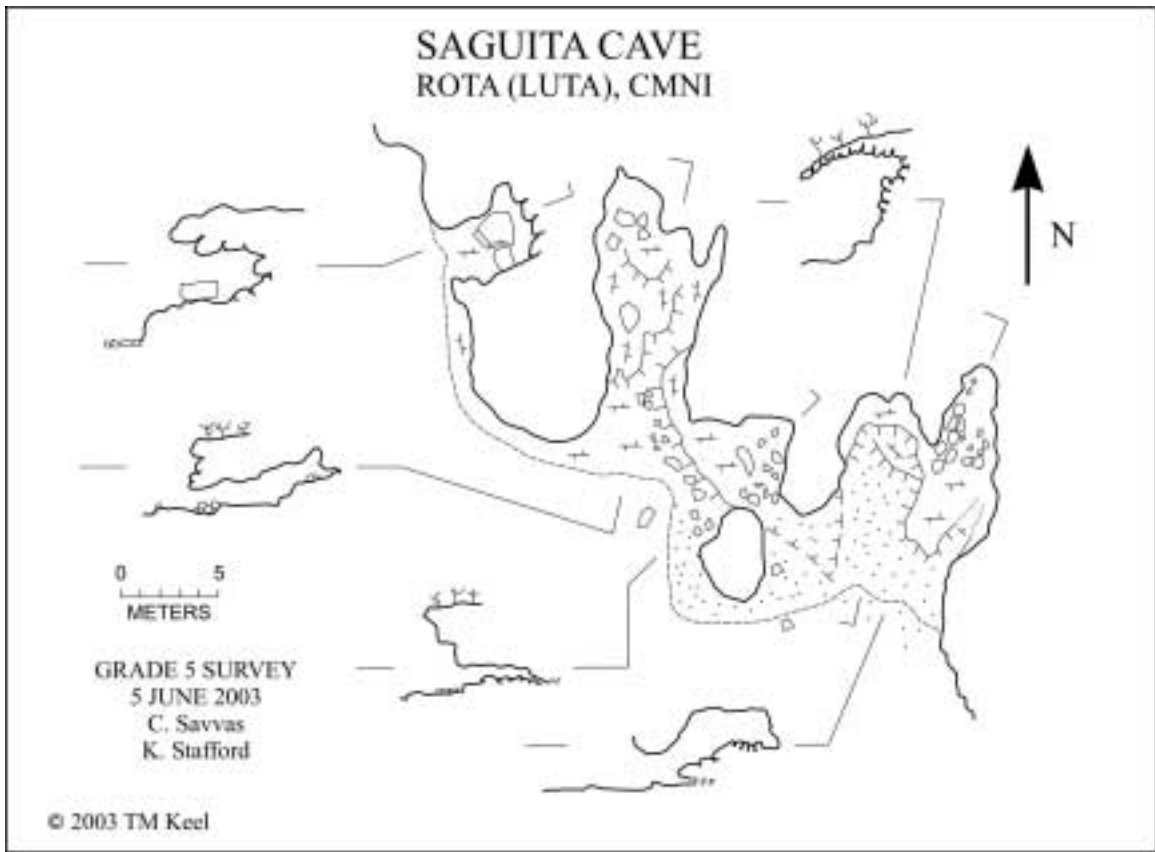
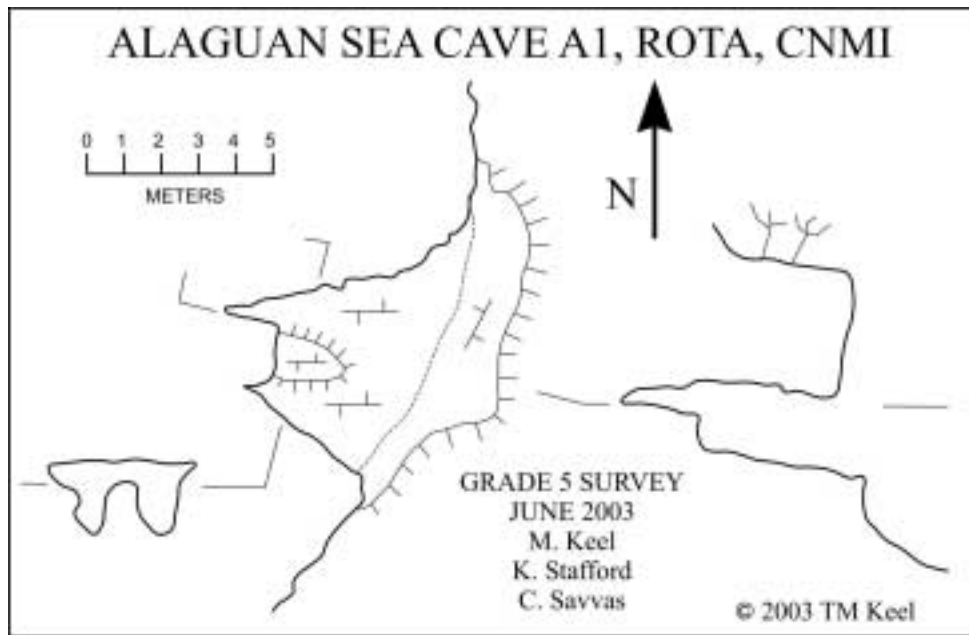


Figure 77. *Sagua Cave Complex, West End*



**Figure 78. Map of Saguita Cave**



**Figure 79. Map of Sea Cave A1**

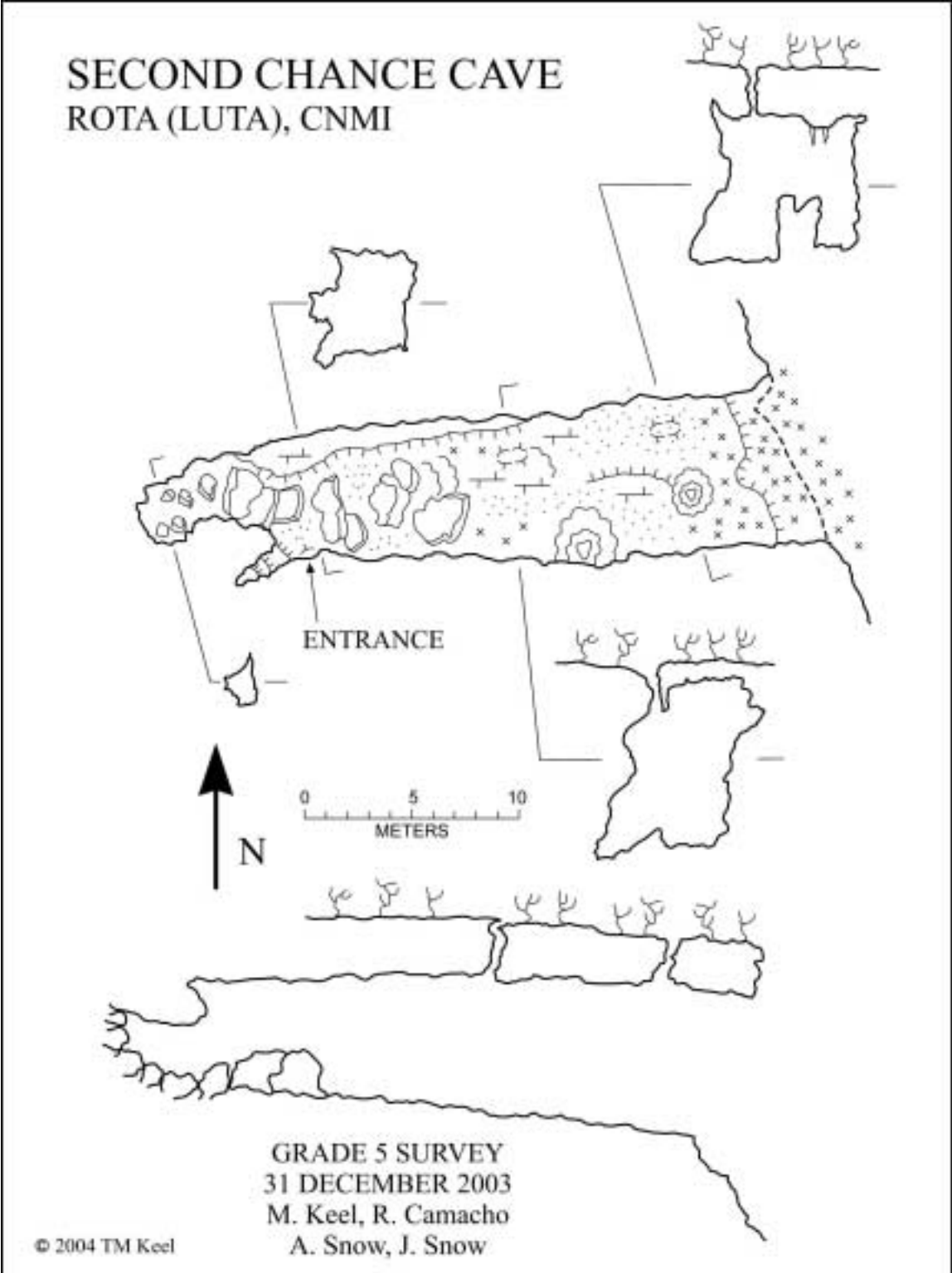
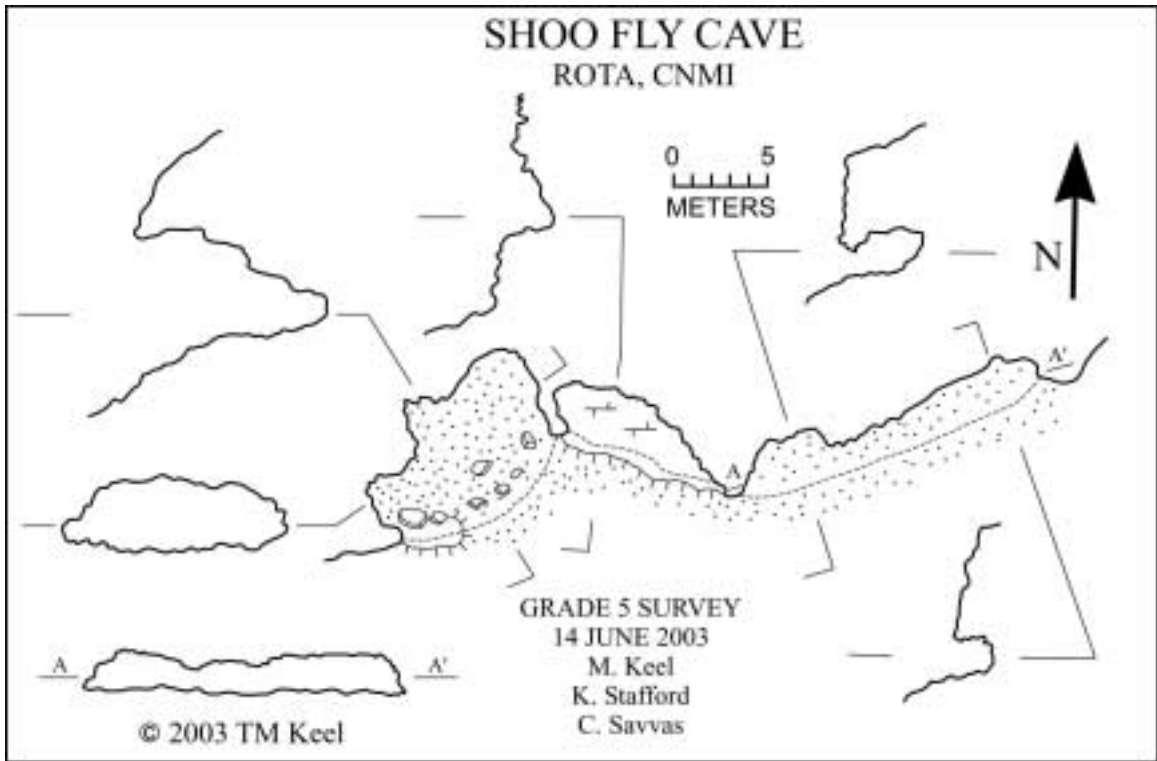
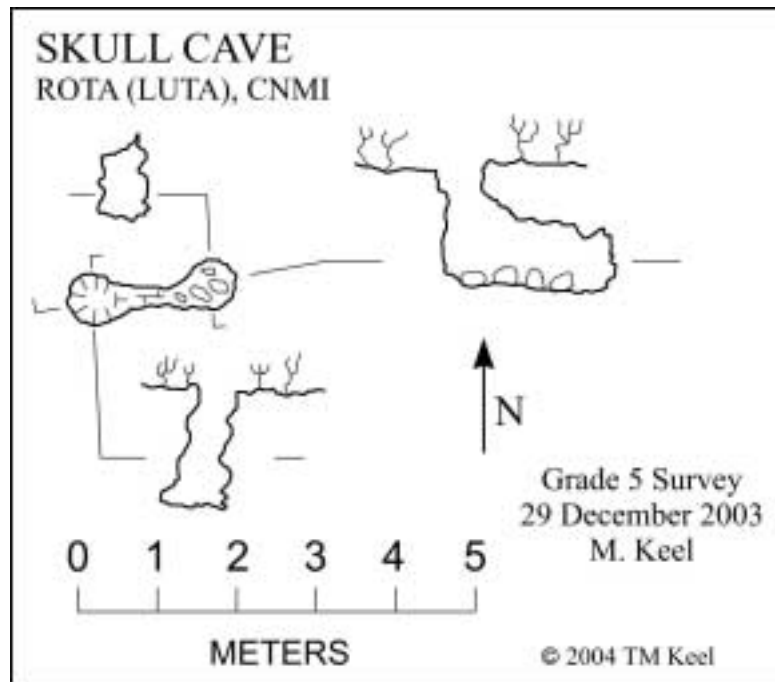


Figure 80. Map of Second Chance Cave



**Figure 81. Map of Shoo Fly Cave**



**Figure 82. Map of Skull Cave**

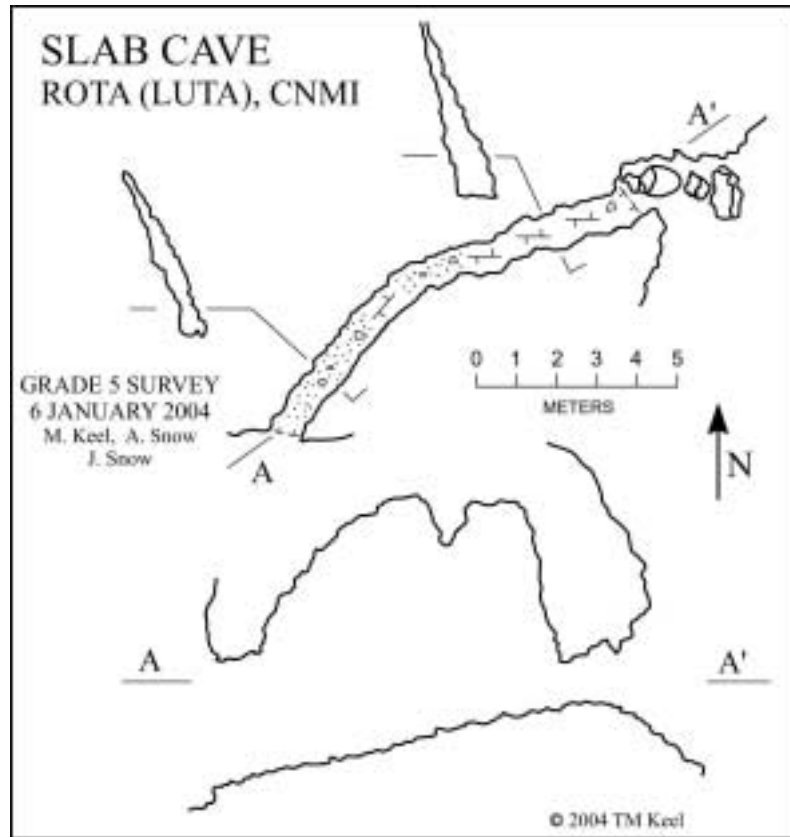
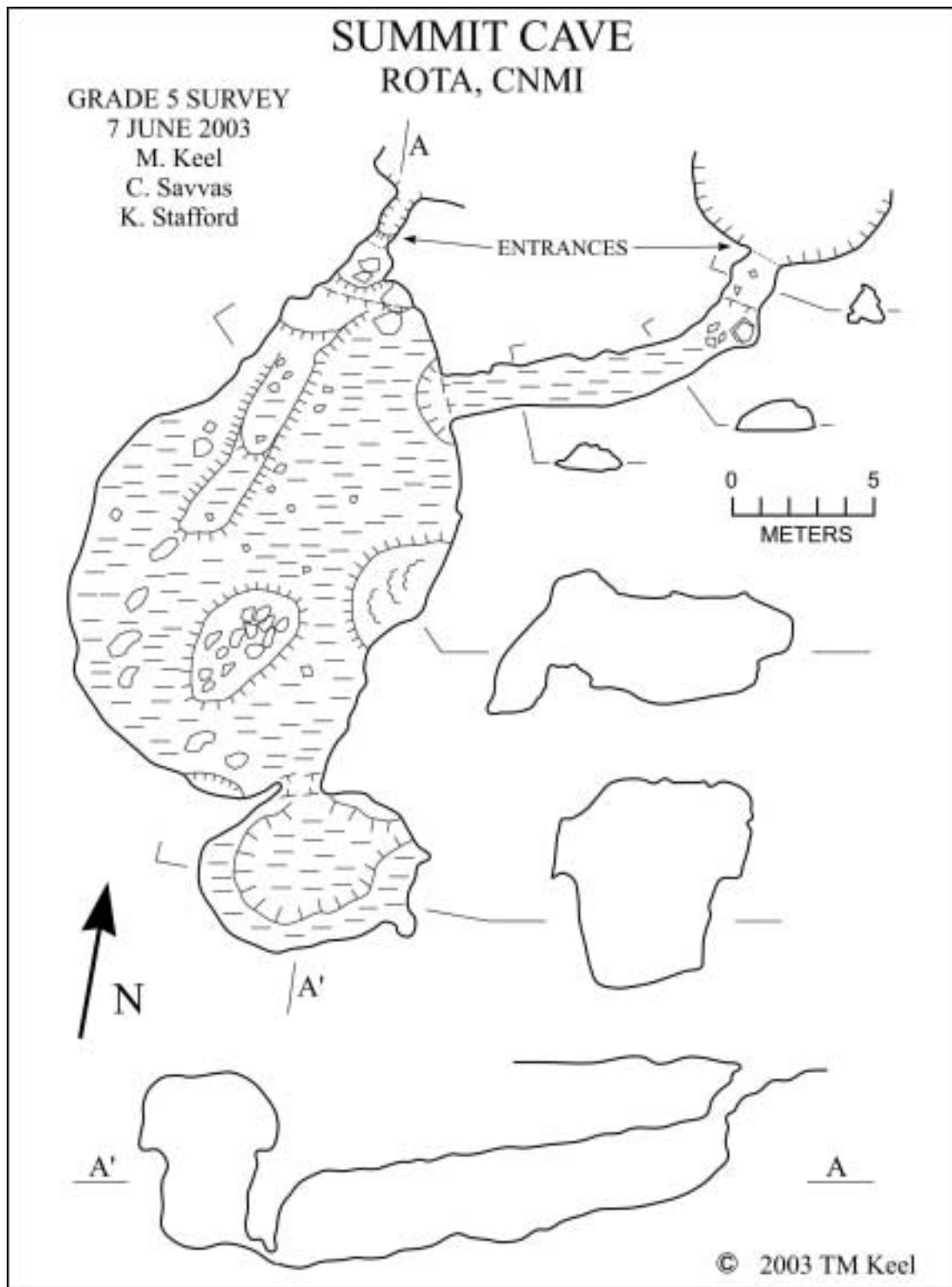


Figure 83. Map of Slab Cave





**Figure 84. Map of Summit Cave**

# THE SWIMMING HOLE ROTA (LUTA), CNMI

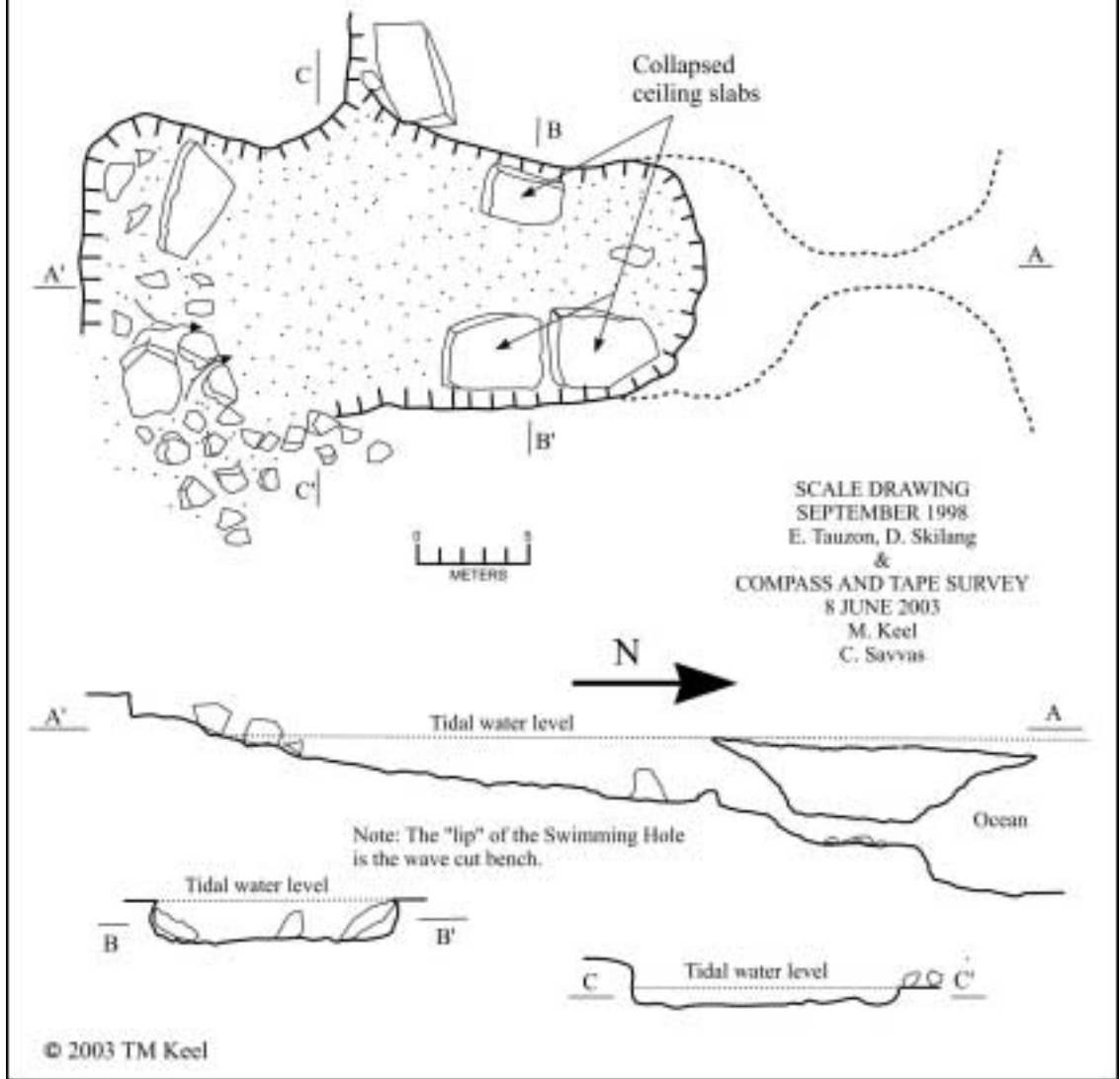


Figure 85. Map of the Swimming Hole

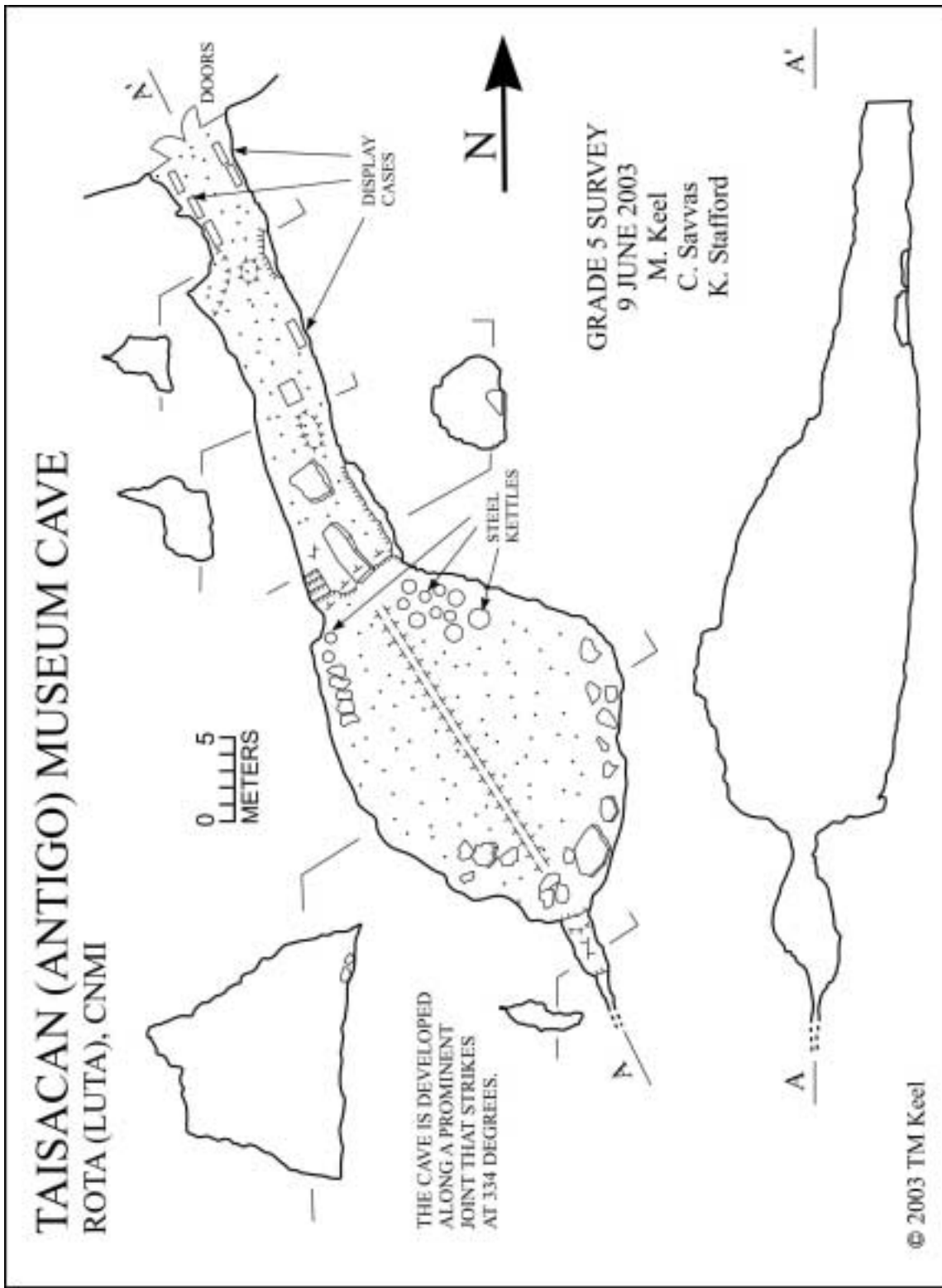


Figure 86. Map of Taisacan Museum Cave

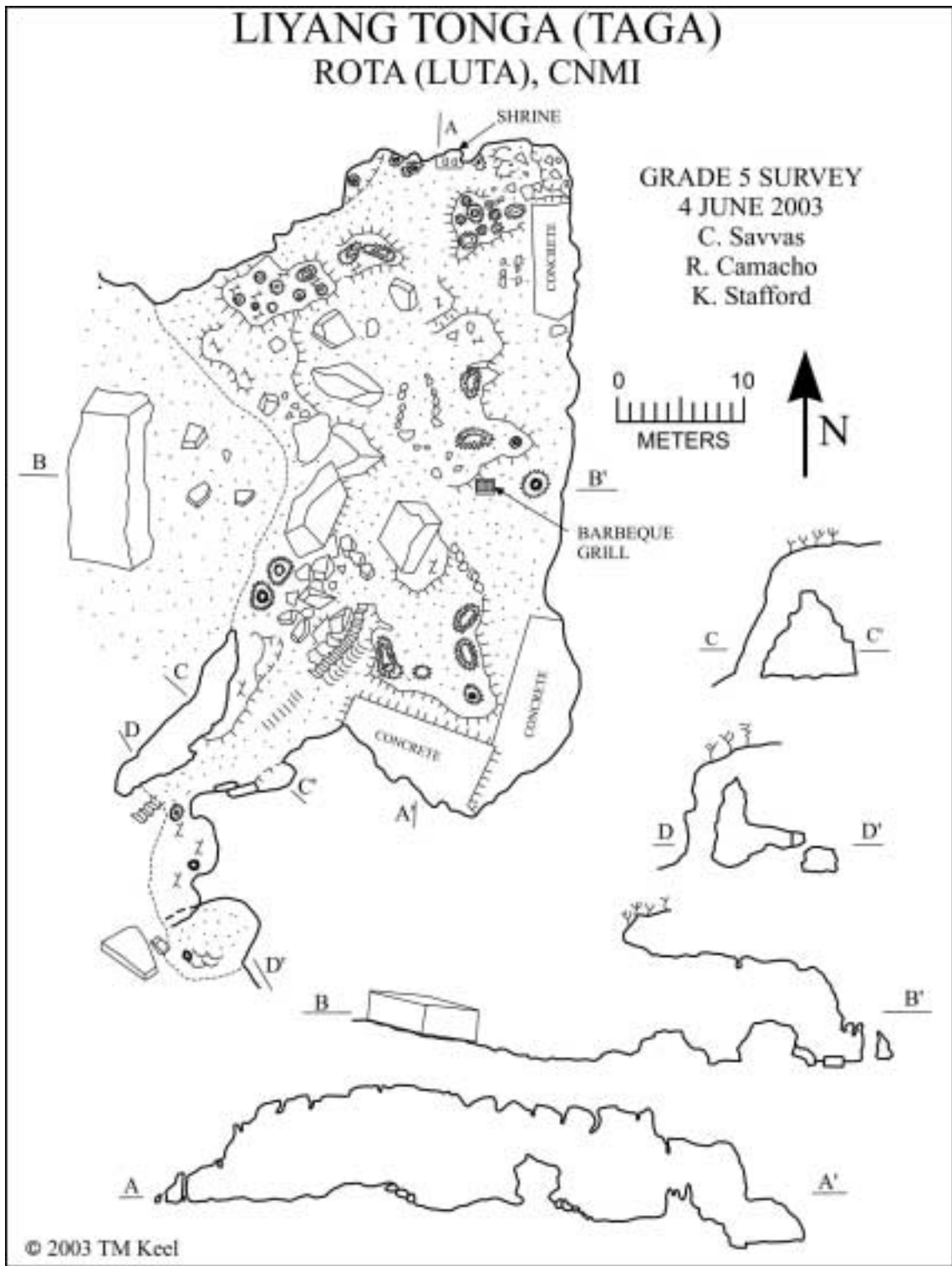


Figure 85. Map of Tonga Cave

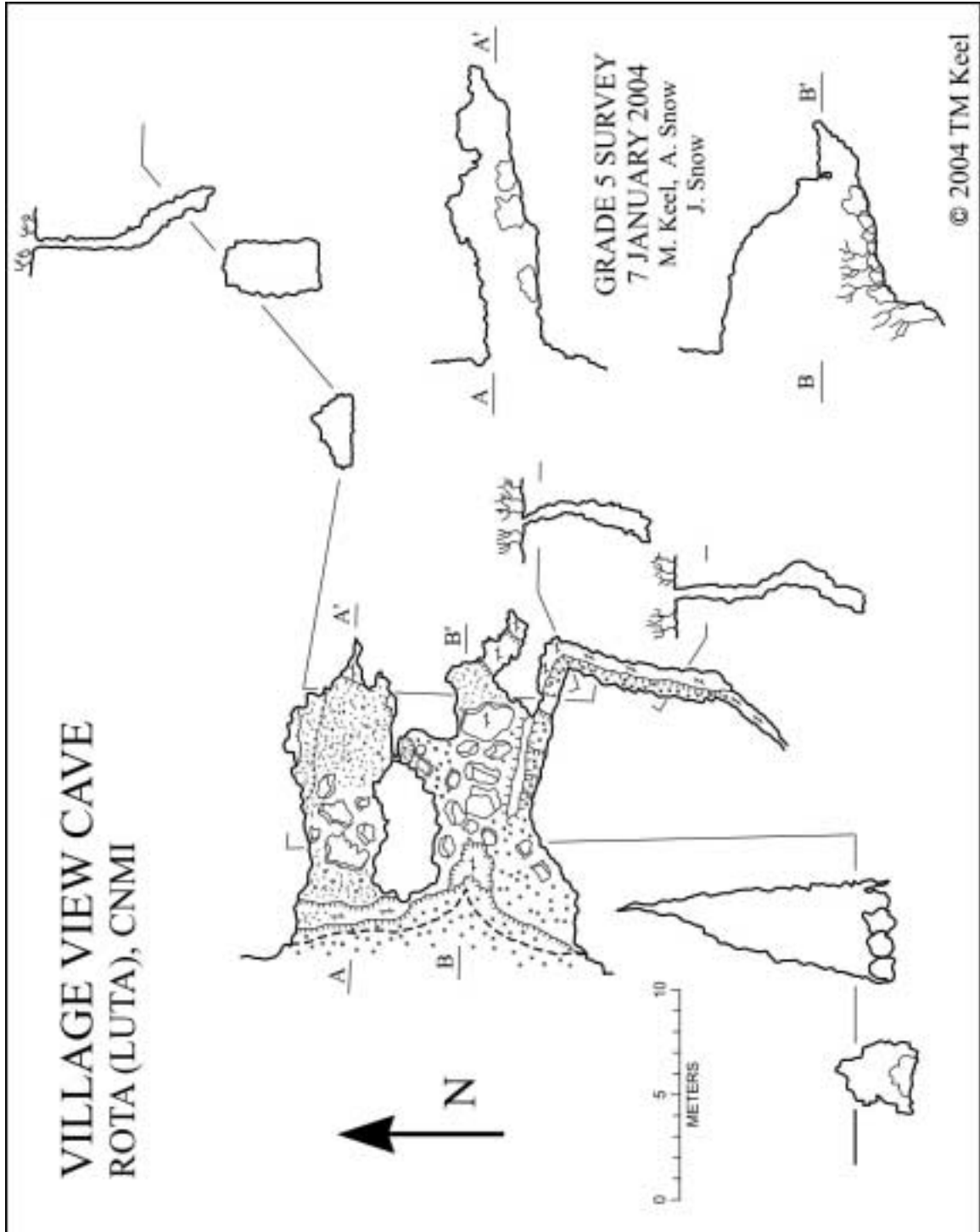


Figure 88. Map of Village View Cave

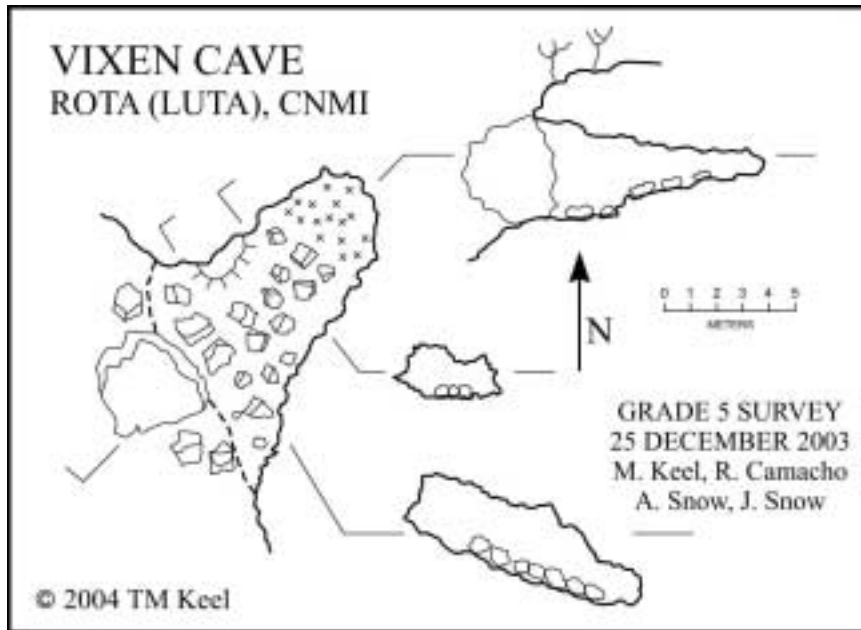
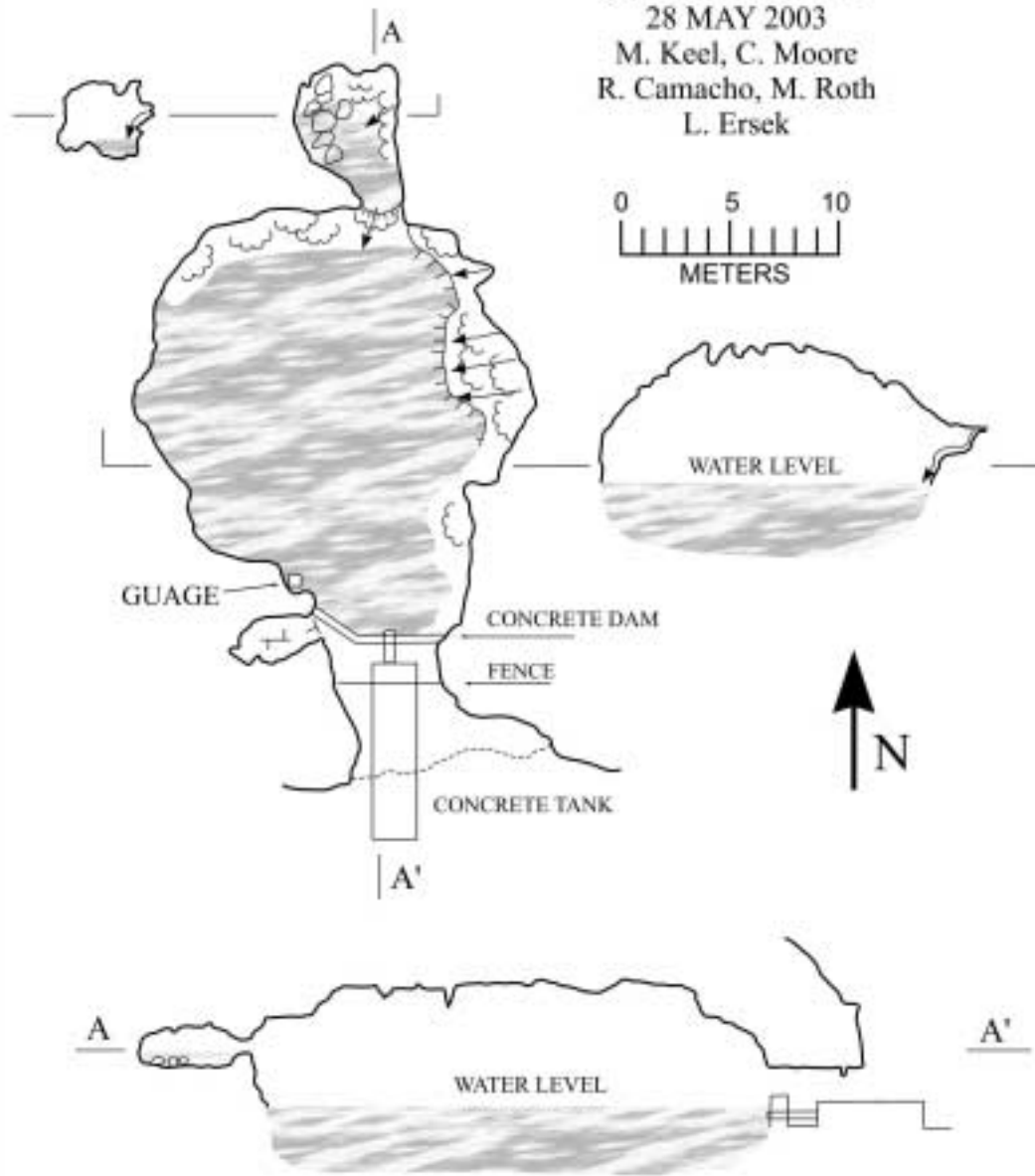


Figure 89. Map of Vixen Cave

# WATER CAVE (MATAN HANUM) ROTA (LUTA), CMNI

GRADE 5 SURVEY  
28 MAY 2003  
M. Keel, C. Moore  
R. Camacho, M. Roth  
L. Ersek



(Called Water Fall Cave in Rogers and Legge, 1992)

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Figure 90. Map of the Water Cave

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