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Front Cover: Rice Bay Formation, looking southwest along Grotto Beach. Photograph by Sandy Voegeli.

Back Cover: Dr. John Milliman, The College of William and Mary. Keynote Speaker for the 13th Symposium. Photograph by Sandy Voegeli.

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FRESH-WATER LENS ANISOTROPY AND FLANK MARGIN CAVE DEVELOPMENT FAIS ISLAND, FSM

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ABSTRACT

Fais Island is a small uplifted carbonate platform that lies about 200 km east of Yap, Federated States of Micronesia, in the Caroline Islands of the Western Pacific Ocean. Modern freshwater lens discharge is concentrated where high relief cliffs extend seaward beyond the beach and reef flats. Freshwater flow from the beaches and reef flats is small to insignificant. Flank margin caves are also concentrated in these headlands and are conspicuously absent in the vertical cliffs inland of beach and reef flat areas. The original porosity in the pre-Holocene carbonate rocks of Fais has been rearranged into high permeability flow systems by repeated exposure to the fresh water lens. The older headlands that extend past the lower permeability beaches and reef flats, conduct water from the lens to the sea. At the same time, flank margin cave development between headlands was diminished by the lack of freshwater lens discharge in those areas. A large closed contour depression containing a freshwater pool looks at first sight like a sinkhole, but is in fact, an ancient well dug into terraced Holocene sands that infill a reentrant in a paleo-sea cliff. The low relative permeability of these sands creates a more substantial fresh water lens than is available elsewhere on the island.

INTRODUCTION

The island of Fais is located 220 km east of the island of Yap in the Caroline Islands of the Western Pacific Ocean. It is an uplifted carbonate island, 1.2 km wide and 2.9 km long with a maximum elevation of 28 m (Figure 1). There are no surface streams or water bodies. As with similarly remote islands in the Western Pacific that are vulnerable to frequent typhoons and prolonged

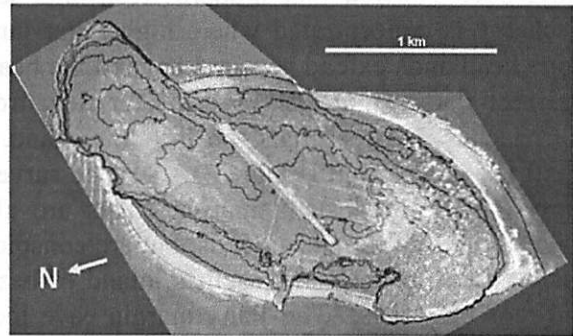


Figure 1. Composite aerial photograph of Fais. Contour interval is 10 ft (3 m).

drought, especially during El Niño events, ensuring a reliable supply of freshwater for island residents is an ongoing concern. Island residents (~320 people) use rainfall catchment as the primary freshwater source, although their main daily source of bodily fluid replenishment is from co-

conuts that grow prolifically on the island (MacCracken, 2006; 2007). Rooftop catchments can be destroyed entirely by the storms and both catchments and associated storage are rendered useless by prolonged drought. Similarly, high winds and prolonged droughts can eliminate the coconut crop. The groundwater resources of the island consist of a few drilled wells and one dug well, that can be brought into service during emergencies. However, water from such wells must be carried in hand containers to the households within the island's three villages. Previous attempts to install additional wells near the villages met with limited success (Zheng, 1996). The purpose of this study was to gain insights into the distribution and potential for groundwater development through a better understanding of the cave and karst features on the island. Such field work has proved useful in the nearby Mariana Islands (Jenson, et al., 2006).

FIELD OBSERVATIONS

Study of the beaches and adjacent terrain in the coastal zone during negative spring tides in May, 2005 showed that modern freshwater lens discharge is concentrated where high relief limestone headlands extend seaward beyond the beach and reef flats (Figure 2). Freshwater flow from the beaches and reef flats, on the other hand, is small to insignificant (Figure 3). Surface surveys show that uplifted flank margin caves are also concentrated in these headlands, but are conspicuously absent in the vertical cliffs inland of beach and reef flat areas. The flank margin cave locations indicate that past mixing zone dissolution occurred preferentially in the headlands, rather than uniformly along the island perimeter. It thus appears that past freshwater discharge was also concentrated in the headlands.

It has been observed in Bermuda and the Bahamas (Vacher and Wallis, 1992) that freshwater discharge is minimized in beaches and related young carbonate rocks, but is enhanced in the older rocks that have experienced the longest contact with the freshwater lens over numerous gla-

ciostatic sea-level highstands. On Fais, tectonic uplift has combined with glacio-eustasy to produce a more complicated exposure and submerision history for the limestone than has occurred in Bermuda and the Bahamas. The original depositional porosity in the pre-Holocene carbonate rocks of Fais has been re-arranged into high-permeability flow systems by repeated exposure to the freshwater lens. The older headlands extend seaward past the Holocene lower permeability beaches and reef flats and constitute preferred high permeability flow routes to conduct water from the lens to the sea. The outer boundary of the freshwater lens exhibits a high degree of anisotropy. Island morphology suggests that the headlands may lie at the end of faults that dissect the island (Figure 2). The presence of flank margin caves in these headlands, in contrast with their conspicuous absence elsewhere, indicates that the current anisotropic flow regime was also active in the past, promoting mixing-zone dissolution in the distal margin of the freshwater lens under the flank of the enclosing headland rock mass. At the same time, flank margin cave development between headlands was diminished by the lack of fresh water lens discharge in those areas. Uplifted flank margin caves on Fais therefore provide a proxy for freshwater discharge patterns on the island today. It should be noted, however, that cliff retreat from wave erosion is active on the headlands, whereas the inland scarps are somewhat protected. Unexhumed flank margin caves could exist in the interior cliffs where cliff retreat has not advanced far enough to breach the caves. Such retreat has made the caves in the headlands obvious, however.

A large closed-contour depression containing a fresh-water pool exists in an embayment in the cliff on the northwest side of Fais (Figure 2). This feature gives the superficial appearance of a sinkhole or blue hole, but more careful inspection shows it to be a dug well set in terraced Holocene sands that infill this embayment in a paleo-sea cliff (Figure 4). The low relative permeability of these sands creates a more substantial freshwater lens than is available elsewhere on the island, where groundwater dissolution has organized

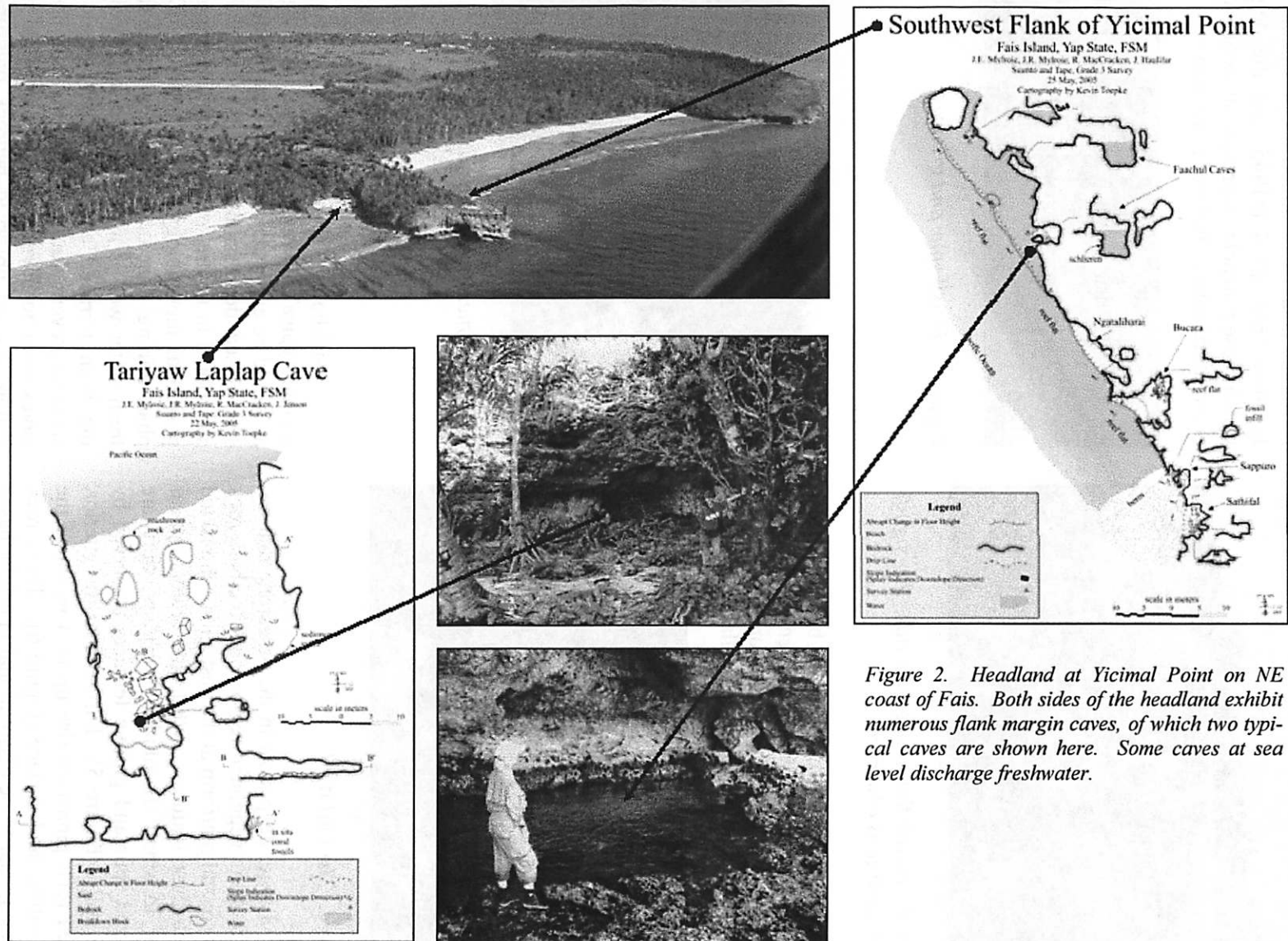




Figure 3. Beach flat at negative tide. No significant discharge is observed.

high permeability pathways in the bedrock. Residents report that the well is ancient, and so was the sole source of freshwater before rooftop rain catchment technology became available.



Figure 4. The Old Well.

Large, deep slots in the limestone that extend from the vegetated region onto the bare rock of the coastal platform at the east end of the island are not karst features. While these slots appear similar to small dissolution corridors, they are fossilized spur and groove features preserved by island uplift (Figure 5). Farther into the interior, isolated rock pinnacles rise up to 4 m above the surrounding land surface (Figure 6). These rock features appear to be dissolutional in origin, based on morphology and the dissection of primary fea-

tures, especially large coral heads in the rock itself. The island was mined for phosphate by the Japanese from 1914 to 1945, and the degree to which these pinnacles represent subaerial features or exhumed subsoil features is not known.



Figure 5. Fossil spur and groove.



Figure 6. Interior karrenfeld.

CONCLUSIONS

Sinkholes, sinking streams, and karst springs typical of continental settings are absent, as would be expected on a small carbonate island. The closed depressions on Fais are either constructional in nature, representing the original depositional morphology, or are artifacts of phosphate mining. The depression containing the dug fresh water well is artificial--the sand walls having been terraced and stabilized by laid stone walls to prevent slumping into the water hole. Pit caves were not identified during the field investigation, and all observed bedrock outcrops were limestone, indicating no allogenic catchment for

meteoric water. All rainfall catchment is auto-genic, and rain that is not caught on roof catchments sinks immediately into the epikarst developed on top of the limestone.

The karst inventory of Fais yielded several useful observations:

- 1) There are no caves in the interior, especially pit caves, so there is no natural access to the water table. To tap groundwater, wells must be drilled, or dug and maintained.
- 2) The old well dug into relatively low permeability Holocene sands provides easy access to the most voluminous ground water resource on the island and can be brought into service with relatively modest effort. The well is remote from current village locations, and water must be carried in hand containers.
- 3) Uplifted, relict spur and grooves forming topography along the coast are not eroded stream caves. All documented dissolution caves are flank margin caves that are concentrated along headlands.
- 4) The uplifted flank margin caves indicate where freshwater discharge occurred in the past, and those areas also proved to be where freshwater discharge occurs today. Flank margin caves are a proxy for fresh water discharge on Fais.
- 5) The freshwater lens is probably present across the entire island, but lens thickness and water quality (chloride concentration) are likely to be variable, so that the success of any given well cannot be easily predicted in advance. In general, water from the interior most likely flows toward faults or fractures that ultimately intercept the headlands.
- 6) Fais Island falls into the *simple carbonate island* category of the Carbonate Island Karst Model or CIKM (Jenson et al., 2006), however, the island demonstrates the complexity that can occur even in this single-lithology setting.

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