REMOTE SENSING BASED SURVEYS OF THE THE GREAT BARRIER REEF OF AUSTRALIA

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ABSTRACT

The Great Barrier Reef (GBR) is the largest and most complex Marine Park in the world. Maintaining a correct balance between its protection and preservation on the one hand and the reasonable utilisation of its resources on the other is a challenge in planning. The decisions to be made require a thorough understanding of the Reef and its environment. This paper describes how enhanced satellite images registered to a geographical co-ordinate system are being used as a primary source of information in the zoning and management of the Great Barrier Reef Marine Park.

BACKGROUND

Situated along the north-eastern coast of Australia the Great Barrier Reef extends 2000 kilometers from north to south and covers an area of approximately 348,700 KM^2. The Reef is not a continuous barrier but a broken maze of some 2500 individual coral reefs and 71 cays, ranging in size from less than one hectare to more than 100 square kilometers and in shape from flat platform reefs to elongate ribbon reefs. (viz. fig 1). It forms the world's largest and most complex expanse of living coral reefs, encompassing many unique forms of marine life.

The Australian Federal Government and the State Government of Queensland co-ordinate the resource management of the GBR Marine Park. This is achieved through a Ministerial Council representing both governments, a formal enactment known as The Great Barrier Reef Marine Park Act 1975 and the operations of the Great Barrier Reef Marine Park Authority.

The Great Barrier Reef Marine Park Authority (GBRMPA) is the agency responsible for recommending declarations of sections of the GBR Marine Park and for developing zoning plans and regulations which form the basis for multiple use resource management of the region. Faced with the need to rapidly acquire information relevant to these objectives, the GBRMPA looked to remote sensing and satellite imagery in particular as a possible solution.

The potential for using Landsat data interpretation for the analysis of reef and shallow sea conditions had been indicated in initial investigations by Smith et al, 1975. In consequence, the Authority approached the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Water and Land Resources (WLR) to carry out a research project to further investigate the application of Landsat imagery and more recently Coastal Zone Colour Scanner (CZCS) imagery to the pressing problems of Reef management.

BRIAN PROJECT

In response to the request from the GBRMPA and in co-operation with the Australian Survey Office (ASO), James Cook University and with financial support from the Australian Marine Sciences and Technologies Advisory Council (AMSTAC), the Division of Water and Land Resources developed the BRIAN (Barrier Reef Image ANalysis) methodology and computer system. (Jupp et al, 1983A)

The BRIAN package is a mini computer based interactive system which has been developed as a means of interpreting large amounts of geographical information quickly and economically. Detailed information of specific sites can be extended to other areas by means of computer classification. This facility is particularly relevant to the management of the Reef where the system is being used as a method for small scale reef inventory and environmental monitoring. (Jupp et al, 1983B)

The BRIAN software is written in standard Fortran and was developed on the Divisions HP 1000/45 mini computer. It may be accessed through a program menu structure or else individual program modules can be operated by direct command. The interactive nature of the package combined with detailed program documentation lends the system to a bureau type facility. The portability of the software has been demonstrated by its transfer to a PRIME mini computer at the ASO, with only minor changes to accommodate for the different operating systems being necessary.

RECTIFICATION OF IMAGERY

A very important pre-requisite of all enhanced Landsat images produced for the Marine Park Authority is that the images be rectified and registered to a geographical co-ordinate system, in this case the Australian Map Grid. The accuracy of the rectification for each image depends on the number and distribution of accurate ground control points available.

The rectification of Landsat satellite imagery and registration of the data with cartographic bases has been the subject of considerable interest and a number of sophisticated image rectification systems have been developed (Van Wie and Stein 1976, Strome et al 1978, Orth et al 1978 and Grebowsky 1979).

From the work done on this particular project it has been shown that Landsat images can be geometrically rectified so that they satisfy the stringent National Map Accuracy Standard for 1:250,000. (Jupp et al 1982A) This is, ... 90% of good independently chosen ground control points must fall within 0.5mm of their known grid reference position on the rectified image.

For Landsat data this means a residual root mean square (RMS) error of about 64 metres. A number of authors have claimed that Landsat data could be rectified to 1:100,000 standards, but it is doubtful if this could be achieved considering the stringent Australian Map Standards.

With a sufficient number of well distributed accurate ground control points, RMS errors of about 50 metres have been consistently achieved. It should be pointed out that the accuracy quoted here refers to the error between the grid coordinates predicted by a model for a given pixel and the grid co-ordinates of the corresponding point on a good base map. This is not the same as the accuracy of a photographic or inkjet product, which may have distortions due to the method of production.

A nominally rectified image is one in which the main satellite orbit and sensor effects and distortions have been removed (Thomas 1975). For many applications, particularly where the spectral information is of major interest, this is sufficient. If, however, the image is to be accurately registered to a base map, the remaining distortions due to instantaneous satellite orbit and attitude variations have to be modelled using ground control.

The rectification package developed at WLR has three basic steps which can be summarised as follows:

1) Firstly, the co-ordinates of points which have been digitized from existing topographic or photomaps are converted to a local co-ordinate system, with the centre of the scene becoming the origin and the longitude of the nominal scene centre used as the meridian for a transverse mercator projection. This ensures there is minimum convergence of meridians and also enables easy conversion between Landsat and standard geographical co-ordinate systems.

2) Assuming an affine relationship between the satellite and ground co-ordinate systems, any ground control points (GCPs) which have been misidentified or incorrectly scaled are identified and can be corrected or deleted from the points file.

3) Finally, a general image to map transformation based on the satellite model which, due to significant attitude variations in the satellite orbit, may be a higher order transformation than affine, is then computed and the original image resampled at the plot stage to fit the map projection.

In the registration process emphasis is placed on removing or not fitting terms in the models which cannot be supported by the data. (Jupp et al 1982A) Although satellite orbital and attitude parameters may vary over a scene, results have shown that unless that variation is significant relative to both the random error in the GCPs and their spatial distribution, a lower order model should be used. Not surprisingly, affine and bilinear models seem to provide the most stable extrapolations.

A measure of sufficiency of control in an area is also available as a by-product of the rectification process in the form of a predictive error image (Jupp et al 1982A). In this image, the predictive error based on a quadratic model may be added as a channel to the image and subsequently plotted as a theme overlay. This has a dual purpose, firstly it allows the user of a rectified image to quickly see the varying accuracy of the map being used. As ground control is still sparse on the Reef the reliability of each image obviously deteriorates away from control. As a result, the predictive error image can be used to determine where further control could be most effectively located.

IMAGE ENHANCEMENTS

There are basically four enhanced Landsat products being produced by the ASO on a regular basis for the GBRMPA and other Federal organisations. To date the areas which have been mapped are the Cairns Section and Far Northern Reefs. The remaining two areas, namely the Southern and Central Sections are programmed for completion in December 1984 (viz fig. 1). All the images have been finally or partially rectified depending on the availability of existing control. It is intended to map the entire GBR to 1:250,000

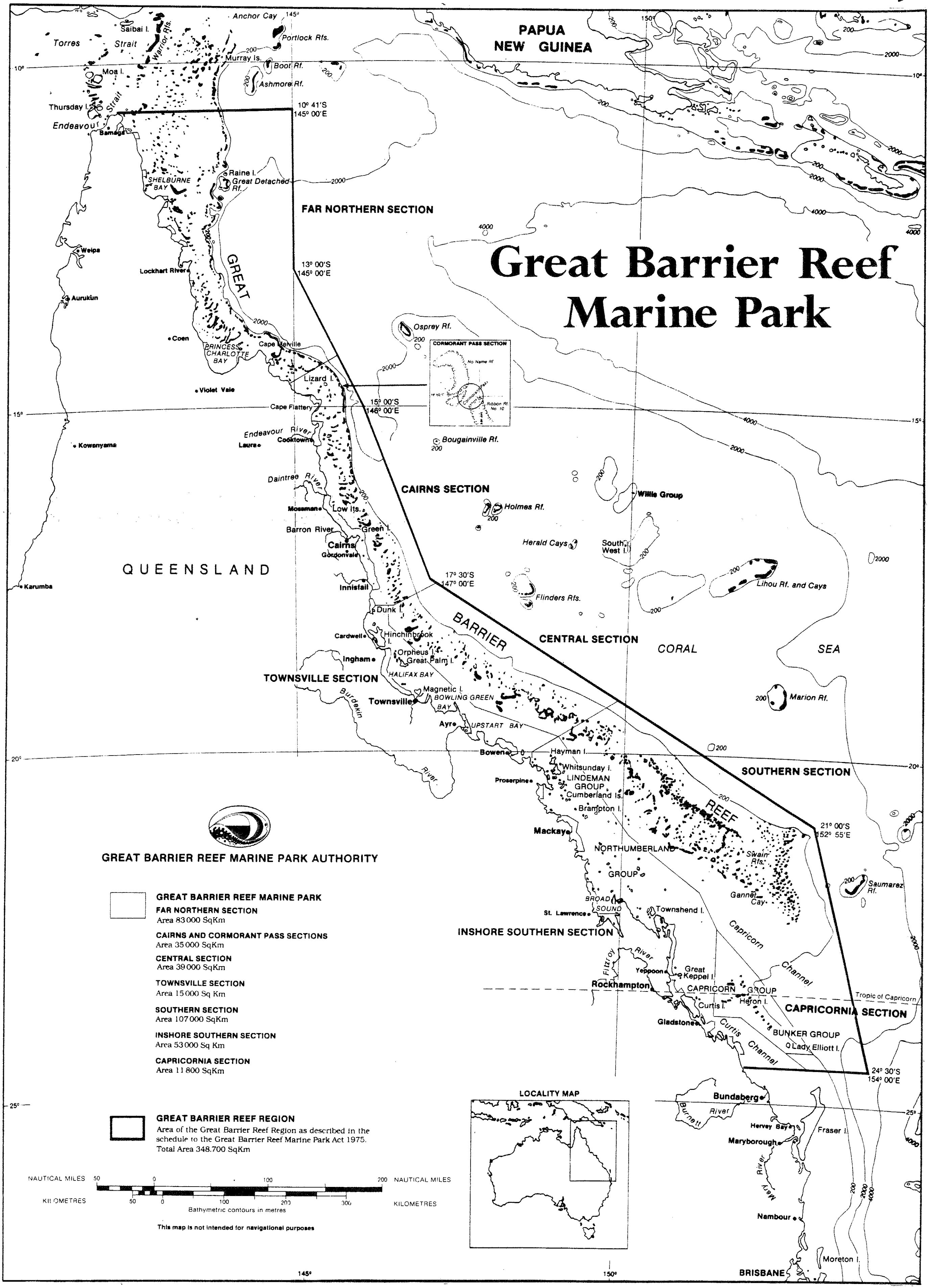

Fig. 1. The Far Northern and Cairns Sections have been partially rectified using existing group control digitised from suitable maps. The Central and Southern Sections are programmed for completion by the end of 1984.

planimetric accuracy and to this end the ASO and other State and Federal mapping organisations are continuing with a program of extending the coverage of large scale photomapping over selected areas of the Reef. This large scale mapping will be used as a basis for selecting GCPs as well as providing detailed information to the Marine Park Authority to assist in management and research on the Reef.

RECTIFIED RAW DATA IMAGE

As previously described, a rectified image is one in which the satellite orbital and optical distortions have been removed and the resultant image registered to a map base, in this case the AMG. In the basic rectified image a linear stretch is applied to enhance the reef detail along with a median filtering algorithm to remove any drop outs. The final product is annotated on a flat bed plotter using standard plot files, has a grid and graticule added and is finally laminated to produce a more stable and robust document. There are two final plot scales 1:250,000 and 1:100,000.

DEPTH OF PENETRATION IMAGE

The attenuation of light by water is strongly wavelength dependent (Moore, 1980, Jupp et al, 1982B). Band 4 in the 400-500 nm region penetrates to the greatest depth, band 5 in the 600-700 nm range less so, band 6 in the 700-800 nm is rapidly attenuated and band 7 in the 800-1100 nm region of the near infrared is fully absorbed by water.

The depth of penetration in this case means that depth which can register a signal which is distinct above the background noise level in the satellite data. This depends on both the water properties at the time of the overpass and also the atmospheric conditions. In oceanic water (Jerlov, 1976) and where there is little haze, the depth of penetration for Landsat bands 4, 5, 6 and 7 are about 15-20 metres, 4-5 metres, 0.5 metres and no penetration respectively. In offshore areas of the GBR these conditions can be closely approached, although when water becomes more turbid and atmospheric haze increases the penetration of the four bands is reduced.

The fact that the attenuation of light by water is strongly wavelength dependent can be employed to plot depth of penetration images. The generation of these images can be summarised as follows:

1) A training set is taken over deep water, that is one where there is no resolvable bottom signal in any band. The 1% and 99% levels of the deep water histogram are used to define lower and upper limits such that all pixels with values between the limits are effectively deep water. This set of bounds may be used to divide the water covered areas of an appropriately pre-processed image into three depth zones. (viz figure 2)

   - Band 4 zone - bands 5, 6, 7 within the deep water limits but band 4 above, indicating it is recording a depth signal. This zone may be approximated to water depth between about 15 and 5 metres when the water is clear.

   - Band 5 zone - bands 6 and 7 within the deep water limits but band 5 above the upper limit. This zone may be approximately associated with clear water between 5 metres and 0.5 metres.

   - Band 6 zone - band 7 within the deep water limits but band 6 above the limit. This zone is probably less than 0.5 metres, but it is a

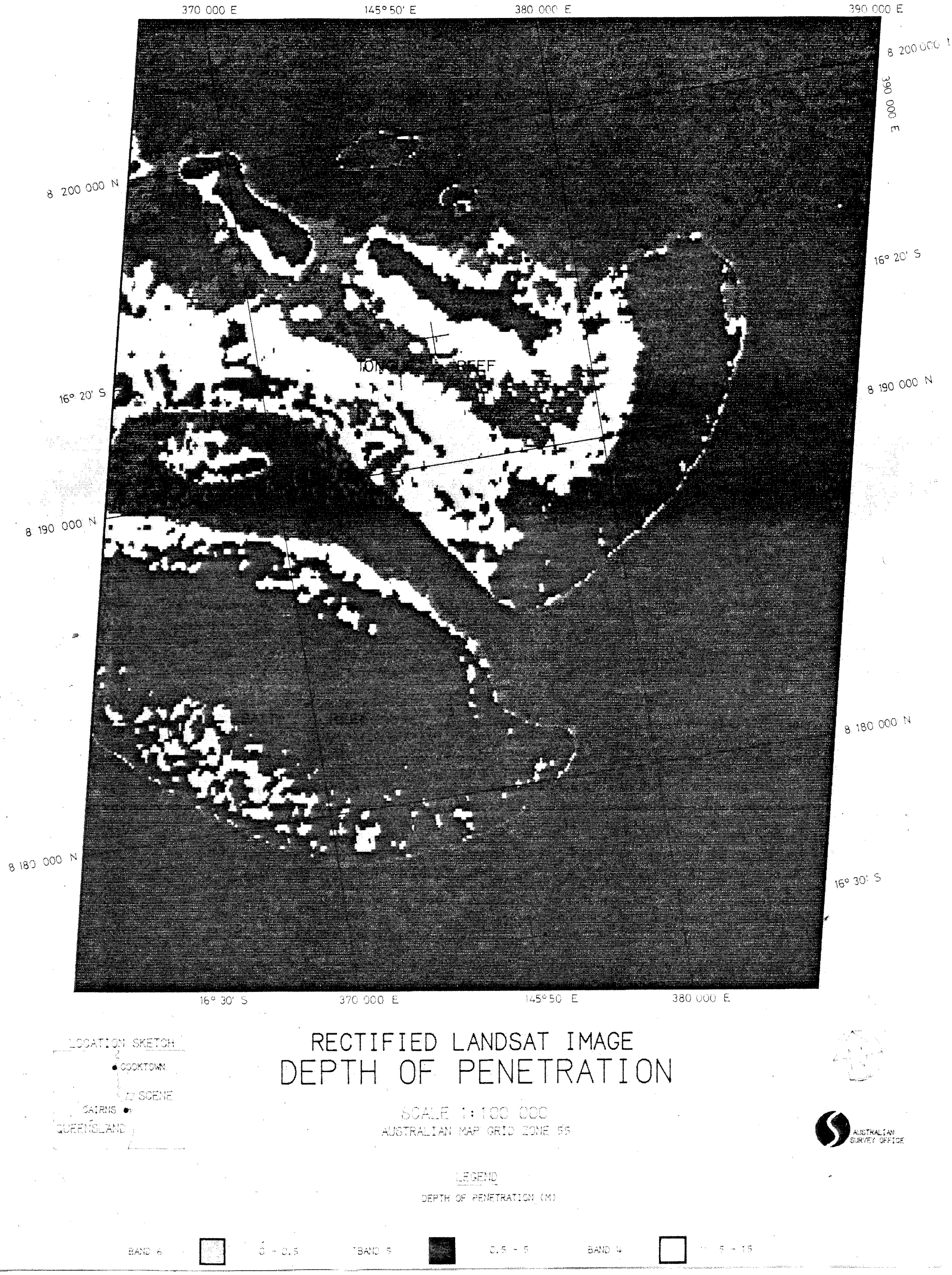

Fig. 2. Batt and Tongue Reefs, Cairns Section, Great Barrier Reef Marine Park. Depth-of-penetration image showing bathymetry or water depth. Mid-grey denotes depths of 0.5-5m, white denotes depths of between 5 and 20m, while black denotes either deep water or exposed areas of the reef.

difficult zone to map on reefs as the variations in substrate greatly influence the signal.

The use of band 7 limits in all cases ensures that the depth zones are in fact water covered areas of the image. For the results to be satisfactory it is necessary to carry out considerable spatial pre-processing which includes destriping, despiking, spectral digitizing and double average smoothing. It is also possible to consistently interpolate between band zones to represent intermediate contours.

When ground data is available and registered to the image it becomes possible to set up regression equations between depth and Landsat band 4 in the band 4 zone and between Landsat bands 4 and 5 in the band 5 zone. This development is being evaluated at present as a specifiable standard product and will be reported on at a later date.

The depth of penetration images give an indication of the amount of water over a reef at the time of the overpass, and only general corrections may be made for tide height. The great advantage, however, is that this information can be generated very cheaply and quickly without the need for additional information or field visits.

EXPOSURE IMAGE

If band 4 is spatially filtered to remove pixel to pixel noise and small variations due to different substrate, the remaining signal is dominated by water depth variations in clear water. In clear, shallow water, the variations in substrate are significant but not as great as depth effects.

The relation between signal and depth can be represented as (Doak et al, 1980).

$$Li = Lwi + (Lbi - Lwi) * Exp(-2K*Z)$$

where,

Li is (band 4) radiance above water of depth Z,
Lwi is the deep water signal (which depends on sea colour)
Lbi is the (wet) radiance of the substrate with no water cover
Z is depth
K is the water attention coefficient.

That is, the Landsat band 4 signal is directly related to depth and can be regarded as a model for sea bed topography down to about 15 metres. The slope and aspect of this topographic model may be computed and used to compute the exposure, which is defined as

$$E = -\left(p \frac{\partial L4}{x} + q \frac{\partial L4}{y}\right)$$

which, for constant substrate type,

$$= 2K\,(L4 - LW4) * \left(p\frac{\partial z}{\partial x} + q\frac{\partial z}{\partial y}\right)$$

p and q are direction cosines for the direction of the prevailing winds, so that (p,q) = (0.707, - 0.707) will give exposure to the south easterly weather. (viz figure 3).

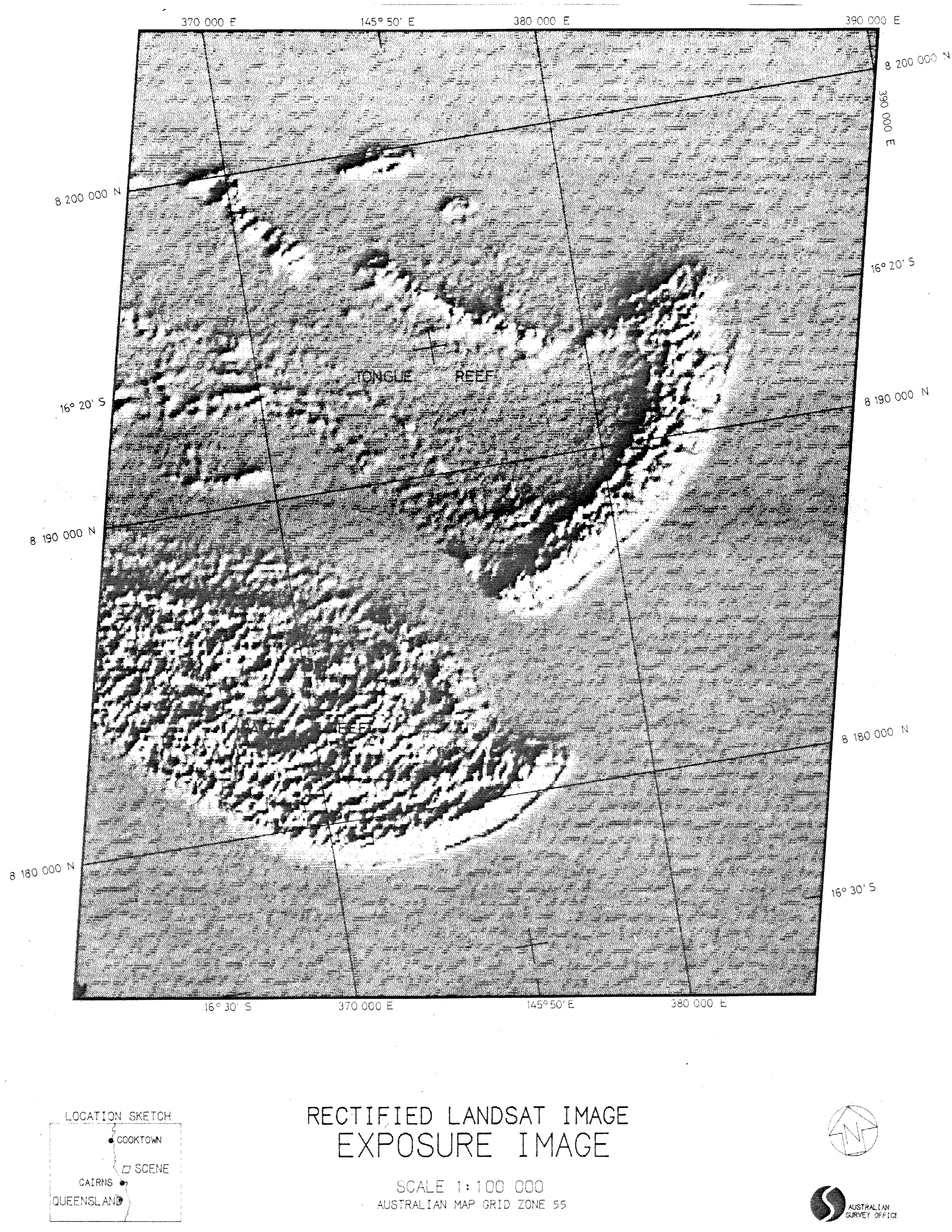

Fig. 3. This image of the same area of the reef depicts the exposure-to-prevailing-wind image as indicated by the slope and aspect of the underwater topography. The prevailing wind is from the south-east. The most exposed areas, those sloping to the south-east, are shown in white, while the darkest areas, those sloping away from the south-east, are the most protected.

The exposure image enhances topographic features on reefs and provides an approximate delineation of exposure to weather of parts of reefs, an environmental factor of great importance for biological survey and mapping.

CLASSIFIED IMAGE

A form of image interpretation which has significant application on the GBR consists of pre-processing the image and using a computer algorithum to identify sets of pixels with similar spectral and textural feature values, called spectral classes. A reduced set of spectral classes, usually 80 to 150, may then be interpreted and labelled in reef cover terms by a reef scientist or manager. The process of image interpretation and classification is fully described in Jupp et al, 1983A and Jupp et al, 1983B.

The computer classified image may be interpreted by interactive labelling. This involves using the mean image in which each pixel is replaced by the mean of the class to which it has been allocated, together with a process of spectral/spatial editing. The classified image may be used as the basis for a number of different interpretations for various scientific and management purposes.

The interpreter labelled image consists of the various aggregate classes plotted over the mean image as theme overlays and given a legend in reef cover, water depth or other terms. This flexibility in aggregation and labelling is a considerable advantage as it allows the same basic spectral class set to be labelled in a variety of ways, according to the purpose of the interpretation.

COASTAL ZONE COLOUR SCANNER IMAGERY

Recently, CSIRO, Division of WLR has used the BRIAN system to process CZCS imagery of the GBR. The CZCS instrument aboard the NIMBUS-7 satellite is a large area (1:1,000,000) tool with 820 metre pixels. The whole of the GBR region is covered by two CZCS scenes compared with twenty-two (22) Landsat scenes.

Launched in 1978, the bands recorded cover the visible blue, green and red as well as the rear infra-red and thermal regions of the spectrum. This spectral sensitivity has provided significant definition of GBR water masses and general zonation of productivity over the entire Reef.

It is hoped that this data, together with integrated Landsat data, may give reef managers and scientists an indication of the broad area productivity of the GBR. On a global scale, corals account for more than three times the primary productivity of phytoplankton in upwelling areas.

OUTPUT DEVICE

The rectification and the results of image interpretation and enhancement need to be produced as a final hard-copy quickly, cheaply and retaining as much of the accuracy achieved during the machine processing as practicable. For this project the output device used has been an Applicon Ink-jet Plotter installed at WLR (Cook, 1982, Jupp et al, 1982C). The plotter consists of jets which direct inks of the three primary subtractive colours magenta, cyan and yellow onto a rotating drum. An image is plotted in a single pass as the ink nozzels are moved from one end of the drum to the other.

The raster basis for the plotter makes it relatively straightforward to incorporate the rectification process into the image writing program and therefore avoid costly computer based image resampling. Writing images at various scales is an easy matter and involves no more machine storage than the original data set. Pixels may be duplicated or omitted along scanlines on the ink-jet image to produce the required scale.

Compared with most alternative means of colour hard copy the ink-jet image has lower resolution, but considerable advantages in terms of cost and convenience for the presentation of results. Best results are obtained for Landsat images at scales of 1:50,000 to 1:250,000 where the plotter pixels closely represent the data pixels. At smaller scales photographic products are more suitable. For cheap and rapid production of hard copy, which is suitable for use in the field, laminated ink-jet images have proven to be a very satisfactory product.

APPLICATIONS

The GBRMPA has already used the rectified and partially rectified images to improve accuracies in mapping the location and orientation of some reefs. The depth of penetration and exposure images, combined with ancillary data derived from local knowledge and navigational charts provide a sound basis for developing reef cover classifications and extending the information over considerable areas. The resultant classified product provides information about reef and shallow benthic conditions of considerable benefit to planning, which could not be obtained by other means without a heavy commitment of human and other resources. In addition, as the Authority is commited to review sectional zoning and management plans at five yearly intervals, the ability to economically upgrade the information base in relation to a constant classification and to review the physical basis of the initial zoning will be invaluable.

CONCLUSIONS

It has been shown that satellite imagery from Landsat and CZCS can provide a cost effective and timely source of information, to assist in the management of the GBR Marine Park. This information in conjuction with more traditional survey products is providing the basis for a geographic inventory over the entire Reef. It is considered that the techniques which have been successfully applied in the GBR region could be equally applicable to the vast area of broken reefs and islands of Australia's near neighbours in S-E Asia and the Indo-Pacific region.

Apart from the very significant research and software development achieved during this project, the other important aspect is the technology transfer. The BRIAN package has been transfered from WLR to the Australian Survey Office where a mapping program to cover the entire Reef is expected to be completed by December 1984. This transfer of technology into the 'market place' has assured the effective utilisation of the techniques developed during research and is providing a continuing service to the GBRMPA and other Federal departments and authorities. The co-operation displayed during this project has been of mutual benefit to all organisations involved.

BRIAN is far more than a package for shallow water mapping, it can be used for most regional planning purposes where there is a need to collect data over a large area in a cost effective and timely manner.

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