Coral Reef Remote Sensing Applications

Deborah A. Kuchler
David L.B. Jupp
Commonwealth Scientific and Industrial Research Organization,
Division of Water and Land Resources,
P.O. Box 1666, Canberra, 2601,
Australia.
Daniel B. van R. Claasen
Great Barrier Reef Marine Park Authority,
P.O. Box 1379, Townsville,
Qld. 4810,
Australia.
William Bour
Office De La Recherche Scientifique Et Technique Outre-Mer, B.P.
A5, Noumea Cedex, Nouvelle Caledonie.

Abstract

Great Barrier Reef work is the major example used to describe how remote sensing technology is being applied in coral reef studies. Such studies include reef geography, reef form, surface cover, vegetation, micro aspects and oceanography. New generation sensors optimized for oceanographic applications, means that coral reef and oceanic studies will adopt more precise and more extensive uses of remote sensing technology.

Introduction

Sunlight reflected from water bodies, shallow seas and submerged features is providing a wealth of information on coral reef ecosystems. Until recently, recording and interpreting this information on a routine basis was not economically feasible. Now, the application of remote sensing[1] technology to coral reef research, management and development has taken a quantum jump with the advent of the space age, which has seen the simultaneous development of advanced sensor systems and platforms to carry them. This technology encompasses three main elements:

- Imagery and other data forms acquired by a wide assortment of sensors aboard ships, aircraft or orbiting satellites.
- Information-processing techniques ranging from conventional visual image interpretation to sophisticated interactive computer systems.
- Means of reducing information to useful formats, such as base-map overlays, color-coded thematic maps, computer-generated maps and statistical data.

For the Great Barrier Reef, it has saved research and management much time and money by providing information which is otherwise unavailable.

The purpose of this paper is to principally use Great Barrier Reef work as an example, to describle how remote sensing technology is being used in coral reef studies. In this sense it is time dependent, because in the near future, remote sensing platforms carrying more specialized instruments will add new dimensions to the remote study of coral reefs. For example, in the space domain, satellite data will be characterized by synoptic scales but have the resolution of traditional aerial photography (e.g. SPOT data[2]). In the time domain, a continuous recording of reefs and oceans will also be available, since data will be more plentiful and recorded according to users requested needs.

Remote sensing's principal advantage is that it can collect some coral reef information more efficiently and less expensively than with ground techniques. Satellite-based sensors have an important advantage over ground based techniques, because they can measure uniformly the abundance and distribution of phenomena in time and space. Land or ship based measurements are only capable of patchy sampling. While methods for deriving chemical information from remotely sensed coral reef and oceanic data are still being tested, research into the nature of remotely sensed physical and biological data is comparatively well advanced. Many potential applications of remote sensing technology to coral reefs have come to mind so far. It is beyond the scope of this paper to cite them all, so only applications in which remotely sensed digital data have been utilized are described.

Reef Geography

The accurate identification, spatial position and distribution of reefs and their associated landforms (e.g. shoals) are required by mariners, researchers and managers. The information is required for coral reef resource assessment; to plan and map shipping routes; to locate potential fishing grounds; to study water circulation patterns; to evaluate and promote accessibility and so on.

Until the processing of twenty-four LANDSAT Multispectral Scanner (MSS)[3] images this year however, maps giving such information were unavailable. The information is now given in standardized rectified LANDSAT satellite image maps at scales of 1:250,000 and 1:100,000.

Rectification is the process of minimizing distortion in a remotely sensed image. Image distortion is any shift in the position of an image in a scene that alters the perspective characteristics of the scene and may be caused by the oblique angle at which the satellite collects data on a spherical earth; motion in the satellite's orbit; scanning system optical and/or instrumental aberrations; and, the earth's rotation. Because tracking and spacecraft altitude details are not known precisely, removal of these distortions results in an image map which is accurate to about ± 200-500 metres. This level of accuracy is sufficient for applications such as individual reef studies; accessibility evaluations; inventories of shoals as potential fishing grounds; identification of reef forms; and, assessing multi-faceted developments. For navigation, cartographic and environmental monitoring purposes however, higher accuracies are required. Map accuracies are improved by registering images with a cartographic base and for the Great Barrier Reef, the Australian Map Grid (AMG) geographical co-ordinate system is used.

The registration process involves identifying ground control points which are any physical feature identifiable in an image and whose location on the ground is known precisely.Using the known ground-control geographic co-ordinates, the image is transformed into an accurate map projection that will register with other maps. The cartographic accuracy of a satellite image map depends on the precision of the ground control co-ordinates and on their number and distribution. Great Barrier Reef LANDSAT image maps at 1:250,000 are being produced at National Map Accuracy Standards (Plate 1) where 90% of good, independently chosen ground control points fall within 0.5 mm of their known grid reference position on the rectified image. This means a residual Root Mean Square (RMS) error of about 64 metres (Jupp *et al.*, 1982).

Information on reef geography is also available from other satellites. Just two Coastal Zone Color Scanner images taken aboard the NIMBUS 7 satellite (Astley-Boden, 1985) provide a synoptic view of the whole 1900 km extent of the Great Barrier Reef. In comparison, a regional perspective is available from images taken by sensors aboard the space shuttle, while local scale information is collected by the SPOT High Resolution Visible (HRV) sensor (see Plate 8) and LANDSAT's Thematic Mapper (TM).

Reef Form

The form of a reef and its surroundings contains an abundance of information which is used at least in biological, zoological and geological investigations, reef description, survey decisions and management.

Because reef topography is virtually unseen from a proximate reef-based perspective and obscure when viewed on a raw LANDSAT image (Plate 2), a reef exposure image has been devised to enhance topographic and aspect information (Plate 3). A visible wavelength band is used as an approximate sea floor elevation model and local slope and aspect are found by numerical differentiation (Jupp *et al.*, 1985b). Through relief shading, the exposure image provides information on reef morphology which can be used to:

(1) facilitate the planning of geophysical field programs on individual reefs;

(2) for updating site morphology;

(3) to give clues to structural or stratigraphic features; and,

(4) to show relationships between structure and site which can be important in determining areas for research.

An exposure image also gives increased reef edge enhancement for the detection and mapping of paleochannels and an indication of a reef's exposure to weather. Information on reef sites and their aspect to prevailing winds is used in biome[4] analyses, since coral growth is partially consequent on climate which is partly governed by concealment or exposure. The exposure image may be produced using for example, the predominant south-easterly wind vector or the cyclone bearing north-easterly wind vector.

A further understanding of reef form is gained from submergence and turbidity levels which can be estimated using remotely sensed data of reflected light from the sea. Such estimations rely on the solar irradiance attenuation by water being strongly wavelength dependent. The reflected light recorded by the four LANDSAT bands (bands 4, 5, 6 and 7) originates from different water depths for each band and for constant water type and submerged bottom types, it varies directly with depth changes in shallow waters. Consequently, depth of (light) penetration images, which show approximate water depths and turbidity levels (Plate

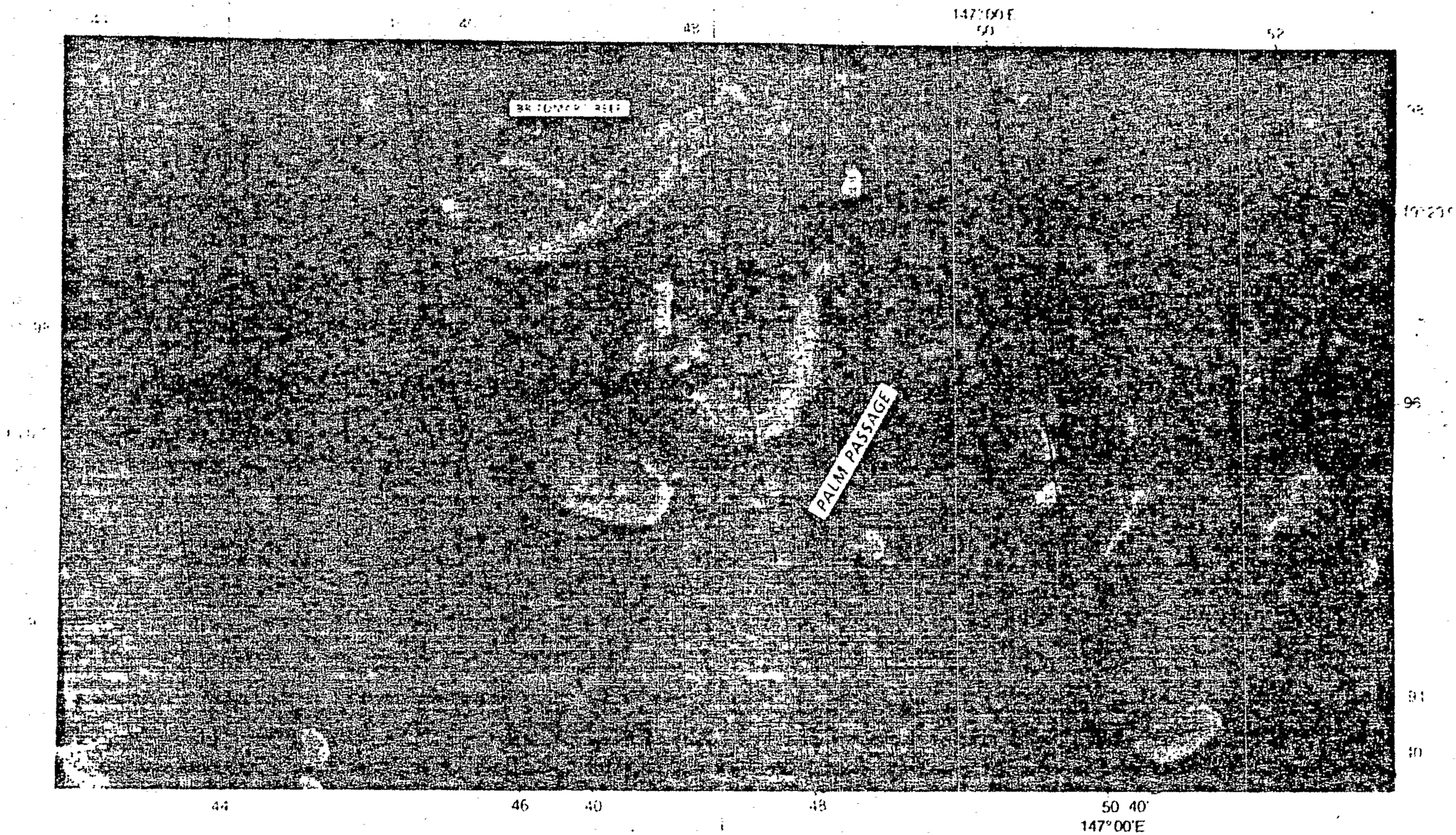


Plate 1: Rectified raw Landsat MSS satellite imagery map at 1:250,000 covering a section of the Great Barrier Reef.

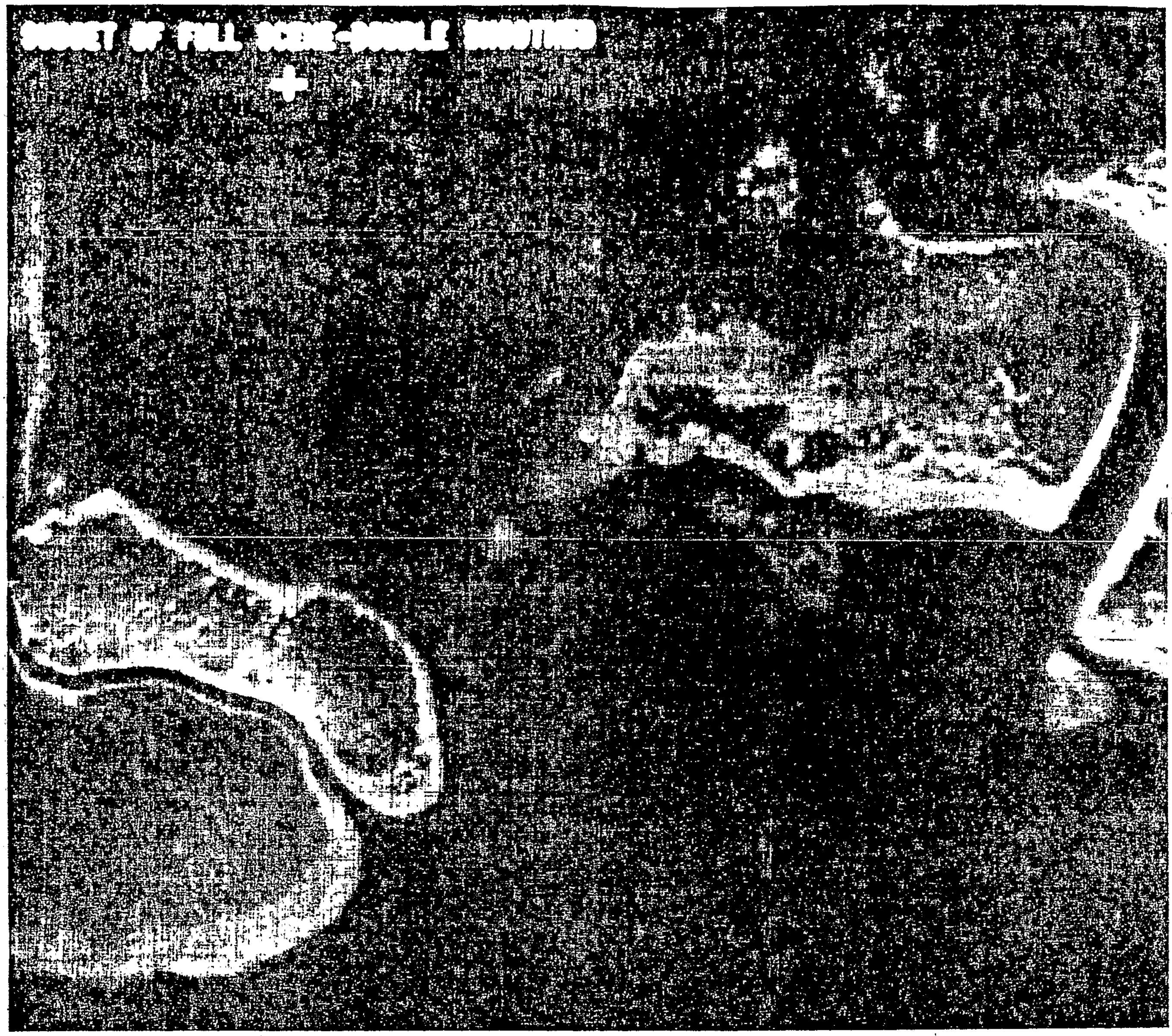


Plate 2: Landsat MSS colour composite image showing (from left to right) Hook, Hardy and Black Reefs, Great Barrier Reef.

4), have been produced for reefs of the Great Barrier Reef (Jupp and Mayo, 1984); the Philippines (Bina *et al.*, 1978); and, French Polynesia (Pirazzoli, 1984).

The water depth from which a LANDSAT band can record light penetration or its depth mapping capability, is delimited when reflected light signals are not distinguishable above clear deep oceanic water signals and from physical and sensor noise. For clear, calm oceanic waters and a clear sky, these depths are approximately 15-20 metres for band 4 (500-600 nm); 4-5 metres for band 5 (600-700 nm); 50 cm for band 6 (700-800 nm); and, the sea surface for band 7 (800-1100 nm) since light in the band 7 visible infrared wavelength is fully absorbed by water (Jupp *et al.*, 1985a).

These four water depth zones may be divided up further into smaller interval depth zones using either of two methods: (i) interpolation procedures for general work, or, (ii) on the basis of field and tide data for precision work. For example, band 4 which maps the broad depth zone ranging from 5 to 15 metres could be mapped in depth zones with narrower ranges from, for example, 5 to 10 metres and 10 to 15 metres. The assumption is that the maximum light penetration depths for each band are correct. The methods for deriving depth of penetration and interpolated depth of penetration images are thoroughly described in Jupp *et al.*(1985a).

Relative turbidity levels can be estimated from the LANDSAT data by the occurrence of characteristically higher 'reflectance' values, since increasing turbidity increases the reflectance scattered back from the water

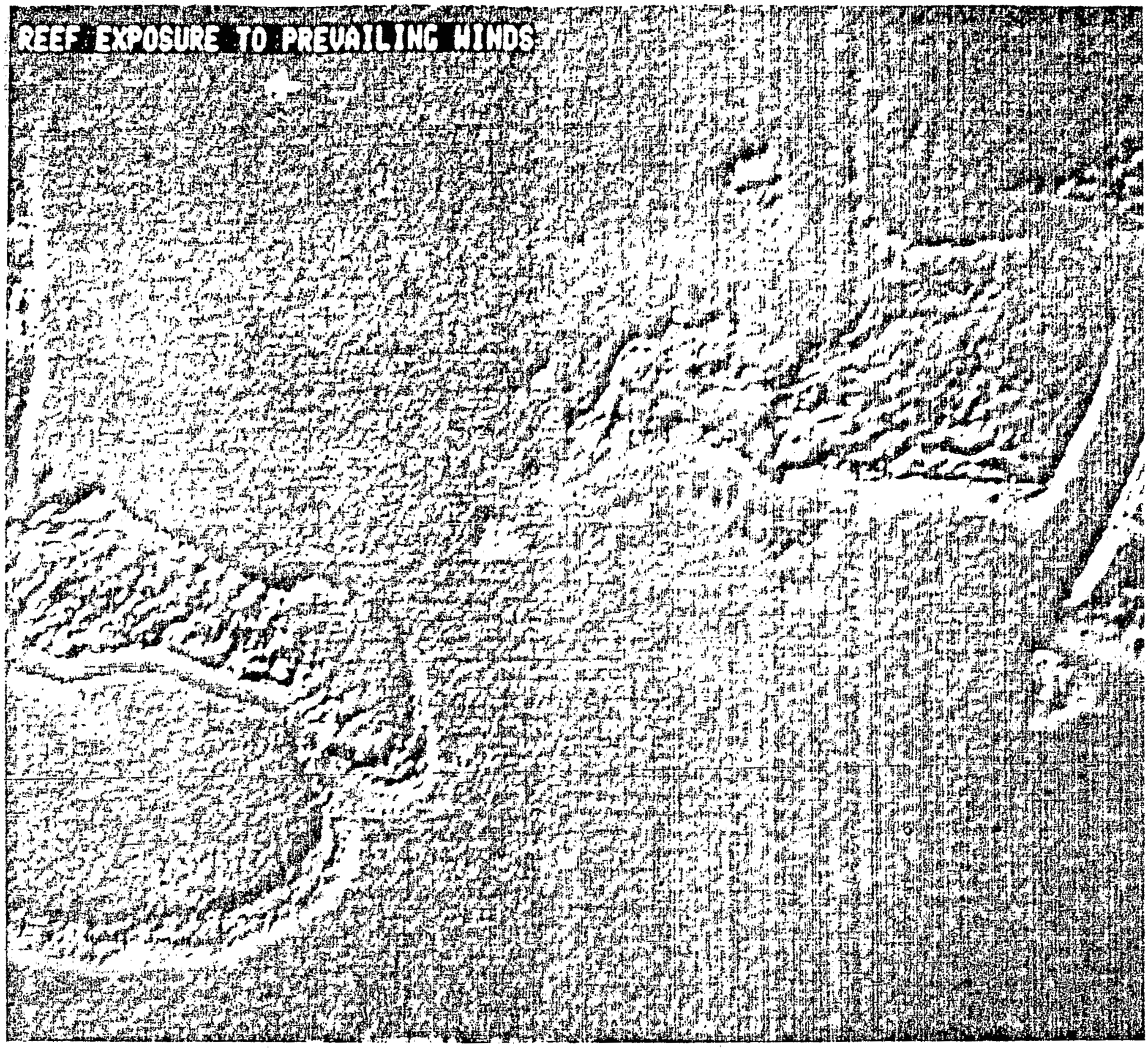


Plate 3: Landsat MSS reef exposure image of (from left to right) Hook, Hardy and Black Reefs, Great Barrier Reef.

column. The depth of light penetration also decreases with increasing turbidity, so signals due to depth and to turbidity need to be resolved.

Reef Cover

A basic goal for research is to both understand and explain the abundance and distribution of reef cover types in time and space. With the availability of LANDSAT data in 1972 (originally called ERTS-1 data), the speed and sophistication of taking an inventory of reef covers has increased significantly. Methods of analysis range from visually interpreted maps (Figure 1 and Plate 5) to advanced computer interpretations.

Variations in light reflected from a submerged reef surface can be collected, interpreted and utilized for a number of different mapping purposes. This is possible because radiance data collected by sensors are converted into digital image data and computer classified into a number of statistical classes (Plate 6). It is the task of interpreters to describe the classes in terms which are meaningful to their discipline. The definition of 'meaningful' is a function of the problem being considered. This flexibility in mapping class definition and mapping is demonstrated in an interpretation of the Cairns section of the Great Barrier Reef Marine Park where maps for geomorphological, sedimentological and biological purposes were created

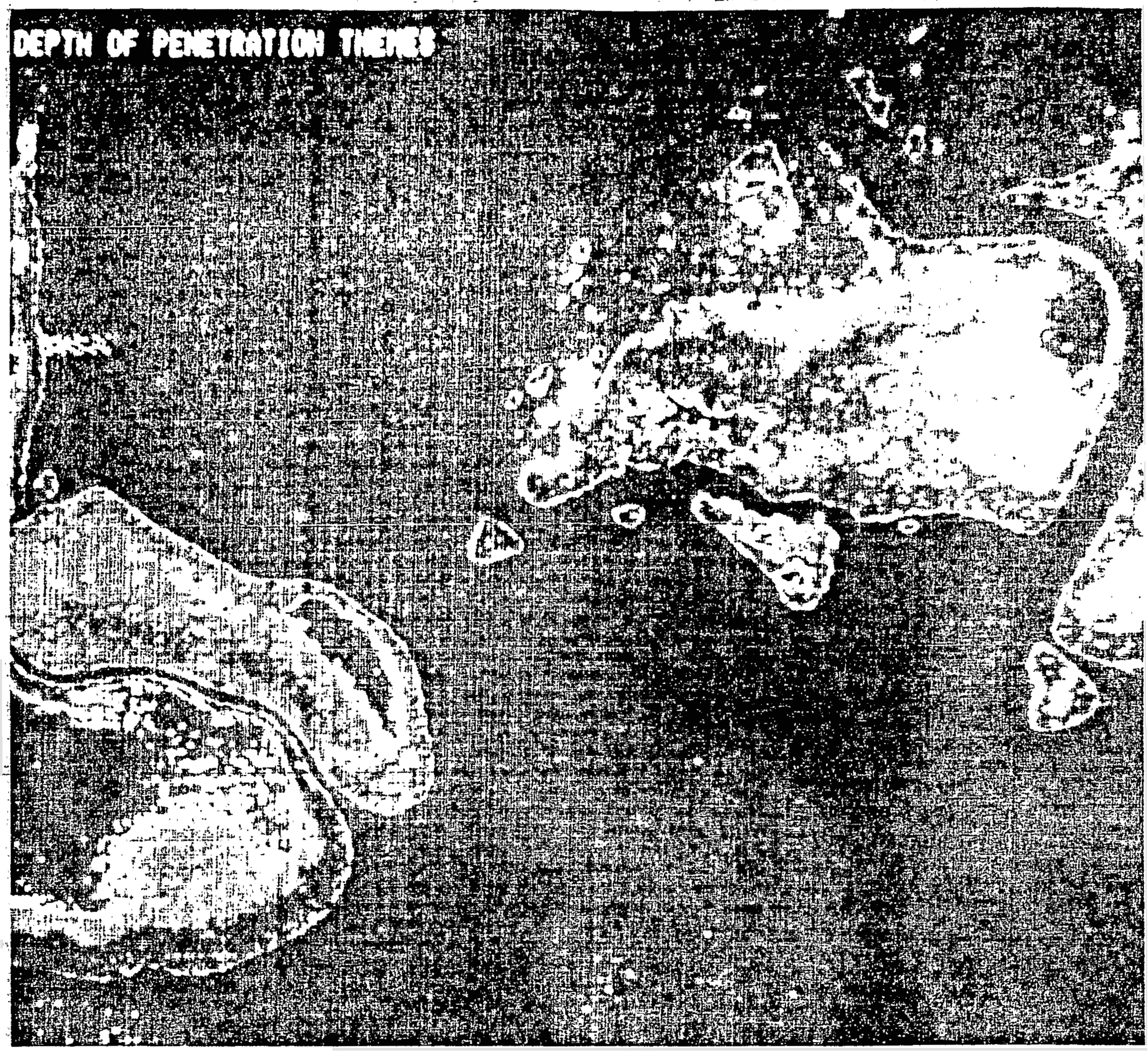


Plate 4: Landsat MSS depth of penetration image of (from left to right) Hook, Hardy and Black Reefs, Great Barrier Reef. The deepest zone (Band 4) from 5 to 15 metres is mapped in yellow while water depths of 50 centimetres to 5 metres are mapped in red.

from single LANDSAT reef images (Jupp *et al.*, 1985a). Studies are currently determining the extent to which LANDSAT mapped classes cross-compare with reef cover classes on the ground (e.g. Kuchler *et al.*, 1986b). So far, the classes cross-compare 85% with reef zones; 82% with reef features; and 64% with reef feature components (Kuchler, 1985; 1986a). The results show that LANDSAT data can be used as a surrogate source of broad scale ground information.

Large scale[5] remotely sensed digital data are also being used to map reef covers. For coral reefs in the Red Sea, digitized aerial photographic data are being used to make periodical surveys of seasonal change (Maniere and Jaubert, 1985), while in New Caledonia, simulated SPOT satellite images (Plate 7) are being used to map possible trochus shell (*Trochus niloticus*) habitats on offshore reefs (Bour *et al.*, 1985).

The higher spatial resolution of a SPOT image (Plate 7) nears that of a high altitude aerial photograph. Such resolution could be used to map the devastating effects that crown of thorns starfish (*Acanthaster planci*) are having on some reefs of the Great Barrier Reef.

Vegetation

Studies are often conducted to provide reef vegetation cover maps either for management inventories, research

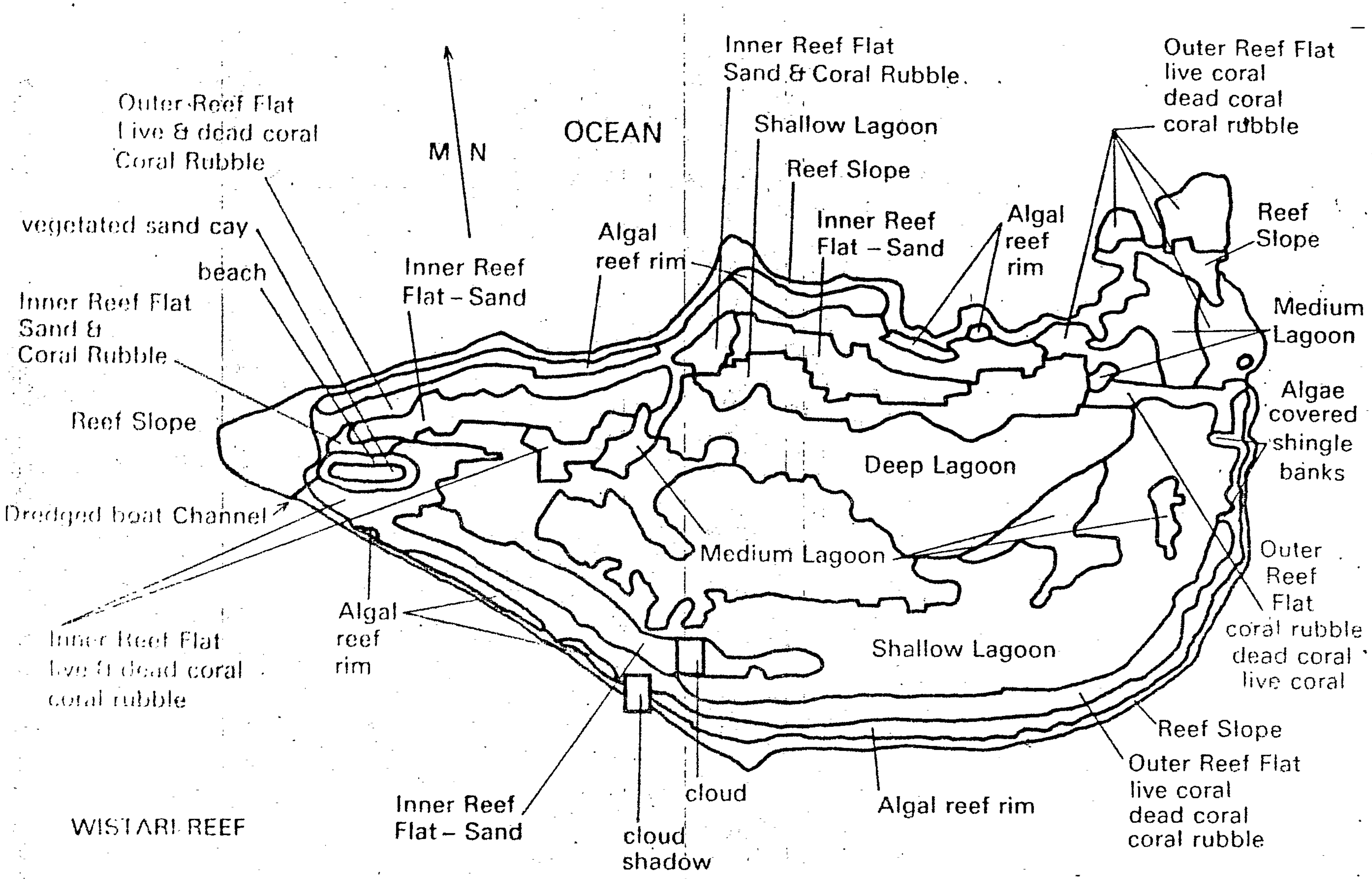
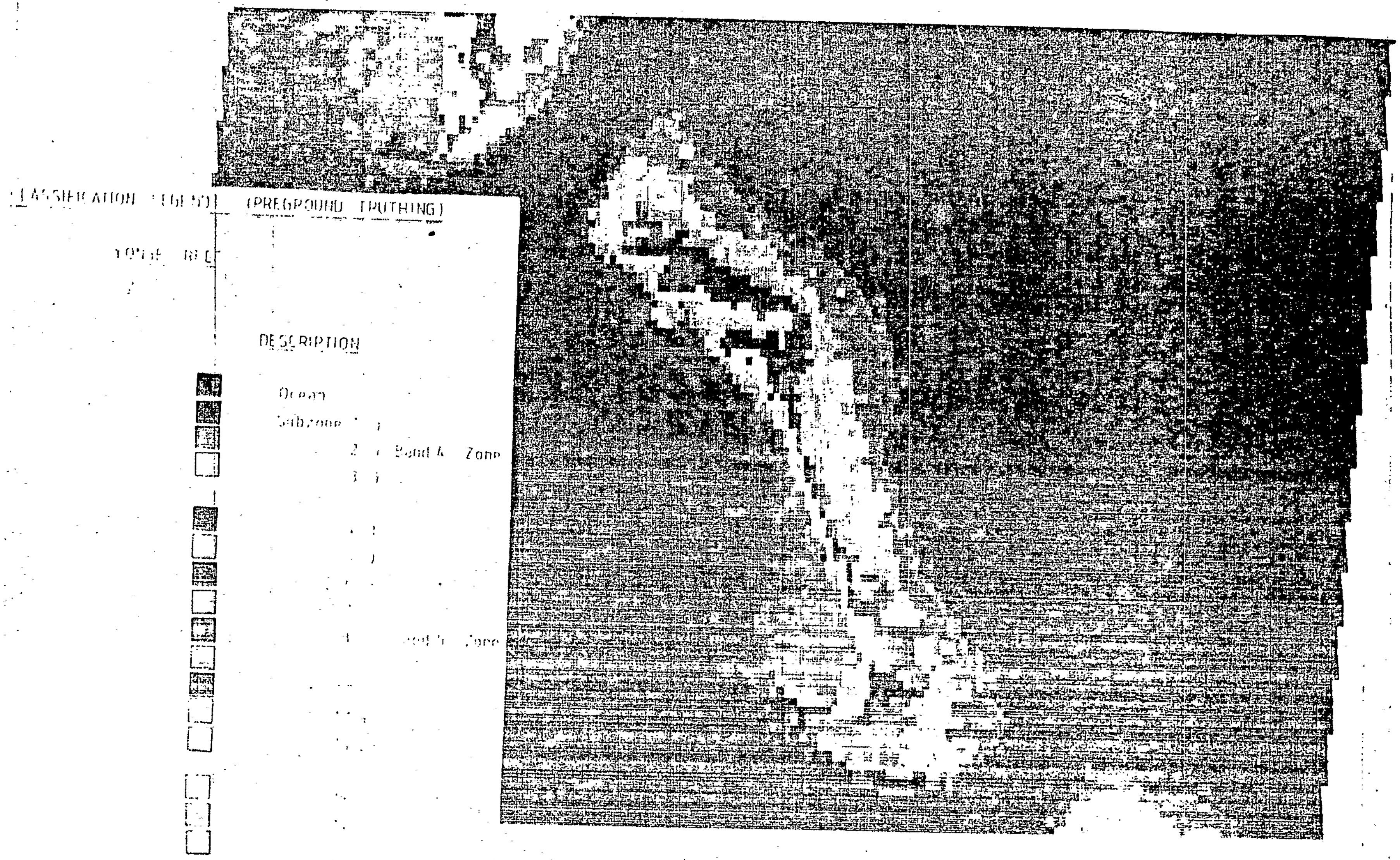


Figure 1: A visually interpreted map of reef zones on Heron Island reef. Map constructed from Plate 6.

Plate 5: Landsat MSS image of Heron Island Reef, Great Barrier Reef, recorded on 12.3.73. The algal covered reef rim which delineates the reef perimeter is mapped in medium red and is highly reflective in the infra-red wavelengths.The terrestrial vegetation of the coral cay is mapped in bright red at the centre left of the photo.



YONGE REEF (PRELIMINARY CLASSIFIED IMAGE) 1.30 000

Plate 6: Computer created reef cover classes on Yonge Reef, Great Barrier Reef. It is the task of interpreters to describe the classes in terms which are meaningful to their discipline.

Plate 7: Simulated SPOT satellite image of Tetembia Reef, New Caledonia.

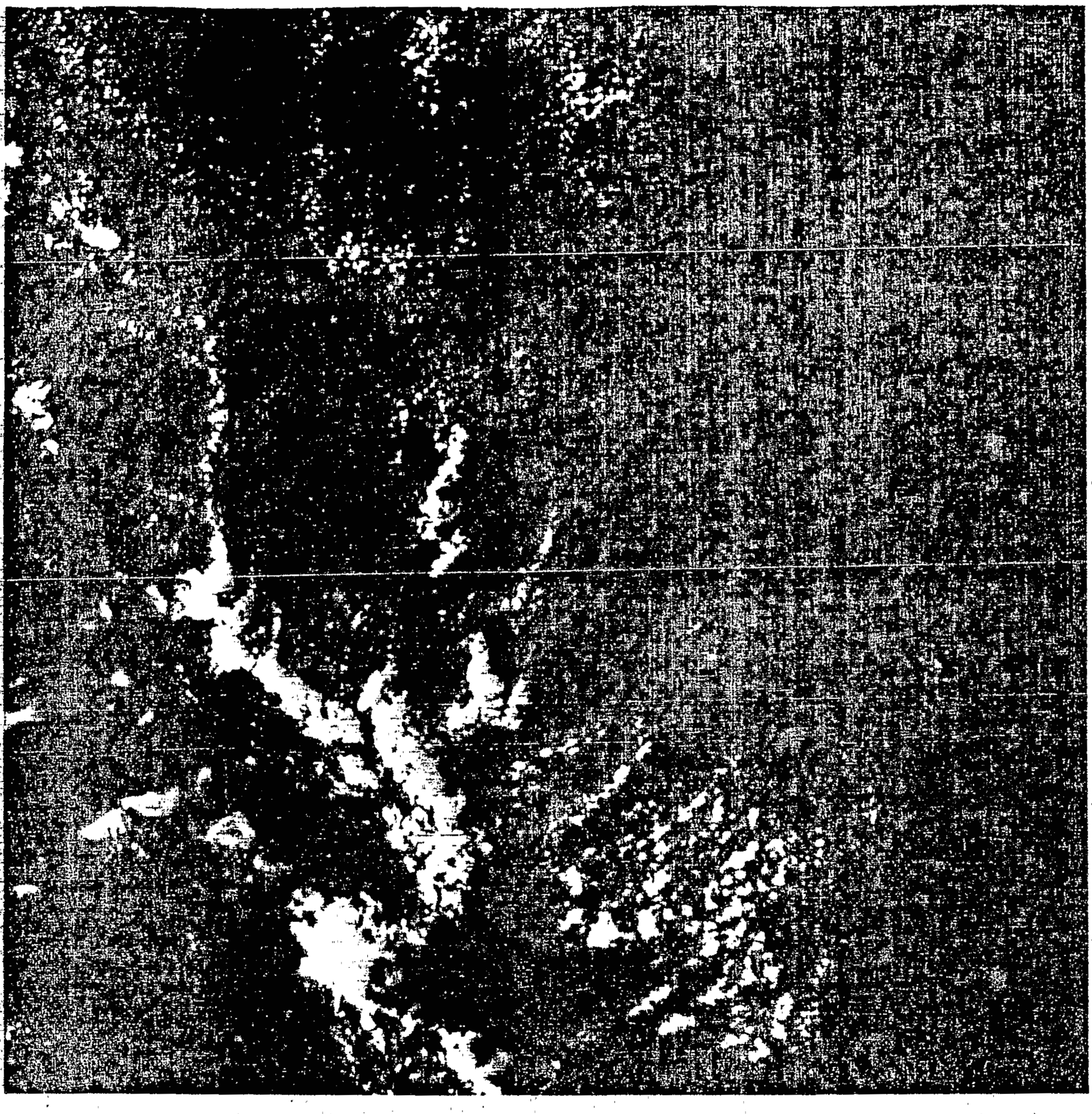


Plate 8: Landsat MSS image of 30.12.72 showing high concentrations of a suspended material (circular feature in centre of image) which is thought to be a Trichodesmium bloom.

projects or environmental impact assessments. Conventional field mapping takes weeks to produce such maps but with computer processing of remotely sensed data it can take only a few hours.

Maps showing the dispersion of vegetated coral cays and algal vegetation on shallow reef flats can be produced from LANDSAT data (Plate 5). Digitized aerial photographic data, LANDSAT TM or SPOT satellite data can be used to map vegetation diversity and human or natural interferences with vegetation cover.

Micro-studies

Coral calcification and accretion studies are now employing remote sensing technology. Coral cross sections are digitized, and growth bands within the resulting images are classified, contoured and measured using image processing techniques.

Remote sensing is providing another mostly broader view of the coral spawning phenomena. The dynamics of coral spawn dispersal and settlement are being examined using a multistage remote sensing approach involving sensors aboard boats, aircrafts and satellites. The research aims to determine the spectral reflectance characteristics of coral spawn so that remote sensing may develop into an operational monitoring tool for coral reef reproduction.

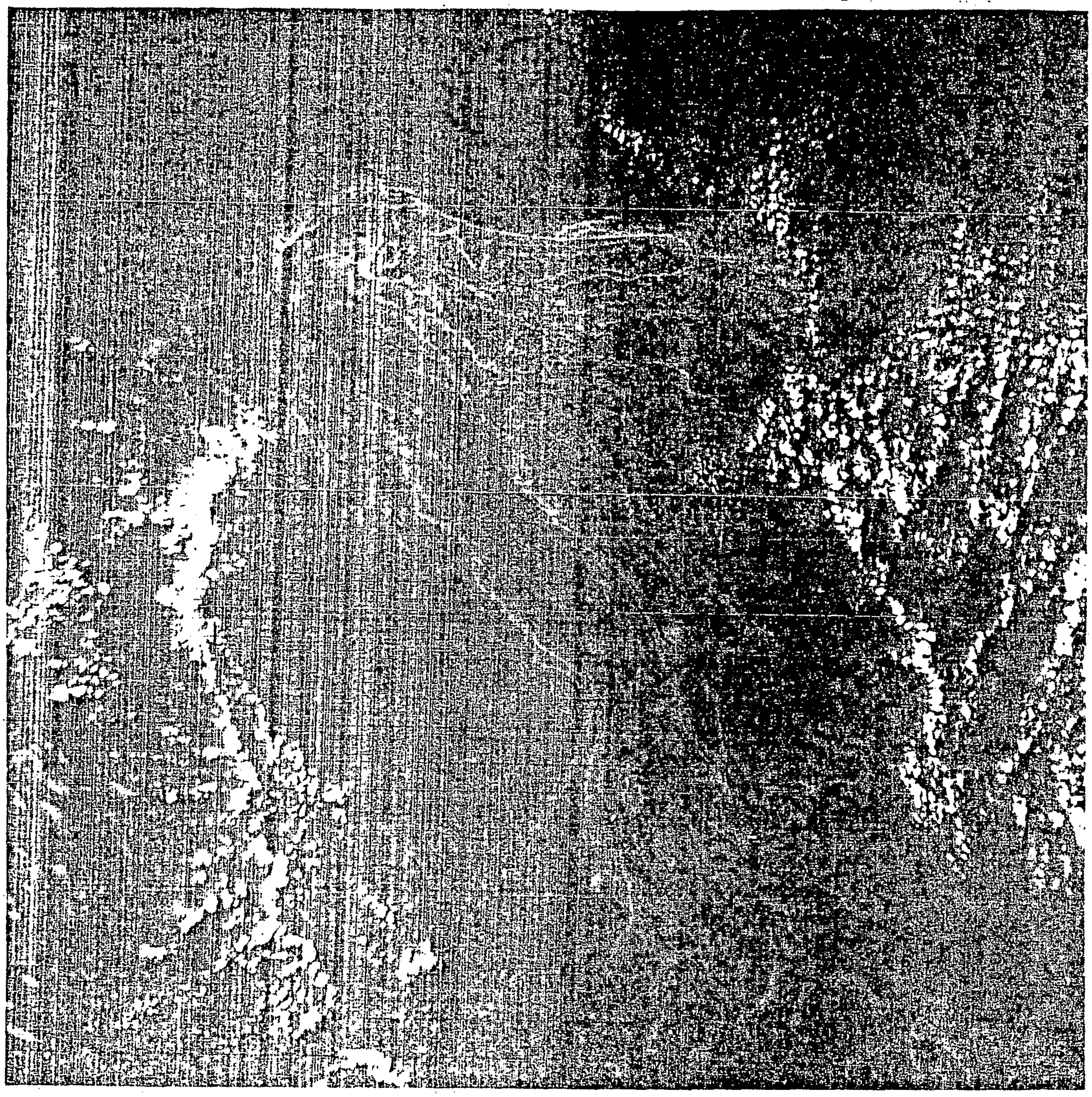


Plate 9: Photographic image taken on 29.11.83 aboard the Space Shuttle during STS-9 mission.

A Broader Look

Since coral reefs are a small subsystem coupled to a much larger oceanic system, they are often studied in this context. Remotely sensed data have been used to study the oceans for many years. Typically, the studies are at synoptic scales because oceanic processes interact over wide ranges of space and time.

Ocean colour studies on the Great Barrier Reef have concentrated on utilizing back scattered radiation in the visible part of the spectrum. Nimbus-7 Coastal Zone Color Scanner data have been used to conduct synoptic surveys of phytoplankton concentrations; to study mesoscale circulation structures; and, to map eddies and wakes (Wolanski *et al.*, 1984; 1986). Other investigations of ocean colour have utilized LANDSAT data to view sediment plumes and to monitor high concentrations of suspended material such as the suspected *Trichodesmium* bloom shown in Plate 8. Remotely sensed information on such blooms has been plentiful since many recordings have been made from the LANDSAT satellite, from a NOAA satellite and the space shuttle (Plate 9).

Conclusion

Interpreting remotely sensed coral reef data is by no means an automatic process. Rather it involves unravelling the spectral and spatial relationships within the data. Researchers are presently focusing their efforts on the collection and analysis of reflected surface radiation from reef cover types. Such emissions will provide the trained interpreter with a vast amount of information about the spectral composition of a coral reef. This knowledge coupled with the new generation of sensors optimized for oceanographic applications, will mean that coral reef and oceanic studies will adopt newer, more precise, and more extensive uses of remote sensing technology.

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Footnotes

1. Deriving information from measurements made at a distance from the object.
2. The SPOT satellite is a high resolution (10 metres) data collection system, from which data will be available in 1986.
3. From here on referred to as LANDSAT. See Colwell, 1983 for a full description of the LANDSAT MSS system.
4. A natural ecological community.
5. Small area, large detail.

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