# SAYA DE MALHA EXPEDITION

*March 2002*

Impressum

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# SAYA DE MALHA EXPEDITION

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# 1. Introduction

The Lighthouse Foundation (LF) in Hamburg, Germany, granted SUN & SEA e.V., Germany, funds for an exploratory expedition to Saya de Malha Bank in the Indian Ocean, planned for March 2002.

The goals of this scientific exploration were defined as performing

- a first assessment of flora and fauna of selected areas of the bank
- the building of a coral ark
- initial assessment of the ecological significance of of the researched area
- documentation and reports on this relatively unknown area in the Indian Ocean

The Saya de Malha Expedition 2002 commenced on March 11 and ended March 28, 2002.


2

**1.1. Summary, July 12, 2002**

The Saya de Malha Banks are one of the least-known shallow marine ecosystems in the world. As they are avoided as a potential hazard to navigation, little mapping or scientific research had been carried there prior to this expedition. They are dominated by seagrasses and coral reefs, are a major whale breeding ground, and are a key stepping stone in the migration of shallow water species across the Indian Ocean. The bottom was found to be composed of a generally flat sloping limestone rock covered by seagrass interspersed with small coral reefs. Drilling of the surface showed that the bottom is made up of layered growths of red calcareous algae, and studies are underway to determine the age and growth rate of this material. The fauna and flora were filmed, and a visual biodiversity encyclopedia will be prepared showing all the species found and their diversity. Coral reefs had suffered extensive mortality between 1997 and 2002, almost certainly due to severe high temperatures in 1998, but there were many new young corals that had settled since then. Because of the rich supply of nutrients and plankton delivered to the banks from adjacent deep waters, the Banks are an oasis of high productivity. Since a large part of the seagrass organic production is swept by the currents into deep waters, where some of it is buried in deep sediments, the banks serve as a significant sink of atmospheric carbon dioxide and a source of oxygen. Future work is needed to map the ecosystems on the bank and characterize their importance in maintaining biodiversity and global geochemical balances. Because Saya de Malha is the largest shallow tropical marine ecosystem in the world that lies mainly in International Waters outside of all territorial jurisdiction, they are in strong need of protection, which will require establishment of an unprecedented International Biosphere Reserve, the first of its kind.

**Saya de Malha bathymetric survey report** *Reported by Steve Evans*


## Abstract

The existing sources of detailed bathymetric data for the Saya de Malha banks are minimal. The aim of the work carried out in 2002 was to survey a 2 km2 part of the bank, map it, and if possible to identify significant changes in depth which could represent underwater structures such as reefs. The results show that it is possible to carry out realtime bathymetric surveys using limited equipment and basic techniques on-board a small research vessel. The advantage of processing at least some of the data in-situ is that the survey can be carried out in a controlled fashion and any potentially interesting survey data can be observed and re-visited for a more detailed inspection. This is extremely important when working on a site as remote as Saya de Malha.

Although the analysis has shown that the area is largely flat, it has shown that there may be some interesting changes in the bathymetry approximately 1km to the north east of the main site. Any further visits to the area should attempt to incorporate diving or underwater viewing at this location for further analysis of the causes of these. It is also apparent that the trend of the bathymetry was to become shallower as we moved in an easterly direction, despite the fact that present day hydrographic charts indicate that we were located on the edge of the bank and the depth should have been increasing. Any future visit to the site should attempt to survey in an easterly direction to ascertain where the edge of the bank actually is.

# 2. *Participants*

**Prof. Wolf Hilbertz M.Arch.**

Expedition leader, 63. First to formulate Cybertecture (1967) and inventor of Mineral Accretion Technology (MAT) (1974), developed corresponding patents. He is founder and president of Sun and Sea e.V., a not for profit organization based in Hamburg and dedicated to applied research and applications of MAT. Wolf is in charge of building coral nurseries at the Global Coral Reef Alliance and a co-founder of Biorock Inc. He works with Tom Goreau since 14 years in the fields of coral nurseries, coastal protection, and solar power generation. In 1998 Tom and Wolf shared the top Theodore M. Sperry Award of the Society for Ecological Restoration. He taught in the US, Canada, and Germany, has five children, and lives in Thailand.

*Prof. Wolf Hilbertz M.Arch.*

**Thomas Goreau Ph.D.**

Science coordinator, 52, is a world famous coral biologist and pioneer in coral restoration. He uses techniques developed together with Wolf Hilbertz to enhance coral growth and survivability in projects in Panama, the Maldives and Indonesia and elsewhere. He is co-founder and president of the Global Coral Reef Alliance, a not for profit organisation based in Cambridge, USA. Tom grew up in Jamaica and lives in the US with his wife and two daughters.

*Thomas Goreau Ph.D.*

**Frank Gutzeit Dipl. -Ing. Architekt**

Logistics, has been a key man in organizing much of the logistics and equipment for Saya 2002. He is an architect with his own practice in Hamburg. He met Wolf in the early '90s while studying at Bremen University, and in '97 worked on the Biorock project in Ihuru Atoll in the Maldives which delivered such spectacular results after the bleaching and mass mortality of '98. Frank is in his mid 30s and married with two small daughters.

**Gabriel Despaigne**

Dive coordinator, 29, student in environmental law at the University of Panama. He is president of the Oceanic Association of Panama. "We set up environmental protection projects, teach people how to take better care of their marine environment, and lobby the government for sustainable development of marine resources". To earn a living – not an easy matter in Panama – he works as a Divemaster with tourists, and sometimes as a diver on marine engineering and recovery operations. Gabriel is a Divemaster.

*Frank Gutzeit Dipl. -Ing. Architekt*

*Gabriel Despaigne*

**Stephen Evans M.Sc.**
Cartographer, 30 – a specialist in Geographical Information Systems (GIS) and 3D computer modeling. He has a bachelor's degree in geography from Exeter University and an MSc from Plymouth. He is a research fellow at the Centre for Advanced Spatial Analysis (CASA) at University College, London (UCL). He was a cartographer for two years with the British Antarctic Survey (BAAS). In addition to his work at CASA, he has a small company, Plannet Visualisations ‹www.plannet.co.uk ›, which provides 3D modeling services to architectural and commercial ventures, plus charities and education. Steve is an experienced amateur diver, and is in reasonable shape for someone who spends most of his time in front of a computer.

*Stephen Evans M.Sc.*

**Peter Goreau Ph.D.**
Geophysicist, 51, Tom Goreau's brother came to Saya to help with underwater construction. Born in Jamaica in 1951, he graduated in geology from Bristol University, England, in 1975, and completed a PhD in the geophysics of the northern Caribbean at the MIT-Woods Hole Oceanographic Institute in Massachusetts a few years later. In 1977 he was part of a survey team led by John Slater of the SW Indian Ocean triple junction, a few hundred miles from Saya. He then taught geophysics in the US for a number of years.

*Peter Goreau Ph.D.*

**Caspar Henderson**

Author and consultant, 38, specializing in environment and energy. He writes regularly in major British and US newspapers, and is a winner of the Reuters-IUCN media award for best environmental reporting in Europe. He also works with voluntary groups, government and others on policy and economic issues.

He was writing a daily internet diary about Saya 2002 that is posted on www.lighthouse-foundation.org and on his own site www.grainofsand.org.uk.

*Caspar Henderson*

**Caroline Mekie**

marine biologist, 32, from Edinburgh, Scotland. She is the only member of this expedition to have been to Saya with Tom and Wolf on their first trip in 1997. "Only four days after we put the structure in the water and had it working I was amazed. You could see that it [Mineral Accretion Technology] really worked. The coral fragments we had attached were doing very well". Since '97 Caroline has completed a masters degree in conservation biology. She is currently doing another masters degree in multi-media technology, and hopes to combine the two areas.

*Caroline Mekie*

**Roman Obrist Dipl.-Ing.**

Captain merchant marine and engineer, 34. A Swiss national, he holds a captain's license and chief engineer's license four years at the Maritime Academy in Hamburg. "Everything which swims I can fix and drive". For a few years he worked on bulk carriers between Latin America and Europe. He and a friend also found the time to sail a small boat all round Latin America, fulfilling a dream since they were young kids high in the Swiss Alps. For the last two years he has been working on sail cruises for tourists to the Amazon and Antarctica. He is also a divemaster.

*Roman Obrist*

**Hartmut Kubitza**

Captain and owner of SY Vaka-Lele which he built himself in Australia. He studied Economics in his native Germany,is an advanced diver, and a very accomplished, even fabulous sailor. Living on his boat with gracious Alexandrine from Madagascar, he has been chartering worldwide and now continues to take commissions for the Eastern Indian Ocean.

Hartmut evolved a great interest in the project and eagerly awaits the next mission to Saya de Malha Bank.

*Hartmut Kubitza*

**2.1. Expedition vessels**

*RV Orphee*

*SY Vaka-Lele*

*MSY Ceres*

a. RV Orphee, 45 ft., steel sloop,
auxiliary Diesel engine
Captain Peter Lucas

b. SY Vaka-Lele, 38 ft.,
fiberglass sloop,
auxily Diesel engine
Captain Hartmut Kubitza
first mate Alexandrine

c. MSY Ceres, 45 ft., steel sloop,
main Diesel engine
Captain Niko Haag
Willy, first mate

There were five dinghies operational

# 3. Travel log

### 3.1. Tropical Cyclone Hary

*March 6*

centerpoint latitude: 10.40.00S longitude: 63.01.05E, practically on Saya de Malha Bank. Sustained winds at 40 knots with gusts up to 50 knots.

*March 8*

11.14.02S 53.30.49E. Winds at 65 knots, gusts up to 80 knots. Later during the day winds were sustained at 120 knots, gusting up to 145 knots.

*March 11*

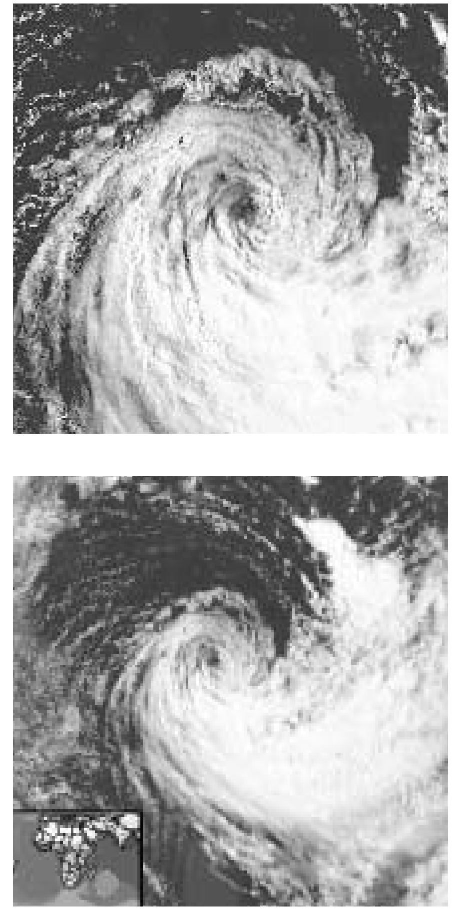
8.53.36S 51.12.49E. Moving SE over open water, the cyclone should maintain intensity. Later during the day winds are 115 knots, gusts up to 140 knots.

*March 12*

27.12.21S 55.39.24E. Winds at 115 knots, gusts up to 140 knots.

*March 13*

29.46.42S 57.22.49E. Winds are sustained at 45 knots, with gusts up to 55 knots.
Source: NOAA



*Tropical Cyclone Hary*

### 3.2. March 11 – 28

*March 11*

RV Orphee and SY Vaka-Lele leave Victoria harbor shortly before noon. Scattered clouds, sunny, northerly wind at 10 kn. Bearing 140 degr., 406 NM to our destination. MSY Ceres leaves at 18:00 h. All boats average 5-6 knots.

*Departure*

*March 12*

While leading RV Orphee still experiences winds of 20 kn., the following boats are nearly becalmed and have to use their engines. A slight swell rolls.

*March 13*

Winds up to 10 kn. RV Orphee crosses the 9th parallel at noon, the seabed is 213 ft. below, part of the North Bank. SY Vaka-Lele and MS Ceres are not far behind, but out of radio range.

*The 1997 structure*

*March 14*

RV Orphee arrives 14:50 h at the destination, 9.11.953S 60.21.002 E. Slight swell and current, overcast sky, easterly winds changing to westerlies.

Around 21:00 h current speed increases setting NW, at 12:00 h changes to setting E at 0.3 m/sec.

By 16:00 h the structure erected by the Saya Expedition 1997 on the sea floor had been located. The boat anchors nearby in 46 ft. of water. Preparations for construction are made and cutting of steel profiles is begun.

*March 15*

MSY Ceres arrived 2:15 h and SY Vaka-Lele 2:20 h. All boats are anchored in proximity. Slight swell, hardly a breeze.

*March 15 - 17*

Swell, moderate breeze.

Surveys of the sea floor are performed, scientific recording instruments are placed, the '97 pyramidal structure is documented, individual and coral colonies are being examined, drilling cores of the upper calcareous seabed cover are taken. Bathymetrical mapping of a selected portion of the North Bank begins. Construction elements are prepared and steel supplies for future projects are stored on the sea floor.

MSY Ceres leaves for Victoria March 17 about midnight.

*March 18 - 19*

Flat sea, moderate breeze.Welding work is started on the coral ark "Saya Star". The ark is launched and positioned.

*March 20*

Slight waves, moderate breeze.

Work on the photovoltaic raft begins.

*Gabriel welding in the swell*

*Preparing the arc to bee launched*

*March 21*

Slight waves, moderate breeze. Corals are placed on the Saya Star. Work on the solar raft continues. Anode/cable connections are encased and all cables are prepared. Mooring chains for the solar raft are fastened to the Saya Star and a huge dead coral head.

*March 22*

Flat sea, hardly a breeze.

The weather service reports an area of convectivity NE of Saya de Malha, moving towards us at 10 - 15 knots. We will have to leave as soon as possible, there is time only for the most essential tasks.

More corals are attached to the ark.

The solar raft is launched and moored, the anode deployed and the cathodic cable connection made. By late afternoon hydrogen bubbles are forming on the Saya Star. We have a accreting coral ark!

SY Vaka-Lele leaves under power, heading NW.

RV Orphee retrieves the scientific recording instruments which we had deployed upon our arrival.

During sunset Orphee slowly drifts with the current away from the building site. When the solar raft and marker buoys are no longer discernable the engine is started and SY Orphee heads NW for Victoria.

*Work on the photovoltaic raft*

*The solar raft is launched and moored*

*March 23 - 26*

RV Orphee catches up with SY Vaka-Lele which reports engine problems, Orphee might have to tow Vaka-Lele. Both boats sail in convoy for one day, then Orphee presses ahead.

The weather takes a turn for the worse. The sea becomes unruly and winds up to 30 knots, gusting to 40, hit both boats on the bow.

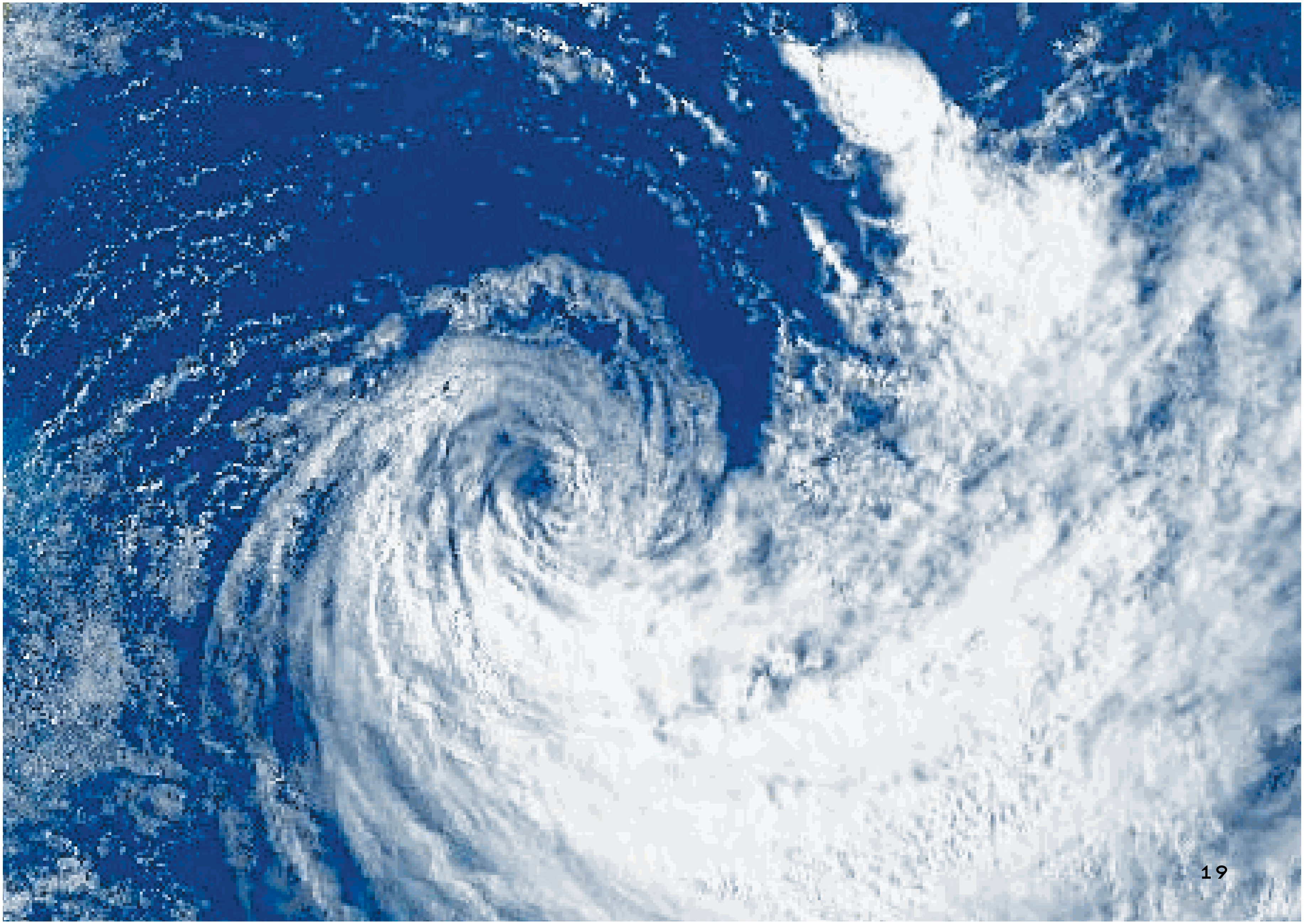
*March 27*

Having had to sail and tack extensively to conserve fuel for the final approach into the harbor, RV Orphee slips into Victoria port past moored MSY Ceres and drops anchor at noon.

*March 28*

SY Vaka-Lele, shaken up, arrives in Victoria port during the morning. Being a slower boat, tropical cyclone Ikala caught up with her. She has three ripped sails.

The Expedition Saya de Malha 2002 has ended.



### 3.3. Tropical Cyclone Ikala

*March 22*

centerpoint latitude: 6.53.04S longitude: 66.50.55E, convectivity NE of Madagascar

*March 26*

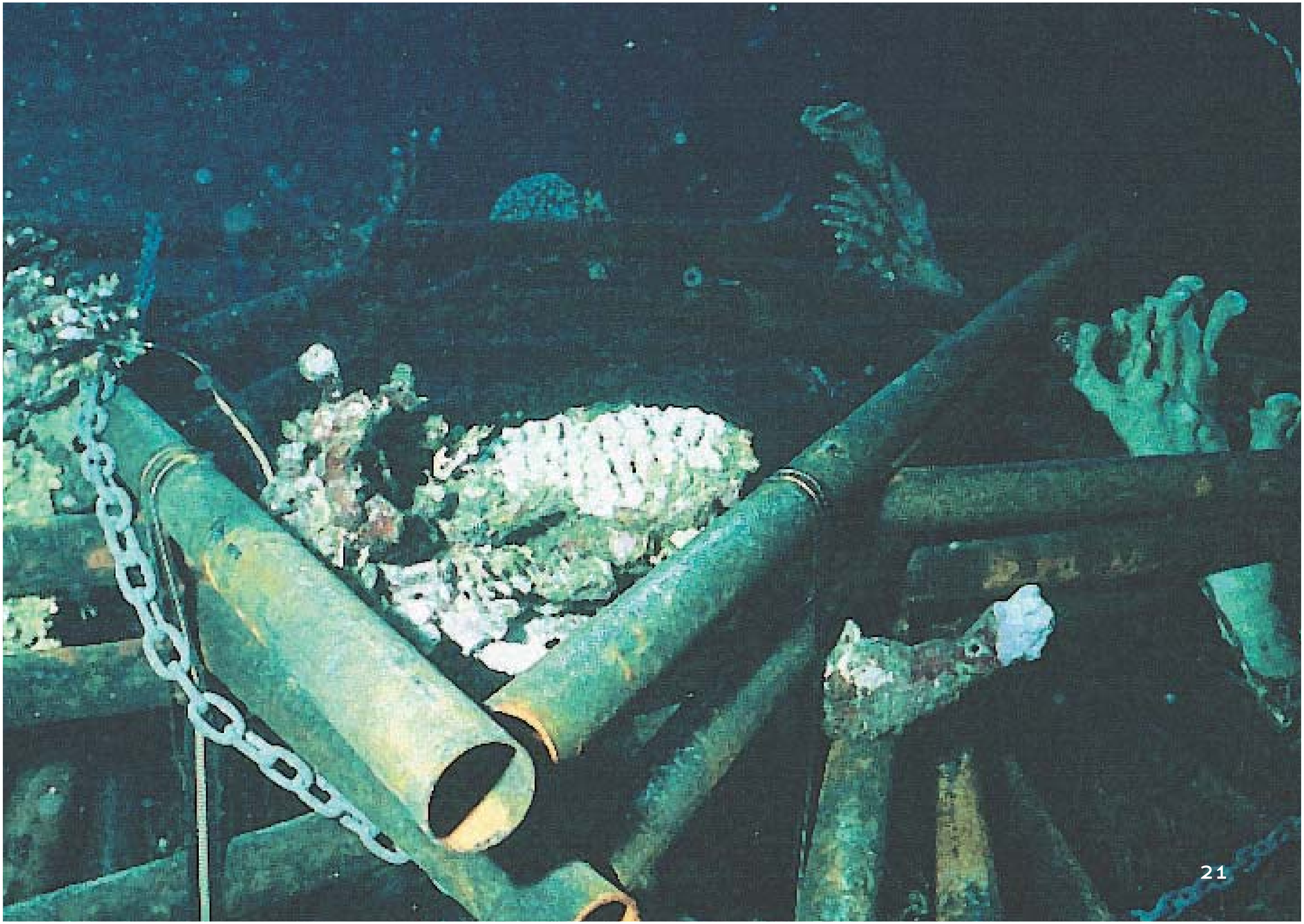
12.23.18S 77.15.04E. Winds sustained at 65 kn., gusts up to 80 kn.

*March 27*

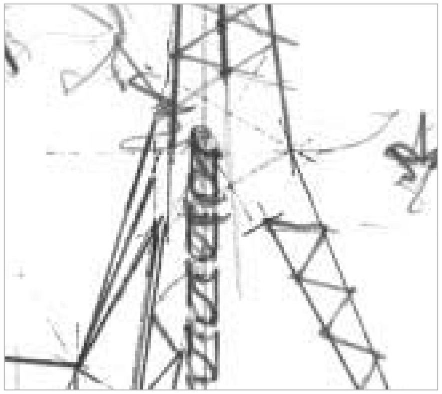
15.18.19S 75.06.14E. Winds at 105 kn., gusts up to 130 kn.

*March 28*

19.57.22S 78.47.53E. Winds at 60 kn., gusts up to 75 kn.; Source: NOAA

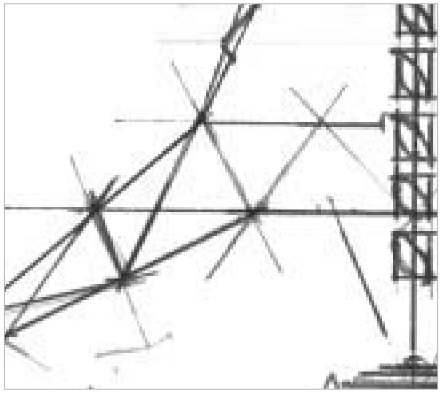


# 4. *Coral ark and solar raft*



Time, deteriorating power supplies, lack of manpower and rapid wear of crucial tools combined to prevent the construction of a coral ark which upper section would have reached out of the sea, designed to carry a powerful array of photovoltaic panels.

To attain one of the key objectives of the expedition W.Hilbertz opted to design and construct a scaled-down version of the ark powered by photovoltaic marinized panels carried on a moored raft.



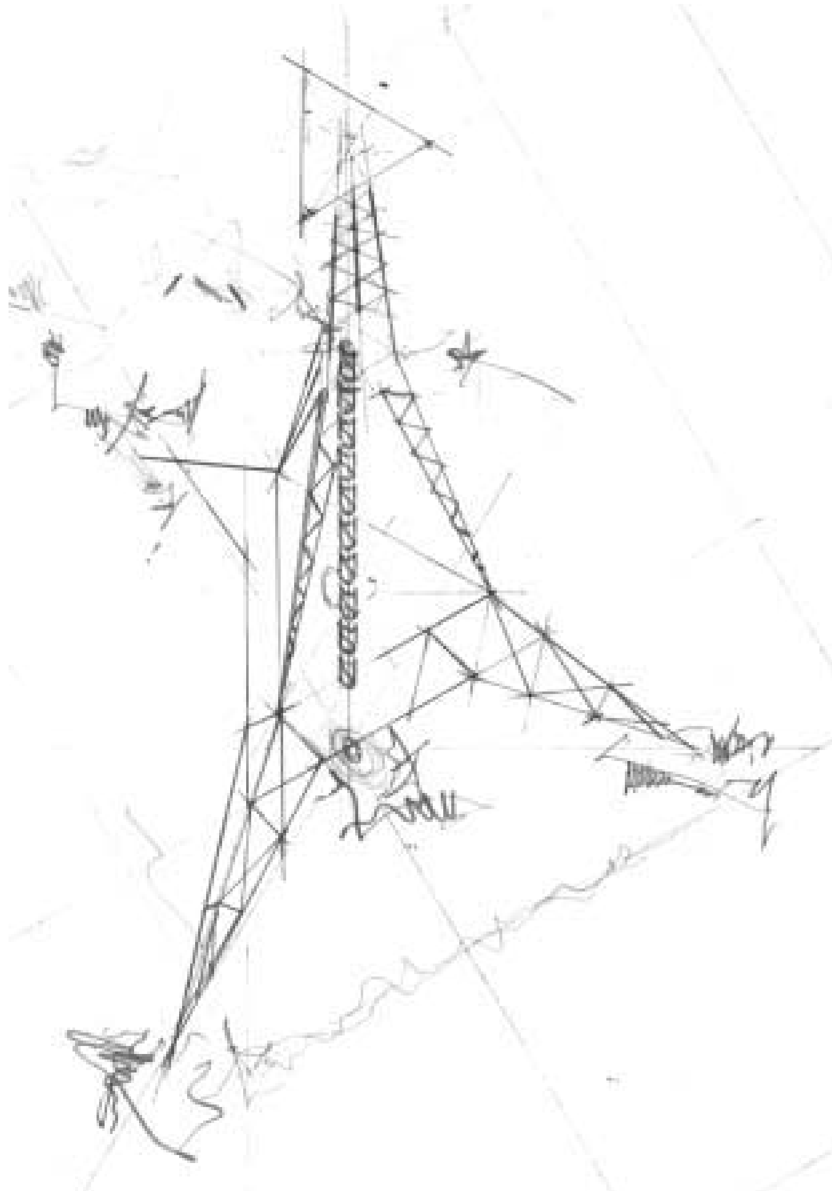
### 4.1. The Coral Ark Saya Star

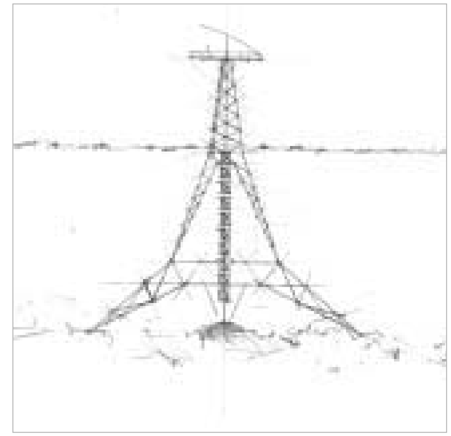
This is a construction of helically stacked 2 - 3 m long horizontal equilateral triangles consisting of 5.5 cm dia. steel pipe. The elements are welded and tied together with specialty wire as well as synthetic fabric tension bands.

The horizontal empty spaces between profiles facilitate easy wedging of live coral transplants and the open-ended pipes should provide fish and octopus habitat. The ark weighs in at about 600 kg.

### 4.2. The solar raft

The frame consists of bolted angle iron profiles with six photovoltaic marinized panels attached. It has two shackled attachment points capable of taking heavy rope and is kept afloat by nine oversized containers.





*sideview*

Two electrical cables are connected to the pohotovoltaics under multy-layered silicone insulation. Electrical output is 140 W peak.

### 4.3. The anode

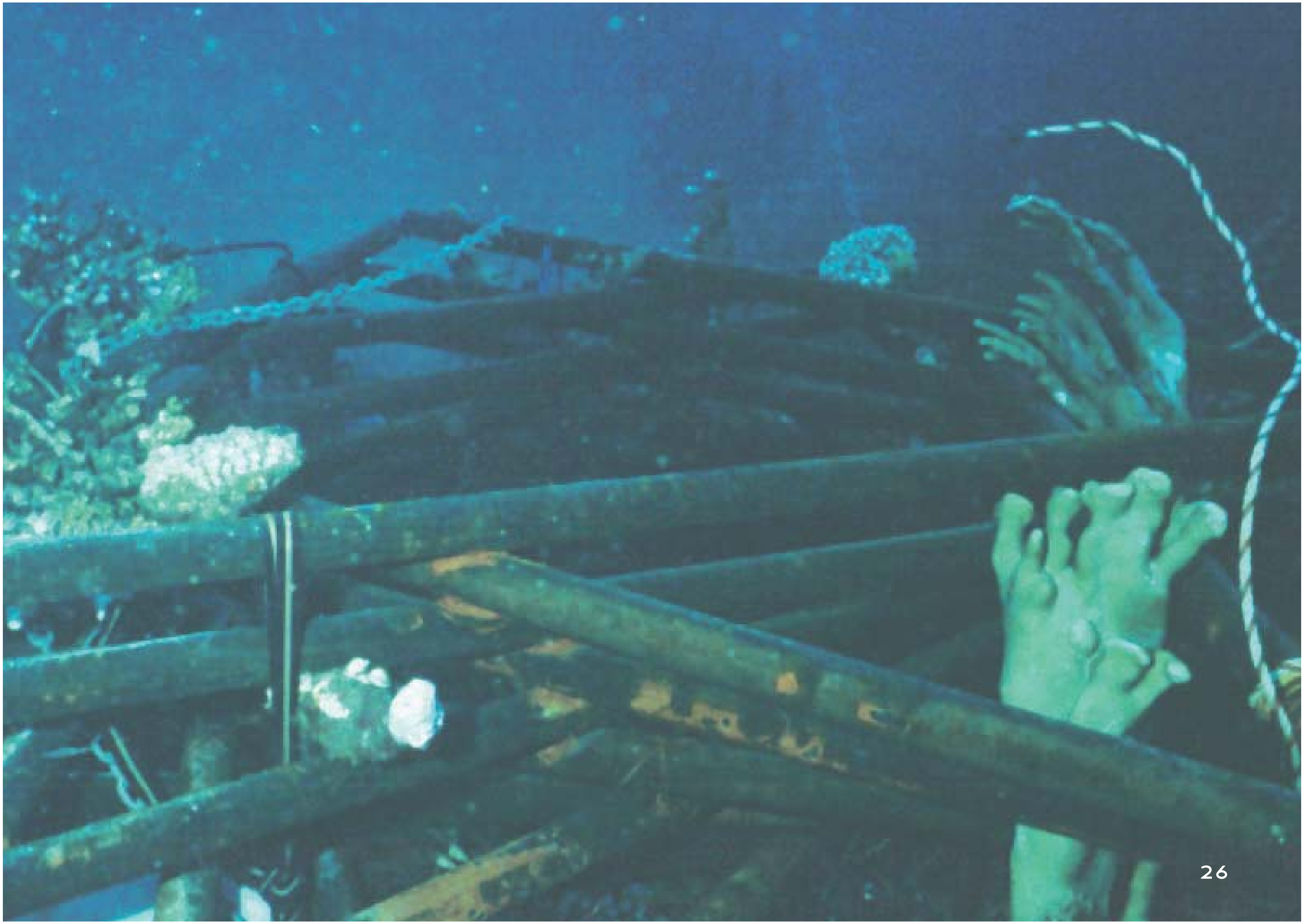
Titanium expanded metal mesh with a specialty coating. Area 4 sq. m with cable connection encased by special marine resin.

### 4.4. Placement and anchoring of the ensemble

When sunk, the Saya Star seefloored upside down. Divers using a liftbag turned the ark around and put it on level ground. Corals were transplanted. The solar raft was positioned and moored to the Saya Star and the coral head, preventing it from swinging with shifting currents and fouling the cables. The anode was deployed on the sea floor and weighed down with dead coral blocks which will 'melt into' the mesh because of its acidic product in the electrolyte and dissolving the coral skeletons where it touches it. After a few weeks of electrolysis, these weights are enmeshed and stay where they were positioned.

The cathodic cable was connected and soon afterwards hydrogen bubbles formed on the Saya Star, the sign of beginning mineral accretion.

*Corals were transplanted*



# 5 Scientific report

**Global Coral Reef Alliance**

A non-profit organization for protection and sustainable management of coral reefs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Web site: http://www.globalcoral.org

# *Prelimary scientific report*

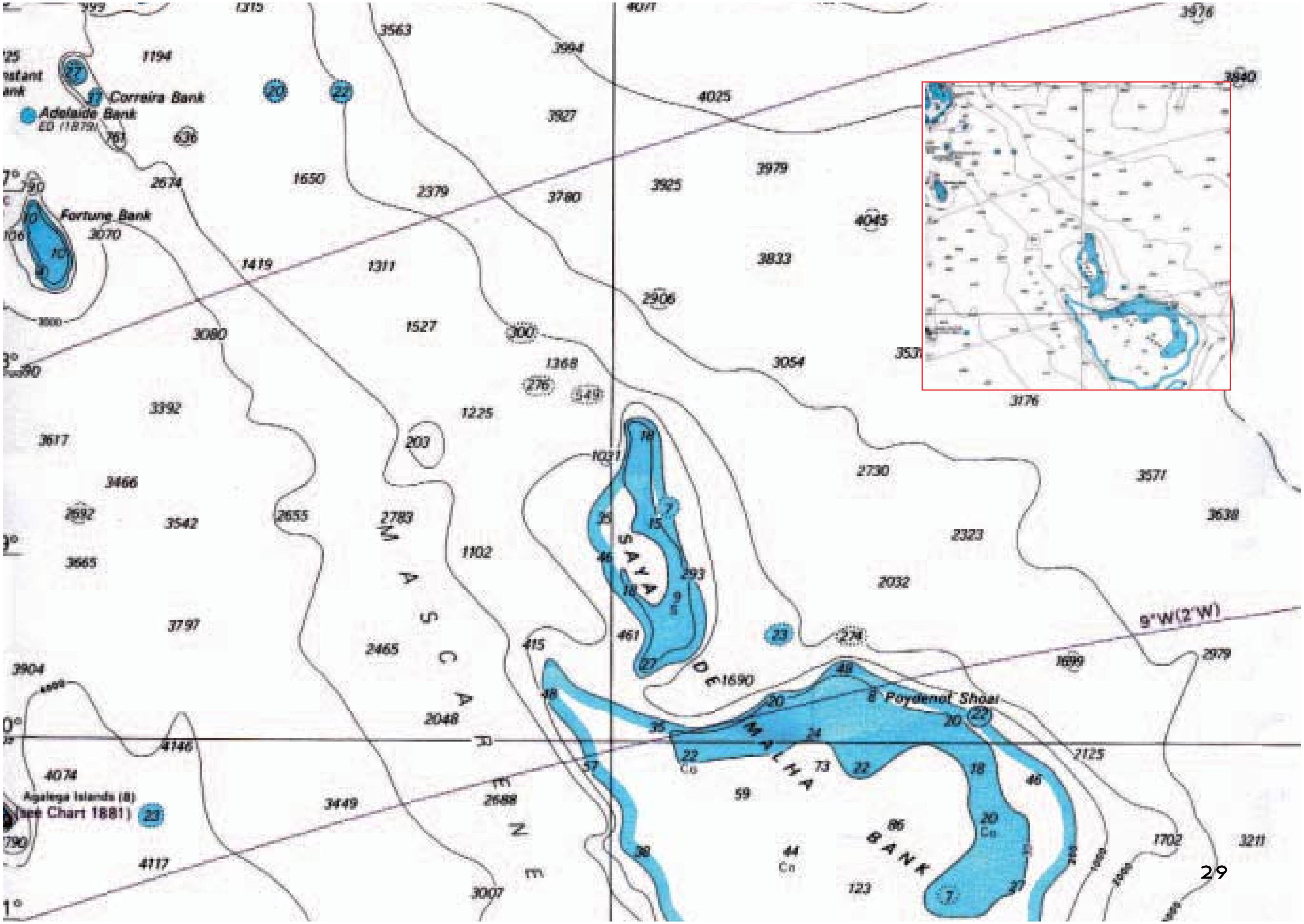
**5.0. Introduction**

The Saya de Malha Banks are one of the most remote and least studied shallow marine ecosystems on Earth. They are located in the central West Indian Ocean, between the Seychelles, Mauritius, and Chagos (*Map 1*). Although small portions of the banks are close enough to the islands of Coetivy and Agalega to lie in the 200 nautical mile Exclusive Economic Zones of Seychelles and Mauritius respectively, the great bulk of the banks lie in International Waters.

The Saya de Malha banks were named by Portuguese sailors 500 years ago. The banks lie on the route from the Cape of Good Hope to India. Their name comes from their spectacular and unexpected appearance. After sailing across the deep blue Indian Ocean, sailors suddenly found themselves over flat shallow banks with dense beds of dark green grass swaying in the currents. The word Saya is an archaic spelling or a mistransliteration of the Portuguese word saia, the third person singular present case of the verb Sair, meaning to go out or to extend outwards, while Malha means a woven cloth or mesh such as a rough blanket or carpet. Saya de Malha therefore is best translated as "It extends outwards like a carpet", based on the appearance of the seagrass seemingly just below the ships.

Although the banks have charted spots as shallow as 7 meters depth, it is possible that there are even shallower uncharted shoals. There are no known shipwrecks on Saya de Malha, but it is quite possible that waves break on the shallow spots

*Map 1. The Saya Banks are located at the bend in the Mascarene Ridge, shown from satellite altimetry maps of the bottom.*


Correira Bank
Adelaide Bank
ED (1879)
Fortune Bank
Agalega Islands (8)
(see Chart 1881)
MASCARENE
SAYA DE MALHA BANK
Poydenot Shoal
9°W(2'W)

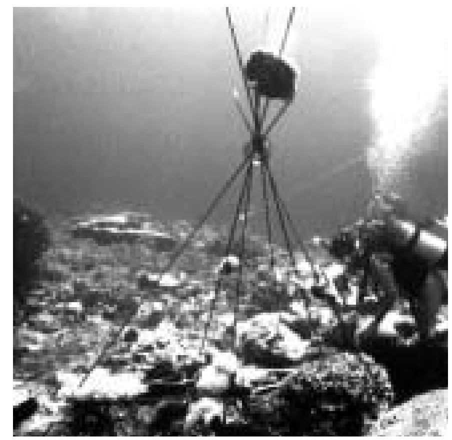
under conditions of intense long distance swells from cyclones in the Indian Ocean. Saya is close enough to the equator to be rarely affected directly by cyclones, but it can be an area where they form, generally drifting to the southwest, but sometimes moving towards the southeast, depending on the prevailing large scale winds. Because it is listed in Pilot's guides as possibly having uncharted shoals, the area is avoided by ship traffic as a hazard to navigation. This is shown in maps of the detailed tracks of ships charting the deep Indian Ocean seafloor by sonar soundings, all of which have avoided going over the banks themselves (*A. Evans, 2001, Generation of a new bathymetric chart of the Mascarene Ridge, p. 3-4, Marine Science, training, and education in the western Indian Ocean, Royal Geographical Society, London*). Smaller yachts that have crossed the banks report that Saya de Malha is a major breeding ground for Sperm whales and Blue whales.

Due to their location, the coral reefs of Saya de Malha are a critical stepping stone for the migration of shallow water species across the Indian Ocean. They may have played a critical role in the colonization of the shores of East Africa and Western Indian Ocean islands by species originating from the Indonesian global marine biodiversity maximum. Prior to 1997 there were no direct scientific studies of the Saya de Malha Banks, although a handful of oceanographic expeditions passed over it on their way to other locations, and took the opportunity to take dredge or trawl samples of the bottom. This has resulted in a very small scientific literature of species identified from such samples listed in various expedition reports. They include a handful of coral specimens from 13 genera (*B. Rosen, 1971, The distribution of reef coral genera in the Indian Ocean, p. 263-299 in Regional Variation in Indian Ocean Coral*

*Reefs, Symposium of the Zoological Society of London, No. 28).*

In 1997 the first Saya de Malha expedition was conducted by Wolf Hilbertz, Thomas Goreau, Kai Hilbertz and Caroline Mekie. Due to the distance and cost of getting there, only 1.5 days could be spent on site on the North Bank. Several dives were conducted, about 1.5 hours of underwater video was taken documenting the fauna and flora, and a small Biorock™ coral nursery was constructed, powered by a single floating solar panel. The area was found to be dominated by seagrasses, but small coral reefs were found with a very high diversity of coral and fish species. Surprisingly these reefs were not dominated by any one group of corals, as is typical of most Indian Ocean reefs. Instead the coral populations consisted of small numbers of many different groups of corals, widely distributed. The larger corals were mostly rounded heads of Porites, or clumps of columnar Heliopora or Millepora, with smaller corals of many kinds around them. Many corals were observed to be loosely attached to the bottom, and many were being attacked by boring sponges, by several distinct coral diseases, or had algae overgrowing their edges.

In 2000 a brief visit was paid to Saya de Malha by a team from the British Royal Geographical Society's Shoals of Carpricorn program. They were unable to dive, but took video of the bottom from cameras lowered from the boat at locations on the North Bank and on the South Bank. The images from the North Bank showed only seagrass and no corals, in contrast to the previous work done in 1997. On the South Bank however an entirely different ecosystem was found, dominated by large stands of a single species of branching Acropora corals, and they noted that "massive slow-growing corals were notable by their absence" (*A. Hagan and J. Robinson, 2001, Benthic*



*1997 the first Saya de Malha expedition.*

*Following Page:*
*The same structure in march 2002 with a self settled coral on one of the edges*

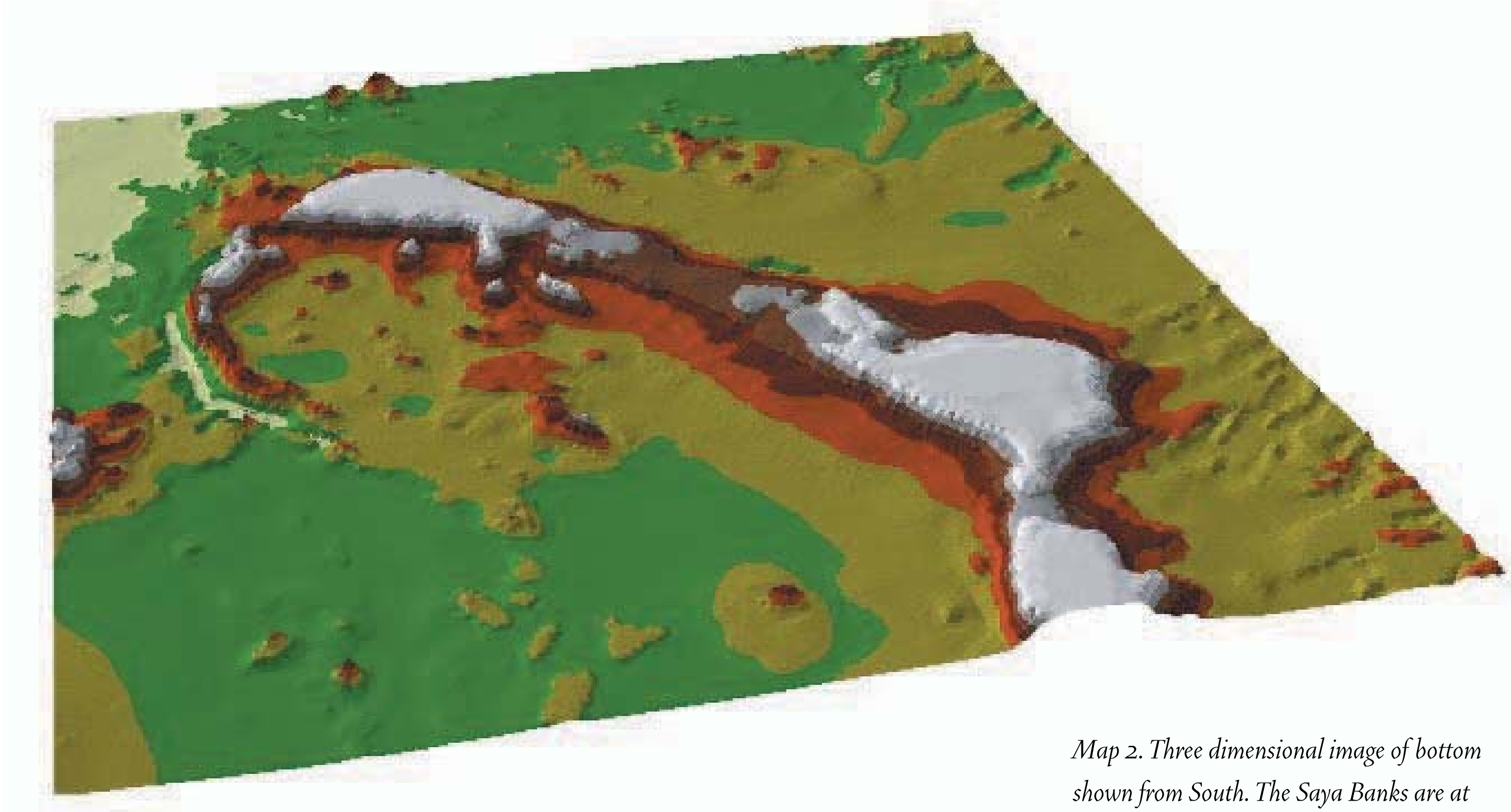
*habitats of the Saya de Malha Bank, p. 26-27, Marine Science, training, and education in the western Indian Ocean, Royal Geographical Society, London*). Apparently they were unaware of the previous studies of the area, for they claimed to have obtained the first video of Saya de Malha Bank ecosystems. Together with previous work, their images indicate that at least two very different types of coral ecosystems exist on the banks, and that their extent and distribution are virtually unknown.

This report presents the results of new studies made in 2002 of the same site previously examined in 1997, contrasts the changes observed, and makes new recommendations for future work to preserve these remote ecosystems that are virtually untouched by direct human influence.

### 5.1. Mapping

The Saya Banks are poorly charted, with only a handful of soundings recorded on nautical charts. Because modern sonar charting of the Indian Ocean is based on ships tracks that have avoided the bank (*see A. Evans, 2001, Generation of a new bathymetric chart of the Mascarene Ridge, p. 3-4, Marine Science, training, and education in the western Indian Ocean, Royal Geographical Society, London*), their detailed topography is poorly known. Three dimensional images of the Saya Banks region based on two different compilations are shown. These images suggest that there are coral reef-like ridges around the edges of the banks, but their sizes and shapes are poorly defined by the existing data. Commonly offshore banks will show well developed coral reef ridges along the windward shelf edge.

The predominant impression gained from visual observations sailing over the banks, diving on the bottom, and sonar tracks taken on our two expeditions, is of extraordinary flatness. Coral communities rise only a meter or two above the sea-grass-covered bottom, interspersed with only very small and isolated sand patches. Detailed mapping of the region studied in the Saya 1997 and Saya 2002 expeditions was conducted by Stephen Evans, Geographic Information Systems specialist at the Centre for Advanced Spatial Analysis (CASA) at the University College of London (UCL). He spent several days running tracks and recording depths in an area or nearly 4 square kilometers surrounding the study site, and his detailed maps and report are included as a separate section below. Although he found some areas as shallow as 10 m, most of the area studied was very flat and about 15 m deep. En route to Saya the expedition found a huge submerged plateau on the northwestern side of the bank at depth of 70 m, of even more extreme flatness. For hours the depth shown on the sonar did not vary by more than a meter. Unfortunately we did not record the transition zone between these two plateaus, which was crossed in the early morning hours. Such large and extremely flat areas, lying at distinct levels, is highly unusual in marine geology, and their origin is uncertain.



*Map 2. Three dimensional image of bottom shown from South. The Saya Banks are at right, the Nazareth Banks are cut off at the bottom right, and the Seychelles Bank is at upper left.*

### 5.1.1.Saya de Malha bathymetric survey report

*reported by Stephen Evans*

**Introduction**

A detailed knowledge of the location and extent of reefs has been important for almost as long as humans and coral reefs have existed in close proximity. Reefs have long been recognised as a hazard to avoid, a source of food and sometimes even a safe haven in rough weather.

The charting of coastlines and reefs has taken place through the ages, from 4000 year old Babylonian stone tablets, Egyptian papyrus maps, to the detailed mapping of the location of coral reefs in the 15th and 16th centuries through to the exploratory and hydrographic expeditions of the 18th and 19th centuries of Cook, Darwin and others.

If some of these early records are consulted then it is clear that the Saya de Malha bank was known about both as a shoal (*see figure 1*) and depicted by Charles Darwin as an noteworthy area (*see figure 2*).

These and many other early map sources should not be overlooked when surveying an area like Saya de Malha, despite the fact that in the last few hundred years, many different techniques have been employed when mapping reefs, as both technology, the scale and the purpose for which the map is required have developed and changed. This is particularly important to note since, although many older surveys were constrained by the mapping techniques available, they still offer an important data source for many remote parts of the ocean. Saya de Malha is one such case; of

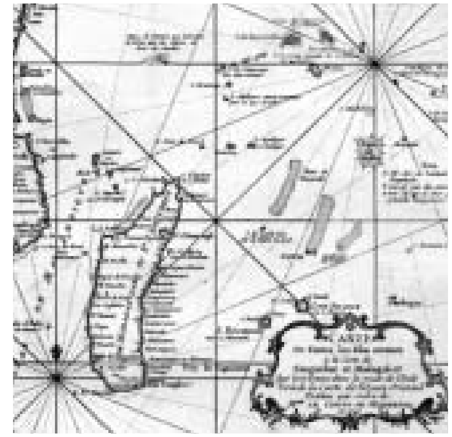


*Figure 1: Chart dated 1740 of the western Indian Ocean clearly depicting Saya de Malha in the top right. The title translates as "Map of all known Islands along the coast of Zanzibar and Madagascar whichone finds on the route to India.Taken from the map of the Oriental (Indian) Ocean Published by order of Monsiour the Count of Maurepas in 1740"*

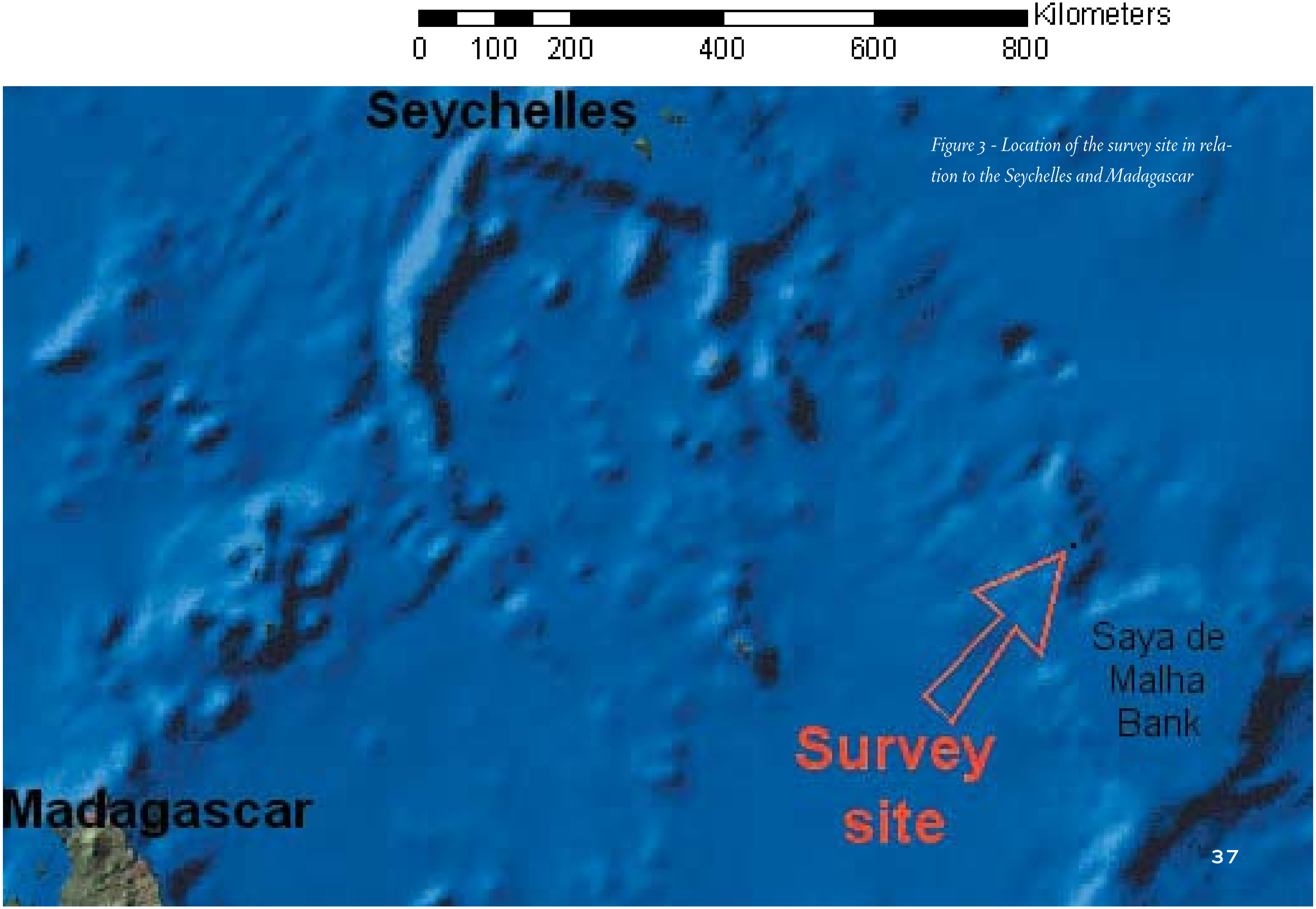



*Figure 3 - Location of the survey site in relation to the Seychelles and Madagascar*

the few depths that are recorded on up to date hydrographical charts of the area, many of them date back to the 19th century.

**The Survey**

The survey was carried out on the 15th and 16th March 2002, using M.Y. Orphee and collecting depth data on a series of transects over an area of approximately 2 km square. The ship's track was recorded directly using a Trimble Pathfinder Pocket GPS connected directly with Environmental Systems Research Institute (ESRI) ArcPad software installed on a laptop computer. This allowed us have a rugged, weatherproof set up that could easily be switched between survey boats as the demands of the expedition changed. While collecting data, it allowed us to directly view and track our realtime position on a digital chart, as well as our previous survey tracks and current direction. This, combined with the use the ships autopilot ensured that we optimised our coverage of the area.

Depth was recorded using a six-beam transducer Hummingbird Paramount echosounder with 53 degree side to side coverage. This was calibrated prior to the start of the survey using a plumbline in order to correct for the depth of the echosounder on the keel relative to the surface of the water and to check for any data inaccuracies. Following these tests, a depth correction of +1.48m was applied to all the recorded data. During the survey, as a precaution against electrical failure, a second recording of the GPS location and GPS time was made using a handheld Garmin GPS every time a depth reading was taken. Over the two days, surface conditions were always extremely calm with a swell of no more than 0.5 metres. A total of 1068


*Figure 2 An extract from Darwn's world map of coral reefs (prepared in 1842 from a study of multiple charts and voyage reports). Note that Saya de Malha is clearly identified.*

depth readings were taken. Average speed during the survey was six knots.

Tidal measurements were collected using sophisticated electronic monitoring equipment but due to a system failure this information was not available following the survey work. To counteract such a possibility all the survey work was carried out at twelve-hour intervals and depth changes over the tidal state were measured. These measurements indicated that the tidal difference between high and low tide at the site is approximately 1.5 metres

It was proposed that a detailed 3-dimensional visualisation of the site would be processed whilst at sea, allowing for some detailed on-site analysis. In the end there was insufficient time and all the data processing was carried out back in the United Kingdom.

The depths and positional data was checked for inaccuracies and then loaded into the Geographical Information System (GIS). The data was then checked again for errors and spikes and the GPS data was checked alongside the detailed ships tracks recorded with the Pathfinder Pocket GPS, using GPS time as a join field between the data sets. After this the data was processed into a gridded surface model using an Inverse Distance weighting algorithm and an output cell size of approximately 10 metres. Contours were derived from this surface model at 1-metre intervals. The results are detailed below.

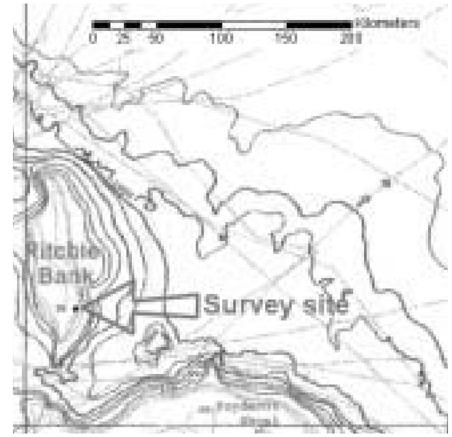



*Figure 4 – The location of the survey shown relative to a recent hydrographic chart (image from Shoals of Capricorn report). Note the faint straight dotted lines which show the passages of survey ship tracks and the lack of survey work that has been carried out on the banks.*

**The results**

The results largely display what many participants observed whilst on site, namely that the area surveyed was extremely flat with a few small-scale variations, which appear as 'bumps'. For the whole area, the average depth recorded was –14.68 metres. The maximum depth was –18.85 metres (recorded at 9° 11' 986 south and 60° 20' 512 east) and the shallowest was –10.62 metres (recorded at 9° 11' 760 south and 60° 21' 819 east). The area was generally shallower to the north east, despite the fact that navigational charts suggested that depth should be increasing in this direction.

Visual observations were also noted during the survey and recorded into the database. Looking at figure 5 below, which shows these observations as labels, it is interesting to note that the locations where the survey team observed significant bumps and blips on the echosounder, almost always occurred in the north eastern corner of the survey. This is an area where the shallowest depths were recorded and the possible outline of a steady change of depth can be observed.

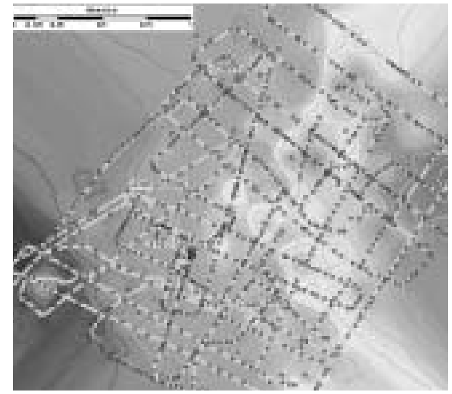
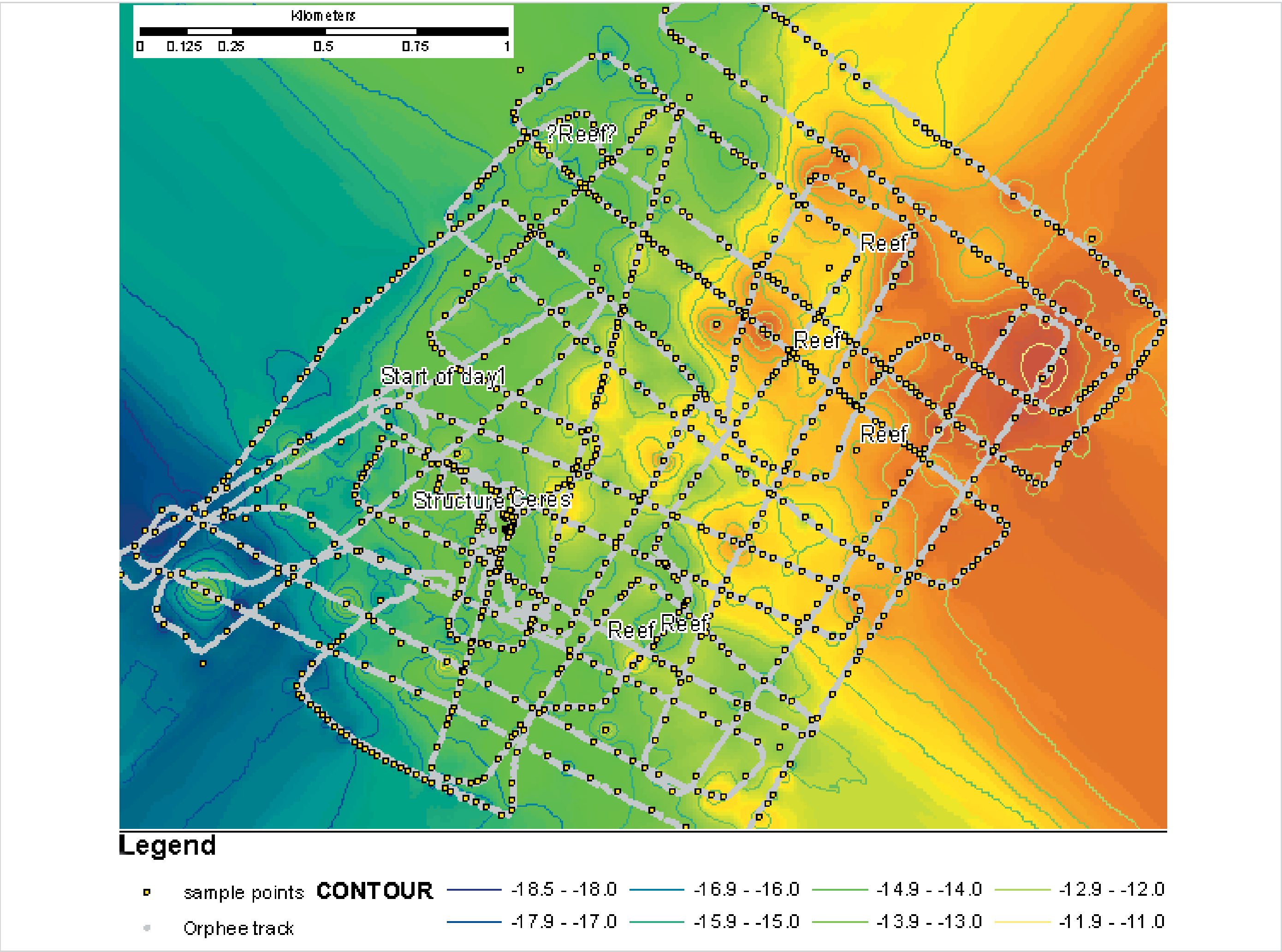


*Figure 5 – The survey site, showing survey points, a digital terrain model derived from the data and bathymetric contours every metre derived from the terrain model. The location of noteworthy features are shown as labels (for details see the enlarged map on next side).*

**Conclusions**

The results have shown that it is possible to carry out realtime bathymetric surveys using limited equipment and basic techniques on-board a small research vessel. The advantage of processing at least some of the data in-situ is that the survey can be carried out in a controlled fashion and any potentially interesting survey data can be observed and re-visited for a more detailed inspection. This is particularly important when working on a site as remote as Saya de Malha.



Kilometers
0 0.125 0.25 0.5 0.75 1
?Reef?
Reef
Reef
Start of day1
Reef
Structure Ceres
Reef Reef
Legend
sample points
Orphee track
CONTOUR
-18.5 - -18.0
-17.9 - -17.0
-16.9 - -16.0
-15.9 - -15.0
-14.9 - -14.0
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-11.9 - -11.0

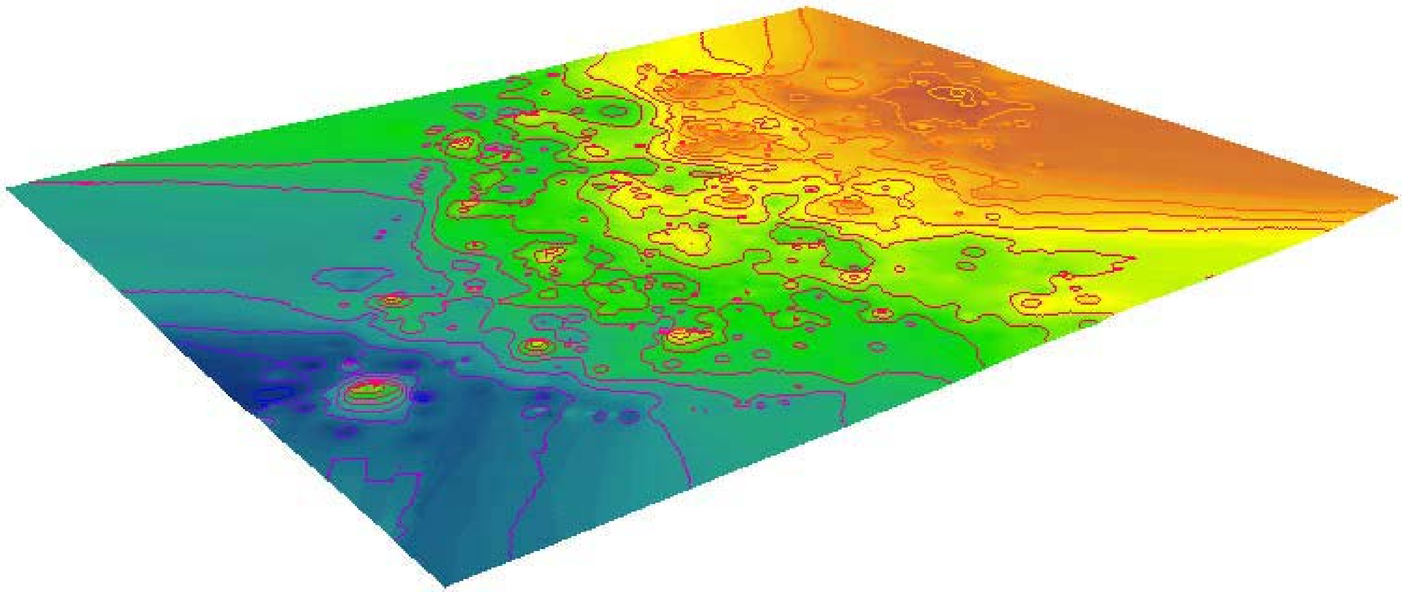


*Figure 6 a– The survey site, shown as a 3-dimensional visualisation.*

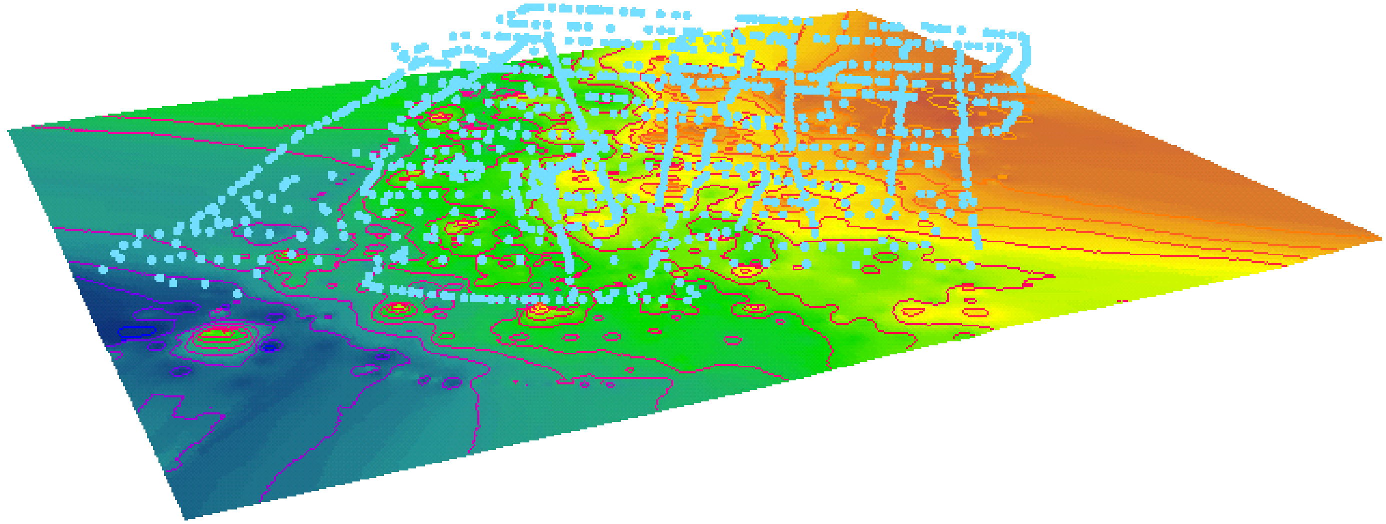


*Figure 6b – The upper image shows the survey data points floating at 'virtual' sea level.*

Although the analysis has shown that the area is largely flat, it has shown that there may be some interesting changes in the bathymetry approximately 1km to the north east of the main site. Any further visits to the area should attempt to incorporate diving or underwater viewing at this location for further analysis of the causes of these.

It is also interesting that the trend of the bathymetry was to become shallower as we moved in an easterly direction, despite the fact that present day hydrographic charts indicate that we were close to the edge of the bank and the bottom should have been dropping away. Any future visit to the site should attempt to survey in an easterly direction to ascertain where the edge of the bank actually is.

**Future work**

The results of the 2002 survey work have shown that the Saya de Malha bank is poorly charted. A great deal of scientific sampling work needs to be carried out in the area before we can start to fully understand the importance of this region of the Indian Ocean. However, it is important that the results of this sampling can be 'pinned against a backdrop' of a detailed hydrographic survey. It has been shown that such data can be captured into a 'live' on-board Geographical Information System. With more time and improved equipment it could be possible to record depth, location, water temperature, salinity and a number of other parameters directly to a Geographical Information System whilst the research vessel transects the area. This would offer the opportunity for live data analysis, survey refinements and comparison of the recorded data with analysis from satellite data and previous expeditions whilst on site. This live spatial data capture is something that researchers at the Centre for Advanced Spatial Analysis (UCL) are currently developing. This is of particular importance when working on a site as remote as Saya de Malha. Useful satellite data would need to include satellite altimetry observations, SeaWiFS and Landsat imagery amongst others. However, it would require a suitable vessel, dedicated to the survey work, a greater length of time in the area and a window of good weather to capture a satisfactory amount of data. It would also require a more detailed study of the tides and tidal ranges in the area before detailed bathymetric data could be processed.

**Equipment for the project was generously provided by:**

Plannet Visualisations Ltd www.plannet.co.uk

Centre for Advanced Spatial Analysis www.casa.ucl.ac.uk

**References**

*A. Evans, 2001, Generation of a new bathymetric chart of the Mascarene Ridge, p. 3-4, Marine Science, training, and education in the western Indian Ocean, Royal Geographical Society, London*

-3343
BASIN
-1068
COCO-DE-MER
SEAMOUNTS
-2919
-4179
-4962
-4025
Seychelles
-4609
-3511
-13
-5406
AMIRANTE TRENCH
-6402
VEMA FRACTURE ZONE
CHAGOS
Saya de Malha
Bank
MASCARENE
BASIN
-1240
-2876
-1525
Tromelin
-5194
Rodrigues
-3996

## 5.2. Geology

The geological composition and history of the Saya Banks is poorly known because there appear to have been few direct investigations. The Saya Banks are two shallow plateaus, some 40,000 square kilometers in extent, lying at the mid point of the Mascarene ridge, a long mountain chain that connects the Seychelles Banks to Mauritius. The Banks are situated at a flexure point or bend. The northern section extends from Saya to Seychelles in a northwest direction. The southern section extends from Saya to Mauritius along a south-southwest direction, and also includes the Nazareth Bank, Cargados Carajos shoals, and St. Brandon's island. This ridge lies roughly parallel to the mid ocean ridge spreading center that runs through the Red Sea, out the Gulf of Aden, and around the Socotra and the Somali peninsula across the Indian Ocean in a southwesterly direction (*Map 1*).

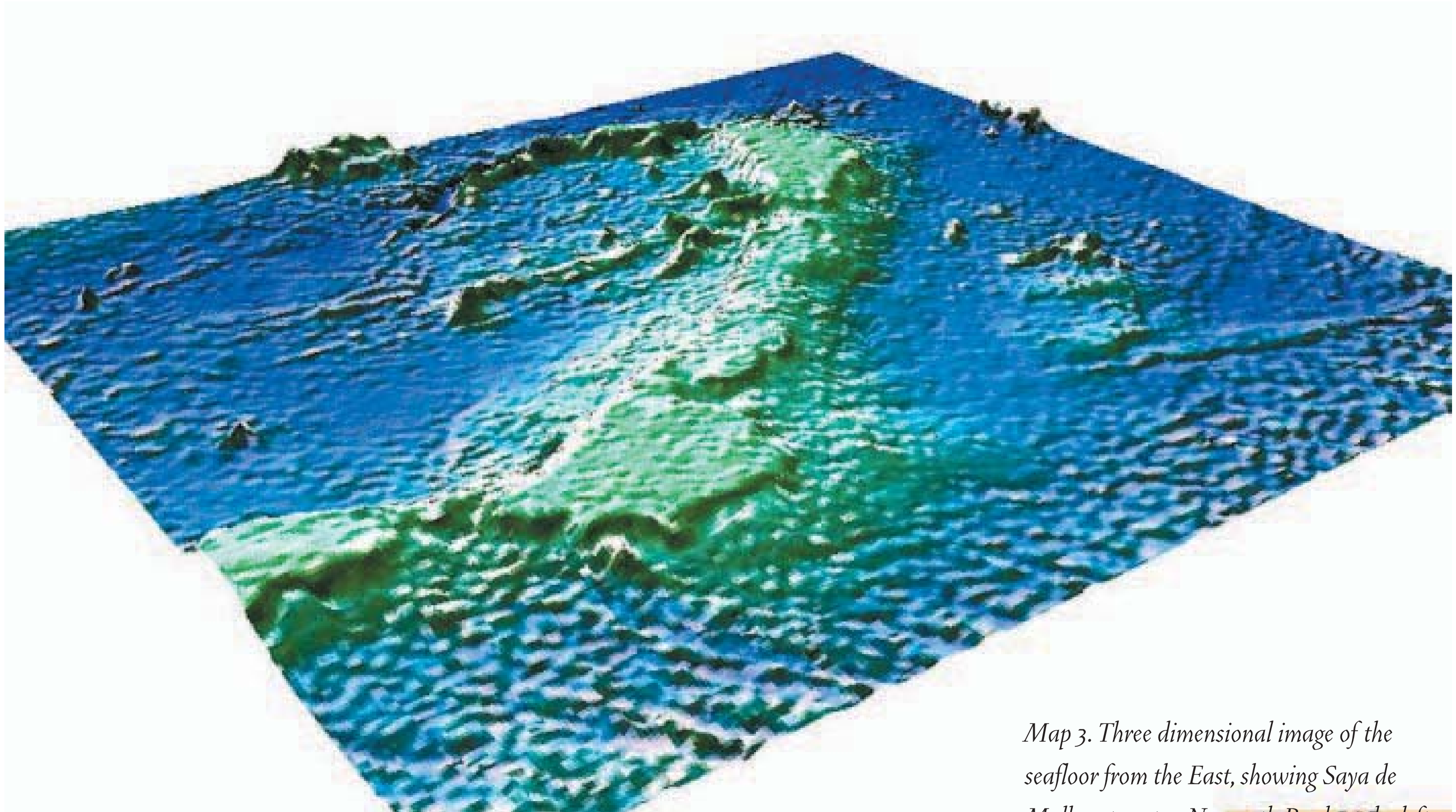
Although the Mascarene ridge superficially appears to be a single structural feature, there are reasons to suspect that it is composed of sections with multiple and different origins. The extremes of the ridge are well known and very different in origin. The Seychelles Plateau is composed of Pre-Cambrian plutonic granite intrusions, about 650 million years old, that have been exposed by weathering. The Seychelles are the only granite islands in the world with the exception of Hinchinbrook Island in Australia, which is a small erosional remnant of a continental formation adjacent to the mainland. The Seychelles are regarded as a mini-continent, a piece of the ancient Gondwanaland continent that got left behind when India separated from Africa around 130 million years ago. As there are no sedimentary formations except very recent soil and beachrock, and hence no fossils, its history can only be inferred from plate tectonic reconstructions. At the other end of the Mascarene Ridge lies Mauritius, which is composed of a geologically recent series of basaltic volcanic lavas only a few million years old. Mauritius was formed by a geological Hot Spot, a steady plume of rising lava originating deep in the Earths mantle that episodically punches through the crust which slides over it. This Hot Spot, which now lies under the volcanically active island of Reunion, Mauritius' neighbour to the southwest, can be backtracked under Mauritius, under the northwest Indian Ocean Mid Ocean Ridge and spreading center, under the Maldives and Lakshadweep Islands (which are atoll reefs formed on top of sinking extinct volcanoes left behind in the track of the Hot Spot), to the immense lava flows of the Deccan Traps in India, one of the world's largest basalt formations, which are approximately 65 million years old. Therefore the opposite ends of the Mascarene ridge have completely unrelated origins.

Backtracking the paleo-positions of the Saya de Malha Banks using symmetry around the Mid Ocean Ridge as a guide and the orientations of the faults that lie at right angles to it, suggests that the basement under the banks, which mark a clear change in orientation of the ridge referred to above, formed when there was a change in the direction of sea floor spreading and that this area was originally located northwest of where Bombay now lies, where the Indian subcontinent merges with the older Asian continental coastline prior to the formation of the Himalayas. Thus the basement could be a relict mini-continental block like the Seychelles left behind by the rupture of Gondwanaland, or it could be volcanic formations resulting from that rupture. Detailed seismic soundings, gravity soundings, magnetic soundings, and deep drill cores are needed to differentiate these possibilities. Although much of this sort of geophysical surveying has been carried out by the Ocean Drilling Program in the West Indian Ocean, these focused on the triple junction region south east of Mauritius where three mid ocean ridges meet, and no work was done on the Saya Bank itself.

A single "wildcat" oil drill core was taken on the northwest corner of the South Saya Bank in 1975, along with one on the Nazareth Bank to the south, in 1975 by Texaco Oil Company. The core on Saya was drilled to a depth of 3,264 meters of which the top 2,342 meters were limestone and the bottom 832 meters were volcanic basalts. The uppermost 1,249 meters were described as "reef carbonates" overlying shallow water limestones and open-marine limestones, but no detailed core logs or fossil lists were given. The Nazareth Bank core reached 1.716 meters, which was composed of shallow bank limestone ending in basalt volcanics. No traces of oil were found. The core logs were not presented, but were provided to oil geologists who wrote up a brief paper on the results (*A. A. Meyerhoff & M. Kamen-Kaye, 1981, Petroleum prospects of Saya de Malha and Nazareth Banks, Indian Ocean, American Association of Petroleum Geologists Bulletin, 65: 1344-1347*). The lead author, Meyerhoff, was a top petroloeum geologist who was also one of the leading opponents of the theory of plate tectonics and continental drift, and who rejected the notion that this was a volcanic island arc in favor of the view that it was an eastward extension of the African Continent.

Subequently the Ocean Drilling Program drilled three cores in the vicinity of Saya de Malha, while completely avoiding the Banks themselves. These were Site

707, located to the northwest of Saya on the saddle joining it to the Seychelles Bank (Shipboard Scientific Party, 1988, Site 707, Proceedings of the Ocean Drilling Program, Initial Reports, 117: 233-276, plus appendices) and Sites 705 and 706, located South of Saya on the deep slopes to the east of the saddle joining Saya to the Nazareth Bank (*Shipboard Scientific Party, 1988, Sites 705 and 706, Proceedings of the Ocean Drilling Program, Initial Reports, 117: 125-153, plus appendices*). These studies concluded that the Saya de Malha bank is based on carbonate accumulation on top of basalts whose origin is the same as the Decccan flood basalts of India, formed at a time when the rupture of India from Africa was taking place in the late Cretaceous, around 64-69 million years ago. These studies show, through backtracking the plate tectonic movements, that Saya de Malha and the Chagos Banks were originally a single feature that were later divided when a mid ocean ridge opened up between them and pushed them apart. The Saya Banks are one of the many surface expressions of the hot spot that formed the Deccan flood basalts, the Lakshadweep, Maldives, Chagos, Saya de Malha, Nazareth Banks, and Mauritius, and now lies under the volcanically active island of Reunion (*Shipboard Scientific Party, 1988, Introduction, Proceedings of the Ocean Drilling Program, Initial Reports, 117:5-15; R. A. Duncan, 1988, The volcanic record of the Reunion Hotspot, Proceedings of the Ocean Drilling Program, Scientific Results, 117:3-10; R. A. Duncan & R. B. Hargreaves, 1988, 40Ar/39Ar geochronology of basement rocks from the Mascarene Plateau, the Chagos Bank, and the Maldives Ridge, Proceedings of the Ocean Drilling Program, Scientific Results, 117:43-51; G. C. Bhattacharya & A. K. Chaubey, 2001, Western Indian Ocean - A glimpse of the tectonic scenario, p. 691-729 in R. Sen Gupta & E. Desa, The Indian Ocean: A Perspective, A. A. Balkema*



*Map 3. Three dimensional image of the seafloor from the East, showing Saya de Malha at center, Nazareth Bank at the left edge, and the Seychelles Bank at top. A marked lineation extending from the right corner is a transform fault, originating at the Mid-Ocean Ridge (off the map to the right). It extends linearly between the North and South Saya Banks.*

*Publishers, Lisse).*

There is a strong likelihood that the North Bank and the South Bank also have different origins despite their proximity. The available 3-D topographic images clearly indicate that they are separated by a transform fault that extends to the Mid Ocean ridge (*Map 3*). Their proximity must then result not from adjacent formation histories but from sideways movement of the two blocks on either side of the fault. As a result the two banks could have formed in different locations, and have been brought into proximity only afterwards by lateral slip motions of the earth's crust, unless their formation is much more recent than movement along this fault. This is unlikely, given that they are likely to have formed atop deep basement features of igneous origin.

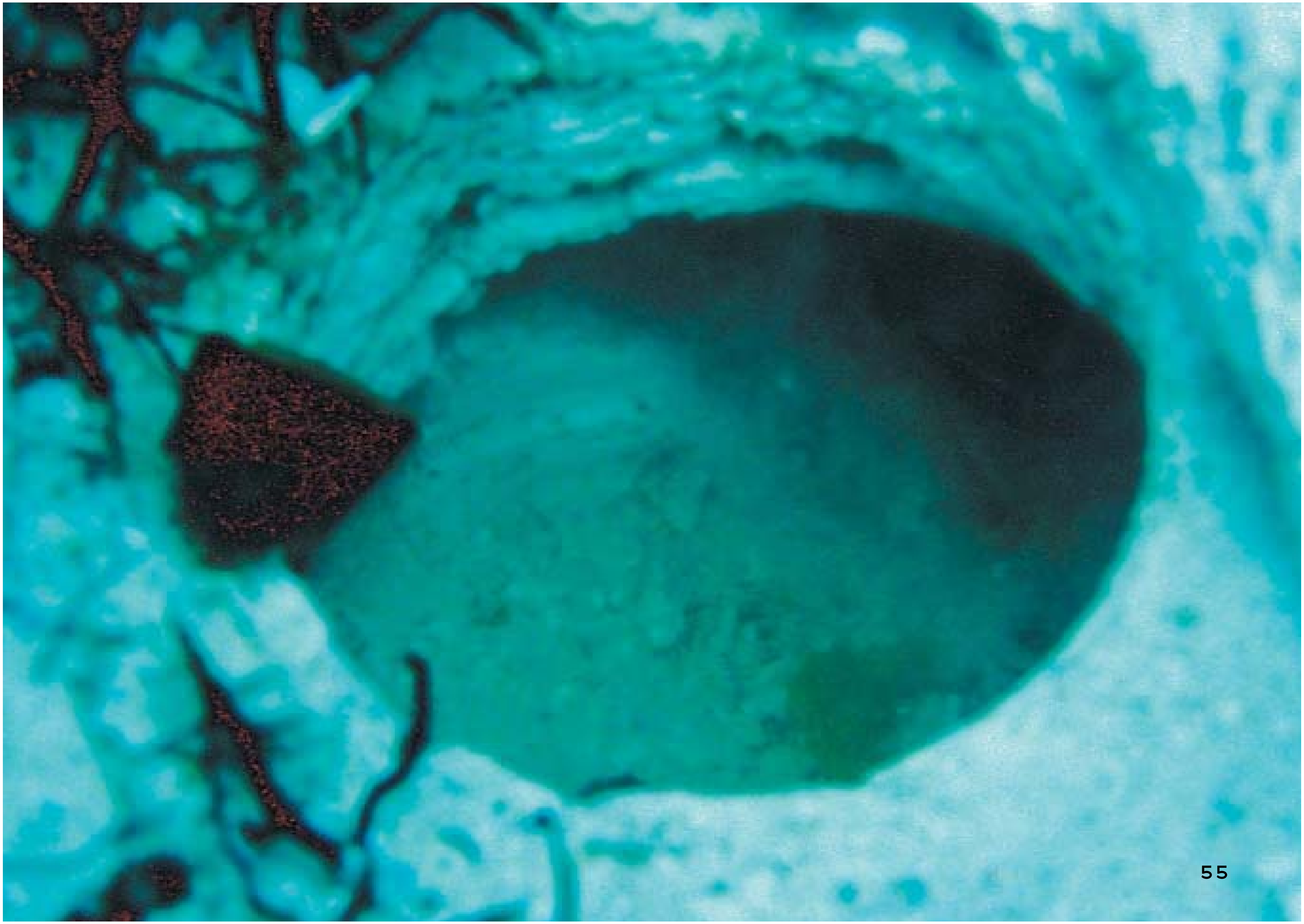
The Banks on the Mascarene ridge are generally thought to be platforms made up by the accumulation of calcium carbonate (limestone), overlying an igneous rock basement of unknown type or depth (*R. Fisher, G. Johnson, & B. Heezen, 1967, Mascarene Plateau, Western Indian Ocean, Bulletin of the Geological Society of America, 78: 1247-1266*). However they differ from most carbonate banks in several striking ways. Deep-sea carbonate sediments are usually made up of the remains of planktonic microorganisms with limestone shells, primarily the protozoan Foraminifera and the uni-cellular Coccolithophorid algae. But these deep sea oozes drape over the underlying formations and follow their topography unless they have filled in low lying basins and produced a flat surface. This is clearly not the case with Saya, which is a topographic high, which is unlikely to have been produced by straight vertical uplift of an impounded basin, although the steep edges of the banks suggest faults. Normally limestone banks are atolls, produced by the growth of coral reefs around the edges of a subsiding volcanic formation. But this produces bowl like topography, as is seen in the Maldives, Lakshadweep, and Chagos archipelagos, not the flat horizontal surfaces seen on Saya. Normally flat horizontal plateaus like Saya are produced only by erosion. If so one would expect to find old rock formations at the surface that have been clearly eroded flat to a well defined base level related to sea level at the time of formation, for example a sea mount formed from an ancient volcano that has been eroded flat to sea level and then subsided below the depth of coral growth. If Saya were primarily constructional and built by corals, it should show clear high topographic rings related to the primary wind directions, but this seems weakly developed, at least until the entire banks can be better surveyed. The third possibility is that the banks are built up by encrusting calcareous red algae, which usually grow in waters that are too deep, too rough, too cold, or too rich in nutrients for coral growth. But flat horizontal growth is extremely unusual and unlikely, given that their growth responds to gradients in light, nutrients, and wave energy.

Our field observations suggest that these banks are largely constructed by calcareous red algae. In this regard they are very similar to the unusual reefs of Tuvalu in the central Pacific, which are strongly influenced by upwelling, but which have well-formed atolls. The surface of the banks is composed of hard limestone covered with encrusting calcareous red algae, which give it a pink color. Seagrasses and corals grow directly on this surface. The sediments are primarily composed of rhodoliths, spherical layered concretions typically a few centimeters to decimeters in diameter that are produced by the growth of calcareous encrusting red algae around a nucle-

us, which grow on the uppermost light exposed surfaces, but which are frequently rolled over by strong currents, giving them a pseudo-spherical form as growth takes place from time to time on all sides. Rhodoliths are typical of areas that are swept by currents strong enough to prevent accumulation of sand or fine-grained sediments. While there are small sand patches on the bottom, these are small in size, widely spaced, and amount to no more than a thin veneer in spots. There is no visible accumulation of sand or formation of sand waves or dunes. This is probably because the currents are sufficiently strong to sweep away sand grains and prevent their accumulation. In geological terms this is a sediment-starved region due to high bottom water velocity preventing accumulation of sand or finer grained material, leaving behind only the larger rhodolith cobbles. It is important to note that the lack of sand is due to high energy, not to lack of sand production. In fact the rate of sand formation, primarily from abundant growth of the sand producing green calcareous alga Halimeda opuntia, and by branching calcareous red algae, appears to be very high. There must therefore be a high rate of sand transport to the edges of the banks, where it must fall down the sides into the deep basins on either side.

To find out more about the nature and origin of the bottom, we took a drill core in a representative seagrass area. The uppermost few centimeters were sampled, before the drill core hit a rubble-filled cavity. The surface core sample is made up exclusively of about 20 distinct layers of encrusting calcareous red algae similar to Porolithon (see photographs). This material has several calcareous tubes of boring Serpulid polychaetes, which are common borers of limestone rock and corals. Photographs of the drill hole show that all the visible material beneath the drilled

*The pneumatic drill went easily through the limestone-layer*



material lining the inside of the cavity was made of the same layered material. It therefore appears clear that the bottom is of constructional origin, is almost exclusively made up by red algae, and is of recent age, with the uppermost layer formed by living algae of the same species as that making the layers below.

In order to determine the age of this material, and the rate of growth, the core sample has been saved and is being sent to a laboratory for Accelerator Mass Spectrometric Carbon-14 dating of each layer. The report below shows the first results.

### 5.2.1. C-14 dating of core

*Reported by Frank Gutzeit*

Two samples were taken, one from the top, one from the bottom, to get a first idea of the age and growth rate of the material. A few grams of the limestone were shaved off and sent to the Leibniz Labor für Altersbestimmung und Isotopenforschung at the Christian-Albrechts-Universität in Kiel. The radiocarbon dating was performed there with the following results:

| | Fraction | Corrected pMC† | Conventional Age | $\delta^{13}C$(‰)‡ |
|---|---|---|---|---|
| *KIA 18394* | *Sample 1, Upper Side, 0.9 mg C* | *99.27 ± 0.40* | *60 ± 35 BP* | *1.45 ± 0.11* |
| *KIA 18395* | *Sample 2, Lower Side, 1.1 mg C* | *93.20± 0.34* | *565 ± 30 BP* | *4.25 ± 0.36* |

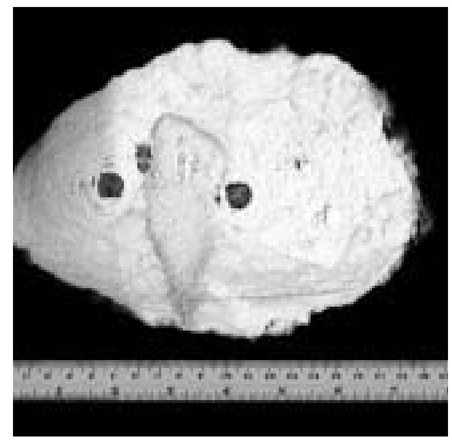
*C-14 dating at the leibniz institute at the university in Kiel: www.uni-kiel.de/leibniz*

*Top- and bottom-view of the core*

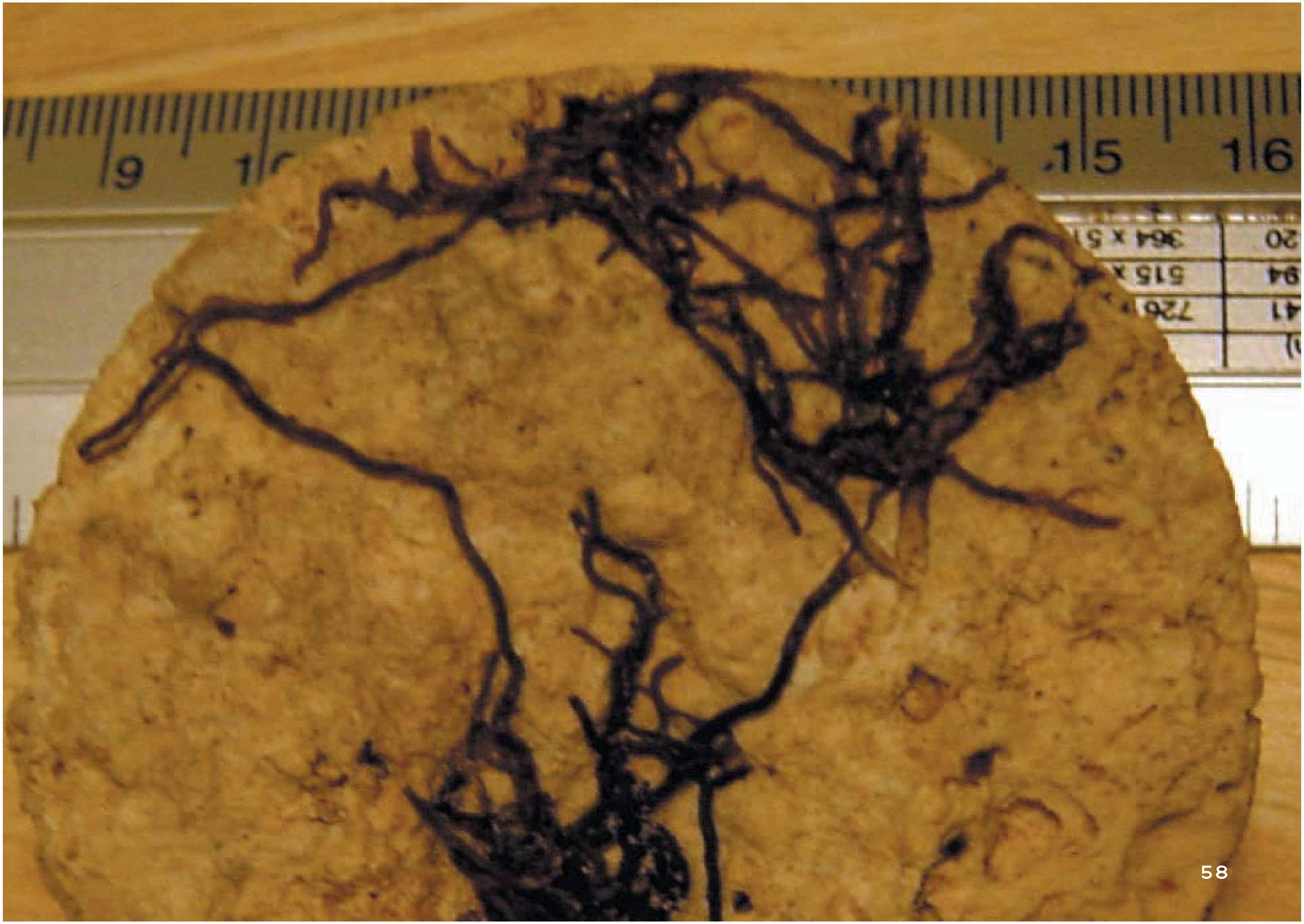
Taking the length of the core, which measures 40 mm, and dividing it by the difference in age of the two samples, which is 500 years, the growth rate is 0.08 mm/year. This is far less than the current rate of sealevel rise, and gives a rough idea of growth rates of limestone in the area.

The pictures on the right show the core from Saya de Malha Bank beneath a mineral accretion sample from Maldives which was grown electrolytically during only five years. Similar dimensions and comparable mechanical strength of the two samples clearly demonstrate the advantages of mineral accretion technology when fast buildup of structurally strong substrate is required.

The dating results may have to be corrected by a factor that includes the age of the ocean water present on site. Inaccuracies can be caused by the nuclear bomb tests in the 50's and 60's of the last century when the C14 readings were elevated up to 200 %. To get more reliable results, additional samples from different layers of the core should be analysed to correlate with nuclear fallout periods. The age of the ocean water on site now and 500 years ago should be determined by consultation with experts.

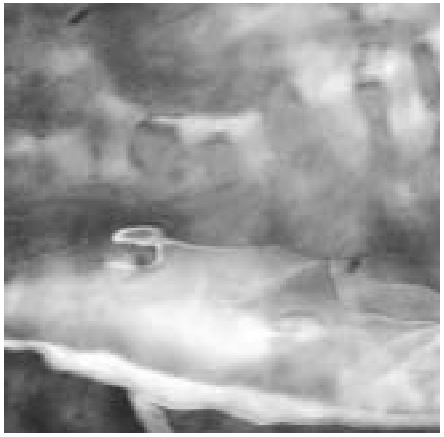


*Mineral accretion sample from the Ihuru Neclace*



**5.3. Biodiversity inventory**

A Saya de Malha biodiversit visual encyclopaedia is being prepared from digital film of Saya bottom habitats and organisms. About 1.5 hours of footage was taken in 2002, and 1 hour in 1997. Many of these show the same corals before and after. For each coral, invertebrate, and fish clearly shown on these video records the clearest frame of each will be captured. These images will be filed by species. By showing each individual of each species, the total numbers of each species encountered will be documented, along with their range of variability in size, shape, and health. Changes in their abundances over the five year interval will be documented. This project will form the Master's thesis research project of Caroline Mekie, and will take the form of a database that will be available on the web, as a CD, or in printed form, which will be added to this report on completion. Such a visual database is a novel approach that is far more useful than a standard list of species, because anyone can look at the images and see the range of colors, shapes, and sizes, that each species comes in, as well as its immediate habitat, providing critical visual information that is lost in standard print listings. This will also allow researchers using the same methods elsewhere to examine regional variations in populations of each species recorded. For those species that cannot easily be separated as individuals or separate colonies, for example clumps of algae or seagrass lawns, representative images of each type will be included, but their abundance will be estimated by their relative areal coverage rather than by counted individuals.

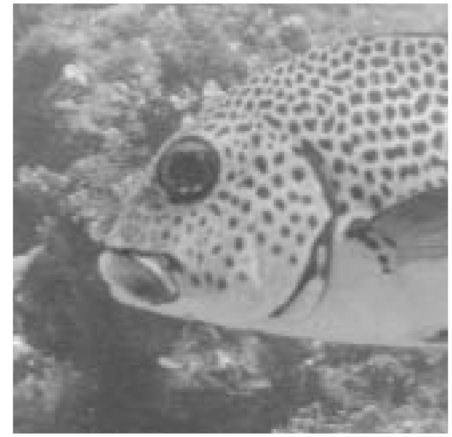


### 5.3.1. Saya report on biodiversity

Much of the recording of biodiversity was carried out using underwater video which is to be collated and catalogued.

Stills of examples of coral species and fish species will be abstracted from the video footage for identification and description of estimated populations and in terms of corals health status. Catalogues will be drawn up in the form of databases containing this information such that it they can be used for reference and also for future inclusion in a Sun & Sea web application should this be required.

Due to the unique nature of the site it is important that this information be analysed both to compare the small sample of biodiversity information gathered there in 1997 with the information gathered in 2002 and for further reference and comparison in future studies. (*Caroline Mekie*)



### 5.3.2. Seagrasses and algae

The Saya de Malha banks may be the largest seagrass beds in the world, potentially covering much of the 40,000 square kilometer area, the size of Belgium. Seagrass covered roughly 80-90% of the bottom, with corals covering around 10-20% (locally higher in small patches), and sandy areas being less than 5%.

Seagrass lawns on Saya de Malha were exclusively made up of a single species, Thalassodendron ciliatum, which is distinguished from other seagrasses by its ability to grow with the rhizomes directly attached to hard bottom by thin root-like rhizoids (most others grow only in sediment) and by the fact that it grows deeper than any other species. Thallassodendron growths looked extremely healthy (see photographs), but the presence in the water of many brown basal leaf sheaths with the leaves eaten off suggests that it is grazed, and that the sheath is not palatable, since fragments dislodged by waves usually have the whole leaves attached. Although green turtles are potentially major consumers, and were seen every day, it is not clear if their density is sufficiently high to consume a major fraction of seagrass production, much of which is apparently lost by fragments being washed over the edge of the banks into deep flanking sediments. There appears to be no significant organic sediment accumulation except perhaps in cavities. Herbivorous fish, including parrotfish, surgeonfish, and rabbitfish, were not seen to eat seagrasses, and instead congregated in coral rich areas, where they were seen nibbling at algae.

The predominant algae are calcareous encrusting and branching red algae, which cover most of the bedrock under seagrass lawns and between seagrass rhizomes, and overgrowing dead corals as well as living ones. The abundant red algae give a distinctly pink appearance to the bottom. There are several species, including species that grow as flat crusts, as rounded lumps, as irregularly lobed attached growths, and as branching forms. These appear to species of Neogoniolithon and Hydrolithon, Sporolithon, and Mesophyllum and Lithophyllum respectively. Most of these families are very difficult to identify to species in the field, requiring direct microscopic examination of reproductive structures by a handful of specialists. Images of all species recorded in the Visual Biodiversity Encyclopaedia will be sent for identification to Mark and Diane Littler at the Smithsonian Institution, the world's top experts on these groups, but specimens may have to be taken for complete identification. Encrusting red calcareous algae are the preferred substrate for settlement by larval

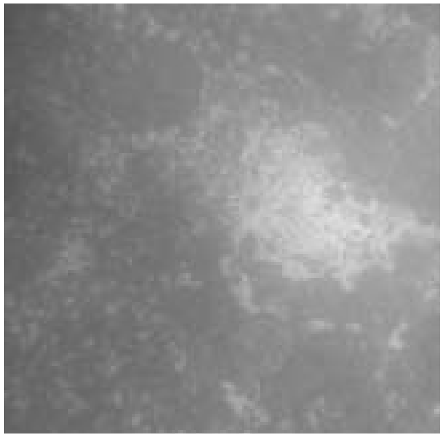
*Seagras over Saya*

*Coral roack in seagras bed*

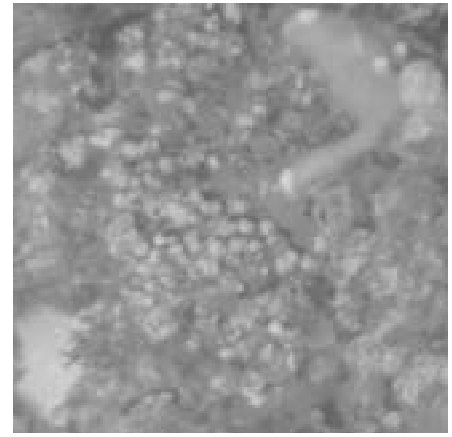
coral planulae, and so promote coral reef regeneration, as witnessed by the predominance of juvenile corals of many species that had settled since the 1998 Global coral reef bleaching event.

A notable feature of the calcareous red algae was the common appearance of a previously undescribed disease on the pink crusts, which T. Goreau has named Coralline Algae Lethal Disease, or CLD. This takes the form of an expanding white ring of dying tissue, surrounded by healthy pink tissue. The white rim is normally only a millimeter or two wide, but can be up to a centimeter thick, and the circular dead interior area is covered with a filamentous alga of olive green color (photograph). CLD has been seen extensively in all three oceans, following the first observations of its rapid spread on inertidal encrusting coralline algae in Jamaica (T. Goreau, unpulblished observations). This disease, although present also in 2002, did not appear to have greatly increased in abundance, and most algae were free of it. Another coralline algae disease seen was Coralline Lethal Orange Disease (CLOD), in which the dying ring is bright orange in color and up to several centimeters wide, and the dead area inside is white. CLOD was much rarer than CLD, being seen only once in 2002.

In 1997 the only common algae besides the calcareous red algae was the soft green alga Microdictyon sp. This formed vertical fan shaped semicircles about 2 cm in diameter, and was widely distributed on top of encrusting red algae, dead corals, and overgrowing the edges of living corals. In 2002 this species was much less common, but was replaced by abundant clumps of the calcareous green alga Halimeda opuntia. This species grows thin rounded plates of limestone skeleton strung in



branches like beads. Upon the death of the algae these become white limestone sand grains that make up most of the loose sand on the surface of the Saya Banks.



The abundance of algae suggests that the average nutrient concentrations are close to the lower eutrophication threshold of coral reefs, that is the level at which high nutrients cause increased growth of weedy algae species that can overgrow and kill corals. These concentrations have been shown to be around 1 micromole per liter of available nitrogen (the sum of nitrate, nitrite, and ammonium), and 0.1 micromole per liter of available phosphorous (the sum of orthophosphate plus dissolved organic phosphorous). Since deep Indian Ocean waters may have up to 40-60 micromoles per liter of nitrate and 3-4 micromoles per liter of orthophosphate, only around one part in 50 of deep water need be mixed with surface waters from which all available nutrients have been stripped out by phytoplankton to provide concentrations sufficient to cause coral reef eutrophication, which is why coral reefs are so extremely sensitive to upwelling conditions. On the other hand the concentrations cannot lie much above this, or the corals would be completely overgrown by algae. An upper limit is provided by the eutrophication limit of seagrasses, which is around 25 micromoles per liter of nitrogen and 1 micromole per liter of phosphorous (*B. Lapointe, D.Tomasko, & W. Matzie, 1994, Eutrophication and trophic state classification of seagrass communities in the Florida Keys, Bulletin of Marine Science, 54: 696*). Levels are clearly well below this threshold, as the seagrass blades are clean of the weedy algae that would overgrow them as concentrations reached these thresholds. The luxuriant growth of healthy seagrasses suggests that concentrations of nutrients rarely get much below the coral eutrophication limit, as seagrasses would be sparse and nutrient-limited below these levels.

**5.3.3. Corals and invertebratres**

Coral reefs and coral communities were observed scattered across the seagrass beds (*see photographs*). Corals are largely islolated and scattered individuals or small clumps growing in seagrass, but also form small clumps to reefs up to a hundred meters long, forming slightly elevated patches no more than a meter or two above the surrounding bottom.

In 1997 coral populations were observed to be made up of a very wide diversity of coral species, but the population was unusually evenly dispersed, that is no one group was dominant. Most coral reefs in the Indian Ocean are primarily composed of colonies of a single family or corals. Prior to the 1998 Global Mass Bleaching Event, most Indian Ocean coral reefs were strongly dominated by Acropora species, and after this event by Porites, the predominant survivor (*T. Goreau, R. Hayes, A. Strong, & T. McClanahan, 2000, Conservation of coral reefs after the 1998 Global Bleaching Event, Conservation Biology, 14:5-15*). In sharp contrast, Saya coral communities had only a few Acropora, but large numbers of corals of other genera that are normally uncommon or rarely found. Large colonies were generally made up of Porites heads up to 2-3 meters in diameter, and clumps of columnar towers of Heliopora and Millepora up to 2 meters across. Between these almost every coral would be of a different species, mostly large-polyped members of the Favid family. The diversity seen by direct diving observations was much greater than that reported from previous dredge haul samples.

Although many corals in 1997 were healthy, many showed signs of bio-erosion by boring sponges, clams, worms, and other invertebrates. Many of the skeletons of

the larger coral heads were being attacked internally by boring sponges of the Clionid family, such as Spheciospongia vagabunda. As a result many of the corals had had their bases eroded and often were weakly attached or broken loose. Such intense bioerosion is characteristic of coral reefs that are subjected to elevated nutrients and organic productivity, which produces large amounts of organic detritus with bacteria or plankton that the boring sponges, worms, and clams capture from the water by filter feeding, with the coral skeleton providing a refuge from predators.

An additional sign of elevated nutrients was the abundance of Microdictyon sp. algae that were overgrowing the edges of many corals in 1997, which had been replaced by Halimeda opuntia in 2002, as well as active overgrowth of some species corals by encrusting calcareous red algae, and attack of corals by red filamentous boring algae.

A further striking feature was the presence of coral diseases. Although only one isolated case of Black Band coral disease was found, there was a high abundance of a previously undescribed disease complex that T. Goreau refers to as Porites Line Disease (PLD). PLD attacks large Porites coral heads, with the dead portions being the same height as unaffected tissue, meaning that they have died in less than one growing season. Observations suggest that this disease expands across coral heads at a rate of centimeters per month. PLD was first observed in the central north Pacific in 1997, and has been seen at every site investigated since in the Pacific and Indian Oceans, with varying intensity. PLD is marked by a thin band of discolored tissure, a few millimeters wide, at the edge of healthy tissue and the dead spreading patches, but the color can vary from light brown, dark brown, nearly black, gray, nearly white,

red, and pink. It is not known if these are different forms of the same disease complex, or unrelated diseases. In Saya de Malha the predominant forms in 1997 were pink and red. Examination of broken corals showed that the red bands were in some cases resulting from overgrowth by calcareous encrusting algae, but that many pink bands appeared to extend beneath the skeleton of healthy tissue, and to be made up filamentous red boring algae. It is not clear if the filamentous algae are a primary pathogen attacking coral tissue or if they are an opportunistic species coming in after the coral has been killed by another agent. All the colonies affected in 1997 were completely dead when re-examined in 2002, including corals 2-3 meters across that were several hundred years old. In the nearby Seychelles, PLD was observed to be affecting large Porites heads in 1997 prior to the 1998 Coral Bleaching Event, and that although most of these coral heads survived the bleaching event, they subsequently died from PLD (*T. Goreau, 1998, Coral Bleaching in the Seychelles, Impacts and recommendations; T. Goreau 1998, Coral recovery from bleaching in Seychelles; T. Goreau 1998, Coral recovery from bleaching in Alpohonse and Bijoutier, all available at www.globalcoral.org*) It is therefore thought that the large Porites heads that were alive but diseased in 1997 but dead in 2002 are also likely to have survived bleaching in 1998 but succumbed to diseases afterwards.

Coral bleaching in 1998 must have had a devastating impact on Saya de Malha, comparable to what happened in Seychelles, Maldives, and Chagos, where the mortality rates were over 90%, but perhaps somewhat less bad, as in Mauritius (*T. Goreau, R. Hayes, A. Strong, T. McClanahan, 2000, Conservation of coral reefs after the 1998 Global Bleaching Event, Conservation Biology, 14:5-15*). In 2002 the great majority of corals that were alive in 1997 were seen to be dead. The overwhelming survivors were the Blue Coral, Heliopora coerula, which suffered partial mortality of colonies but which largely survived. As a result Heliopora is now the dominant coral, making up most of the coral colonies by area (see photographs), a situation very different than in 1997 when they made up only a minor portion. Only a few Porites heads that were free of disease survived and are still healthy. It is not known if these are resistant varieties or simply lucky ones that did not get infected.

Although live coral cover in 2002 was greatly reduced from 1997, coral diversity was much less impacted because of the large amount of new coral settlement. Young corals of many kinds were abundant (*see photographs*). The calcareous red algae bottom and crusts over dead coral are their preferred substrate for baby coral settlement. The only problem these new corals seem to face is the risk of being shaded and overgrown by Thallasodendron ciliatum or by Halimeda or Microdictyon, before they are big enough to grow above the seagrass-algae lawn. The prognosis for reef recovery is therefore excellent, as long as more mass bleaching events do not take place, or if Biorock powered mineral accretion can be used in increase coral resistance to bleaching, as in the Maldives (*T. Goreau, W. Hilbertz, & A. Azeez A. Hakeem, 2000, Increased coral and fish survival on mineral accretion reef structures in the Maldives after the 1998 Bleaching Event, Abstracts 9th International Coral Reef Symposium, p. 263*). A solar powered coral nursery built on Saya in 1997 appears to have only functioned for a short while before the solar panel was lost, but the structure has already been settled on by several corals, primarily Pocillopora verrucosa. A much larger structure, The Saya Star, was built in 2002 and powered by 6 solar panels.

The number of invertebrates other than corals was relatively low, being primarily soft corals, boring sponges, and a few starfish. A complete listing with images of each colony seen will be presented in the visual encyclopaedia of Saya Biodiversity that is under preparation by Caroline Mekie. When this is complete we will be able to present quantitative data on the abundance and diversity of the corals and all invertebrates large enough to provide good images on the video camera. This will allow a full quantitative comparison of the changes in abundance of each species before and after the 1998 bleaching event.

Although the bottom dwelling invertebrate community was the focus of this study, It was observed that there was an extremely active fauna on the surface of the ocean made up by Water Treaders, Hemipteran bugs of the genus Halobates. Several species of widely differing sizes were abundant running around on the surface of the sea, with the vast majority of very tiny species. They appeared to be most abundant near the shelf edges. These organisms are very hard to see, but under calm conditions and low angle lighting conditions near sunrise and sunset one can see extraordinary numbers of these insects and the dimples they make on the water as they move on it. Their abundance was repeatedly observed to be in the range of 10s to 100s per square meter under the right lighting conditions.

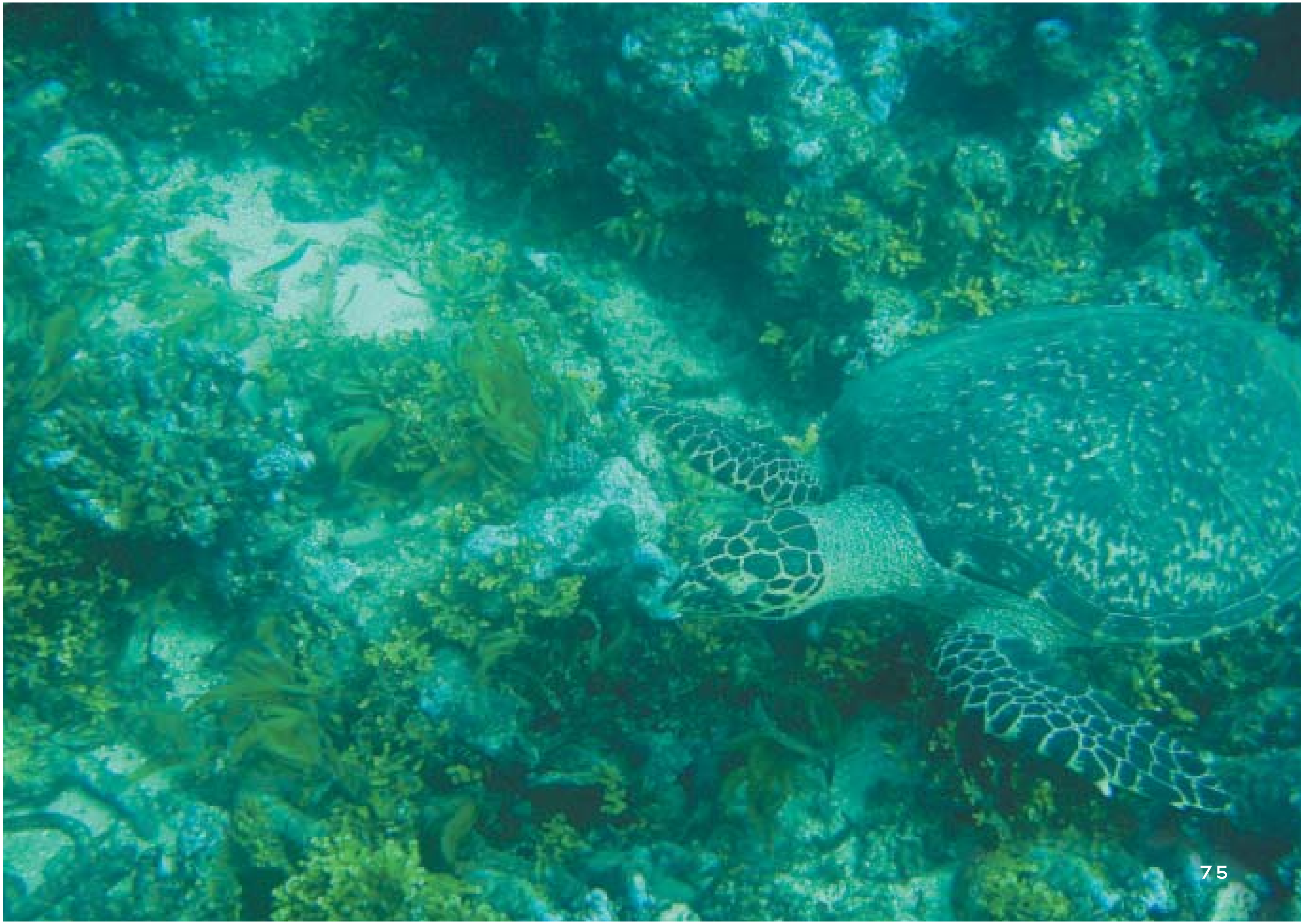
### 5.3.4. Fishes, turtles and marine mammals

A highly diverse population of coral reef fishes was found on Saya, with the greatest diversity in close proximity to the bottom and strongly concentrated in areas of high coral cover. Although many kinds of reef fish were present, including groups feeding on plankton, invertebrates, algae, seagrass, and fish, their numbers were moderate. Full listings of fish species and their abundances will be made when the digital video records are analyzed, and will be included in the future Biodiversity report.

In contrast pelagic fishes were rarely observed over the shallow banks. Their numbers appeared to be much higher over the edges of the shelf, where far more flying fish, bonito, and tuna were seen. No sharks were observed.

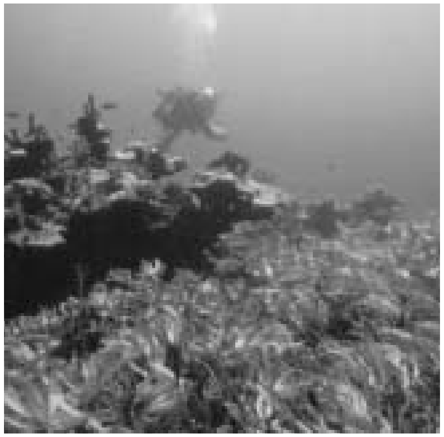
Green turtles (Chelonia mydas) were observed frequently. These feed on seagrass and on algae. The effects of their feeding was seen by the large numbers of floating residual bases of seagrasses from which the leaf blades had been eaten.

Schools of spotted dolphin, spinner dolphin, pilot whales, and beaked whales were seen. These were seen on the bank and at the bank edges, in small groups or in medium sized aggregations encircling fish schools (and attracting flocks of terns overhead to areas of jumping fish), or in large packs swimming parallel to each other in long lines. No large whale species were seen, perhaps because it was not breeding season, or because they prefer the bank edges rather than shallow water.



### 5.3.5. Water quality

Water quality over Saya de Malha showed strong and clearly visible semidiurnal oscillations. Tidal currents reversed four times a day, flushing the banks twice a day from the west and twice a day from the east. When the current was from the east, the waters were green in color, when they were from the west they were blue. These changes in color are most obvious to divers looking horizontally and upwards, since the changes are masked looking downward from a boat by the green seagrass at the bottom. However under blue conditions every coral, sand patch, and seagrass blade is clearly visible from the surface (*see photographs*) while under green water conditions the bottom seems to be an opaque green and no details can be made out.

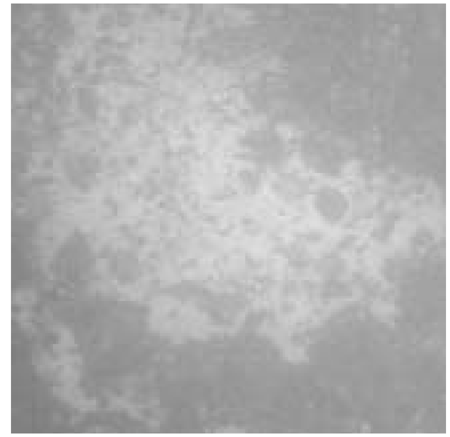


The enhanced density of microscopic algae in the water provides a green color over the bank that can be clearly seen on satellite chlorophyll images. Green water conditions had greatly elevated levels of planktonic Ctenophores (or comb jellies), transparent gelatinous animals that are commonly confused with jellyfish, although they are much more complex anatomically, possessing a gut with a mouth and anus at either end, whereas jellyfish have a bag-like stomach with one opening that must serve as both mouth and anus. Jellyfish must finish digesting and eliminating waste food before they can feed again, while ctenophores are able to feed and evacuate continuously, making them more efficient feeders. Ctenophores reached very high densities throughout the water column during green water conditions, presumably because the green water was full of phytoplankton and the microscopic zooplankton food that eat them and which ctenophores and jellyfish live off. There were several kinds of ctenophores, as well as less common greenish-brown thimble jellyfish

(Linuche unguiculata), and a few larger Scyphozoan jellyfish. The ctenophores and jellyfish could not be examined visually clearly enough to be identified, but the ctenophores were distinguished by the intense blue irridescence caused by light interference in their comb like filter feeding apparatus when in direct sunlight.

These dramatic changes are caused by changes in the availability of nutrients in the different water masses sweeping across the banks. The Banks plunge rapidly into very deep ocean basins on either side. This allows deep, cold, and nutrient rich waters to reach shallow surface bank waters through three mechanisms: physical entrainment, tidal pumping, and breaking of internal waves. Strongly flowing surface currents pull up deep water at the edges of the banks, which mix with the surface flow. This acts to basically suck deep water up along the shelf edges. The oceanic tides are a large wave that propagates around the Indian Ocean in a rotary fashion. When these tidal flows cross from the deep ocean to the shallow banks the tidal amplitude increases as the wave feels the bottom, and the velocity increases as the amount of water must flow through a much narrower vertical cross section. The Saya Banks are a major site of global tidal energy dissipation. This acts to pump water back and forth across the banks from either side, with the nearest bank edge (the east side at the site studied) predominating in nutrient delivery. Internal waves propagating across the ocean along density interfaces can break and greatly increase their amplitude when they hit a shallow bank, sloshing deep water up over the edge.

The influx of deep-water nutrients are accompanied by temperature variations that can be felt by divers, with green waters cooler than blue. This influx makes the banks an oasis of high biological productivity, fueling much higher levels of primary



production and secondary production (such as fish) than in waters over deep basins.

To quantify these variations, instruments to continuously record temperature, salinity, oxygen, chlorophyll, pressure, tidal height, and current speed and direction were moored to the bottom. Unfortunately these failed to operate properly. One instrument did not start recording when it was supposed to, because the software-driven initialization did not work properly. The other suffered corrosion from a leaking battery, that appears to have shorted out key electronic components. Therefore little quantitative information could be obtained about the magnitude of changes in all of these parameters.

*Diver working on the seaground*

### 5.4. Future work

The work described in this report is no more than a first step, and was severely limited by lack of time. This was caused by the fact that the expedition was forced to leave late because of development of strong cyclone (Harry) and to leave early because of another (Ikala) (Both of these began in the vicinity of Saya, but the first moved southwest and second southeast, see satellite photographs). Much more work on Saya can and should be done. Some of these steps could include the following, organized according to the major sections of this report.

#### 5.4.1 Mapping

The entire Banks should be mapped in detail to determine the extent of the different surface levels, features, and reefs, and their relationship to the edges of the Banks. This should be carried out sonar tracks similar to those carried out by Steve Evans,

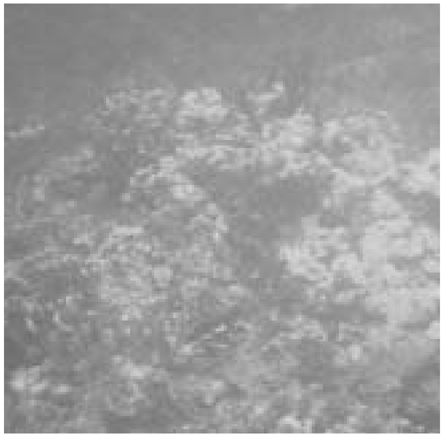
but far more extensive and complete, using recording depth sounders. The entire bank should also be surveyed using side scan sonar to map all the features on it. One member of the expedition, Dr. Peter Goreau, is a marine geophysicist with expertise in side scan sonar mapping, and mapping gravity and magnetic fields. Gravity and magnetic surveys require extremely expensive instrument arrays that need much larger ships than are practical, but new side scan sonar equipment is small and affordable for smaller boats.

### 5.4.2. Geology

The origin and history of the Saya Bank can be best understood by more extensive drilling in a wider range of locations. The first step will be to get dates on the core that was taken in 2002, and follow through with longer cores at more locations.

### 5.4.3. Biodiversity inventory

The Biodiversity Encyclopaedia, when completed, will provide the fullest documentation of the abundance of all species filmed and their variability. Future work should be extended over larger areas and a wider range of biological communities on both banks, including the branching coral habitat on the South Bank. It is ineffiicient to do so only by diving, due to the limited area that time will allow to be covered. What should be used is a remote, manoeverable, video camera that can take sharp continuous images of all the bottom habitats encountered in transects from one edge of the bank to the other. A brand new, state of the art video camera with these capabilities was ordered for the Saya 2002 expedition, but due to delays from the manufacturer, could not be shipped in time for use. A future expedition should use this camera as the major workhorse tool in documenting biodiverstity, because it allows enormous amounts of bottom to be continuously recorded without vast amounts of bottom dive time. Divers will need to spot dive only at especially interesting locations where unusual organisms require closer examination or direct sampling for identification. We are confident that the list of species known from Saya would be greatly increased over what we were able to record in a few days of diving at a single location.

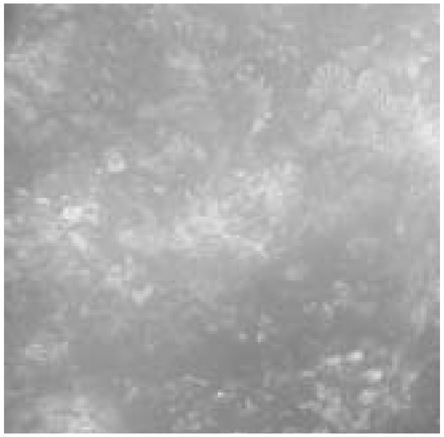


**5.4.4. Corals and invertebrates**

Coral recruitment should be tracked to determine the number, diversity, and growth rate of new corals. The existing coral nurseries should be maintained and expanded to turn the Saya Bank into a true Coral Ark capable of playing a significant role in maintaining these isolated populations which are so crucial to maintaining species and genetic flow in the Indian Ocean. Tidal and solar energy could be used to create very large Biorock™ coral nurseries to maintain coral species and gene flow across the Indian Ocean.

**5.4.5. Seagrasses and algae**

The seagrrass lawns of Saya may be the largest in the world. Future work should concentrate on determining their productivity, relationship to nutrients, and the amount of organic matter lost to deeper waters. By producing large amounts of organic matter that are lost and buried in deep sediments, the Saya Bank is serving as a significant sink of atmospheric carbon dioxide, whose magnitude should be determined. Patterns of change in the algae should be followed to see if these are seasonal or result from episodic nutrient upwelling events, or from long term changes in upwelling rates. The large amounts of seagrass biomass being washed from the banks into deeper water may make them a globally important carbon dioxide sink, whose magnitude should be determined.



### 5.4.6. Fishes, turtles, and marine mammals

Fish populations are highly diverse, but numbers are not high enough that they could be sustained if they were fished. The whole area should be protected from destructive fishing practices such as bottom trawling and drift net use, so that they can serve to maintain the straddling stocks that supply much of the catch in neighbouring waters of Seychelles and Mauritius. The marine mamals should be better studied to estimate population sizes, and they should be strictly protected from all fishing activities, especially the large whales that use Saya as a breeding ground. Saya may also maintain globally important concentrations of green turtles. The amount of seagrass that they consume should be estimated.

### 5.4.7. Water quality

Quantitative studies should be carried out documenting changes in temperature, salinity, oxygen, chlorophyll, nutrients, waves, tides, and current speed and direction. These should be recorded continuously over time ranges including tidal cycle to annual variations. They would best be done by installing recording instruments on a mineral accretion monitoring tower, and transmitted by satellite transponder for remote downloading and analysis.

**Conservation**

Please see following section.

### 5.5. Conservation recommendations

Saya de Malha is in many ways a marginal habitat for corals, being much better for seagrass, but it nevertheless is a crucial habitat for coral species survival because as global warming accelerates coral survival will be best in marginal habitats, especially those affected by enough upwelling to keep the water slightly cooler than surrounding areas. On the other hand, because of elevated nutrients, corals are prone to algae overgrowth, but Saya at present appears to have a balance where nutrients are not high enough to cause excessive growth of weedy algae that inhibit coral settlement, but are still sufficient to promote the growth of encrusting red algae that promote coral settlement. This, and it's remoteness from direct sources of anthropogenic stress, make it a crucial reservoir to maintain biodiversity in surrounding inhabited islands and shores of the Western Indian Ocean, as seen by the high rates of new coral settlement since bleaching. However the reefs are very vulnerable to damage from trawling and bottom fishing, and need to be protected from destructive fishing methods if they are to remain a natural coral ark.

Shallow water ecosystems lying in international waters pose a special case for conservation. Freedom of the high seas means that they can be utilized at will by all

who can reach them without any national supervision or management. A special case is recognized in the case of straddling fish stocks that are divided between national and international waters, requiring a special series of UN sponsored negotiations between interested parties. Note that these parties are humans with an interest in specific economic resources, which poorly serves sustainable management and resource conservation because the interests of the species subjected to human activities is not taken into account.

Nevertheless ecosystems like Saya de Malha are of extreme importance to global conservation, because they may provide a crucial refuge that allows species to survive without excessive harvesting, and because they may serve as critical stepping stones allowing species to spread into new habitats and maintain genetic flow between remote and otherwise isolated populations. A shallow water ecosystem as remote as Saya de Malha is subjected to far less direct human stress than those more accessible. It seems to be in the long term interest of humanity to save these very few refuges, which may prove to be critical in the future if more accessible ecosystems collapse from the pressures they are under, especially from increasing population-dependent stresses such as overfishing, global warming, sea level rise, escalating pollution, and emerging diseases. An area like Saya could well prove to be a Noah's ark for many species, and should be declared a Special International Protected Area or Biosphere Reserve. It should be managed by an international body, in cooperation with the Seychelles and Mauritius, which have a clear interest in maintaining their straddling stocks on Saya.

The Saya Banks are known to be a significant breeding ground for many species of dolphins and whales, including Blue Whales and the Sperm Whales. They require strict protection for this reason alone.

We therefore recommend that the entire Saya de Malha Banks be declared an International Biosphere Reserve by the Governments of Seychelles and Mauritius, the United Nations Environment Program, the United Nations Educational, Scientific, and Cultural Organization, the United Nations Convention on the Law of the Sea, and other interested international bodies, and that funding be provided for their sound and sustainable management by the Global Environment Facility of the World Bank.

# 6. *Pictures and poems*

*by Peter Goreau*

**20. March 13, 2002**

Roman woke me before dawn, too tired to steer on
He found Willie fast asleep
One hundred and fifty degrees off course
And had taken the wheel to keep
Us from heading back, due north!

I took over two hours before dawn
And carried on 'till eight
When the breeze picked up
We set our sails. I tell you this is great!
With flying fish taking off from the crest of every swell
As our hull disturbs their world in which all seems well
The dawn came gentle, behind layers of high cloud
While at a lower level, small purple puffs abound
The sea is a proud oceanic blue, the same low swells are found
True, we make a gentle passage, and we are gaining ground
We're half way there already, to Saya, where we're bound
The sails are filled with wind; the furrow follows free
I'm thinking of Coleridge caught on his glassy sea
The differences are manifest, I'm sure you will agree

We just killed two bonitos; Nikko looks for number three
But, seabirds are safe with us; we love their majesty
As we do the greater creatures of the deep
But, have yet to hear a whale's song, or see a dolphin leap
I am looking constantly. It would be so neat
To see whale sharks and manta rays that graze the plankton heaped
In these productive waters, where upwelling keeps
Dancing to the tide, to wind, and where these great currents meet
With submarine topography, below the oceanic sheet
Although the depth of this place exceeds six thousand feet

We've slowed for Vakalele, Nikkos a good sport
She is heeled before the wind, two miles off our port
We were ahead most of yesterday, 'till Willie fell asleep
Now we're exactly even, I think it's good to keep
Together on these remote blue seas
Orphee has gone ahead, since a prize had been agreed
A bottle of French Cognac. So they're way in the lead
Ceres has it over both, with a greater hull speed
But, Nikko has Madagascar rum, and doesn't feel the need
Thus, we sail in convoy with the Vakalele

The high cloud has broken up; the middle cloud remains
By the way, the lower puffs, remain about the same
The wind is blowing at five knots, coming from the south
The line appears not to have caught a careless fishes mouth
The sun has become a lion, not the mouse it was at dawn
It has doused the cloud with light, and the cloud is gone
I am sitting in the mainsails shade
Which is made of Dacron, sailing grade
In which four battens and two reef lines have been laid
The jib is up as well, and we are making way
"All is claar! All is claar!" when the evidence is weighed

**21.**

Of things seen floating on the sea
Plastic trash seems to be
Dominant. After that, sea weed
Either sargassum, or thallasia from bank off shore
Then of course there are fish, the store for
Seabirds, always looking for free lunch
But, since they put in flying time, are a hardworking bunch
There goes a school of flying fish erupting from the bow
For all their freedom, I'd never wish to be one of them some how
They make such a tasty dish to tuna or dorado
So they respond with splendid force to every moving shadow
Course through the air on extended flattened fins
Spreading out like perfect wings, until the final splash which brings
Them back to the Dorado

We set a hook, hoping to cook the high browed rainbow fish
The mahe mahe, or the dolphin, if you wish
Not the mammal though, that's a forbidden dish
Strong taboos govern those who even think of this!

**22.**

One flat plastic bucket lid floats on the central ocean
Hid on board, a swimming crab sits alone on the floating slab
Which a passing seabird tries to grab.   No luck!
The crab is watchful, and it ducks
Underwater where algal fronds
And goose necked barnacles grow on
The flotsam.  Soon after the bird is gone
The crab climbs back on the floating lid
Fleeing a predatory fish, or squid

This, the cycle of life it lives
As day and night are slowly slid across the sphere
It receives sufficient; it's fat, that's clear
There's abundant sustenance, right here
Amid the blue and motion
Of the equatorial Indian Ocean

**23.**

As the sun reaches zenith the shadow of the sails
Is diminished to a sliver, and it ultimately fails
To give protection to the rays, those photonic nails
Pouring from the sun.  You know what this entails
We must seek protection, but I won't regale
You with more on this subject, I'd rather speak of whales
That was for poetic purposes, we haven't seen one yet
But, you never know when we will, and we must be set
Lunch is on the way; more fish caught the other day
Tommi peels potatoes for Nikko who will cook
Ripe avocadoes, at least from their brownish look
Will become guacamole.  Cuisine without the book

**24.**

The sky is clearing up; the lower puffs are gone
Nothing interrupts the power of the sun
Save a single thin high cloud
Which gives a halo standing proud
Around the white hot sun
The jib casts a thinning crescent
Soon we'll have to run
To the shadow of the mainsail
Now casting to the east
Early afternoon, we are about to feast

One good thing about being a poet
You don't get interrupted. Somehow people know it

Is bad luck to cut the flow of words
So, as I write, cooking occurs
They didn't care for breadfruit. Potatoes are preferred
By Nikko, Willie and Roman, to whom I now refer
So, it's classic mashed potatoes today, I have heard

**25.**

Roman has a stricture of his esophageal tract
Today at breakfast, a carrot chunk got trapped
And, he was completely blocked
I hung him upside down and shook, until the carrot dropped
He's a happy sailor now, having been unblocked
But, I'll tell you, getting something caught
Leaves the occluded victim pretty severely fraught

**26.**

Seabirds, thousands of miles out to sea
Do not appear lost. Is it the magnetic field?
The sun and the stars? I believe they must feel
Just where they are. Flying six thousand miles a week
And, this is normal. It is no great feat
It's what they do. They have to eat
But. They are never lost, and, that is neat

We met a pod of tuna feeding out on the clear blue sea
Either that or they were fleeing a great attack apparently
They were jumping to great height
But, whether eating or in plight, I cannot say
Anyway it was an awesome sight
On such a clear blue day

We just ate bonito, which is tuna in a way
Although our local fishermen wish tuna took their bait
It hasn't happened yet. So, we will have to wait

**27.**

Vakalele, in a fit of speed, overtook us; she's in the lead
The breeze has freshened, all she needs
Being a light boat with larger sails
Hull speed be damned, she prevails

Now Ceres is painted in a yellow light
As the earth turns inexorably towards night
In the stratosphere, thin clouds
Have many wave patterns, now
Now the sun drops out of the lower masses

Onto the horizon.   It's a classic!

**28. March 14, 2002**

Dawn starts gray again today
›From some convection heads, rain
But not on us, it stays dry
Tom is steering; a log floats by
Then, suddenly, the engine dies
"Captain" I call, "We need your help"

He's up in a flash, and down the shaft
To the engine room aft, where, after pumping fuel
Is restarted pretty soon, but not before "The Mariner"
Jumps into my head: "Day after day, day after day
We stuck, no breath nor motion
As idle as a painted ship upon a painted ocean
All in a hot and copper sky, the bloody sun at noon
Right up above the mast did stand, no bigger than the moon"

The ocean is a silent place, when it is being kind
Where only slapping stays tap out the pace of time
Where the motion of the ocean, is in a dancing line
Or a masthead tracing it's designs against the sky

**29.**

I steer the boat from morning until early afternoon
To say the sun is blazing hot, and shade gives little room
May be repetitious, maybe not, it dominates the daily tune
This is the killing sun.  Ignore it to your doom

And, also repetitious, is the Indian Ocean blue
This, the mothering water, her colors only soothe

Nikko says the tuna are feeding when they jump
Their attack coordinates bait fish into a lump
Then swim through vertically feeding as they move
Which is at high speed, surfacing, they lose
Contact with the ocean, up fifteen, twenty feet
Before plunging back into the school, continuing to eat
Using a mass of boiling chaos to have a tuna's feast
It is very impressive.  That is to say the least!

**30.**

The thing about the deep ocean swell
Those great moving mountains?
They are gentle as well
Never too steep, as near as I can tell

It's when they're up against a powerful wind
They rise steep, to compete, and damage begins

Today, the wind is almost absent; it's not worth setting sail
So we motor on regardless, towards Saya, without fail
Vakalele's dead ahead. Sometime during night
We lost seven miles. We've made some up all right.
She's three miles ahead of us, her engine is quite light
This is where hull speed, in the end, will win the fight
We'll overtake in an hour or two, but it might well be three
Time slows on the ocean; I know you will agree
Pursuit is a relative term
When you're conserving the fuel you'll burn
So, we're idling along at 1700 turns per minute
Making 5.5 knots, as if there were nothing in it
We close at a knot per hour, but at that speed, we'll devour
Vakalele

**31.**
We just sailed through a pod of whales
Ten to fifteen feet long, dark gray
Dolphins? We thought. But, they failed
To behave as dolphins do, I think they may
Be pilot whales. They were feeding, clear and plain
Birds, attracted to the melee of fish jumping out of the way

There were several dozen whales in groups dispersed over a square
Kilometer. Each had a curved dorsal fin, and
Seemed to swim without a care for the fact that we were there
If anything, actively avoiding us, didn't think it worth the fuss

**32.**
Vakalele has been beside us for the whole afternoon
Sometimes within a hundred feet, something of that tune
She's a mile ahead right now; we will catch up to her soon
We stopped to check our gearbox oil, that's what I assume

The sun is seven fingers high over the horizon
This, the fourth sunset we have set our eyes on
Sea state, calm, with a gentle breeze
It is cooler now, at eighty-five degrees
The force of the sun is diminished on the limb
A length of air saps its strength; shorter waves are trimmed

The sun sits on a pyramid of rays

Created by the lower clouds
The ones I've made so much about
The stratospheric high cloud must be made of ice
It has two nice sundogs twenty two degrees to either side
Hey.  This is a poetic log.  My subject range is wide

Here we have a vision of the Mother planet
One of water air cloud and sun, can it
Be?  That we have come all this way
Just to see the precious globe in blue and white and gray?

Birefringent fringes completely surround the sun
It's display of spectral colors in concentric rings, which run
In every cloud around it.  I am completely stunned
At the beauty of the evening.  Saya, here we come
We'll arrive late tonight, sometime before dawn
Now, as the sun sets, in the anti-solar point
Converging orange rays clearly appoint
A radiant display,of great rarity, I'd say
Since the anti-solar point is not often anointed
In this specific way

Now the golden orange gloaming, which the ocean reflects
Displays the range of sunset colors to their maximum effect

**33.  March 15, 2002**

We have arrived on Saya; the water is dark green
A mixture of pure ocean, with an algal sheen
In this case, sea grass beds down at forty feet
Thallaso dendron in Linneus's Latin for elites

The morning is beautiful, but it's the tide that keeps
The boats keel steady across a wind, which blows
Forty degrees off the strong tidal flows
Sea state is calm, waves one to two feet
Local showers falling in long drifting sheets
When the rain falls, it beats down the seas
Flattens the white caps picked up by the breeze
It really is quite something to see
The power of small drops, I mean