A Geodetically Positioned Shallow Submarine Platform for Tectonics and Oceanographic Research

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ABSTRACT

We suggest that it is possible to use GPS to position seafloor platforms and monuments in shallow water (say < 10m) by use of a mast which will hold a GPS antenna above the sea surface. With commonly used technologies, the vector between the antenna and the seafloor monument on which it sits would be precisely determined. A reef-capped seamount west of the Vanuatu (New Hebrides) Island arc offers an ideal location to build a submarine platform and mast of this kind both to develop and test this technology, and to use it to monitor crustal motion and sea level change. The site at Sabine Bank (SB) is remote from land, but shallow (4 - 10 m), and would be serviced at least annually by the R/V Alis, a French research vessel, based nearby at New Caledonia. GPS measurements from SB to sites on islands only 80 to 150 km across the nearby convergent plate boundary would measure plate subduction rates believed to be in the range of 10 to 20 cm/yr. However, any type of instrument or experiment that would benefit from regular GPS positioning, such as an inverted echo sounder, is a candidate for the permanent submarine platform. The total

facility at SB would consist of three components: (1) a primary bench mark (BM) and subsidiary BMs cemented into the reef hardground; (2) a permanent frame on the seafloor that has a reference plane precisely related to the reference point on the primary BM; (3) a mast permanently deployed over the primary BM that extends well above sea level and supports instruments including a GPS receiver and antenna, and determines the vector from the BM to the GPS antenna. We expect to locate the seafloor BM with an accuracy of 10 mm or better relative to a network of monuments located on nearby islands. These monuments would in turn be incorporated into the existing regional GPS network which is defined in a global geodetic reference system. In addition to the tectonic information from the GPS system and tide gauge data, the facility should provide ancillary and ground-truth data for remote sensing satellites including TOPEX/POSEIDON and ERS-1. Our approach to seafloor positioning addresses only the special case where water depths are shallow enough for a rigid mast to extend from the seafloor to support a GPS antenna above sea level. However, there is a significant subset of ocean locations where this approach may be feasible.

1. INTRODUCTION

The problem of positioning seafloor monuments in the deep oceans using GPS is technically daunting (Spiess, 1985) and will be expensive to implement in a routine operational mode. In contrast the problem of submarine positioning in shallow water (<10 m) can be reduced to that of relative positioning of monuments on land, which is a very mature technology. Although a shallow seafloor positioning capability has a greatly restricted range of application relative to a general seafloor positioning capability, it can be implemented relatively quickly, at relatively low cost, and could be useful in a fairly wide variety of contexts.

The institutions with which the authors are affiliated are designing a system for geodetic positioning of a shallow submarine platform and benchmarks on a shallow reef in the Southwest Pacific to support research in tectonics, sea level and oceanography. The origin of this plan lies in our existing Southwest Pacific GPS Program to measure plate tectonic movements in the Vanuatu-Fiji-Tonga region (Fig. 1). The Sabine Bank offers a location from which we could make GPS measurements on very short baselines across the Vanuatu convergent plate boundary (Fig. 2). However, we recognize that an open sea GPS-located site could be of interest for global sea level studies (Carter et al, 1986) and for calibration and verification of remote sensing satellites.

Sabine Bank is a reef capped seamount on the d'Entrecasteaux ridge, which is a 3 km high, 100 km wide bathymentric feature oriented perpendicular to the Vanuatu arc trend (Fig. 2). Because the relative motion between the Indo-Australian plate and the Pacific plate is about 10 cm/yr nearly normal to the arc trend, the ridge and Sabine Bank are being rapidly subducted beneath the island arc. Figure 3 shows the trajectory that Sabine Bank has probably followed as it rides the Indian plate's oceanic lithosphere toward the Vanuatu subduction zone. If the subduction rate is about 15 cm/yr then this model would predict that Sabine Bank is presently subsiding at a rate of approximately 1 mm/yr. It is likely that the seamount was formerly above sea level prior to the most recent postglacial sea level rise and when it was farther west and higher on the "outer rise", the bulge in oceanic lithosphere that occurs due to bending of an elastic plate as it approaches a subduction zone.

Although we have not processed the bathymetric data collected during a ten day April 1990 cruise to the Sabine Bank made by the ORSTOM Research Vessel/Alis, a schematic diagram based on the data is given in Fig. 4 to illustrate the main features. The bank is roughly 8 km long in the E-W direction by 3-4 km N-S. Its perimeter rises very steeply from depths of hundreds of meters to a shallow rim that is generally 8 to 12 m deep and on the order of 50 m wide. The inner area is a depression varying in depth between 12 and 20 m. On the rim are at least two particularly shallow areas 4-8 m deep. The sea floor at these shallow areas, fortunately, consists of massive corals that are well cemented together to form a reef hardground. This means that the reef rock resembles concrete sufficiently that it can provide a suitable foundation for drilling holes to cement benchmarks and attachment bolts for the equipment that we propose to emplace on Sabine Bank. We plan an additional visit to the site within a few months to drill several meters into the hardground for core samples to be used to quantitatively design the foundations for facilities at Sabine Bank.

2. THE SABINE BANK FACILITY

Our initial plan was to deploy and recover a mast (Fig. 5) to support the GPS antenna over the mark at Sabine Bank each time we visited the site to take data. However, during the April cruise we experienced unseasonably strong winds and waves that demonstrated that we can not count on good weather suitable for deploying and recovering the mast even in the calmer seasons. We elected to investigate designing a permanent mast that would leave only the task of mounting and removing the GPS receiver and antenna during each visit. Preliminary consideration by Dr. Lymon Reese, a marine civil engineer with UT-Austin's Offshore Technology Research Center, indicates that very little modification of the design in Figure 5 is required to build a mast that would survive hurricanes. The critical parameters in designing such a permanent mast have to do with knowing the strength of the substrate on which it would be mounted. In fact, besides avoiding delays in GPS operations, there may be numerous advantages in having a permanent mast from which data from instruments in the facility could be telemetered. Indeed the mast itself could serve as a settling tube for a continuously operating tide gauge.

A principal characteristic of our mast design is that it will allow us to center a GPS anntenna precisely over a reference mark cemented into the sea floor. While recording GPS data the top of the mast with the antenna would not sway more than 5 mm horizontally assuming a wave height of 3 m, wind speed of 20 km/hr (5.5 m/s) and a current velocity of about 0.5 m/s. We expect to be able to directly measure the height of the antenna above the mark to within 2-3 mm.

To ensure that we do not lose the position of the primary benchmark, we would have a local submarine array of subsidiary benchmarks within a few meters of the primary mark. Simple direct measurements between marks would define the relative positions of marks and allow recovery of the primary location should the primary mark be damaged. To test stability of the primary site we have proposed a secondary site that would be located on the second shallow part of Sabine Bank several km from the primary site. GPS measurements of the distance between the primary site and the secondary site should always be the same if both are stable. This procedure requires that we have a second portable mast, but we could deploy it when convenient and not very often.

A permanent submarine platform (Fig. 6) would be located within a few meters of the primary benchmark. It would consist of a steel frame attached to the sea floor by bolts cemented into the reef. The upper surface of the frame would be level. Direct distance measurements from several reference marks on the level surface of the frame to the primary reference point would allow us to precisely define the relationship of any point on the frame to the primary mark and thus to the global GPS frame of reference. The submarine platform would house instruments of any type that would benefit from regular GPS measurements such as tide gauges, wave meters, current meters, etc. Data from these instruments could be recorded and stored internally or it could be telemetered via an antenna on a permanent mast.

Existing support for this proposal consists of commitments by two of our collaborators to make substantial contributions to the operation from resources at their disposal. The National Geodetic Survey has agreed to provide at least one tide gauge for the submarine platform. Jacques Recy of ORSTOM-Noumea has commited a minimum of 110 days of R/V Alis ship time over five years plus the services of 3 professional divers, technical support and the participation of several scientists. Several potential collaborators have expressed their intention to utilize the Sabine Bank Platform if we obtain funding to build it.

REFERENCES

Carter, W.E., Robinson, D.S., Pyle, T.E. and Diamente, J., 1986. "The application of geodetic interferometric surveying to the monitoring of sea-level." Geophysical Journal of the Royal Astronomical Society, Vol. 87.

Spiess, F.N., 1985. "Suboceanic geodetic measurements." IEEE Trans on Geoscience and Remote Sensing, GE, Vol. 23.

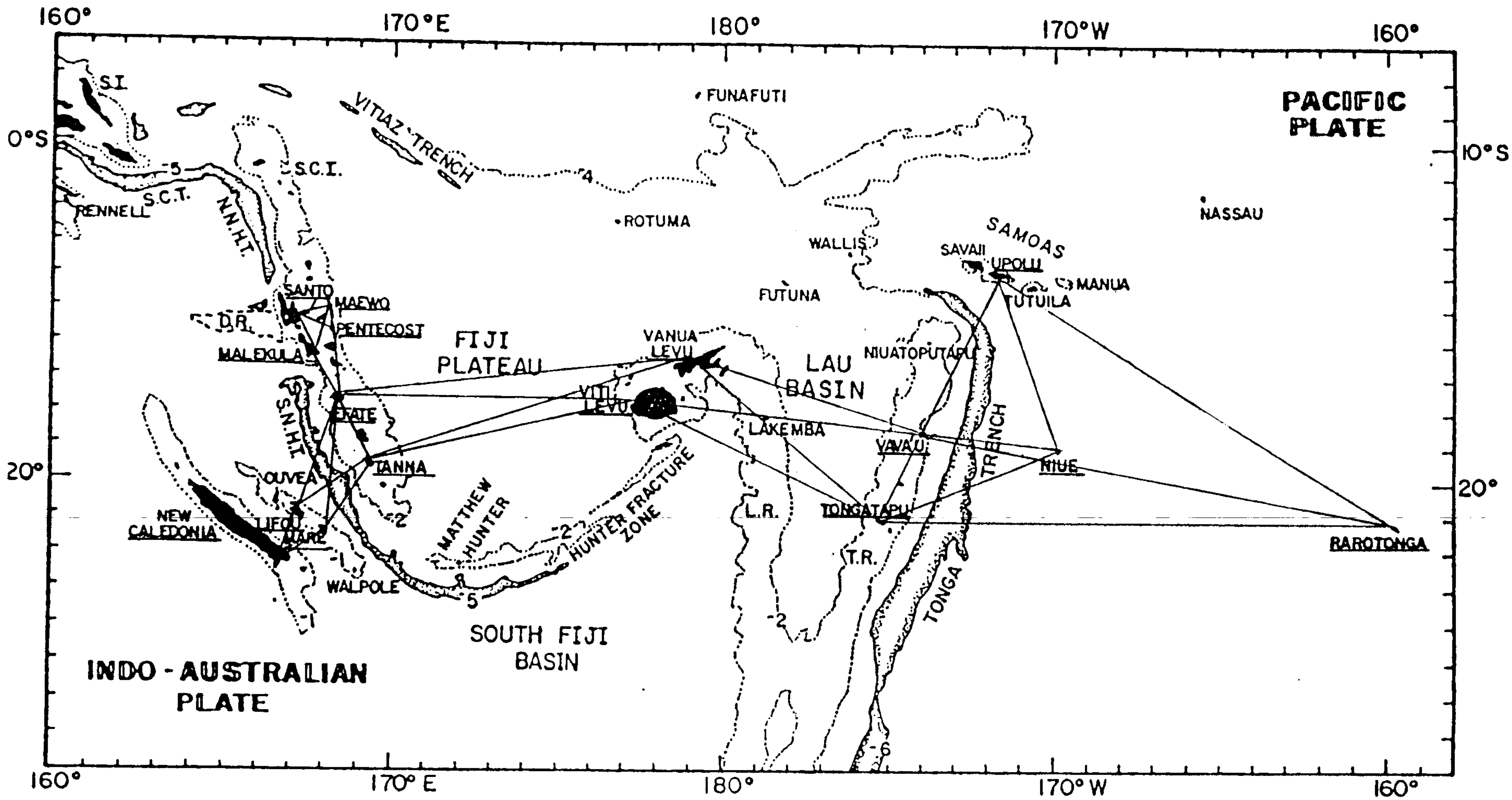

Figure 1: Regional setting of the Vanuatu arc and baselines of the Southwest Pacific GPS Project (SWPP). This NSF-funded project involves annual occupations of benchmarks from 1988 through 1992, except for 1991 when observations are not scheduled. A subarray of the network extends into the central Vanuatu arc area because of the rapid deformation rates and subduction of the d'Entrecasteaux ridge (DR). Some proportion of the back arc basin opening rate of the Fiji plateau (N Fiji basin) must be added to the I-A/PCFC relative motion of 10 cm/yr at central Vanuatu for an average net convergence rate on the order of 15 to 20m cm/yr. GPS sites of the SWPP are located on islands whose names are underlined.

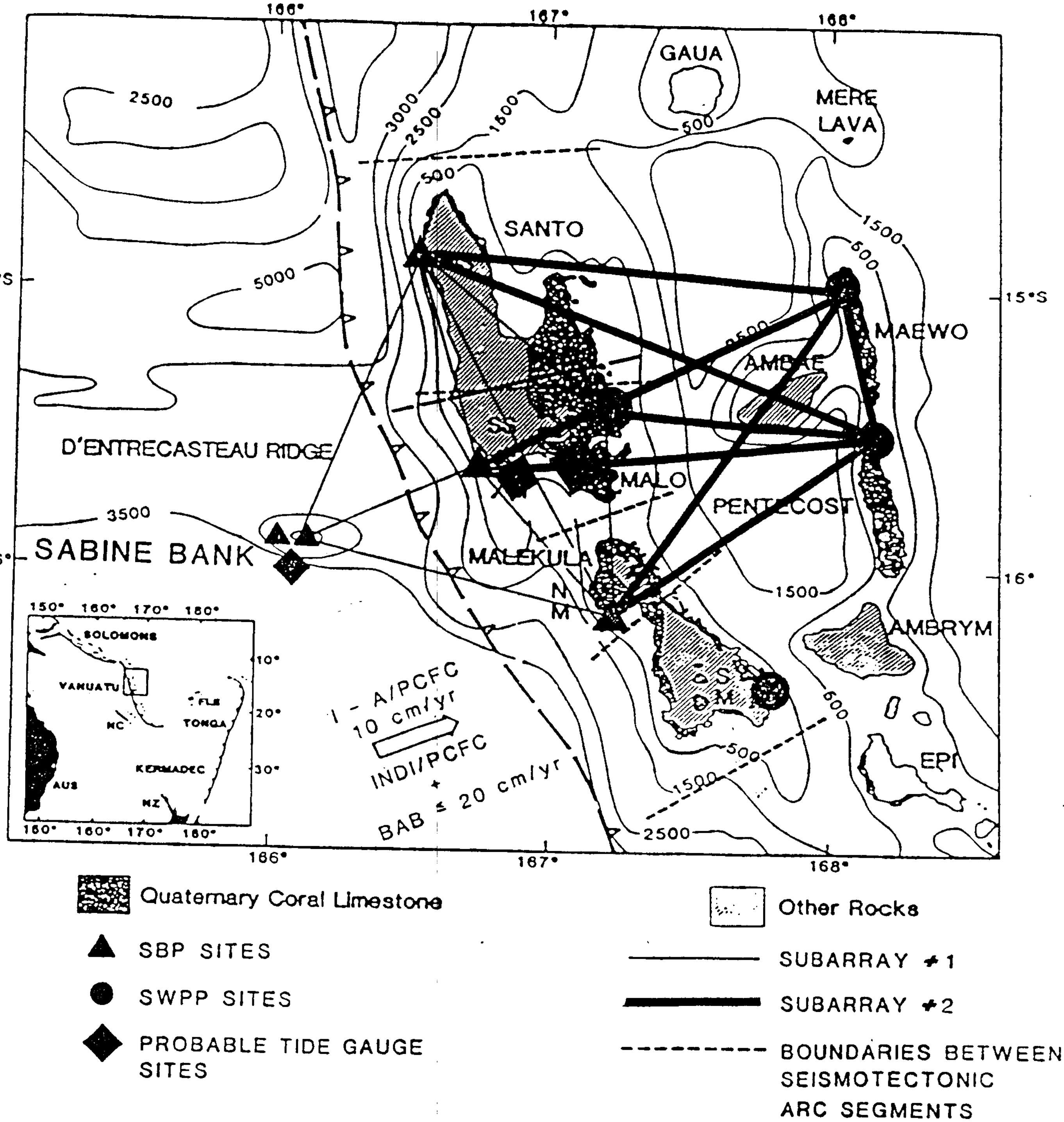

Figure 2: Tectonic setting and bathymetry of central Vanuatu with locations of the 5 SBP and 4 existing SWPP GPS sites and suitable sites for John Beavan's tide gauges on SB and south Santo (Appendix III). The 3 SBP sites on W Santo and Malekula are positioned to provide minimum baseline lengths and a variety of azimuths to obtain as pure a measure of slip on the main thrust zone as is possible but with a site on each of 3 arc segments. Crustal motion between these sites and those farther east on the Vanuatu arc will measure upper plate strain. The SBP and SWPP sites must be linked, but this will require that we have 2 subarrays and 2 observing sessions if we have only 6 GPS receivers. Some baseline azimuths and distances from SB to island sites are: NW Santo - 130 km; N20 E. SW Santo - 78 km; N63 E. E Santo - 128 km; N64 E. NW Malekula - 121 km; N102 E. SE Malekula - 186 km; N108 E. Pentecost - 224 km; N77 E.

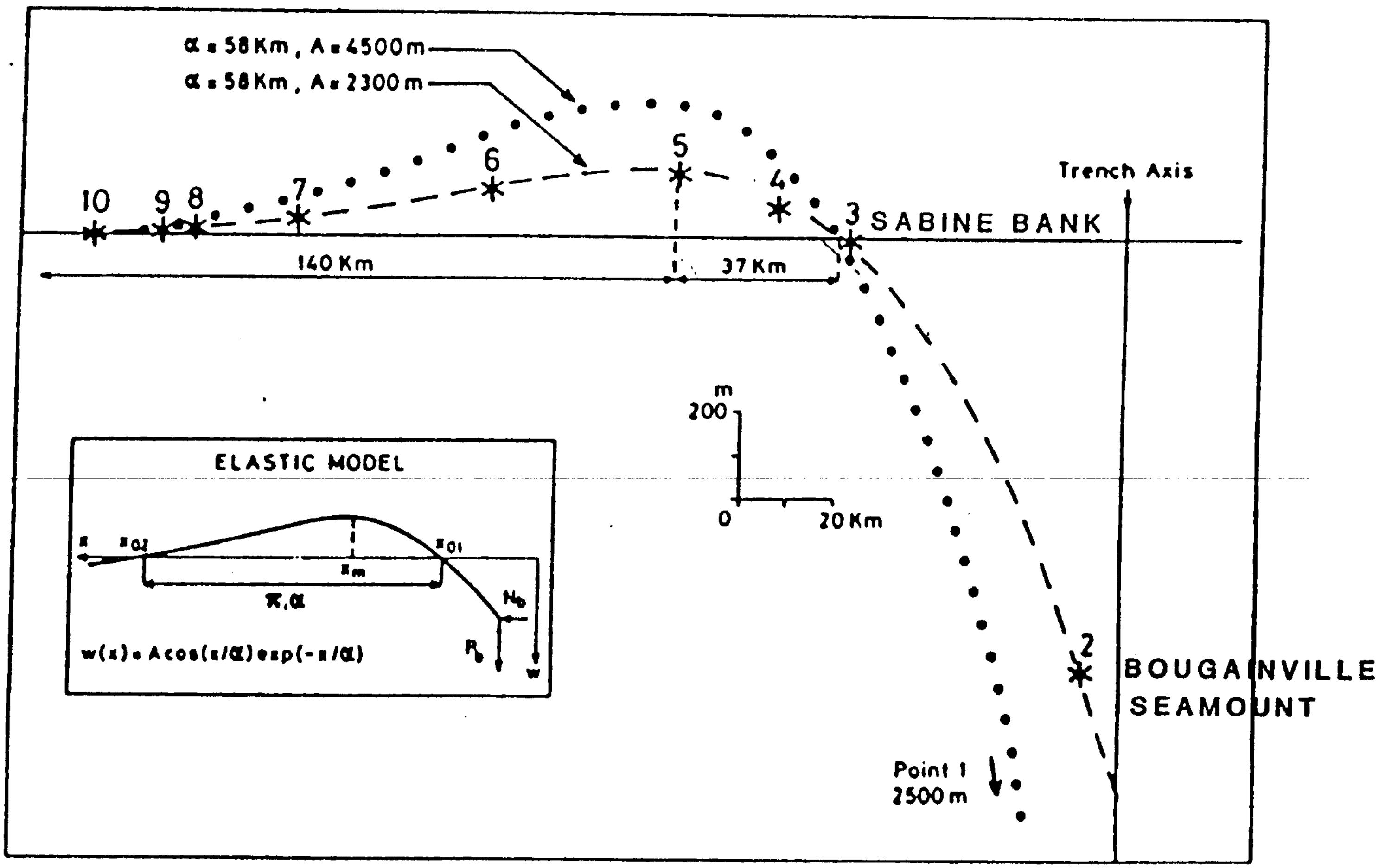

Figure 3: Plate bending model for the downgoing plate based on the heights of emerged and submerged reefs including Sabine Bank and Bougainville guyot (after Dubois et al., 1989). The basis for this model includes the heights of atolls in the Loyalty Islands that emerged from the sea as they approached the outer rise. Sabine Bank has passed over the outer rise and on its way down toward the convergent plate boundary at accelerating subsidence rates. Its present mean subsidence rate depends on its rate of convergence with the Vanuatu arc, but should be approximately 1 mm/yr.

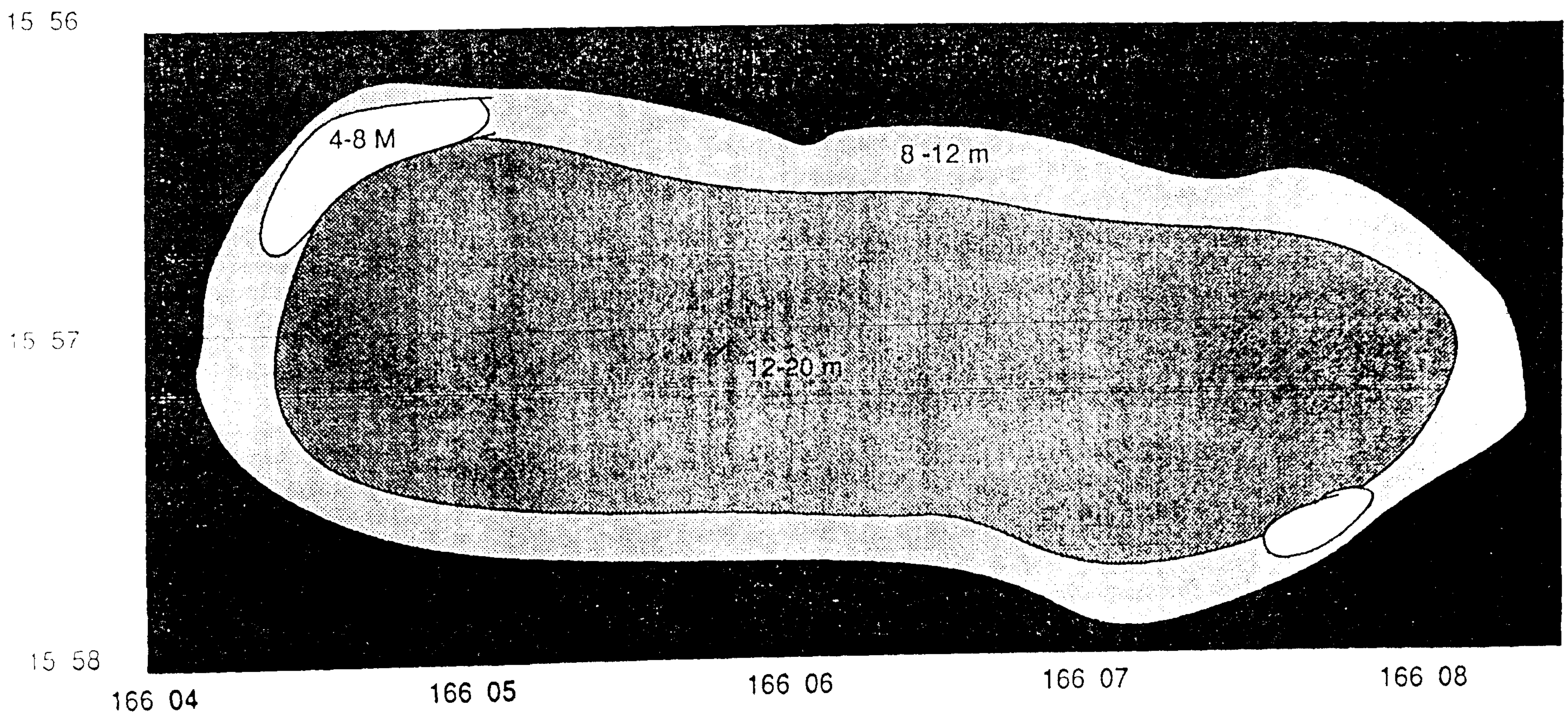

Figure 4: Sketch of Sabine Bank Bathymetry

Conceptual Design for SBO GPS Mast (not to scale)

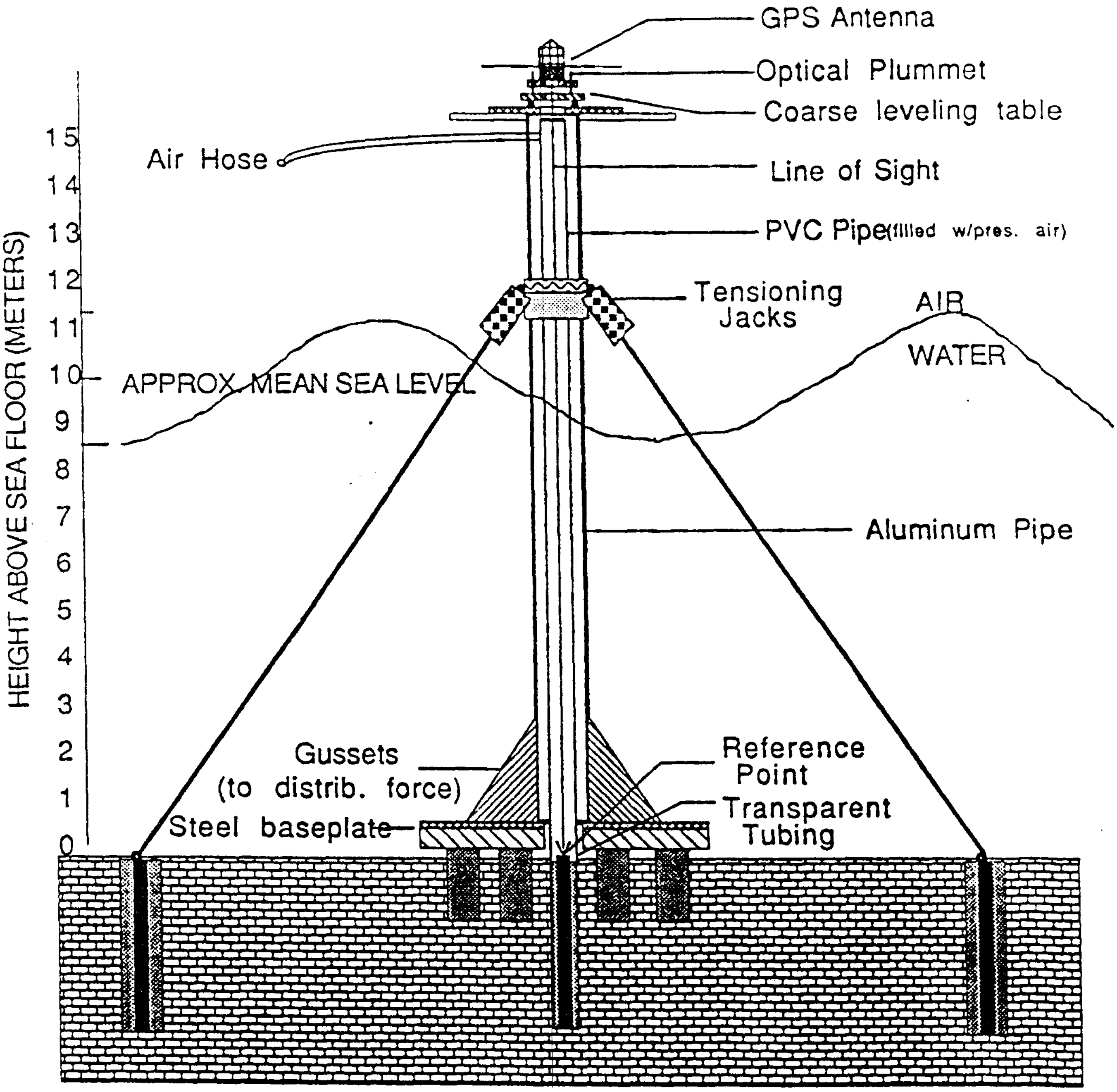

Figure 5: Conceptual diagram of the Sabine Bank Observatory mast and bench mark. The essential features of the mast are that it is not physically connected to either the submarine bench mark or the geodetically positioned submarine platform which will be located nearby. The mast is to support a GPS antenna positioned precisely over the reference point on the submarine monument without swaying more than 5 mm off the mark during GPS data acquisition. Other instruments could be mounted on the mast for special experiments.

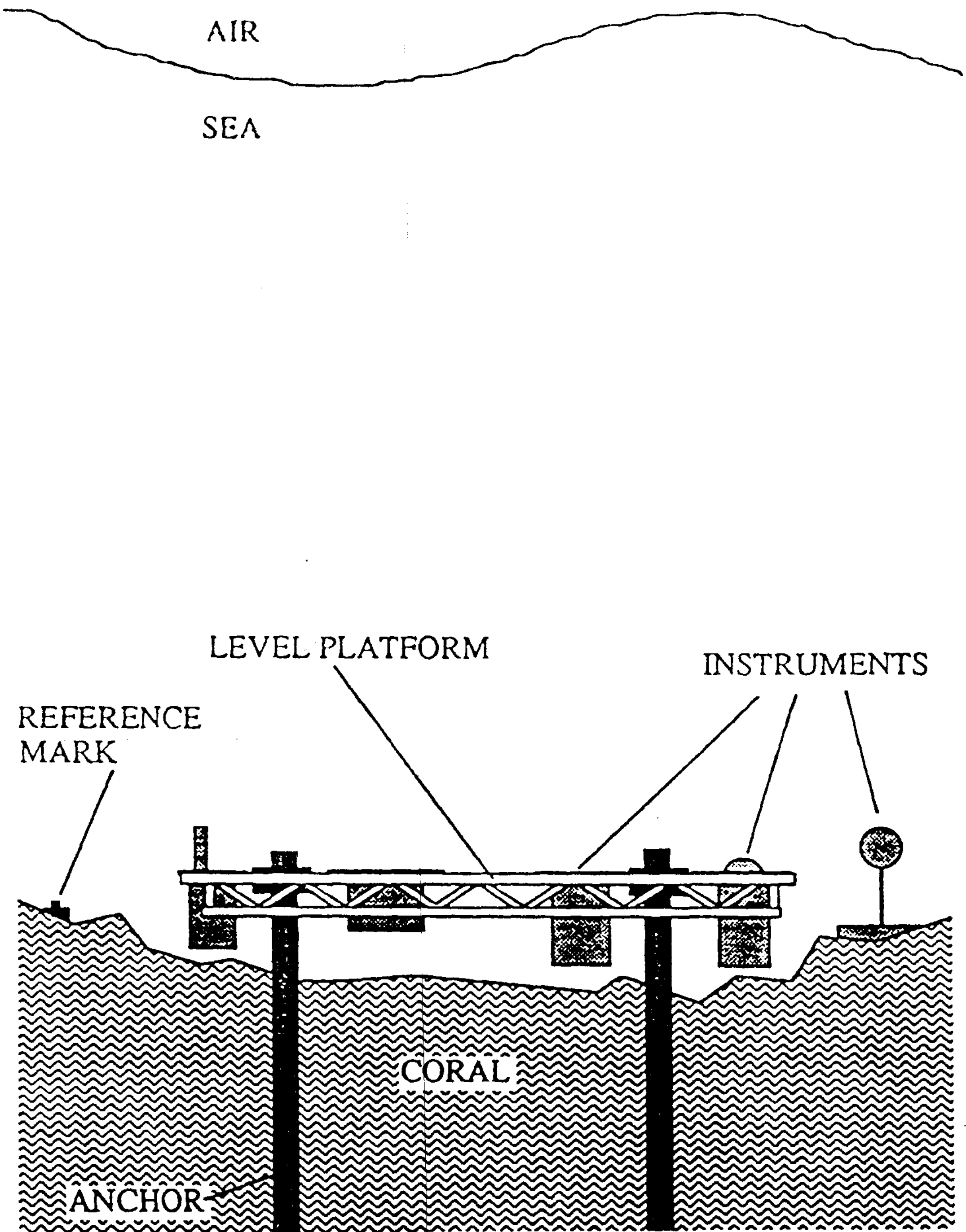

Figure 6: Conceptual diagram of the geodetically positioned shallow submarine platform. This facility will be designed to survive any conceivable weather conditions. We will find or create a depression in which to build it so that the instruments will be afforded maximum protection. The upper surface is a leveled reference plane to which each instrument will be related. The platform will be related to the bench mark by measurements from at least 3 points on the reference plane surface to the bench mark reference point. These measurements will precisely define the relationship of the submarine platform to the reference mark because the reference plane is level. The geometry of the submarine platform can be measured so that the geodetic position of every instrument is precisely known in 3 dimensions.