



**THE CAVES AND KARST  
OF ROTA ISLAND,  
COMMONWEALTH OF  
THE NORTHERN  
MARIANA ISLANDS**

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**WATER AND ENVIRONMENTAL RESEARCH INSTITUTE  
OF THE WESTERN PACIFIC  
UNIVERSITY OF GUAM**

**Technical Report No. 107  
November 2005**

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Technical Report No. 107  
November 2005

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## **ABSTRACT**

Rota Island, in the Mariana Islands, has the types of caves previously documented on other limestone islands in the Mariana Arc: Aguijan, Guam, Tinian and Saipan. Caves developed in the mixing zone at the edge of the fresh water lens are most common, with flank margin caves being most common. However, mixing zone fracture caves, apparently formed by mixing dissolution in pre-existing fractures are also common. The mixing zone caves of Rota reflect the interaction of eogenetic limestone, glacioeustasy, local tectonics and enhanced carbonate dissolution via mixing of disparate waters. The development of mixing zone caves on Rota is in agreement with the Carbonate Island Karst Model (CIKM). Rota has a few caves developed along the contact between limestone and volcanic rock. Rota also two extensive zones of vertical fissures developed along bedrock fractures.

Keywords: Rota, Commonwealth of the Northern Mariana Islands, cave, karst, flank margin, eogenetic, limestone, CIKM, Carbonate Island Karst Model

## ACKNOWLEDGEMENTS

We want to thank the US Geological Survey for the primary funding for this work through the Water Resources Research Institute Program administered by the Water and Environmental Research Institute at the University of Guam. The Department of Geosciences at Mississippi State University also provided matching funds to support part of the field work. The wonderful people of Rota and officials at several CNMI government agencies made our work on Rota pleasant and productive. We would particularly like to thank the Honorable Benjamin T. Manglona, Mayor of Rota, Charles Manglona with the Commonwealth Utilities Corporation, Ben Atalig with Department of Lands and Natural Resources, and Jun Duenas with the Historic Preservation Office. We would also like to thank those who assisted in the survey of caves on Rota: Lica Ersek, Andy Grubbs, Aubri Jenson, Chris Moore, Charley Savvas, Abby Snow, Jay Snow, Monica Roth, Matt Lichty and Scott Moen.

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# THE CAVES AND KARST OF ROTA ISLAND, COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

## CHAPTER I

### INTRODUCTION

The objective of this study is to document a representative sample of the caves and karst landforms of Rota Island, Commonwealth of the Northern Mariana Islands so that this assemblage of caves and karst can be evaluated relative to the existing Carbonate Island Karst Model.

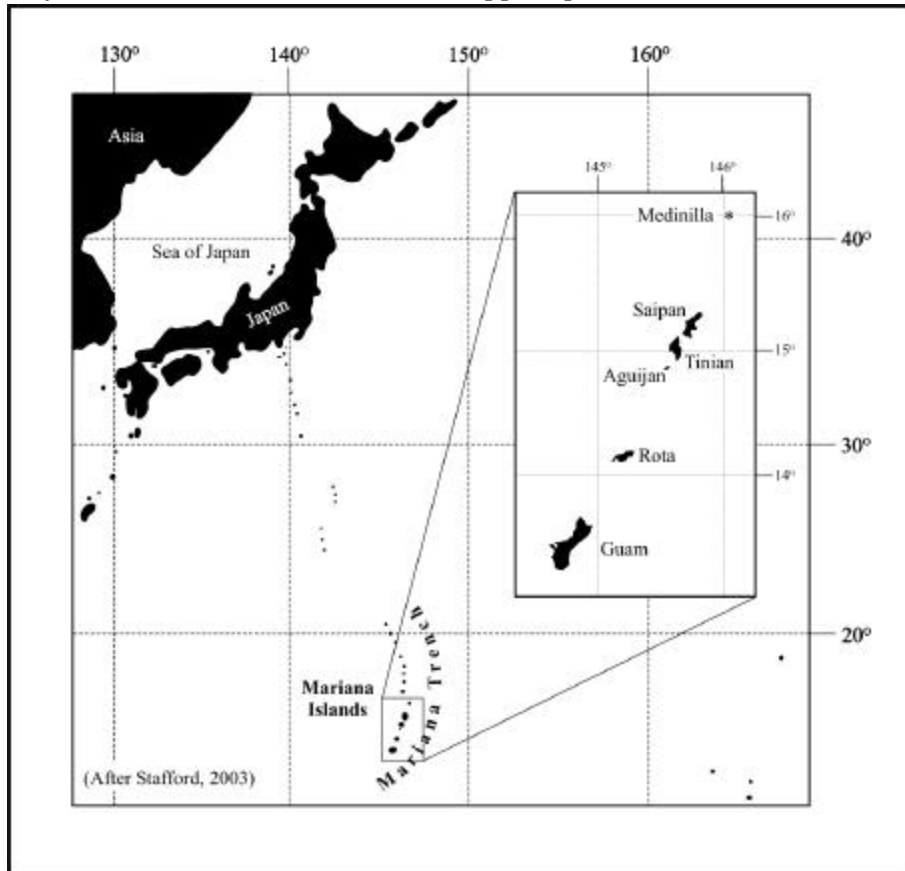
Rota, located on the Mariana Ridge in the western Pacific Ocean, has received very little documented geologic study. Therefore, this survey of the caves and karst landforms adds significantly to the basic knowledge of the geology of this island. The primary method of data collection for this study was field exploration to reach/discover caves and physical survey to document the size and shape of each cave. Intensive study and detailed familiarity of the USGS topographical map of Rota (1999), information from island residents, and familiarity with the previous limited documentation of caves on Rota (Rogers and Legge, 1992; Stafford et al., 2002) were used to determine particular areas to investigate. When possible, handheld GPS units were used to record the location of each cave. The location, size and morphology were used to classify each cave relative to the cave types previously documented on similar islands. When possible, each cave documented in this study was surveyed using standard cave survey techniques; compass, inclinometer and tape (Dasher, 1994). The survey data and sketch produced for each surveyed cave was used to create a map using a computer graphics program. Since it is known that caves and other karst features on other small carbonate islands, such as Rota, develop primarily 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. Since many place names in the native Chamorro language begin with prefixes that are also English words (e.g. *As* and *I*), Chamorro place names taken from the USGS topographical map (1999) and cave names based on Chamorro words will be italicized for clarity.

## CHAPTER II

### SETTING

#### Physiographic Setting

*The Marianas Islands (Fig. 1), located in the western Pacific Ocean, are composed of fourteen islands that are the exposed parts of the Mariana Ridge just west and north of the Mariana Trench, which includes the Challenger Deep, the deepest point in the ocean at ~11 km. The Mariana Trench-Ridge system is a product of the subduction of the Pacific Plate westward under the Philippine plate.*



*Figure 1. Location of the Mariana Islands*

*Figure 2 shows that the Mariana Islands are composed of two concentric island arcs on top of 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 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 Mariana Arc, which have probably been active since the Pliocene (Dickinson, 2000). Anatahan, on the eastern arc was active in 2003, 2004 and 2005. 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 (Fig. 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 (Fig. 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

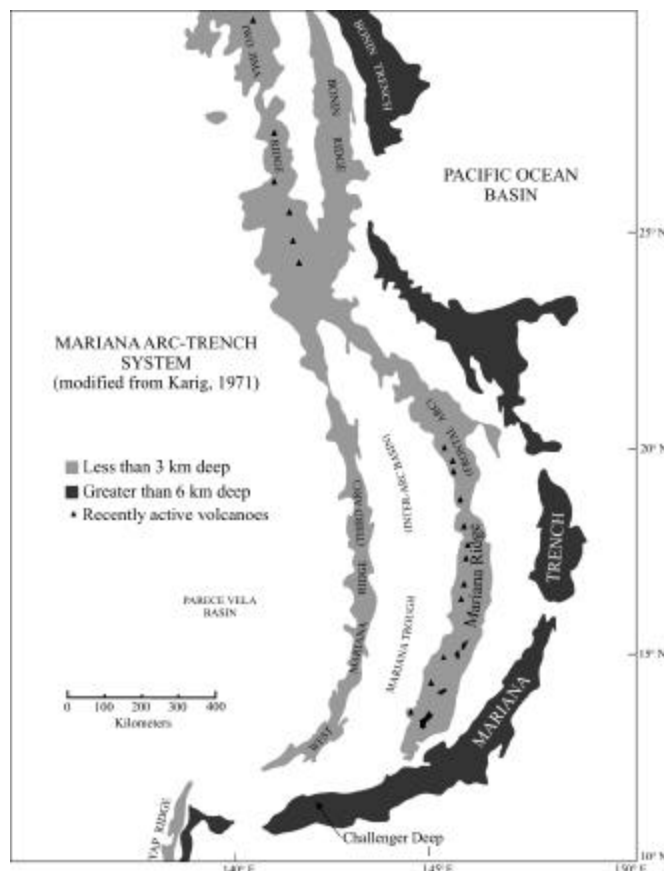
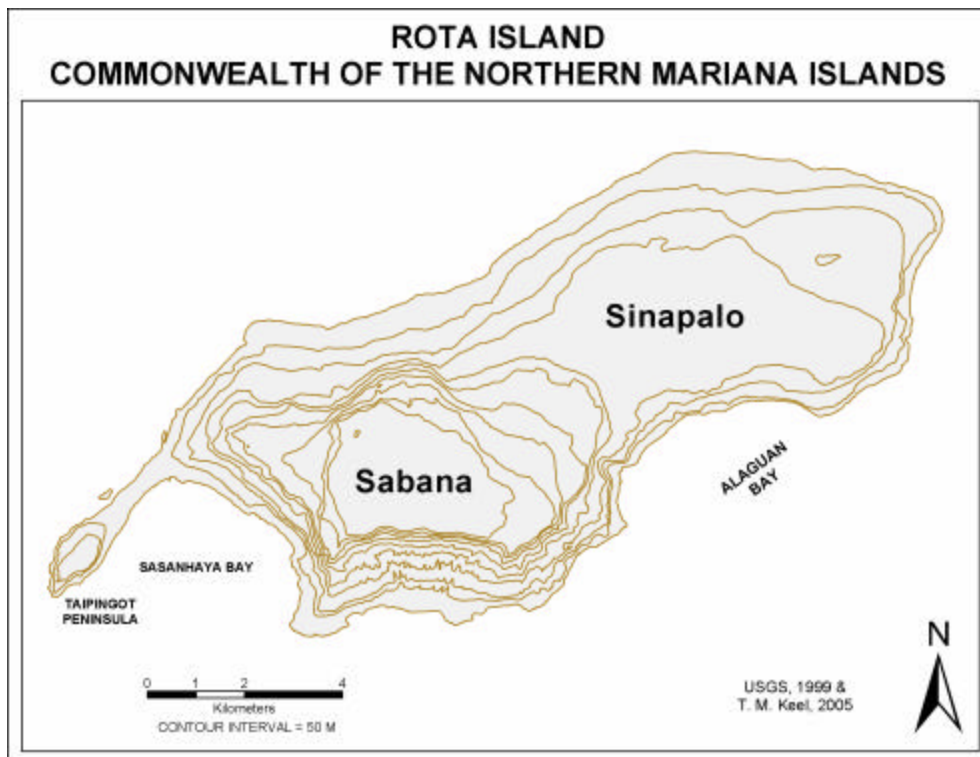


Figure 2. The Mariana Arc-Trench System

Asia at E 145° 12', N 14° 10'. Rota (Fig. 3) has a surface area of ~85 km<sup>2</sup> and a coastal perimeter of ~52 km. Sugawara (Sugawara, 1939 [1949]) described Rota as having six distinct terrace levels (see Previous Investigation section below). While Rota can be described as "terraced", focusing on the terrace levels tends to oversimplify the shape of the island. Rota is oriented east-west with the elevations on the north side of the island generally lower. For the purposes of this report, Rota has been divided into 3 informal regions; Taipingot is the western peninsula, Sinapalo Region is the northeastern plateau and Sabana Region is the central part of the island. The Sinapalo Region and Sabana Region are named for the most prominent areas within each region. 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 and the highest elevation in the older limestone-mantled islands of the outer arc of the Marianas. 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 volcaniclastic material. 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. At 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) and has a relative small outcrop of volcanics at Puntan Senhanom. Rota has a wet-dry tropical climate with a distinct rainy season (July – September) and dry season (February – March). Rainfall typically totals ~200 cm per year. Temperature on Rota is quite uniform and averages 27°C (USDA, 1994).



## Historical and Political Setting

Rota was settled by the Chamorro people around 1500 BCE. Ferdinand Magellan landed 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*. Spanish missionaries began the "reduction" of the islands in 1668 shortly after the islands were claimed by Spain (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 possession of Guam and 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 the Caroline Islands (the present Federated States of Micronesia and Palau) to Germany to pay 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

*Figure 3. Rota Island, Commonwealth of the Northern Mariana Islands*

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*. A report by Kanehira (1936[1960]) on the forest plants of Rota indicates that large scale clearing of land for sugar cane agriculture began after 1932. During the Japanese administration an area on the *Sabana* south of the summit, was mined for phosphate-rich soil which was transported to the coast using an aerial tramway that ended at the processing plant at *Sagua*, east of *Songsong Village* (Rodgers, 1948). During World War II, the United States forcibly took possession of the Saipan and Tinian from Japan in 1945, 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 administered the northern Mariana Islands, as well as the Marshall Islands and Caroline Islands. After it was approved in a plebiscite in the northern Mariana Islands, the United States ratified the *Covenant to Establish the Commonwealth of the Northern Marianas 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, yet is part of the United States. Several federal agencies, including the US Postal Service, National Park Service, FBI, 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.

## CHAPTER III

### STATEMENT OF PROBLEM

The geology of Rota has had very limited systematic examination. The caves and karst of Rota have been studied even less. Sugawara (1939 [1949]) 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 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 absent from the geologic literature.

Rota is unique among the islands of the Mariana Arc in that it does not normally get municipal water from the fresh water lens. All the municipal water on Rota (Fig. 3) presently comes from two contact springs on the *Talakhaya* (see Setting above), Water Cave, a.k.a. *Matan Hanum*, and *As Onan* Spring. Rota has three reserve production wells in *Sinapalo*. However, these three wells combined have a sustained yield less than half the typical demand on Rota (pers. comm., C. Manglona, Commonwealth Utilities Corporation). 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. This study of the caves and karst of Rota provides a foundation for further investigation of Rota's hydrologic system(s) and should become the basis of a comprehensive study of the island's geology and hydrology.



## CHAPTER IV

### PREVIOUS INVESTIGATIONS

#### Caves on Eogenetic Carbonate Islands

Cave development in young carbonate islands is significantly different from that normally found in limestone in continental settings. A series of papers published over the last 15 years documents the development of ideas regarding the formation of caves in young carbonate islands (e.g., Mylroie and Carew, 1988, 1990; 1995a; 1995b; Mylroie et al., 1995; Mylroie and Jenson, 2001). The Carbonate Island Karst Model (CIKM) has been developed to summarize the present understanding of the development of caves in young carbonate islands (Mylroie et al., 2004). The CIKM is assumed the presence of a freshwater lens controlled by the Dupuit-Ghyben-Herzberg principle (Fig. 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. The idealized diagram of the Dupuit-Ghyben-Herzberg principle is intended to depict an island consisting of a non-carbonate core mantled by eogenetic limestone. Eogenetic limestone has been defined as limestone that has never been out of the range of meteoric diagenesis (Vacher and Mylroie, 2002). Basal water is the part of the freshwater lens underlain by salt water, while parabasal water is underlain by non-carbonate rock.

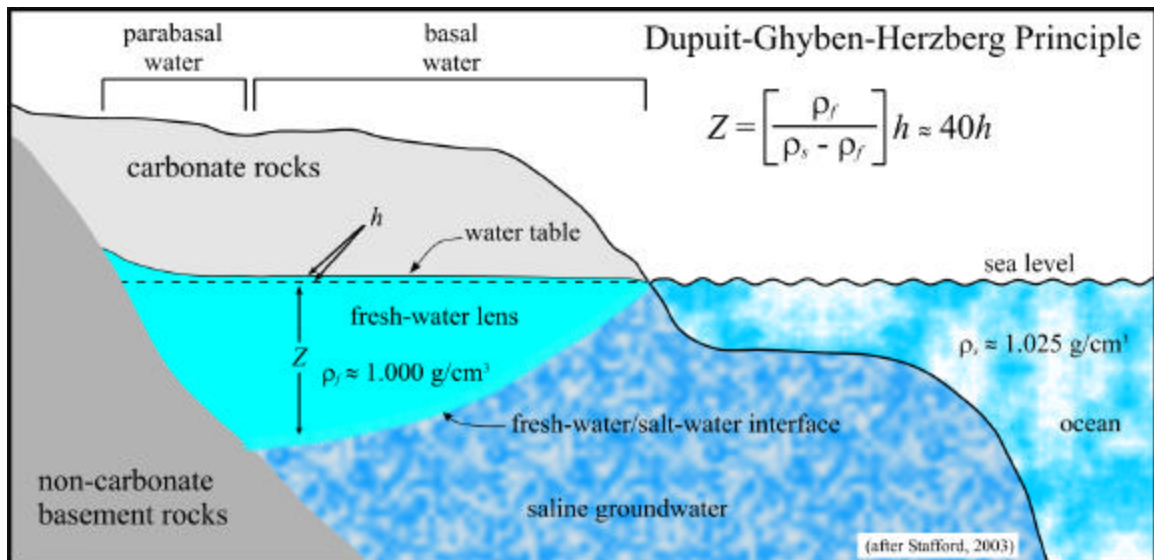


Figure 4. The Dupuit-Ghyben-Herzberg Principle

The Carbonate Island Karst Model (CIKM) was first developed to explain the caves and karst on relatively simple carbonate islands such as those of 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 at the interfaces of the freshwater lens
2. Glacioeustasy has moved the fresh-water lens up and down through a vertical range of over 100 m in the Quaternary.
3. Local uplift and subsidence can complicate the record by overprinting the effects of glacio-eustasy.
4. The CIKM primarily applies to eogenetic carbonate islands; i.e. islands with carbonate rocks that have never been buried out of the range of meteoric diagenesis.
5. Four classifications of carbonate islands are based on basement rock/sea level relationships, etc.
  - 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  $\text{CO}_2$  partial pressure.” Figure 5, after Dreybrodt, presents  $\text{Ca}^{++}$  concentration as a function of carbonic acid ( $\text{H}_2\text{CO}_3$ ) concentration. Since  $\text{H}_2\text{CO}_3$  concentration is a function of  $\text{CO}_2$  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 under saturation. For example, if water at points A and B on the saturation curve are mixed, the resulting mixture would be represented by some point 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 of  $\text{H}_2\text{CO}_3$ . The greater the difference in  $\text{H}_2\text{CO}_3$  concentration, the greater the degree of unsaturation in the mixture. In Figure 5, the mixture of A and B result 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.

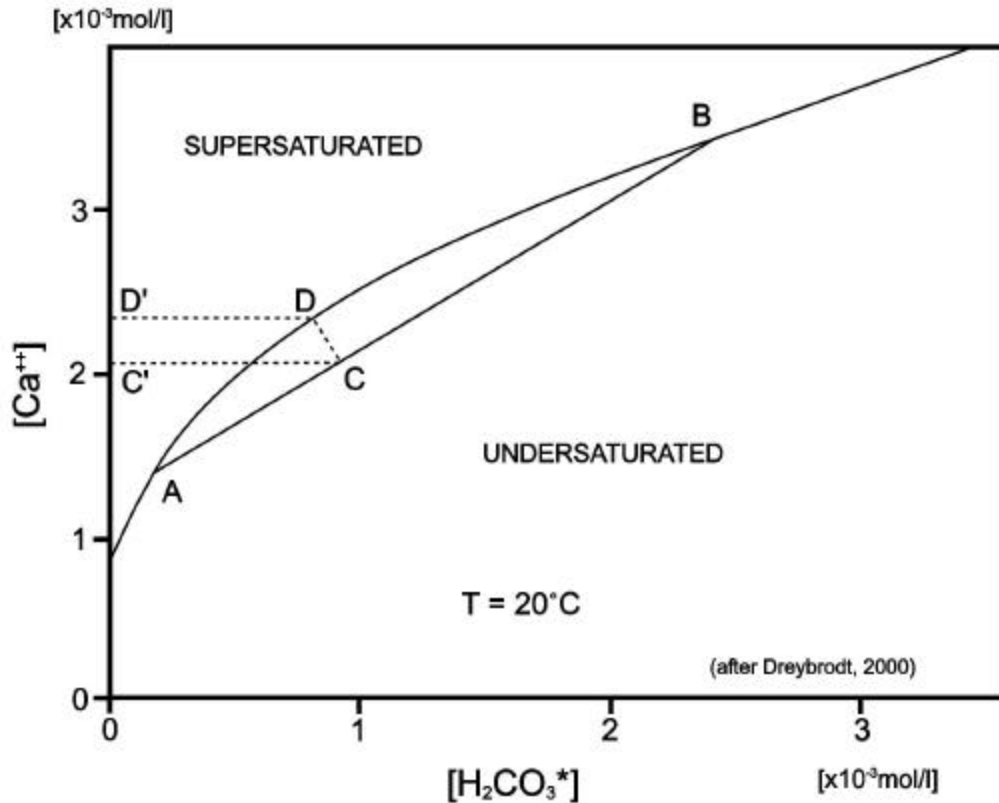


Figure 5. Calcite Solubility versus Carbonic Acid Concentration

At the edge of the freshwater lens in a carbonate island, the  $\text{H}_2\text{CO}_3$  mixing effect and the salinity mixing effect are additive, creating a zone of enhanced dissolution. Although not directly related to mixing of different solutions, Bottrell et. al (1993) proposed that the upper and lower boundaries of the freshwater lens can act as density traps for organic material carried down from the surface. Micro-organisms fed by these organics produce  $\text{CO}_2$ . The  $\text{CO}_2$  thus produced would lead directly to the dissolution of  $\text{CaCO}_3$  at the density traps. If sufficient organic matter is present, anoxic conditions can develop that lead to the production of other acids, such as  $\text{H}_2\text{SO}_4$  from the oxidation of  $\text{H}_2\text{S}$ . Even a small amount of  $\text{H}_2\text{SO}_4$  produced by this process would have a tremendous dissolution potential.

**Glacio-eustasy:** Since an island fresh water lens floats on top of 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 (Carew and Mylroie, 1995).

**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 (flank margin caves, etc.) are later found.

**Eogenetic Carbonate Islands:** The CIKM is primarily applicable to islands at least partly composed of eogenetic limestone. 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 (Vacher and Mylroie, 2002).

**Four Classifications of Carbonate Islands:** The first three classifications of carbonate islands (Mylroie 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 hypogenic cave development can occur at the top, bottom and edge of the fresh water lens. (Fig. 6) The following figures of the Carbonate Island Karst Classifications are from Mylroie et al. (2004) except for Figure 7 which is modified from Mylroie et al. (2004).

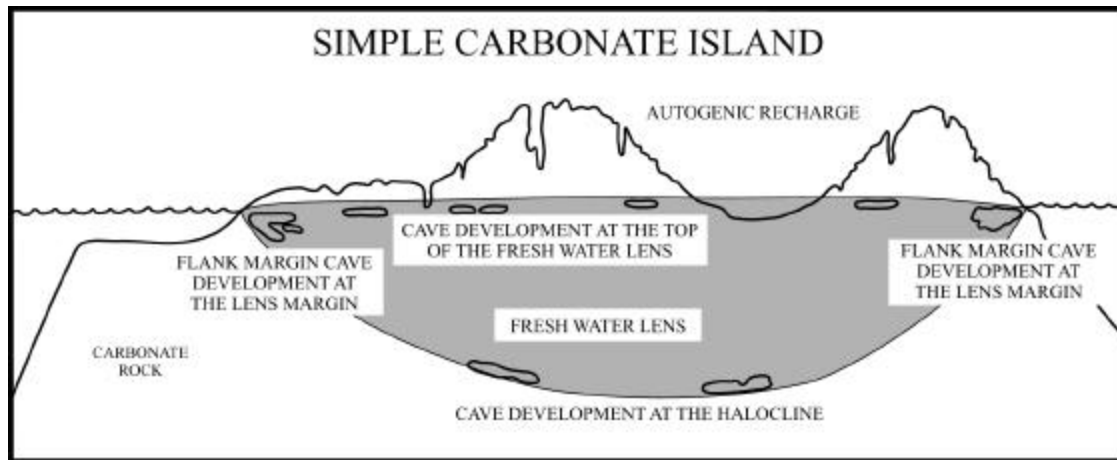


Figure 6. The Simple Carbonate Island Karst Classification (Mylroie et al., 2004)

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 saline lakes as a result of negative water budgets and up-coning of seawater as meteoric water evaporates (Fig. 7).

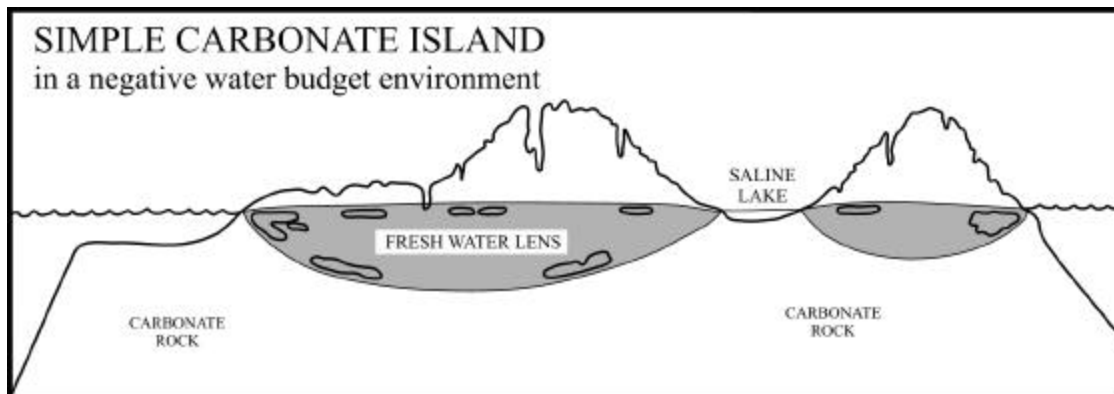


Figure 7. Simple Carbonate Island in negative water budget environment (modified from Mylroie et al., 2004)

In a Carbonate Cover Island (Fig. 8), non-carbonate rock is shallow enough to partition the lens but is not exposed on the surface. Recharge is autogenic, and hypogenic caves can form at the top, bottom and edges of the lens. The lens is partitioned by the non-carbonate rock. Caves can also form along the contact of the non-carbonate rock and the 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. For example, Bermuda is presently a Simple Carbonate Island but has been a Carbonate Cover Island when sea-level was lower (Myloie et al., 1995).

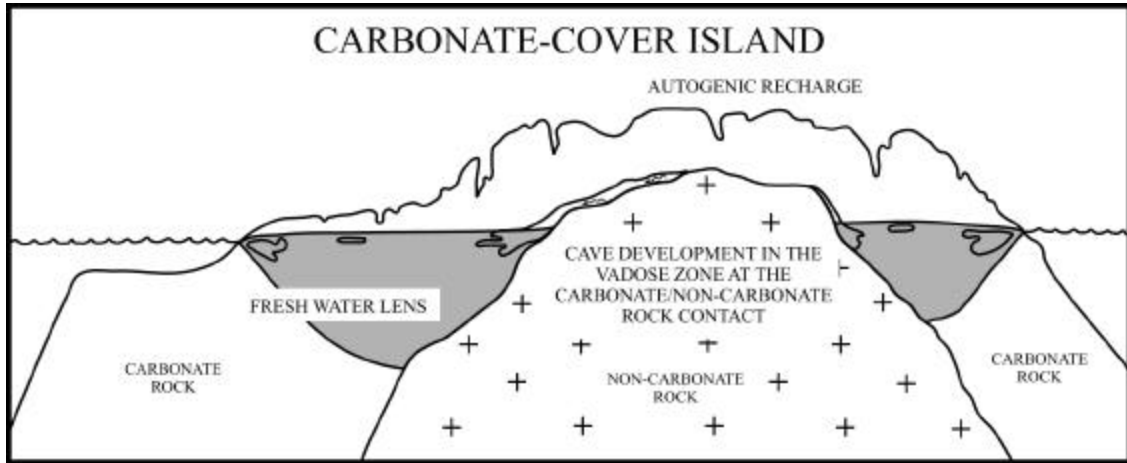


Figure 8. Carbonate-Cover Island Karst Classification (Myloie et al., 2004)

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 (Fig. 9), and the lens is partitioned.

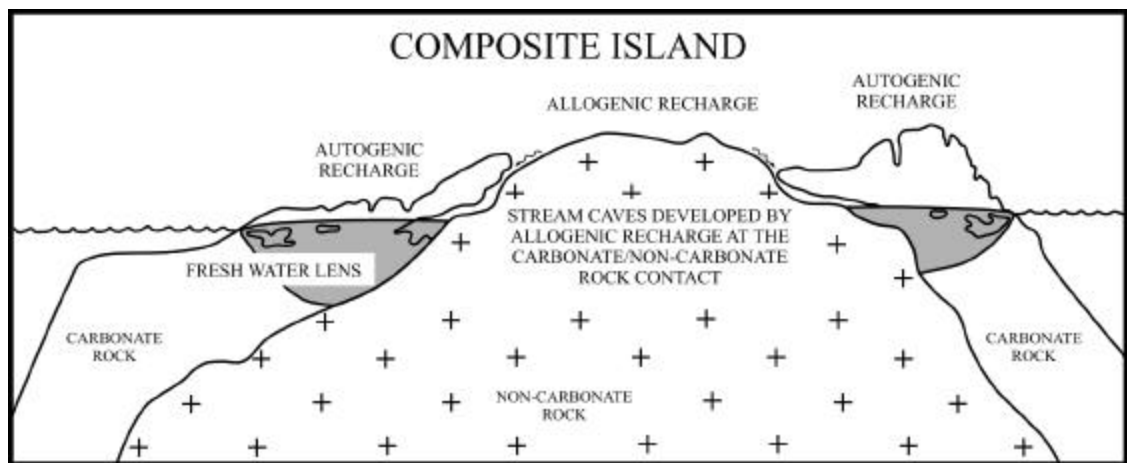


Figure 9. Composite Island Karst Classification (Myloie et al., 2004)

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 confined aquifers. Parts of Saipan and Guam were the archetypes for development of the Complex Island classification (Jenson et al., 2002) (Figure 10).

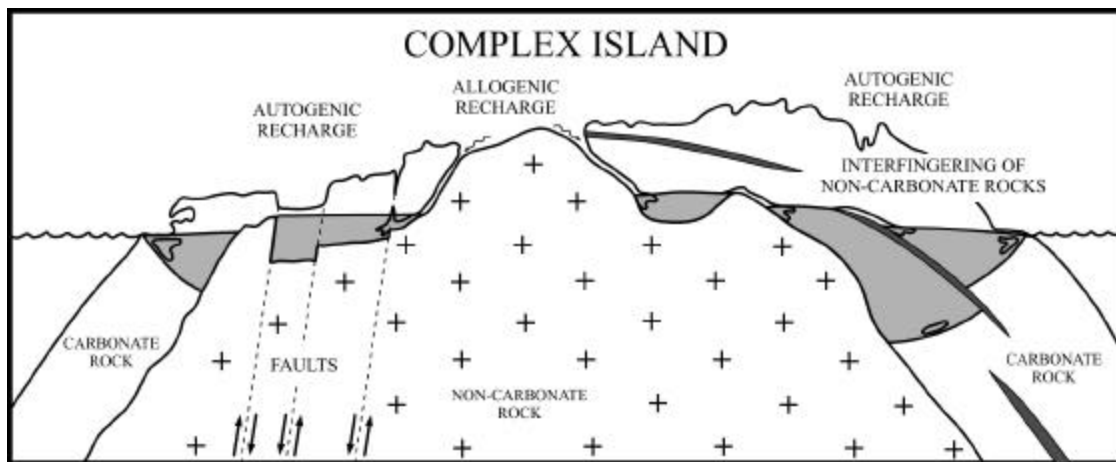


Figure 10. The Complex Island Karst Classification (Mylroie et al., 2004)

Caves developed along the interfaces of a fresh water lens are hypogenic; i.e. they develop without conduit connections to the surface (Palmer, 1991). The caves thus developed are only enterable when breached by erosion. The primary cave type formed in the carbonate island environment develops at the edge of the freshwater lens where vadose-phreatic and fresh-water salt-water mixing effects are superimposed and additive. These caves are called flank margin caves because they develop at the margin of the freshwater lens under the flank of the landmass. Flank margin caves are not true conduits as they develop by diffuse flow mixing of freshwater from the lens with marine water and thus they form without entrances. They are only enterable when breached by erosion. Flank margin caves typically have a morphology that fits the spongiform and/or ramiform cave shapes described by Palmer (1991), with chambers further inland typically being smaller (Mylroie and Carew, 1995b). The complexity of flank margin caves is often increased by the intersection of previously separate mixing chambers. Flank margin cave development can be extensive parallel to the coast. The inland development is usually limited relative to coast parallel development. Harris et. al (1995) showed that voids can develop at the top of the fresh water lens due to  $H_2CO_3$  concentration mixing effects that occur as meteoric vadose water is added to the lens. When these voids are breached by erosion they are referred to as “banana holes” in the Bahamas. Voids are thought to develop along the interface at the bottom of the freshwater lens due to mixing effects and organic trapping.

The unique morphology and genesis of flank margin caves were first recognized in the Bahamas (Mylroie and Carew, 1988, 1990). Since that time they have been

identified on Bermuda (Mylroie et al., 1995), on Isla de Mona Puerto Rico (Frank et al., 1998), in the Marianas (Mylroie et al., 2001) and in Yucatan, Mexico (Kelley et al., 2004). Because the position of the fresh-water lens determines the location of flank margin cave development, their development is also tied to sea level position. The residence time of the lens at any given position is a limiting factor in the development of flank margin caves at that position. The flank margin caves of the tectonically stable Bahamas primarily represent the Oxygen Isotope Substage 5e high stand, ~131 to 119 ka. The flank margin caves of Isla de Mona formed prior to the onset of Quaternary glacioeustasy and are thus extremely large (up to ~20 km of survey) due to very long residence times for the lens position. The flank margin caves of Isla de Mona have been preserved by subsequent tectonic uplift that moved them well above later glacioeustatic sea level fluctuations. The islands of the Marianas have been tectonically active throughout the Quaternary. Dramatic uplift and some probably minor subsidence has combined with glacioeustasy to insure that the fresh-water lens has not remained at any given elevation for an extended period. This has produced numerous caves that are rarely as large as those in the Bahamas. Recent work in the coastal carbonates of Yucatan, Mexico (Kelley et al., 2004) has shown that flank margin cave development is not limited to islands.

Caves and karst features similar to those documented on Rota have been documented on some of the other islands in the Mariana Island Arc. The recent work of Stafford (2003) on Tinian and Aguijan documented numerous flank margin caves and what he referred to as fissure caves. Within the fissure cave classification, Stafford included features developed along fractures that are parallel to island margins and scarps the probably have a significant mechanical opening component to their development (8 features) as well as a few features developed along fractures that appear to have been enlarged primarily by dissolution that occurred in the mixing zone at the edge of the fresh water lens (4 features). Since the mode of genesis for these two types of features is significantly different, in this report features that are mainly developed by mechanical opening will be called fissures or fissure caves and features that primarily formed by dissolution along a fracture in the mixing zone will be called mixing zone fracture caves. In the fourth edition of the Glossary of Geology, Jackson (1997) defines a fissure as “A surface of fracture or crack along which there is a distinct separation” and indicates that fissure is synonymous with “open joint”. Jackson (1997) also defines a fracture as “...any surface within a material across which there is no cohesion , e.g. a crack”. These definitions support this change in nomenclature. On Tinian, Stafford (2003) documented one pit cave, which Harris et al. (Harris et al., 1995) defined as having a depth to width ratio greater than 1. In the Mariana Arc there are documented pit caves on Guam (Taborosi and Jenson, 1999) and well known, undocumented pit caves on Saipan. On carbonate islands, pit caves can develop as an interconnected series of shafts and typically act as vertical fast flow routes for water collected in the epikarst (Mylroie 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 cave stream perched on non-carbonate basement rock. Barbados is a good example of an island with contact stream caves (Mylroie et al., 1995). Point source recharge features (insurgences) 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 (1939 [1949]) and translated into English by the United States military in 1949. English translation of Sugawara's (1939 [1949]) map and diagrams of Rota are not available. Sugawara's (1939 [1949]) approach was primarily to define the physiography and geology 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 foraminifera 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 stillstands and thus long periods of stability for the freshwater lens.

Piper (1947) produced a short report, apparently for the US military which included very general observations on the geology of Rota. Piper also discussed the potential for ground water exploitation and described the system that had been installed by the Japanese for collecting water at Water Cave and transporting it to *Songsong Village* and up to the *Sabana*.

Kanamori (1908[1955]) reported on a plant growth study that indicated that guano taken from unidentified caves on Rota was not effective as a fertilizer.

In a report on the mineral extraction potential of some of the islands of Micronesia, Otsuki (1915[1947]) indicated that there were reports of phosphate deposits on Rota that might be worth extracting. From the date of this report, it is clear that mining of phosphate did not begin on Rota until after 1915.

Hanzawa (1957) produced a compilation of the foraminifera samples taken from several of the islands of Micronesia. All the samples from Rota that Hanzawa refers to were collected and reported on by Sugawara (Sugawara, 1939 [1949]).

Yoshii (1936) reported on the non-carbonate rocks of Micronesia and briefly mentions Rota, indicating that the non-carbonate rock examined from there were calc-alkaline.

The observations of this author along with the work of Sugawara (1939 [1949]), 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 geology of Rota. 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 by the coral and algae. Uplift and subsidence, driven by the volcanism and tectonics, produced a complex set of faults, some of which are masked by subsequent 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 local 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 ~100 m elevation and covered with a continuous band of limestone along the coast up to ~40 m elevation. 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 land slide about 700 m long and 300 – 400 m wide. The historic Japanese Canon sits on this probably ancient slide. The *Talakhaya* contains the only perennial surface streams on Rota. The other known volcanic outcrops on Rota do not have perennial streams. All the limestone-covered parts of Rota are classic island karst terrain with autogenic recharge.

The two springs that normally 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, a.k.a. *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 that contact from the recharge area on the *Sabana*. Most of the water collected by 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 exploited for municipal water.

Rota is fringed for much of its perimeter by Holocene reef limestone that was exposed by recent tectonic uplift. Estimates of the maximum amount of Holocene 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 much of the island.

Bell (1988) and Wietrychowski (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 (1939 [1949]) 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, the 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, published cave names 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 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*, reported on their visit to *Taisacan Museum Cave*, 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.

Based on 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 was expected to have a high proportion of flank margin caves, some mixing zone fracture caves, some fissure caves, a few sea caves and possibly some pit caves, some stream caves and more contact springs than previously documented.

## CHAPTER V

### 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) at the University of Guam. The reconnaissance work of Stafford et. al (2002) and advance study of the USGS topographical map of Rota (1999) were 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 during the field work for this project (see Acknowledgements).

When possible, significant cave and karst features located were classified as one of the following: mixing zone cave, fissure cave, sea cave, contact cave, pit cave. Mixing zone caves are subdivided into flank margin caves and mixing zone fracture caves. When appropriate, cave and karst features were surveyed using standard cave survey techniques as documented by Dasher (1994). Azimuths and inclinations between survey stations was recorded to the nearest half degree and distance between survey stations was recorded in meters, to the nearest 0.01 meter. Along with the survey data, sketches of the plan and profile of each cave were recorded. The survey data and sketches are the primary field records on which this work is based. 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 unless vegetation blocked the GPS signal. When GPS signal was not available, locations were estimated from the USGS topographical map of Rota (1999). Cave locations were recorded as UTM coordinates and stored in a relational database and used within a geographical information system (GIS) to generate the included maps.

#### **Data Processing**

The survey data from each cave was reduced using the WALLS Project Editor (McKenzie, 2004) computer program. The line plot of each cave produced by WALLS Project Editor (McKenzie, 2004) was imported into the XaraX (Xara Ltd., 2001) drawing program. The sketch map of the cave was scanned and converted to a digital file which was then imported to XaraX (Xara Ltd., 2001). The line plot and the sketch were properly sized and oriented so that a map of the cave could be 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 cave maps produced are included in Appendix B of this report.

## CHAPTER VI

### RESULTS AND DISCUSSION

#### **The Cave and Karst Features of Rota**

Descriptions of the individual named cave features on Rota are listed alphabetically in Appendix A of this report. Cave maps generated by this project are included in Appendix B of this report. Eighty five of the to 120 caves surveyed on Rota were formed in the mixing zone at the edge of the fresh water lens. Fifty three of those are flank margin caves and the remaining 32 are mixing zone fracture caves. The investigations of caves on other islands in the Mariana Arc documented relatively few mixing zone fracture caves compared to the number found on Rota. Perhaps the steeper average gradients on Rota have led to more bank normal fractures along which mixing zone fracture caves could develop. Eleven fissures and fissure caves were documented on Rota but these are only a representative sample of the features found primarily in two extensive zones of such features and one smaller fissure zone. Rota has a few obvious sea caves, a pit cave, and a few contact caves.

#### **Mixing Zone Caves**

As described above, this classification includes flank margin caves, developed by diffuse flow at the edge of the fresh water lens, and mixing zone fracture caves, developed as fractures discharging fresh water from the lens migrate vertically through the mixing zone.

#### *Flank Margin Caves*

Flank margin caves were found across various parts of Rota, from sea-level to as high as 350 m elevation. In order to simplify the discussion, discussion of the various types of caves has been divided by the general regions of Rota. Flank margin caves of the Sinapalo Region will be addressed first (Fig. 11).

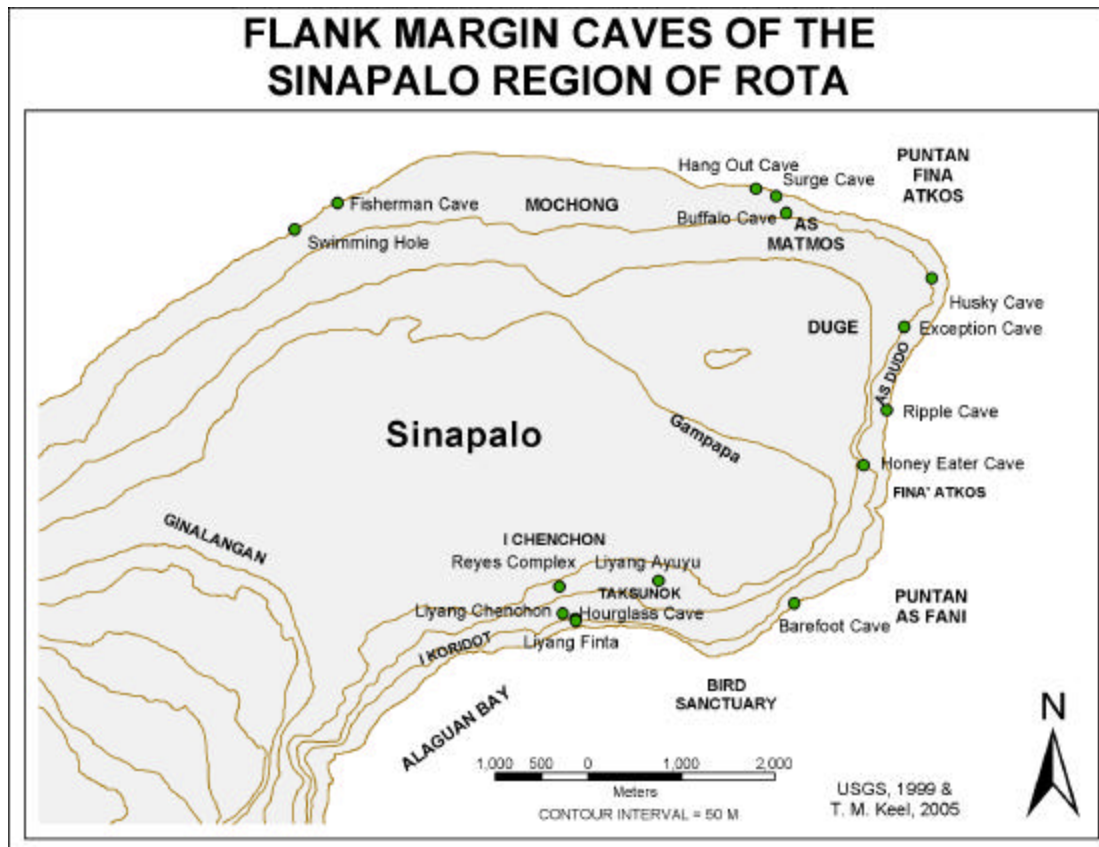


Figure 11. Sinapalo Flank Margin Caves

The *Reyes Cave Complex* (fig. B.97), 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 caves formed primarily by mechanical 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* (Fig.B.69) 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.

Hourglass Cave (Fig. B.58) and Monkey Cave (Fig. B.83) 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 stillstands. The larger Monkey Cave has a somewhat linear character indicating that a fracture in the bedrock may have affected its formation, yet its overall morphology indicates that it is a flank margin cave.

Exception Cave (Fig. B.43) 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* (Fig. B.113), located on the north coast of Rota, is 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 Swimming Hole includes a submerged passage that connects to the ocean.

Fisherman Cave (Fig. B.45) is a flank margin cave located ~1 m above sea-level about 400m northwest of the Swimming Hole on the north coast of Rota. This section of coast contains many features that are apparently remnants of flank margin cave. Fisherman Cave is by far the most intact feature found in this area.

Surge Cave (Fig. B.112) is also located on the north coast of Rota, but is at *As Matmos*, ~5 km east of the Swimming Hole. Surge Cave is apparently the remnant of a large flank margin cave with very little roofed cave remaining. Prior to the documented Holocene uplift (Dickinson, 2000; Kayanne et al., 1993), Surge Cave would have been a much larger version of the Swimming Hole.

Buffalo Cave (Fig. B.27) is one of several remnant flank margin caves in the cliff face at *As Matmos*. The upper and lower section of Buffalo Cave obviously developed at different sea-level stillstands. The relative position of these two cave sections suggests the presence of increased permeability in the adjacent bedrock.

Ripple Cave (Fig. B.98), located at sea-level on the east end of Rota at *As Dudo*, is a flank margin cave developed in limestone that has preserved ripple marks eroded out in relief on both sides of the cave entrance. Ripple cave has the classic lobed flank margin caves morphology. No other similar caves were found along this section of coast.

There are extensive horizons of apparent flank margin caves in cliff faces 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 yet been fully explored or surveyed due to limitations of this project.

The Sabana Region contains some of the best examples of flank margin cave development on Rota (Fig. 12)

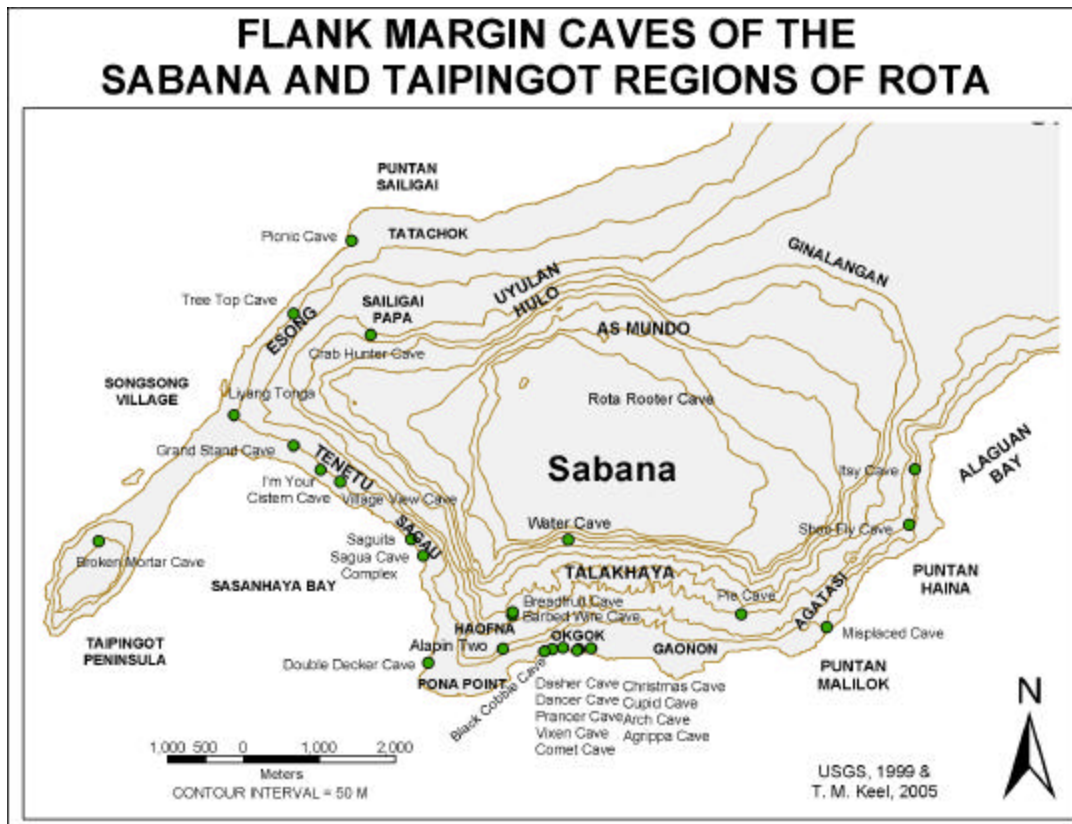


Figure 12. Sabana Flank Margin Caves

The most outstanding horizon of flank margin caves documented on Rota is the *Sagua Cave Complex* (Figs. B.102, B.103, B.104), 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 Cave Complex*, *Saguita Cave* (Fig. B.105) is another remnant flank margin cave similar to those in the *Sagua Cave Complex*.

Although more dispersed than those in the *Sagua Cave Complex*, the caves along the coastal cliff west of *Okgok* represent significant flank margin cave development. These include Christmas Cave (Fig. B.29), Dasher Cave (Fig. B.36), Dancer Cave (Fig. B.35), Prancer Cave (B.94), Vixen Cave (Fig. B.119), Comet Cave Fig. B.31), Cupid Cave (Fig. B.34), Agrippa Cave (Fig. B.1) and Arch Cave (Fig. B.7). These caves may simply be individual flank margin caves or they may be the remains of a formerly more extensive complex. Based on Agrippa Cave's location about 2 m above a spring apparently perched on volcanic rocks, its formation was probably affected by fresh-water lens interaction with volcanic rocks as well as by fresh water discharge, although no volcanic rocks are visible inside the cave.



Picnic Cave (Fig. B.90) is located at the coast, adjacent to the road, at *Puntan Sailigai*, 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 is affected by storm waves.

Culturally and hydrologically, the Water Cave. a.k.a. *Matan Hanum* (Fig. B.120), 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 and is now at an elevation of ~350 m on the *Talakhaya*. The topography of the volcanic/limestone contact concentrates the flow of water that recharges on the *Sabana*. This concentrated flow appears from impassable 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 (~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* (Fig. B.10), 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. Several springs along the volcanic/limestone contact between the Water Cave and *As Matan* were flowing significantly greater in January 2004 than in June 2003. Discharge at the Water Cave is known to vary seasonally.

Crab Hunter Cave (Fig. B.33) 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.

Bay Cave Remnant (Fig. B.16) 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.

*Alaguan Bay Cave* (Fig. B.2) 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.

Grandstand Cave (fig. B.51), located in the cliff face at *Tenetu*, overlooking the site of the annual Rota Fiesta motocross, is apparently a flank margin remnant. This feature is about 65 m long oriented roughly northwest-southeast. It is completely open to the south for most of its length and the open section is 5-8 m high and ~6 m wide. At the northwest end there is a section of cave about 10 m long that is oriented east-west. The outer wall of the cave section is primarily flowstone (columns).

The shape of the upper section of Double Decker Cave (Fig. B.41), located on the west side of *Poña Point*, indicates that it is probably the remnant of a flank margin cave, although wave erosion must have played a role in its later expression. The lower section is clearly developed along a fracture and is primarily the product of wave erosion. Discharge of fresh water does not appear to have been a significant factor in the

development of the lower level of Double Decker Cave, thus it is not classified as a mixing zone fracture cave.

At Haofña, along the road to the Water Cave, there are several caves visible in the cliff face. The caves in the upper part of the cliff face are inaccessible. Along the base of the cliff, Breadfruit Cave (Fig. B.23), Barbed Wire Cave (Fig. B.13), Stacked Wall Cave (Fig. B.110) and Pie Cave (Fig. B.92) were surveyed. All of these caves and other caves in this same area that were not surveyed are all apparently flank margin caves. Breadfruit Cave is especially interesting because the rock face immediately above the cave contains a linear series of holes parallel to the cave ceiling apparently formed at a sea-level stillstand only slightly higher than the one during which the larger cave formed. Stacked Wall Cave contains a manmade wall of loose laid limestone cobbles and boulders.

Tree Top Cave (Fig. B.116) is a remnant flank margin cave reached by climbing up a southwest facing section of cliff face at *Esong*, southeast of *Taisacan Museum Cave*. Tree Top Cave, like many remnant flank margin caves on Rota, is completely open on one side, having been partially destroyed by cliff retreat.

Misplaced Cave (Fig. B.83) is a small flank margin cave developed in a rubble facies at the base of the inland cliff at *Agatasi*, on the southeast coast of Rota. Although firmly cemented, the bedrock over the entrance to Misplaced Cave appears to be on the verge of collapse. There are other caves along this section of coast that were not surveyed due to time constraints and difficulty of access to this area. The presence of volcanic basement rock and some apparent significant changes in limestone lithology make this an area that should be further explored.

I'm Your Cistern Cave (Fig. B.60) 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.

Some other, smaller flank margin caves include: Alapin Two (Fig. B.6), a small flank margin cave located a few meters away from *Liyang Alapin*; *Liyang Chenchon* (Fig. B.71), located just inland from the cliff top at *I Koridot*; Itsy Cave (Fig. B.62), a very small flank margin remnant near Deer Cave; Shoo Fly Cave (Fig. B.108), located near the east end of the *Talakhaya* near the road; and Husky Cave (Fig. B.59), located a few meters west of the mouth of *Liyang Matan*, near *As Matmos*.

Broken Mortar Cave (Fig. B.26) is the only flank margin cave on the *Taipingot Peninsula* surveyed by this project. It is a very open, small rock shelter that is the remnant of a flank margin cave. The floor of the cave contains several native bedrock mortars, one of which is broken.

### *Mixing Zone Fracture Caves*

Mixing zone 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 have a maximum length of about 100 m. Most mixing zone 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 are usually composed of a mixture of soil, breakdown and flowstone. With some significant exceptions, the floors of mixing zone fracture caves tend to have low relief. Almost all the mixing zone fracture caves have ceilings that extend up into the fracture along which the cave is

developed. 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. This type of cave is believed to form as fresh water discharging from a fracture at sea-level mixes with marine water. The mixture of the discharging fresh water and sea water would have an enhanced ability to dissolve  $\text{CaCO}_3$ , even if the fresh water and sea water were both saturated with  $\text{CaCO}_3$  (see above and, Bögli, 1980; Palmer, 1991; Plummer, 1975). It is hypothesized here that development of these caves progresses as the mixing zone works its way headward in the discharging fracture, analogous to the headward erosion of a waterfall. The vertical development of these caves is attributed to relatively slow sea-level change moving the different parts of the fracture vertically through the mixing zone. The morphology of the mixing zone fracture caves on Rota support this model. The ends 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. In several places on Rota, mixing zone fracture caves have formed in clusters that are close enough to suggest that they formed synchronously. The largest mixing zone fracture caves on Rota are significantly larger than the largest ones documented by Stafford (2003) on nearby Tinian and Aguijan. Taborosi and Jenson (1999) document caves on Guam that are presently discharging fresh water; e.g., No Can Fracture. The number of mixing zone fracture caves documented here is greater than that documented for any of the other islands in the Marianas. 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* (Fig. B.75) and Knuckle Bone Cave (Fig B.64) near *As Matmos*, *Liyang Botazon* (Fig B.70) at *Fina’ Atkos* and Deer Cave (Fig. B.37) , 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.

Mixing zone fracture caves on Rota will be described starting with those located in the Sinapalo region (Fig. 13). At the base of the cliff in the *Chenchon Bird Sanctuary* there are two clusters of mixing zone fracture caves. The northernmost cluster consists of *Liyang Paluma* (Fig B.77) and *Liyang Lu’ao* (Fig. B.74), plus the much smaller Letterman Cave (Fig. B.65), which are within about 40 m of each other. Further south, Arrowhead Cave (Fig. B.9) and *Liyang Neni* (Fig. B.76) are about 30 m apart. *Liyang Siete* (Fig. B.79) 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.

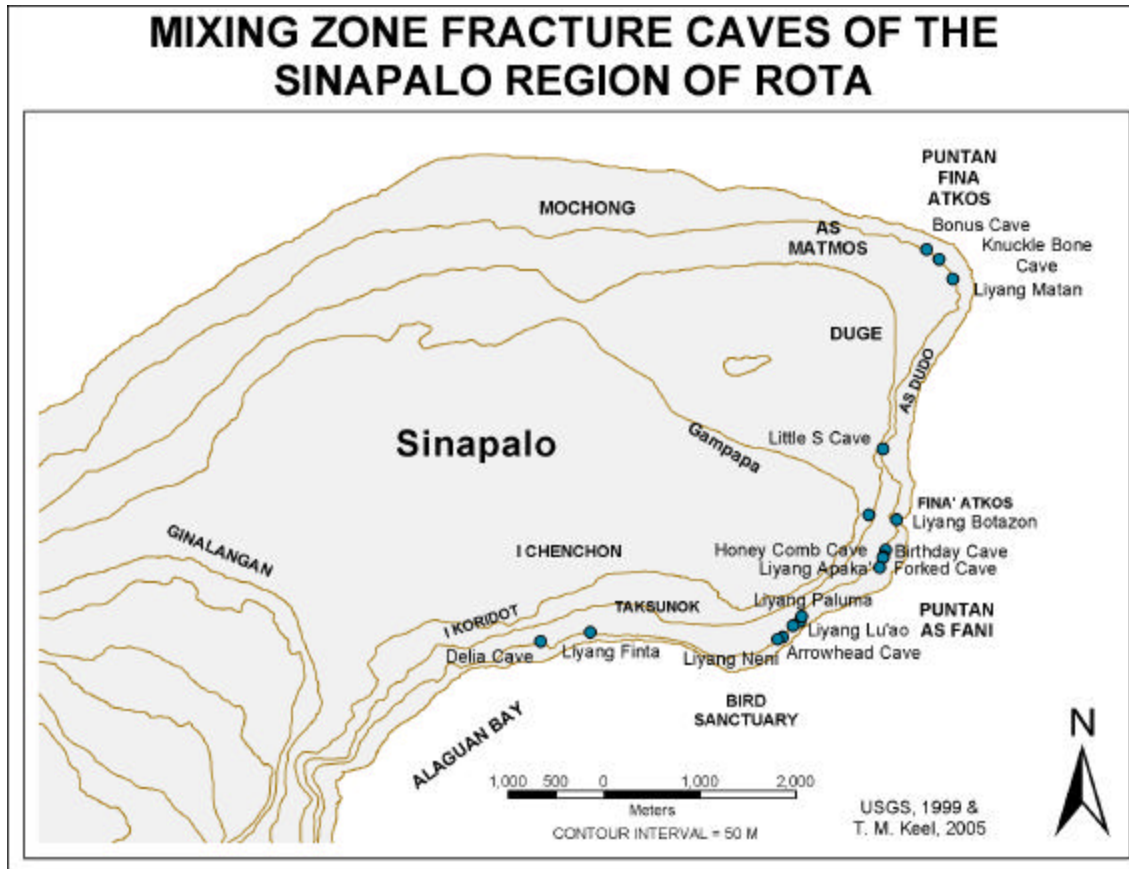


Figure 13. Sinapalo Mixing Zone Fracture Caves

Another cluster of four mixing zone fracture caves was found at the base of the cliff, inland from *Puntan As Fani*, on the eastern end of Rota. *Liyang Apaka'* (Fig. B.68) Honey Comb Cave (Fig. B.56) , Forked Cave (Fig. B.48) and Birthday Cave (Fig. B.19) 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.

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, then it might be expected that larger fracture caves would be more widely spaced. *Liyang Matan* (Fig. B.75), Knuckle Bone Cave (Fig. B.64) and Bonus Cave (Fig. B.22) 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 pairs of parallel fractures along which each of these caves is developed. 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 but has been documented in the Bahamas and in the Yucatan Peninsula, Mexico (Jenson et al., In Press; Kelley et al., 2004).

Pictograph Cave (Fig. B.91), 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 mixing zone fracture caves on Rota.

*Liyang Botazon* (Fig. B.70), 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 terraces and extending up to the wide bench below Pictograph Cave, suggests that development of this feature is along a significant fault, although no evidence of displacement is documented. The sets of apparent conjugate fractures and small caves of the Banyan Complex (See Fissure Cave, below), appear to be aligned with the *Fina Atkos* canyon. Further inland, in a cliff face, there is a vertical notch, also in alignment with the *Fina Atkos* canyon.

Near *Taksunok*, *Liyang Finta* (Fig. B.72) is developed along a fracture that is also expressed on the cliff top above it. Many broken and re-cemented speleothems and the rubbly facies below *Liyang Finta* within which Basement Cave (Fig. B.15) is developed suggest that this fracture is in fact a fault that has had movement since the development of *Liyang Finta*. Along the coast below and to the east of *Liyang Finta* are fault surfaces roughly in alignment with the fracture along which *Liyang Finta* is developed.

Delia Cave (Fig. B.38) is a mixing zone fracture cave located in the cliff face at *I Koridot*. It is exceptional for mixing zone fracture caves on Rota, in that the floor is highly irregular, with a vertical displacement of ~25 m. Near Delia Cave is the remnant of a mixing zone fracture cave that was not surveyed.

Little S Cave (Fig. B.66) is a small mixing zone fracture cave in the large cove at *As Dudo*. Numerous small caves in this cove remain un-surveyed. In the northeast facing wall of the cove at *As Dudo* is Honey Eater Cave (Fig. B.57), accessible via a difficult climb. Honey Eater Cave is apparently a mixing zone fracture cave but also displays some morphology suggestive of a flank margin cave. Honey Eater Cave contains large deposits of guano, 1+ m thick.

As depicted in Figure 14, the Sabana Region also has numerous mixing zone fracture caves. Although the Sabana region has some significant mixing zone fracture caves, clusters of them are not as prominent as in the Sinapalo region.

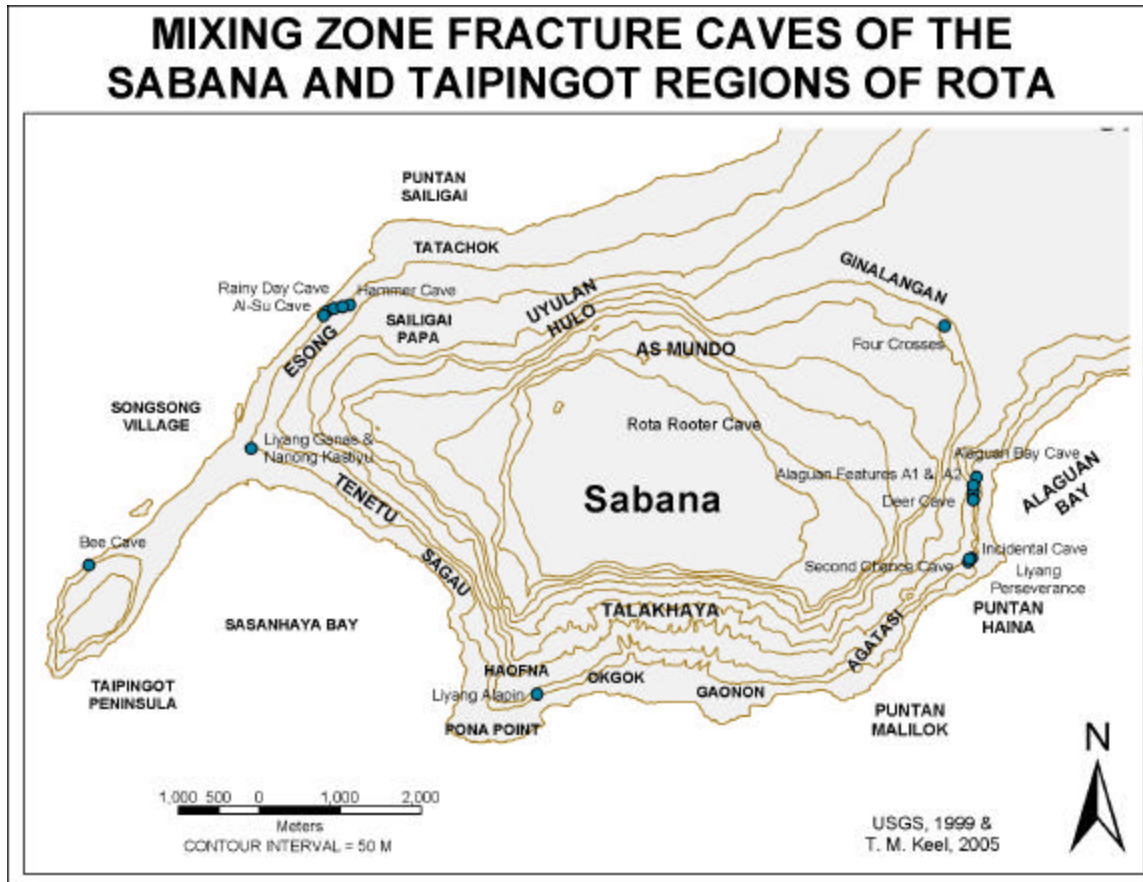


Figure 14. Sabana Mixing Zone Fracture Caves

*Liyang Alapin* (Fig. B.67) 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 (Fig. B.37) 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* (Fig. B.3) and *Alaguan Feature A3* (Fig. B.4), which are shallow cave-like features developed along bedrock fractures that possibly have a genesis related to mixing zone fracture caves.

*Liyang Ganas* and *Nanong Kastiyu* (Fig. B.73), 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 the two caves. These caves were first reported by Rogers and Legge (1992). 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.

*Taisacan Museum Cave* (Fig. B.114), near *Esong*, is significant for its size, but is not part of a cluster of mixing zone fracture caves, although there are some other mixing zone fracture caves relatively close.

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* (Fig. B.78) and Second Chance Cave (Fig. B.107) are located just below the cliff top while Incidental Cave (Fig. B.61) 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.

The topographical map of Rota (USGS, 1999) depicts a small inland cove just west of *Sailigai Papa*. This cove contains three relatively small mixing zone fracture caves that are too dispersed to be considered a cluster, Hammer Cave (Fig. B.53), Rock Pile Cave (Fig. B.99) and Rainy Day Cave (Fig. B.95). Just outside the cove, to the southwest, is Al-Su Cave (Fig. B.7), another small mixing zone fracture cave.

Hang Out Cave (Fig. B.54) is a small cave on the north coast of Rota, developed along a fracture. Its genesis probably involved mixing zone discharge and wave erosion. Canyon Cave (Fig. B.28) 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 if the trend of this canyon coincides with Deer Cave, which is developed along a linear fracture.

Along the inland cliff face south west of *Ginalangan* are the Four Crosses (Fig. B.49) and Kaigun 223 Japanese Command Post (Fig. B.63). 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.

## **Fissure Caves**

This study documented on Rota two extensive zones of a karst landform characterized by a very high density of dissolutionally enlarged vertical to near vertical fractures with rugged pinnacle karst between the fractures. These zones are herein called fissure zones and the individual enlarged fractures called fissures or fissure caves. Most of the known fissure and fissure cave on Rota are located within two fissure zones. The *As Mundo Fissure Zone* is located southeast of *As Mundo*. Fissure City fissure zone is located northwest of *As Mundo* and northeast of *Uyulan Hulo*. Although dramatically different from the two zones above, The Banyan Complex (Fig. B.12) is noteworthy as

well. The location of fissure caves and one fault cave on the Sabana Region are shown in Figure 15.

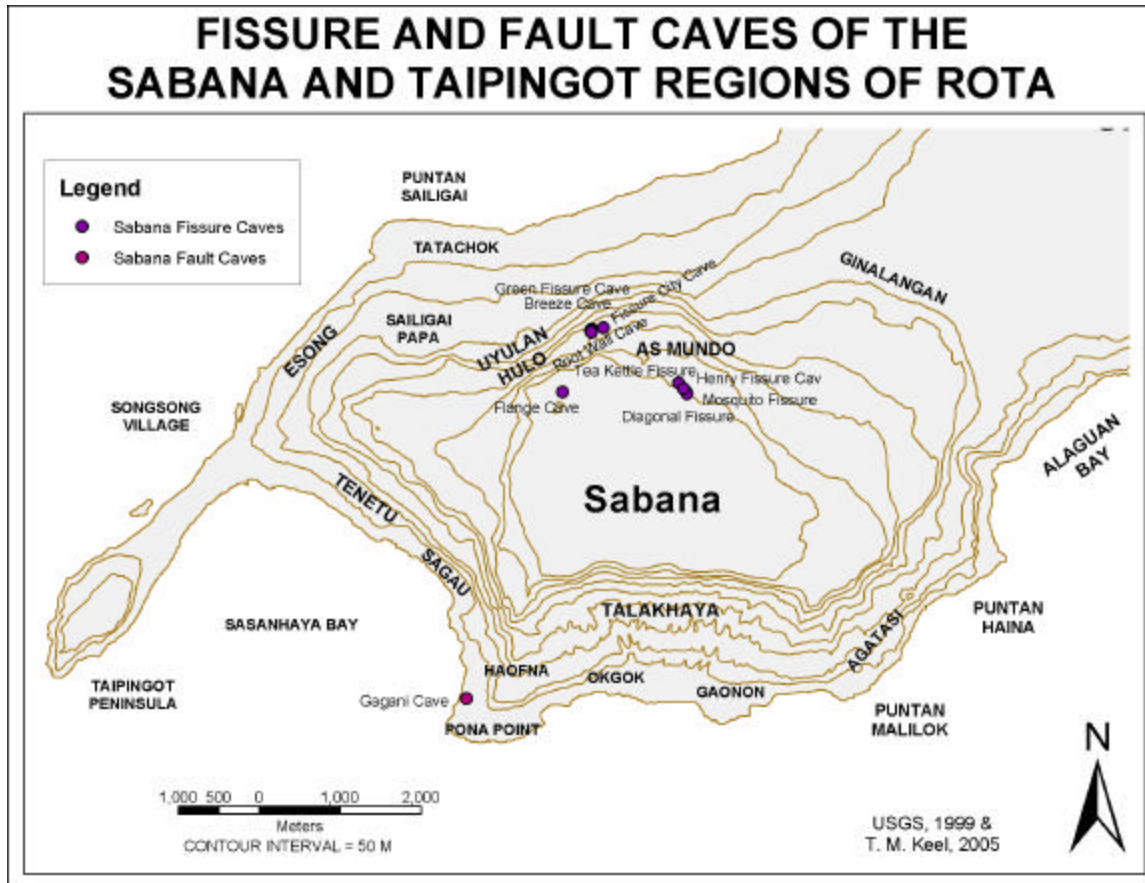


Figure 15. Sabana Fissure Caves and Fault Caves

The *As Mundo Fissure Zone* (Fig. 16) extends for ~450 m along the northeast flank of the *Sabana* and is 40-100 m wide. While the overall relief across the zone is small (40-50 m total), the *As Mundo Fissure Zone* contains some of the most rugged terrain on Rota, earning it the well-deserved field name “Fissure Hell”. The terrain is difficult to describe, consisting of a multitude of dissolutionally enlarged fissures and the relatively small spaces between them. The spaces between the fissures are generally covered with rugged pinnacle karst and thick vegetation. The fissures range in depth from 1-2 m to 10+ m. The fissures in the *As Mundo Fissure Zone* are far too numerous for each fissure to have been surveyed. A representative sample was documented, including Henry Fissure Cave (Fig. B.55), Tea Kettle Fissure (Fig. B.115), Mosquito Fissure (Fig. B.84) and Diagonal Fissure (Fig. B.39). Northwest and southeast of the *As Mundo Fissure Zone*, aligned with its long axis, are scarps defining the northeast flank of the *Sabana*. The scarp to the northwest has several exposures of the contact between the



limestone and the underlying volcanics. There are at least two plausible explanations for the genesis of the fractures that led to the formation of the *As Mundo Fissure Zone*. One is that the scarps adjacent to the ends of the zone are fault scarps and that the fissure zone is a cluster of high angle normal faults. The other slightly more plausible explanation is that the fissures formed as a large block of limestone slid over the underlying volcanics that had been previously weathered to clay. The fissures in the *As Mundo Fissure Zone* appear to have been mechanically opened and subsequently modified by vadose water flowing down the walls. No evidence was found that phreatic water had any effect on the formation of the *As Mundo Fissure Zone*.

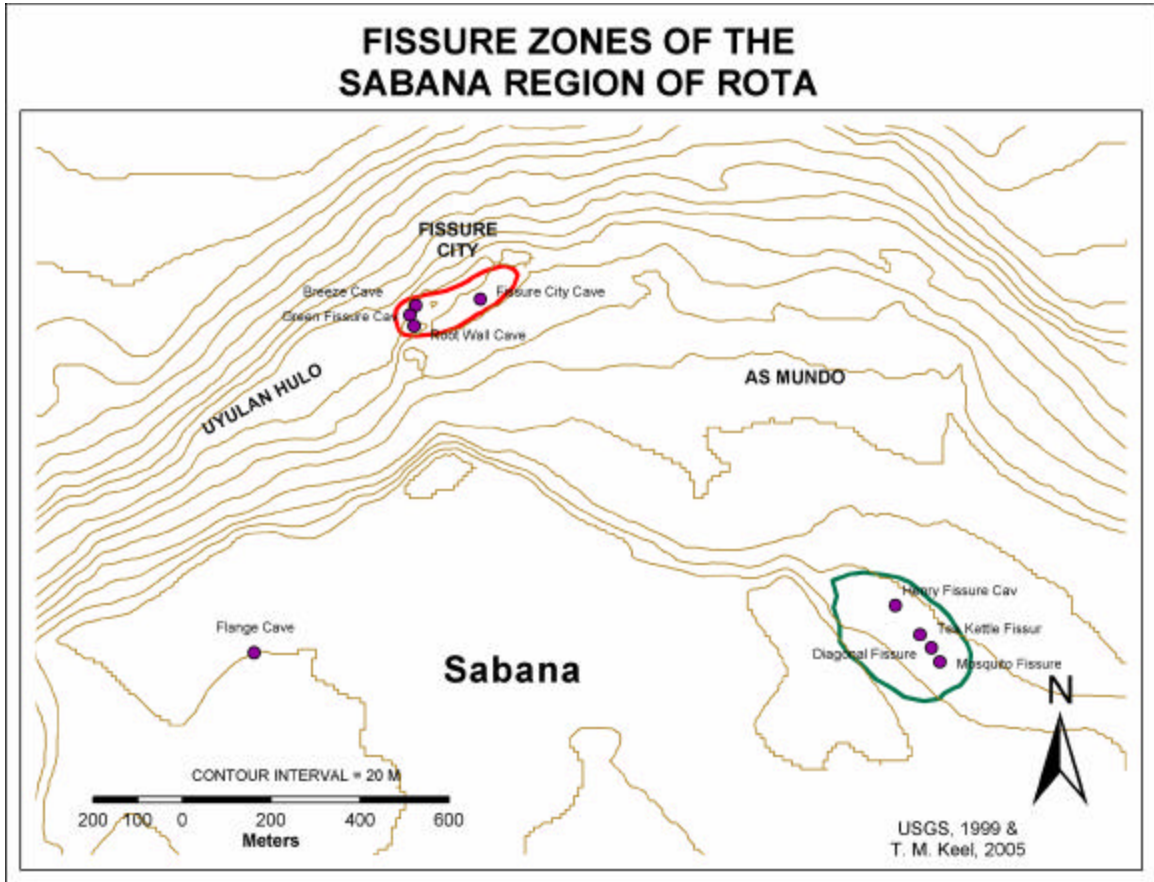


Figure 16. Sabana Fissure Zones

Fissure City (Fig. 16) is thought to have the same possible origins as the *As Mundo Fissure Zone*. The large closed depression that dominates this area and appears on the USGS topographic map (1999) may have formed as a large block of limestone slid on the underlying weathered volcanics. Within Fissure City, Fissure City Cave (Fig. B.46) was surveyed to a depth of 33 m, making it the deepest known cave on Rota. The Fissure City Cave fracture can be seen to extend below the deepest navigable point in the cave. The surveyed depth does not include the depth of the closed depression in which the entrance to Fissure City Cave is located. There are numerous fissures within the

closed depression that were not surveyed. Outside the closed depression, Root Wall Cave (Fig. B.100), Breeze Cave (Fig. B.25) and Green Fissure Cave (Fig. B.52) were also surveyed. Like Fissure City Cave, each of these consists of a mechanically opened crack that has been subsequently modified by vadose water flow. As in the *As Mundo Fissure Zone*, there is no evidence of the phreatic zone playing a role in the development of Fissure City.

The Banyan Complex (Fig. 17) is located on the widest intermediate bench above *Fina' Atkos*. The terrain in the Banyan Complex is very subdued, without the pinnacle karst and deeply carved fissures that characterize the *As Mundo Fissure Zone* and Fissure City. However, the Banyan Complex does contain a fracture set probably related to stress from the apparent fault that cuts through the coastal benches adjacent to *Fina' Atkos*. Several small caves developed along the fractures of the Banyan Complex were surveyed by this project; including Banyan Complex Cave (Fig. B.12) and Not Much Cave (Fig. B.86). There are several undocumented caves within the Banyan Complex.

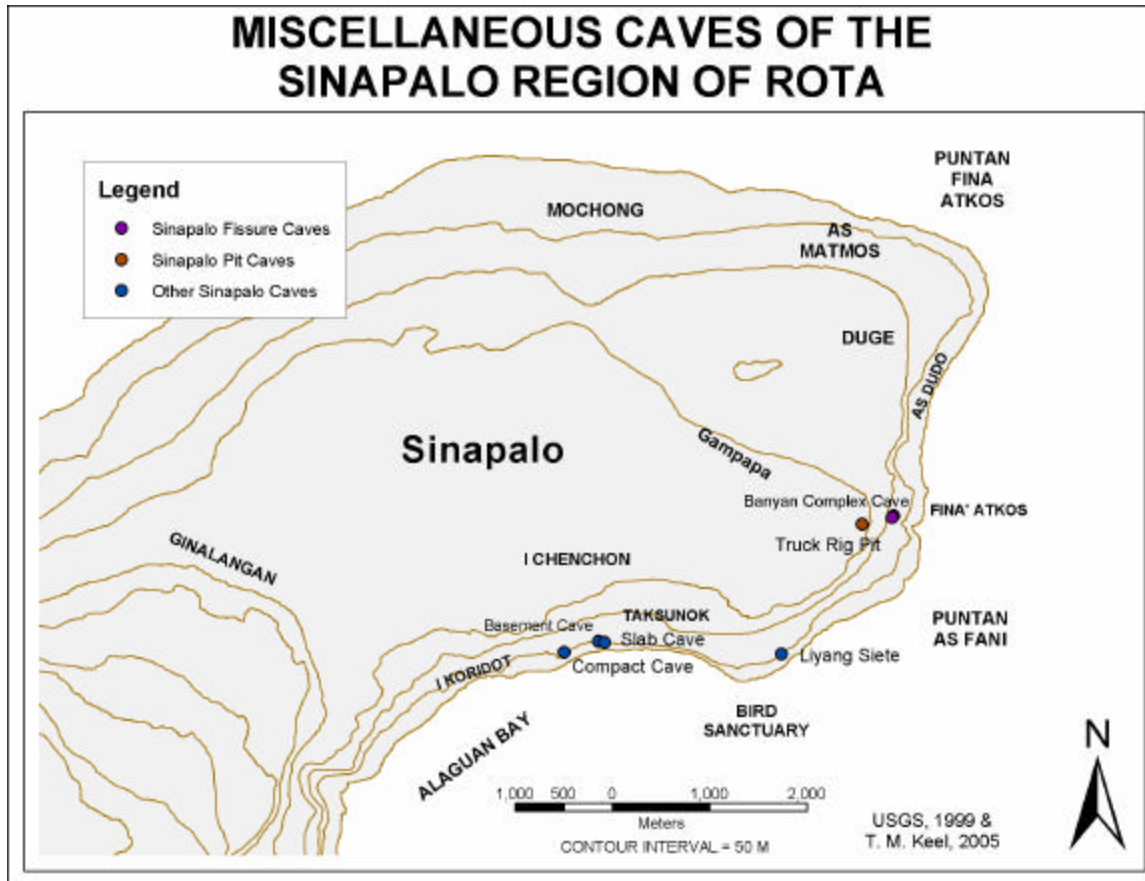


Figure 17. Sinapalo Miscellaneous Caves

Flange Cave (Fig. B.47), while not part of an extensive zone of deep fissures, is worth noting. It is set at the northern edge of the closed depression depicted on the USGS topographical map (1999), on the east side of the *Sabana*, at the base of the prominent (fault?) scarp, among numerous shallow fissures and rugged pinnacle karst. Flange Cave is developed along one or more fractures parallel to the scarp.

Southwest of Tachok, near the Rota Zoo, Village View Cave (Fig. B.118) is prominently visible from the road. While there is a 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 linear dimensions of well over 10 m and is a potential threat to the houses below.

Slab Cave (Fig. B.109), 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 (Fig. B.20), Bee Cave (Fig. B. 117), and One Shot Cave (Fig. B.87) are much too small to be helpful in gaining an increased understanding of Rota's caves.

### 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 contact caves on the *Sabana* proper (Fig. 18). Summit Cave (Fig. B.111), by far the largest of these, is located at the bottom of sinkhole (closed depression) on the south side of the summit of *Mt. Sabana*. Summit Cave was observed to recharge a large volume of surface water from the clay and volcanic rock exposed on the highest parts of *Mt. Sabana* when observed during a rain event. Summit Cave is a likely choice for an input point for a dye trace of the *Sabana* Watershed/*Talakhaya* contact discharge system. Discus Cave (Fig. B.40) and Rota Rooter Cave (Fig. B.101), in the large closed depression north of the *Sabana* Peace Memorial, are located near the contact but neither was observed to act as an insurgence during rain events. A few meters from Rota Rooter Cave, in the same banana patch there is, however, a very significant insurgence, receiving on the order of hundreds to thousands of liters per minute during heavy rain events. Discus Cave is slightly higher than the adjacent flow path along the contact and does not act as an insurgence. Several other unenterable insurgences were found along the contact on the north side of the *Sabana* Peace Memorial.

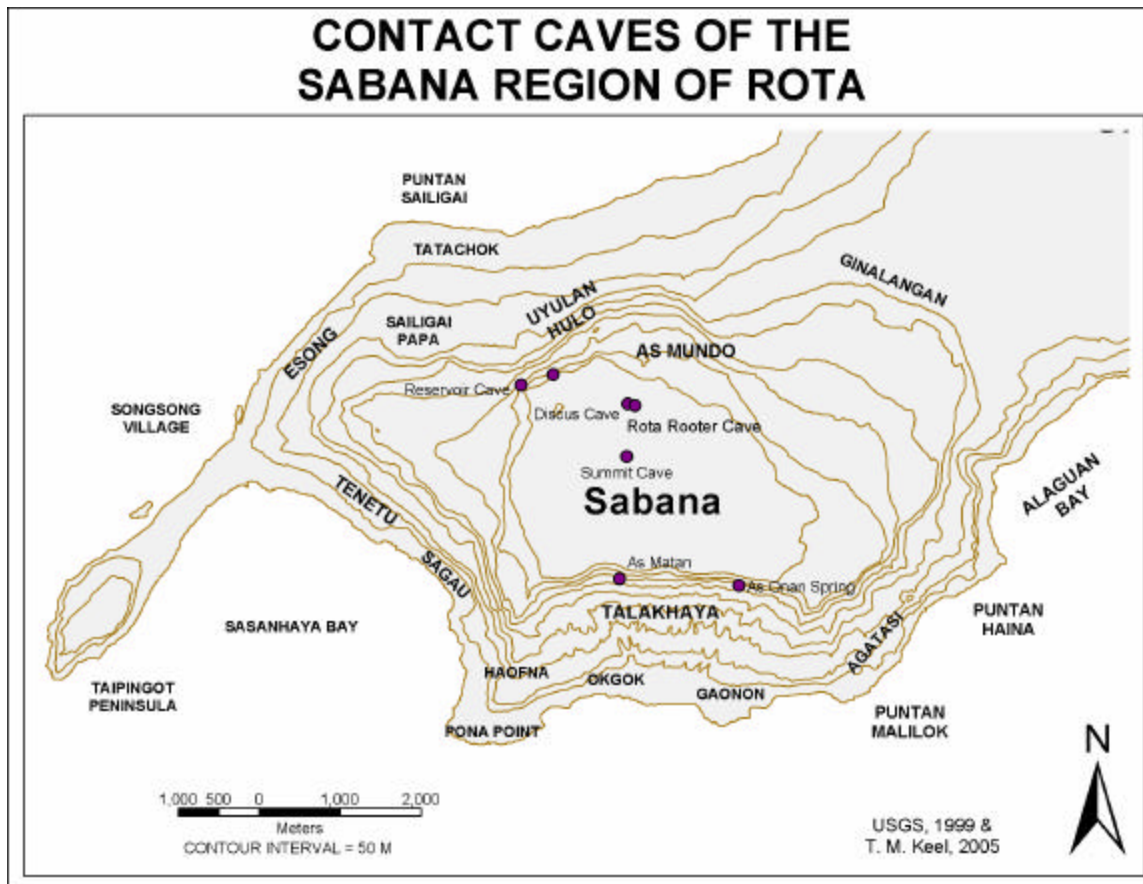


Figure 18. Sabana Contact Caves

On the north flank of the *Sabana*, at *Uyulan Hulo*, there are two caves at the contact of the volcanic rock with the overlying limestone, each of which was observed to discharge a small amount of water. The eastern most contact cave is North Side Trickle Cave (Fig. B.85). In May 2004, it was observed to be discharging ~1 liter per minute and did not show evidence of ever having significant discharge. There is no stream channel on the steep slope below the cave. Further west is Reservoir Cave (Fig. B.96), which has a manmade berm partially blocking the entrance, suggesting that there was an attempt to store water in the cave. In June 2004, the discharge from Reservoir Cave was measured at 1 liter per minute. There is no stream channel on the slope below Reservoir Cave and no evidence that it ever has a significant discharge. On the same contact, near *As Mundo*, there is a small spring with an un-surveyed cave that shows significant human modification. This spring was discharging ~1 liter per minute in July 2004 and has no evidence of ever having significant discharge. Despite the presence of several significant insurgences on the north side of the *Sabana*, extensive exploration discovered no significant springs at the contact on the *Sabana's* north flank at *Uyulan Hulo* and *As Mundo*.

The other cave on Rota whose development was influenced by a volcanic/limestone contact is very different from the ones already discussed. Black

Cobble Cave (Fig. B.21) is the largest cave along the coast between *Okgok* and *Poña Point* (Fig. 12) and was probably formed by the breaching and erosional modification of a flank margin cave that developed 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 in which the cave is developed.

### **Pit Caves**

Truck Rig Pit (Fig. B.117) is located adjacent to the parking area for Pictograph Cave at *Gampapa* (Fig. 19). This small cave (8 m deep) is significant as the only pit cave documented on Rota. The morphology of Truck Rig Pit indicates that this cave is developed along a fracture with approximately the same orientation at Pictograph Cave (N60E).

### **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 caves on Rota appear to have formed almost exclusively by physical erosion of the bedrock by waves.

The largest known sea cave is Double Cave (Fig. B.41) at the base of the cliff, along the beach between *Puntan Malilok* and *Gaonon* (Fig. 19). It is presently well within the reach of storm waves and contains much debris. The walls of the cave and the cliff face along this stretch coast exhibit dramatic, large scale cross bedding that are apparently fore reef deposits.

The other known sea caves are Paupau Sea Cave (Fig. B.88), on the south side of the isthmus connecting the Wedding Cake (*Taipingot*) to the rest of Rota, and Sea Cave A1 (not mapped), in the wall of a coastal notch along *Alaguan Bay*.

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

### **Problematic Caves**

A few of the documented caves on Rota have morphologies and settings which make a definitive determination of their genesis difficult.

Fall-In Cave (Fig. B.44) and Big Fern Cave (Fig. B.18) are somewhat similar to the caves in Fissure City but are not part of a zone of fissures. The location of Big Fern Cave and Fall-In Cave are shown in Figure 19. The difficulty in diagnosing these caves is complicated by their proximity to an ancient landslide scar that is prominently visible from the air and on the USGS topographical map (1999). Big Fern Cave is especially notable because it contains a large open sink hole entrance with vertical to overhanging walls and because, at 27 m, it is the second deepest cave documented on Rota.

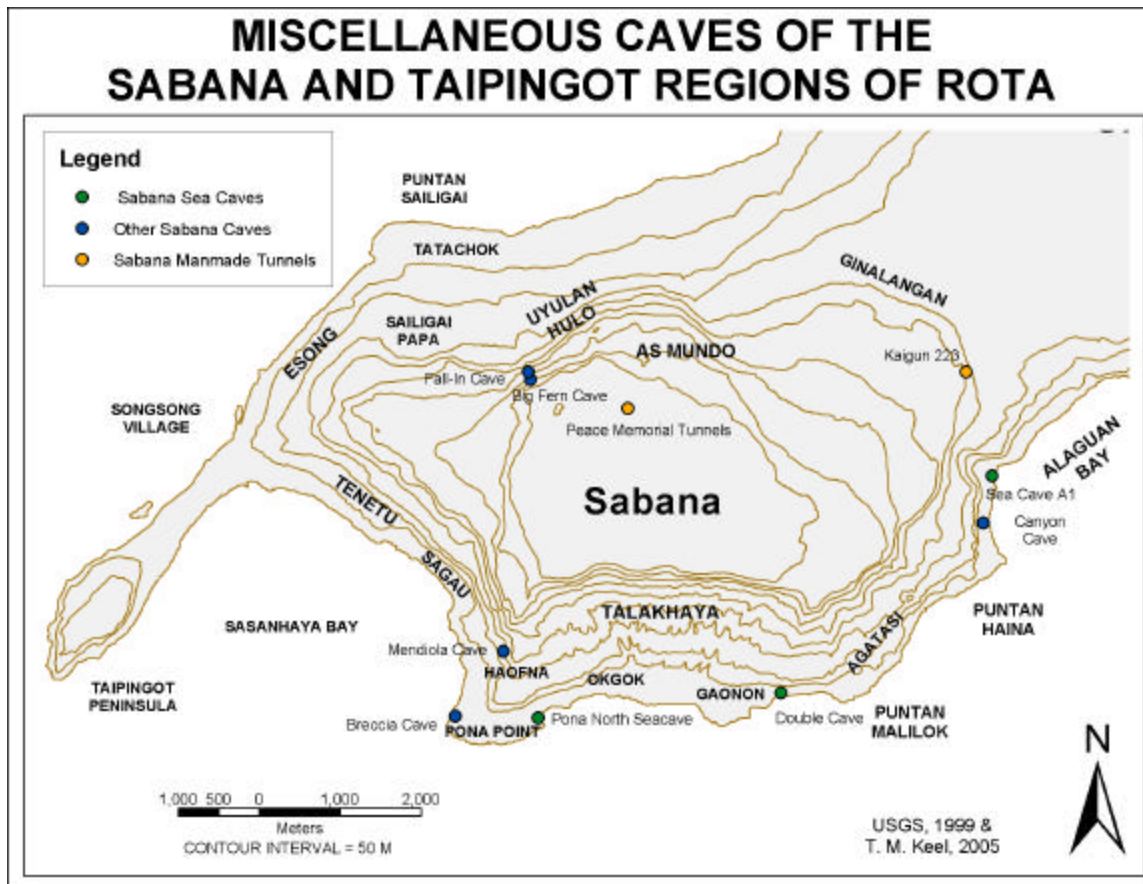


Figure 19. Miscellaneous Caves of the Sabana Region and Taipingot

Mendiola Cave (Fig. B.81), located off the Water Cave Road, is a large, mostly open, sloping chamber, about 18 m deep. The morphology suggests that it might be a collapsed flank margin cave, but that diagnosis is complicated by the presence of a small exposure of fast flowing water in the lowest part of the cave. This stream suggests that the development of Mendiola Cave may be related to the contact with the underlying volcanic basement rock. The location of Mendiola Cave is shown on Figure 19.

Although clearly developed along a fracture, *Gagani Cave* (Fig. B.50, location Fig. 15) on the west side of *Poña Point*, is unlike any other fracture cave discovered on Rota. It is located in an area where faults are expressed at the surface and where Sugawara (1939 [1949]) reported the presence of faults. Probable fault surfaces are expressed in several places in *Gagani Cave*. *Gagani Cave* is quite linear, with passage dimensions of only a few meters compared to an overall length of ~100 m. The fracture along which *Gagani Cave* is developed does not seem to have been significantly modified by the vertical flow of vadose water. Morphology similar to continental stream caves suggest that *Gagani Cave* was formed by phreatic stream flow along the fracture. However, *Gagani Cave* does not have the morphology now associated with mixing zone fracture caves, suggesting that enhanced dissolution by the mixing of fresh and salt water was not a significant contributor in its development.

*Sen Hanom Cave* (a.k.a. The Grotto, a.k.a. Rota Hole) is a popular dive site on the west side of the tip of the Taipingot Peninsula, *Puntan Senhanom*. Although it was not surveyed as part of this project, the author was able to make one visit to this interesting feature. It is develop along the apparently irregular contact between the underlying agglomerate and pyroclastic volcanics and the limestone. The commonly used entrance to *Sen Hanom Cave* is at about 20 m below sea level. This entrance opens into a chamber that has a large sky light. The wall of the sky light chamber appear to composed of limestone, while much volcanic rock exposed below the water. The sky light chamber connects above and below the water to a somewhat smaller room that requires a light to safely navigate.

### **Non-cave Features**

The Peace Memorial Tunnels (Fig. B.89) near the *Sabana* Peace Memorial and the tunnels of the Kaigun 223 Japanese Command Post (Fig. B.63) at *Ginalangan*, near *Sinapalo* were surveyed as examples of the numerous tunnels and tunnel complexes dug on Rota during the Japanese era (Fig. 19). Locally, manmade tunnels are often referred to as caves with no distinction between natural features and manmade features.

## CHAPTER VII

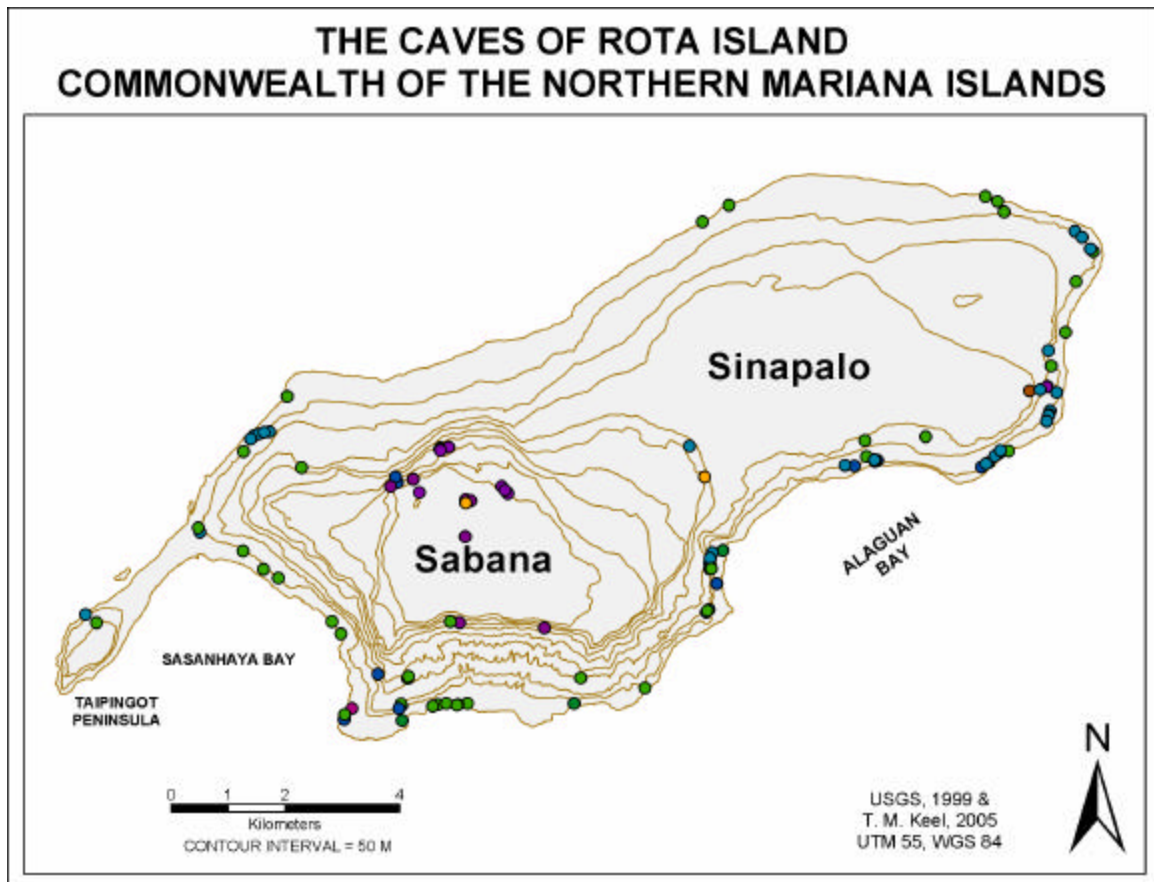
### SUMMARY AND CONCLUSIONS

This study explored and documented 120 caves, karst features and pseudokarst features on Rota (Fig. 20). While no cave inventory of a geologically complex island in a tropical environment, such as Rota, can claim to have documented every feature, it is believed that the variety and number of caves documented during this study allow some valid generalizations and conclusions about the caves of Rota to be drawn. There are two primary types of caves on Rota; caves developed at the edge of the freshwater lens primarily by the action of mixing dissolution (flank margin caves and mixing zone fracture caves) and caves developed along extensional fractures (fissure caves).

Flank margin caves are found from sea-level up to 350 m elevation and range from caves only a few meters in dimension up to some that span many tens of meters. As predicted by the Carbonate Island Karst Model (CIKM), there are extensive horizons of flank margin caves that represent previous sea-level stillstands (e.g. *As Matmos*, *Chenchon*, *Alaguan Bay*, *Sagua Cave Complex*). Probable differential uplift across Rota prevents the specific correlation of these flank margin cave horizons, as has also been noted on Tinian (Stafford, 2003). The development of flank margin caves on Rota is essentially in agreement with the Carbonate Island Karst Model.

Previous investigators have applied differently classifications of the CIKM to different parts of the same island (e.g., Stafford, 2003). Using that concept, the Sinapalo Region of Rota would clearly fit the Simple Carbonate Island Model, as it has no known volcanics above sea-level and no known partitioning of the fresh water lens. The presence of large mixing zone fracture caves above sea-level suggests that fractures presently below sea-level may be discharging water and distorting the lens, but this has not been demonstrated. Submarine investigation adjacent to some of the large mixing zone fracture caves might help determine the presence and magnitude of discharge from the lens via these fractures. The Sabana Region is best classified by the Composite Carbonate Island Karst Model since there are known large volcanic outcrops that affect the movement of ground water. The Taipingot Peninsula is best classified by the Carbonate Cover Island Karst Model since the only known volcanic outcrop along the coast near sea-level is in one relatively small area, *Puntan Senhanom*.





*Figure 20. The Caves of Rota Island*

While fracture caves had been previously documented in the Mariana Islands, the high proportion of fracture caves on Rota was not anticipated by these previous investigations or by the Carbonate Island Karst Model. However, the greater influence of fractures on the karst development of Rota might have been anticipated if higher gradients of Rota had been taken into account. Rota is slightly higher than Guam but is roughly one fifth the size, giving Rota the highest average gradients of the limestone mantled island of the southern Mariana Arc. The morphology and locations of the fracture caves developed normal to the cliff faces and coastlines led to the conclusion that these caves developed by the action of zones of enhanced dissolution created when fresh water discharging from the lens along the fractures mixed with sea water. Thus the name used here for this type of cave; mixing zone fracture cave. While previous investigations of island karst have documented caves and karst features developed along mechanically opened vertical fractures (fissures) that have subsequently modified by the flow of vadose water, this study is the first in the region to document a karst landform, fissure zones, characterized by an extremely high density of such fissures. The *As Mundo Fissure Zone* and *Fissure City* collectively contain on the order of hundreds of fissures and fissure caves. While the fissures surveyed as part of this study are believed to be representative,

the logistics of this study limited the number of fissures that could be surveyed to a small fraction of the total. The geomorphology of the *As Mundo Fissure Zone* and Fissure City suggest two possible modes of formation for the fractures that have been solutionally widened. The first is that the fractures are closely spaced normal faults, but evidence for such faulting was not visible in the caves themselves. The second possible mode of formation, probably more applicable to both sites, is gravity sliding of a large mass of limestone along the limestone-volcanic contact with the fissures formed by extension of the limestone block. Although it is not as extensive and lacks the dramatic relief of the other two fissure zones, the Banyan Complex might be considered a smaller analog of the larger fissure zones. The Banyan Complex is apparently developed along the fractures of a joint set related to the probable fault at *Fina' Atkos*, along which *Liyang Botazon* is developed. The zone of shallow fissures and pinnacle karst adjacent to Flange Cave, on the *Sabana*, can be considered a miniature version of the two documented fissure zones on Rota.

*Gagani Cave* is unique among the documented caves of Rota in that it is a linear cave developed along a fracture (fault?), yet it does not show the morphology associated with mixing zone fracture caves.

Although contact caves are not numerous on Rota, several of the ones documented in this study are hydrologically significant and should be of interest to land and water resource managers since they act as points where water directly enters and leaves the aquifer. Summit Cave, on the *Sabana*, is very significant; acting as a resurgence for part of the water that collects on the impermeable volcanics that outcrop at the highest part of Rota. Other smaller, undocumented features, particularly on the north side of the *Sabana* volcanic outcrop, also so act as aquifer recharge points. Reservoir Cave and North Side Trickle Cave, on the north flank of the *Sabana* at *Uyulan Hulo*, are significant in that they do not discharge a significant amount of water, indicating that there are other contact springs along this slope or (probably) that a significant amount of water does not discharge to the surface along the north flank of the *Sabana*. This leads to the conclusion that water recharged on the northern part of the *Sabana*, at known resurgences, drains beneath the more gently sloped east and west flanks of the *Sabana*. It is remotely possible, however, that water recharged on the northern part of the *Sabana* drains to the south and discharges at the Water Cave and/or other springs along the *Talakhaya* contact. If the Water Cave and As Onan Spring are considered as contact caves (as opposed to flank margin caves) they are among the most significant hydrologic and cultural features on Rota, since they are the source of water for Rota's municipal system. There are other springs along the contact at the top of the *Talakhaya* that discharge a significant amount of water for at least part of the year. However, these springs are probably not suitable as municipal water supplies primarily because their flow is expected to be lowest during the dry season when they are most likely to be needed. Other negative considerations to developing these springs are cost and environmental impact.

The one pit cave documented on Rota, Truck Rig Pit, does not provide enough information to draw any conclusions. It should be noted that Truck Rig Pit is apparently developed along a fracture.

A few of the caves on Rota are classified as sea caves since their development appears to be primarily driven by erosion. These caves are obviously not hydrologically significant and are not particularly note worthy.

Some caves on Rota are difficult to classify and warrant further investigation. The primary caves among these are Big Fern Cave, Fall-In Cave, Mendiola Cave, and *Gagani Cave*.

As previously noted, the previous geologic investigation of Rota has been severely limited. It is hoped that this investigating the caves and karst of Rota is a valuable addition to the limited literature in this field and also that it can act as a foundation for much needed further investigation.

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## 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 (1999) will be italicized. Please note that some Chamorro words contain prefixes that are the same as common English words, i.e. “*I*” and “*As*”. If a feature name contains Chamorro and English words, the entire name will be italicized for consistency. All numerical values will be presented as numerals (e.g. “4” not “four”), except that numbers beginning sentences will be spelled out.

#### **Agrippa Cave**

Agrippa Cave is one of several caves 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 volcanic bed rock. Despite Agrippa Cave’s proximity to an active spring, the shape of this cave suggests flank margin 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 being 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.

#### **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 in 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. This feature may 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 that are 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 bed rock 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 section 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 bed rock wall near the rear. In plan view, the cave is a truncated oval about 6 m in diameter.

### **Al-Su Cave**

Al-Su Cave is located about 200 m east of Taisacan Museum Cave. Al-Su Cave is about 20 m long and is oriented roughly north-south, with the entrance on the north end. The entrance is triangular and about 2.5 m high. The ceiling of Al-Su Cave quickly drops so that by 12 m into the cave the passage is less than 1 m high. At the rear of the crawlway is a small extension about 1 m long and wide.

### **Arch Cave**

Arch Cave is one of several caves 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 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 ceiling. In one place, 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 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 crumbly, incompetent, argillaceous limestone. 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 piped to the *Sinapalo* region of Rota. This feature 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 an apparent conjugate joint set. 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.

### **Barbed Wire Cave**

Barbed Wire Cave is one of several caves located along the base of the cliff next to the Water Cave Road at *Haofña*. The cave consists of one open chamber about 10 m long and 5 m high oriented north-south, and a small mostly enclosed room extending from the north end of the open chamber. The mostly enclosed room is apparently developed along a fracture.

### **Barefoot Cave**

Barefoot Cave is located at sea-level in the *Chenchon Bird Sanctuary*, below a large reddish patch of rock in the inland cliff. Barefoot Cave has two entrances, both of which contain sea-level pools. The two entrance areas are connected via multiple, small sea-level passages, only one of which was found to be passable below the surface. The southwest section of Barefoot Cave extends about 22 m inland while the northeast section extends about 17 m. The morphology of Barefoot cave suggests that it is a sea cave developed primarily by physical erosion with some possible contribution by mixing dissolution.

### **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 a fracture, becoming cemented, then some of this bouldery facies material being removed.

### **Bay Cave Remnant**

Bay Cave is located south of the embayment at *Alaguan Bay*, in the 3 m bench along the coast. It consists primarily of an embayment in the cliff about 15 m by 25 m. 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 bee hive hanging over the entrance to this small feature.

### **Big Fern Cave**

Big Fern Cave is located at about 370 m elevation in *Uyulan Hulo*. Big Fern Cave is a complicated cave developed along fractures that may be related to the very large landslide scar the is located just to the east. Big Fern Cave has two entrances, one of which is the only collapsed sink cave entrance found on Rota to date. The floor of the sink contains vegetation including two large trees and some ferns as tall as 2 m. This sink is clearly the result of the collapse of a cave chamber of considerable size. The sink entrance is about 18 m long and about 7 m wide, oriented east-west. The east end of the sink has an overhanging section about 4 m long and about 5 m high. The west end of the sink has a cave-like section that slopes down about 8 m before pinching out. About mid-

way along the north wall of the sink, the floor slopes down and to the north. Under the overhang, one passage runs parallel to the sink and has small openings up to it. Another passage starts as a short climb down. This climb leads to a sloping room about 15 m long that reaches a maximum of about 10 m high. At the west end of this room is a short crawlway between formations into the Pinnacle Room, that receives light from the other entrance. The Pinnacle Room is about 16 m north-south and about 13 m east-west. The Pinnacle Room dips very steeply to the north, with the floor at the north end about 18 m below the Pinnacle Entrance. The ceiling of the Pinnacle Room is well decorated with stalactites while the floor has stalagmites in some places. Three different passages leading from the lower part of the Pinnacle Room converge and lead down a series of small stair-stepping rooms to a terminal room about 25 m below the surface.

### **Birthday Cave**

Birthday Cave is one of a cluster of four linear caves located 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 with 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 apparent flow deposit of volcanic material. The volcanic be 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 volcanic deposit, meaning that the buff-colored limestone is younger than the cave.

### **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 section of cliff face. The entrance is visible as a 20 m 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”. 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.

### **Breadfruit Cave**

Breadfruit Cave is one of several caves located along the base of the cliff next to the Water Cave Road at *Haofña*. Breadfruit Cave consists of an overhang about 20 m long oriented north-south. The overhang contains speleothems that indicate that Breadfruit is the remnant of a probable flank margin cave. Located about 0.5 m above the ceiling of Breadfruit Cave is a line of solutional holes each less than 1 m across, indicating a separate dissolutional horizon.

### **Breccia Cave**

Breccia Cave is located in south wall of the small cove on the west side of *Poña Point*. Breccia Cave consists of two sections; a large open overhang and a low wide cave section with two entrances. The overhang section of Breccia Cave is about 35 m long, oriented about 30° east of north. This section has partial enclosure at the north end. The overhang section of Breccia Cave is 8-9 m high at the north end and 2-3 m high at the south end. Exposed in the vertical back wall of the overhang section are poorly sorted to unsorted beds of un-lithified sand and gravel with clasts of various colors from off-white to brown to black, suggesting mixed lithology. There are also thin beds of brown clayey material. These beds are parallel to and interbedded with the adjacent limestone. The apparent mixed lithology beds and clays are interpreted as distal debris flow deposits. At the south end of the overhang section of Breccia Cave is a passage that leads to a room about 20 m long. The north end of this room is 1-1.5 m high, about 9 m wide and divided by a bedrock pillar. At the south end, the ceiling of this room rises in an irregular dome to about 4 m. In the center of this dome is a rough vertical shaft that extends up a total of about 9 m. On the west side of the dome is the other entrance to Breccia Cave.

### **Breeze Cave**

Breeze Cave is one of many caves in Fissure City, east of *Uyulan Hulo*, on the north flank of the *Sabana*. The entrance to Breeze Cave is a large overhang open on the south and west. This outer part of Breeze Cave extends about 10 m north-south and about 15 m east-west. The east end of the outer part of the cave contains several bedrock pillars. The floor of the outer part of Breeze Cave curves steeply down to the north to form a trench. This trench leads to the more enclosed part of the cave that is about 1-3 m wide and extends for about 10 m.

### **Broken Mortar Cave**

Broken Mortar Cave is located at *Liyo* on the *Taipingot* (Wedding Cake) at about 100 m elevation. Broken Mortar Cave is an overhang about 12 m long east-west and 4-5 m

wide. It appears to be a remnant of a larger cave and also contains some bedrock mortars, one of which is broken in half.

### **Buffalo Cave**

Buffalo Cave is a section of the flank margin cave horizon at *As Matmos*. Buffalo Cave consists of two levels, both of which are completely open on the north side. The lower level opens at the same elevation as the adjacent coastal bench, extends about 30 m east-west and a maximum of about 6 m into the cliff face. The east end of the lower section is 1-2 m high and includes a bedrock pillar. The west end of the lower section is more enclosed and contains a manmade wall of loose laid limestone cobbles and boulders, below a point where the ceiling reaches about 3 m. The upper section of Buffalo Cave extends back from the drip line a maximum of about 12 m and is about 40 m long east-west. The upper section contains numerous phototropic speleothems, and extensive flowstone.

### **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 limestone in which Christmas Cave is developed exhibits dipping fore-reef beds.

### **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 narrow “V”. It apparently formed by wave action dissolutionally widening a fracture.

### **Comet Cave**

Comet Cave is one of several caves 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.

### **Compact Cave**

Compact Cave is located at the base of the cliff below *I Koridot*. Compact Cave is about 15 m long, 2.5-3 m wide and oriented about 20 degrees east of north. The overall cross section of the cave is triangular. A small entrance opens near the south end of the cave, adjacent to three other holes that connect to the outside but are impassable. Compact cave appears to be the result of solutional modification of a detached bedrock slab.

### **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. 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 floors of both room are parallel to the dipping beds.

### **Cupid Cave**

Cupid Cave is one of several caves 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 penetrates from above 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 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 along the coast between *Poña Point* and *Okgok*. Dasher Cave consist 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.

### **Delia Cave**

Delia Cave is one of three large entrances located in a series of breaks in the cliff face below *I Koridot*. Of the other two entrances, one is not safely reachable and the other is only a remnant of a cave, which was not mapped. Delia Cave extends for about 40 m into the cliff face from the drip line. The floor of Delia cave is a very steep series of vertical offsets and slopes, making the cave about as tall as it is long. The main section of Delia Cave is about 7 m wide and has a large skylight about 17 m back from the drip line. To the left of the main section of the cave is a small parallel section containing deep deposits of apparently old guano.

### **Diagonal Fissure**

Of the numerous fissures in the *As Mundo* fissure zone, Diagonal Fissure is one of four that were mapped. Diagonal Fissure curves from an east-west orientation at the west end to almost north-south at the east end. Diagonal Fissure ranges from about 3 m wide at the west end to less than 1 m at the east end and is about 30 m long. From west to east, the bottom of the fissure falls away such that there is no floor on the east end. The cave continues downward as an impassable fissure. The passable depth of Diagonal Fissure is about 18 m.

### **Discus Cave**

Discus Cave was reported by Stafford et al. (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 consist of one shallow ovoid chamber about 3 m across, breached at the top by a 1.5 m hole. This cave does not act as a recharge feature during moderate rainfall, but there are un-enterable recharge features located on the contact within a few tens of meters.

### **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 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, and storm tossed debris. A low, narrow section of the cave extends from the east end of the eastern most large chamber. Double Cave is either a flank margin cave heavily overprinted by wave driven erosion or is simply a sea cave formed primarily by erosion.

### **Double Decker Cave**

Double Decker Cave is located in the sea cliff just south of the lagoon below *Gagani*. Double Decker Cave is oriented northeast-southwest. The upper section is about 33 m long, about 5-7 m high and extends about 9 m from the drip line. The large entrance to the upper section takes up the northern 2/3 of the northwest facing side of the cave and is visible from across *Sasanhaya Bay* at *Songsong Village*. The entrance to the lower section is behind a large boulder that is detached from the cliff just below the upper section. The lower section opens at sea level and is developed along a pair of linear fractures. The lower section extends for about 22 m to the southwest, where it narrows into the fracture. The ceiling in the lower section is 2-3 m high.

### **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 ceiling averages about 2 m but drops toward the rear of the cave. 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 many of the other caves documented on Rota, Exception Cave shows very little to no apparent lithologic control on its morphology and development.

### **Fall-In Cave**

Fall-In Cave is located near the end of the drivable road at *Uyulan Hulo*. The cave was discovered by literally falling partially into the smaller entrance that is located in the road bed. Fall-In Cave is a complicated cave developed along fractures that may be related to the very large landslide scar that is located just to the east. Climbing down through the Fall-In Entrance leads to the main room of Fall-In Cave. The main room extends for about 22 meters roughly east-west. About 4 m from the Fall-In Entrance, the floor drops away and leads down about 8 m to the lower section of the cave. The lower section is parallel to the upper section and is about 15 m long. There is a small room, containing extensive speleothems, extending to the south of this part of the cave. About 8 m east of the Fall-In Entrance the cave branches to the south of the main passage. The south branch extends for about 4 m to the Pineapple Entrance, a climb of about 2 m. Beyond the branch, Fall-In Cave extends for another 14 m. The flow of this section of the cave descends to about 7 m below the Fall-In Entrance.

### **Fisherman Cave**

Fisherman Cave is located northeast of the Swimming Hole on Rota's north coast at about 1 m above sea level. Fisherman Cave is roughly shaped like an “8” oriented northeast-southwest, with two entrances on the northwest side. The cave is about 19 m long and floored mainly with loose cobbles and boulders.

### **Fissure City Cave**

The entrances to Fissure City Cave are located in Fissure City at the bottom of the large closed depression depicted on the USGS topographic map of Rota (1999), east of *Uyulan Hulo*. There are other fissures in the bottom of the same closed depression that have not been mapped. The upper part of Fissure City Cave consists of a connected series of rooms that range from 2 to 5 m wide and from 2 to 10 m high. From the largest room in the upper part of Fissure City Cave a passage leads down along a fracture to a maximum depth of about 35 m below the bottom of the closed depression, making this one of the deepest caves on Rota. The deep passage is a fracture with minimal solutional modification. The passable part of the cave ends but the fracture continues.

### **Flange Cave**

Flange Cave is located on the northwest side of the *Sabana*, beside the 30 m scarp that strikes at 55 degrees east of north. Flange Cave is a relatively small but complicated that is apparently a 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 a cluster of four linear caves located 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 that both end at impassable fractures.

### **Four Crosses**

In the cliff face southwest of *Ginalangan*, 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.

### **Gagani Cave**

The entrance to *Gagani Cave* is located at the south end of the beach below *Gagani*. The outer part of *Gagani Cave* is only about 10 m long and oriented sub-parallel to the cliff face; north-south. Just inside the cave entrance there is a small hole at the floor on the east wall. Beyond this small hole, the cave opens into a room about 6 m wide. The passage leading from the east end of this room continues, ranging from 0.5 to 2.5 m high and from 2 to 3 m wide. The floor of this passage rises and falls as much as 2 m. At about 20 m from the entrance, where the main passage turns toward the northeast, a low room opens to the south. About 20 m beyond that, the passage widens to about 5 m. A lead on the northwest side of this room was not explored due to blockage by speleothems. A short climb down in the northeast corner of this room leads to the continuation of the cave. About 10 m beyond the climb down, a room less than 1 m high, 4 to 5 m wide and about 8 m long opens to the southeast. Just beyond this room, the passage narrows to two very small parallel constrictions that excluded larger explorers. Beyond these constrictions, *Gagani Cave* continues for about 20 m as a room about 1 m high and 4 m wide. Unlike most of *Gagani Cave*, the floor and ceiling of this room are almost completely covered with speleothems. A fracture is visible in the ceiling for almost the full length of *Gagani Cave*. In most places the fracture is tightly closed and very planar, suggesting that the fracture is actually a fault and the planar nature is the result of fault motion. Some of the features in *Gagani Cave* suggest that there might have been fault motion after the cave formed. Several apparent faults are visible on the surface near *Gagani Cave*. Sugawara (1939 [1949]) reports faults in this area.

### **Grand Stand Cave**

Grandstand cave is the largest cave overhang at *Tenetu* (Teneto), just east of *Songsong Village*. Grandstand Cave is in the cliff face immediately north of the site traditionally used for motocross racing during the Rota Fiesta. The cave is reached by a climb of about 4 m. Grandstand Cave is about 55 m long, 6-10 m high and 4-5 m wide. Except for the northwest end, the cave is completely open. The outer wall of the northwest end is a series of large, closely spaced columns.

### **Green Fissure Cave**

Green Fissure Cave is located adjacent to Breeze Cave in Fissure City, east of *Uyulan Hulo*. Green Fissure Cave is oriented northeast-southwest. The northeast end is an open sink about 3-4 m wide and up to 3 m deep, that leads down into the cave. The cave appears to be developed along two near parallel fractures. The fracture on the north leads up to a skylight entrance. Excluding the sink, Green Fissure Cave is 4-5 m wide, 10 m long and about 7 m tall.

### **Hammer Cave**

Hammer Cave is located in the cove west of *Sailigai Papa*, at about 60 m elevation. Hammer Cave is a linear cave developed along an obvious bedrock fracture. The entrance opens to the west and the cave is about 8 m long. The ceiling in the outer part of the cave is about 3.5 m high, but drops to less than 1 m about half way to the back. Hammer Cave

is about 3 m wide at the entrance and gradually tapers toward the back. To the north of the entrance there is a small (< 1 m) passage that extends back parallel to the main cave for about 4 m.

### **Hang Out Cave**

Hang Out Cave is located on the north coast of Rota, near *As Matmos*. Hang Out Cave is about 150 west of the much larger feature called Surge Cave. Hang Out Cave is oriented northeast-south west and has entrances at both ends. The entrance on the northeast end is just above sea-level about 9 m from the entrance on the southwest. This pit-like vertical entrance is about 3 m deep. The cave is quite linear between the two entrances and is developed along an obvious fracture. The fracture forms a skylight along the length of most of the cave.

### **Henry Fissure Cave**

Henry Fissure Cave is located in the northern part of the *As Mundo* fissure zone. Henry Fissure is oriented roughly WNW-ESE but is not linear. It can probably be best described as a series of linear segments of lengths from 3 to 10 m. The depth of Henry Fissure varies from 3 to 14 m. About midway along the length of Henry Fissure, a shallower fissure extends to the south. This shallow side fissure continues straight for about 10 m before it the depth tapers to zero. About 15 m of the west end of Henry Fissure is roofed cave. The passage is mostly less than 1 m wide, with the ceiling 10-12 m high. The traversable part of the cave ends where the fracture becomes too narrow.

### **Honey Comb Cave**

Honey Comb Cave is one of a cluster of four linear caves located 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 bee hives 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.

### **Honey Eater Cave**

The entrance to is the large hole in the south wall of the cove at *As Dudo*. The cave is reached by a difficult climb over friable limestone, inside the drip line. The entrance to Honey Eater Cave is at the west end of the large overhang. The entire overhang was not surveyed due to the presence of a very large bee hive. The more enclosed part of the cave was safely entered and mapped. Honey Eater Cave extends back about 20 m from the drip line. The main section of the cave is about 10 m wide and about 5 m tall. The walls of the main chamber of Honey Eater Cave exhibit cusps that suggest phreatic dissolution. From the south side of the main section extends a passage that quickly narrows to impassable. This small passage can be seen to continue for several meters. Except for a

4 m diameter, 3 m high mound of limestone, the entire floor of Honey Eater Cave is covered with guano. The guano is at least 0.5 m deep in some places.

### **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 Cave 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 extend about 5 m back from the drip line. This part of Hourglass has evidence of resolution of speleothems. Hourglass Cave 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 tube about 1 m in diameter and 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 (Four Crosses). This site has extensive human modification including at least four pill boxes, three cisterns, a defensive wall running about 160 m, and several man-made tunnels most of which have 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 large linear 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 collapsed 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.

### **Little S Cave**

Little S Cave is located on the west wall of the cove at *As Dudo*. The cave is developed along a fracture that trends northeast-southwest. The entrance to Little S Cave faces northeast and is reached by a 2 m climb. The cave is about 1.5 m wide for the first 5 m, then widens to about 6 m. The rear of the cave has an inverted "T" profile, developed along the genetic fracture. Little S Cave is about 25 m long.

### **Liyang Alapin**

*Liyang Alapin* 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. 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 cave in a cluster of four linear caves located at about 30 m elevation, in the cliff face inland from *Puntan As Fani*, south of *Fina' Atkos*. The entrance to *Liyang 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 drops irregularly toward the rear of the cave. The total length of *Liyang Apaka'* is over 60 m. It ends at a small impassable passage at floor level. *Liyang 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 dipping fore-reef beds. 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 *Fina' Atkos*, below the steep canyon that cuts across several terraces and opens at sea-level. The entrance is about 50 m wide and about 15 m tall. About 10 m from the drip line, there is a large skylight about 15 m across that spans most of the width of the cave. The entrance area of *Botazon* is mostly covered with very 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 then gradually narrows 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 which 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. The entrance to *Liyang Finta* is dominated by several large boulders. For about 4 m beyond these boulders, the cave floor slopes gently downward, while the ceiling rises to about 6 m. The ceiling has a skylight in the fracture along which the cave is developed. At the rear of the main room is a large pile of boulders. To the southeast of the main room, there is a room about 3 m high floored with loose cobbles and soil.

### **Liyang Ganas and Nanong Kastiyu**

Adjacent to Songsong Village, about 70 m ESE of *Tonga Cave*, are *Liyang Ganas* and *Nanong Kastiyu* (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 terraces held in place by stone walls. Compared the somewhat globular morphology of *Liyang Tonga*, these two caves are much more linear. The smaller, western-most *Nanong Kastiyu* 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. *Liyang 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. *Liyang 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. *Liyang 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, *Liyang Lu'ao* gradually widens to about 9 m before narrowing at the rear. *Liyang 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 cobble. Along the left wall, mid-way back in the cave are two pieces of a breakdown slab the 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 bed rock 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 the 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* (Eye Cave). 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” before 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 reaches 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 across. *Liyang 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 *Liyang 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 of *Liyang 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. 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 key hole 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 mixing zone fracture 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 prominent land mark 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 barbeque 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 with 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.

### **Misplaced Cave**

Misplaced Cave is located at the base of the cliff just inland from the coast, northeast of *Puntan Malilok* and is developed in a very bouldery facies. The entrance to Misplaced Cave faces southeast and is about 9 m across. Misplaced Cave extends back about 10 m over a floor that is mostly loose soil with some cobbles. The cave is about 2.5 m high for most of its length.

### **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 mixing zone fracture caves. 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.

### **Mosquito Fissure**

Mosquito Fissure is a 13 m long fissure segment located in the southeastern part of the *As Mundo* fissure zone. It averages about 1 m wide and ranges from 4 to 7 m deep and is oriented about 55 degrees west of north.

### **North Side Trickle Cave**

North Side Trickle Cave is located at the contact of the volcanic rock and overlying limestone, at the base of the cliff at Uyulan Hulo, at about 400 m elevation. The entrance to North Side Trickle Cave is about 5 m wide and faces nearly north. The cave quickly narrows such that it is less than 1 m wide at the rear, about 10 m from the entrance. At the rear there is a short climb to a 3 m passage that “doubles back” over the main passage. A small (<1 liter/minute) flow of water was observed coming from the cave on 25 May 2004. The area outside of the cave shows no evidence of ever having significant stream flow.

### **Not Much Cave**

Not Much Cave is located on the nearly level bench, north east of Pictograph Cave, near the Banyan Complex. Not Much Cave is developed along the same conjugate joint set 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.

### **Peace Memorial Tunnels**

Located under the volcanic boulders just north of the *Sabana* Peace Memorial, this feature is clearly a set of manmade tunnels and were surveyed as an example of such.

### **Picnic Cave**

Picnic Cave is a flank margin cave located just above sea level, beside the main road, at the coastal notch adjacent to Puntan Sailigai. 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 storm debris. 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. 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. The cave contains extensive evidence use in modern times. The nature of many of the artifacts indicates that the cave was used during the Japanese era.

### **Pie Cave**

Pie Cave is one of several caves along the Water Cave Road near *Haofña*, near the “cave” symbol on the USGS topographical map (1999). Pie Cave opens to the south and is about 11 m long and 7 m wide. The cave consists of one low, steeply sloping chamber less than 1 m high. The drip line of the Pie Cave coincides with what appears to be a bio-erosion notch.

### **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 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 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 fractures that lead up to the surface.

### **Rainy Day Cave**

Rainy Day Cave, located in the south wall of the cove west of *Sailigai Papa*, is reached by a 4 m climb. The cave is about 15 m long and 2-3 m wide before tapering into a fracture at the rear. The Rainy Day Cave is developed along a fracture that is expressed along the full length of the ceiling of the cave. The ceiling ranges from 2.5 to 7 m high. The floor slopes steeply up at the rear.

### **Reservoir Cave**

Reservoir Cave is located at the contact of the volcanic rock and overlying limestone, at *Uyulan Hulo*, at about 380 m elevation. The 4 m wide entrance to Reservoir Cave faces north and is almost completely blocked with a manmade berm. The inside wall of the berm is stacked stones and the outside slopes down to the natural grade. Behind the berm is a room about 3 m north-south and about 7 m east-west. The entrance opens at the west end of this room. On 9 July 2004, this room contained a shallow pool of water about 1.5 by 3 meters. At the southeast side of this outer room, the floor rises about 0.5 m at the entrance to a tapering passage. This passage extends about 7 m before narrowing to the point that it is impassable. The trickle of water flowing from this passage into the outer pool was measured at 1 liter per minute. There is no evidence that water ever flows beyond the pool in the entrance room. The ceiling of both parts of Reservoir Cave are very flat and appear to be limestone. The walls appear to be in weathered volcanics.

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

This horizon 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 southernmost section is about 30 m long and about 4 m wide. The next section to the north is almost 40 m long and about 4 m wide. 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 flank margin 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 still-stand. Southeast of the complex there are more flank margin remnants that are not tied in to this survey.

### **Ripple Cave**

Ripple Cave is a flank margin cave located about 2 m above sea-level on the coast at *As Dudo*. The entrance to Ripple Cave faces just east of south and the main axis of the cave (17 m) is on the same orientation. The plan of Ripple Cave is roughly ovoid and it is about 11m wide. The floor of most of the cave is bare limestone and the ceiling height is about 1-1.5 m. Two large boulders dominate the center of the cave. One of these boulders reaches the ceiling. Ripple Cave is named for the well preserved wave(?) ripples that are eroded out in relief on both sides of the entrance.

### **Rock Pile Cave**

Rock Pile Cave is located in the cove west of *Sailigai Papa*. The 4 m wide by 5 m tall entrance is reached by a 3 m climb. Rock Pile Cave faces north and extends for about 10 m from the drip line. The floor on the east side of the cave is bare limestone with a few cobbles. On the west side of the cave, the floor drops away into a solutionally widened fissure that extends down about 5 m below the main floor of the cave. Rock Pile Cave is developed along the same fracture as this floor fissure.

### **Root Wall Cave**

Root Wall Cave is located in Fissure City, east of *Uyulan Hulo*. The entrance to Root Wall Cave is in an area of rugged pinnacle karst that also contains the entrances to some smaller caves that were not mapped. The entrance to the cave is divided by a moss covered “curtain” of roots, growing from the ledge above, thus the name Root Wall Cave. The central room in Root Wall Cave spans about 8 m by 8 m and has a floor sloping to the south. The south wall of the central room has speleothems that are several degrees from their original growth position, indicating relatively recent movement of the fractures along which Root Wall Cave is developed. From the south side to the central room, a passage extends down into a smaller room floored in breakdown. There is a small passage extending down into the breakdown for a short distance. There are upper and lower passages extending from the northeast corner of the central room. The lower passage is reached by a 2 m climb down and is developed along a linear fracture oriented 60° east of north. This passage continues for about 12 m to a 3+ m climb down. Root Wall cave has not been explored beyond this climb down. The upper level leading from the central room is about 5 m long, oriented 60° east of north, has a floor sloping steeply to the southwest and is densely decorated with speleothems. Root Wall Cave is developed along a complex set of fractures that show evidence of substantial motion since the cave developed.

### **Rota Rooter Cave**

This cave was reported by Stafford et al. (2002) as *Sabana Cave #1*. The name is herein changed to Rota Rooter Cave. This cave is located on the *Sabana*, in a banana patch 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. Observation of this area during a rain event showed that Rota Rooter Cave was not acting as in resurgence. However, there is a major resurgence a few meters away at the low point of the depression.

### **Sagua Cave Complex**

The *Sagua Cave Complex* is located at sea-level below *Sagua*, 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 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 facility for moving processed phosphate 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.

### **Sea Stack Cave**

Sea Stack Cave is at about 20 m elevation, about half way between *Tachok* and *Takta*, inland from the houses along the road. The entrance to Sea Stack Cave is in the bio-erosion notch in an apparent former sea stack. The cave is a 6 m long chamber less than 1 m high, reached by an entrance facing east. The outer part of Sea Stack Cave shows evidence of ancient human occupation.

### **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 meters 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 bed rock 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 at *Taiapu* on the east end of the *Talakhaya*, just north of the road, at about 140 m elevation. It consist 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 section is 10 m long, 3 m deep, with a ceiling the tapers up into the cliff face and a bed rock floor. The westernmost section is 10 m long, 7 m deep and 7 m high with a floor mostly covered with sand. Fore-reef beds 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 is 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.

### **Stacked Wall Cave**

Stacked Wall Cave is one of several caves along the Water Cave Road near *Haofña*. The cave consists of one dirt floored chamber about 12 m east-west and about 9 m north-south. The ceiling is about 3-4 m high except for a dome on the west side that reaches about 5 m. The most distinctive features of Stacked Wall Cave are the fore reef beds eroded out in relief and the 4 m long 1.5 m high dry-laid stone wall that spans most of the cave entrance.

### **Summit Cave**

This cave is located at about 470 m elevation, about 300 m south of the summit of *Mt. Sabana* (also known as *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 3 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 day light 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.

### **Surge Cave**

Surge Cave is a complex feature, located on the coast at *As Matmos*, that is apparently the remnant of a flank margin cave, the development of which was influenced by two fractures that extend to the coast. The main section of this feature is an open depression that slopes up to the southwest, grading into the elevation of the coastal cliff. On the northeast side of the depression, where it is about 5 m deep, there is an arch through the coastal cliff out to the sea level bench. The pool under this arch is tidal and connects to the ocean via one open channel and one passage below sea level. Both connections are apparently developed along fractures. Just inland from the arch, below the floor of the depression is a partially collapsed flank margin chamber no more than 1 m high but several meters in horizontal extent. Parts of the lower chamber were not enterable due to waves.

### **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 rocks 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 0.3 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 Museum (Antigo) 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 154°. The fracture along which the cave is developed is prominent in the ceiling for most of the length of the cave. 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.

### **Tea Kettle Fissure**

Tea Kettle Fissure is located in the *As Mundo* Fissure Zone adjacent to the south side of the road through this area. Tea Kettle Fissure consists of three segments. The westernmost segment is about 47 m long, 5-8 m deep and about 10 m wide. The middle segment is a more open area about 30 m wide extending about 25 m to the southeast. A shallow extension of the middle segment runs parallel to the westernmost segment. East of the open middle segment and aligned with it, is a much narrower 20 m long segment that includes roofed cave sections at each end. This easternmost segment is about 10 m deep and floored with boulders jammed in the fissure. Small passages can be seen extending below the floor.

### **Truck Rig Pit**

Truck Rig Pit is located adjacent to the parking area or Pictograph Cave at *Gampapa*. The entrance to the pit is about 1X1 m. Truck Rig Pit is developed along a fracture that strikes about 60°, the same general strike as Pictograph Cave. The pit reaches a

maximum depth of about 9 m, and is 1-2 m wide. The fracture along which Truck Rig Pit is developed can be seen to continue laterally and vertically.

### **Village View Cave**

Village View Cave is located in the cliff face near the south east 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 mostly with loose sand and a few breakdown boulders near the entrance. This northern chamber is connected to the larger part of the cave through a body-sized hole. 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 turns 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. The relative lack of dissolution and deposition in this crack suggests that it is significantly younger than the solutional part of the cave.

### **Vixen Cave**

Vixen Cave is one of several caves 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 fore-reef beds. 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.

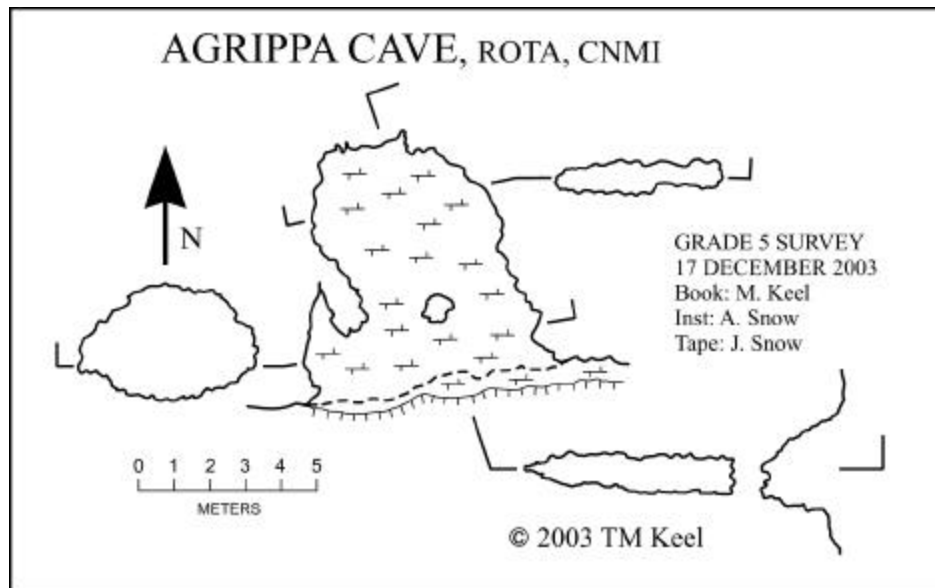
### **Water Cave (Matan Hanum)**

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 of the volcanic rocks 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 from the issues from springs just outside the cave. The entrance to the cave has floor to ceiling chain link fence and a concrete dam. 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

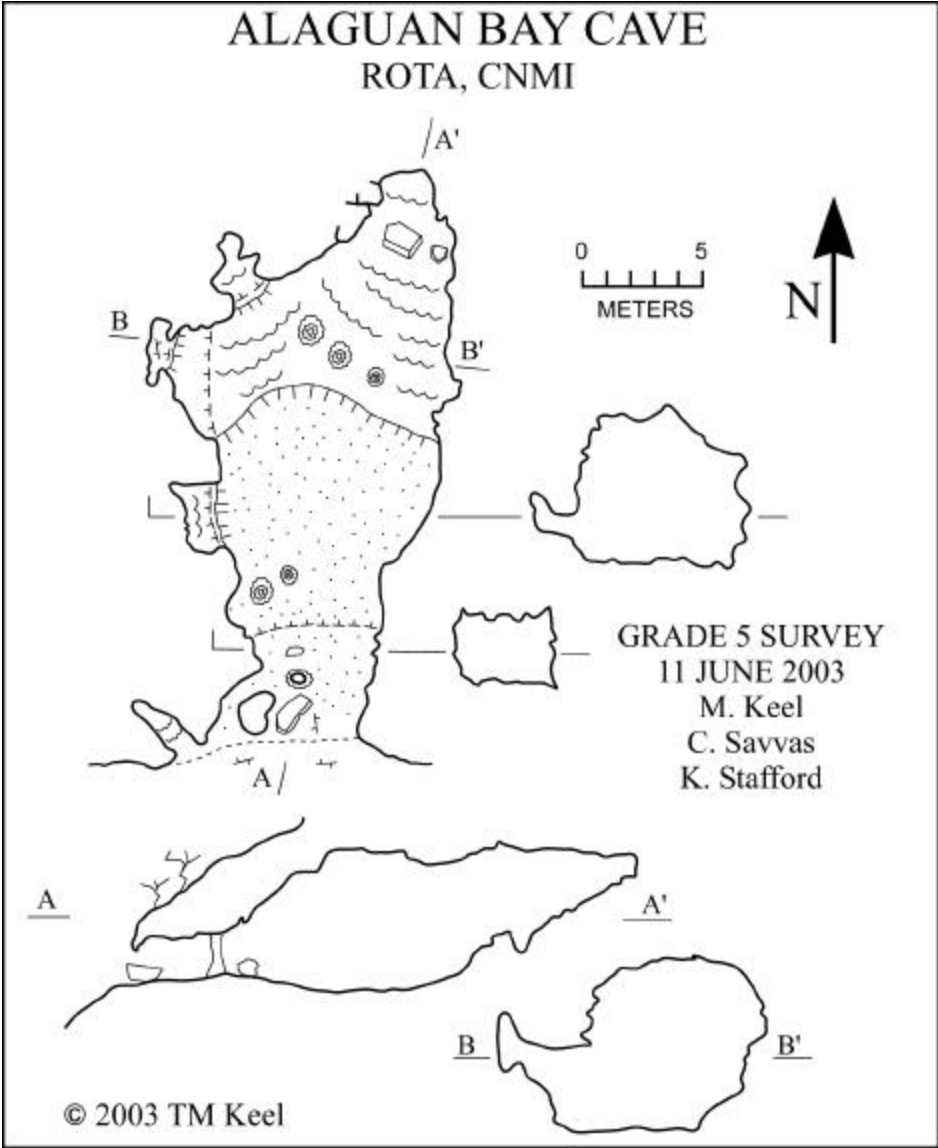
high room that also has much water coming into it from the east wall. The estimated height of the main chamber of Water Cave only includes the space above the water level. No attempt was made to measure the water depth. The water cave is thought to be a flank margin cave which happened to develop at the contact and later intercepted water flowing along the contact. The local geology leaves little doubt that this water comes from the *Sabana* on the top of Rota.

**APPENDIX B**  
**MAPS OF THE CAVES OF ROTA**





*Figure B.1 Map of Agrippa Cave*



*Figure B.2 Map of Alaguan Bay Cave*

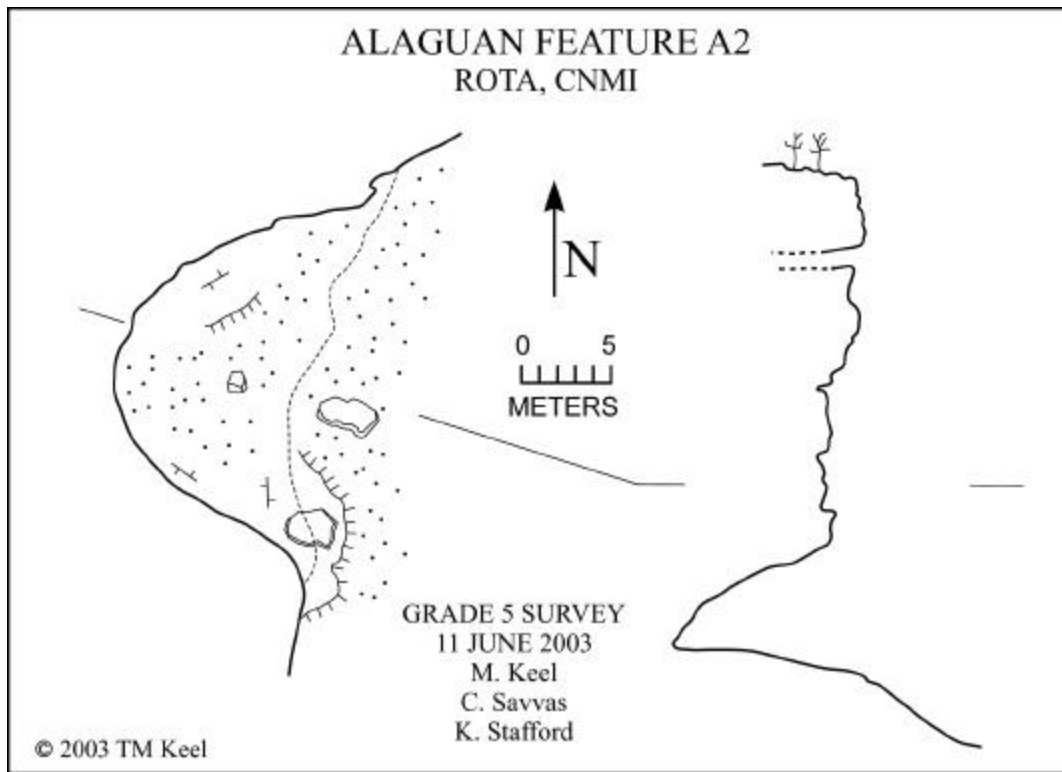


Figure B.3 Map of Alaguan Feature A2

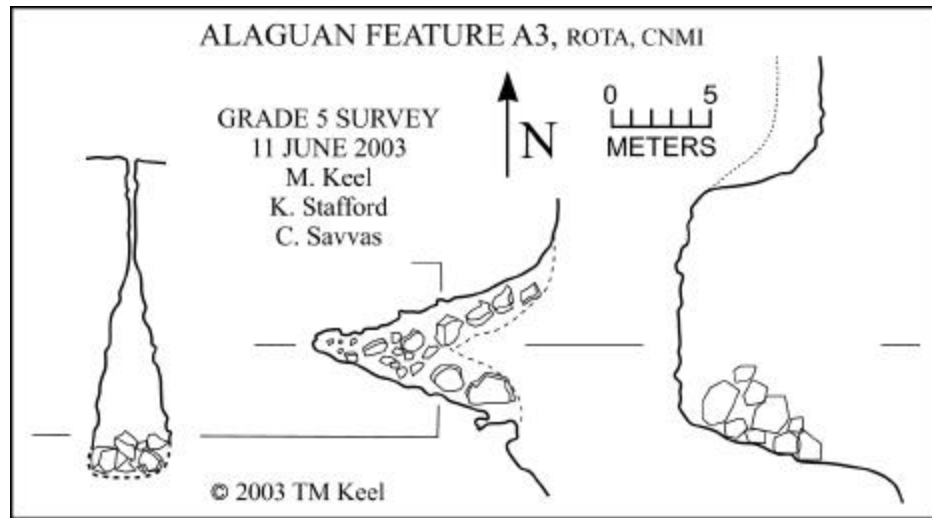


Figure B.4 Map of Alaguan Feature A3

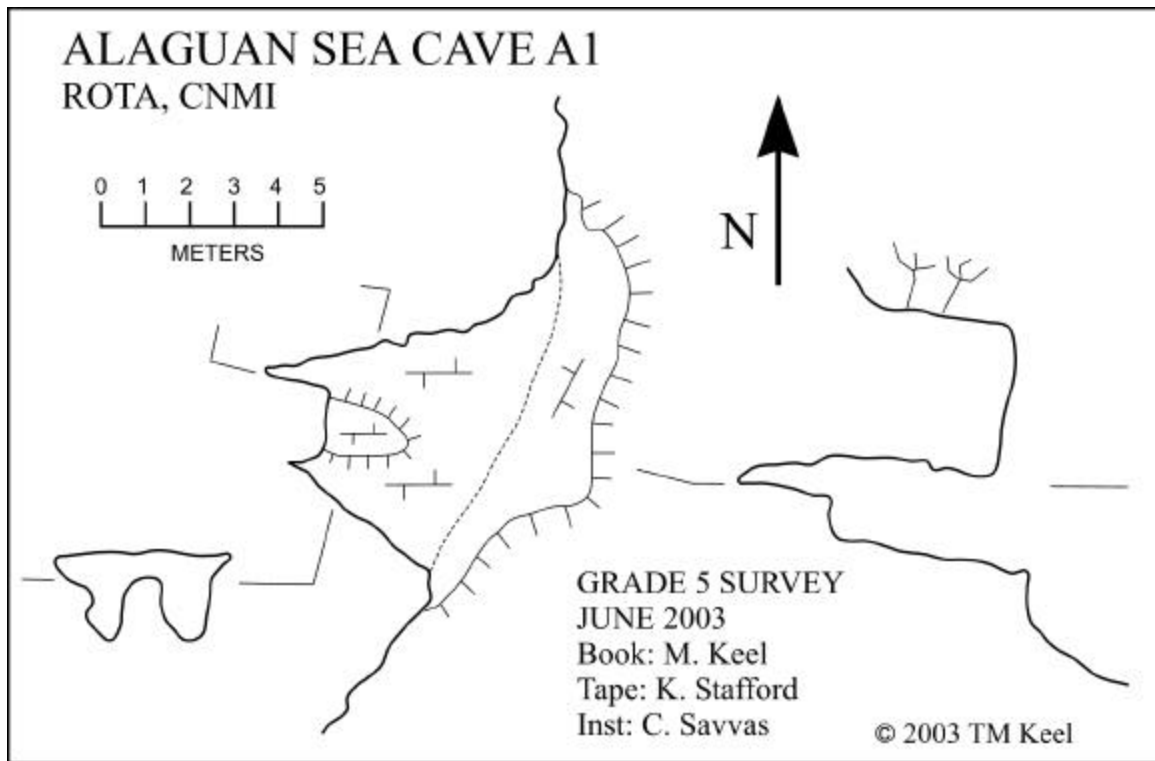


Figure B.5 Map of Alaguan Sea Cave A1

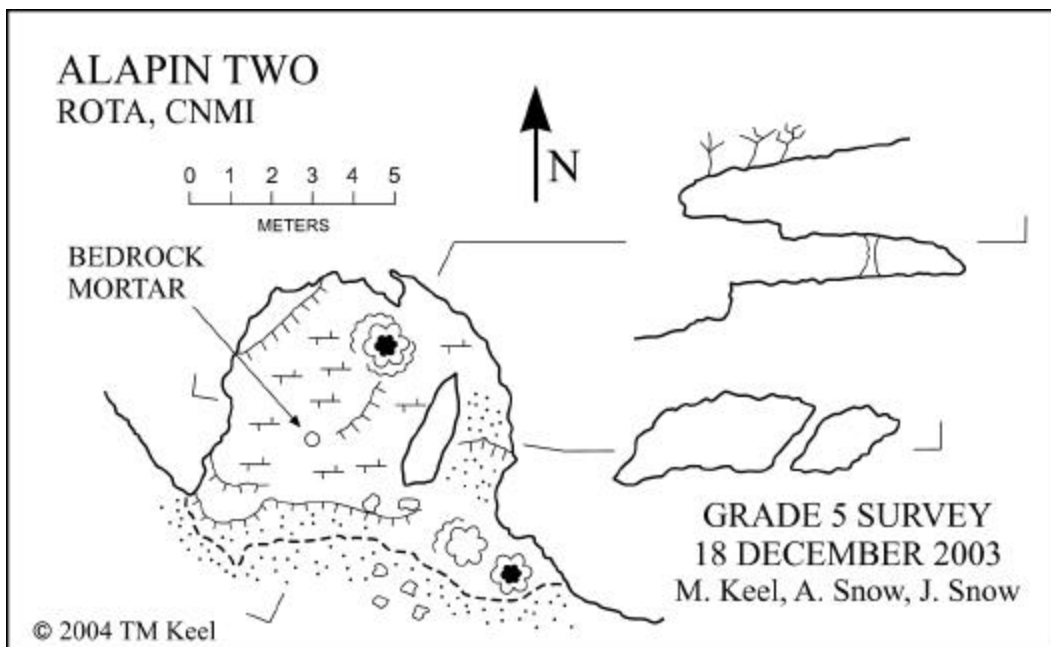


Figure B.6 Map of Alapin Two Cave

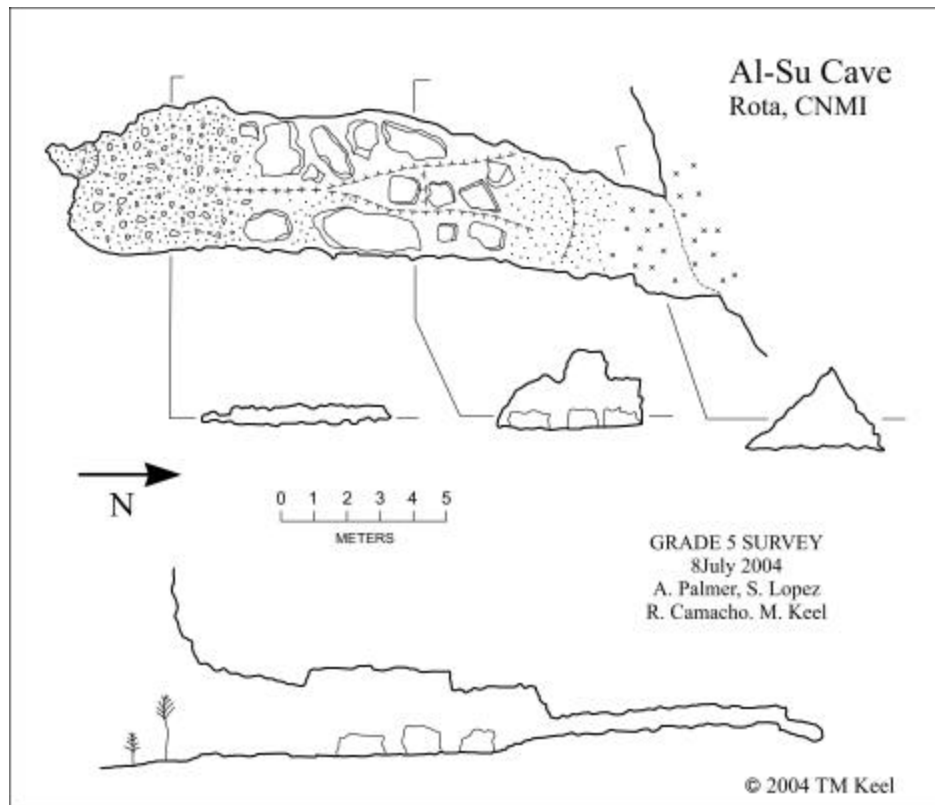


Figure B.7 Map of Al-Su Cave

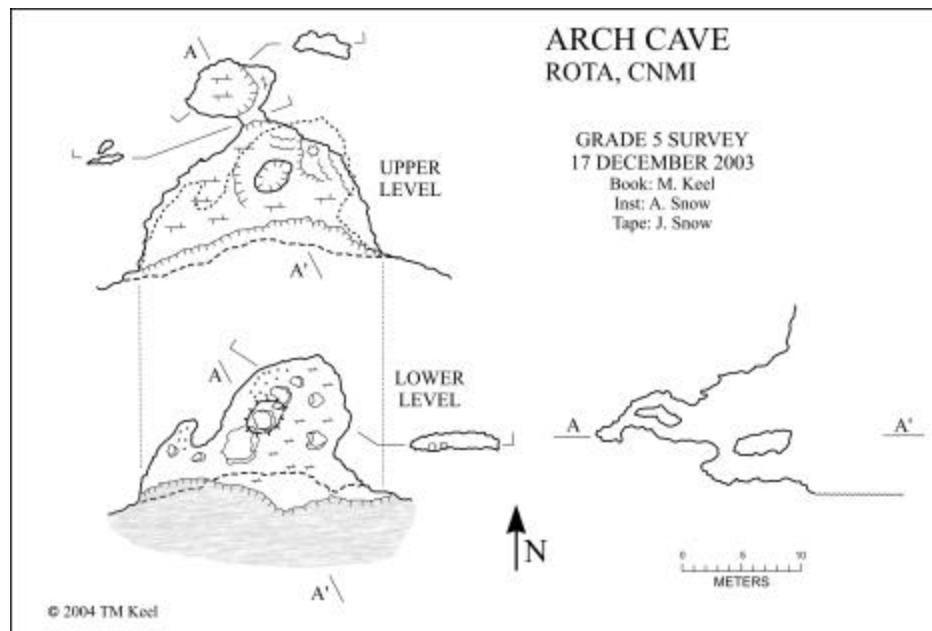


Figure B.8 Map of Arch Cave

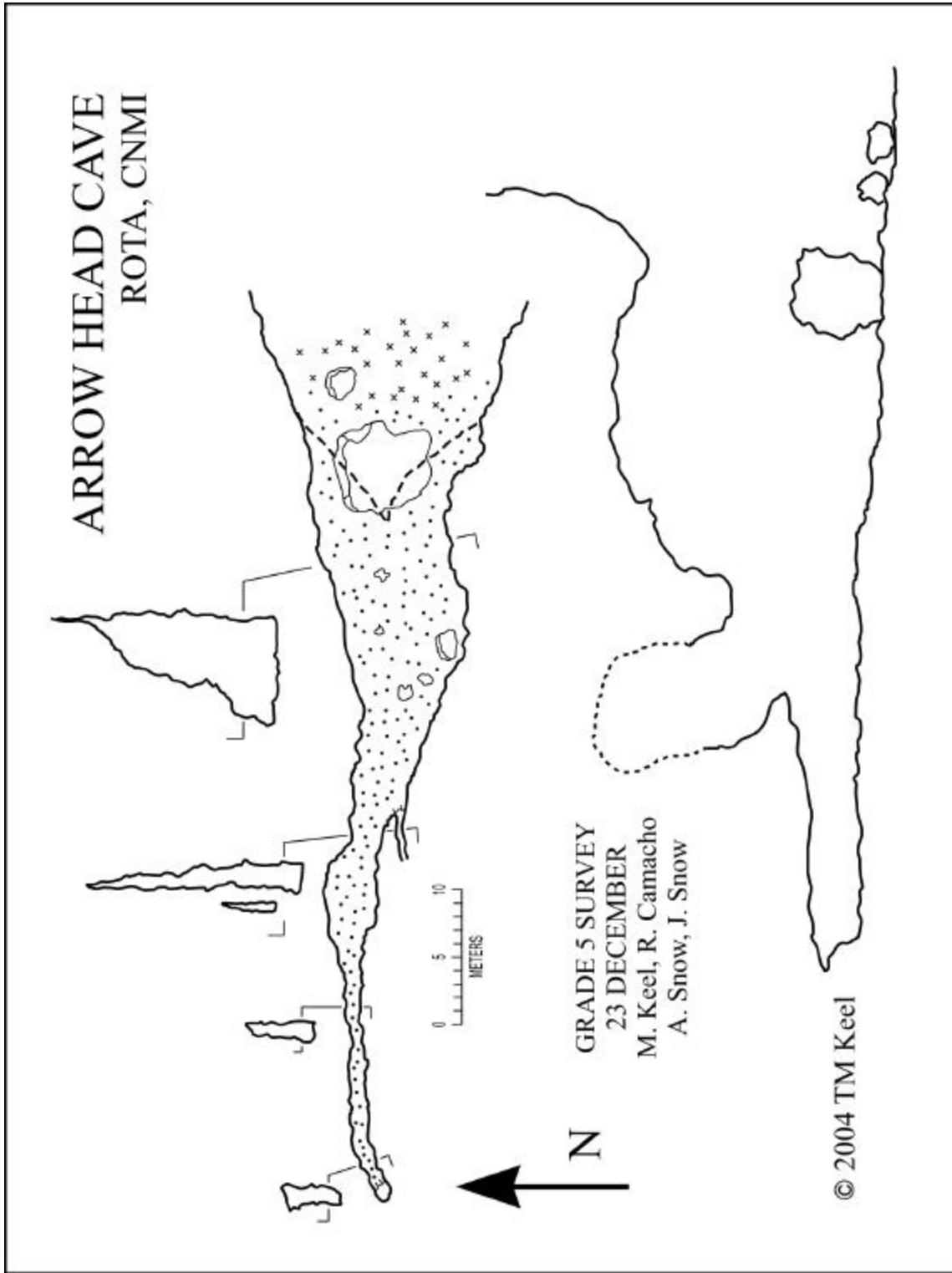
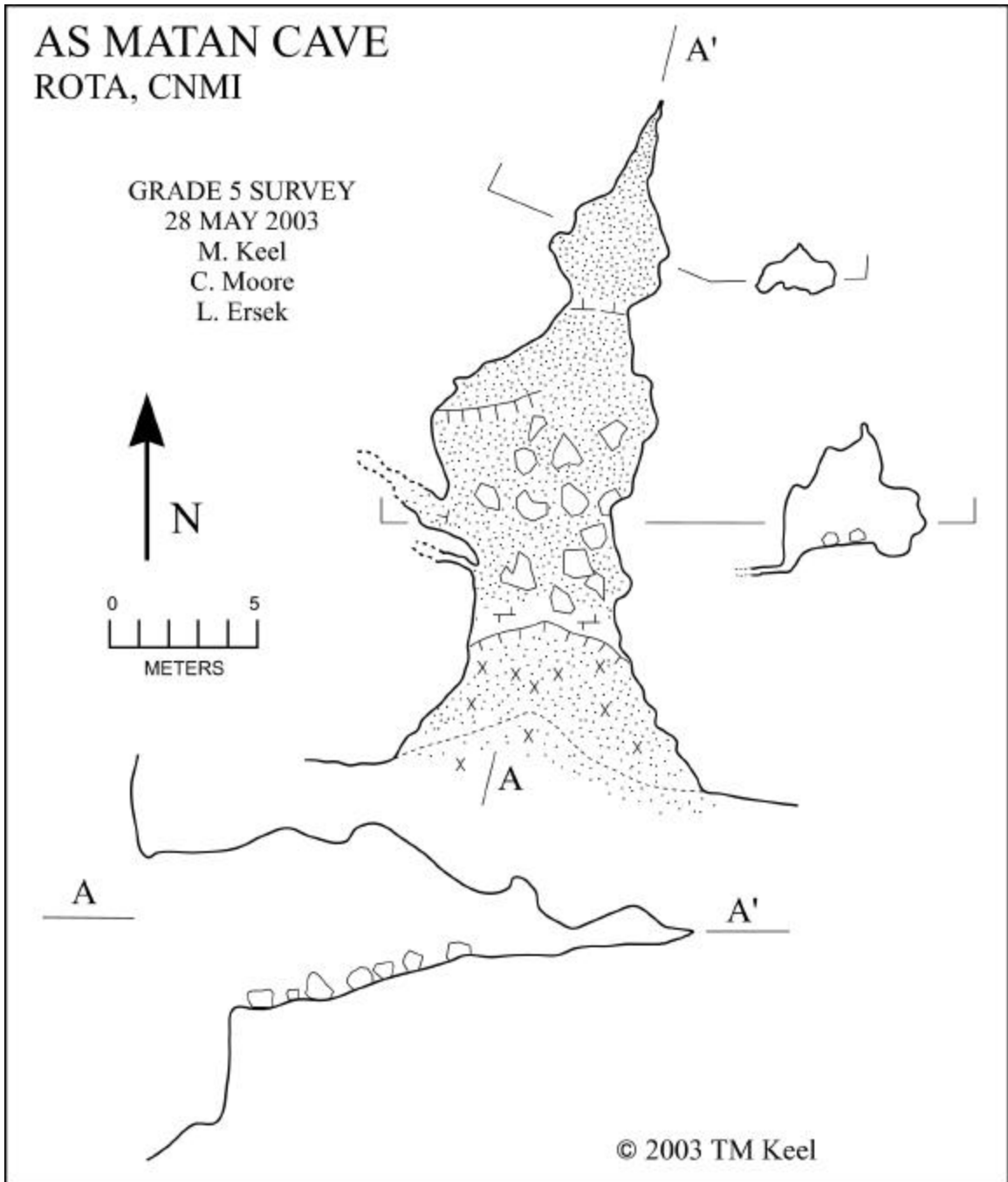


Figure B.9 Arrowhead Cave



*Figure B.10 Map of As Matan Cave*

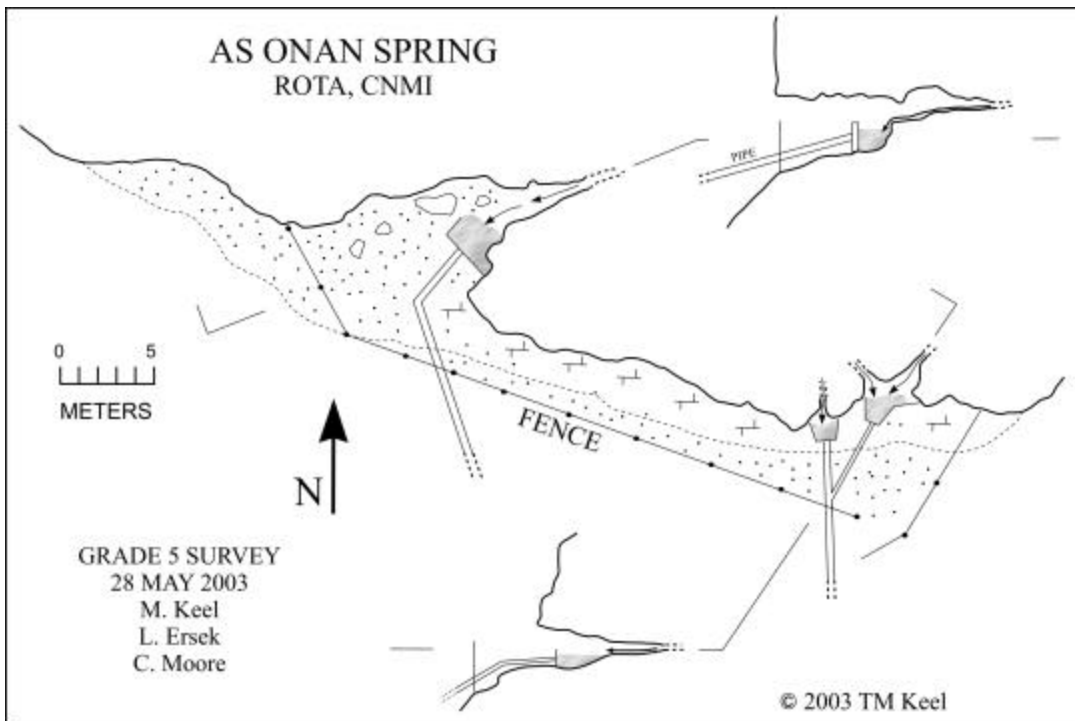


Figure B.11 Map of As Onan Spring

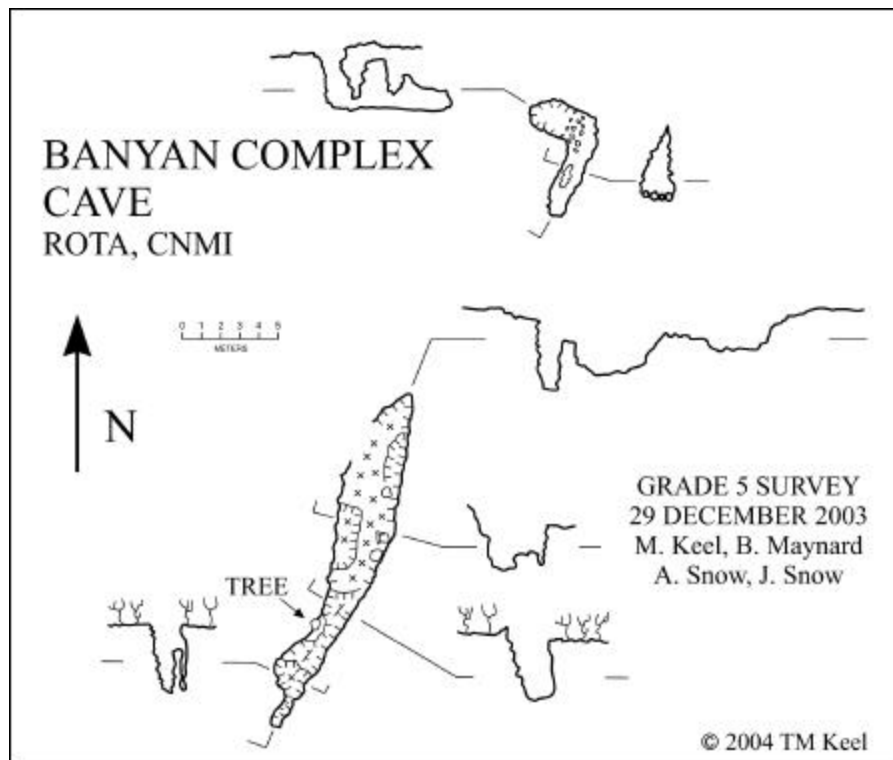
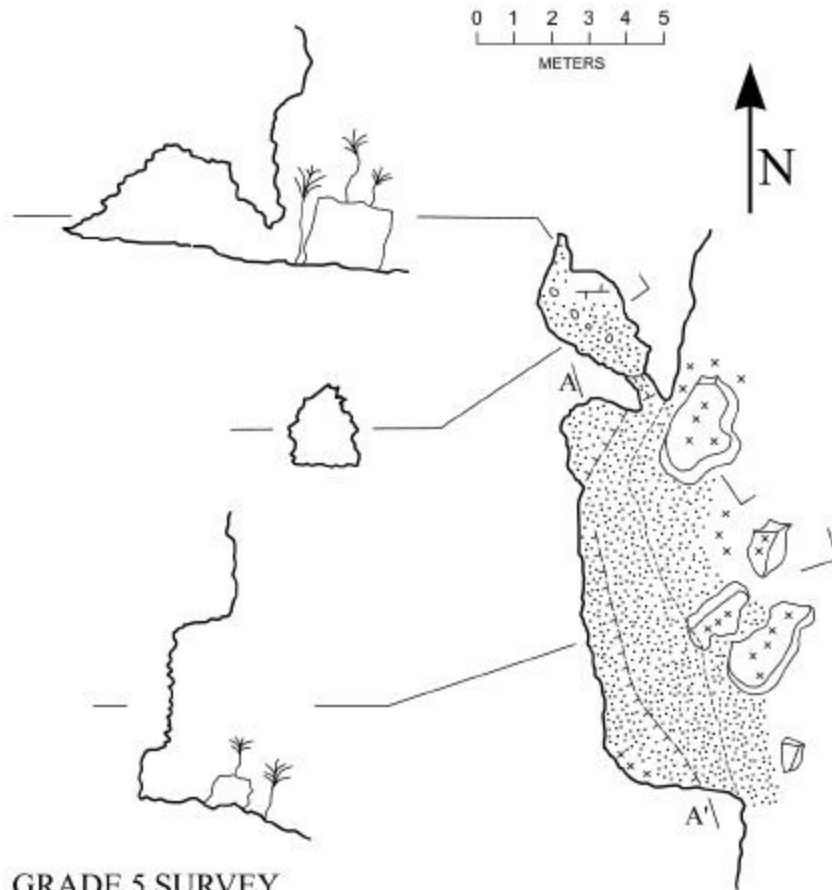


Figure B.12 Map of Banyan Complex Cave

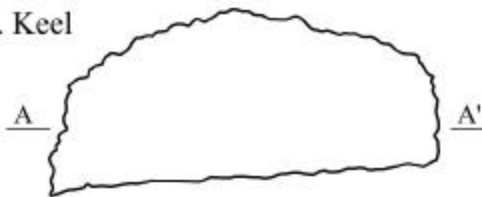


# BARBED WIRE CAVE

ROTA, CNMI



GRADE 5 SURVEY  
18 June 2004  
R. Camacho, M. Keel



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Figure B.13 Map of Barbed Wire Cave

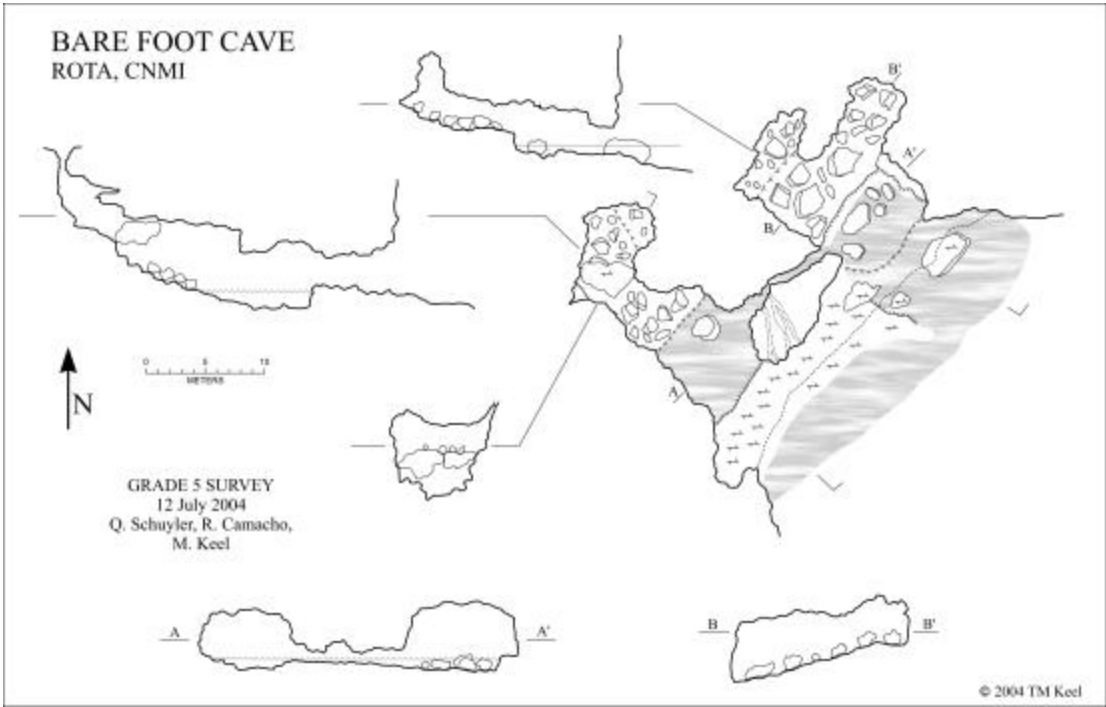


Figure B.14 Map of Barefoot Cave

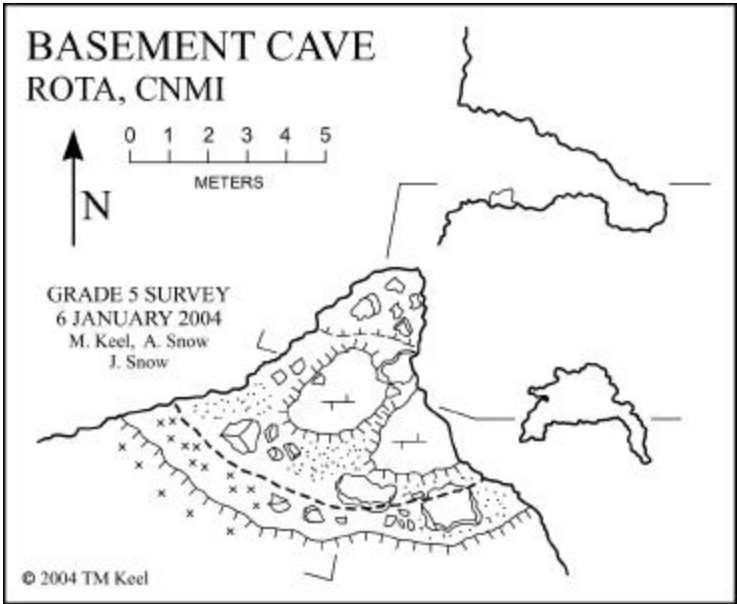
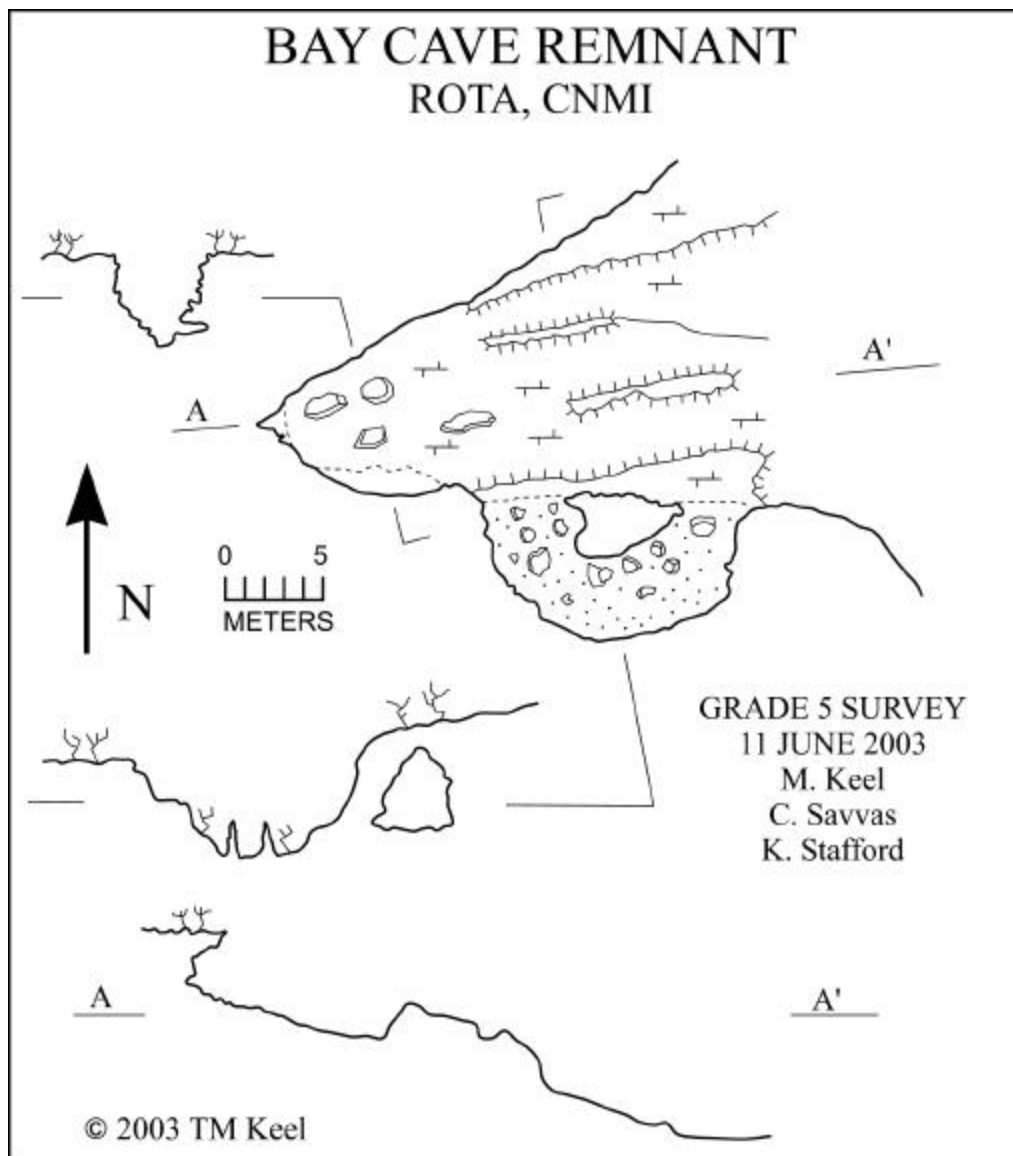
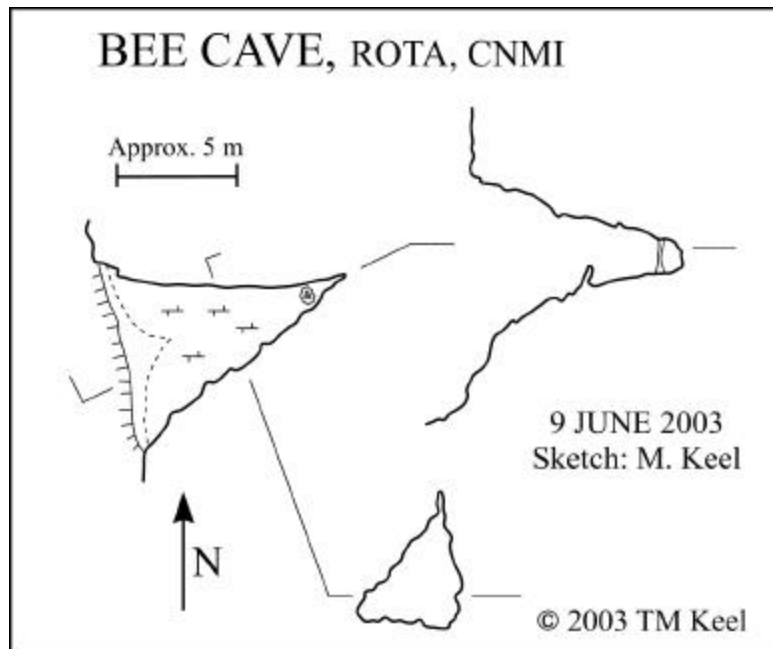


Figure B.15 Map of Basement Cave



*Figure B.16 Map of Bay Cave Remnant*



*Figure B.17 Map of Bee Cave*

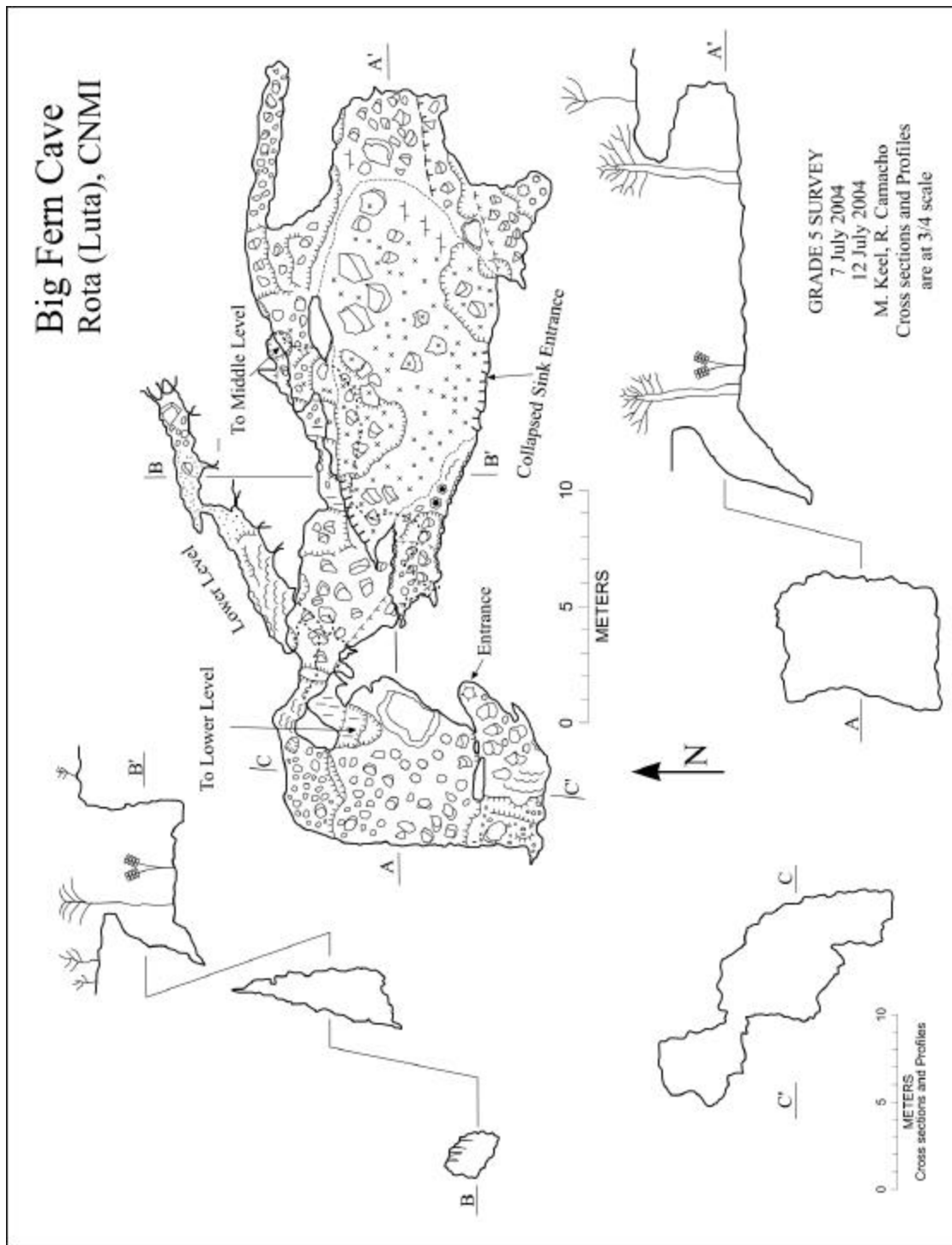


Figure B.18 Map of Big Fern Cave

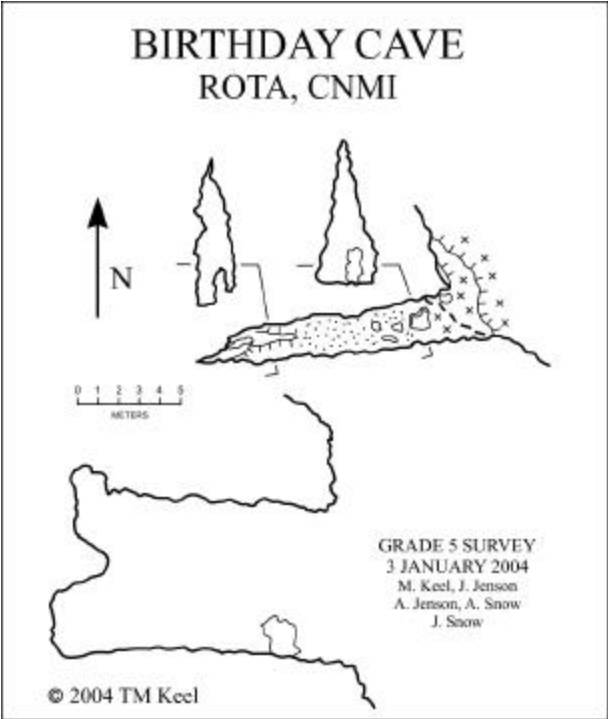


Figure B.19 Map of Birthday Cave

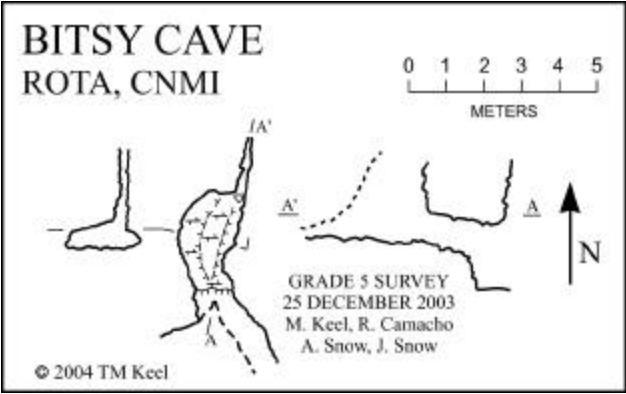


Figure B.20 Map of Bitsy Cave

# BLACK COBBLE CAVE

ROTA, CNMI

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

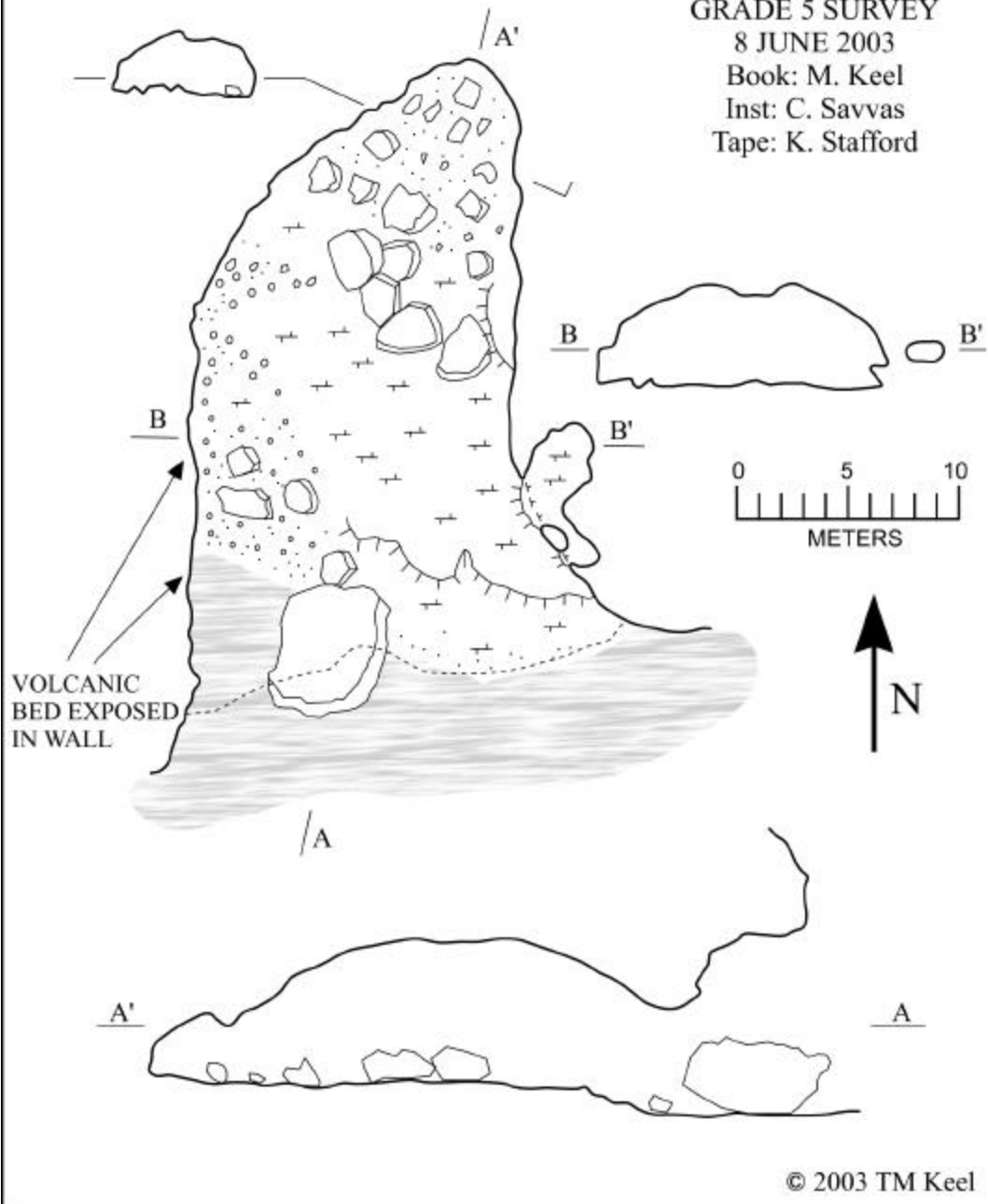


Figure B. 21 Map of Black Cobble Cave

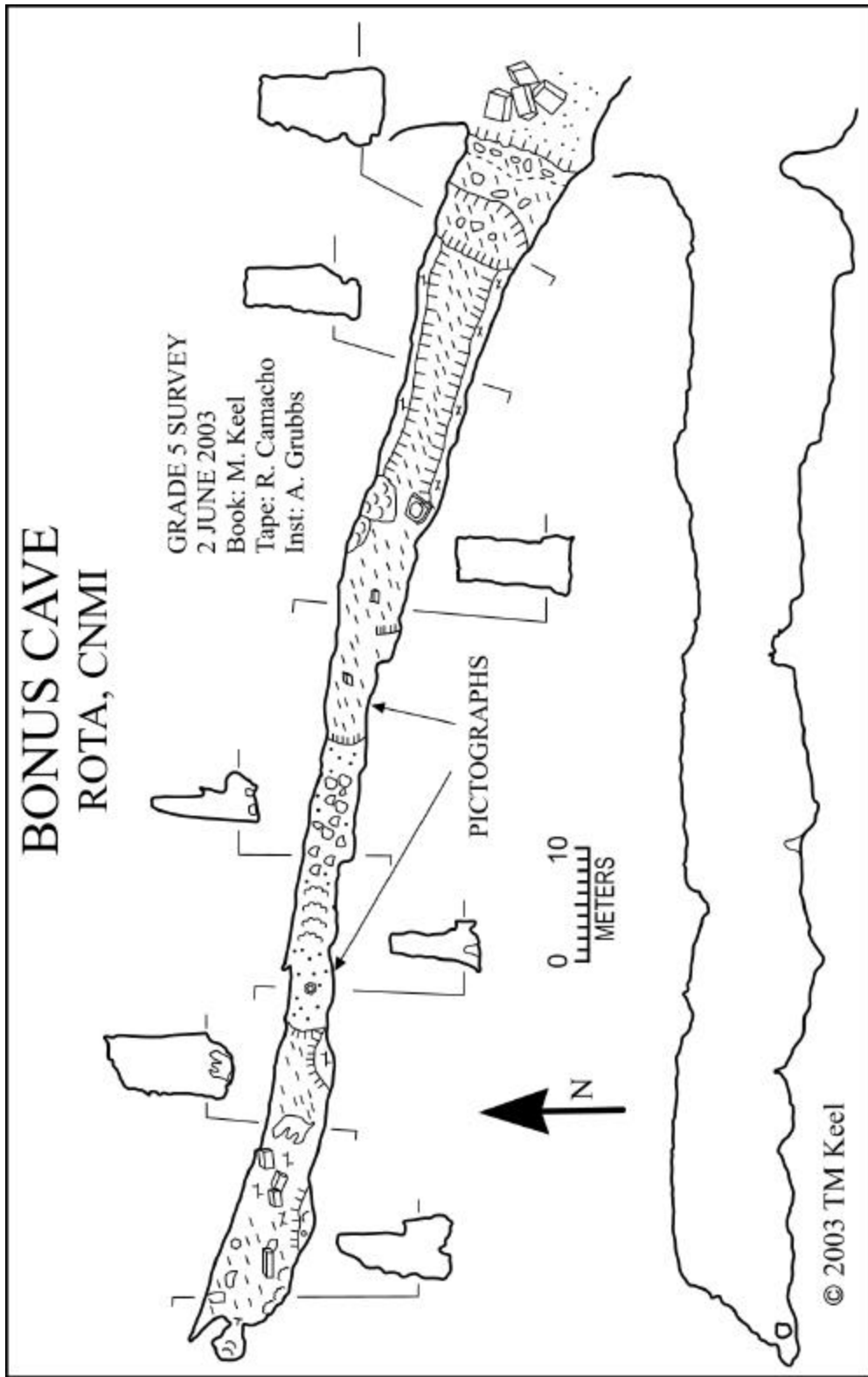
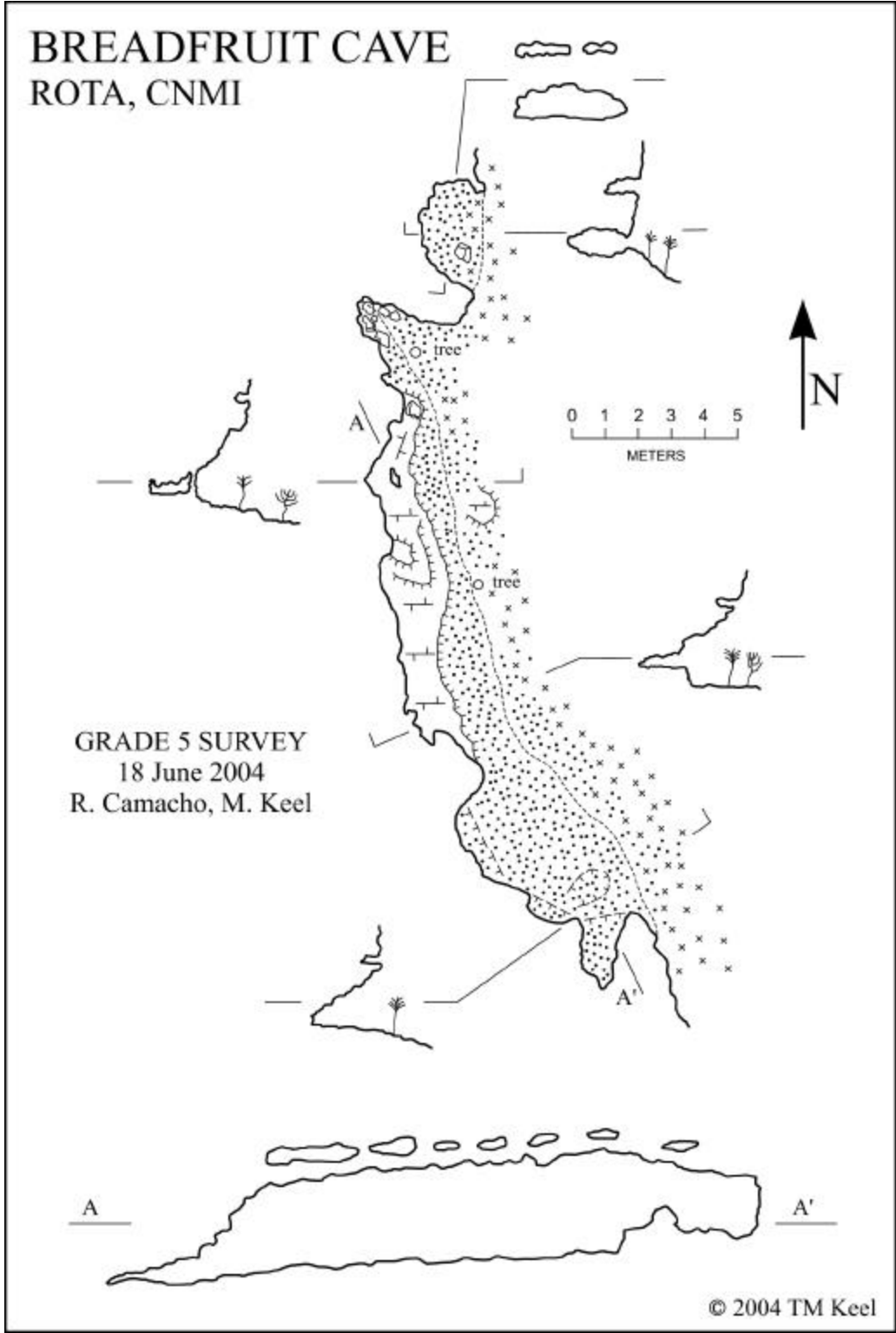
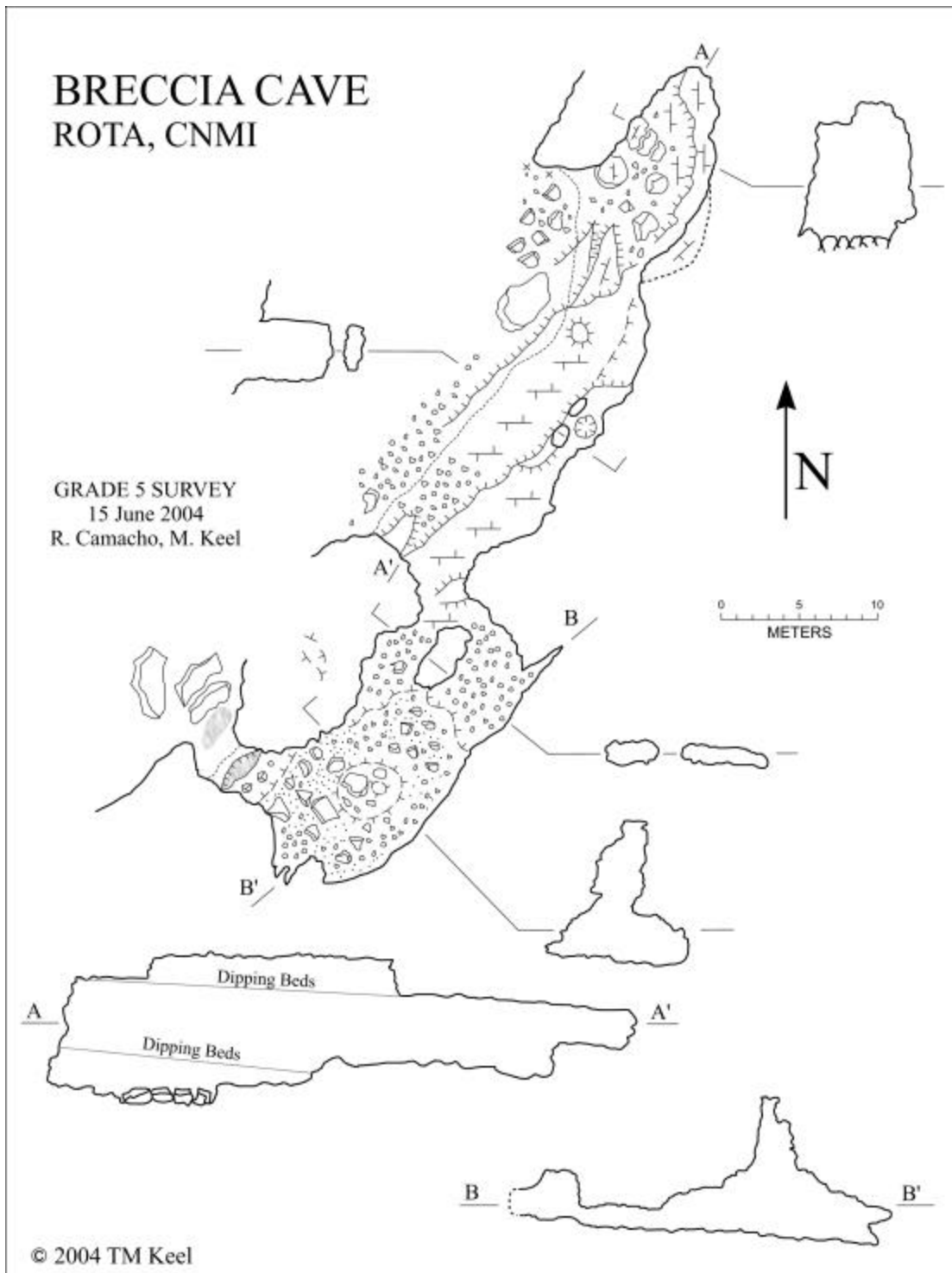


Figure B.22 Map of Bonus Cave





*Figure B.23 Map of Breadfruit Cave*



*Figure 24 Map of Breccia Cave*

# BREEZE CAVE ROTA, CNMI

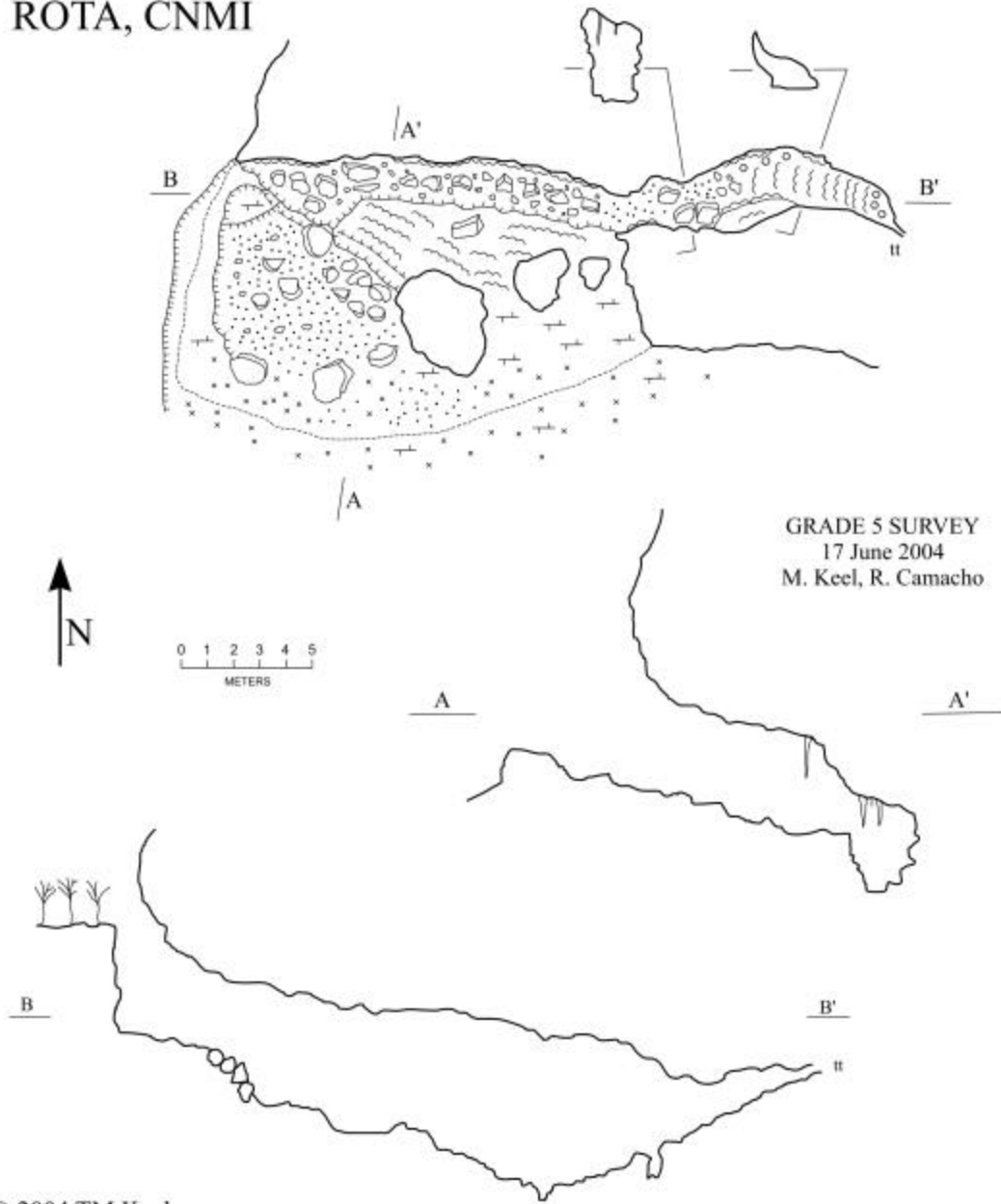
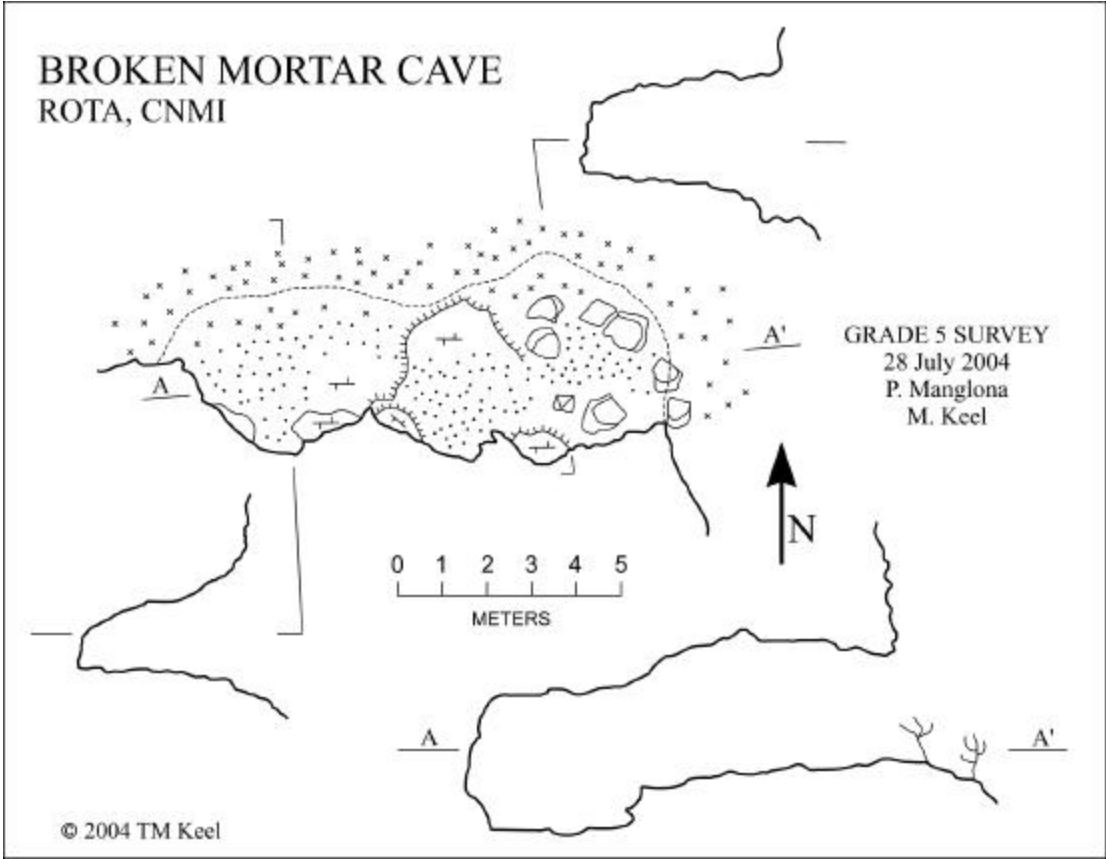
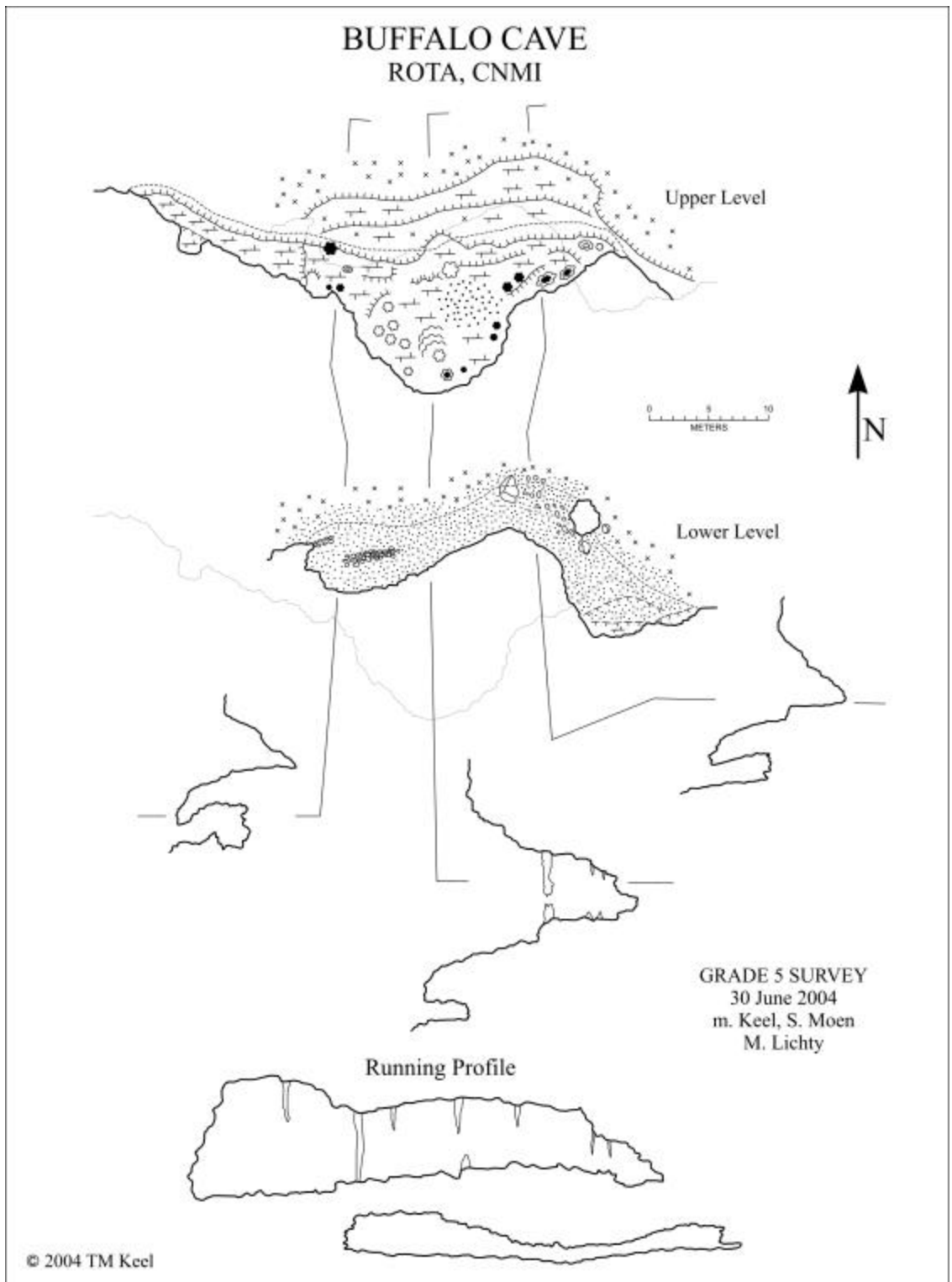


Figure B.25 Map of Breeze Cave



*Figure B.26 Map of Broken Mortar Cave*



*Figure B.27 Map of Buffalo Cave*

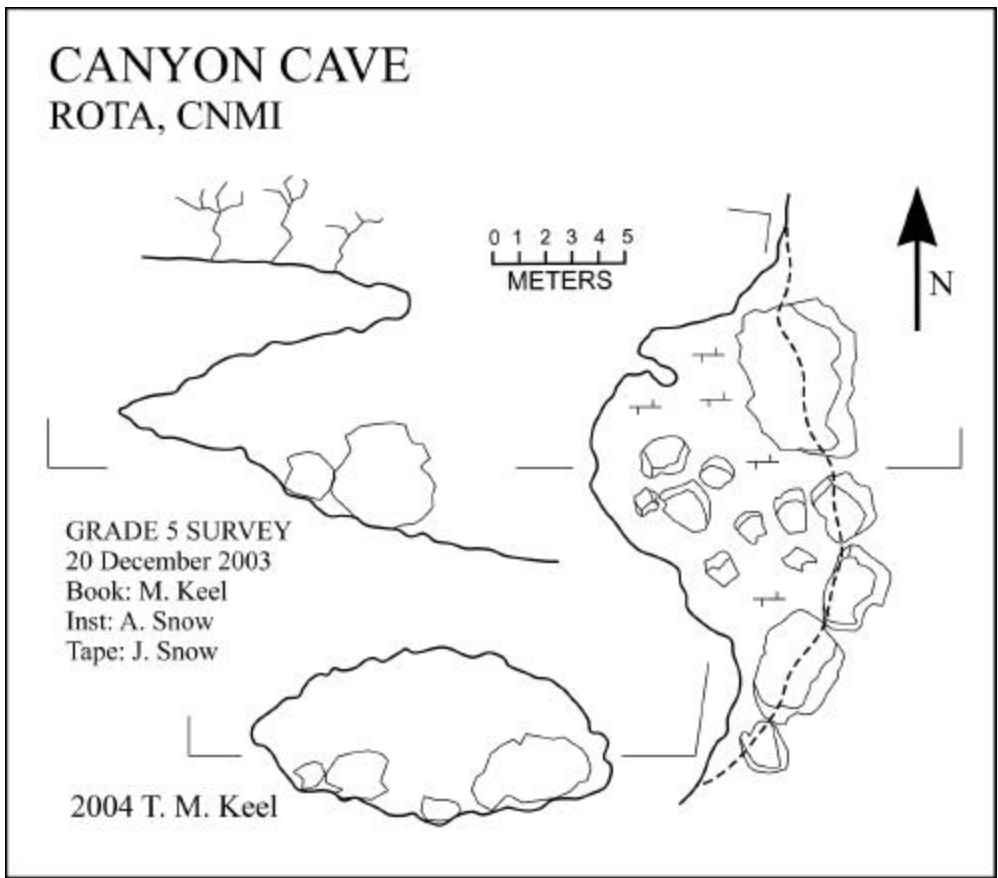


Figure B. 28 Map of Canyon Cave

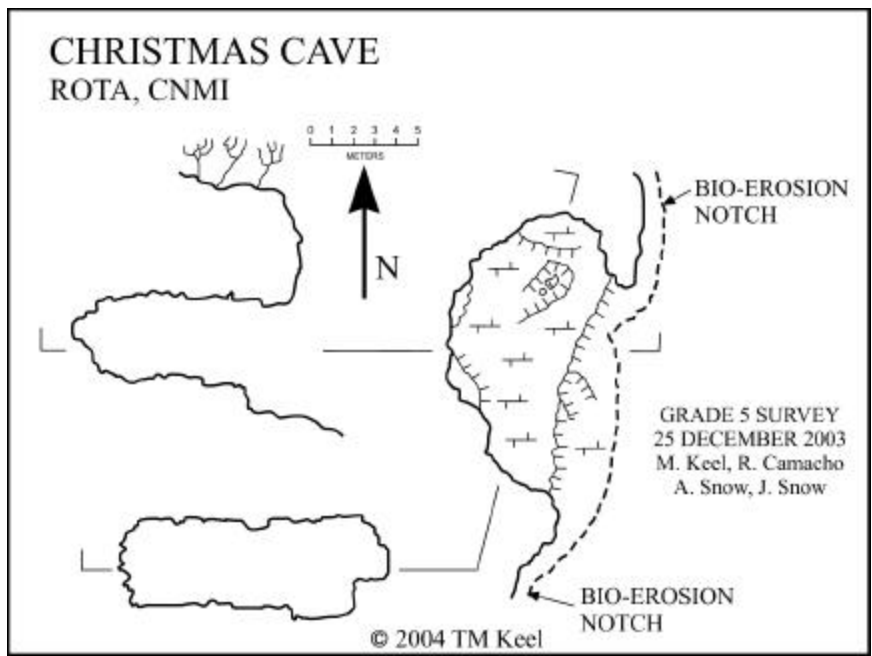
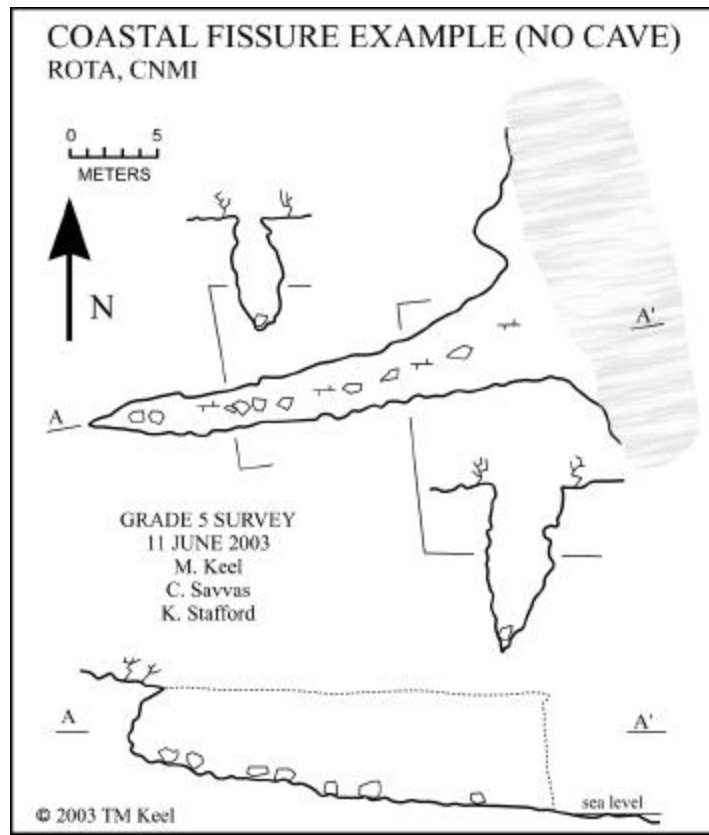
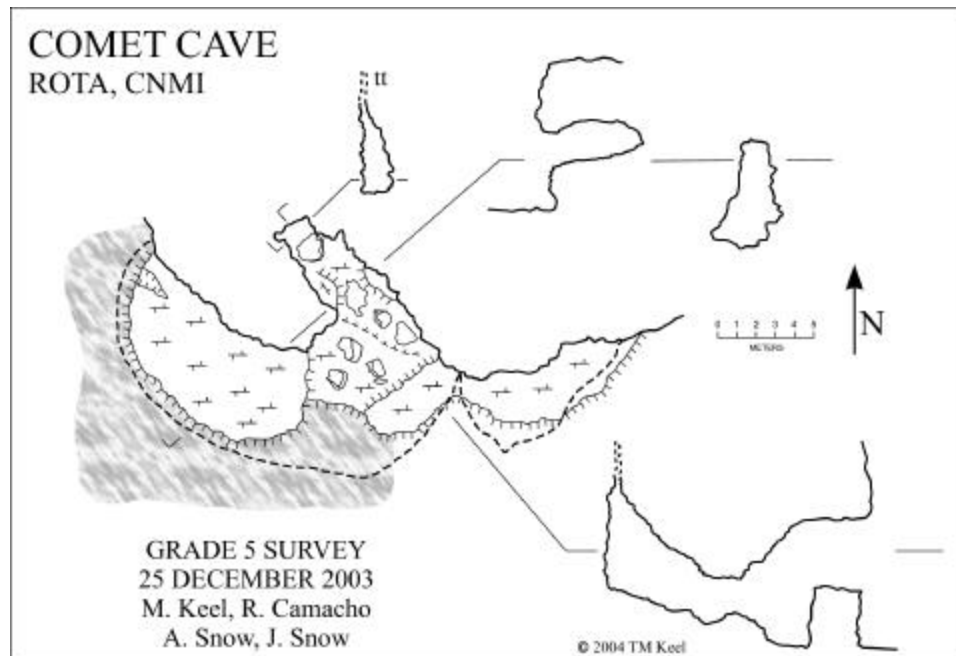


Figure B.29 Map of Christmas Cave



*Figure B.30 Map of Coastal Fissure Example*



*Figure B.31 Map of Comet Cave*

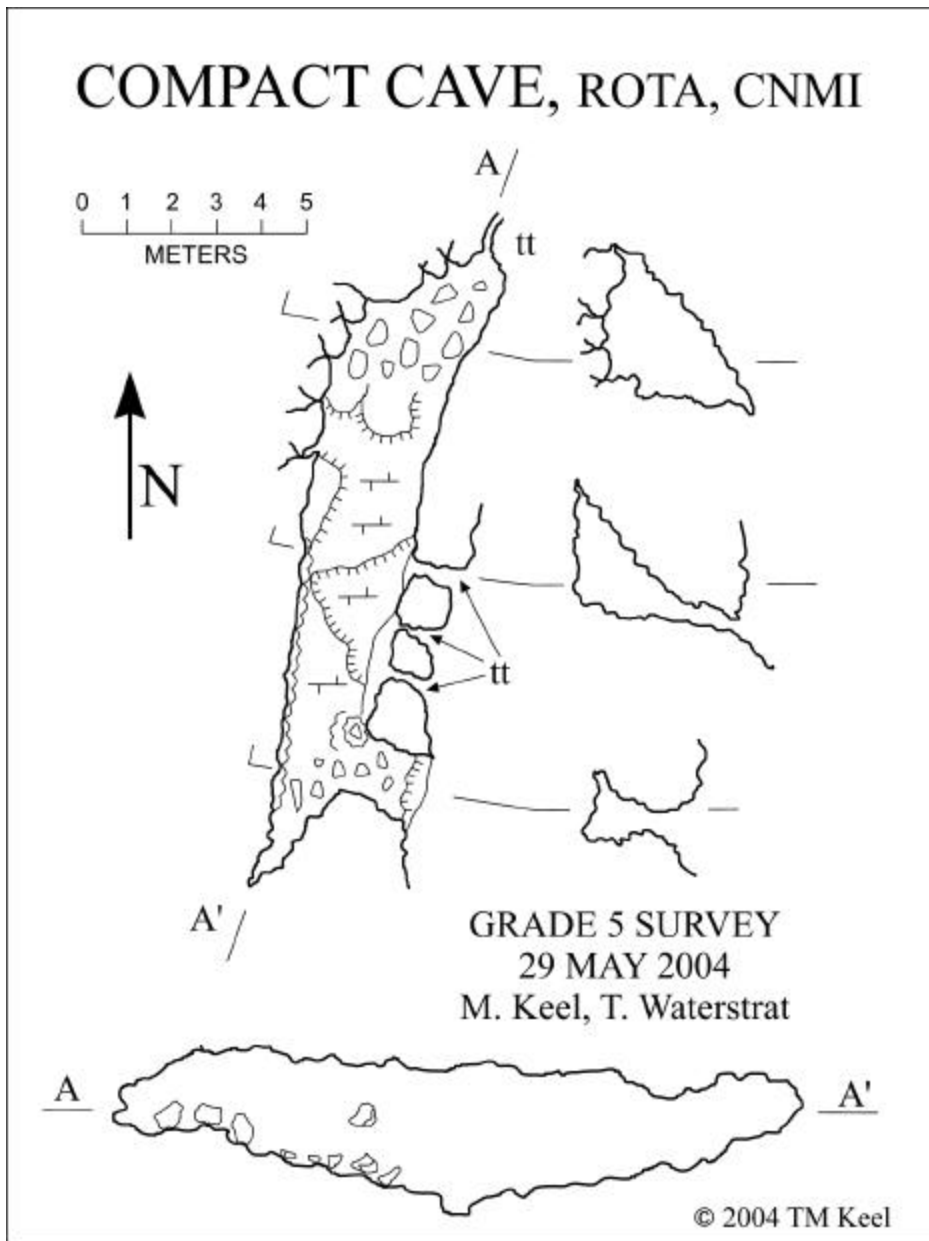
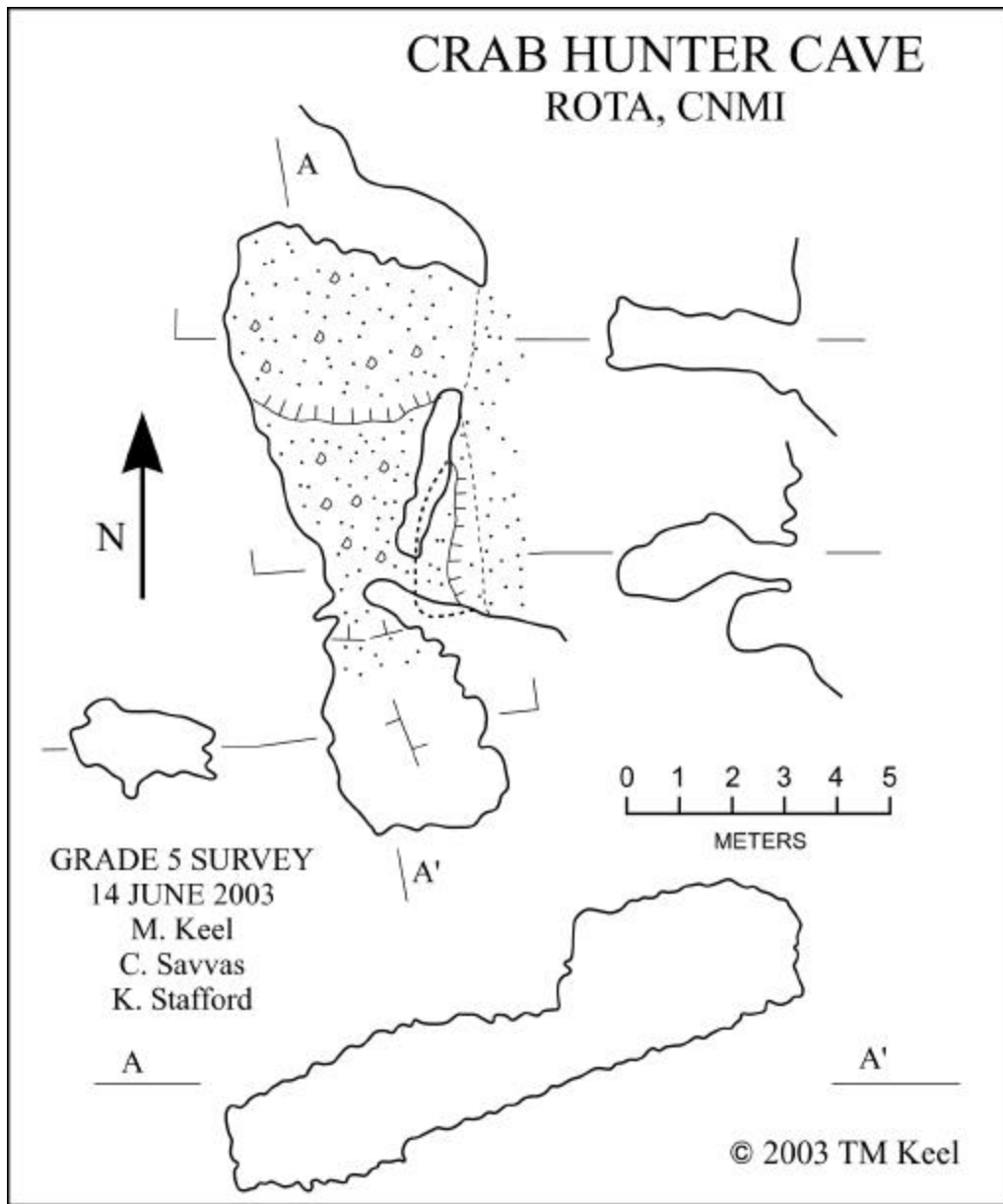


Figure B.32 Map of Compact Cave





*Figure B.33 Map of Crab Hunter Cave*

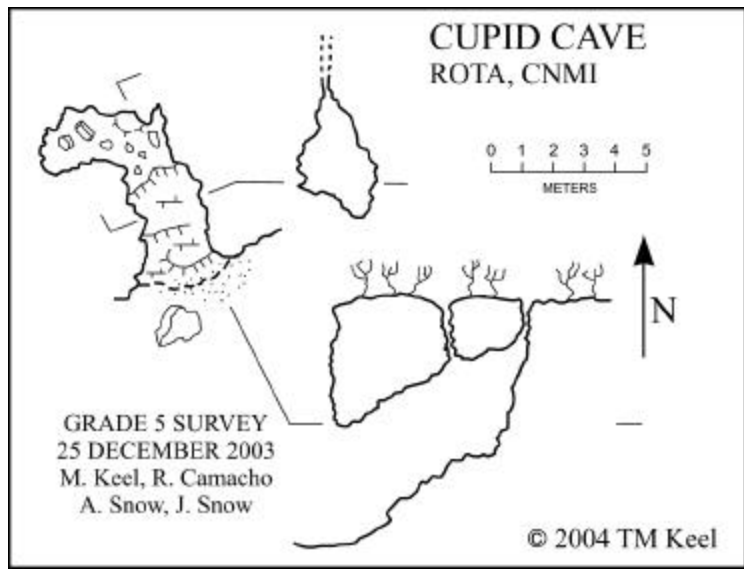


Figure B.34 Map of Cupid Cave

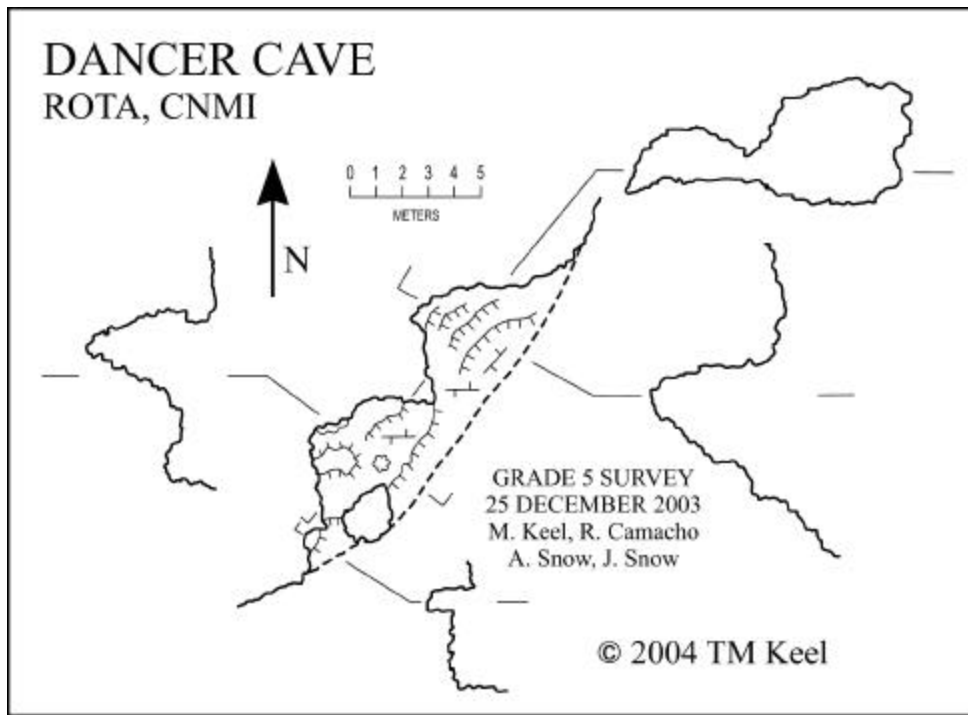


Figure B.35 Map of Dancer Cave

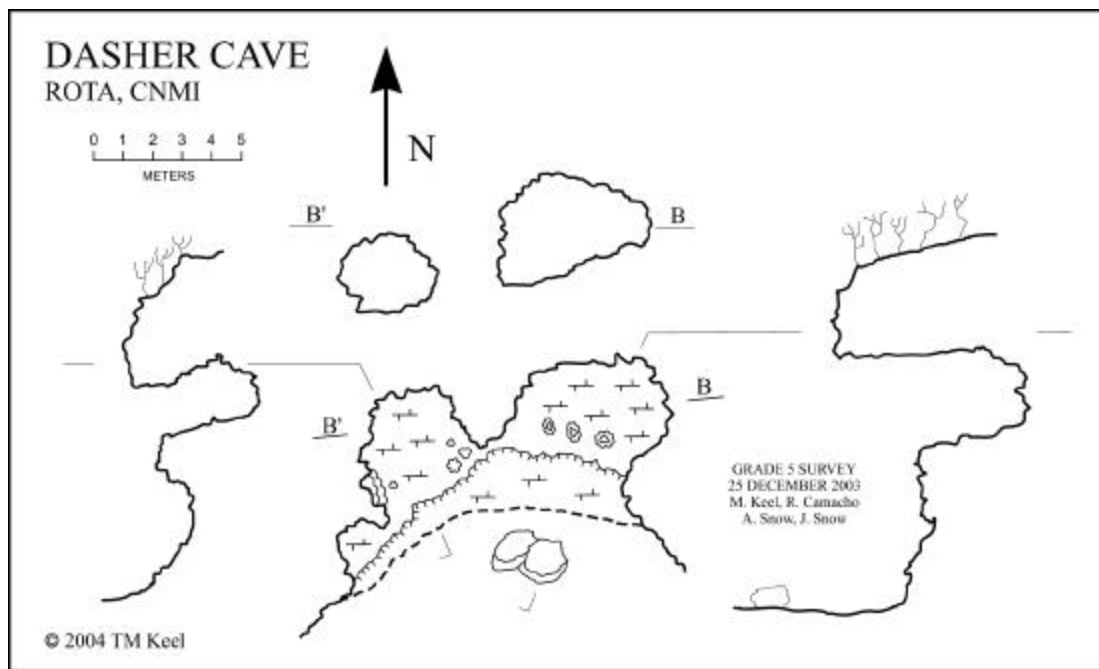


Figure B.36 Map of Dasher Cave

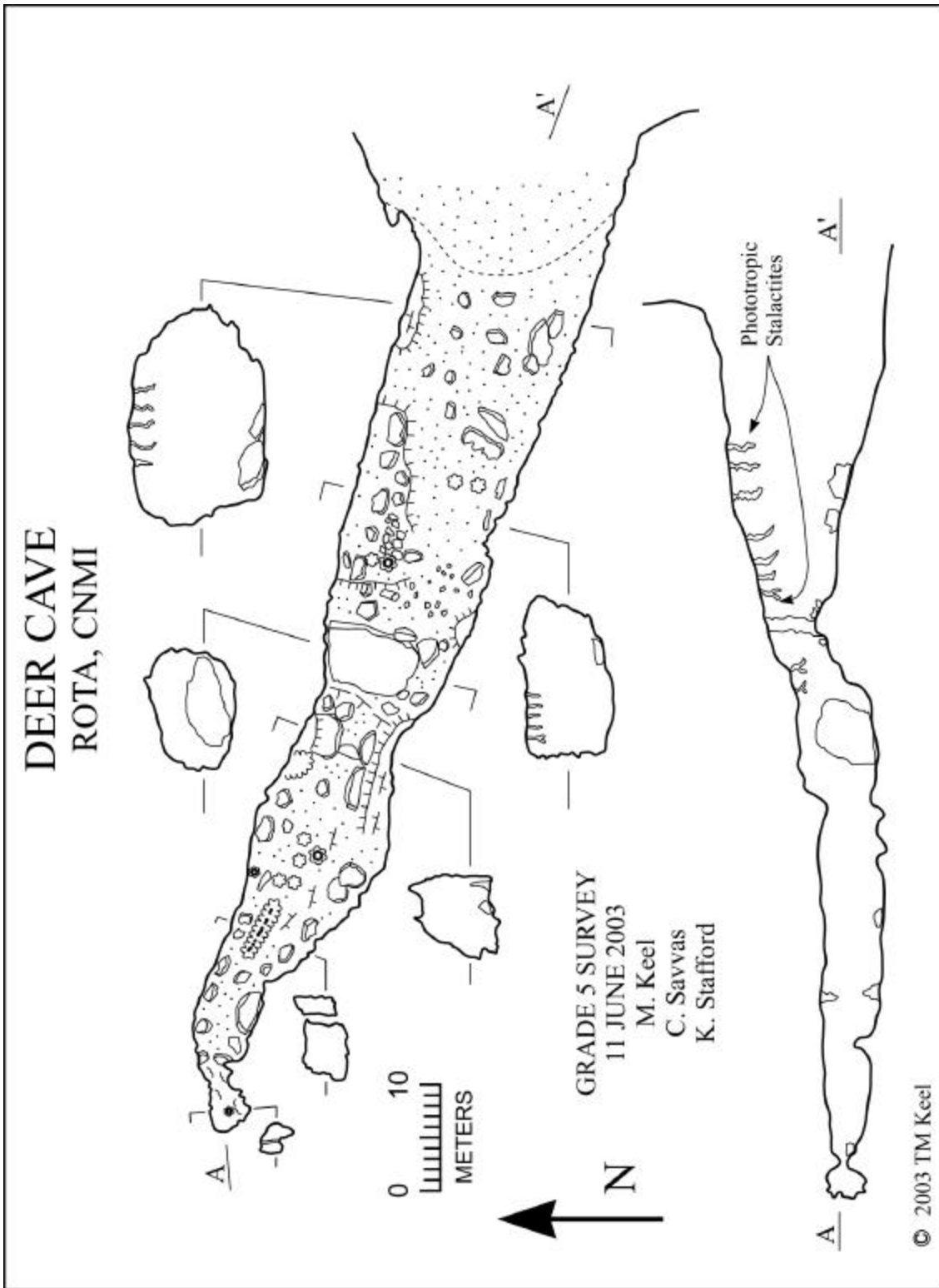
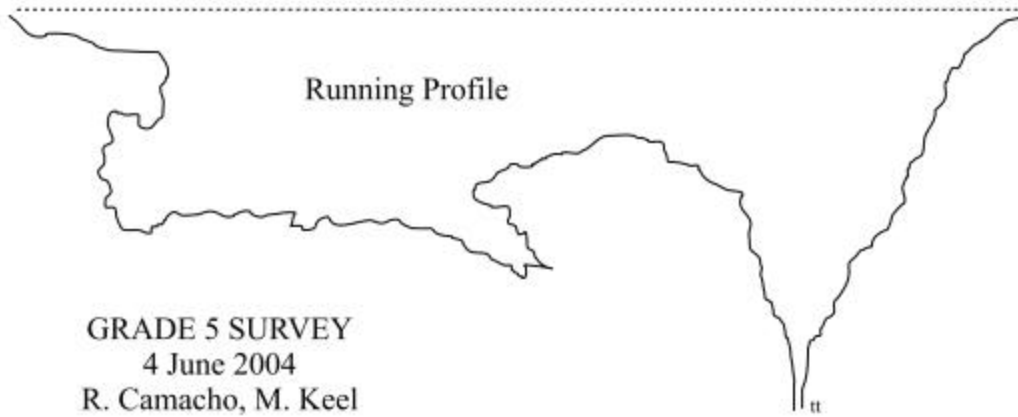
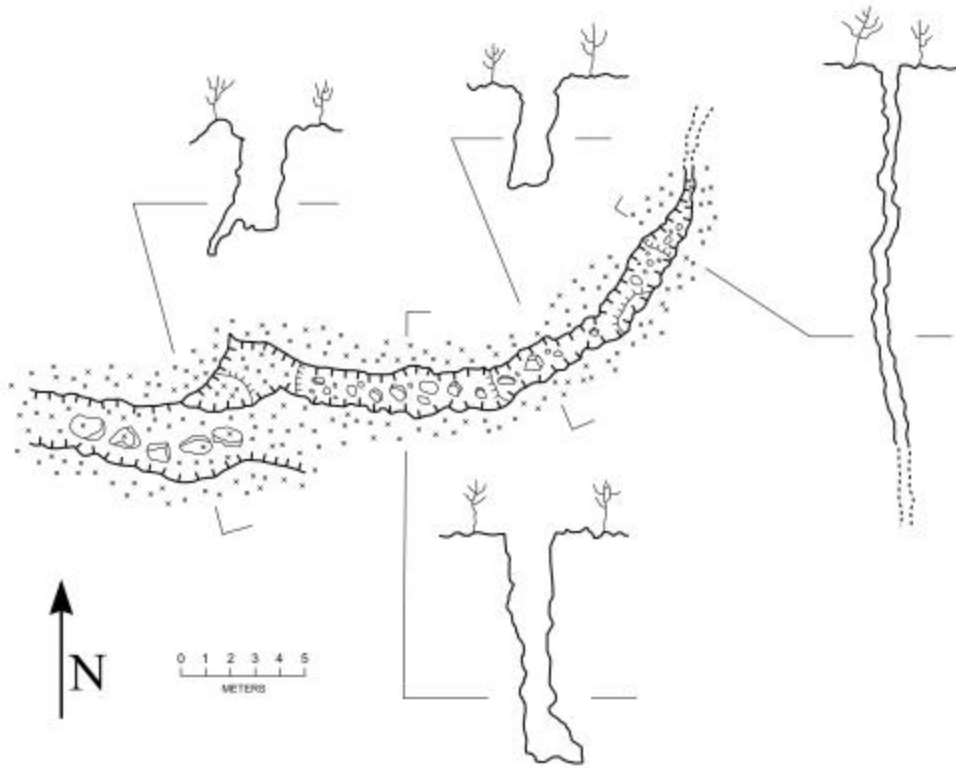


Figure B.37 Map of Deer Cave



# DIAGONAL FISSURE

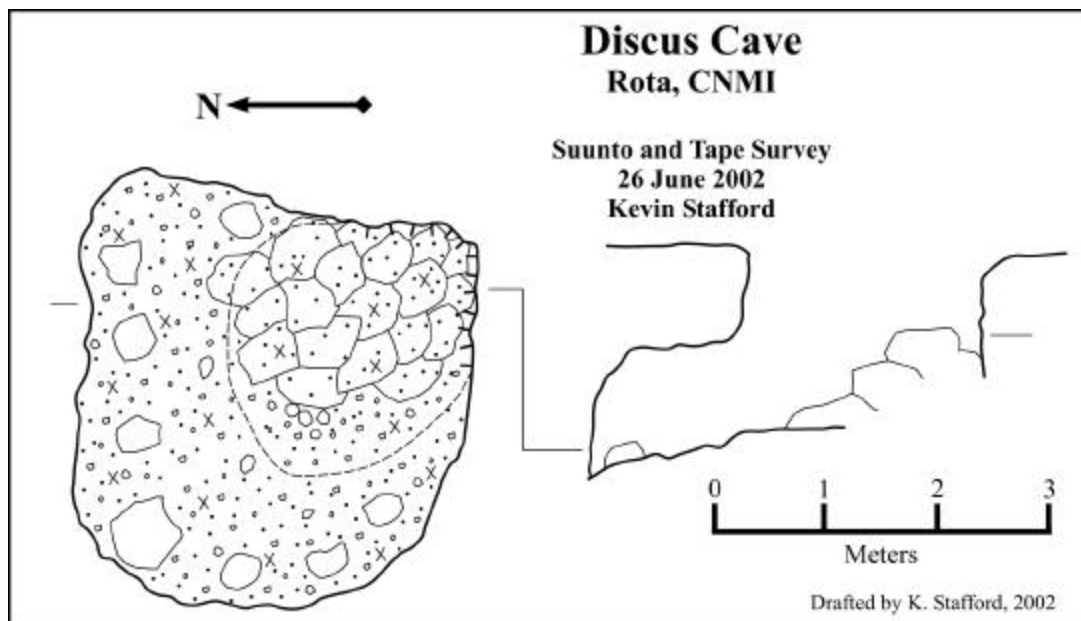
ROTA, CNMI



GRADE 5 SURVEY  
4 June 2004  
R. Camacho, M. Keel

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Figure B.39 Map of Diagonal Fissure



*Figure B.40 Map of Discus Cave*

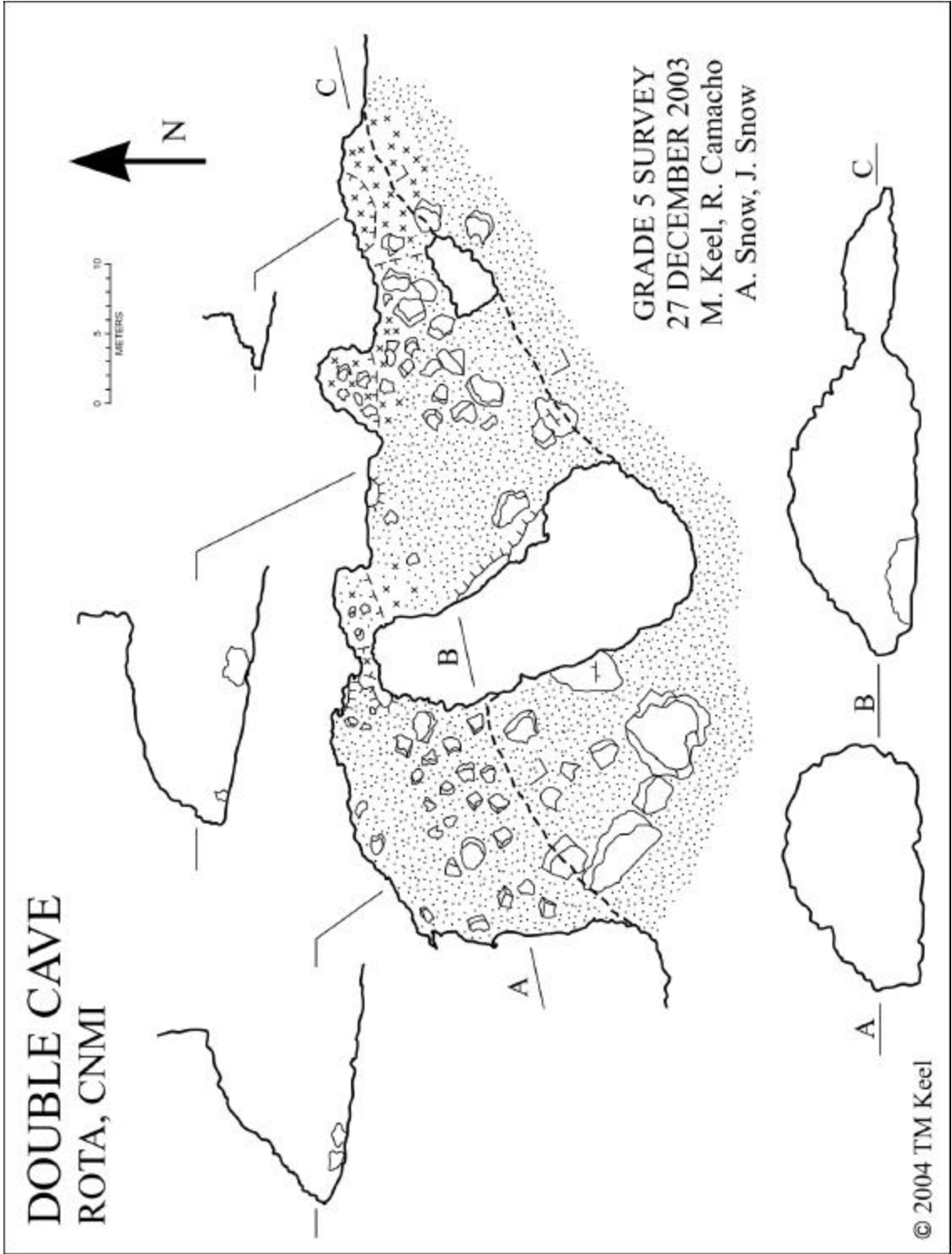
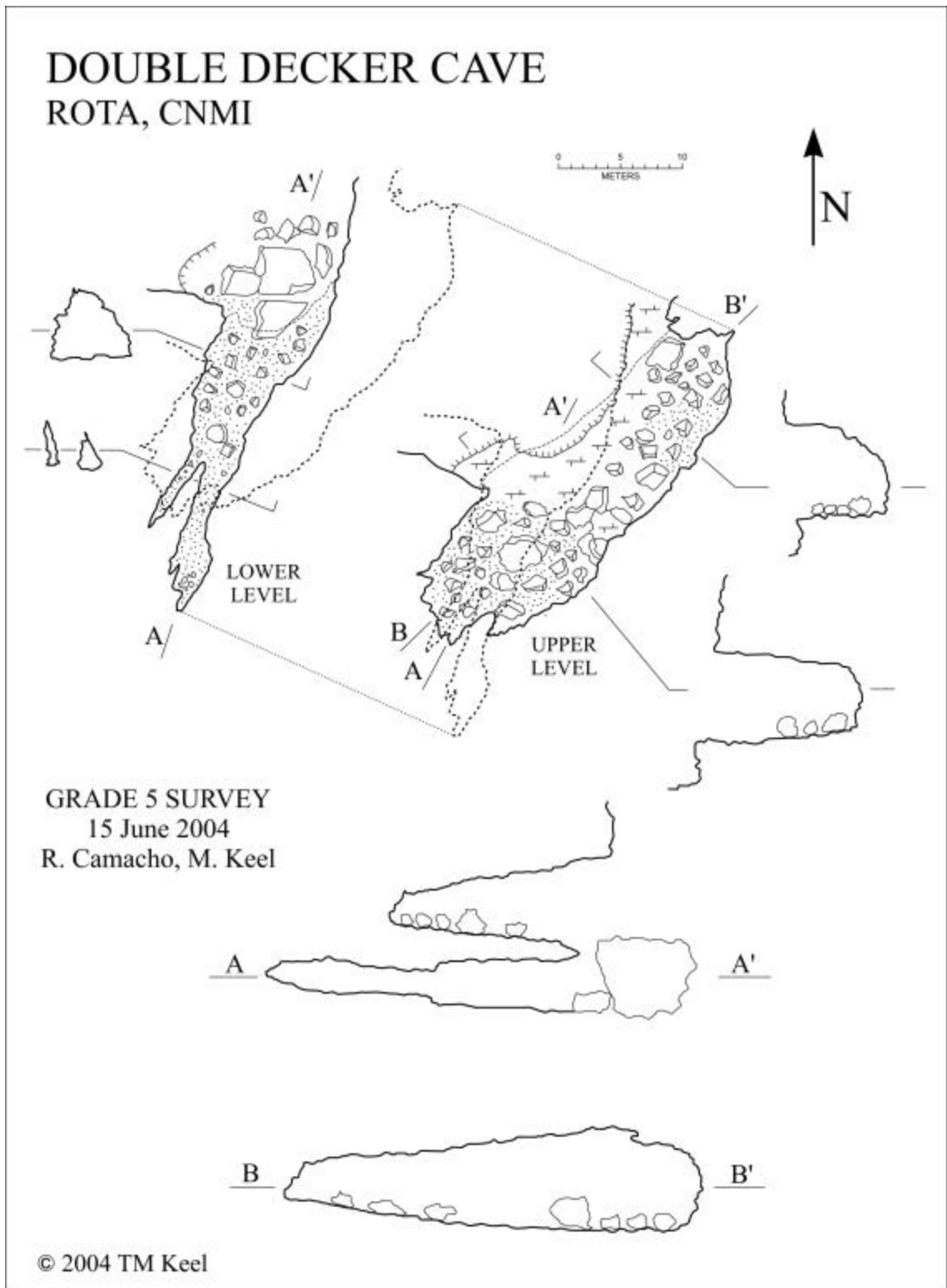
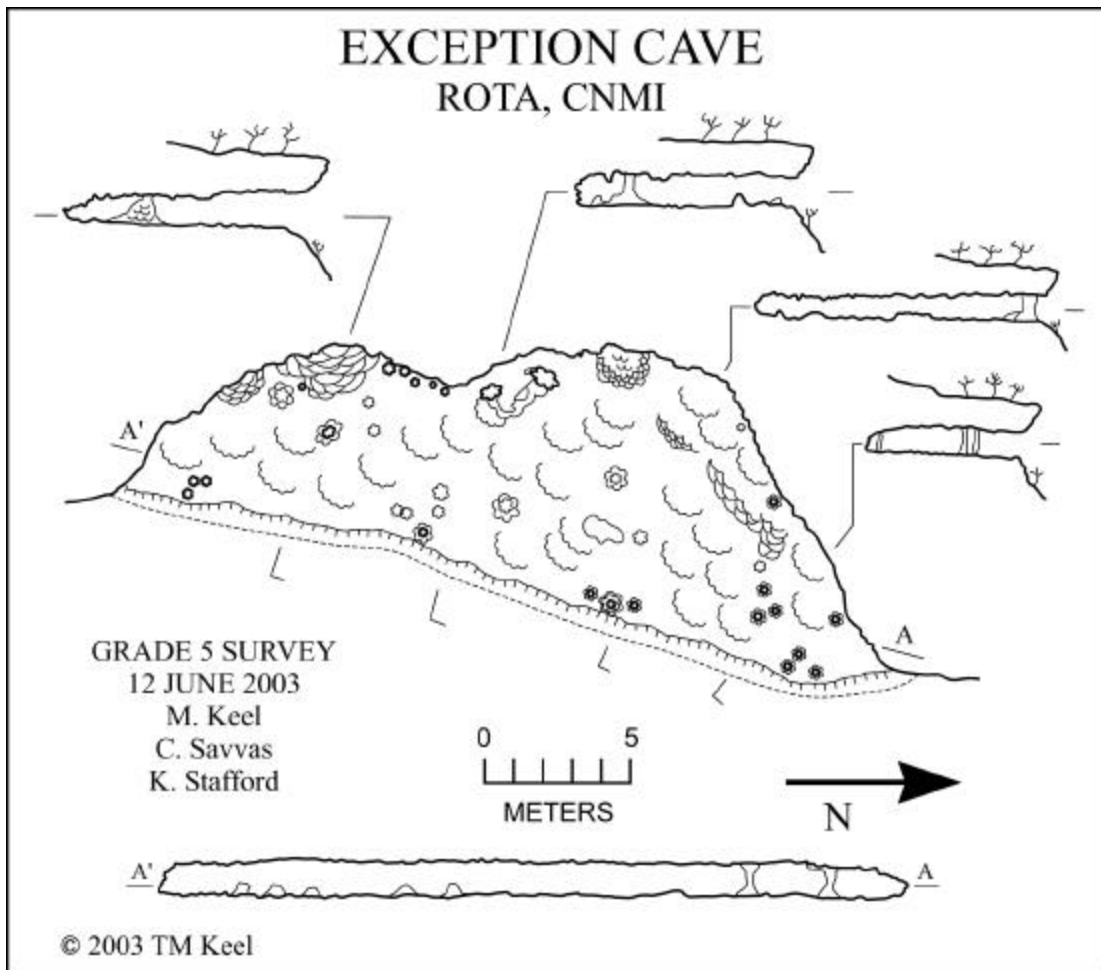


Figure B.41 Map of Double Cave





*Figure B.42 Map of Double Decker Cave*



*Figure B.43 Map of Exception Cave*

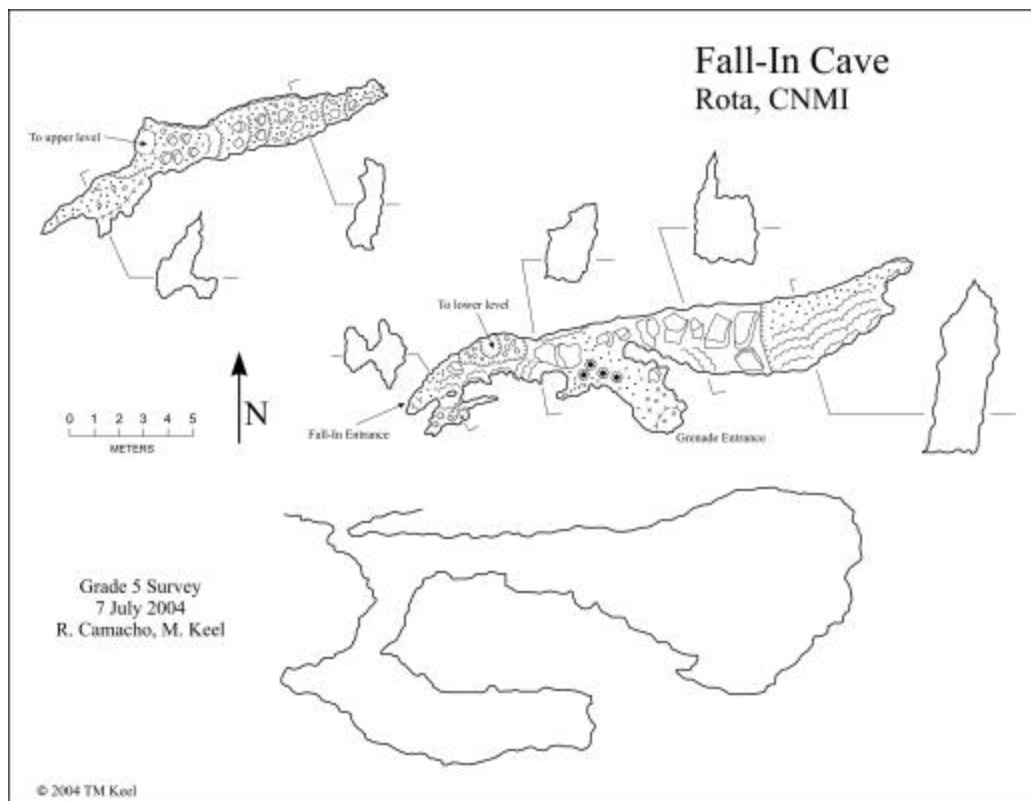


Figure B.43 Map of Fall-In Cave

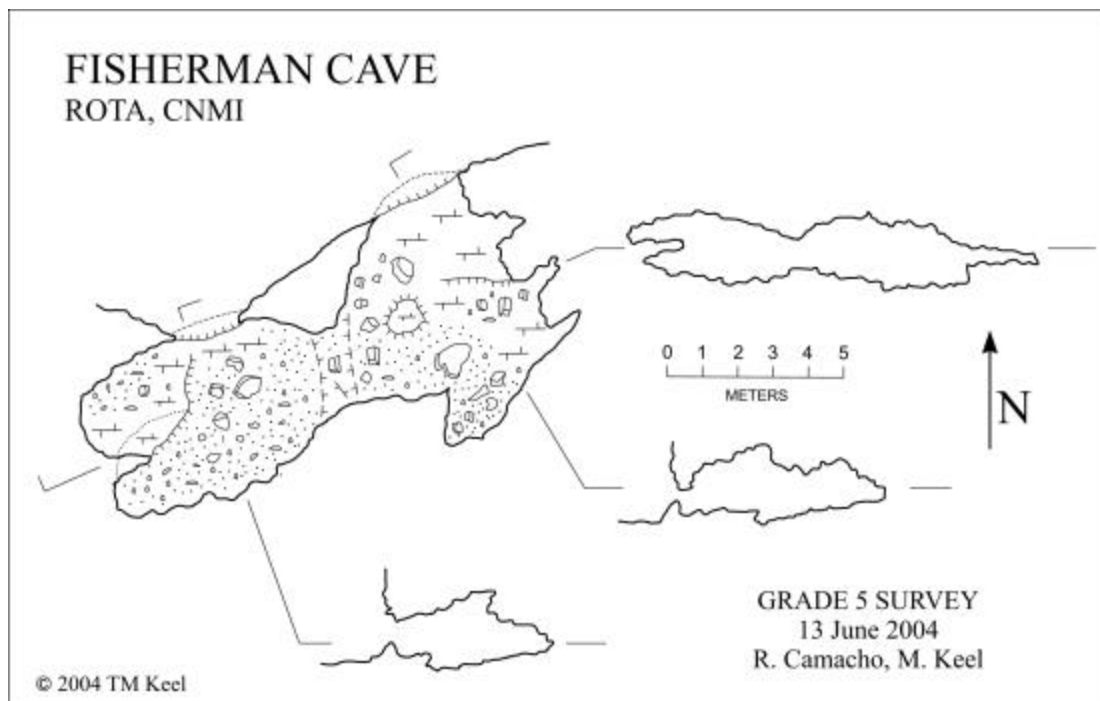
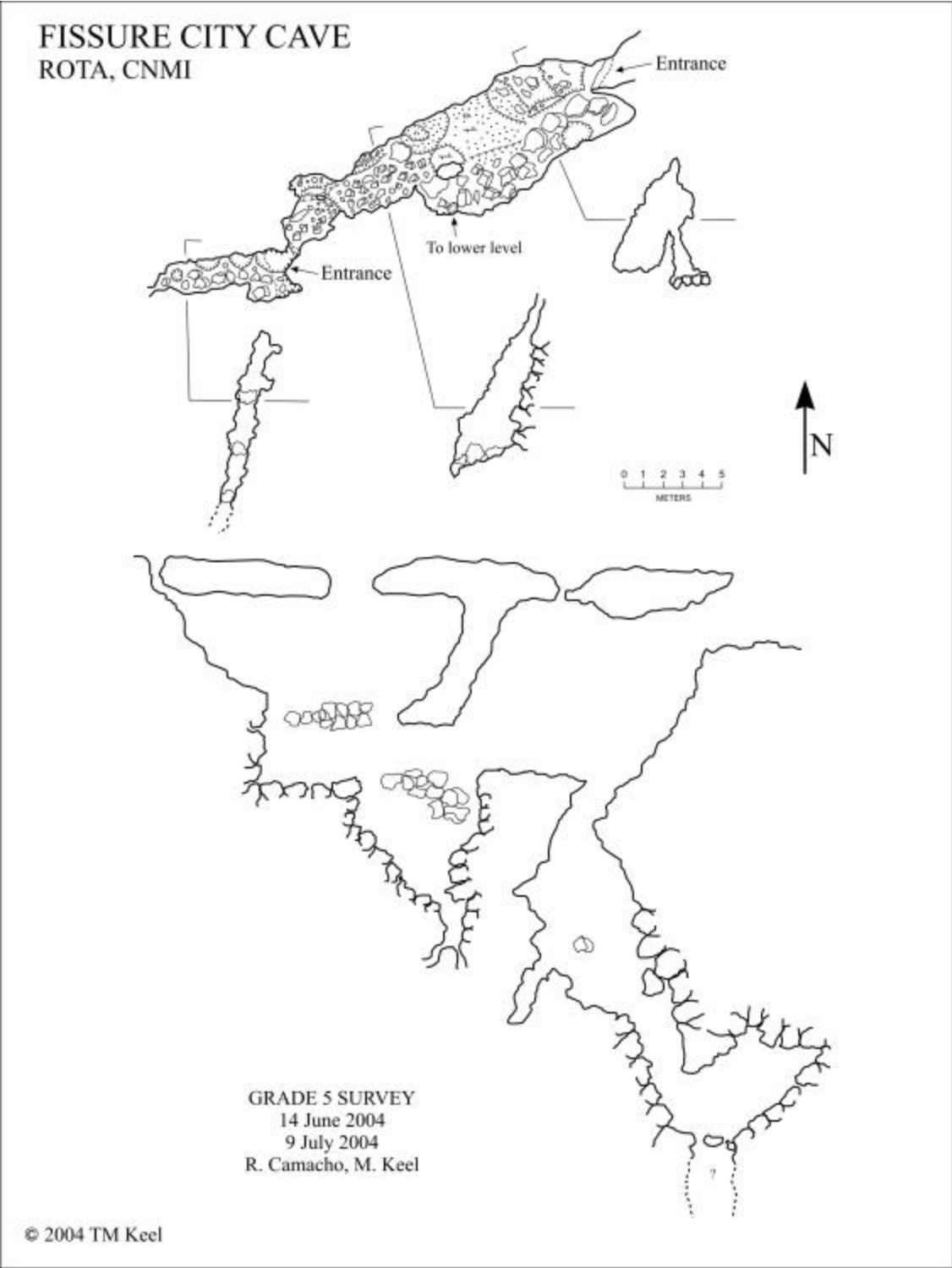
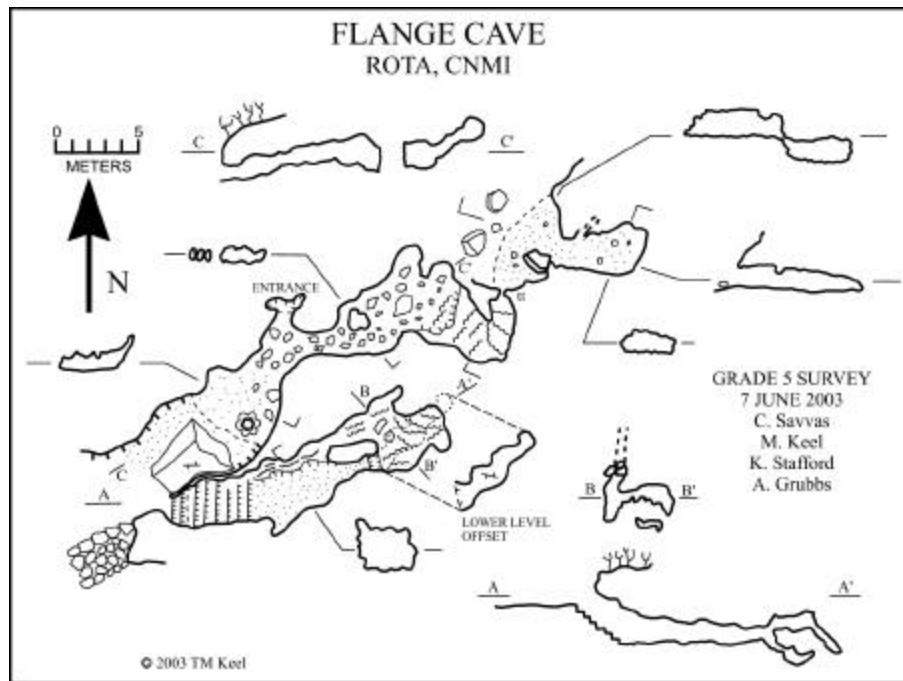


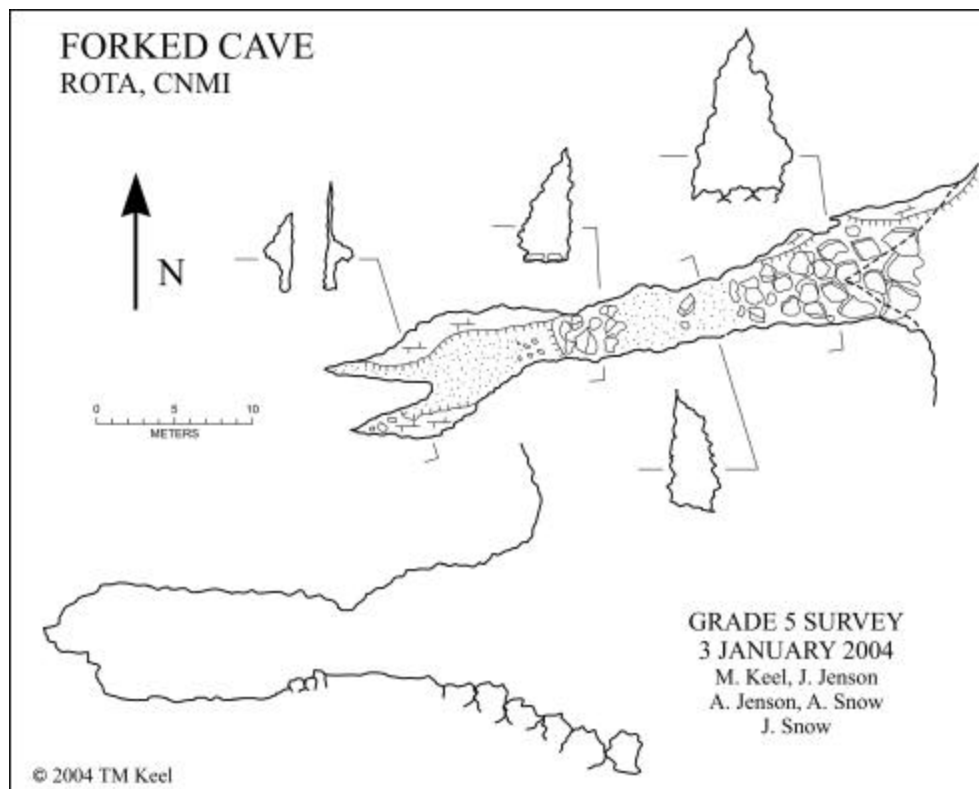
Figure B.45 Map of Fisherman Cave



*Figure B.46 Map of Fissure City Cave*



*Figure B.47 Map of Flange Cave*



*Figure B.48 Map of Forked Cave*

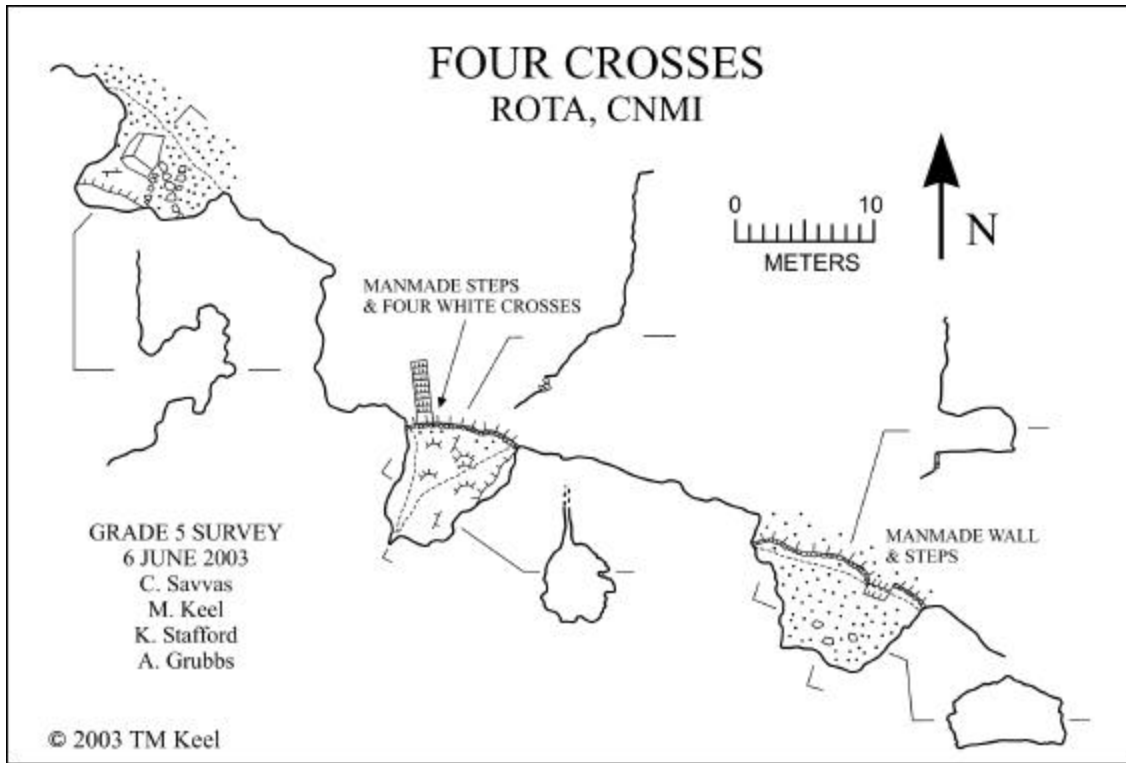


Figure B.49 Map of Four Crosses

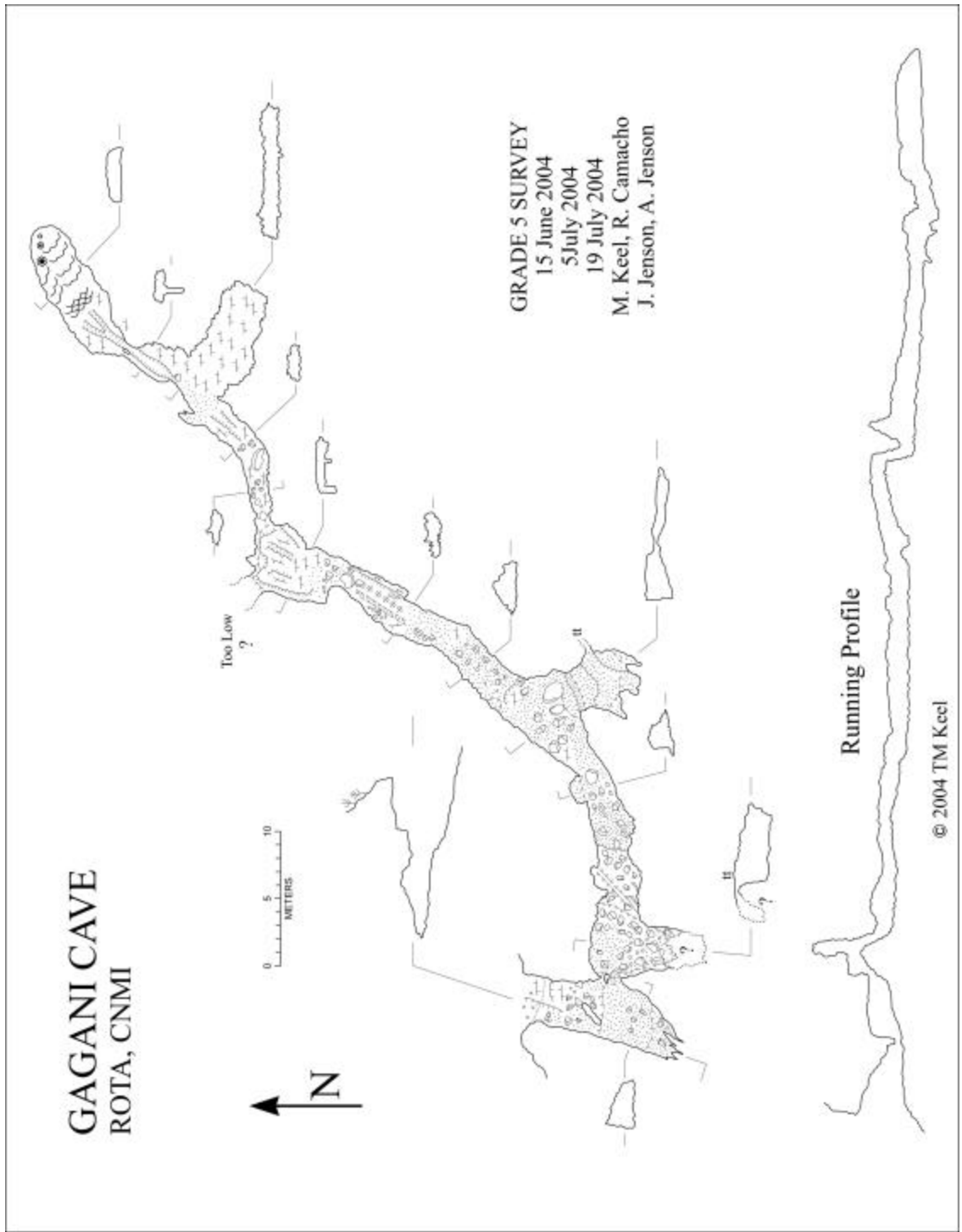


Figure B.50 Map of Gagani Cave

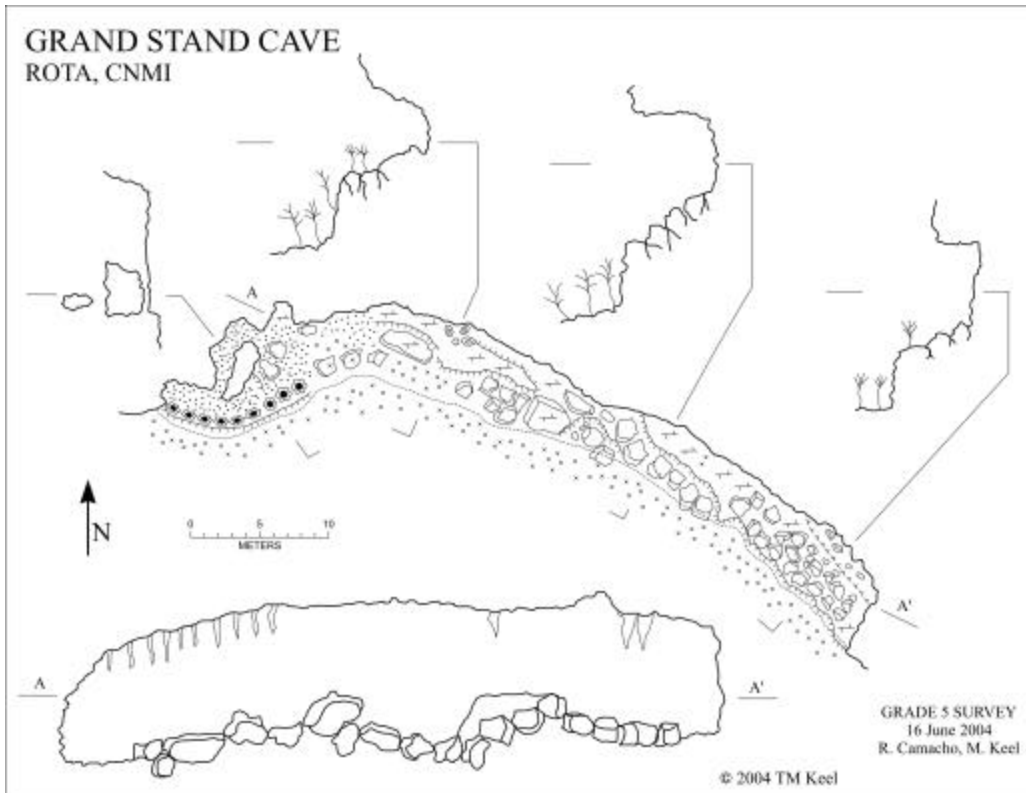


Figure B.51 Map of Grandstand Cave

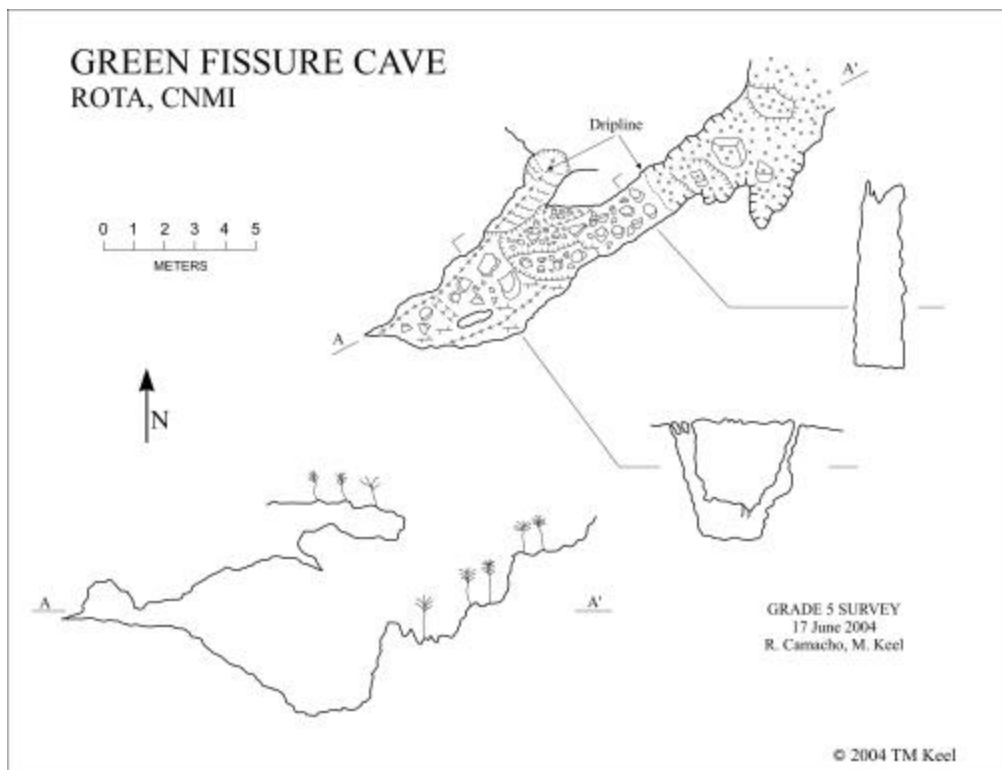
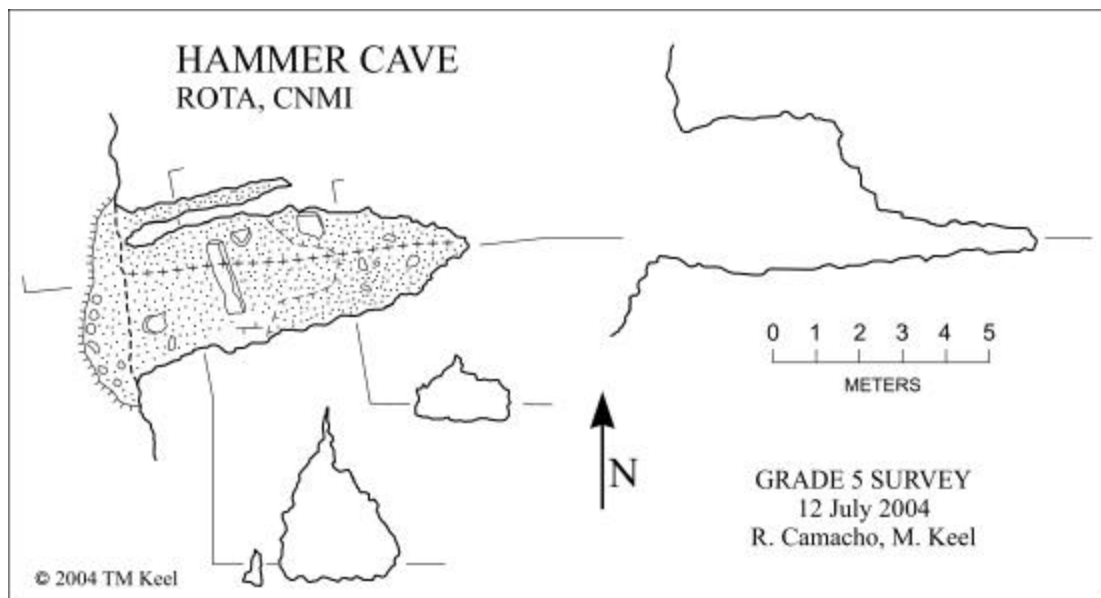


Figure B.52 Map of Green Fissure Cave





*Figure B.53 Map of Hammer Cave*

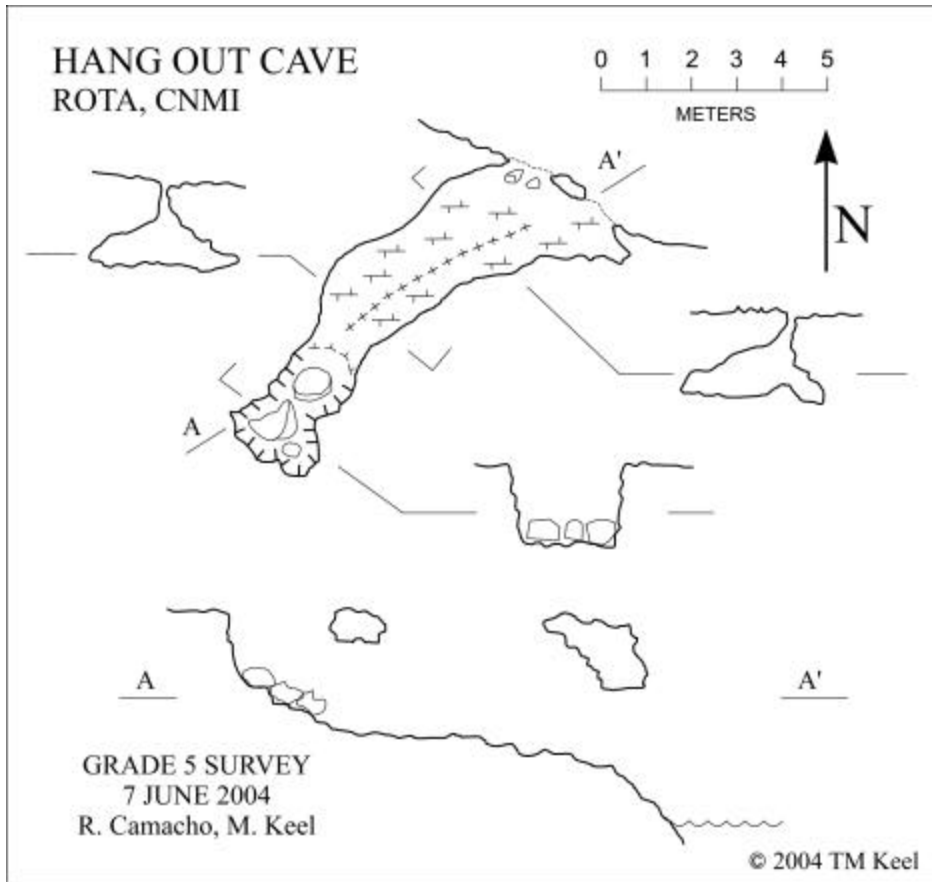


Figure B.54 Map of Hang Out Cave

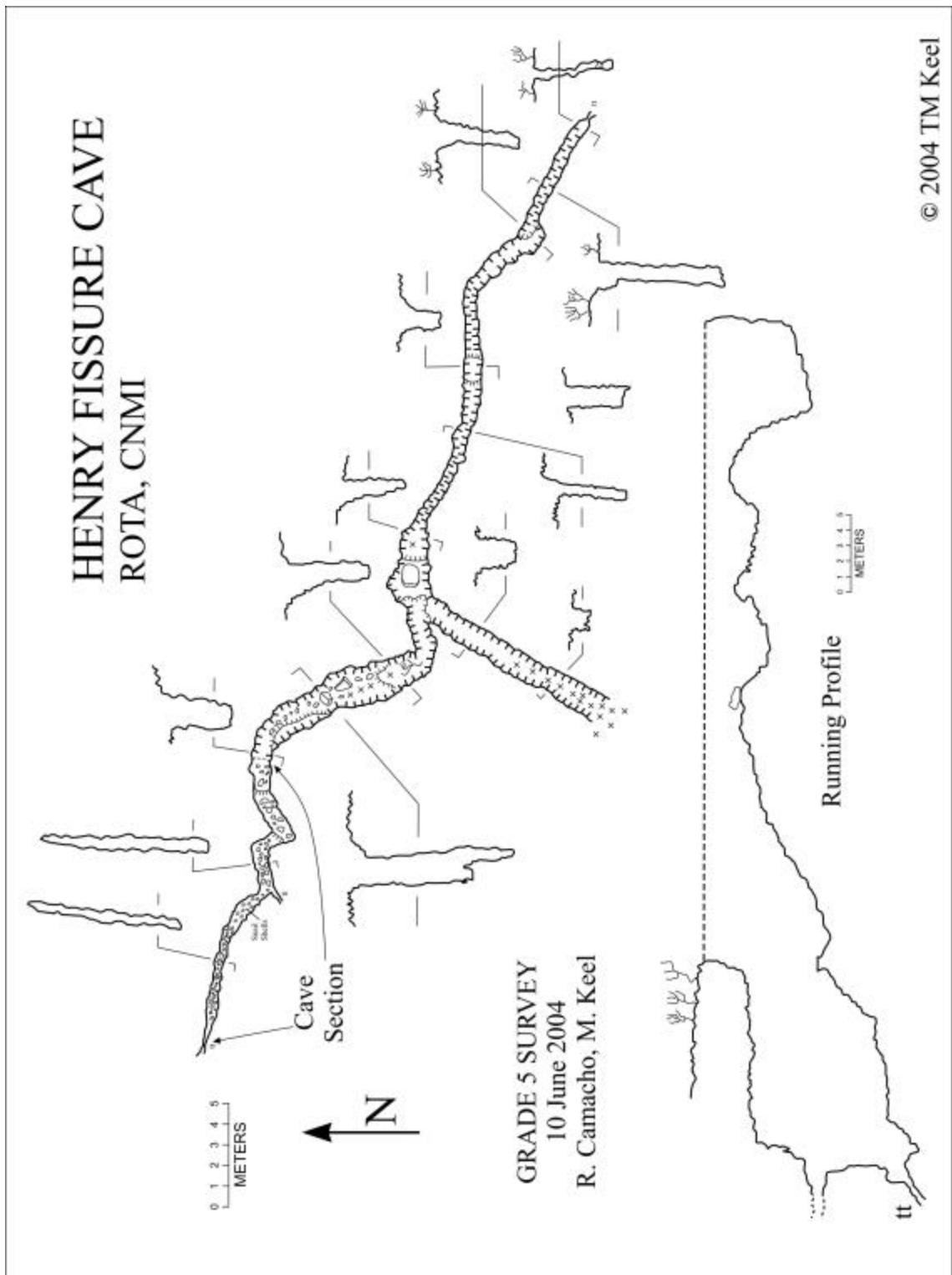


Figure B.55 Map of Henry Fissure Cave

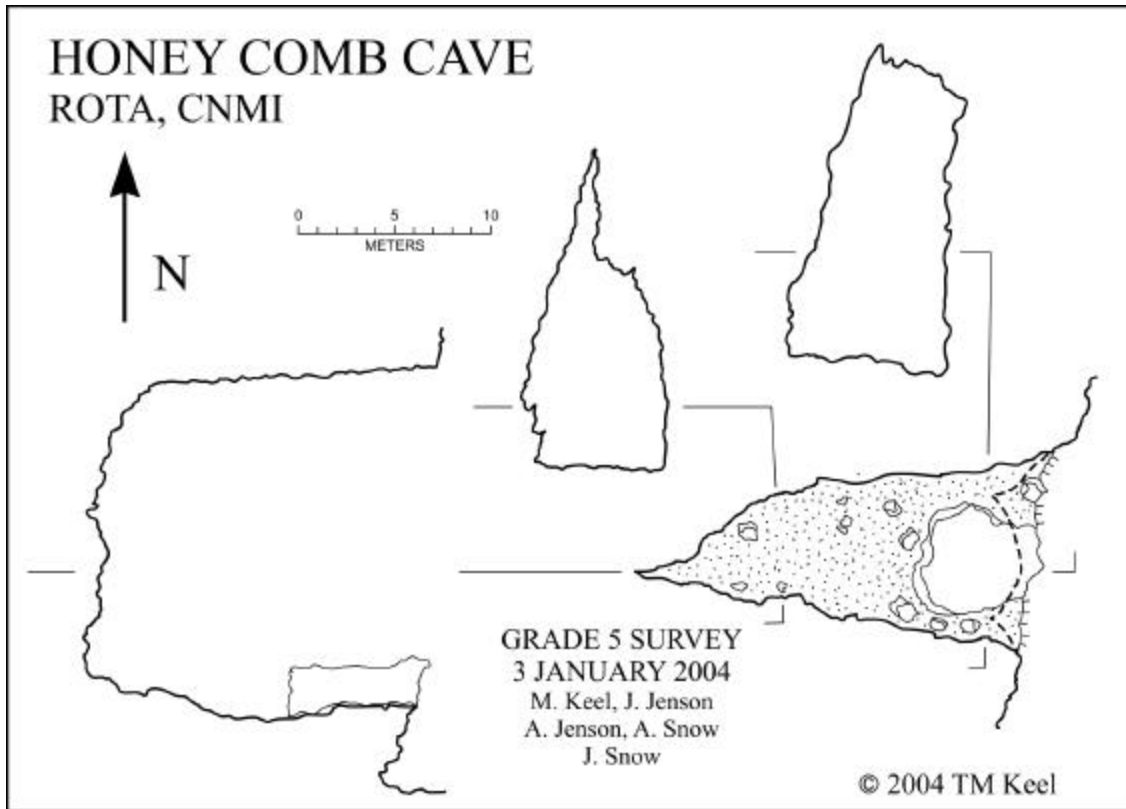


Figure B.56 Map of Honey Comb Cave

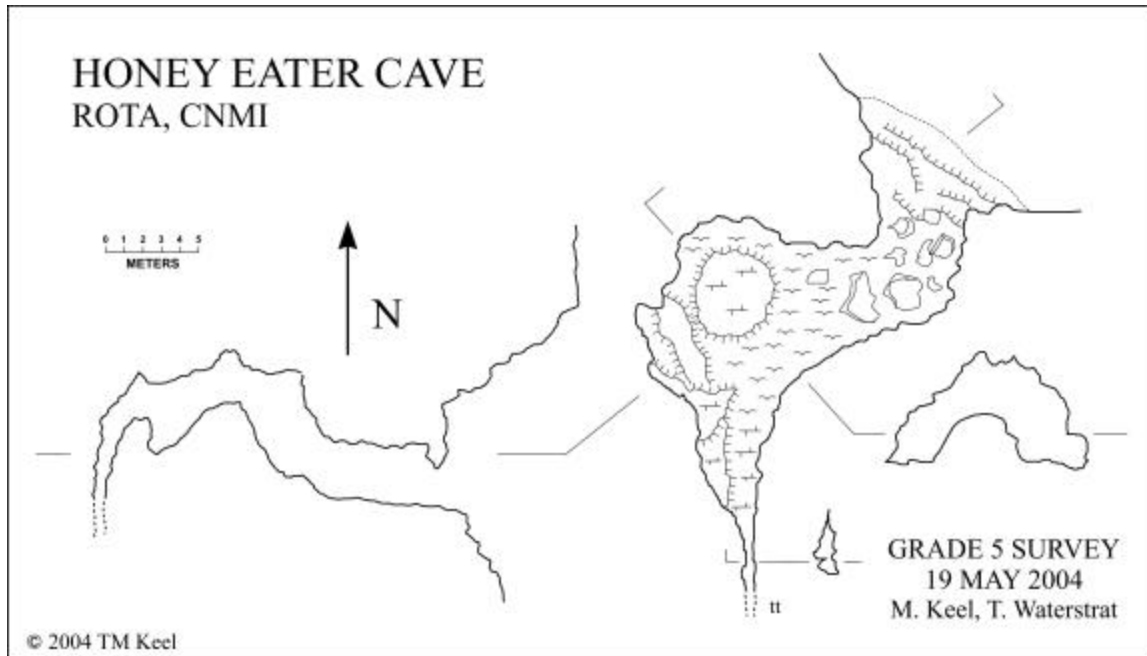


Figure B.57 Map of Honey Eater Cave

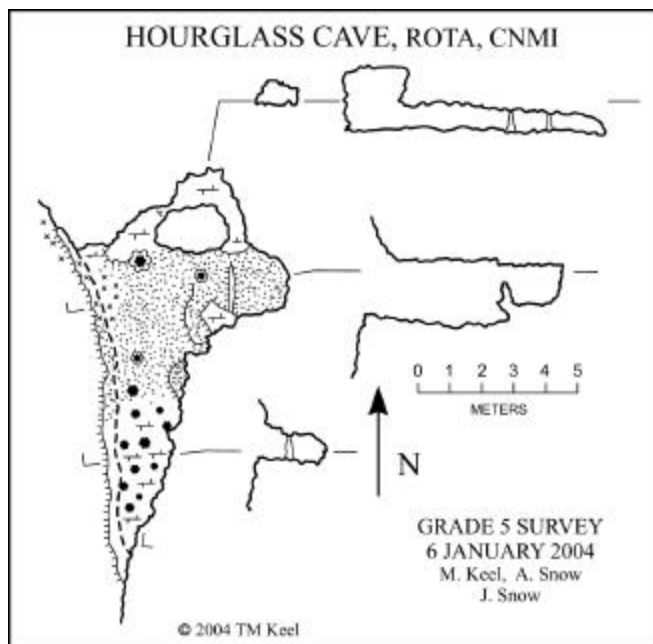


Figure B.58 Map of Hourglass Cave

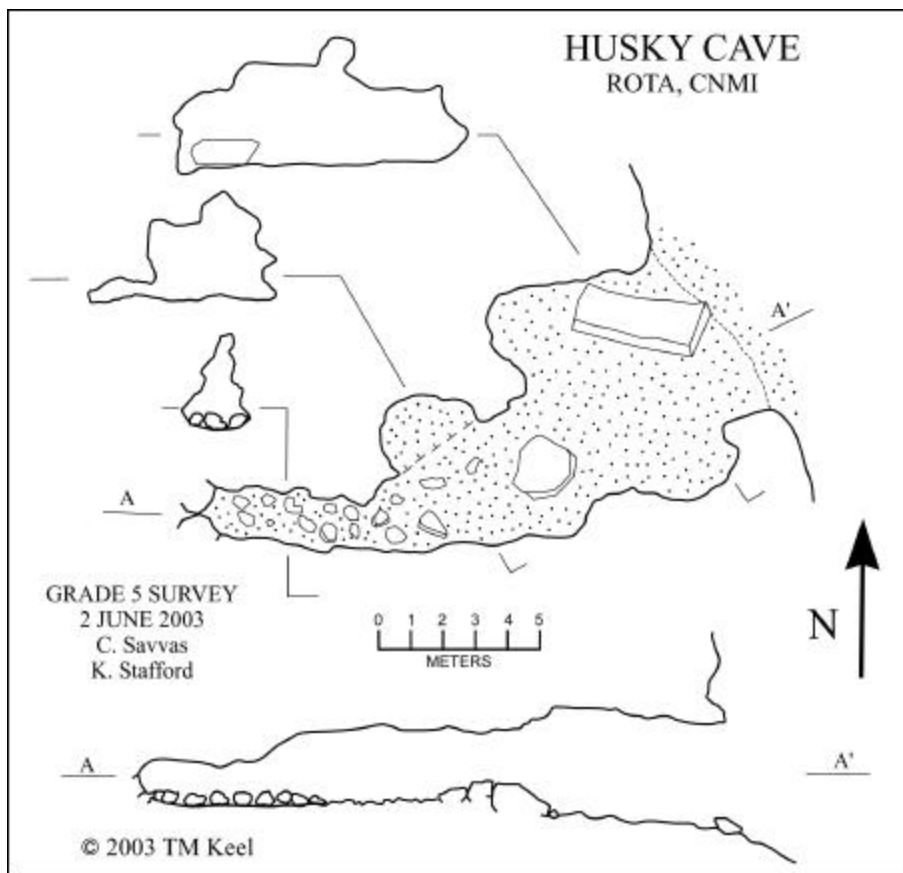


Figure B.59 Map of Husky Cave

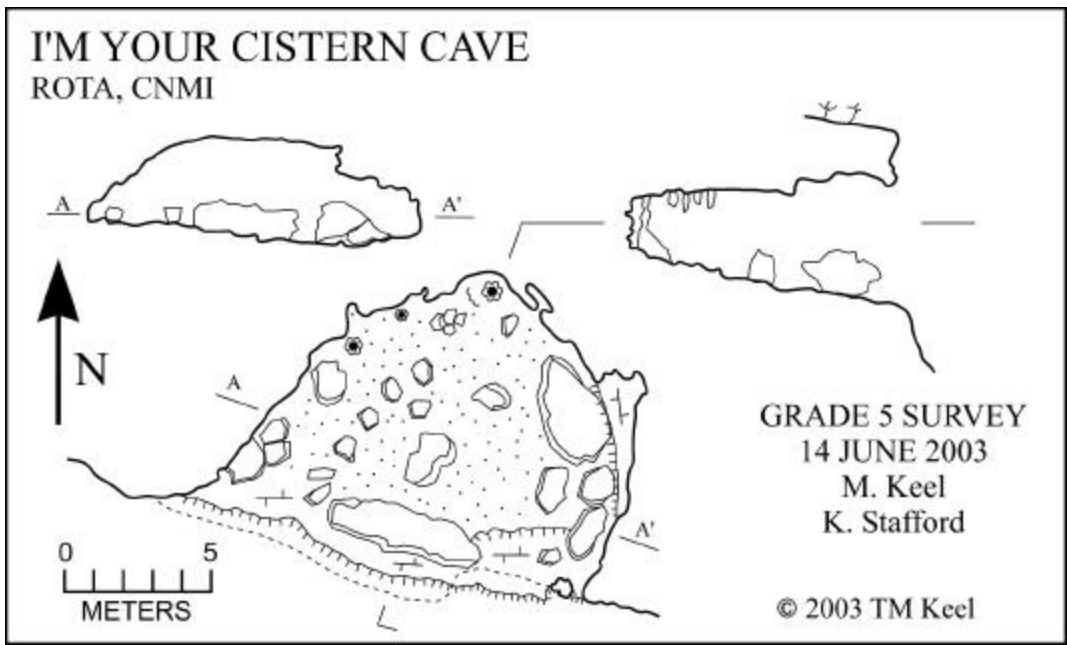


Figure B.60 Map of I'm Your Cistern Cave

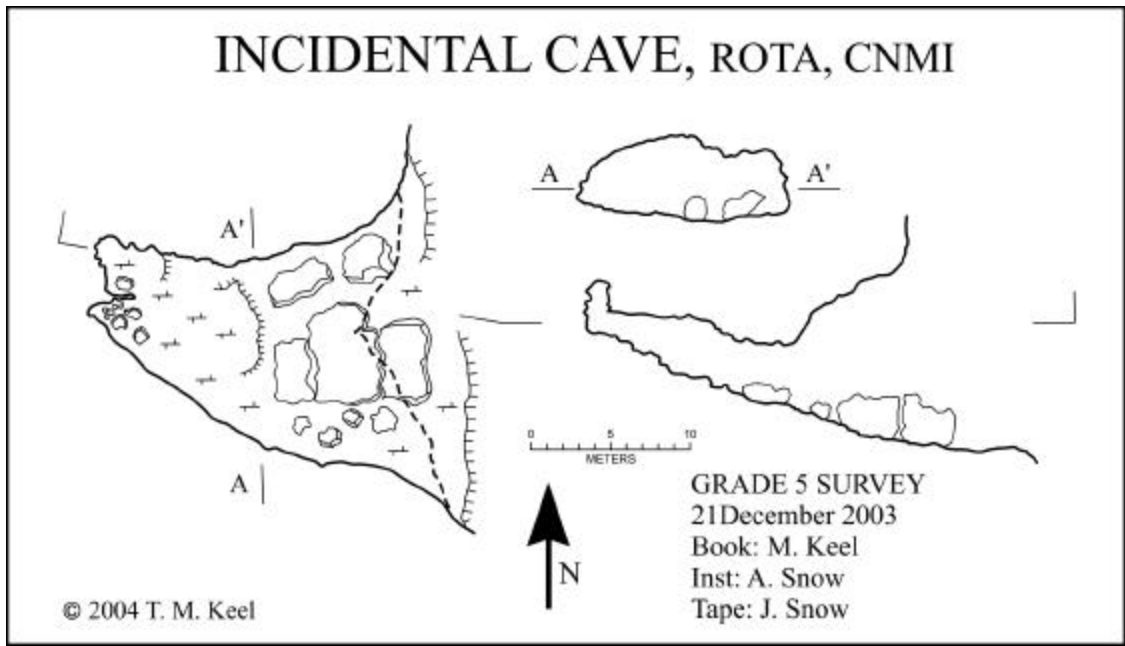


Figure B.61 Map of Incidental Cave

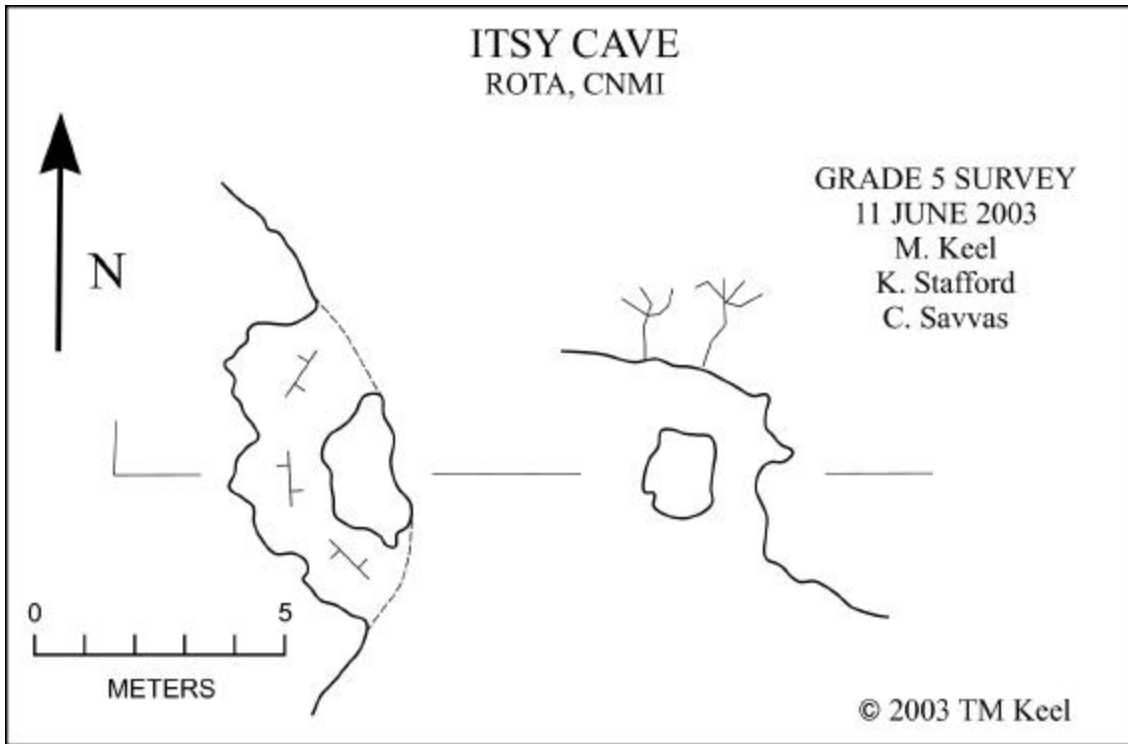


Figure B.62 Map of Itsy Cave

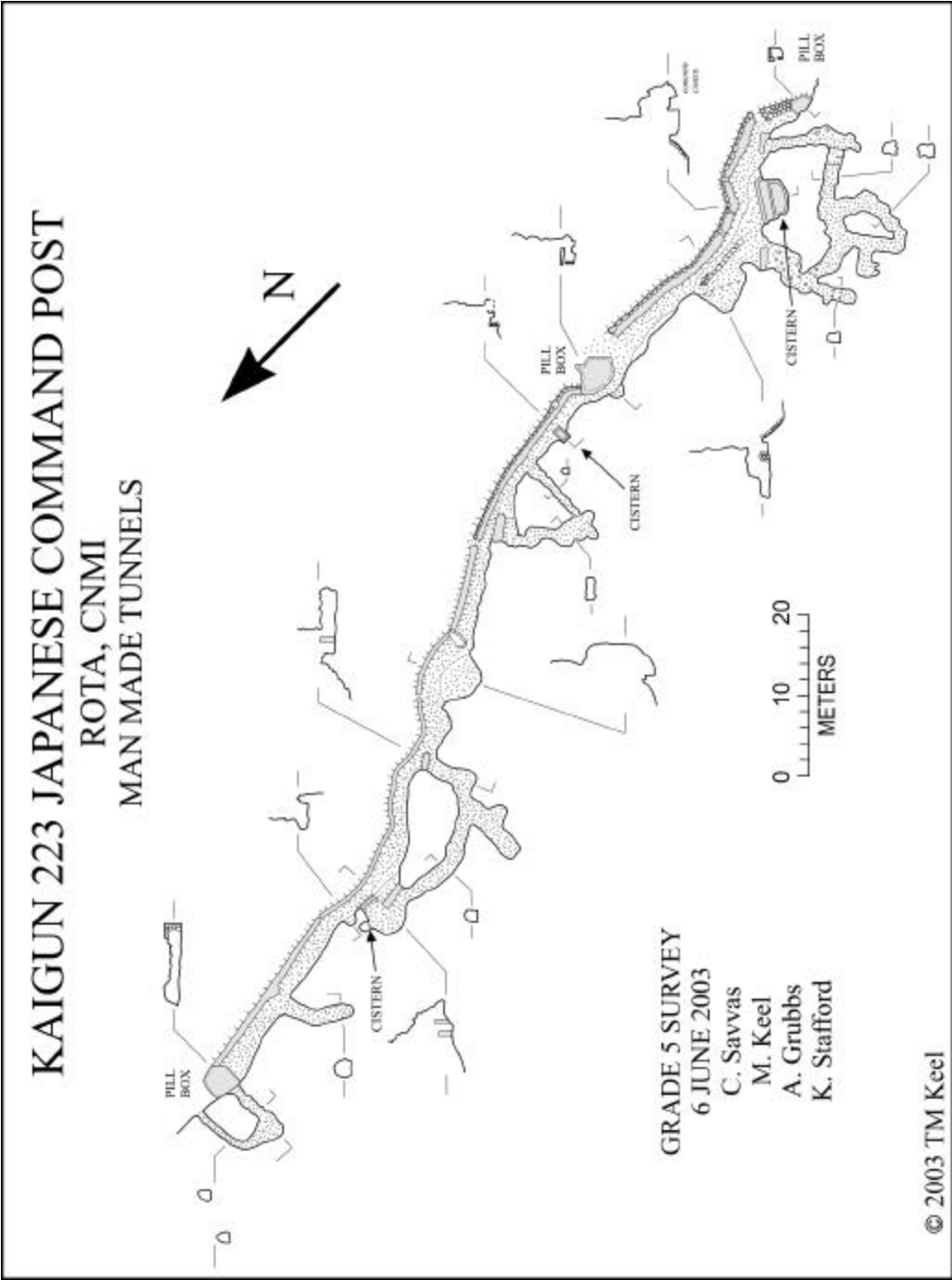
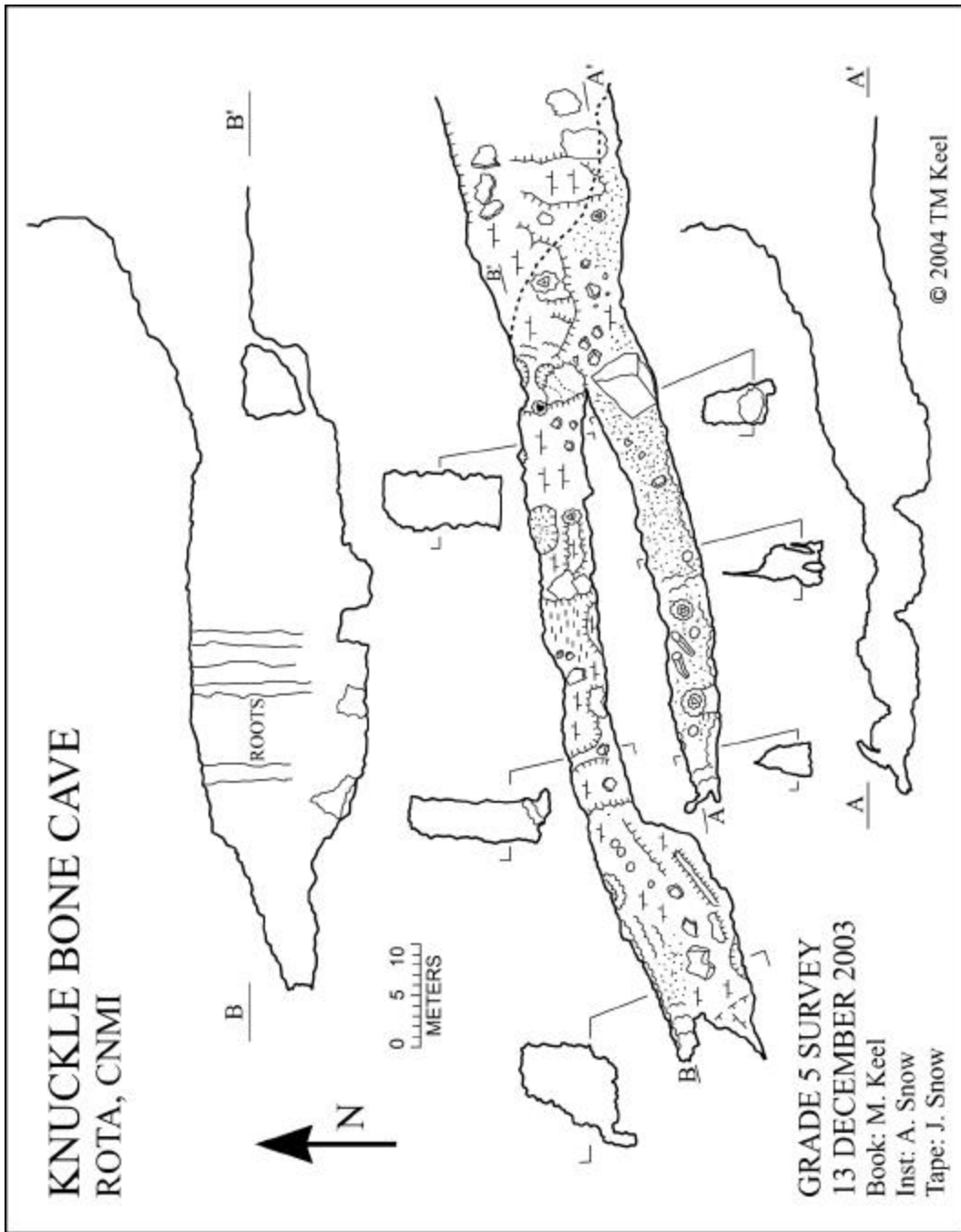


Figure B.63 Map of Kaigun 223 Japanese Command Post





*Figure B.64 Map of Knucklebone Cave*

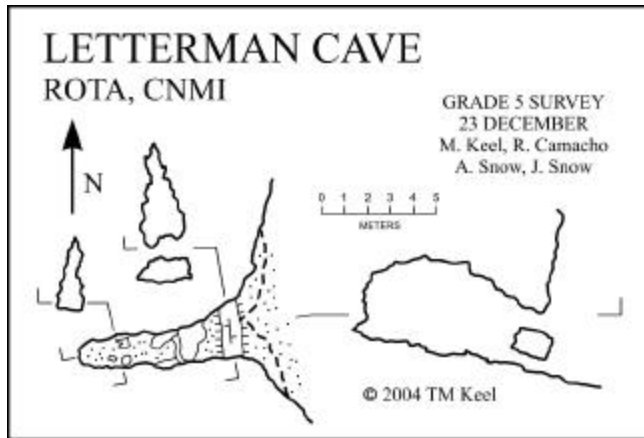


Figure B.65 Map of Letterman Cave

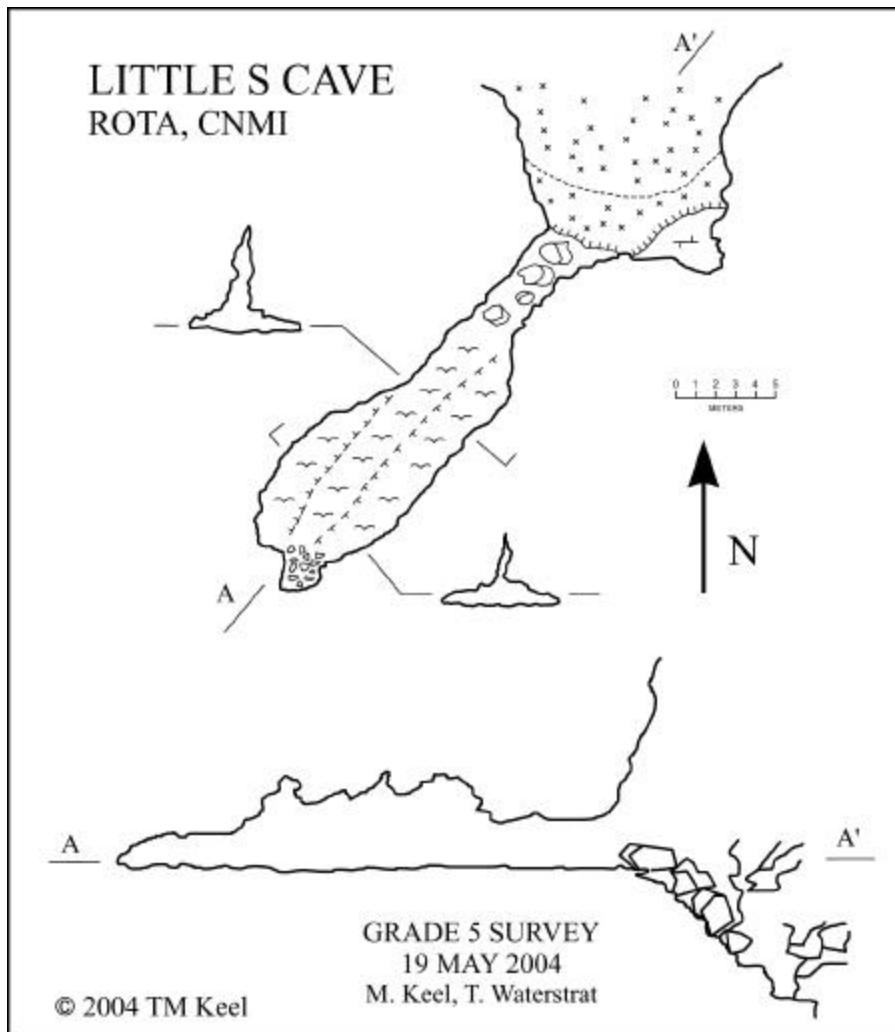


Figure B.66 Map of Little S Cave

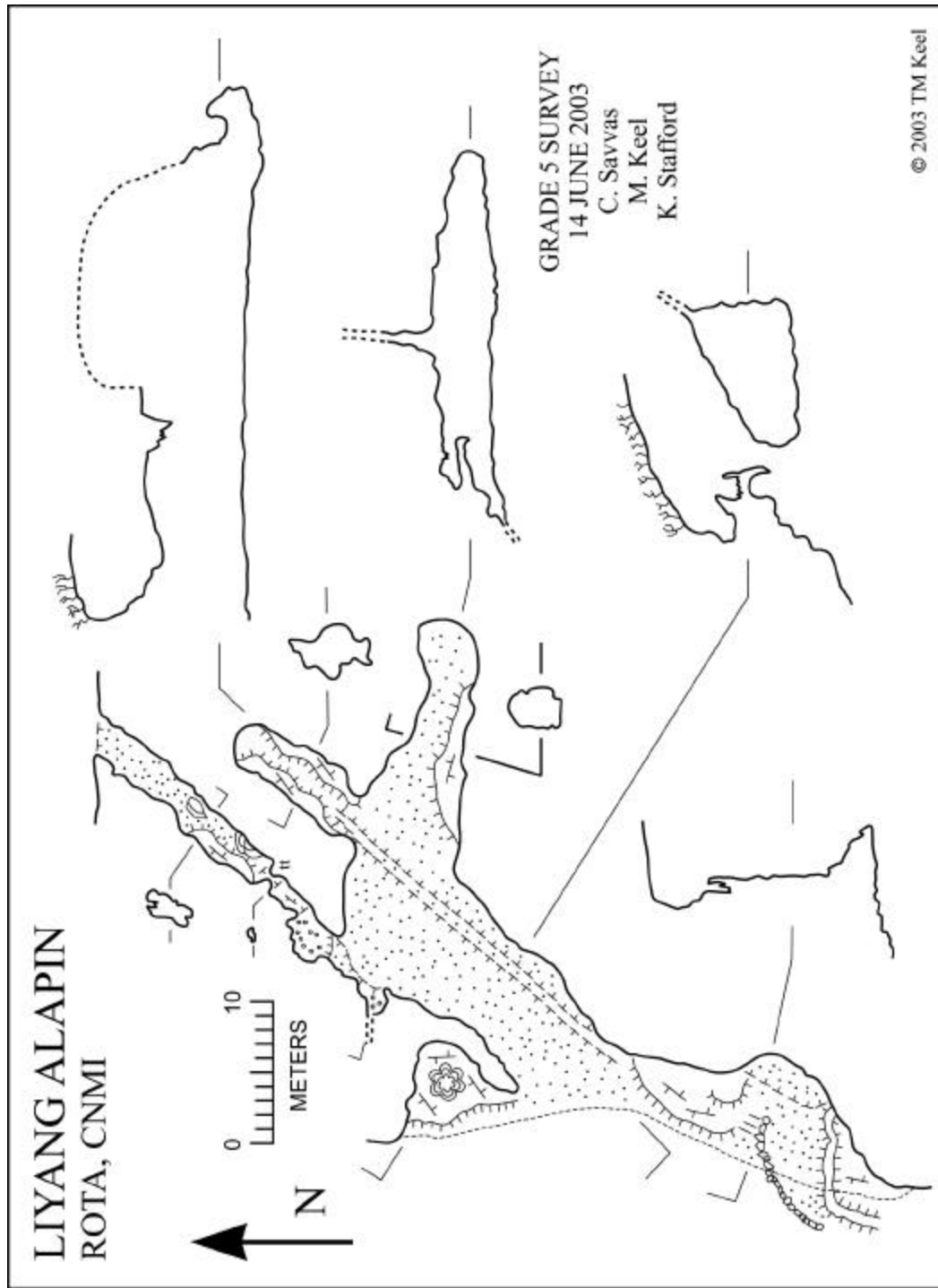


Figure B.67 Map of Liyang Alapin

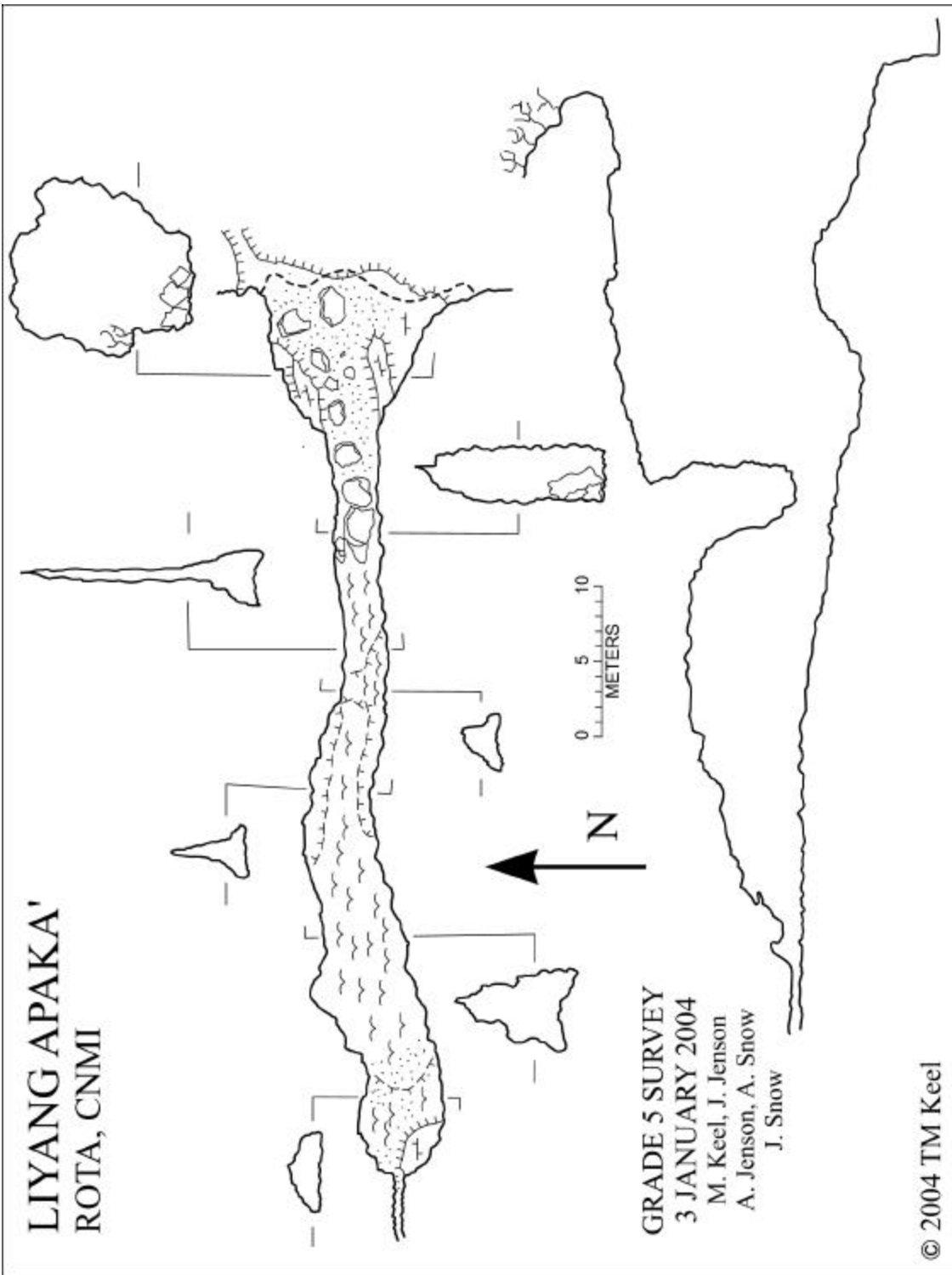
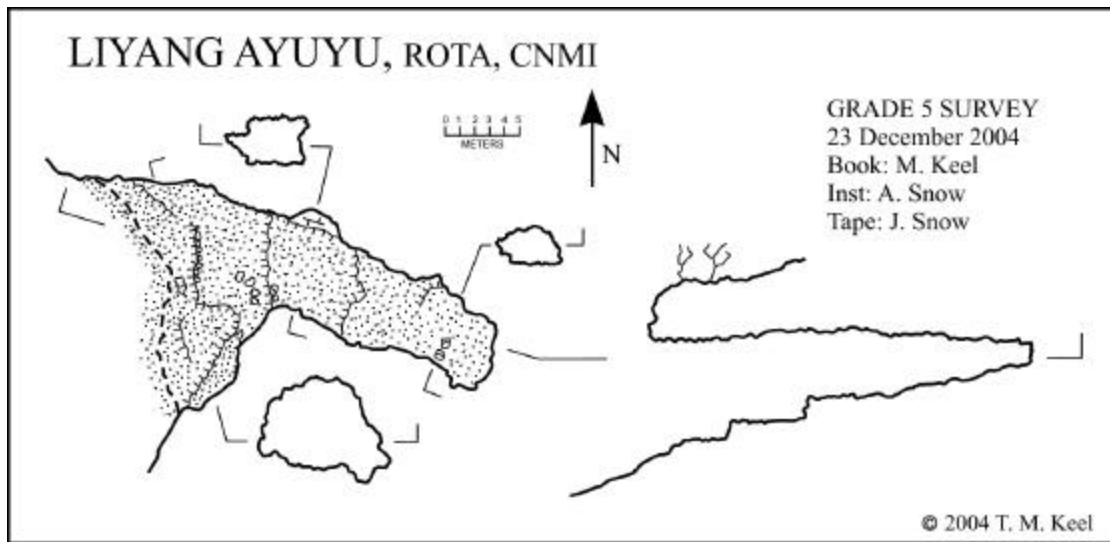


Figure B.68 Map of Liyang Apaka'



*Figure B.69 Map of Liyang Ayuyu*

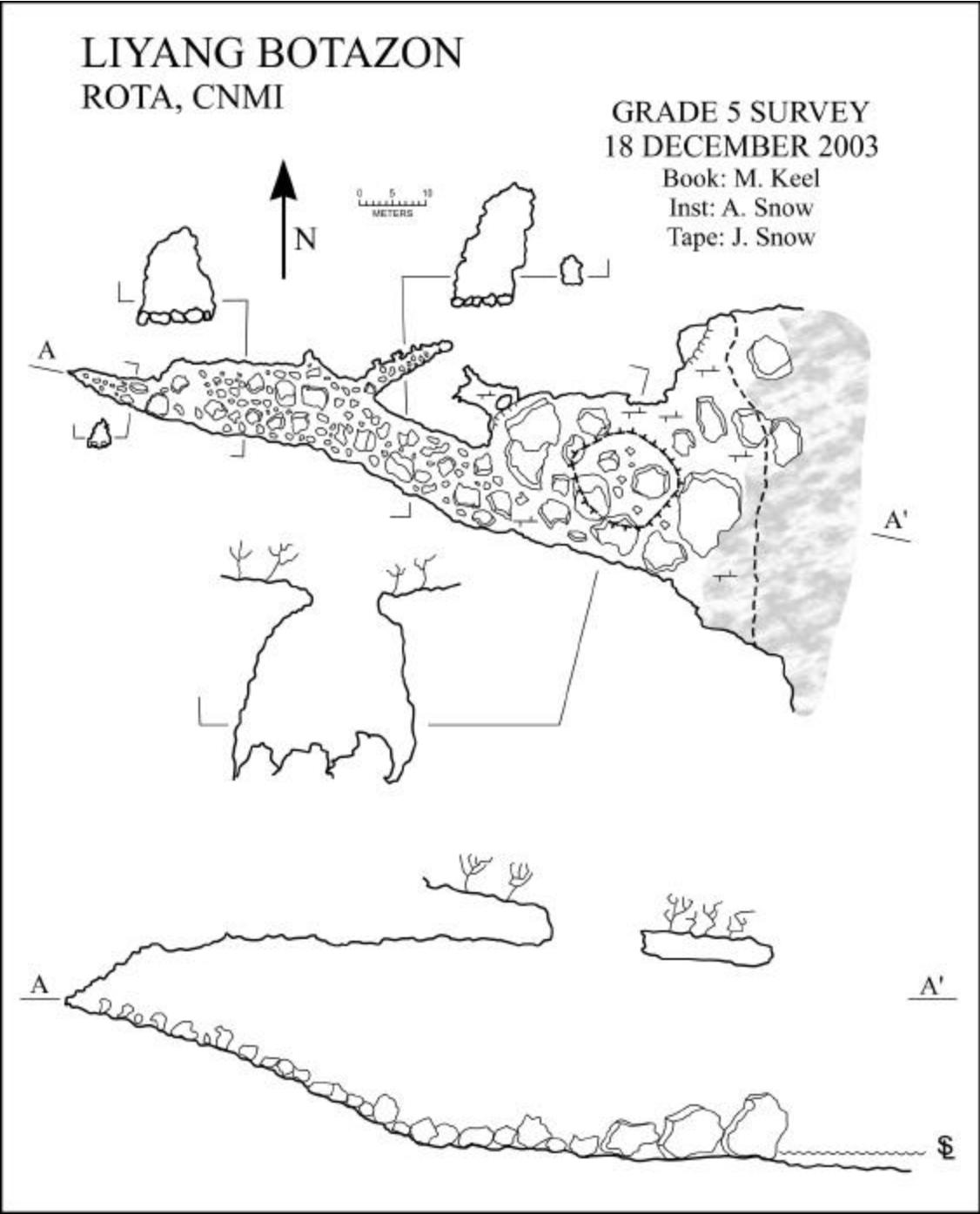
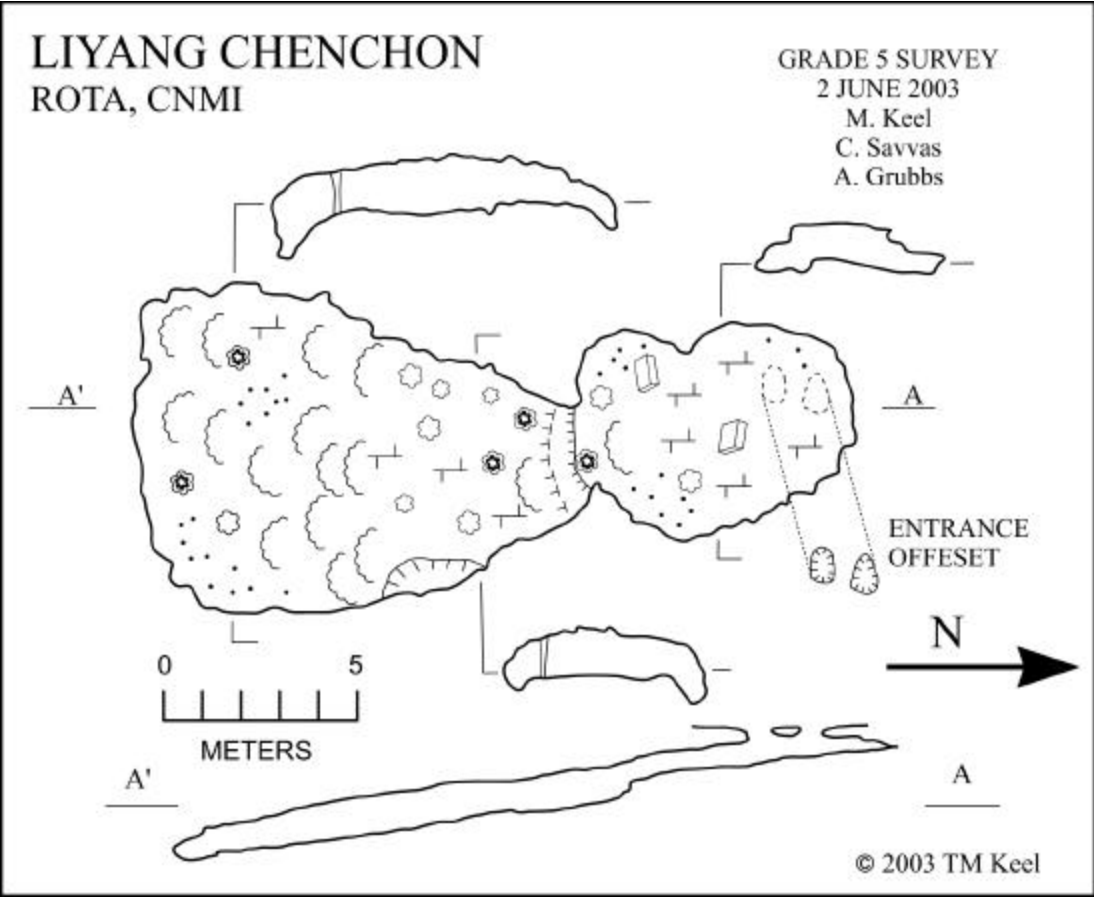


Figure B.70 Liyang Botazon



*Figure B.71 Map of Liyang Chenchon*

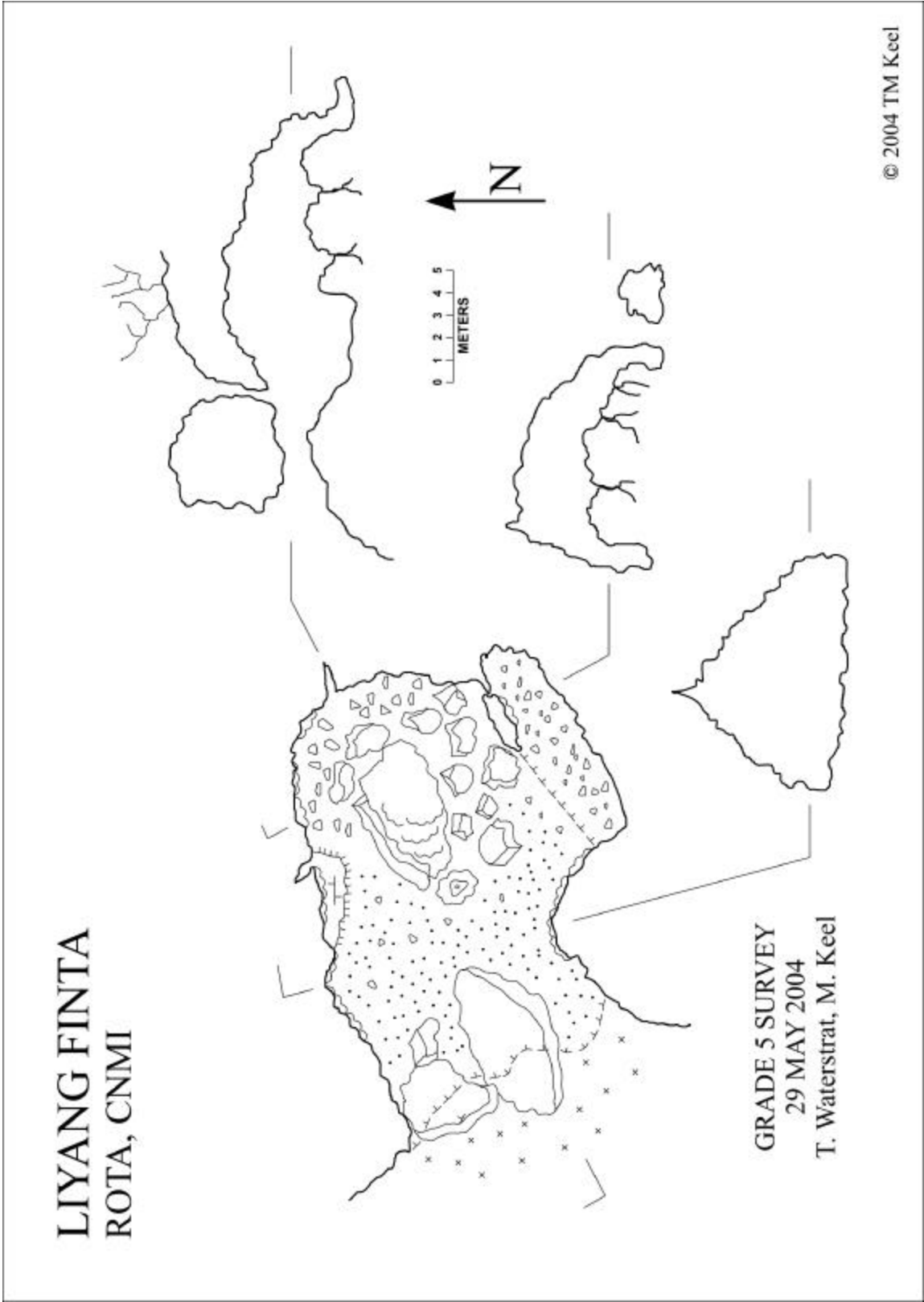


Figure B.72 Map of Liyang Finta



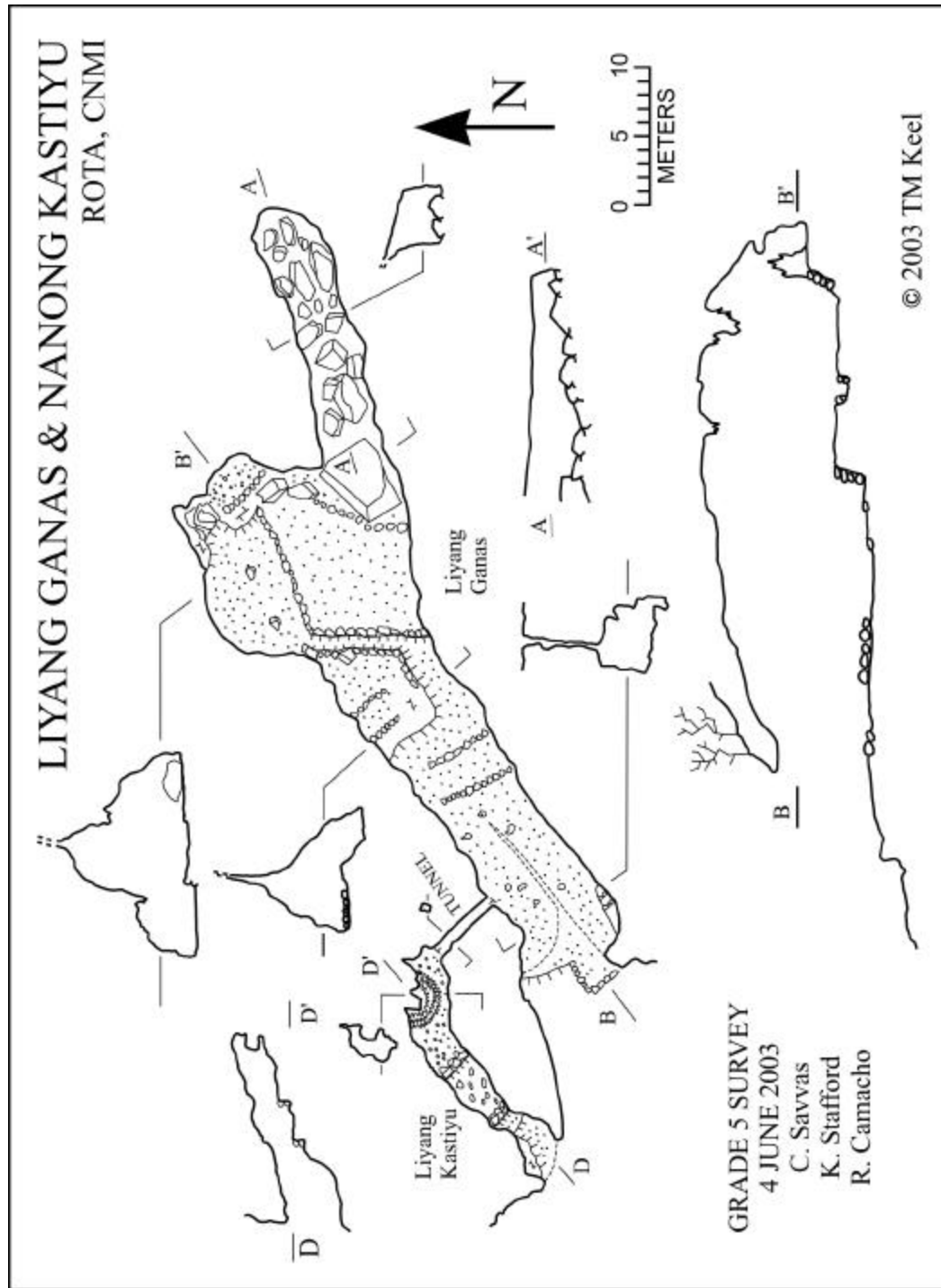


Figure B.73 Map of Liyang Ganas and Nanong Kastiyu

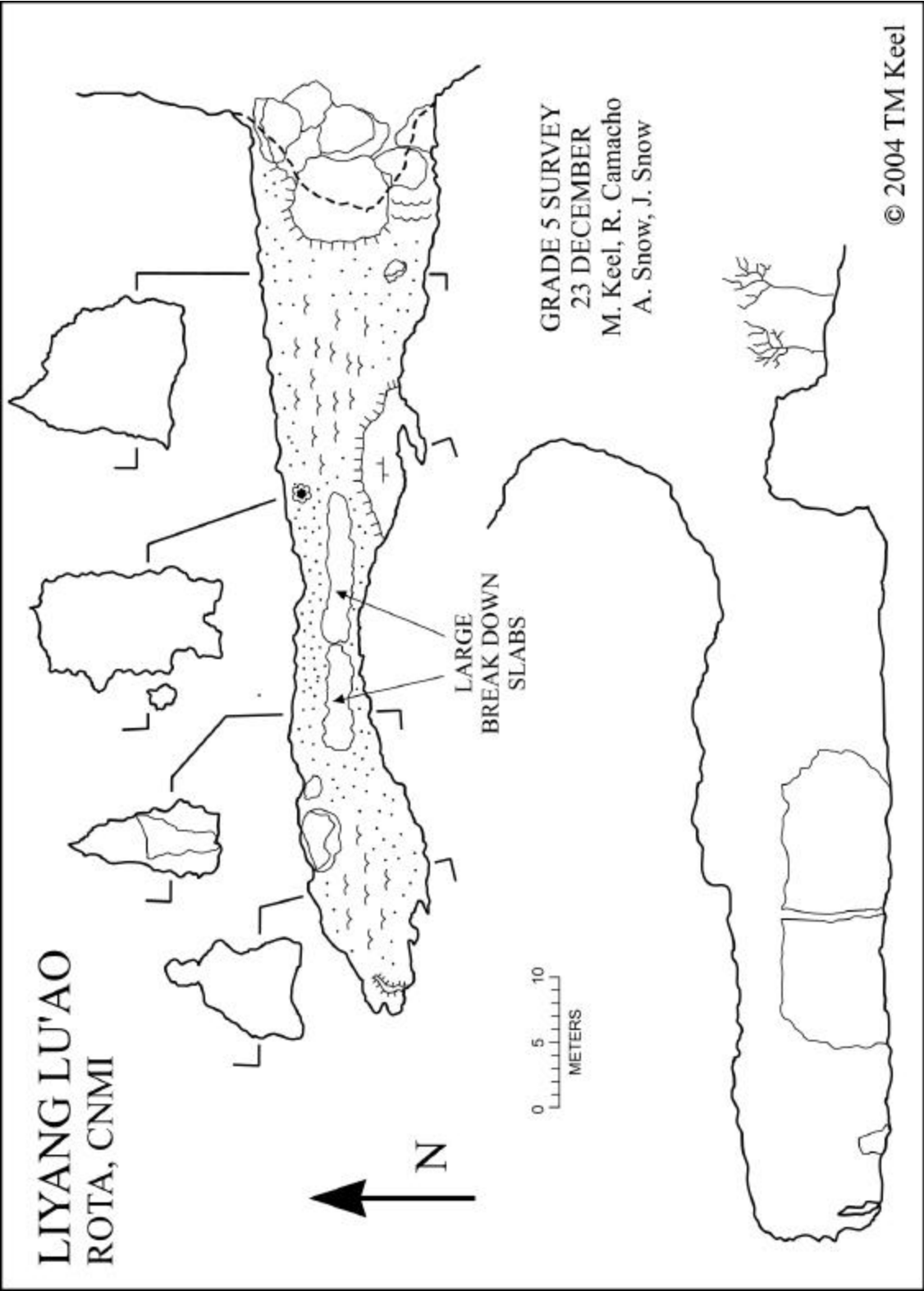


Figure B.74 Map of Liyang Lu'ao  
136

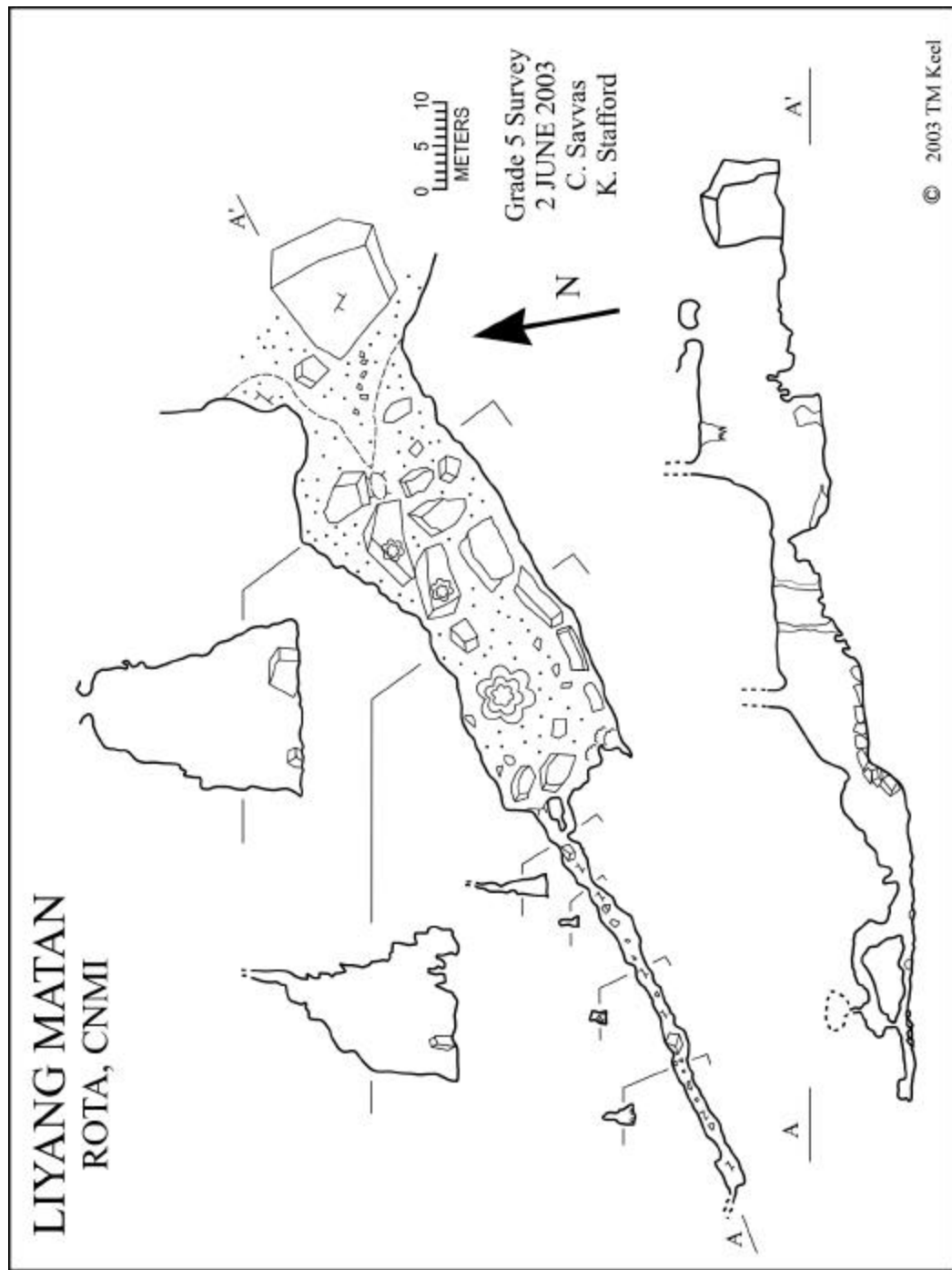


Figure B.75 Map of Liyang Matan

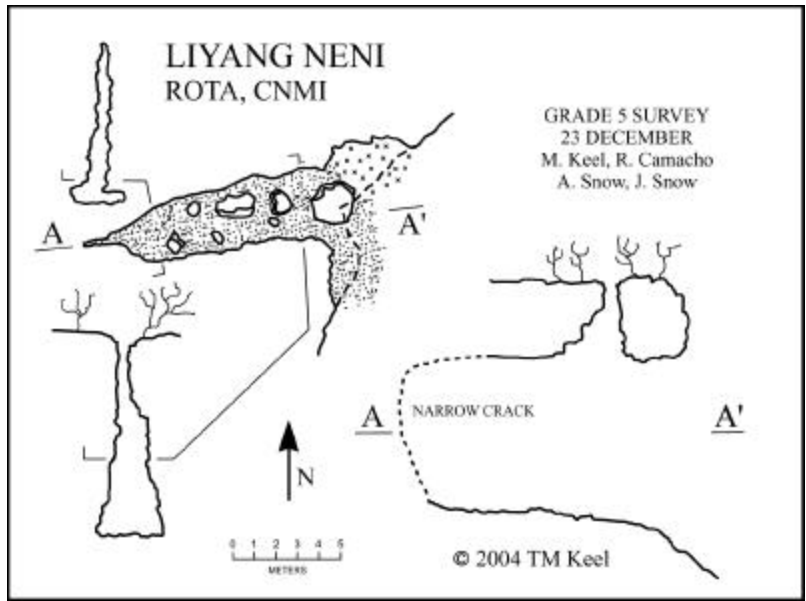


Figure B.76 Map of Liyang Neni

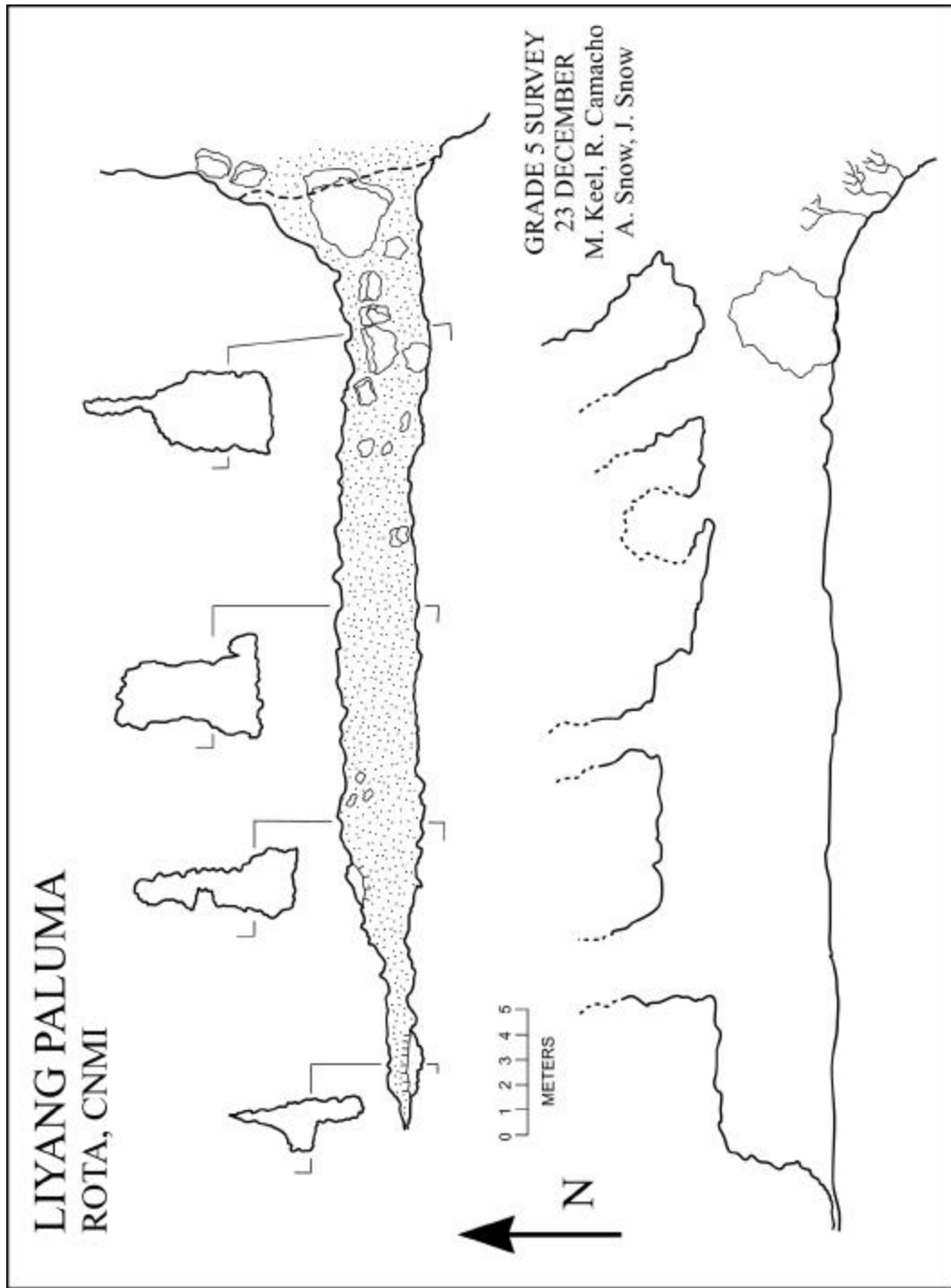


Figure B.77 Map of Liyang Paluma

# LIYANG PERSEVERANCE

ROTA, CNMI

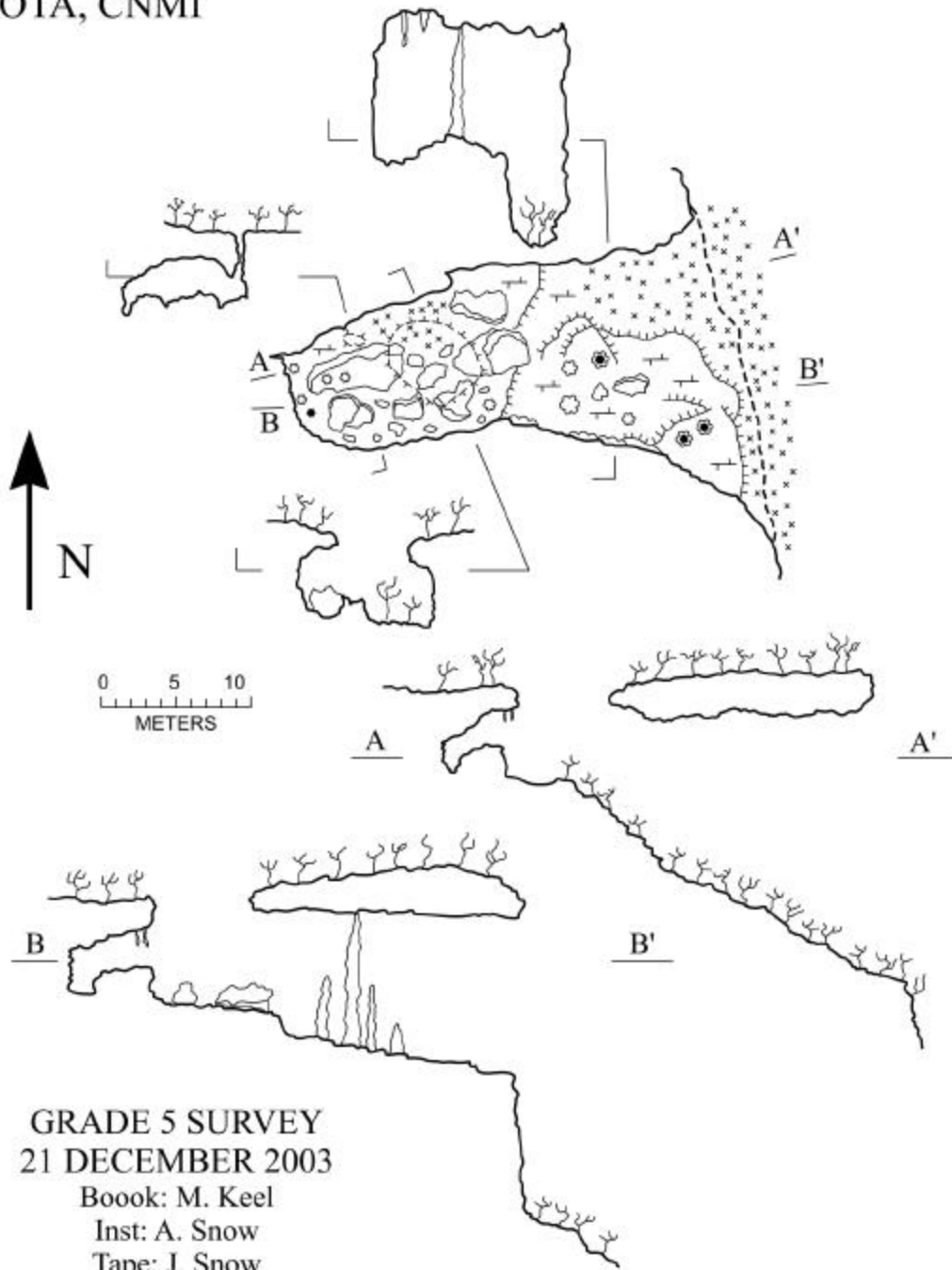


Figure B.78 Map of Liyang Perseverance

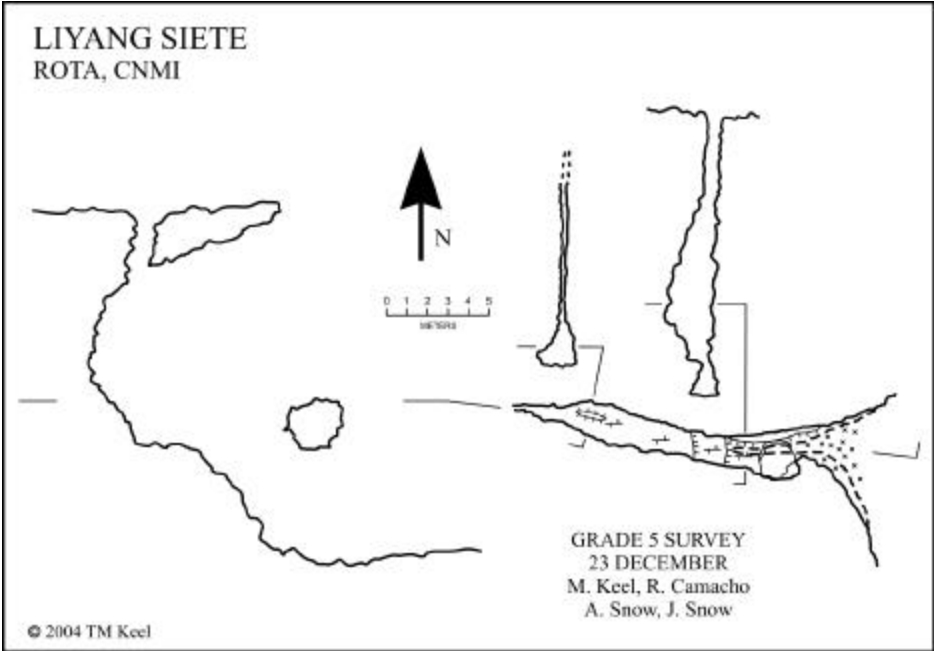


Figure B.79 Map of Liyang Siete

# LIYANG TONGA (TAGA) ROTA, CNMI

GRADE 5 SURVEY

4 JUNE 2003

C. Savvas

R. Camacho

K. Stafford

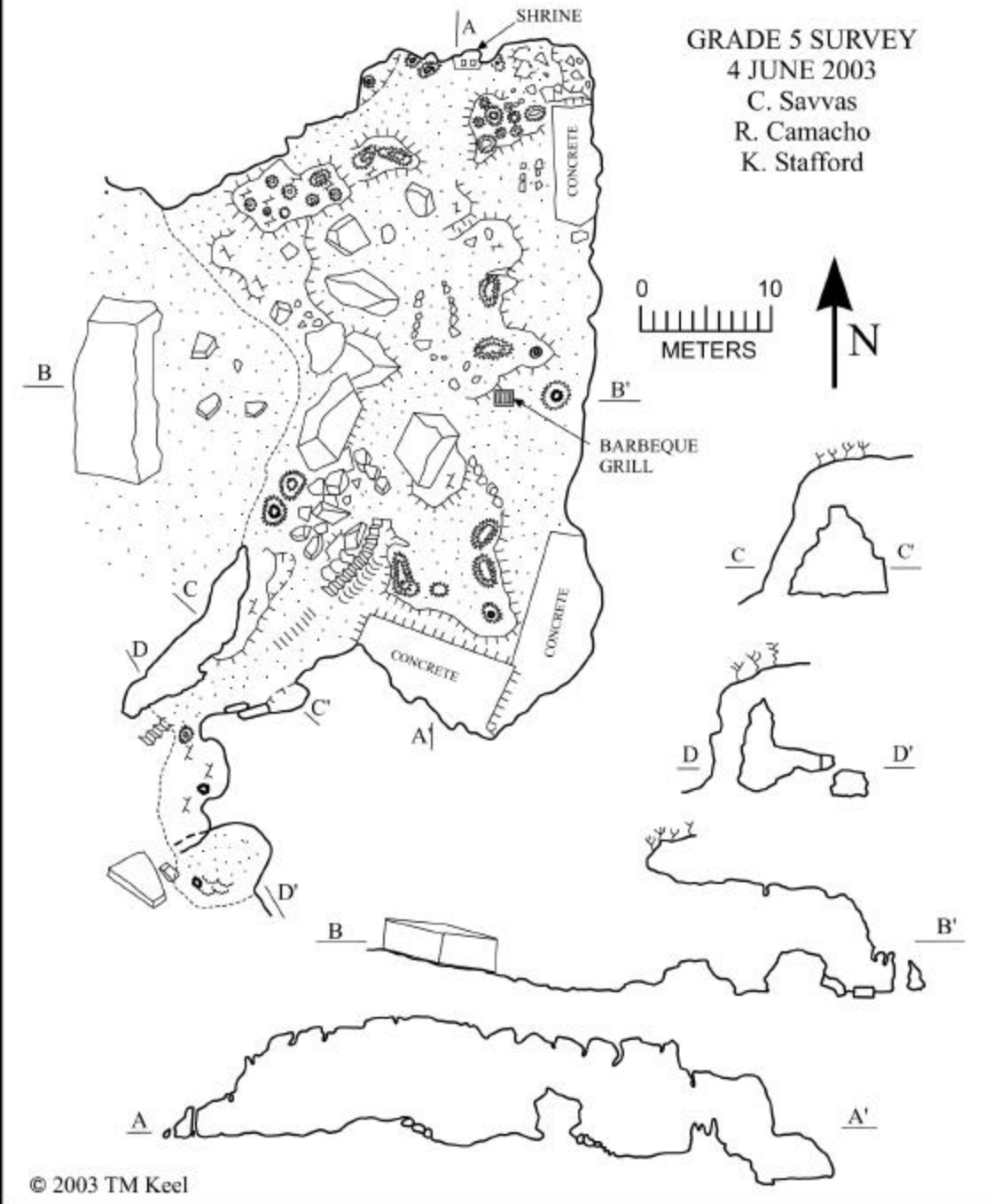
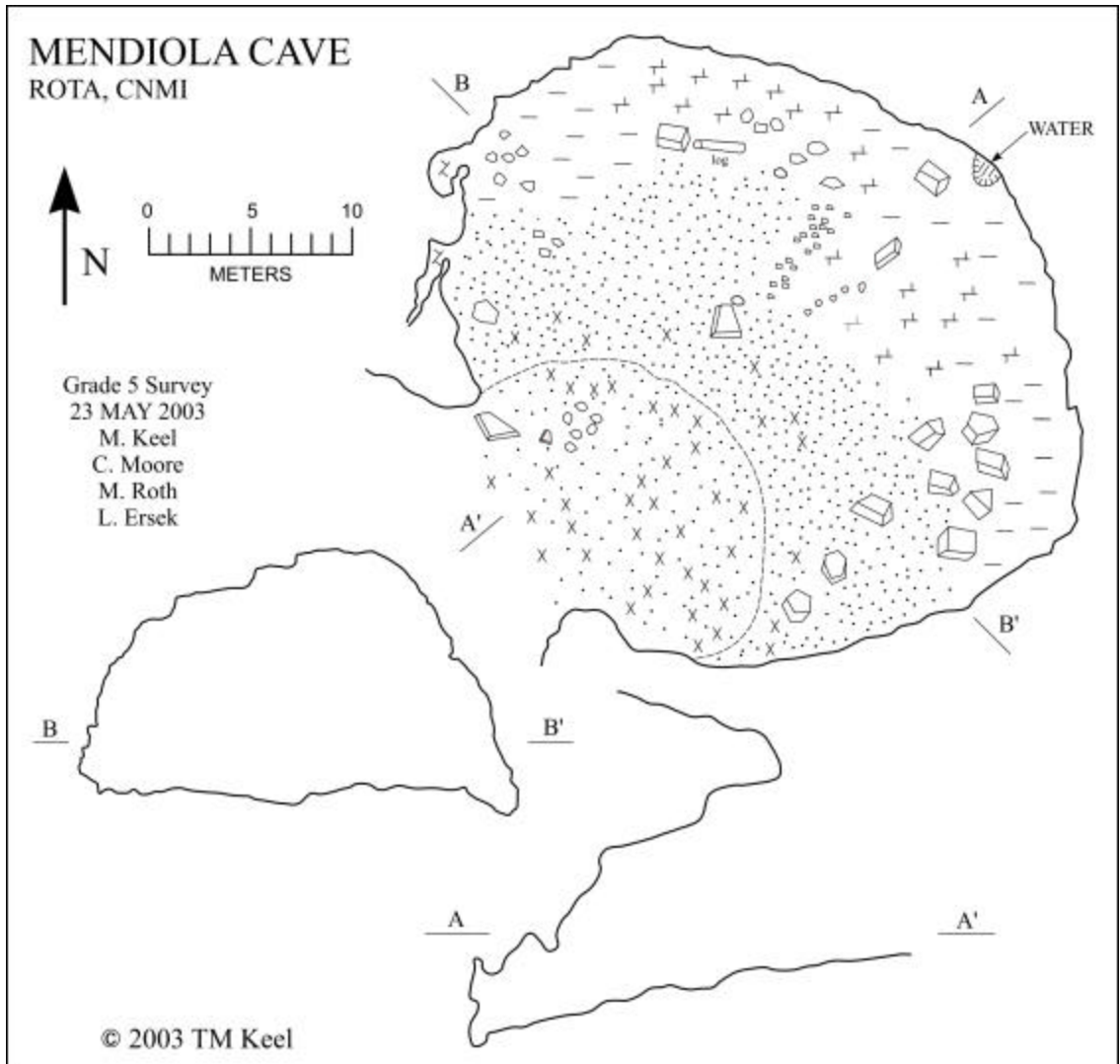


Figure B.80 Map of Liyang Tonga





*Figure B.81 Map of Mendiola Cave*

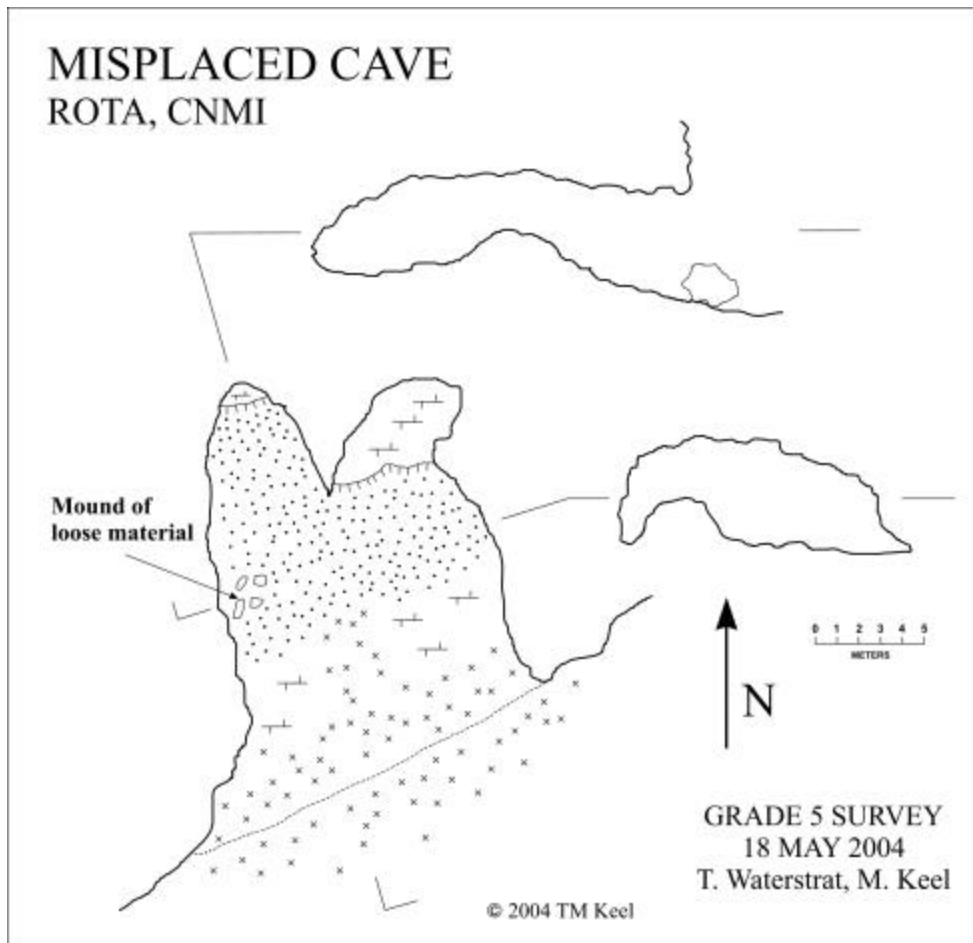


Figure B.82 Map of Misplaced Cave

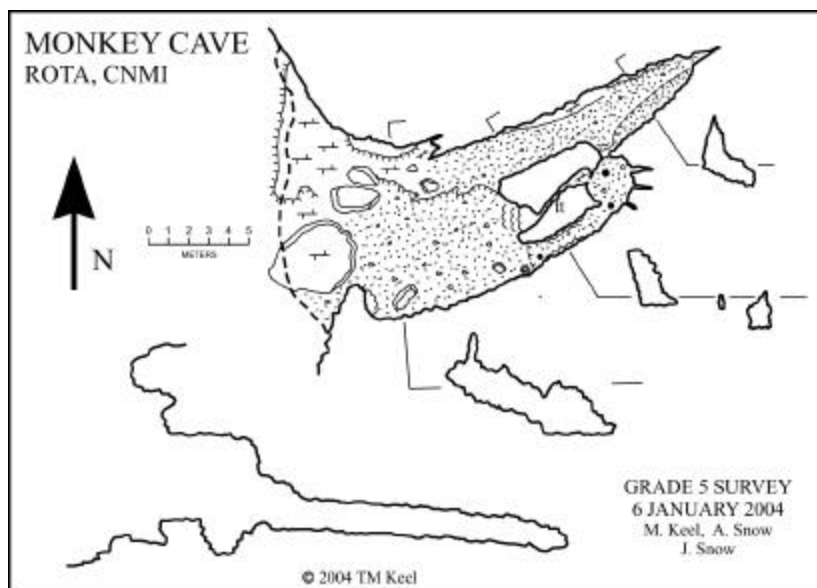


Figure B.83 Map of Monkey Cave

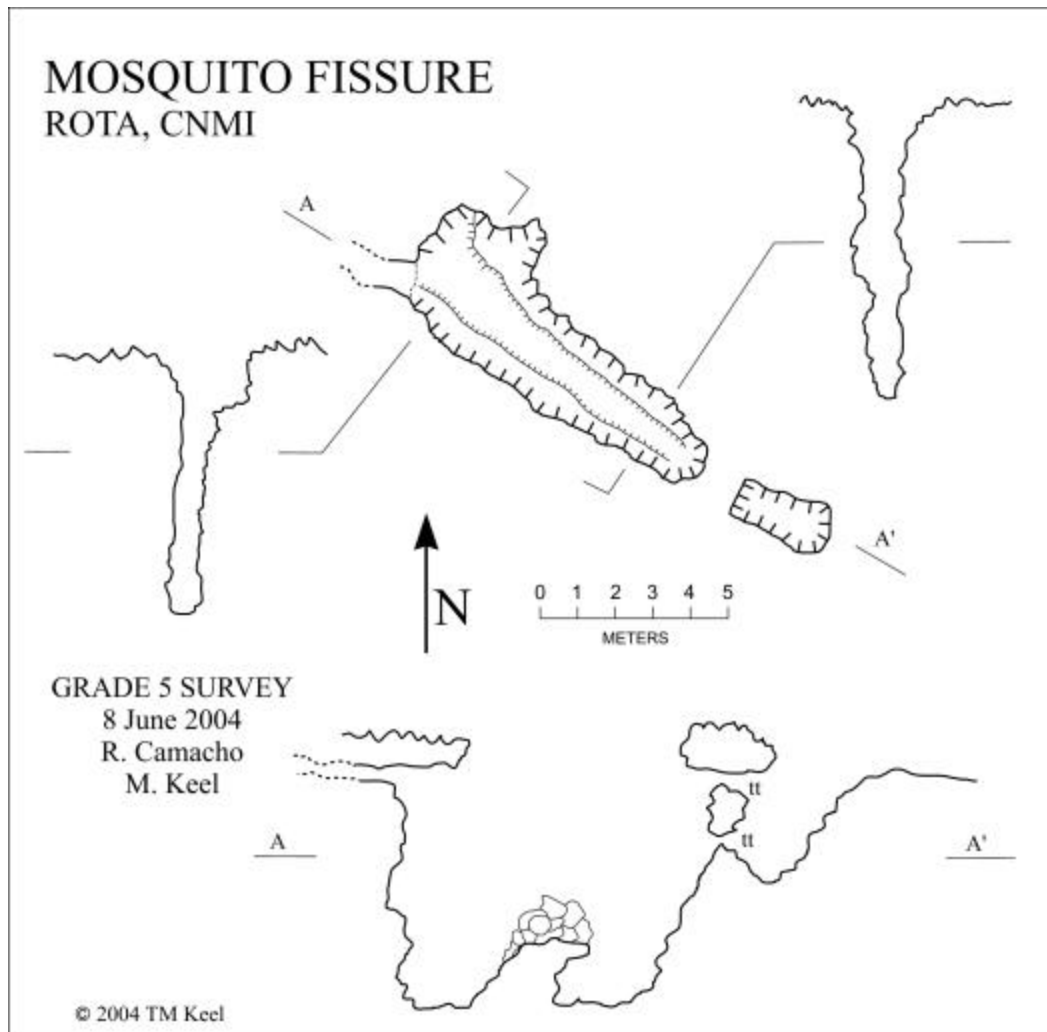
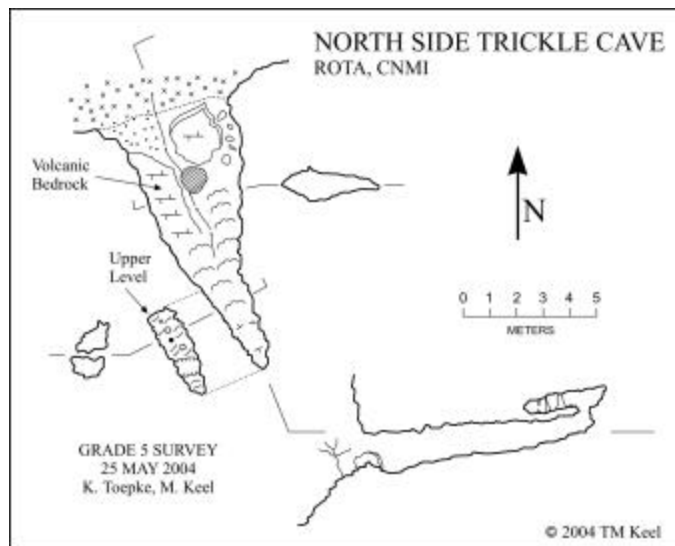


Figure B.84 Map of Mosquito Fissure



145  
Figure B.85 Map of North Side Trickle Cave

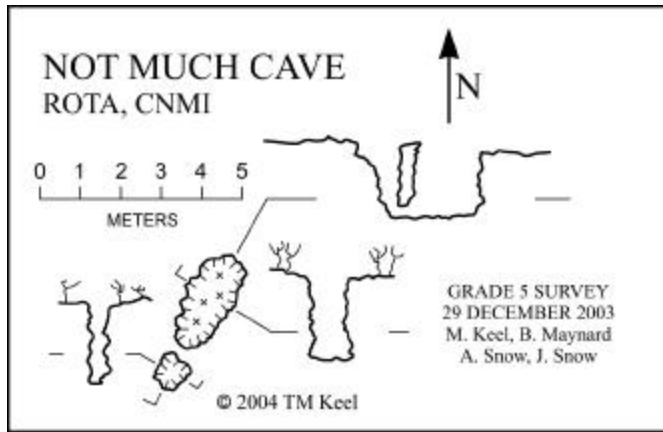


Figure B.86 Map of Not Much Cave

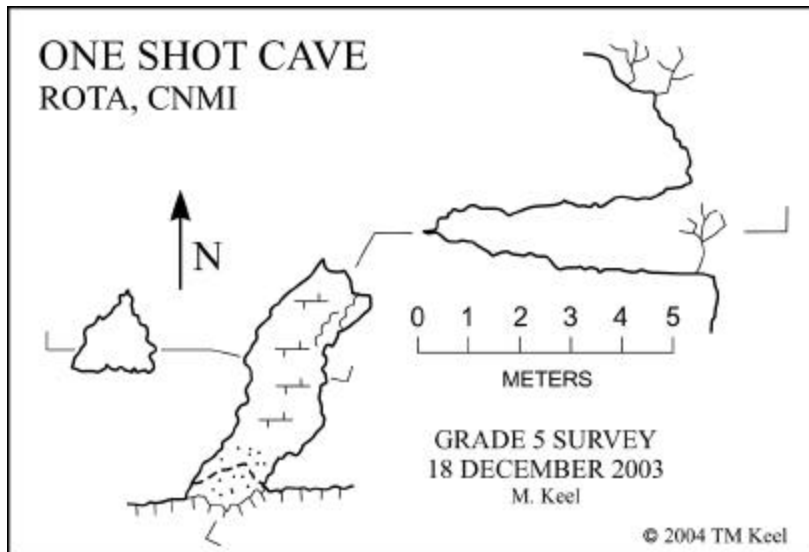
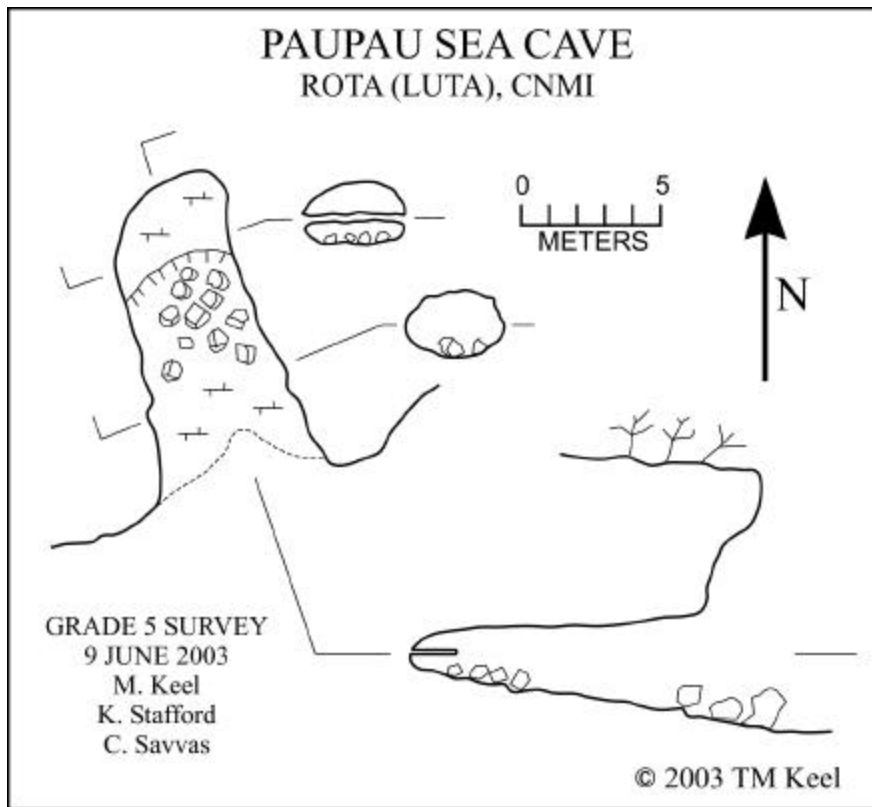


Figure B.87 Map of One Shot Cave



*Figure B.88 Map of Pau Pau Sea Cave*

# PEACE MEMORIAL TUNNELS ROTA, CNMI

These features are not natural caves.  
They are manmade tunnels, apparently from the Japanese era.

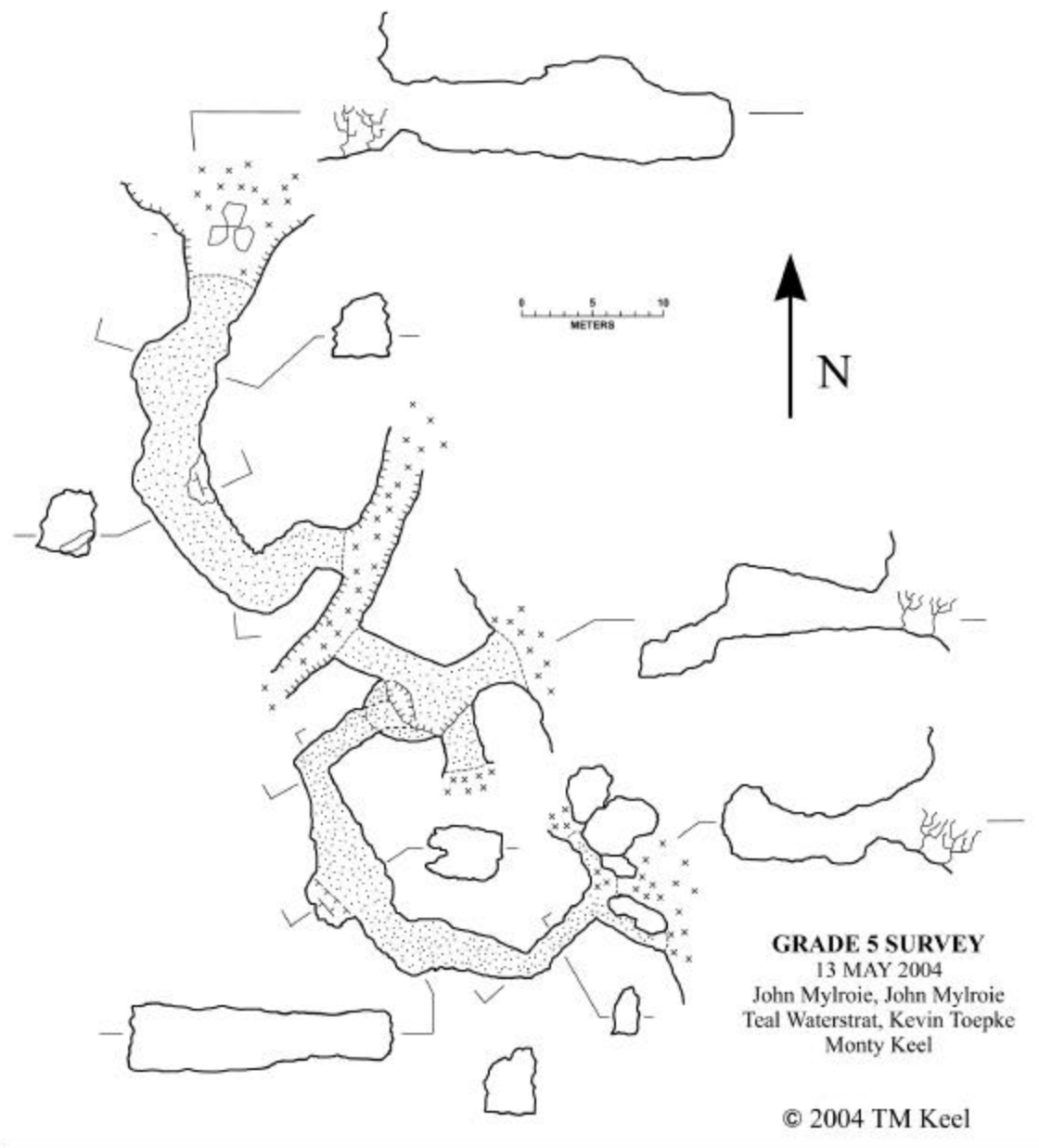


Figure B.89 Map of Peace Memorial Tunnels

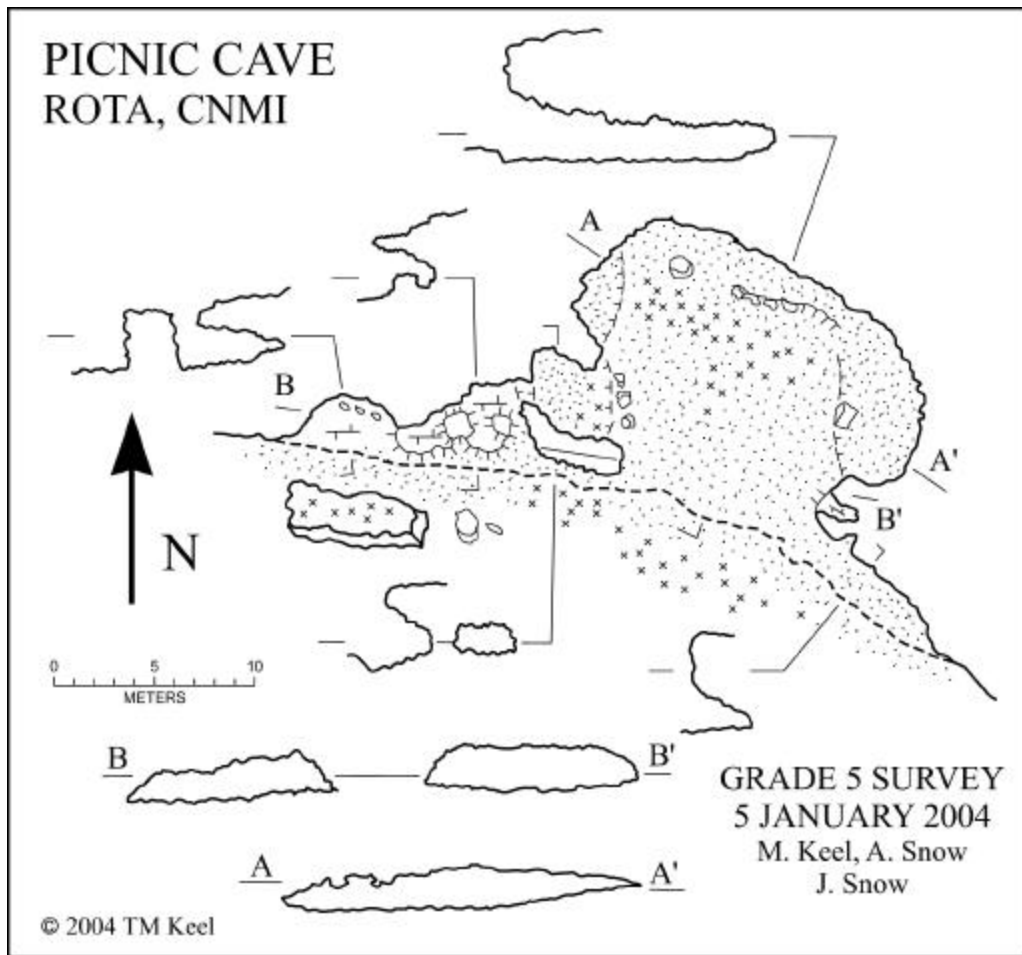


Figure B.90 Map of Picnic Cave

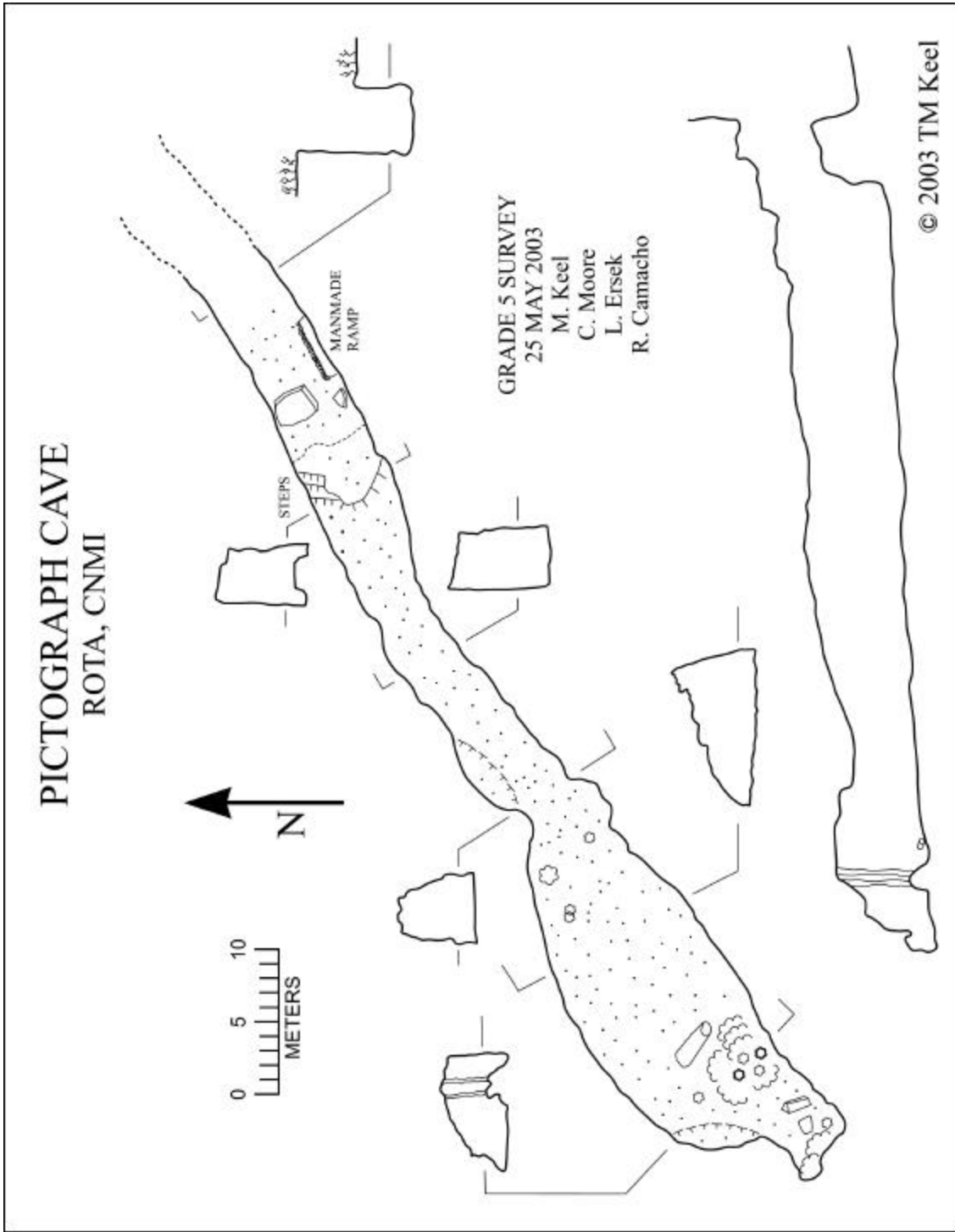


Figure B.91 Map of Pictograph Cave



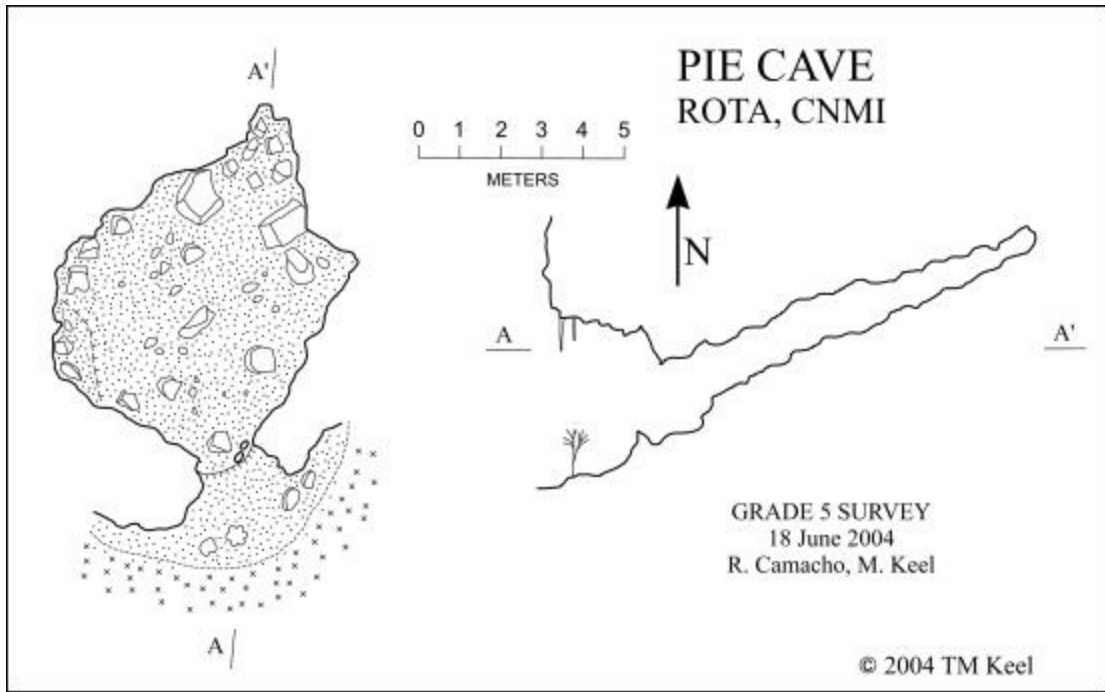


Figure B.92 Map of Pie Cave

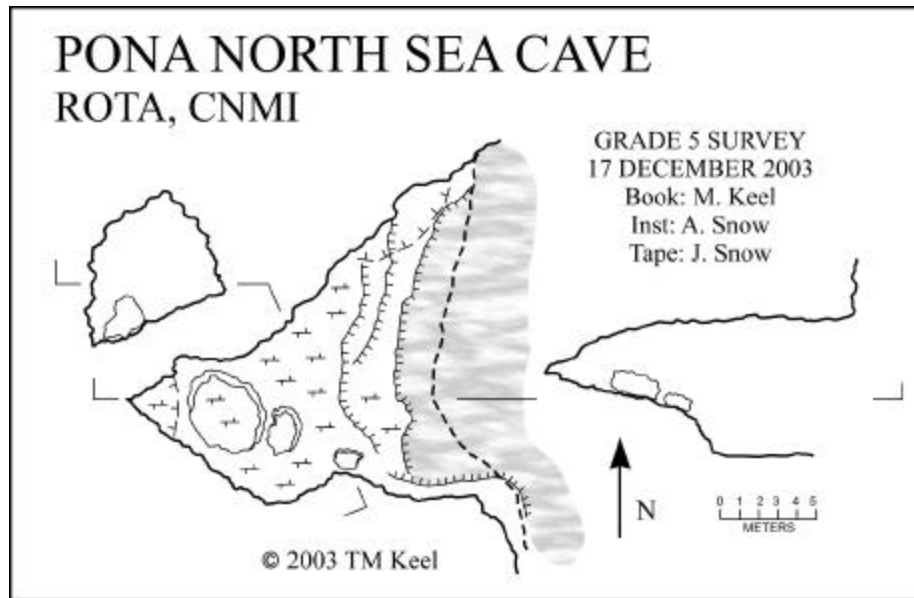


Figure B.93 Map of Poña North Sea Cave

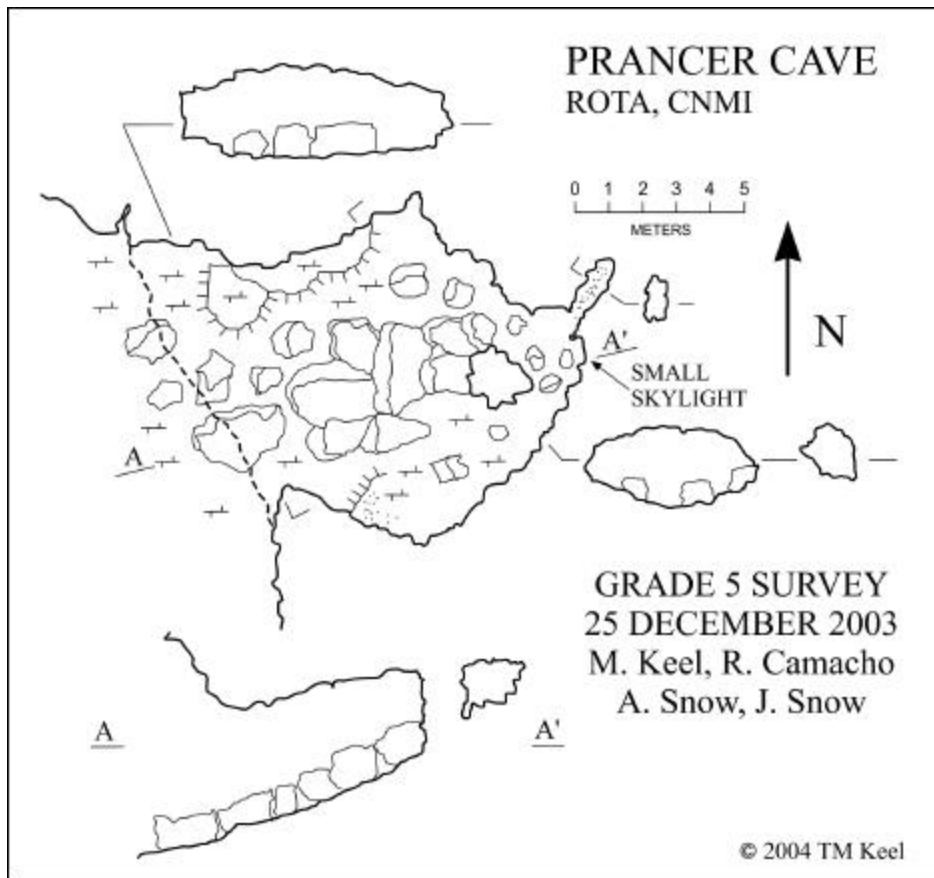


Figure B.94 Map of Prancer Cave

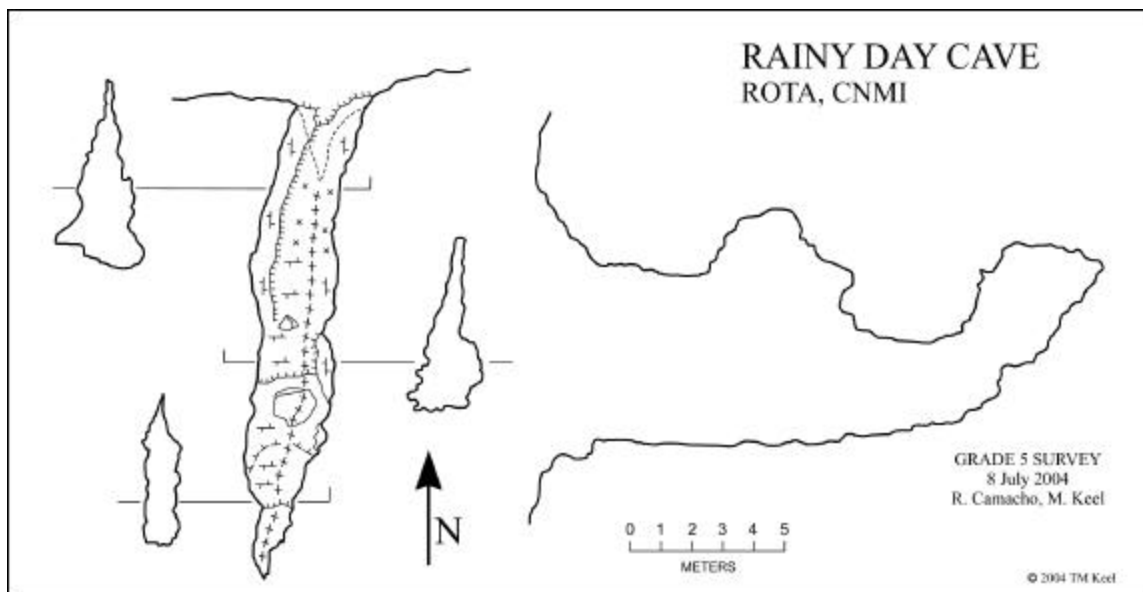


Figure B.95 Map of Rainy Day Cave

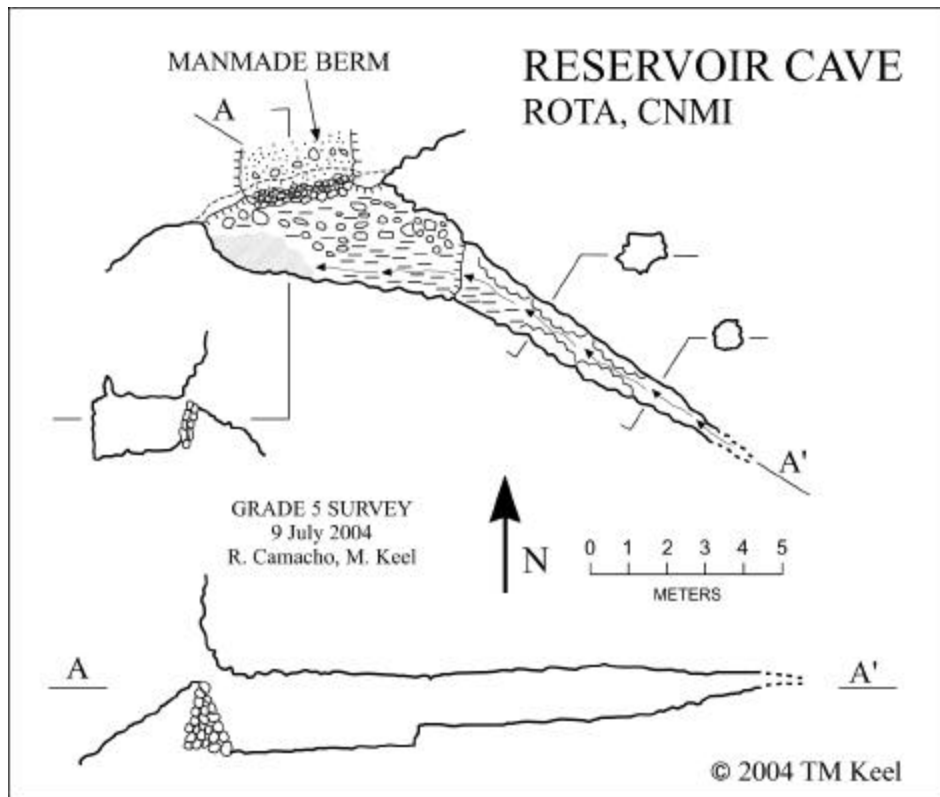


Figure B.96 Map of Reservoir Cave

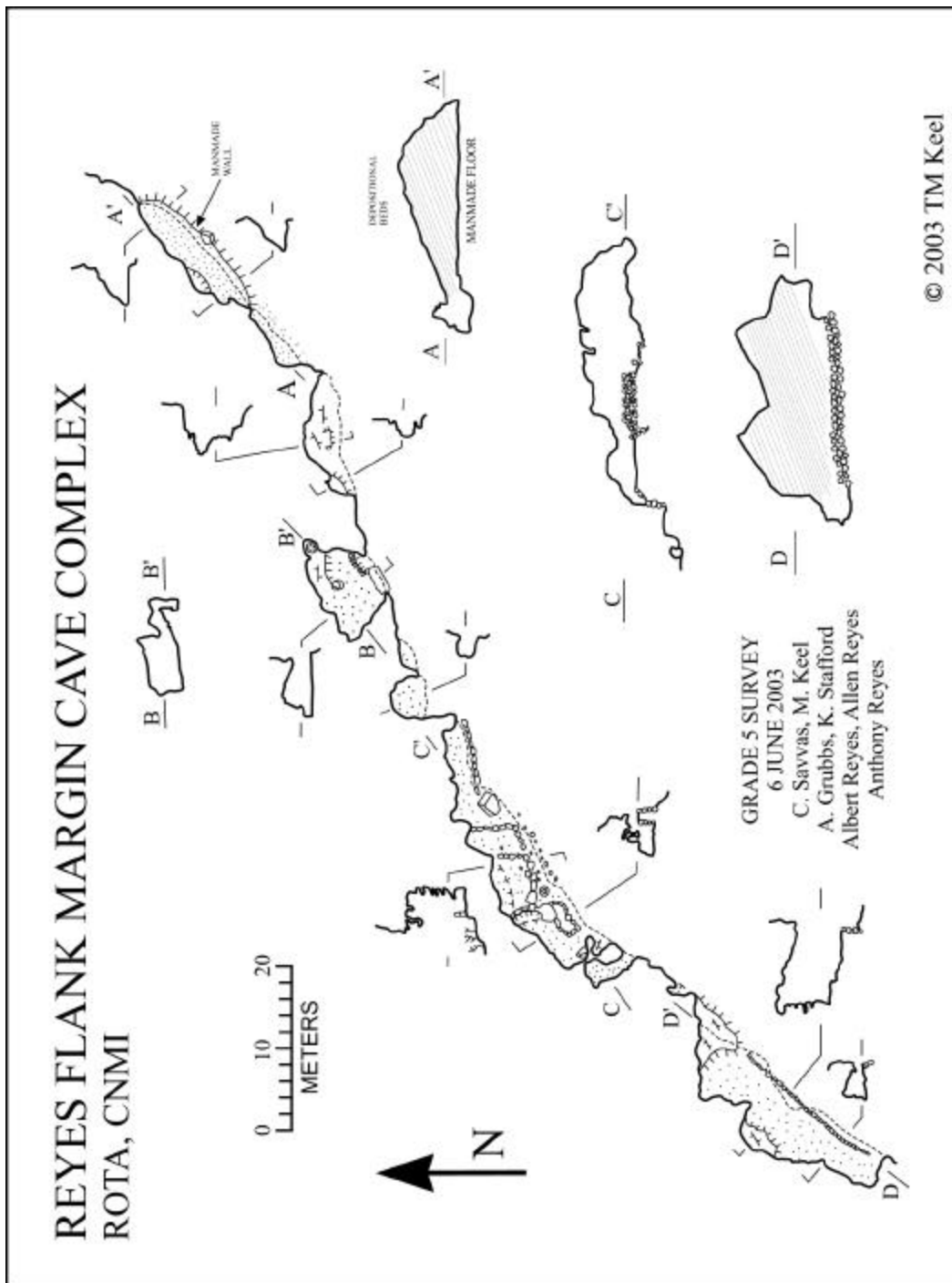


Figure B.97 Map of Reyes Flank Margin Cave Complex

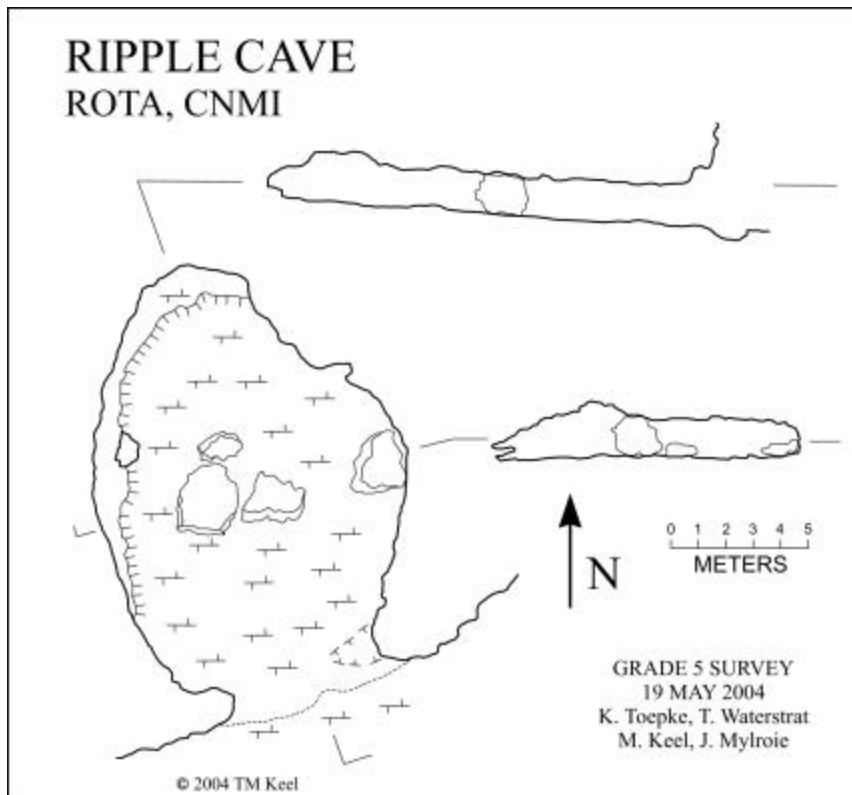
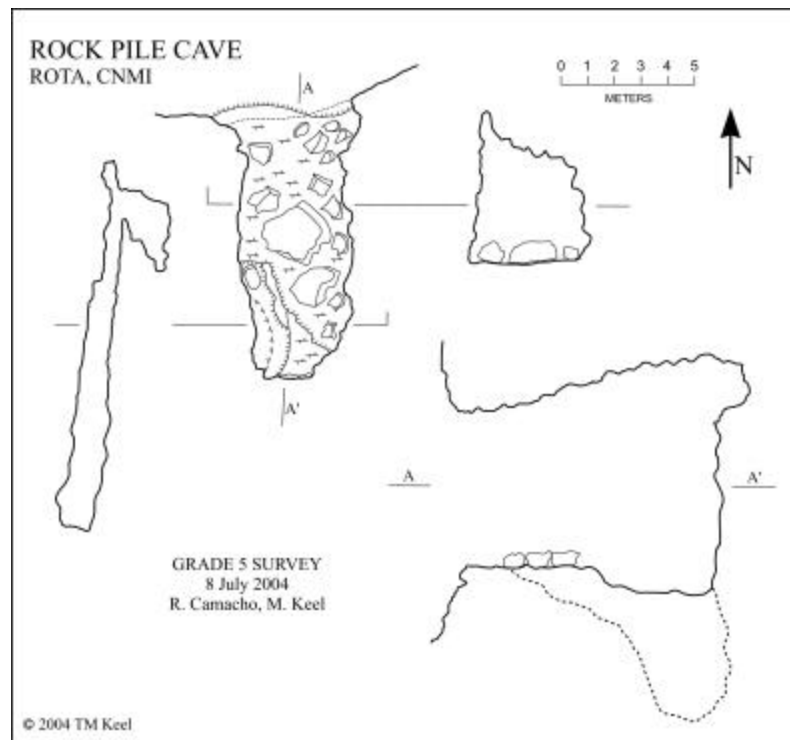


Figure B.98 Map of Ripple Cave



155  
Figure B.99 Map of Rock Pile Cave

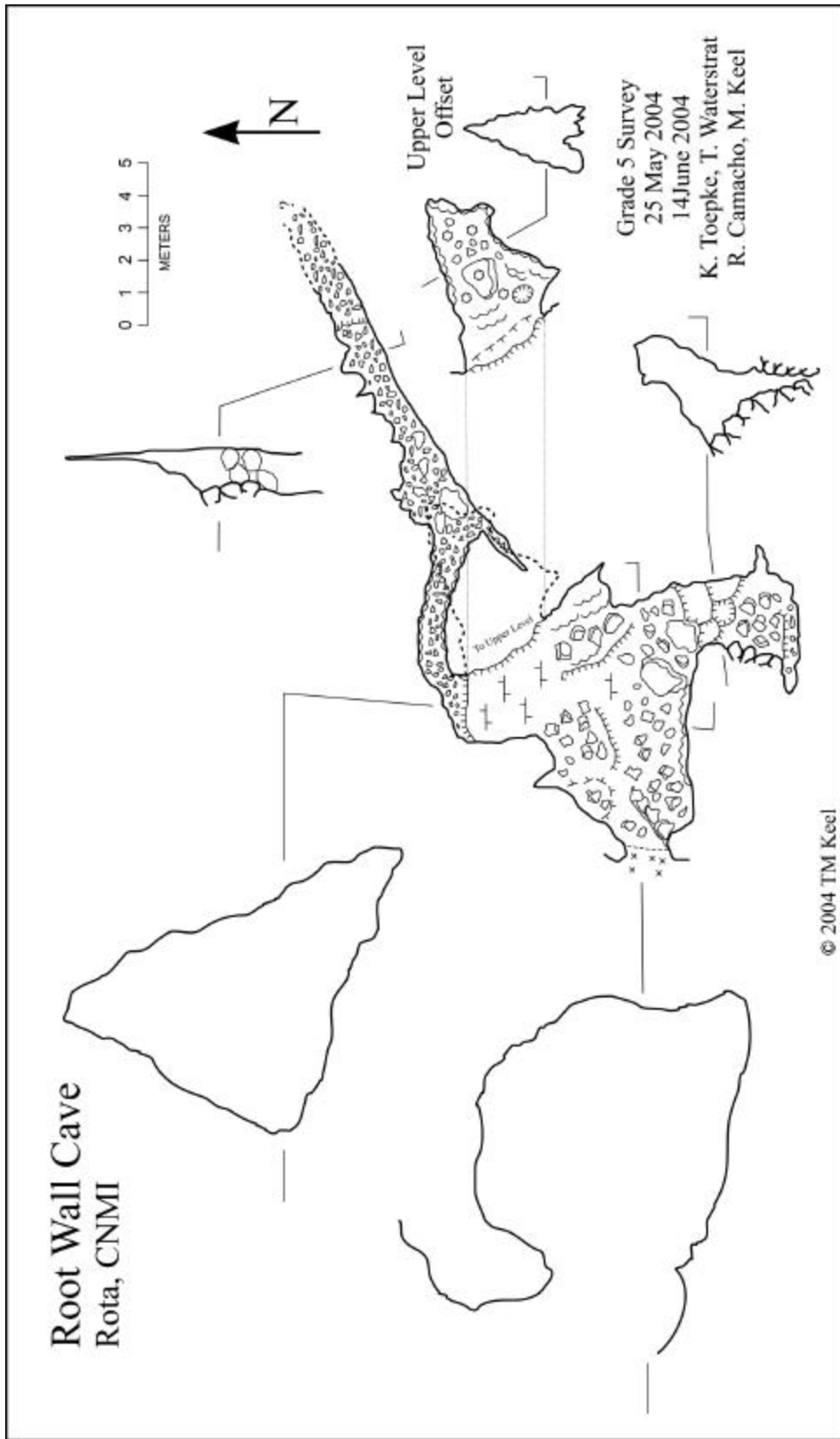


Figure B.100 Map of Root Wall Cave

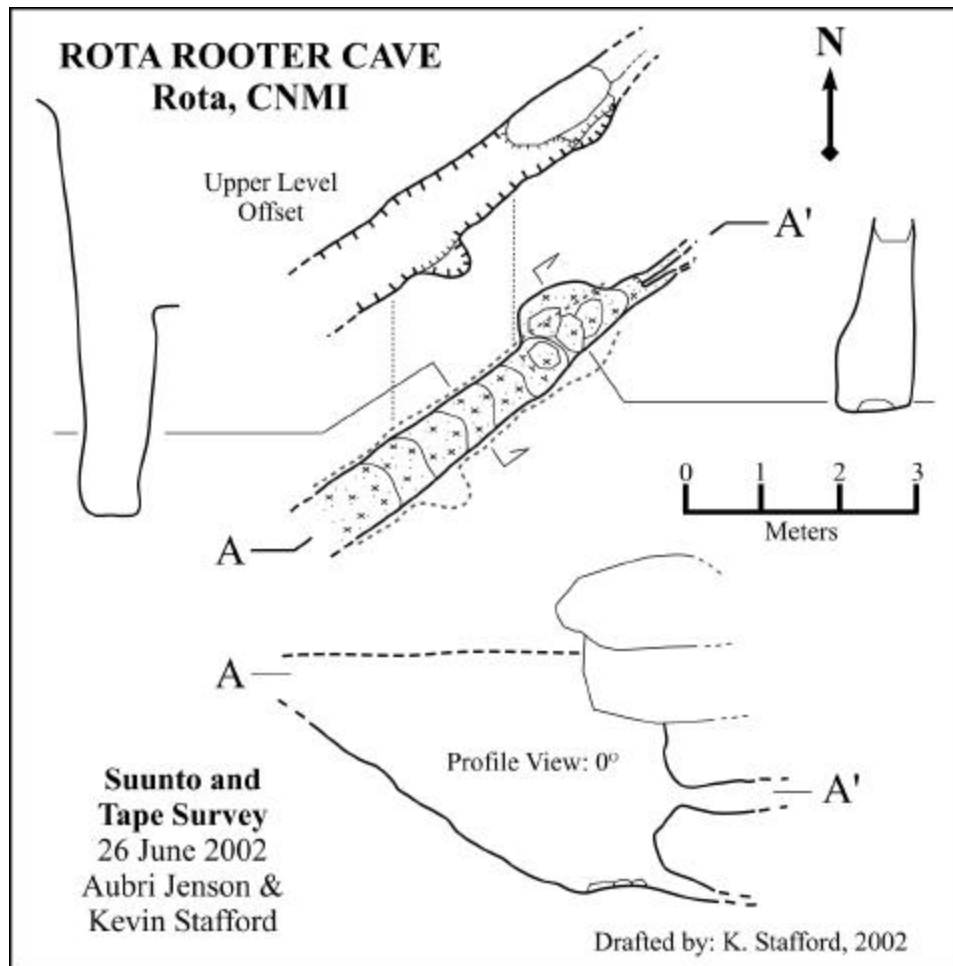
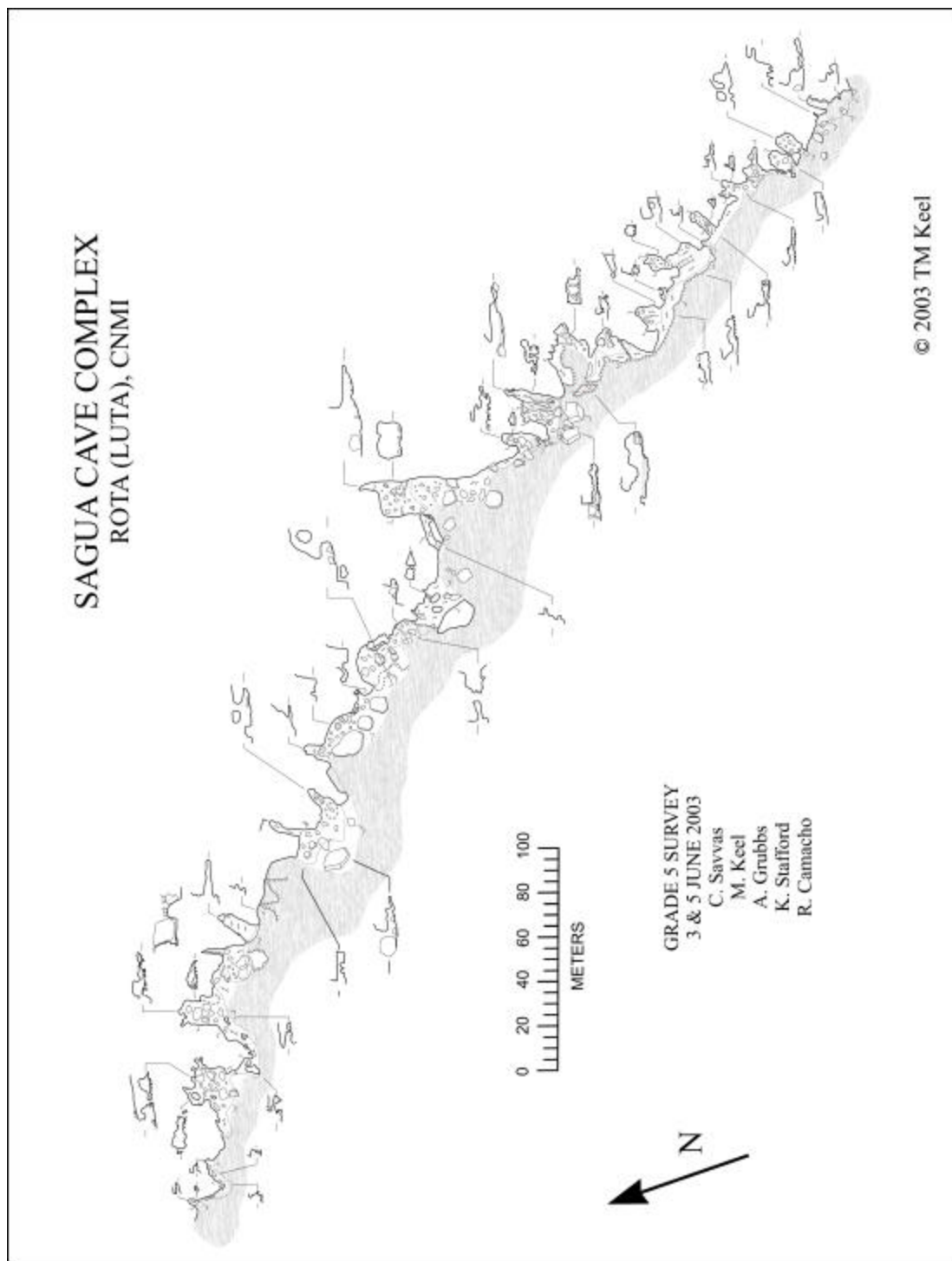


Figure B.101 Map of Rota Rooter Cave



*Figure 102 Map of Sagua Cave Complex*



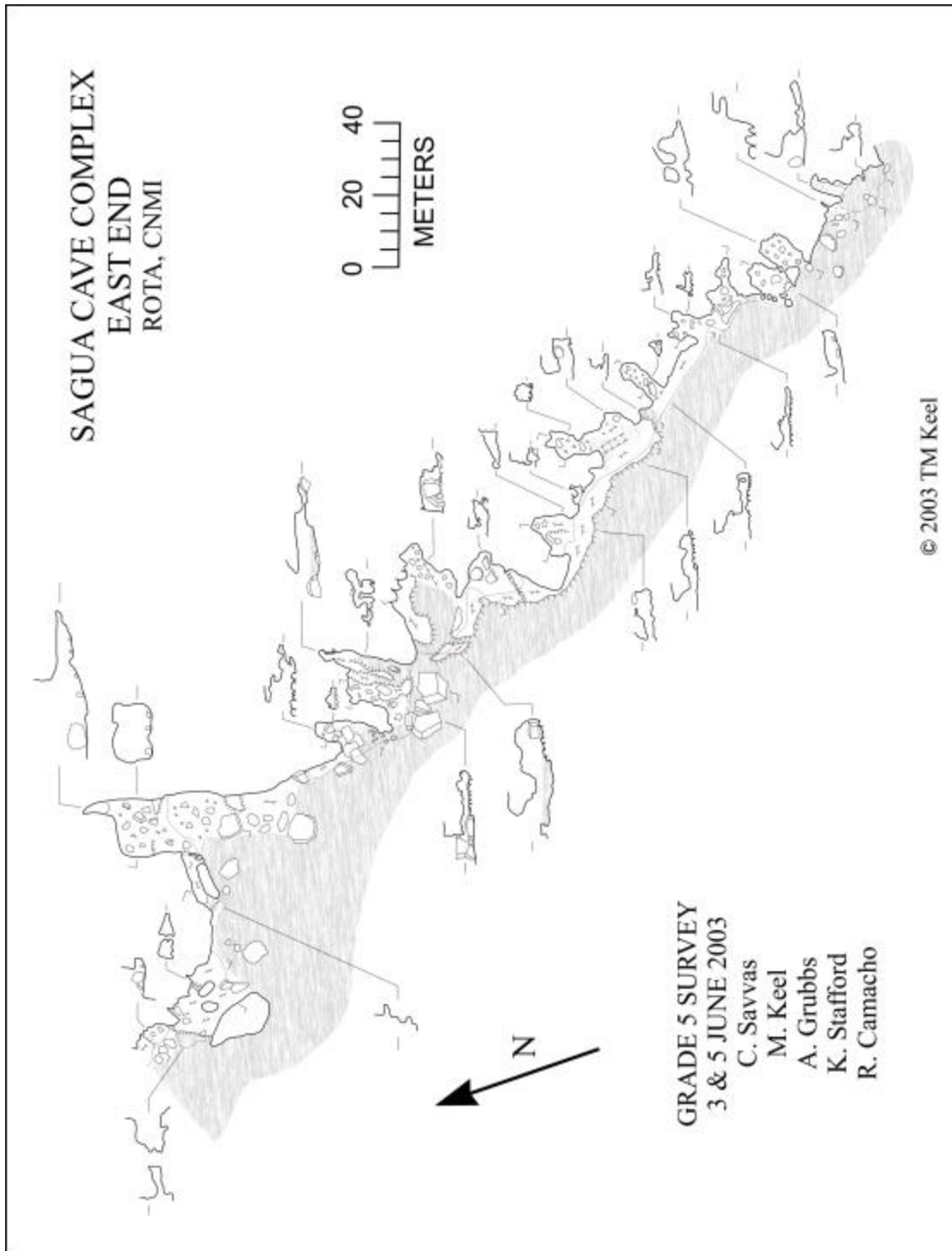
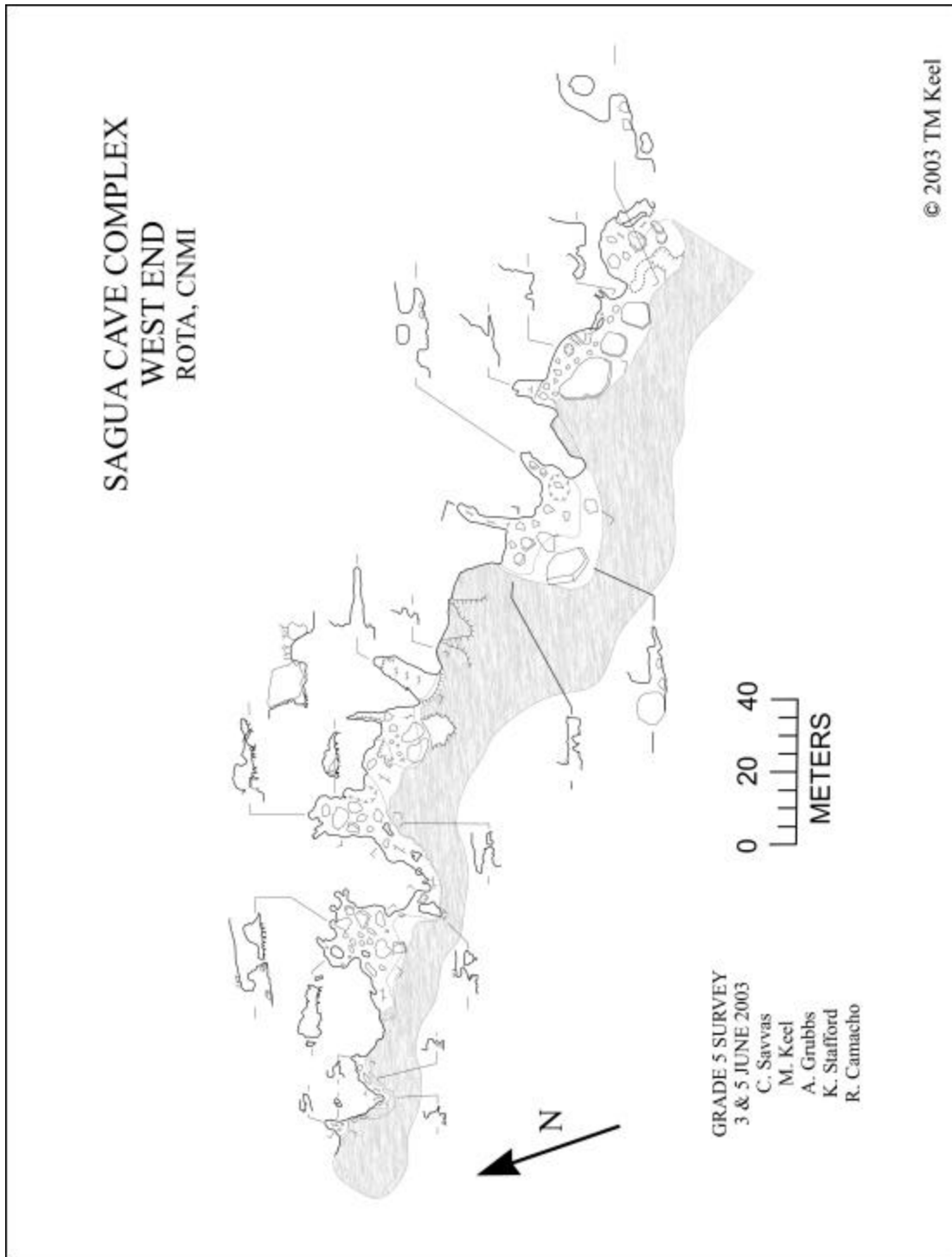


Figure B.103 Map of Sagua Cave Complex, East End



*Figure B.104 Map of Sagua Cave Complex, West End*

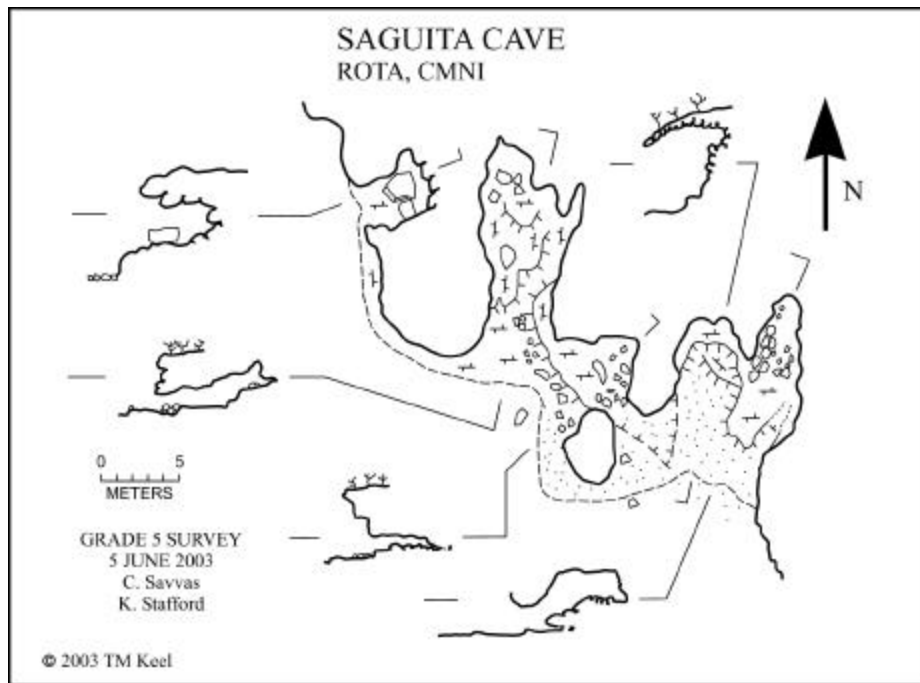


Figure B.105 Map of Saguita Cave

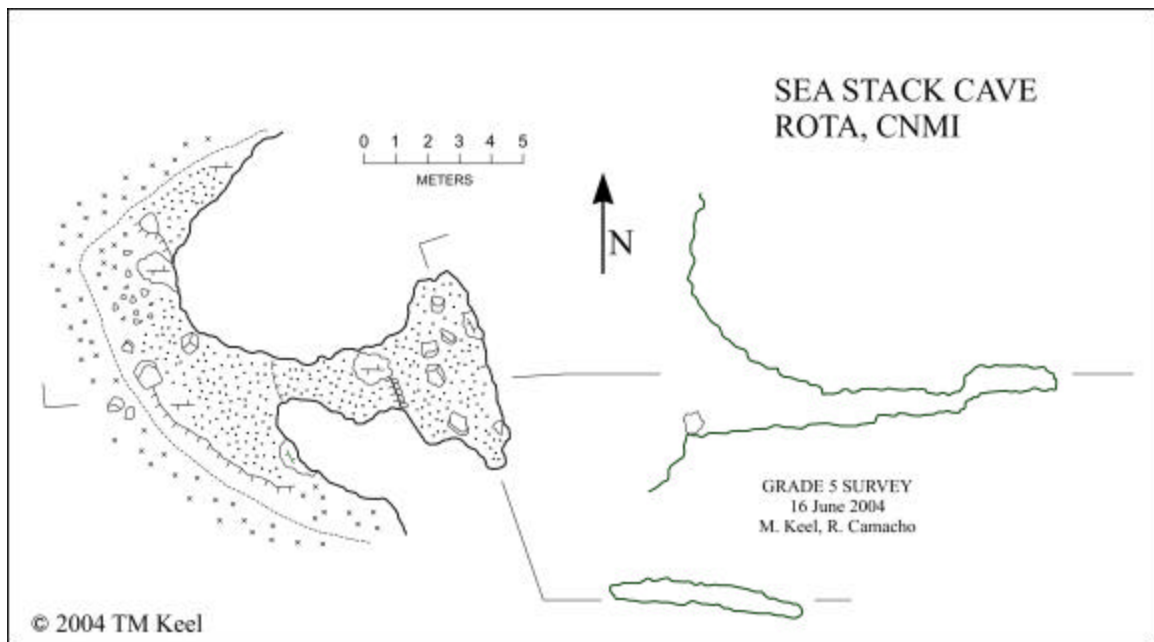
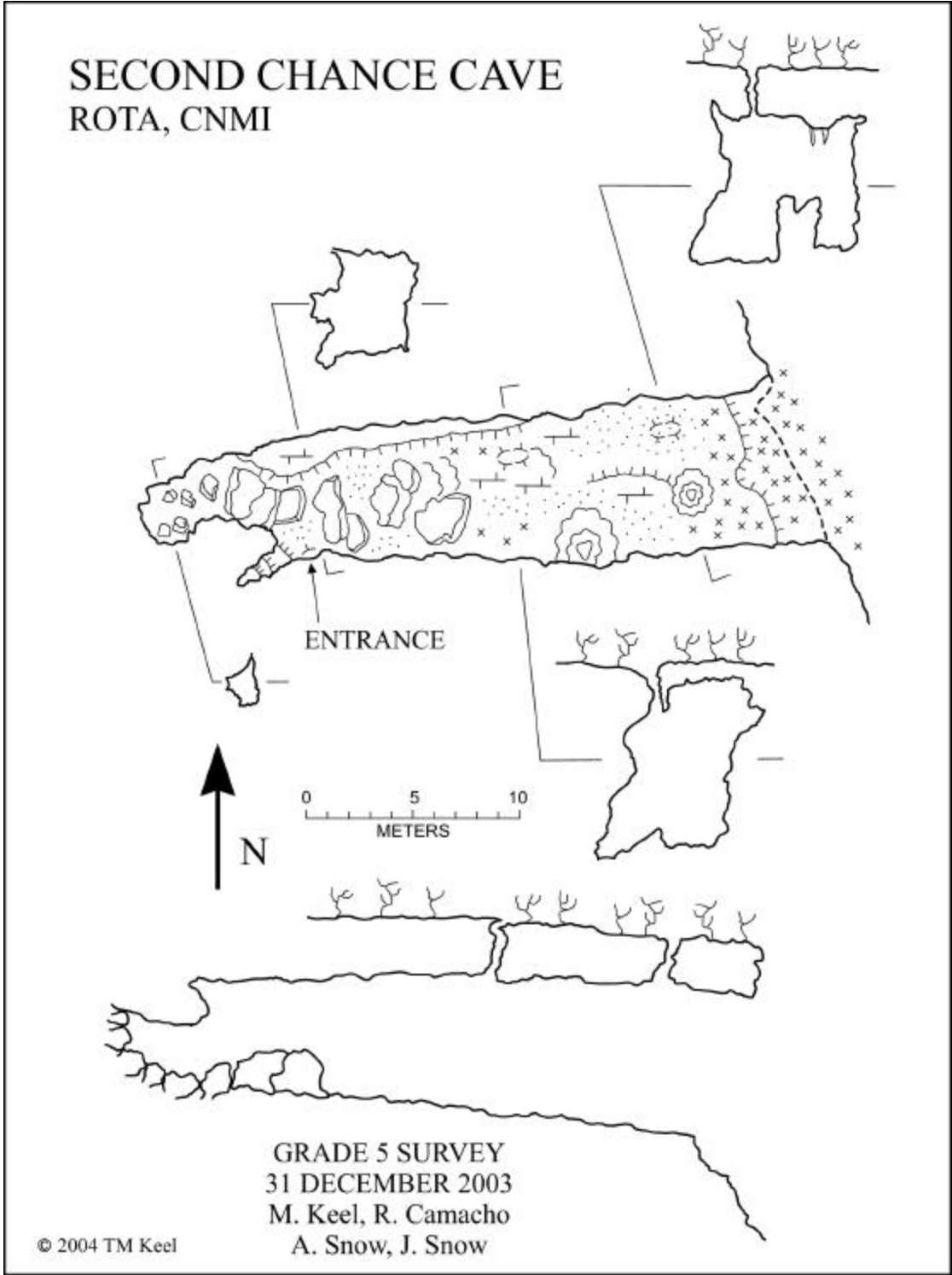


Figure B.106 Map of Sea Stack Cave



*Figure B.107 Map of Second Chance Cave*

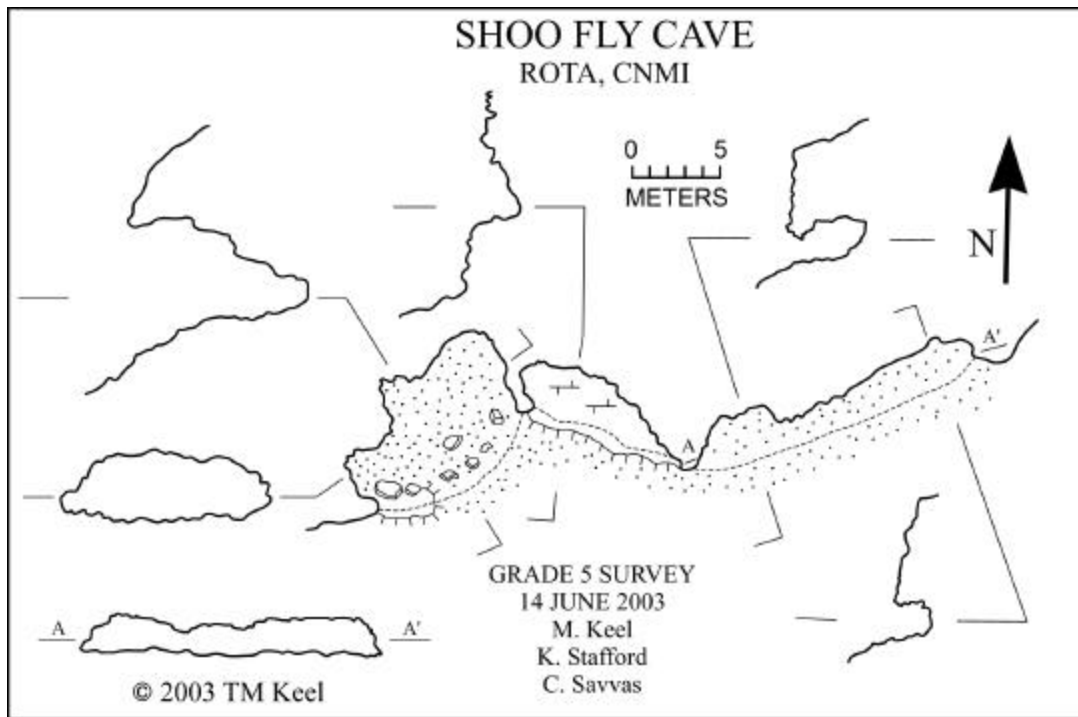


Figure B.108 Map of Shoo Fly Cave

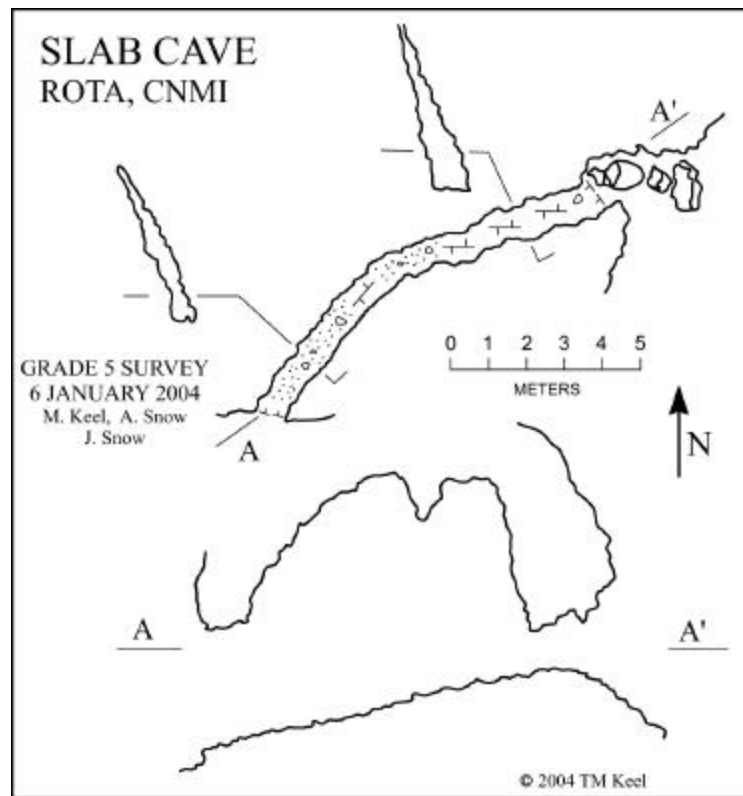
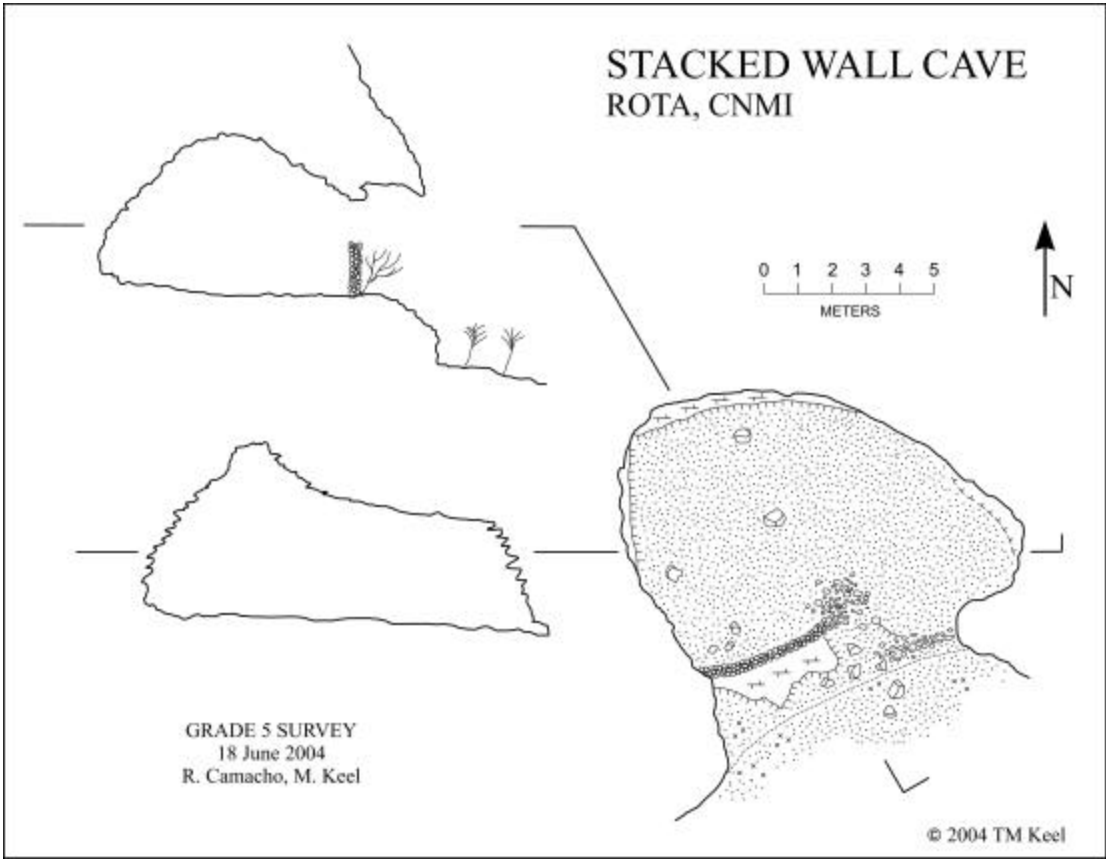


Figure B.109 Map of Slab Cave



*Figure B.110 Map of Stacked Wall Cave*

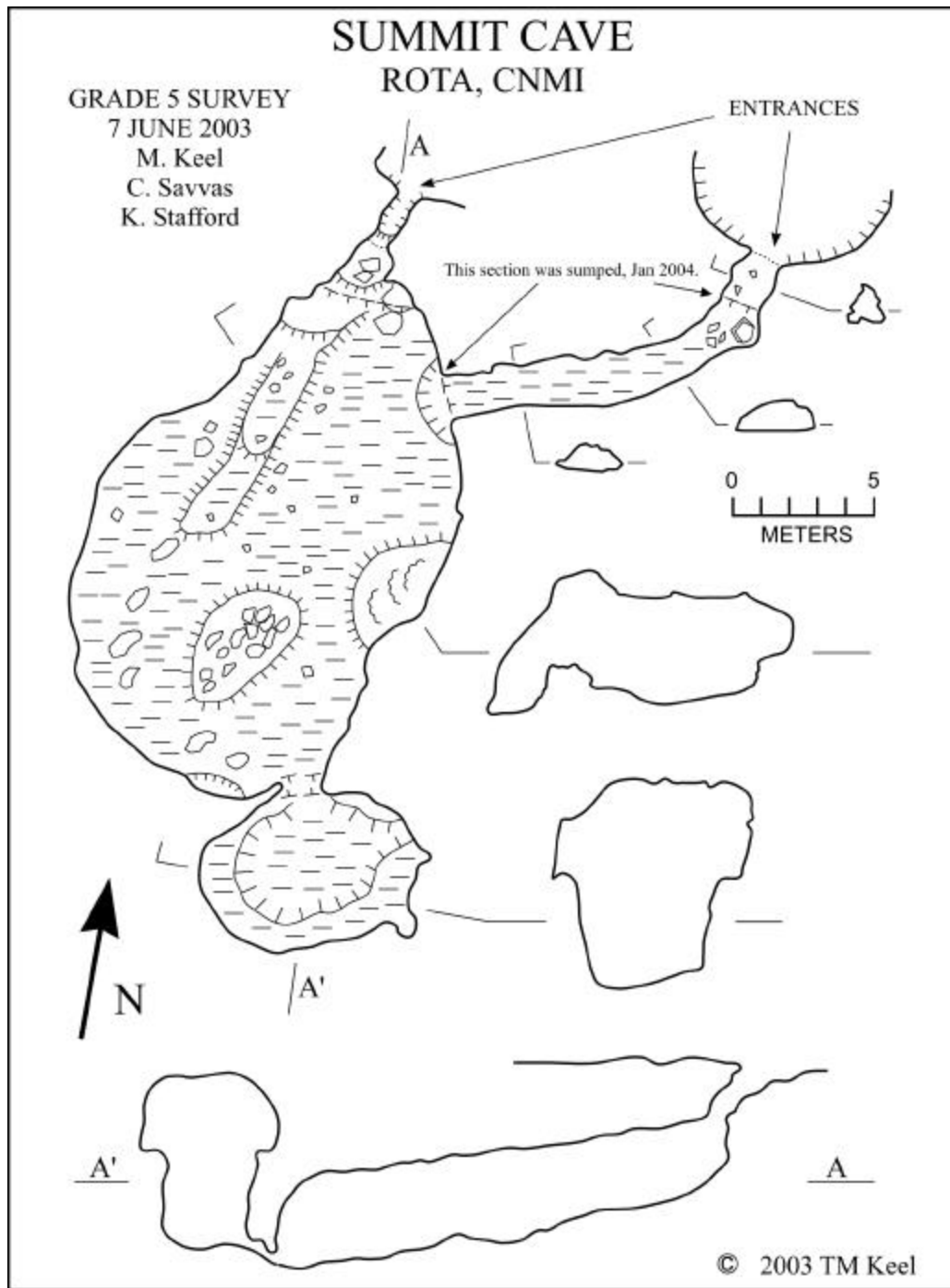
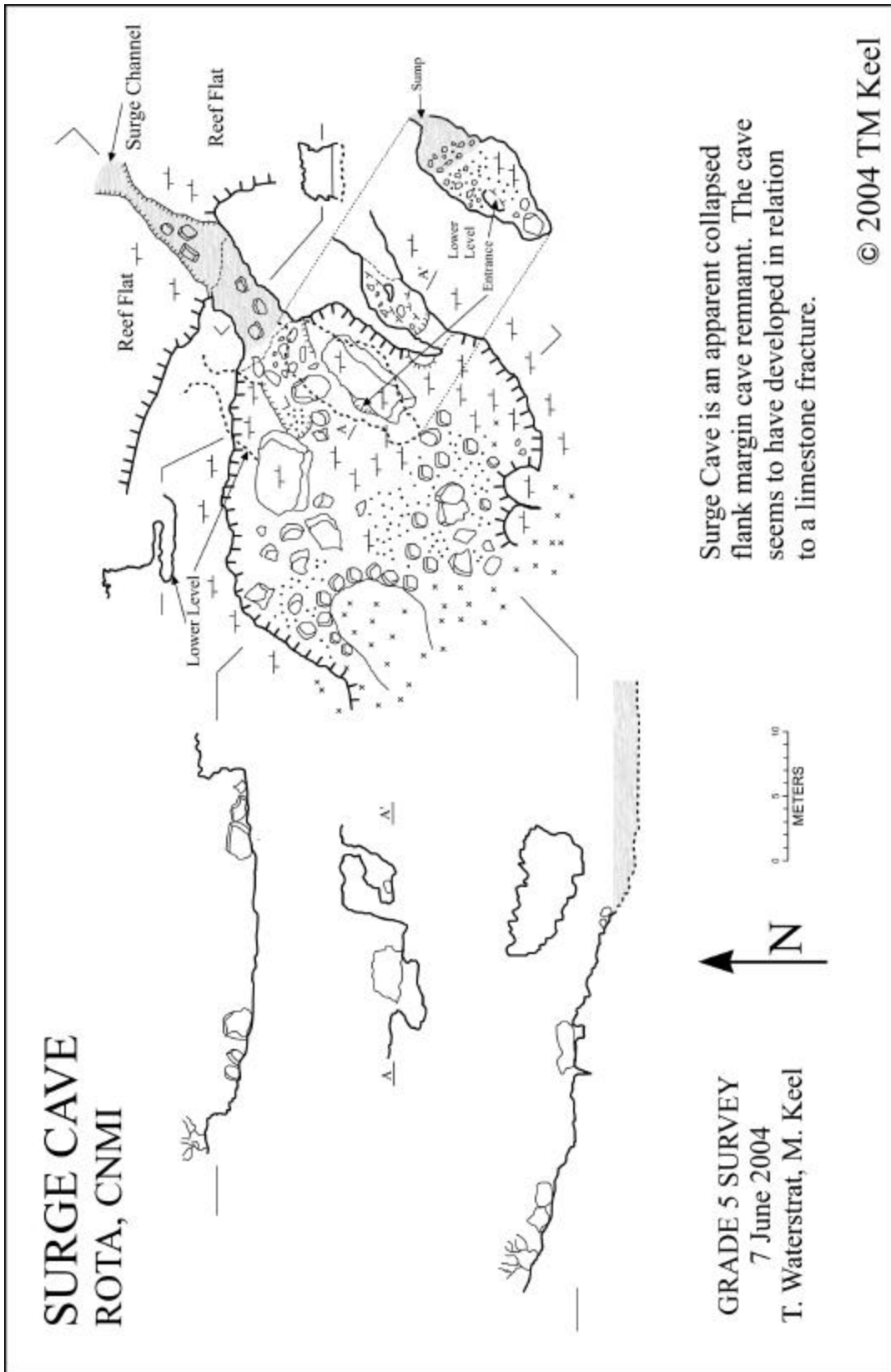
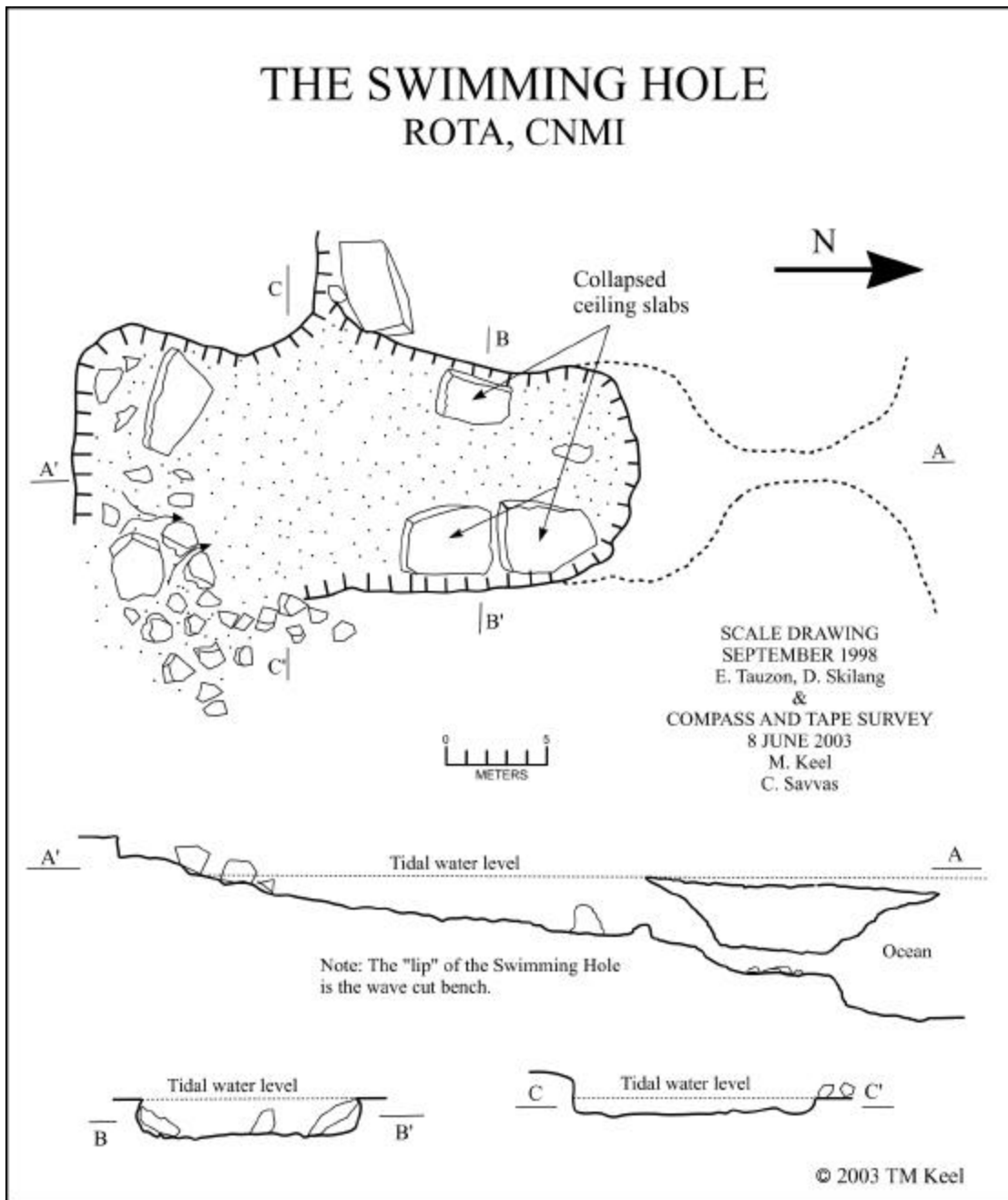


Figure B.111 Map of Summit Cave



166  
Figure B.112 Map of Surge Cave





*Figure B.113 Map of The Swimming Hole*

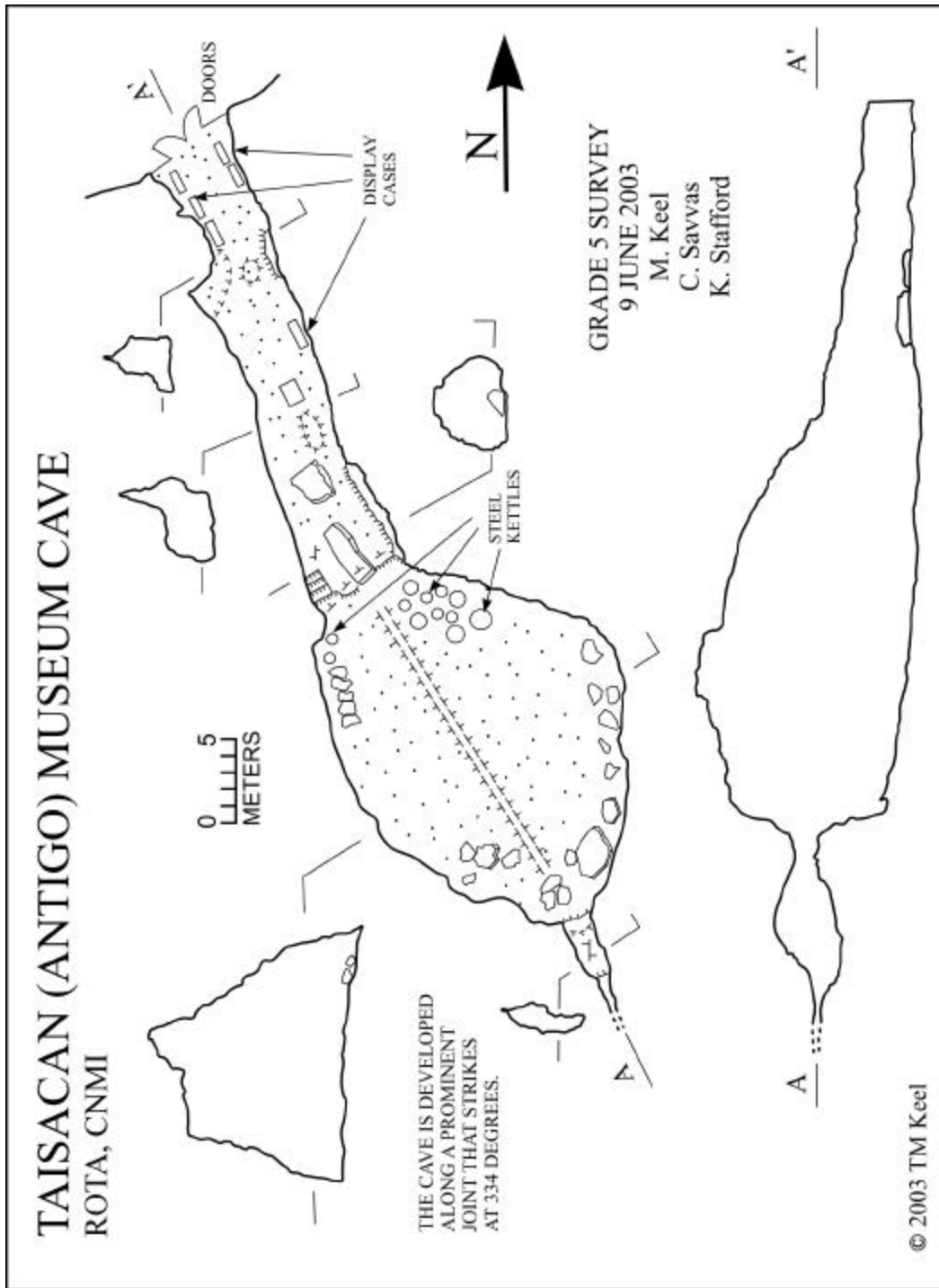


Figure B.114 Map of Taisacan Museum Cave

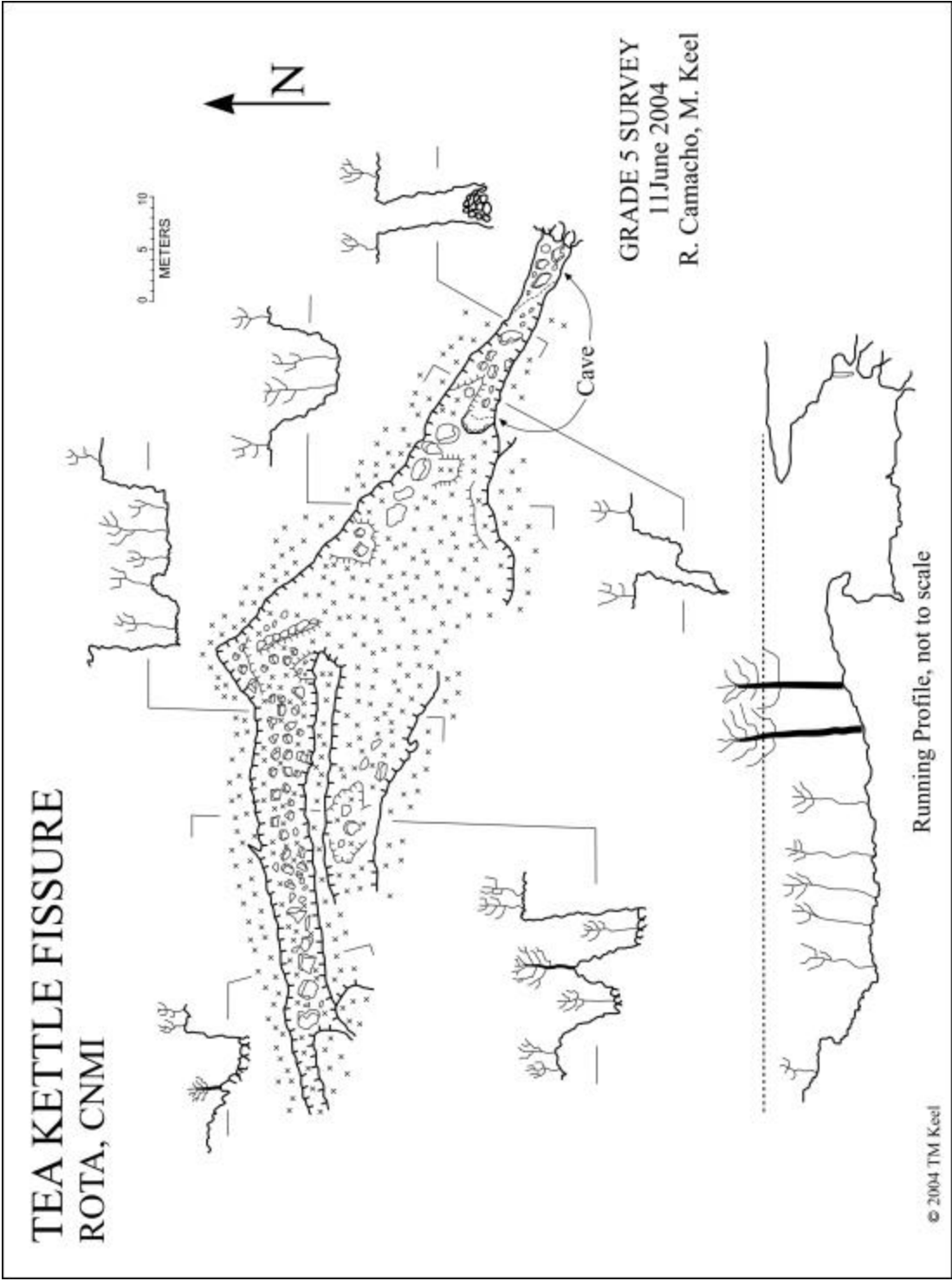
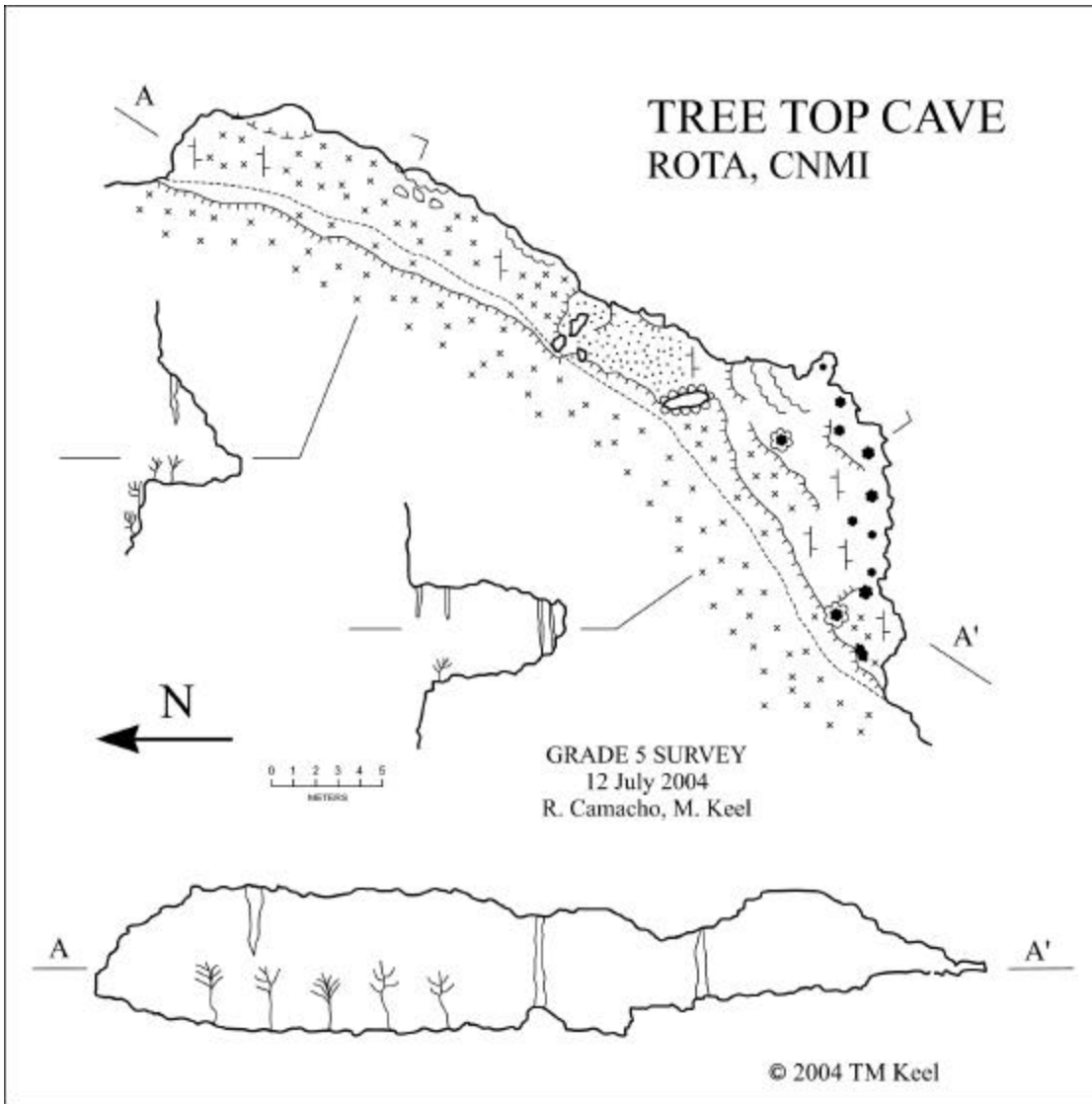


Figure B.115 Map of Tea Kettle Fissure



*Figure B.116 Map of Tree Top Cave*

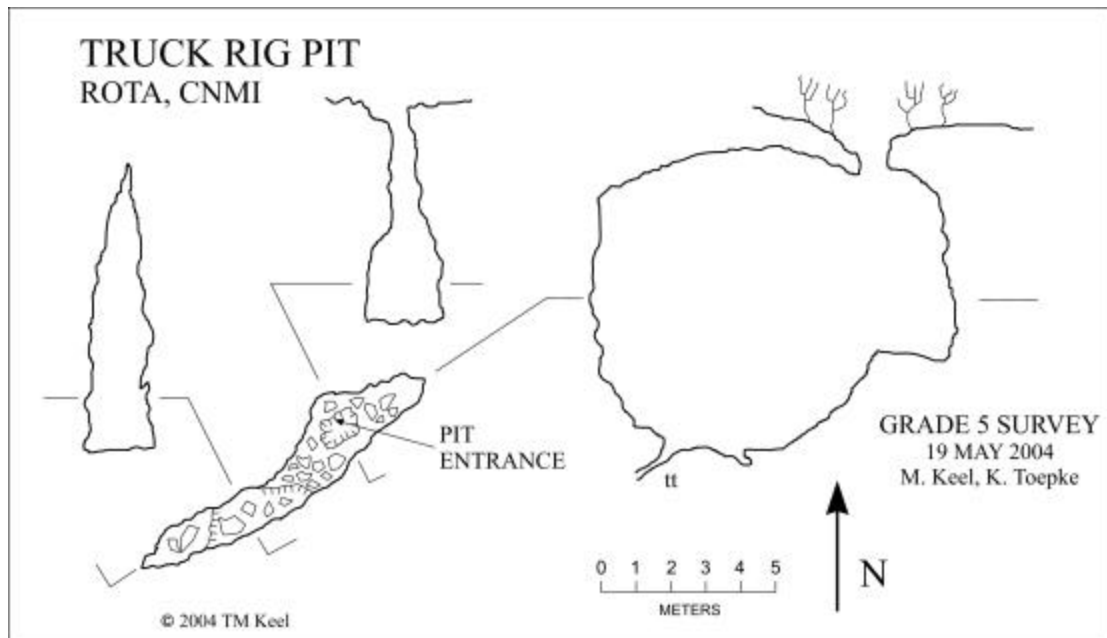


Figure B.117 Map of Truck Rig Pit

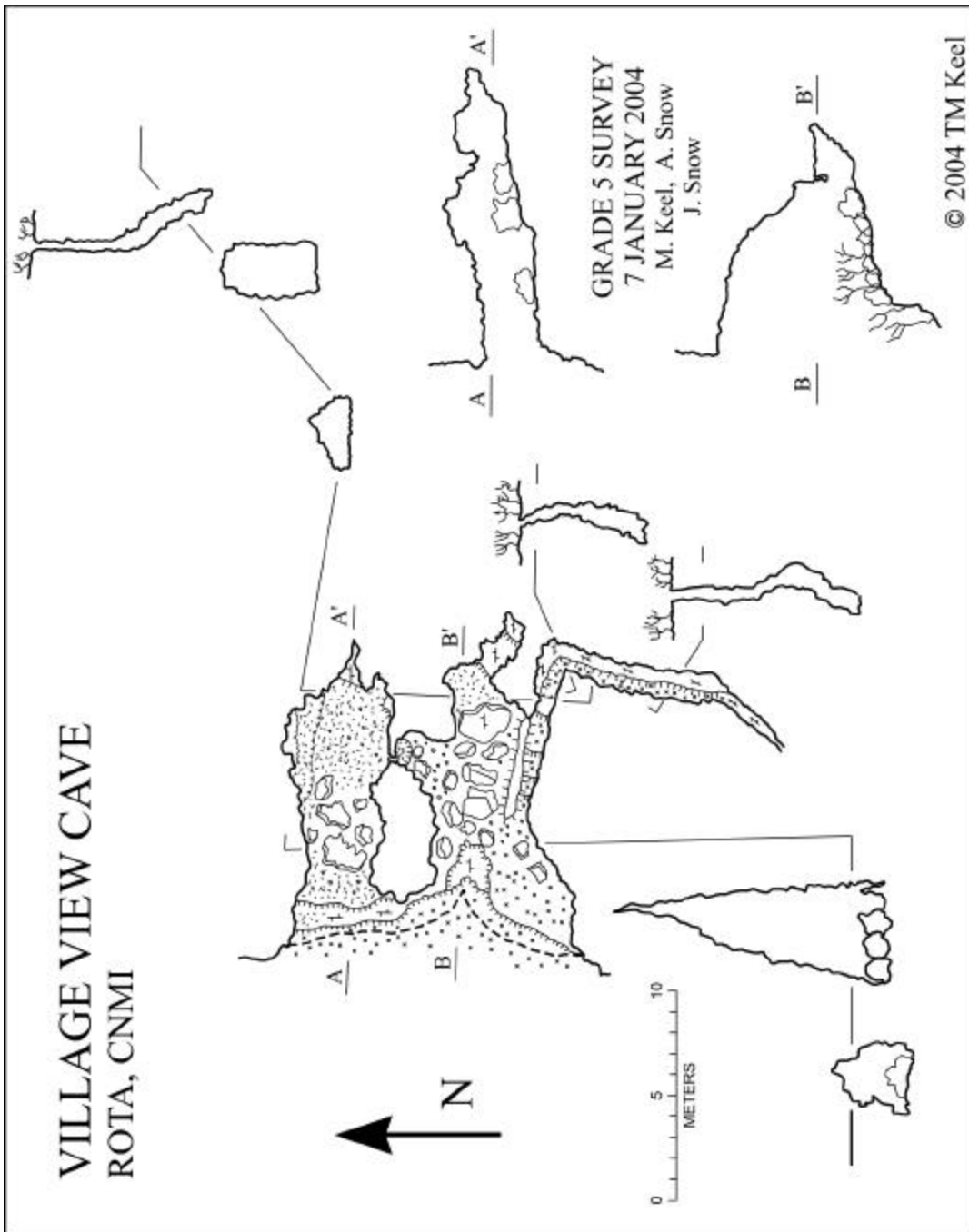
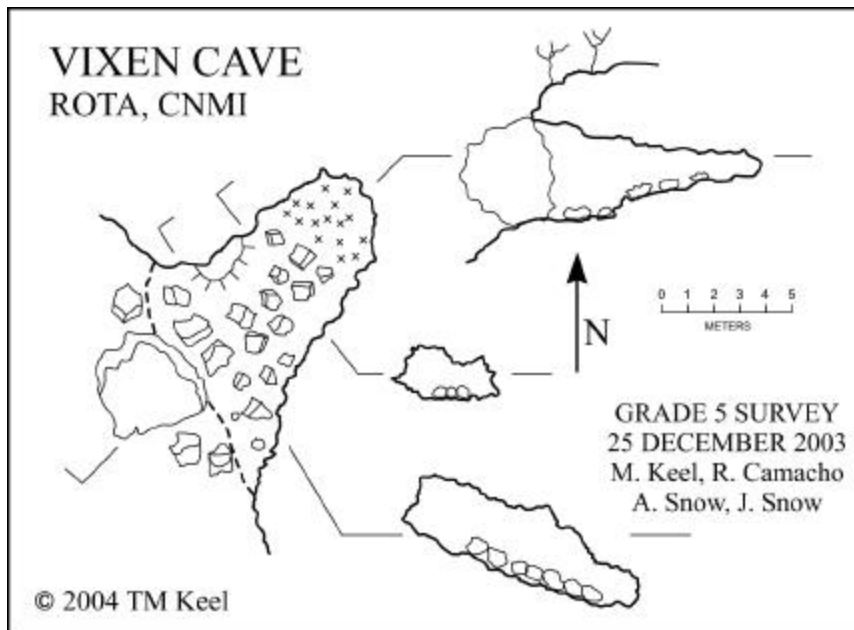


Figure B.118 Map of Village View Cave



*Figure B.119 Map of Vixen Cave*

# WATER CAVE (MATAN HANUM) ROTA, CMNI

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

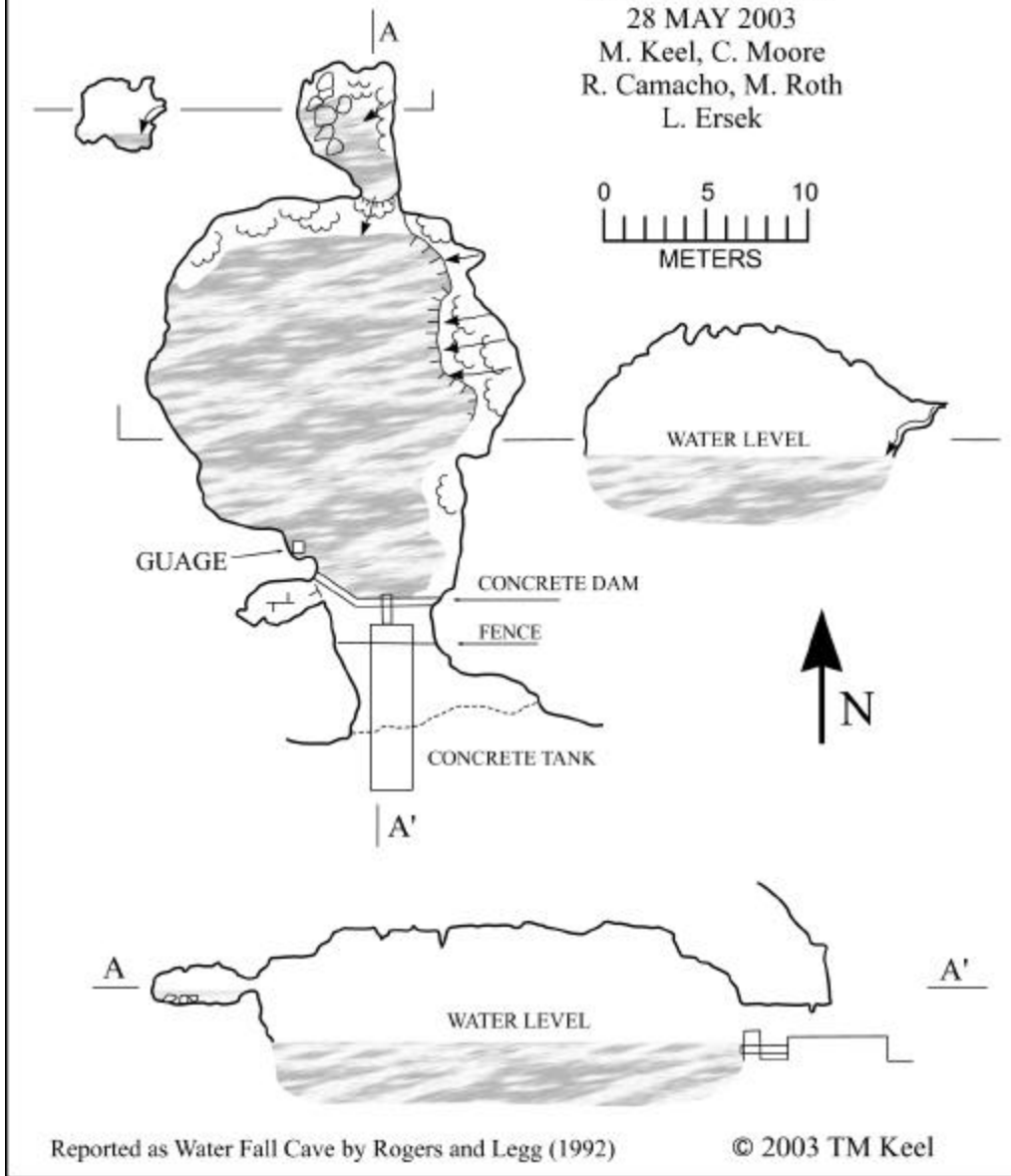


Figure B.120 Map of Water Cave (Matan Hanum)