Reef Cover and Zonation Classification System For Use With Remotely Sensed Great Barrier Reef Data

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Great Barrier Reef Marine Park Authority

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REEF COVER AND ZONATION CLASSIFICATION SYSTEM FOR USE WITH REMOTELY SENSED GREAT BARRIER REEF DATA

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SUMMARY

An integral part of any land cover mapping program is the selection of a suitable classification scheme for use at any specified scale, for any designated area, and within the capability of the information gathering techniques being used. Presented in this paper is a classification system which can be used in ground data collection or with aerial and orbital imagery for making surface cover and zonation interpretation maps. The classification system is designed to facilitate rapid and accurate identification, labelling and determination of significance of geomorphological reef features by the image interpreter and ground data collector.

KEYWORDS: reef cover and zonation mapping, classification system, remotely sensed data, Landsat MSS, aerial photography, GBR.

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1. INTRODUCTION

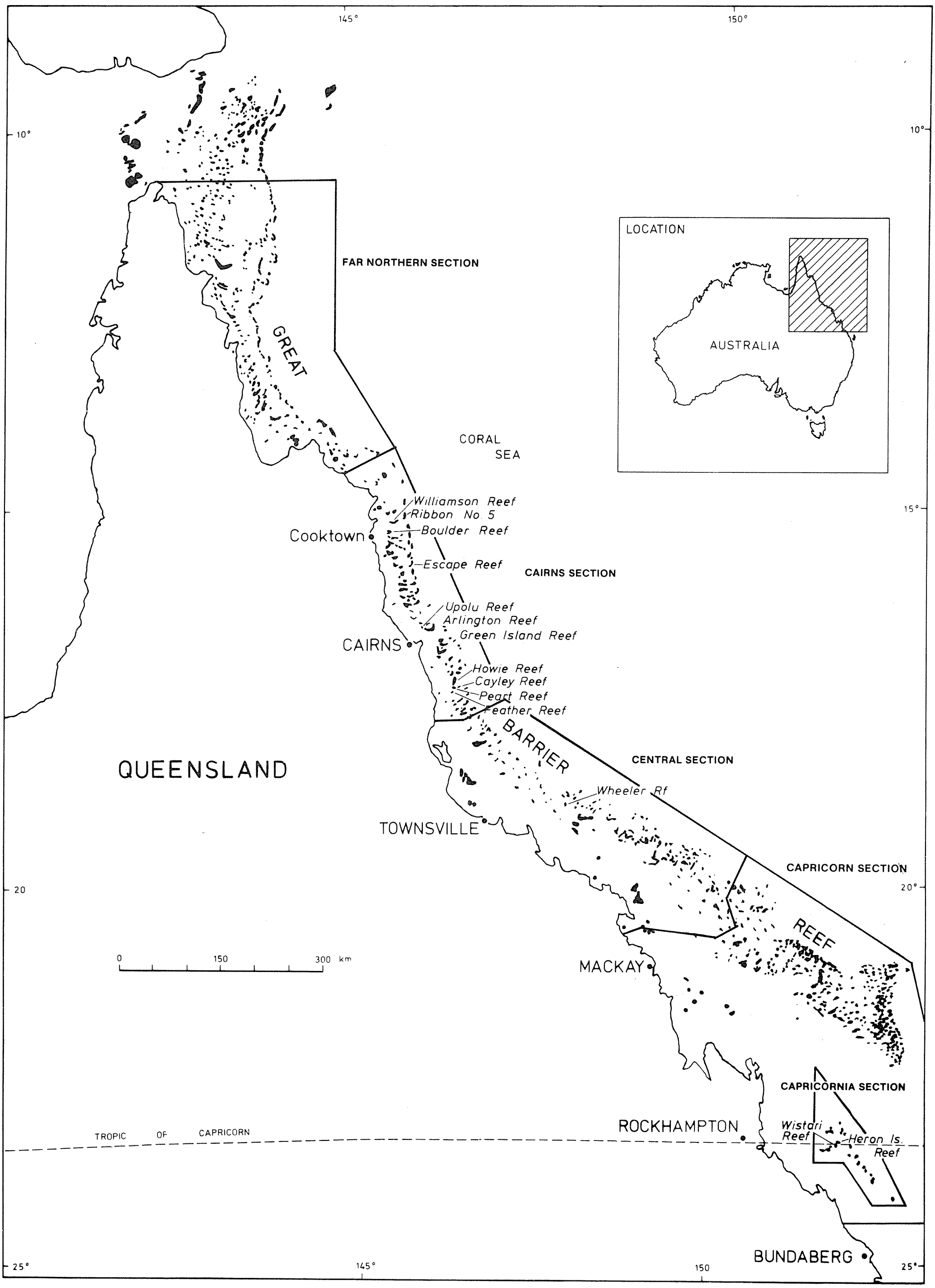
An integral part of any mapping program is the selection of a suitable classification scheme for use at any scale, for any area, and within the capability of the information gathering techniques being used (Anderson, 1971). In this paper, a classification system for reef covers and zonation for use with remotely sensed Great Barrier Reef (GBR) data is presented. It is designed for use with ground data and with aerial and orbital imagery for the labelling and recording of interpreted reef features on coral reefs of the GBR.

This paper is one of a set of three Technical Memoranda (TM) prepared for the Authority, the other two being of secondary importance. One, titled "Reef cover and zonation classification system for use with remotely sensed Great Barrier Reef data: User Guide and Handbook (TM-9)" (Kuchler, 1986b), describes and illustrates the operational use of the system presented here. A model handbook is detailed for easy and efficient user operation of, and recording from, the classification system. In the other paper, titled "Geomorphological nomenclature: reef cover and zonation on the Great Barrier Reef (TM-8)" (Kuchler, 1986a), a nomenclature for reef covers and zonation is detailed. It forms the basis of the classification system presented here.

The nomenclature paper was designed as a secondary document since this paper (TM-7) is the principal reference and therefore has primary relevance to data description and labelling operations.

A nomenclature was required for the classification system because scientists tend to label reef features without the aid of any generally accepted nomenclature, and therefore without consistency (Kuchler, 1986a).

Figure 1. Location of reefs.



Ground data and image interpretation maps of the GBR are required for a major study, the Barrier Reef Inventory ANalysis (BRIAN) project (Jupp et al., 1981a,b; Jupp et al., 1985). BRIAN is evaluating the cost-effectiveness of remote sensing methods for detecting and monitoring geomorphological features on reefs of the GBR. Standardised definitions and labelling of such features is of prime importance because of the need to cross-compare various maps and data sets.

The interpretation of remotely sensed imagery involves the completion of four steps;

- detection of features;
- recognition and identification of features;
- analysis and delineation of patterns;
- and classification of features.

In steps two and four, observed features are identified by interpretation of spatial patterns and 'colour' (or spectral data) and then classified into known categories. This is possible only if the interpreter has a certain knowledge or reference level which may be either of a general nature, such as knowledge of the whole GBR region; or be associated with the interpreter's specific professional knowledge, such as the resolution of the remote sensing system, the scale of data and the user's data needs (Witmer, 1978).

Use of a classification system, then, requires some background knowledge of the specific subject being classified, and is a requirement of the GBR system presented here.

2. CLASSIFICATION PURPOSE

According to Harvey (1969), the many purposes of classification can be grouped into two types; general or 'natural' classification, and specific or 'artificial' classifications. Two classification systems are currently being presented for the GBR, namely the "Reef cover and zonation classification system for use with remotely sensed Great Barrier Reef data" presented here, and the 'Simple entropy classification of surficial cover types on reefs' developed by Radke (1983).

The classification systems are both of the 'artificial' type and have been devised for specific purposes. The two systems differ however, because of the specific and different needs of users, and in the criteria by which reef features are classified into comparable assemblages.

Radke's classification system was developed for geologists requiring a classification based on the distribution and nature of sedimentological facies within the reef complex. Radke (1983) states that 'the classification has a substrate and sedimentological bias but is intended to complement other classifications by superimposition'.

In comparison, the classification system presented here is developed primarily for GBR remote sensing where a classification based on surface reef covers and zonation (as observed both on the ground and through varying marine and atmospheric conditions on aerial and orbital imagery) is required.

Adoption of these classification systems will allow a more clear and efficient communications between GBR scientists. Stoddart (1969a, in Longman, 1981) points out that "what is needed is standardised procedures to ensure comparability of reef studies and the identification of variations in reefs both on local and regional scales..." and Longman (1981) adds; "...through time."

The first step to providing the standardisation is to recognize the user's needs (needs of geologists differ from those of biologists), and then to classify reefs into comparable assemblages according to the parameters which are important. Harvey (1969) states that purpose and classificatory form are inextricably bound up together and the utility of a given system of classification cannot be assessed independently of its purpose.

The classification system presented here (Appendix II) was devised for two principal purposes:

- Firstly to provide an objective and consistent framework for geomorphological information on surface reef covers and zonation which could be derived from remote sensors and field data. This information could then be applied to coral reef resources planning and management throughout the Great Barrier Reef province.

- Secondly to provide a means for comparing and evaluating the various interpretations of aerial, orbital and ground data on the Great Barrier Reef.

3. METHOD

Grigg (1965) states that classification is the grouping of objects into classes on the basis of properties they have in common. The system presented here evolved from generally accepted classification concepts, and from a combination of two approaches to land cover classification.

3.1 Classification concepts

Given the two purposes listed previously, the following concepts were used in designing the classification system:

- The concepts of land cover mapping and its classification, as outlined in Appendix I, should be followed as closely as possible.

- The system should be a utility for recording interpretations of at least, Great Barrier Reef Landsat satellite and high and low altitude airborne imagery and ground data.

- Reef cover mapping can be done at many levels of detail. Image interpretation and ground data indicate that the classification should be designed on a least five levels of detail.

- The classification categories and classes should be expressed in the coral reef nomenclature proposed for adoption by Kuchler (1986a).

- The categories and classes presented should at least include the information sought by the remote sensing of coral reefs project conducted by Jupp et al., (1981a, b) and Kuchler (1984).

- The classification should be open-ended and easy to revise, since this work should be regarded as a focus for constructive criticism which will, with recommendations, evolve after revision into a classification system which will have considered all possibilities for the GBR (cf Ryerson and Gierman, 1975). Recommendations for revision should arise from colleagues after observations on currently unvisited and undocumented reefs.

3.2 Approaches to land cover classification

The first land cover classification approach used to construct the classification system is the image or classification approach. Here a geomorphological study of the available remotely sensed imagery, available ground data, and available GBR literature determines the types of reef zones and covers occurring on the GBR. Each feature is examined individually and some property (or properties) of it is used as the criterion (or criteria) for relating it to other features.

The second approach used is the logical division approach, where the classification system is built on information needed by the potential user (Ryerson and Gierman, 1975). In the classification system a created class is sub-divided into hierarchical levels on the basis of need. In the situation considered here these comprise reef zones and covers. In this deductive process, the entire range of GBR cover types should be considered before classes are created, since this makes the classification applicable to all reefs in the GBR. However, the total applicability to the GBR of the classification system presented here is constrained by research being concentrated on the more accessible reefs, and by the lack of ground and low level aerial data for many reefs (Kuchler, 1986a).

3.3 Listing reef terms

The classification system resulted from a combination of both these inductive and deductive processes. In the inductive process, pilot interpretation studies of the color aerial photographic and orbital multispectral scanner imagery available for Arlington, Green Island, Wheeler, Boulder, Upolu, Wistari, Heron Island and Howie Reefs (Figure 1) resulted in a listing of the reef zones and reef cover classes which occurred.

The pilot studies involved constructing interpretation maps from the color aerial photographic imagery at 1:12 000, 1:25 000 and 1:50 000 scales and interpreting sample sites approximately 79 by 59m in size, on LANDSAT MSS satellite imagery. These sample sites are approximately equivalent to the smallest unit of resolution on a Landsat image (pixel). Then the available ground data, collected mainly by transect methods for Heron Island, Green Island, Escape, Peart, Feather and Cayley Reefs (Figure 1), were examined to see if any additional reef zones and surface covers could be added to the list. The GBR literature survey of reef terms (Kuchler, 1986a) was finally consulted for additional reef zones and reef cover classes.

In the inductive process, however, the entire range of possibilities of reef cover types were not included in this data list. Also excluded were all the possible properties which could be used as criteria in assigning reef covers to classes at the various levels in the classification system. This is because of three factors;

- only a small number of reefs (eight) in relation to the total number of reefs (more than 2 000 individual reefs) (Done, 1982) on the GBR were used in the pilot study;

- the inadequate coverage of the GBR in the literature (Kuchler, 1986a); and,

- the inadequate present coverage of the GBR by low level aerial photography.

The classification system may therefore need to be extended when applied to some of the presently undocumented reefs north of Cooktown on the Queensland coast and some of the Ribbon Reefs (Maxwell, 1968) on the outer barrier of the GBR (Figure 1) because the collection of data from these two regions has been neglected (Kuchler, 1986a).

Consequently, the inductive procedure frequently results in the need to re-examine the use of particular criteria so that the relative importance may be adjusted to the hierarchy created within the classification system (Grigg, 1965).

In the deductive process, information about the type of reef cover class generated in the inductive process and needed by the interpreter of the reef imagery and the collector of field data is added to the list. Thus, the initial list of reef cover classes created in the inductive process is supplemented, in the deductive process, by additional information on all possible occurrences being considered. A final list was then sub-divided as far as possible into hierarchical levels on the basis of the purpose for the classification. Witmer (1978) states that since the US Geological Survey land-use and land-cover classification system is capable of being extended to more finite levels of classification, the inductive and deductive processes meet at the particular level in which the user has the most interest.

4. RESULTS

The classification system is based on a standardised nomenclature (Kuchler, 1986a) and is designed to facilitate rapid, accurate and consistent labelling of geomorphological reef features by the image interpreter and field data collector. A library reference of definitions and illustrations for each feature is provided with the classification system (Appendix IIb). Bigelow (1963) states that the interpreter, in using a classification system for reference, creates memory associations between mapping features and this process will often increase an interpreter's ability for deductive reasoning.

4.1 Classification component

In satisfying the two principal purposes for the classification system a semi-hierarchical five-level classification system was designed (Appendix IIa).

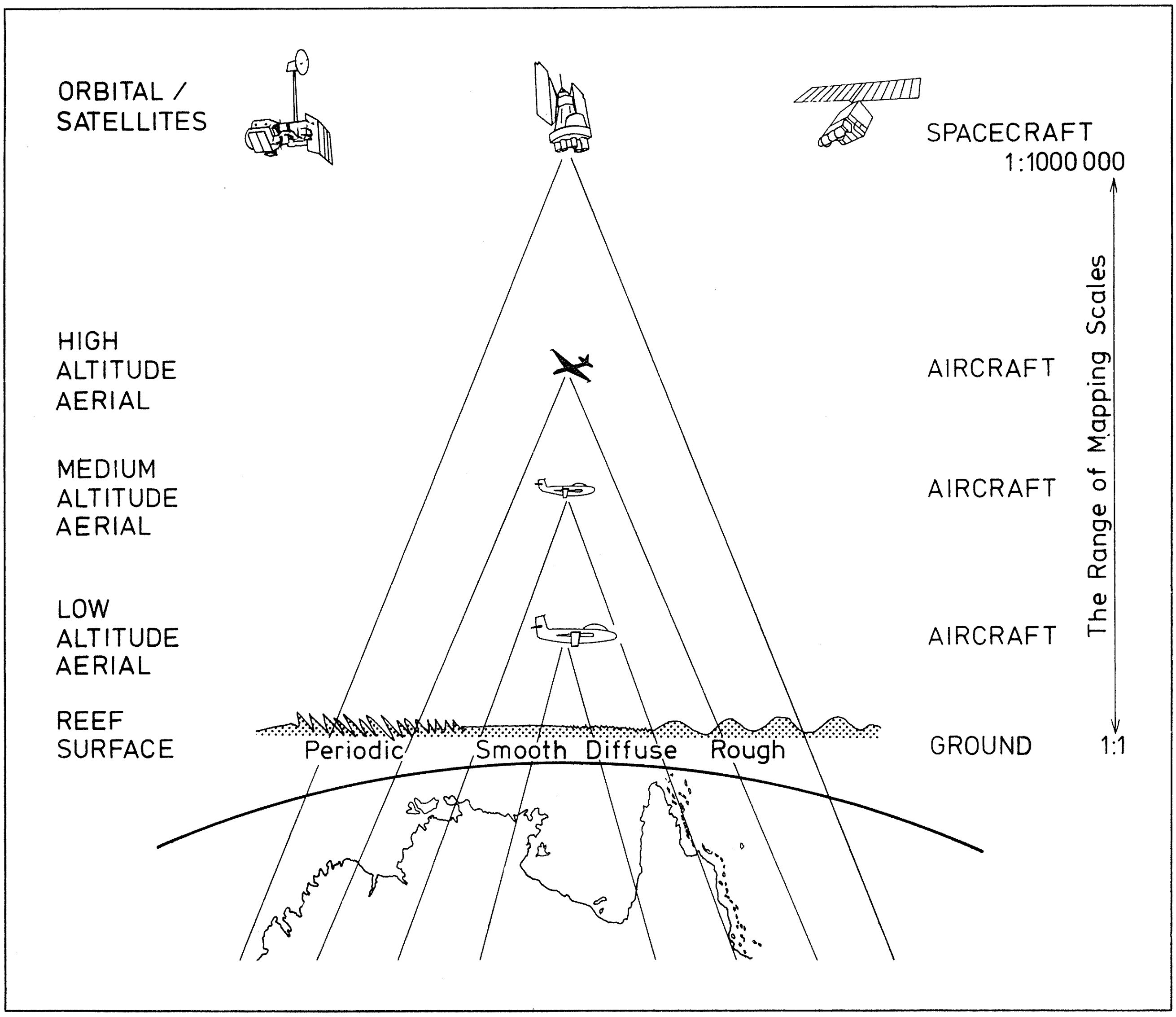
4.1.1 Hierarchical component

The classification system becomes hierarchical when the user records 'unit 1 is included in unit 2' because the inclusion of one unit within another induces a simple hierarchical structure. Also, hierarchical criteria such as 'zones'; 'reef features'; 'composition and position'; 'condition, pattern and morphology'; and 'presence' are used to categorise the entries into five levels. This means that a 'reef feature' is a smaller unit included within a larger unit, a 'zone'; 'composition and position' are smaller units included within a larger unit, a 'reef feature' and so on.

Such a hierarchical component allows data which refers to the different spatial scales of surface reef covers within ground-based and aerial and orbital imagery mapping to be classified. For example, the interpreter of Landsat imagery would use this hierarchical component but in the detailed mapping of ground data it would not be used.

Thus, the design of any classification system for use with remotely sensed and ground data must consider the various scales of the data being categorised. The design of the classification system presented here had to allow for the use of the classification system at any scale in the range from 1:1 to 1:1 000 000 (Figure 2).

Figure 2. The mapping scales for which the GBR classification system is designed.



4.1.2 Non-hierarchical component

The hierarchical structure breaks down when unit 1 can be included in unit 2 as well as in unit 3. This non-hierarchical component was included to allow for the classification of mixed data.

Mixed data occurs when a mapping unit is composed of a mixture of surface covers and/or zones. Thus, it can be classified into more than one category within any hierarchical level in the classification system. Two examples of mixed data are:

- the mixed pixels or 'mixels' which occur on GBR satellite imagery and which result from a combination of a relatively high spatially resolving data recording system and the small spatial extent of coral reefs;

- and, ground data collected from sample sites which, when determined by random sampling methods, can often occur on the boundaries between reef zones (Kuchler, 1984).

At the zonation and reef feature mapping scales, often the surface reef cover is not of a single type but rather of diverse and multiple reef cover types. Consequently, these situations require the interpreter of remotely sensed imagery and the ground data recorder to consider several similar class entries simultaneously. The classification system has therefore to allow several class entries to be chosen from each classification level, thus giving it a non-hierarchical component.

Hallum (1972) states that, from space altitudes, many of the ground resolution elements are individually composed of a mixture of object categories and many of the data points generated by multispectral sensors are not characteristic of any one object category. This problem is commonly referred to as the 'category mixtures' problem.

4.1.3 Categorised entry component

The classification system also has some multi-categorised entries which result because some entries group into more than one of the levels. For example, the entry 'beach' is categorised into both Levels II and III (Appendix IIb). This occurs because a 'beach' is both a feature (Level II) and the composition of a feature (Level III), as in the term 'beach ridge' where 'ridge' is the reef feature and 'beach' is the composition.

The five-level classification system (Appendix IIb) is designed specifically to categorise data recorded at many scales;

Level I of the classification system is for the classification of data into zones;

Level II for reef features;

Level III for composition and position;

Level IV for condition, pattern and morphology; and,

Level V for presence.

These specific levels of the classification system proved to be appropriate for data classification when tested using ground and aerial and orbital image data.

The definition and illustration of the nomenclature (Kuchler, 1986a) used in the classification system is given in Appendix II together with the classification system itself. The definitions of the nomenclature are those given in the comment sections of Figure 4 in Kuchler's PhD thesis, "Geomorphological Separability, Landsat MSS and aerial photographic data: Heron Island Reef, Great Barrier Reef, Australia".

The definitional and illustrative information presented together with the classification system means reef class information may be transmitted in a standardised form; reef classes may be replicated; or, compatible information may be added to the classification. The central characteristics of each classification category are defined in the heading of the category and the boundaries or limits of each entry are provided by the definitions and illustrations.

As the classification system was partly designed for recording interpreted data from remotely sensed imagery, features which can occur on an image but which are not 'purely' geomorphologic (Kuchler, 1986a) were also included. Examples are:

- the imagery features in Level I (Cloud Shadow);
- the artificial features (Wharf, Boat) and crude biological differentiations (Algae - Macro, Algal Encrustation) in Level III;
- the environmental states in Level IV (Live State, Mixed live/dead State);
- and, the water depth categories in Level V.

4.2 Coding symbols

Numerals, special characters, upper and lower case alphabetical letters and combinations of alphabetical letters and numerals were all considered as possible coding symbols for the entries. The numerals 5 to 49 were chosen for two reasons:

- The aim was to employ a simple coding symbol that could be used in a systematic recording system from which the five levels of the Classification System could be deduced and not included in the method of recording. In transferring data a shorter, simpler and therefore more accurate communication exists with numerals than with alphabetical letters. In creating computer files of coded data, numerals can be typed into a file considerably faster than classified data in the form of upper and/or lower case alphabetical letters. This time factor is especially important when a large number of data entries are involved.

- The combination of a simple coding symbol and a systematic recording system, from which the five levels of the classification system could be deduced and not included in the method of recording, was not possible with either special characters, upper and lower case alphabetical letters or combinations of alphabetical letters and numerals. By using numerals greater than four and less than 50, a simple coding system was established.

4.3 Testing of classification system

Harvey (1969) states that we possess no means of assessing the adequacy of efficiency of a given classification independently of the job it is designed to do. The "Reef cover and zonation classification system for use with remotely sensed Great Barrier Reef data" was tested against eight of Anderson's (1971) 10 criteria (Appendix I). The first two criteria, that;

- the level of accuracy in the interpretation of the imagery should be 90 per cent or better; and,

the accuracy of interpretation for several categories should be about equal;

were not strictly tested because they depend heavily on the interpreter,s skills, background knowledge of remote sensing and ground knowledge of the individual reefs used in the tests.

Four image interpreters and seven ground observers were used in the tests which took place during the following:

- ground data collections using both transect and sample site methods on Heron Island and Green Island Reefs;
- the construction of interpretation maps (1:5 000, 1:12 000, 1:50 000) from colour aerial imagery of Heron Island reef, Green Island and Arlington Reefs;
- the interpretation of 361 sample sites equivalent to a 40 m ground radius on 1:12 000 and 1:25 000 aerial imagery of Heron Island Reef; and,
- the interpretation of 361 sample sites of approximately 79 x 59 m each (size of one pixel) on each of Escape, Peart, Cayley, Feather and Howie Reefs (Figure 1).

The classification system manifested repeatable results between users; to accommodate for multiple selections from any classification level (as required by 'mixels' for example); to be satisfactory for the classification of ground, aerial and orbital data from the eight reefs used in the test; and to be suitable for use with seasonal data.

The minimum mapping level utilised in the classification system proved in the tests to depend on the user's needs and purpose, the scale of the data (ground, aerial or orbital), the interpreter's skills, quality of the imagery or ground conditions, type of imagery, and degree of image manipulation.

The five levels of the classification system were used at least in the classification of ground data and in the classification of interpreted data from high resolution low altitude aerial photographic imagery. Level I, and Level II using ancillary information support, were specifically designed and incorporated into the classification system for the synoptic mapping level of Landsat MSS satellite imagery. Entries in Levels II, III and IV were detectable on high and low altitude aerial imagery and on the ground. Level V was designed specifically for data categorisation at all scales. During the testing of the classification system against ground data and aerial and orbital imagery, the specific levels of the classification system were found to be appropriate for data classification.

Any surface cover type, any activity, or any image feature can be categorised or included in the classification system because the design of the system is sufficiently open-ended and flexible to allow for addition and definition of extra levels and entries of categorisation.

Comparisons between present and future categorised reef cover and zonation data will be possible because the data which are categorised and stored by the standardised numerical symbols of the classification system are easily retrievable.

The classification system proved to be a useful facility for recording interpretations of GBR Landsat MSS satellite, high and low altitude aerial imagery and ground data.

4.4 Use of the classification system

Use of the classification system has two components; classification of the data, and, recording of the classification.

These two components are only outlined here in theory, since the operational use of the classification system and of a data recording handbook is outlined and demonstrated in detail in the accompanying work, "Reef cover and zonation classification system for use with remotely sensed Great Barrier Reef data: user guide and handbook (TM-9)", (Kuchler, 1986b).

In classifying data and recording the classifications, the user has to work systematically through two dimensions of the classification system; a vertical dimension and a horizontal dimension. A vertical dimension was built into the classification system to allow for the multiple categorisation of data at any one level, since this was the particular requirement of mixed pixel data on satellite imagery. The horizontal dimension was built into the classification system to allow for the classification of data at many scales.

Systematic use of the classification system demonstrated here ensures that:

entries which are categorised into more than one level are not confused (for example, the entry 'beach' is both a reef feature in Level II and a composition in Level III; Appendix IIb); and,

the data is efficiently categorised. This ensures compact recordings, for example, an 'aligned coral zone' would be inefficiently classified and bulkily recorded in the following classification:

LEVEL I
19 Outer Reef Flat

LEVEL II
N Level II Not Used

LEVEL III
23 Coral

LEVEL IV
10 Aligned Pattern

which in the recording system equals **19N2310**;

but efficiently classified and recorded in the following classification;

LEVEL I
19 Outer Reef Flat
23 Aligned Coral Zone

which in the recording system equals **19**
23

In addition, a systematic use of the classification system produces the recording system from which any of the five levels of the classification system can be deduced. This is important when a data recording card (Kuchler, 1986b) is not used and when classified data on computer files need deciphering. The recording system has been designed to allow deduction of any level of the classification system for any of its entries and a consequent retrieval of the data. This is possible because it has a strict horizontal and vertical layout and the classification system has five levels within the entries, coded by numerals from 5 to 49.

The use of the classification system with a data recording card is outlined in the accompanying paper, TM-9 (Kuchler, 1986b). In the following, the use of the classification system without the aid of a data recording card will be described first together with the use of the vertical and horizontal dimensions of the classification system. The retrieval of the classification levels from the recording system will be described second.

4.5 Use of the classification system without the aid of a data recording card

The use of the classification system without the aid of a data recording card is outlined in the following flow diagram (Table 1). The vertical and horizontal dimensions of the classification system are also indicated. The example given is complex but it was chosen because it covers most of the possibilities in using the classification system.

Table 1. Systematic use of the classification system.

VD = Vertical Dimension
HD = Horizontal Dimension of classification system

	START	Systematic Recording
HD	**LEVEL I**	System: An Example
	Read each entry	
HD	Select one entry	32 Cay
Start of Systematic Recording System	Record entry as per code symbol	32
VD	Scan LEVEL I to determine if there are any other entries for use	Yes
	If there are others mentally take note of them	Cloud
HD	Go to LEVEL II **LEVEL II**	

VD	Read each entry	
VD	Select one or more entries	6 Moat 32 Spit 37 Unvegetated
<u>Systematic Recording System</u>	Record symbol of one of the entries selected from LEVEL II directly next to and on the right side of the symbol for LEVEL I	326
	Record symbols of each of the other entries selected from LEVEL II directly under the previous LEVEL II symbol	326 32 37 (Note single digits (6) always take the first position allocated for the level)
	Go to LEVEL I and re-record vertically the entry for LEVEL I to equal the number of entries for LEVEL II	326 3232 3237
	Go to LEVEL I and re-record vertically the entry for LEVEL I to equal the number of entries for LEVEL II	326 3232 3237
	Go to LEVEL III	
	LEVEL III	
	Read each entry	
	Select one or more entries	13 Leeward 26 Sand
	Record symbol of one of the entries from LEVEL III directly next to and on the right side of the first symbol for LEVEL II	32613 3232 3237
	Record symbols of each of the other entries selected from LEVEL III directly next to and on the right side of the other entries for LEVEL II	32613 323226 3237
	Go to LEVEL IV	

LEVEL IV

Read each entry	
Select one or more entries	N Level IV Not Used
Record symbol of one of the entries selected from LEVEL IV directly next to and on the right side of the first symbol for LEVEL II	32613**N** 323226 3237
Record symbol of each of the other entries selected from LEVEL IV directly next to and on the right side of the other entries for LEVEL III	No other Entries Chosen
Go to LEVEL V	

LEVEL V

Read each entry	
Select one or more entries	**N** LEVEL V Not Used
Record symbol of one of the entries selected from LEVEL V directly next to and on the right side of the first symbol for LEVEL IV	32613N**N** 323226 3237
Record symbols of each of the other entries selected from LEVEL V directly next to and on the right side of the other entries for LEVEL IV	No other entries Chosen
Go to Level I	
Recall any other entries	Cloud **34**
If any, record in Level I position	32613NN 323226 3237 **34**

END

In the horizontal layout of the systematic recording system, the symbols from each level must be kept in chronological place order, that is; Level I first, Level II second, Level III next, then Level IV and finally Level V.

Multiple selections from all levels in the classification system are possible and these are outlined fully in the accompanying technical paper (Kuchler, 1986b). However, in remote sensing of GBR geomorphological features, the multiple selection vertical dimension of the classification system will not be fully utilised. It may be fully utilised, however in 1:5 000 scale aerial photographs for example, and in very detailed geomorphological mapping of the reef surface.

4.6 Retrieval of the levels from the recording system

The recording system allows the retrieval by means of deduction, of any data in the classification system. This is because it is based on a strict horizontal and vertical layout and because the classification system is both of five levels and coded by the numerals 5 to 49.

In determining the classification level of any code symbol in the numerical recording of the classified data, the user must start at the first line of the recording and work horizontally across from left to right. Deductions are based on the knowledge that any numeral less than 5 or more than 49 does not indicate a code symbol, and therefore, a level from the classification system is not indicated.

Also, in making deductions the strict horizontal and vertical layout of the recording system must be followed. The process of deducing the classification level from the recorded numerals can be easily completed visually and is summarised below. The example used to illustrate this process of deducing is that used previously in section 4.5.

A	Recorded data example	32613 323226 3237 34
B	Start at the first numeral at the left of the first line of the recording and work horizontally across to the last numeral	32613 323226 3237 34
C	IF (a) the numeral is 5 or more or is the code symbol N then it is a code symbol from LEVEL I. IF (b) the first numeral is not the code symbol N and is less than 5 THEN combine the numeral with the next numeral to the right and these combined numerals which will always be less than 50, equal the code symbol from LEVEL I.	For the example, (b) is the case, SO 32613 323226 3237 34
D	Retrieve data by Level and code symbol in the classification system	classification system: LEVEL I Symbol 32 = Cay
E	Start at the next numeral to the right	Level I ... 32613 323226 3237 34

F	IF (a) the numeral is 5 or more or is the code symbol N then it is a code symbol from LEVEL II
	
	IF (b) the first numeral is not the code symbol N and is less than 5 THEN combine the numeral with the next numeral to the right and these combined numerals which will always be less than 50, equal the code symbol from LEVEL II
		For the example (a) is the case, SO
		Level I ...
		32613
		323226
		3237
		34

G	retrieve data as for Level I	classification system: Level II, Symbol 6 = Moat
H	Continue this deduction process for all the numerals on the horizontal line.	
I	Go to the second horizontal line and repeat the deduction process from Step B.	
J	Go to the third horizontal line and so on until all the data has been retrieved for the recording.	

5. DISCUSSION

Separate classification systems for each separate data scale as shown in Figure 2 would result in a number of purely hierarchical classification systems and a non-hierarchical component would not be needed. However, separate systems would not allow the cross-comparison of the categorised remotely sensed and ground data and this is the principal need of the BRIAN project (Jupp et al., 1981a, b; Kuchler, 1984).

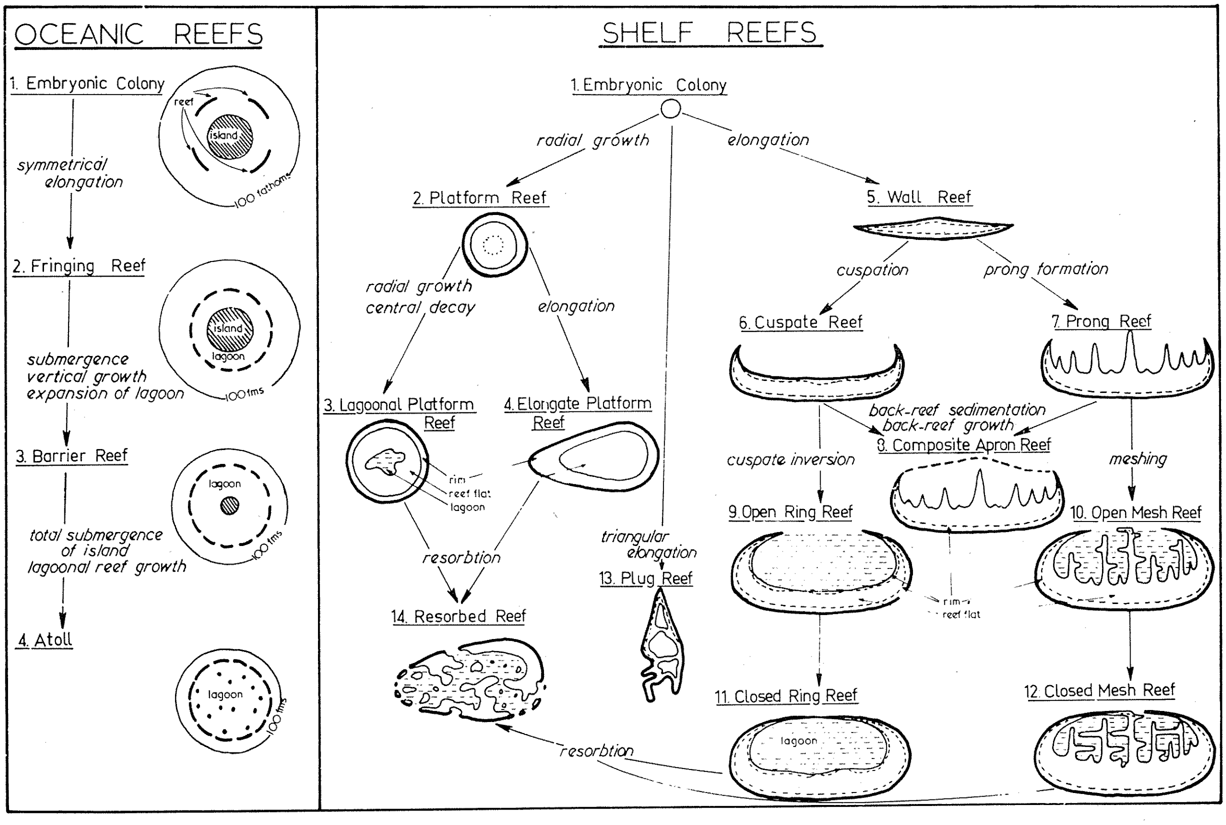
A need for the comparability of data between individual reefs, and between the remotely sensed and ground data has resulted in a semi-hierarchically designed classification system.

A five-level classification system based on the ground data requirements and the resolution capability of the various types of imagery was constructed to enable comparisons between ground data and the aerial and orbital data acquisitions presently being utilised. The spatial resolution of the imagery and the abilities of the interpreter and field data collector determine whether the semi-hierarchical classification system presented here in Appendix II is utilised for its hierarchical and/or non-hierarchical components.

The "Reef cover and zonation classification system for use with remotely sensed Great Barrier Reef data" (Appendix IIb) does not include a classification of reef types. A classification of reef types is not an immediate requirement of the BRIAN Great Barrier Reef mapping project. The research involved in a classification of reef types would further delay the fulfilment of the immediate need by the BRIAN project for a classification of reef covers and zonation.

An extensive classification of reef types has already been provided by Maxwell (1968). Maxwell's (1968) classification of reef types for the GBR is summarised in Figure 3.

Figure 3. A classification of reefs (reproduced with permission from Maxwell, 1968).



6. CONCLUSION

The search for a single, general, reef zonation and surface cover classification system which would serve all people mapping reef cover units for all time is a fruitless one because it would be so general that it would not fulfil specific needs. Consequently, special purpose classification systems have evolved. Here, a semi-hierarchically arranged classification system concerned with geomorphological reef covers and zonation on reefs of the Great Barrier Reef is proposed as a necessity to allow the recording of ground data and interpretations of remotely sensed imagery of the Great Barrier Reef. Further, an explicitly defined classification system such as this one can provide a consistent basis for comparing interpretations and comparing reefs of the GBR region.

The classification system now allows consistent and comparative interpretations of aerial and orbital imagery and ground conditions to proceed. It also allows other GBR scientists to be involved in a more meaningful communication about the Great Barrier Reef. But, as Harvey (1969) states "we should be prepared to change our classifications when it becomes clear that they have outlived their usefulness ... because classification is essentially a means to an end".

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APPENDIX I.

LAND COVER CLASSIFICATION CONCEPTS

The following is a synthesis of the concepts of land cover classification which are of most relevance to a surface reef cover and zonation classification system of the Great Barrier Reef.

For the present purpose of reef cover classification four of Clawson's nine basic concepts of land cover classification were of concern, namely:

1. 'Location', or the relation of a specific parcel of land (**reef**) to the poles, the equator, and the major oceans and land pieces;

2. 'Natural' qualities of the land (**reef**), including its surface and subsurface characteristics and its vegetative (**coral**) cover;

3. 'Activity' on the land (**reef**), man-made structures; and

4. 'Intensity' of land (**reef**) cover, or the amount of land (**reef**) cover per unit of area.

(Clawson, 1965)

Two other basic ideas were utilized in the construction of the Classification System presented here:

1. At the basic data collection stage, land (**reef**) cover should be recorded in as much detail as possible. It is possible to aggregate categories but it is operationally impossible to separate detailed information from a generalized data base;

2. At the basic data collection stage, data should be recorded for individual units of land (**reef**) cover, that is, land (**reef**) covers of the smallest aerial extent.
(Clawson, 1965)

In addition to Clawson's (1965) basic concepts and ideas presented above, the characteristics of a 'good' classification of land cover were observed. 'Good' is discussed by Clawson (1965) in terms which are qualitative generalities based on the usefulness of the data. The five characteristics of a 'good' classification which were observed are:

1. The classification should deal exclusively with land (**reef**) cover;

2. It should be flexible in detail of aggregation and combination;

3. It should be based on what is observed. The interpretation should do only a minimum of grouping. Work should be based on the smallest unit which can be differentiated;

4. It should be amenable to machine processing; and

5. The classification may be restricted so as to be compatible with any existing systems. (Clawson, 1965)

One constraint on this ideal classification system of Clawson's (1965) is the use of remote sensing as a data source. The basic concepts and ideas of land cover classification as presented by Clawson (1965) are suitable for the design of a classification system for use with a single data source, that is, a classification system for use with aerial data or with orbital data. However Clawson's (1965) basic concepts and ideas need to be modified to allow the design of a classification system for use with multistage data sources, that is, a classification system for use with combinations of ground, aerial and orbital data. Anderson (1971) overcomes the constraint of Clawson's system (1965) in presenting ten criteria for a land cover classification system for use with orbital imagery.

Anderson's 10 criteria were modified for application to the reef cover and zonation classification system and for use with the range of scales in the aerial and orbital imagery. However, in the classification system presented in Appendix B no distinction has been made between the different scales of the aerial and orbital imagery. Anderson's modified criteria are listed below:

1. The level of accuracy in the interpretation of this imagery should be 90 per cent or better. However, this will depend on resolution, quality, and scale of the imagery, and the skills of the interpreter;

2. The accuracy of interpretation for the several categories should be about equal. However, this will depend on the interpreter's skills and the degree to which deduction is used at each level in the Classification System;

3. Repeatable results should be obtainable from one interpreter to another and from one time of sensing to another. However, this will depend on the interpreter's background and previous experience;

4. The classification system should be usable or adaptable for use with all reefs of the Great Barrier Reef;

5. The categorisation should permit reef cover types to be used as surrogates for activity when the activity is not listed;

6. The classification system should be suitable for use with seasonal or multidate imagery and with multistage data;

7. Effective use of sub-categories should be possible. These can be obtained from ground surveys, large scale and enhanced imagery;

8. Collapse of categories is desirable. Although this is only partly true in the devised semi-hierarchical system presented here (Appendix II);

9. Comparison with present or future reef cover and zonation information should be possible;

10. Multiple aspects of reef cover units or heterogeneity should be recognized whenever possible.

(after Anderson, 1971)

Some of the remote sensing characteristics as related to reef cover may be inferred from the criteria given by Anderson (1971). These characteristics are:

1. The interpretation from one interpreter to another will vary greatly for certain types of interpretation where insufficient guidelines are poorly constructed and defined classes are used. This problem can be minimized by the interpreter referring to the definitions and illustrations of the nomenclature given in Appendix II or to the accompanying technical paper 'Geomorphological Nomenclature: Reef Cover and Zonation, Great Barrier Reef, Australia' when the definition of a reef term used in the Classification System (Appendix II) is in doubt;

2. Reef cover appearance may change seasonally, over time or with varying atmospheric and marine conditions;

3. Reef cover may not be able to be 'read' or interpreted directly from some imagery and therefore may have to be inferred;

4. Data obtained from an imagery is dependent on scale.

A fifth criterion, drawn from Ryerson and Gierman (1975) is:

> Terrain appearance and the size of similar features change from place to place, and the level of available detail may therefore change for similar imagery scales.

The guidelines for classification developed by Anderson (1971) and Clawson (1965) are general and therefore in attempting to form a specific classification system for geomorphological reef cover and zonation on reefs of the Great Barrier Reef, the explicit inter-relationships in the reef cover data need to be considered.

APPENDIX IIa.

LISTING OF REEF COVER AND ZONATION CLASSIFICATIONS

APPENDIX IIb.

REEF COVER AND ZONATION CLASSIFICATION SYSTEM FOR USE WITH REMOTELY SENSED GREAT BARRIER REEF DATA

LEVEL I: CLASSIFICATION ACCORDING TO ZONES

5 Ocean

(Plate 1)

6 Off-Reef Floor

Maxwell (1968) provides a definition: Whatever the depth, the zone immediately surrounding a reef is named the 'off-reef floor'. (Figure 1)

7 Reefal Shoal

Maiklem (1968) provides a definition: The term 'reefal shoal' has been coined to represent the upper surface to reeflike growths. In general, (in the Capricorn Complex) they come within 5 to 10 fathoms of the sea surface, and their tops, although not showing the well developed zones of the reefs proper, are covered by clumps of coral growth separated by sand or rubble patches. The 'reefal shoals' have two forms of occurrence. Commonly, they are formed as long shoals between two true reefs, or as extensions to a reef; for example, one occurs between North West and Broomfield Reefs. Others such as Rock Cod Shoal and many smaller ones throughout the area rise as individual mounds from the sea floor. They are surrounded by fore-reef slopes similar to those around reef tops. (Plate 6)

8 Reef Flank

A 'reef flank' is the side of the reef, that part of the reef which occupies the side position between defined and stated points on the reef. The number of sides identifiable on a reef will vary according to the reef type or the users reference purpose. The location and horizontal extent of a 'reef flank' should be referred to by using the compass points; for example, the south to north 'reef flank', and the south-west to west reef flank. The vertical extent of a 'reef flank' should be assumed to be equivalent to the vertical extent of the reef slope. The 'reef flank' is a submarine feature and therefore its resolution on aerial photographs and LANDSAT 3 MSS satellite imagery is only partial and dependent on the marine and atmospheric conditions during acquisition.

9 Multiple Reef Front

Hopley (1982) describes a 'multiple reef front' which he also terms a double reef front at Moss Reef: On the double reef front of Moss Reef ($17^{o}56'S$) the outer reefal wall is partly attached to the main reef by narrow bridges of algal-crusted reef top. These separate long narrow gutters or moats which are 6 to 8m deep. Coarse rubble floors the gutters. The outer reef is 1 to 2m below the lowest tide levels. (Figure 2)

10 Spur and Groove

In a 'spur and groove' structure a spur is a projection of the reef slope while a groove is a channel or valley between two spurs. The front of the spurs may carry luxuriant coral and coralline algae. The sides of the spurs support lesser coral growth and the sandy rubble floors of the grooves support little or no coral or algal growth. This is because of the scouring action of waves and the tidal run-off through the gullies. 'Spur and grooves' may be developed on both the windward and leeward sides of the reef. Their dimensions may vary considerably both on a single reef and between reefs. (Plate 4)

11 Reef Slope

The 'reef slope' is the subtidal portion of the reef mass extending seaward from the perimeter of the horizontal reef surface (on some reefs this will be the edge of the reef rim) and descending towards and terminating at its intersection with the off-reef floor on the continental shelf. An average seaward 'reef slope' approaches 30^{o} (Maxwell, 1968). The 'reef slope' may be interrupted by major or minor terraces. For purposes of specific spatial reference, the 'reef slope' may be divided vertically into the upper reef slope, middle reef slope and lower reef slope. The user must decide and state the criteria on which this division is made, for example, slope angle, coral abundance, coral species etc... as these criteria will vary depending on the situation. The upper reef slope may be steeper than the lower reef slope producing an overall concave upward slope. The steeper slope of the upper reef slope may have been created by luxuriant coral growth. Coral growth is usually more luxuriant on the upper reef slope than on the middle and lower reef slopes. The horizontal extent of the reef slope can be divided up for purposes of specific spatial reference into 'windward' (meaning the extent of the reef slope facing predominantly windward) and 'leeward' meaning the (extent of the reef slope facing predominantly leeward to the wind). The definition and therefore delineation of a reef slope varies greatly between reefs and within a reef. On any individual reef the features on a 'windward reef slope' may be similar but vary in magnitude and abundance to those on a 'leeward reef slope'. (Plates 3 and 4)

12 Reef Rock Slope

The Great Barrier Reef Committee provide a definition for a 'reef rock slope': The 'reef rock slope' and the rubble crest compose the reef rock rim. The gentle seaward slope of reef rock is usually 20 to 80m wide and 0.5 to 0.9m in vertical extent. Reef blocks may occur here as well as on the rubble crest. The slope may be smooth or potholed, but, typically, it is shallowly and irregularly terraced. The rock surface is mainly obscured by a dense mat of small, sand-binding algae.

13 Back-Reef Zone

Hopley (1978c) states: The back-reef area on the ribbon reefs consists of a steeply inclined sand ramp sloping into water depths of approximately 14m from which rise isolated massive coral colonies. However, Veron and Hudson (1978) and Orme (1978) disagree with the depth given by Hopley (1978c). Veron and Hudson (1978) state: In the back reef area (Ribbon Reefs of the northern region, GBR) the depth of water is variable and while it does not generally exceed 36m, it is more commonly in the order of 28m, while Orme (197) claims: In the back-reef zone the water deepens to between 30 and 40m. Maxwell (1968) provides the following information: With reefs of the linear group: wall, cuspate and prong: the sand flat gradually descends into the open backreef zone which may be extremely wide (2 miles) and which supports large scattered reef clumps that are always submerged. At low tide they may be covered by less than 3ft of water. The submerged reef clumps are referred to commonly as 'bombies'. The back-reef area generally ends abruptly where the floor descends steeply into the off-reef floor. Orme (1978) observes an extensive wedge of sediment accumulates in the back-reef area. Orme, Flood and Sargent (1978) add: On the Outer (Ribbon) reefs in the northern province of the GBR, the central part of the back-reef environment is characterised by submarine banks and ridges. Veron and Hudson (1978) describe infilling of the back-reef area with secondary coral growth. (Plate 7) (Figure 2)

14 Patch Reef Zone

'Spur reef' is a term used conversationally among some scientists to describe a linear grouping of patch reefs. These patch reefs in aerial view appear to be extensions of the present reef rim or remnants of a pre-existing reef rim. The term 'patch reef zone' is proposed as a label for these linear groupings and for any grouping of patch reefs. (Plate 1)

15 Reef Rim

The 'reef rim' occurs on a reef between the reef slope and the outermost part of the reef flat. On reefs of the GBR the 'reef rim' is highly variable in its width, length, height, aspect and surface composition. The width may vary from a narrow strip to a broad zone (up to 160m) on a single reef and from one reef to another. The length of the 'reef rim' is dependent on the reef type and the size or extent of the reef. The 'reef rim' may or may not form a continuous perimeter around the reef mass. For example, on Heron Island reef the 'reef rim' extends around the perimeter of the reef as 'the reef rim is continuous except for a few places on the western and northeastern margin' (GBRC, 1978). On a Ribbon Reef on the outer barrier, the 'reef rim' is often absent from the back-reef area and therefore it does not enclose the plane of the reef surface. An example is Carter Reef, a Ribbon Reef in the north of the GBR. The height of the 'reef rim' varies from reef to reef and a part of all of it may be high enough to be exposed in a supra-tidal or inter-tidal environment. Authors have given examples of the 'reef rim' being a platform, stepped and terraced and having ridges. Jell and Flood (1978) observe the 'reef rim' on the Capricorn-Bunker group of reefs usually slopes gently seaward. The surface of the 'reef rim' as observed by all authors may be a pavement formed by encrusting coralline algae. This pavement itself may be covered by small isolated colonies of coral, algae, echinoids, molluscs, large sediments (for example, shingle and rubble) sometimes accumulated in the form of banks, spits, ramparts, and reef blocks. (Plate 4)

16 Algal Reef Rim

An 'algal reef rim' is a reef rim which has become so colonized by algae that it appears as an algal surface. This algal surface may be soft and mat-like or it may be hardened and crust-like, the type of surface which results from the reef rim being colonised by encrusting species of algae. An 'algal reef rim' is easily identifiable on the ground, and on aerial photographs.

17 Reef Top

'Reef top' is undefined in the literature but it is the term used most frequently to describe the total horizontal reef surface. It is the term used in very broad scale mapping of reefs and it would be used mostly in the construction of maps from low resolution satellite images (for example, a LANDSAT MSS image of the GBR recorded under high tide and high turbidity conditions.) 'Reef top' is a term used in reference to reef location, size and horizontal aspect. (Plate 1)

18 Reef Flat

A 'reef flat' is a relatively flat area on the surface of the reef. Its aerial extent and location vary depending on the reef type but generally, the reef flat is identifiable because it covers a comparatively large area of the surface of a reef and it usually extends inwards from the reef rim. The 'reef flat' varies from a broad expanse on the leeward side of reef rims, for example, Lady Musgrave Reef to narrow zones near the edge of reefs, for example, Three Isles Reef. The 'reef flat' is generally inter-tidal or together with the reef rim the shallowest part of the reef at low tide. The broad scale 'reef flat' when considered against Maxwell's (1968) finer scale physiographic zones in Figure 3 would include the areas labelled coral zone and sand flat. The boundary between a 'reef flat' and an adjacent zone or feature may be clearly identifiable by an abrupt change in the composition of the surface covers. Such an abrupt change makes the delineation of the 'reef flat' on the ground an easy task. However, when the boundary between the 'reef flat' and the adjacent zone is transitory, the ground-worker needs to use an aerial view of the reef (for example, aerial photographs) to define the boundary, as then the transitional boundary is given a relative perspective. The 'reef flat' my be sub-divided into two sub-zones, the 'outer reef flat' and the 'inner reef flat' (see below) or into even finer mapping units such as 'live coral zone' and 'dead coral zone'. (Plate 1)(Figure 2)

19 Outer Reef Flat
20 Inner Reef Flat

The 'outer reef flat' is bordered by the reef rim on one side and the 'inner reef flat' on the other side. The inward side of the 'inner reef flat' may be bordered by a cay, a lagoon, back-reef zone, or a reef slope depending on the reef type. Either can be one heterogenous zone or a number of homogeneous sub-zones, for example, live coral sub-zone, coral rubble sub-zone, coral heads, dead coral sub-zone, seagrass beds, and sand sub-zone. When the 'outer reef flat' or 'inner reef flat' are heterogeneous zones then usually a mixture of dead and live coral structures, coral rubble, algae and sand is found. The mixture is highly variable but is sufficiently different to distinguish the 'outer reef flat' from the 'inner reef flat'. An 'outer reef flat' and an 'inner reef flat' are very easily defined when the 'outer reef flat' is dominated by an aligned coral zone and the 'inner reef flat' is dominated by a sand cover. Heron Island Reef is an example. (Plates 2 and 4)

21 Living Coral Zone
22 Dead Coral Zone

An area which has a surface cover dominated by living coral or dead coral and which can be delineated on the basis of this domination over other surface covers is termed a 'living coral zone' or a 'dead coral zone'. 'Living coral zones' or 'dead coral zones' are highly variable in extent and occurrence. For example, a 'living coral zone' may cover the entire reef flat or only a small section of it. These zones may occur for example, on the reef slope, reef flat, lagoon, or back-reef zone. The minor surface covers in these zones are usually sediment of various sizes, algae and dead coral in the 'live coral zone' and live coral in the 'dead coral zone'. The 'dead coral zone' usually has the same morphology and density as the 'live coral zone' which it replaced but generally algae, seaweed and seagrass are more abundant. (Plate 6)

23 Aligned Coral Zone

An 'aligned coral zone' is an area which is characterised by a pattern of striations perpendicular to the reef margin. It usually occurs on the outer reef flat and/or near the reef rim. The striations may be composed of live coral, dead coral, rubble, sand, algae or an algal encrustation. A well developed alignment is clearly visible both on the ground and on aerial photographs. The GBR Committee (1978) provides a definition: This zone may be characterised by living or dead coral, both with extensive algal encrustation. Sand patches are restricted to coral pools or narrow channels and are aligned perpendicular to the reef rim, giving this zone a radial pattern. This zone is found on the outer reef flat of platform reefs. On aerial photographs it appears to be merging and sloping back from the Lithothamnion rim. It is characterised by striations perpendicular to the reef margin. In aerial view, the arrangement is remarkably regular. (Plate 4)

24 Rubble Zone

A 'rubble zone' is an area where the surface cover is dominantly rubble. The dominance of any other surface cover indicates the boundary of this zone. The rubble may be covered by algae and other coral reef sediments or features (for example, sand, shingle, small coral outcrops) may be present in minor amounts. The 'rubble zone' is easily interpreted on 1:12 000 aerial photographs. A 'rubble zone' may be located on any part of the reef surface.

25 Sand Zone

An area which has a surface cover dominated by sand and which can be delineated on the basis of this domination over other surface covers is termed a 'sand zone'. 'Sand zones' are highly variable in extent and occurrence. The minor surface covers in this zone are usually dead and live coral clumps, rubble, shingle and algae.

26 Seagrass Zone

Seagrass grows on the surface of fine sediment on the reef flat in an area which usually does not dry completely at low tide. It is usually restricted to intertidal or shallow marine environments. Various species of seagrass are found in various stages of growth on the reefs of the GBR. Conversationally, seagrass is often called Dugong Grass or Turtle Grass. On colour aerial photographs it appears dark brown or dark green and fine textured. (Plate 2)

27 Lagoon

A 'lagoon' is a depressed area in the reef surface near the reef flat. The morphology of this depressed area or 'lagoon' varies depending on the lagoon type. Generally, 'lagoons' are either enclosed (for example, Heron Island Reef), partially open (for example, Cairns Reef), or fully open (for example, Williamson Reef and the Outer Ribbon Reefs). In enclosed 'lagoons' the perimeter of the 'lagoon' is easily detected. With partially or fully open 'lagoons' the perimeter of the 'lagoon' abuts the reef flat but has to be inferred when it becomes a relatively deep submarine feature in the open area. Most 'lagoons' are subtidal and therefore are never dry or exposed. This factor provides favourable conditions for the growth of corals. The floor of a 'lagoon' is dominantly covered by sand-size sediments but other dead coral fragments and algae are usually evidenced. A reef surface may or may not contain a 'lagoon' and one or more 'lagoons' may be identified.

28 Shallow Lagoon
29 Medium Lagoon
30 Deep Lagoon

The terms 'shallow', 'medium' and 'deep lagoon' represent specific water-depth conditions along a water-depth scale. Publishing scientists do not provide any clear and consistent criteria on which to separate these 'lagoons'. Therefore, the decision to classify a 'shallow, medium or deep lagoon' will be left up to the user of the terms, but the decision should be based on empirical knowledge which is classified according to time and space. The decision-making procedure would involve the user firstly scanning the area to be mapped, either on the ground or on aerial photographs for empirical knowledge, secondly, listing the time and space criteria for 'lagoon' classification (the strictness of the criteria will be application dependent), and thirdly, classifying and mapping the 'lagoons' into 'shallow' and/or 'medium' and/or 'deep'. As no precise criteria are available in the literature for the author to devise precise clear-cut definitions, users must select their own criteria. These criteria will vary between users and applications. Ideally for the field worker specific water depths should be standardised for these 'lagoons' to give their definition a greater qualification. However, the imposition of such water depths on the categorisation of 'lagoons' would not ensure a standardisation of 'lagoon' types because of the high variability in tide heights. To standardise water depths would mean restricting the classification of the 'lagoons' to specific conditions (for example, 4m depth on a 2.0m high tide) which would mean restricting the time of the field recorder. In addition, such rigid requirements would make classification technical and time consuming on remotely sensed imagery, and the accuracy of such a classification may still need determining. However, colour, tone, shade and pattern can all easily be applied to remotely sensed imagery to determine a shallow to deep scale for the 'lagoons' and thus classify them. (Plates 1, 4 and 5)

31 Blue Hole

From the descriptions of the five 'blue holes' given in the literature a 'blue hole' may be defined as a circular steep-sided feature which may have a depth ranging between 10 and 40m. The sides of the blue hole may have luxuriant coral growth. On colour or black and white aerial photographs, a 'blue hole' is a distinct interpretable feature. On a LANDSAT 3 MSS image only a 'blue hole' with a large diameter will be identifiable, for example, the 'blue hole' on Molar Reef (295 by 260m). On the ground 'blue holes' are easily detected because of the circular shape of a deep blue area of water. (Plate 1)

32 Cay
33 Island

The term 'island' is used within two contexts in the literature. It is used to refer to a 'cay' composed of reefal sediments and to an 'island' composed of continental material. As these two contexts are significantly different in the GBR environment, it is necessary to restrict the use of the term 'cay' to supra-tidal reef derived sediment accumulations and the use of the term 'island' to supra-tidal continent derived material accumulations. 'Cays' vary mostly on the basis of their composition and surface cover, for example, sand, shingle, coral rubble, beachrock, mangroves, vegetated or unvegetated and so on. Similarly, islands vary mostly on their geological composition and vegetation coverage. (Plates 2, 3 and 6)

34 Cloud

On LANDSAT 3 MSS images, clouds appear white and they may cast shadows. Clouds appear as shadows on aerial photographs. (Plate 2)

35 Shadow

(Plate 2)

X Data Anomaly

On a Satellite image, a data anomaly often appears as an obvious continuous or broken horizontal lines(s) across the image and its colour is often in strong contrast to the neighbouring colours on the image. (Plate 2)

? Field Data Required

Field data is required to verify the interpretation. (Plate 1)

N Level I Not Used

LEVEL II: CLASSIFICATION ACCORDING TO REEF FEATURES

5 Slope

Any inclined surface. (Plate 5)

6 Moat

A 'moat' is a linear excavation in the surface of a reef and it may vary in size from a narrow gutter to a shallow wide depression. A 'moat' on the outer reef flat is a ponding of seawater between adjacent geomorphological features or between irregularities in the surface of the outer reef flat. A long linear 'moat' below the general level of the inner reef flat may circle a cay at the beach/reef flat interface or at the plunge line of the main body of breaking waves. 'Moats' appearing on the inner or outer reef flat appear to be associated with the degree and type of exposure to wave action. Consequently, a 'moat' may be a permanent or temporary feature. (Plate 2)

'Moats' may also occur in the submarine environment at the junction of the reef front and the continental shelf/ocean bottom and as such may be formed by the scouring action of ocean bottom currents. Due to the variability of currents, these 'moats' may also be temporary features.

8 Patch Reef

A 'patch reef' is a single isolated coral structure which may be connected to another patch reef or another reef feature by a minor extension of the coral structure. To differentiate between a 'patch reef' and a coral head, a 'patch reef' can be defined as having a vertical extent which is smaller than the radius of its horizontal extent, while a coral head can be defined as having a vertical extent which is greater than the radius of its horizontal extent. The 'patch reef' coral structure has 'varying degrees of complexity produced by growths of coral varying from isolated pinnacles to massive patches' (Hopley, 1982). 'Patch reefs' may rise from any part of the reef surface to which they are connected but growing 'patch reefs' are restricted to sub-tidal environments. 'Patch reefs' are commonly found in lagoons, in back-reef zones, and on reef slopes. (Plate 4)

9 Coral Head

A 'coral head' is a single standing solid outcrop of coral which may be alive and/or dead and/or covered or encrusted by algae. A 'coral head' unlike a patch reef is never connected to other reef features, other than the reef floor. Its vertical and horizontal extent varies from approximately 0.5m to several metres. A 'coral head' can be defined as having a vertical extent which is greater than the radius of its horizontal extent. 'Coral heads' are commonly found in medium and deep lagoons, and on the outer reef flat, the reef rim, and the reef slope. However, because they may be storm deposited, 'coral heads' can be found on any part of the reef surface. 'Coral heads' of more than one metre horizontal dimension are clearly visible on aerial photographs. They appear as dark toned circular features which may cast shadows. (Plate 2)

10 Coral pool

Teichert (1950) provides a definition: With rims of coral growth and a sandy bottom, 'coral pools' are depressions in the (reef) surface or (specifically) the sanded zone. They appear as white patches with hard edges on photographs. 'Coral pools' occur in the 'living coral zone' (and may occur on any part of the reef surface. A 'coral pool' is easily delineated and identified because of its contrasting circular depressed morphology in relation to the surrounding surface covers. Minor occurrences of algae and rubble may be seen).

11 Microatoll

A typical 'microatoll' is a single coral colony commonly massive and circular in plan, with a dead, predominantly flat, upper surface and living lateral margin. A 'fossil microatoll' has the same morphology but with no living polyps. They vary in size from a few centimetres to a few metres in diameter (Scoffin and Stoddart, 1978). 'Microatolls' are found generally on reef flats or areas that have ponded water during low tide. (Plate 5)

12 Pool

A contrasting circular depressed morphology in relation to the surrounding surface covers.

13 Rock

On reefs it is consolidated reef material, for example, beachrock; phosphate rock, rampart rock, boulder rock, reef rock (Plate 2). On islands, it is consolidated continental material. (Plate 3)

14 Ridge

A 'ridge' may be referred to as the line at the junction of two surfaces sloping upwards towards each other. 'Ridges' may occur singularly or in multiples and they are variable in width and height. They may be found located on the cay ('beach ridges') or on the reef flat ('shingle ridges'). Stein and Urdang (1967) define a ridge as: a long narrow elevation of land; the long and narrow upper edge, angle or crest of something, any raised narrow strip; the horizontal line in which the tops of the rafters of a roof meet.

15 Rim

A definable border around a usually circular reef feature or reef top. A circular reef feature or reef top. An example is a 'reef rim'. (Plate 4) (Figure 1)

16 Rampart

Descriptions of 'ramparts' in the literature are only given for the northern reefs of the GBR. On these reefs, they have a characteristic plan and profile form. 'Ramparts' are asymmetric ridges of coral shingle with a steep inward face, locally reaching 80^{o}, and a gentle seaward slope of less than 10^{o}. Their outer margin is a feather edge of shingle on the reef flat and is often too indistinct to map; in plan it roughly parallels the edge of the reef. The inner edge is arcuate, with occasional shingle tongues which on the windward side are at right angle to the reef edge but elsewhere are at an angle to it. 'Ramparts' may be found located on the reef flat and may be wholly or partially submerged at high water. In general, they consist of clean white shingle which would make their delineation on aerial photographs or satellite imagery easy to interpret. 'Ramparts' may occur singularly or as several roughly parallel sets separated by moats which may be filled with water. A 'rampart' composed of shingle is referred to as a 'shingle rampart', and a 'rampart' colonised by mangroves is referred to as a 'mangrove rampart'.

17 Bassett Edge

Publishing scientists provide a definition for the term 'basset edge': 'Bassett edges' are the cemented basal portion of ramparts (Hopley and Van Steveninck, 1977). 'Bassett edges' are remnants of lithified rampart foreset beds forming projecting steeply dipping ridges. They occur on the reef flat where the uncemented upper rampart materials have been eroded (Hopley, 1978c). They are straight or more often arcuate in plan, recording former locations of the inner edges of unconsolidated ramparts (Steers, 1937).

18 Bank

A 'bank' is a long pile or heap; mass; a bank of accumulated sediments; a slope or acclivity; a broad elevation of the sea floor around which the water is relatively shallow (Stein and Urdang, 1967). 'Banks' may be submerged. (Plate 5)

19 Tongue

Stein and Urdang (1967) define a 'tongue' as a narrow strip of land extending into a body of water; cape; a section of ice projection outward from the submerged part of an iceberg; and a rampart as a broad elevation or mound of earth raised as a fortification around a place and usually capped with a stone or earth parapet. Syn.: breastwork, barricade. Thus the terms 'tongue' and rampart have similar lateral extents but they differ in the magnitude of their height. In the literature, only examples of 'shingle tongues' are given but they probably vary to include rubble, sand and boulders depending on their spatial location on the reef surface. A 'tongue' may become lithified and vegetated, thus indicating a non-transient state. (Plate 5)

20 Platform

A 'platform' is composed of cemented coral fragments (usually shingle size), a conglomerate, and has a horizontal upper surface. 'Platforms' are the lithified equivalents of shingle ramparts and occupy comparable positions on the reefs. Stoddart, McLean and Hopley (1978) give detailed information on 'platforms'. Stein and Urdang (1967) define a 'platform' as: a flat, elevated piece of ground. Syn.: stage, dais. and a 'promenade' as- an area used for leisurely walking; derived from 'promener': to lead out, take for a walk or airing. (Plate 5)

21 Boulder Tract

A 'boulder tract' is a continuous deposit of discrete boulders of massive corals usually found on the leeward side of the reef rim or outer reef flat as at Low Isles and Watson reef. However, on Bewick Reef, a 'boulder tract' is found near the island shore. A 'boulder tract' is the coarser equivalent of a shingle bank and it may or may not be colonised by vegetation.

22 Wedge

The term 'wedge' is used to refer to any feature on the reef which has a wedge-like shape. A wedge shape is formed when two principle faces meet in a sharp acute angle. So, a 'wedge' can be composed from many surface cover types, for example, 'boulder wedge', 'sand wedge', 'rubble wedge'. (Plate 6)

23 Terrace

'Terraces' are raised levels which may occur as a single level or as multiple levels. They may be covered by or composed of sand, shingle, fauna, live or dead coral, algae or vegetation. 'Terraces' exist in varying widths and sediments deposited in a fan shape may accumulate at their base. Examples of 'terraces' on cays, reef slopes, reef flats and spurs and grooves are given.

24 Shoal

A 'shoal' is a submerged sandbank, a submerged sand bar, or a submerged platform which causes a depth of water to change to a shallower depth. The surface of a 'shoal' is usually sand and they are mostly found offshore from coasts. (Plate 1)

25 Chute

Teichert (1950) provides a definition: 'Chutes' are radial surge channels dissecting the edge of the reef platform, the Lithothamnion rim (algal rim) and the upper part of the living coral zone and possible reaching 30 feet below low tide. On photographs they are dark, radial, irregular, sometimes anatomising lines of varying length, merging downward into deeper water, separate by Lithothamnion-covered buttresses.

26 Sand Patch

A 'sand patch' is a small contrasting area on the reef top which is dominated by sand. A 'sand patch' can be easily delineated and identified because of its contrasting nature in relation to the surrounding surface covers and thus considered an individual feature. Minor occurrences of other surface covers, for example, algae and rubble, may be evidenced in a 'sand patch'. (Plate 2)

27 Reef Rim Lagoon

Hopley (1982) states that 'reef rim lagoons' can occur within 100m of the reef front. Some occur on the outer ribbon reefs where the reef top width is greater than average. (Plate 1)

28 Lagoon Wall

The feature termed a 'lagoon wall' can be found in some lagoons either around all the perimeter or only on parts of the perimeter. A 'lagoon wall' is the vertical outermost part of the hollow lagoon structure. It is most noticeable when its vertical extent resembles a wall in appearance or effect, that is, sufficient to result in the identification of a boundary between an adjoining feature, for example, a reef flat and the lagoon floor. A 'lagoon wall' may be sloping but only to the extent that it retains its identifiable wall-like character, its individuality and its boundaries with abuting features, for example, on its upper side, the reef flat and on its lower side, the lagoon floor. 'Lagoon walls' may be bare surfaces or they may be colonised by live and/or dead coral outcrops (having the effect of camouflaging the vertical extent of the lagoon wall), algae etc. Leeward lagoon walls of growing corals are evident on One Tree, Fitzroy and Lady Musgrave Reefs and appear in a modified form on Heron Island Reef. 'Lagoon walls' may cast shadows depending on the sun angle. These shadows are visible both on the ground and on aerial photographs (1:12 000). (Plate 5)

29 Lagoon Floor

A 'lagoon floor' is relatively flat, but may take the overall shape of a horizontal plane, a concavity or a gentle "v". The general characteristics of the 'lagoon floor' vary with lagoon type, for example, open lagoon, closed lagoon, deep lagoon, shallow lagoon. (Plate 4)

30 Beach

On cays and islands of the GBR a 'beach' is composed of coral sediments of varying sizes which may be sorted. Generally, the lower slope of the 'beach' abuts the reef flat with the upper slope terminating at the vegetation line on a vegetated cay or a dune on an unvegetated cay. A clearly defined 'beach' is evident on all vegetated cays on the GBR. (Plates 2 and 3)

31 Dune

A hill of sediments (usually sand) heaped up by the wind and usually near the shore. A 'dune' may be vegetated. (Plate 3)

32 Spit

A 'spit' is an elongated sediment body which is associated with a cay and which usually takes the direction of the prevailing winds and currents. 'Spits' may also be composed of shingle and rubble and therefore the term 'spit' through its higher level of generality accommodates such variations. 'Spits' and their characteristic morphology may be in a permanent/stable or temporary/transient state. The stability of a 'spit' may be deduced from the presence or absence of vegetation. A 'spit' which is easily identifiable both on the ground and on aerial photographs is evident on Heron Island and Green Island reefs. (Plate 2)

33 Spur
34 Groove

See Spur and Groove, Level I, entry 10. (Plate 4)

35 Perimeter

The bounding line of any reef or reef feature. (Plate 1)

36 Vegetated

On the Great Barrier Reef, vegetation can be found growing on some cays ('vegetated cays') and most islands. However, the species of vegetation on an island are generally different from those on a cay. On a cay the species of vegetation are restricted to those tolerant of a salt-laden atmosphere and a non-retentive calcareous soil. On the margins of a vegetated cay, the vegetation is subject to considerable fluctuations due to the erosion and deposition of sediments by winds, waves, etc. Therefore, it is not unusual for a species on the margins of a cay to be lost for a time and reintroduced subsequently. (Plate 2)

37 Unvegetated

Without vegetation. (Plate 6)

38 Channel between Reefs

(Plate 1)

39 Channel in Reef Top

(Plate 3)

40 Channel in Deltaic Pattern

When applied to a reef, the definition of a 'channel(s)' needs to recognise the three major spatial locations of the feature, namely, on the reef top between reef flanks and the back-reef zone. Firstly, 'channel(s)' may be found between the reef flanks of separate reefs, that is, it is the area connecting neighbouring reefs. These 'channels' are usually navigable courses through a body of water and on charts are named separately, for example, Raine Island Entrance. The depths and widths of these 'channels' are highly variable. Hopley (1978c) states 'narrow channels separating these elongate reefs have depths ranging from 25 to 30m' while Veron and Hudson (1978) claim 'the depth of water in channels between reefs is largely unknown'. Secondly, the term 'channel' is used to describe an identifiable course on the reef top along which water and sediments are collectively moved and directed. These 'channels' are usually long narrow shallow depressions which have been eroded in the reef top. Thirdly, channels are significant features in the 'deltaic pattern' on some reefs. A 'channel' usually has the morphology of a strip, that is, its length is greater than its width. (Plate 7)

? Field Data Required

Field data is required to verify the interpretation. (Plate 1)

N Level II Not Used

LEVEL III: CLASSIFICATION ACCORDING TO COMPOSITION AND POSITION

Most of the entries in Level II are self-defined and therefore only selected entries are defined below.

12 Windward

Any part of the reef that faces predominantly windward.

13 Leeward

Any part of the reef that faces predominantly leeward.

14 Phosphate
15 Reef
16 Rampart
17 Beach
18 Boulder

These compositions are used in describing and differentiating a feature termed a rock in Level II (entry 13).'Beachrock', 'cay rock', and 'phosphate rock' occur on cays and on this basis can be differentiated from 'rampart rock', 'boulder rock' and 'reef rock' which occur on reef flats and/or reef rims. Nevertheless, all rocks form by the same process, that is, lithification/cementation. 'Beachrock', 'cay rock', 'phosphate rock', 'rampart rock' and 'boulder rock' are all organically cemented while an inorganic cementation forms 'reef rock'. All rock types except 'cay rock' and 'phosphate rock' are intertidally cemented. Cay and 'phosphate rock' are supratidally cemented on cays. Based on these similarities and the lack of any differentiating information, the author has taken 'cay rock' to be equivalent in term and meaning for 'phosphate rock'. Consequently, 'cay rock' is eliminated from the proposed nomenclature.

19 Algal Coating
20 Algae (macro)
21 Algal Encrustation

The term 'algal' is used in conjunction with any feature named in the proposed nomenclature when the surface of the feature is coated and dominated by algae. Examples of use of the term are: 'algal pavement', 'algal ridge', 'algal reef rim'. (Plate 5)

22 Seagrass

See Seagrass Zone Level II, entry 26.

28 Conglomerate

Consisting of loosely cemented heterogeneous reef material.

29 Living Margin

The term 'living margin' is adopted for the term 'living lateral margin' which is used in the literature. (Plate 5)

31 Breaking Waves

(Plate 4)

32 Partially Vegetated

(Plate 3)

33 Cleared Vegetation

(Plate 2)

34 Dune Vegetation

(Plate 2)

35 Mangrove

A 'mangrove' is a type of tree found in salt or brackish water areas. This salt-tolerant tree is characterised by a strongly developed system of aeriferous spaces especially in aerial roots and pneumatophores. Flood (1978) states: 'Mangroves' occur on the reef flats of the low wooded island variety.

A 'mangrove swamp' is the area and environment in which a clustered group of mangroves are growing. 'Mangrove swamps' form only in protected areas or along open areas that are reached by waves of low energy. Several species of mangroves may be found in a 'mangrove swamp'. (Figure 1)

38 Boat

Any vessel for transport by water. (Plate 2)

39 Wharf

Any structure built on the reef for the purpose of mooring vessels. (Plate 2)

40 Building

Anything built or constructed on cays or islands. (Plate 2)

41 Walking Track

(Plate 2)

42 Engineering Construction

(Plate 2)

43 Wreckage

Remains or fragments of anything that has been wrecked.

? Field Data Required

Field data is required to verify the interpretation. (Plate 1)

N Level III Not Used

LEVEL IV: CLASSIFICATION ACCORDING TO CONDITION, PATTERN AND MORPHOLOGY

Most of the entries in Level II are self-defined and therefore only selected entries are defined below.

10 Aligned Pattern

(Plate 4)

13 Reticulate

Closely developed small patch reefs which connect to form a 'reticulate pattern'. Patch reef displaying a 'reticulate pattern' generally have a regular size and a regular distribution. An example is One Tree Reef lagoon. (Plate 5)

14 Dispersed Pattern

Small patch reefs which are isolated, discrete and widely dispersed. An example is the lagoon on Heron Island Reef. (Plate 5)

15 Remnant Pattern

The patch reefs are of irregular size and distribution. In some cases, this pattern is reminiscent of the submerged reefs that occur in the back-reef zone, and it is quite possible that they represent the relics of the back-reef zone that was surrounded by the converging ends of the ring or mesh reef. In other instances they appear to be the remnants of an old prong system that has degenerated as the lagoonal area was sealed off by marginal growth. Because of their remnant appearance, these patch reefs display a 'remnant pattern' (Maxwell, 1968). (Plate 5)

16 Deltaic Pattern

The following definition is provided by Veron (1978b): The 'deltaic pattern' is at the reef back in the deltaic reef system. (Moving northward over the deltaic reefs), the deltaic appearance becomes increasingly more complex; major channels become less distinctive and are increasingly confused with an interlocking network of smaller channels. Thus at latitude $10^{o}10'$S, the 'deltaic pattern' consists of a thoroughly confused network of irregular elongate patches intermixed with a mass of channels, most of which are small and shallow. the general appearance is broadly similar to the outer edge of a mature river delta. (Plate 7)

LEVEL V: CLASSIFICATION ACCORDING TO PRESENCE

The entries in Level V are self defined in the classification system.

Figure 4. Reef profiles of the more common reef types showing the physiographic zonation (reproduced with permission from Maxwell, 1968).

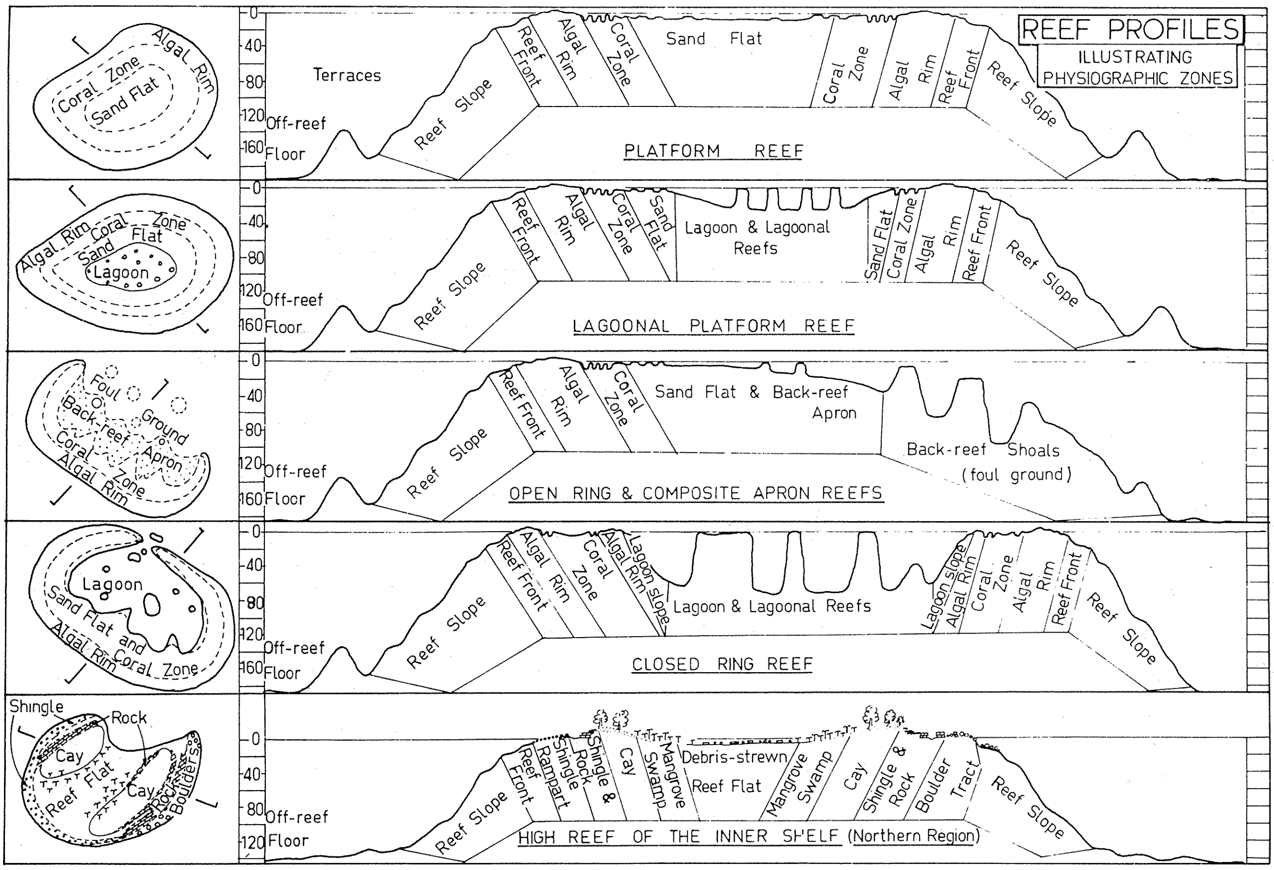

Figure 5. Schematic diagram of Unnamed reef (18°15'S) illustrating zonation (from an image by Hopley, 1982).

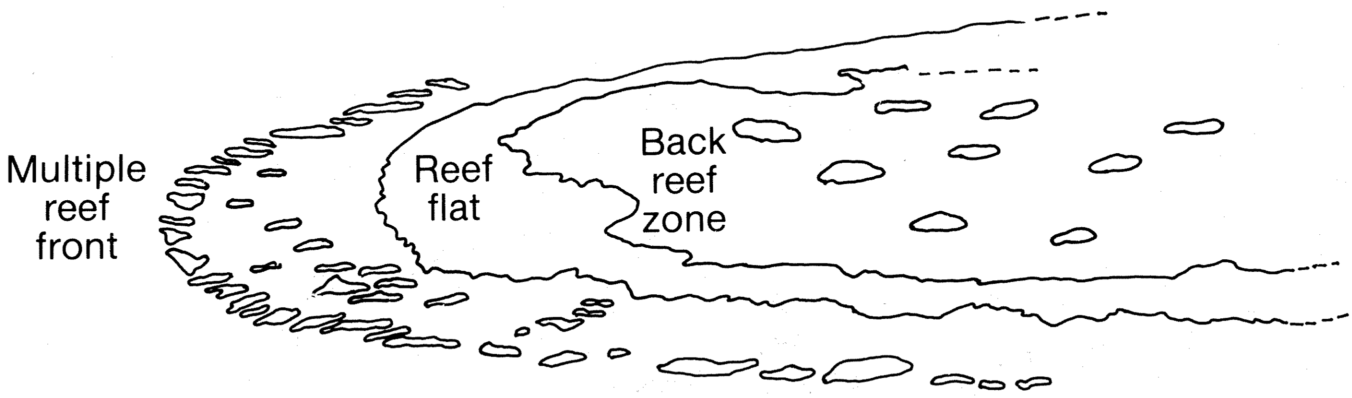

Plate 1. Percy Isles group of reefs (20^{o}S). Landsat 3 MSS image produced by CSIRO Division of Water and Land Resources.

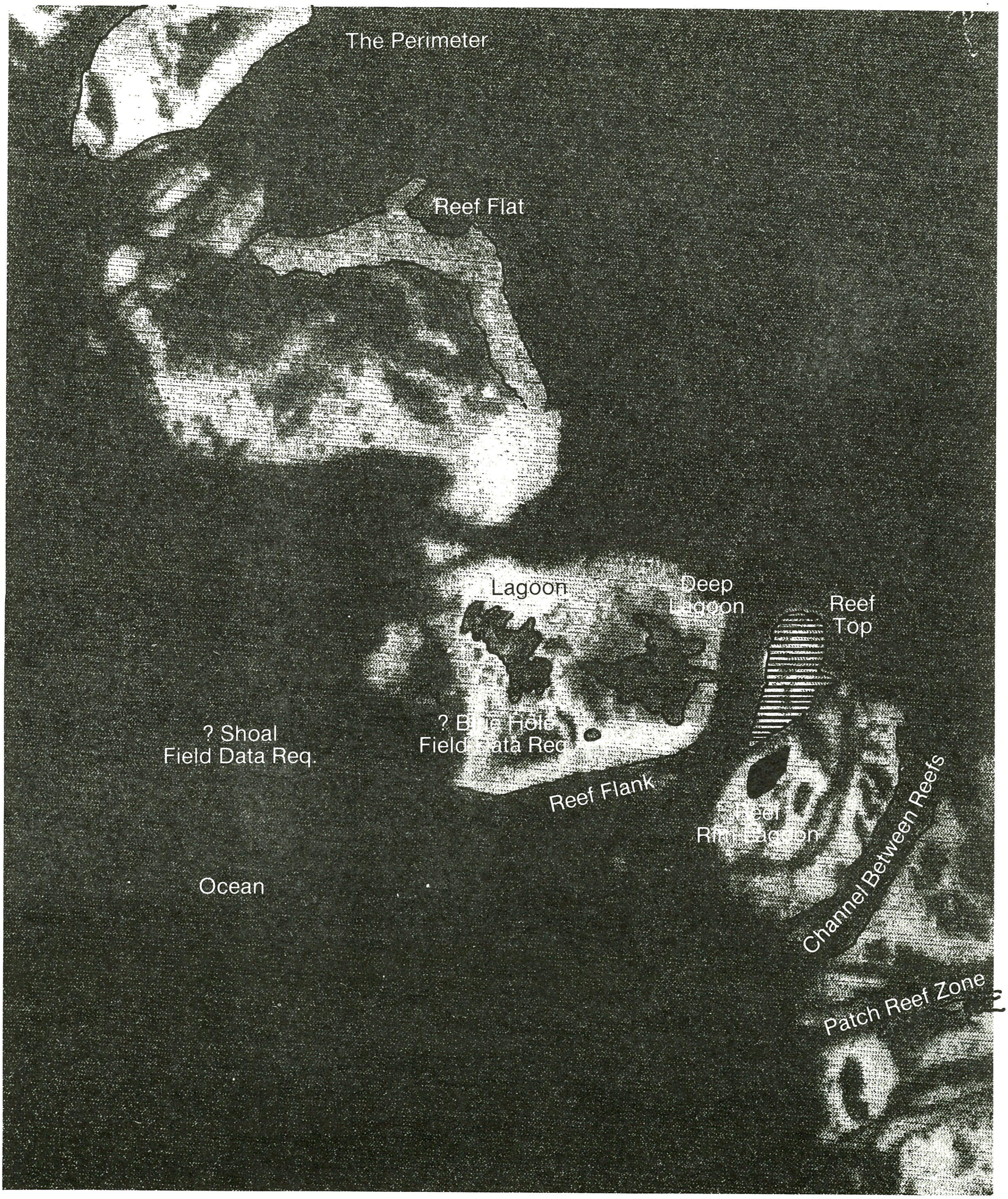

Plate 2. Green Island Reef, 20/7/78, 0915 hours.

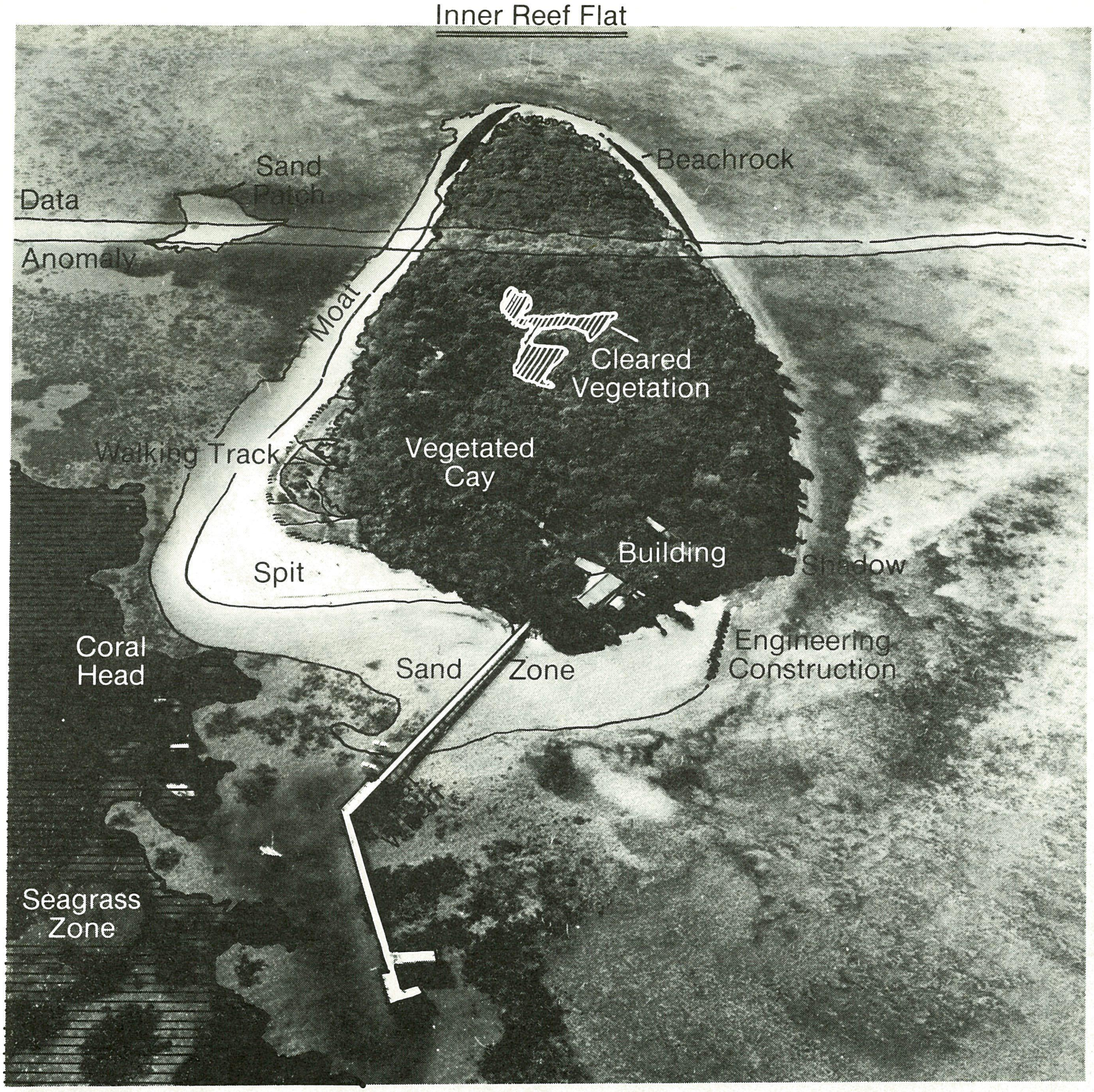

Plate 3. Lizard Island and fringing reef. Photograph reproduced with permission from the Australian Survey Office.

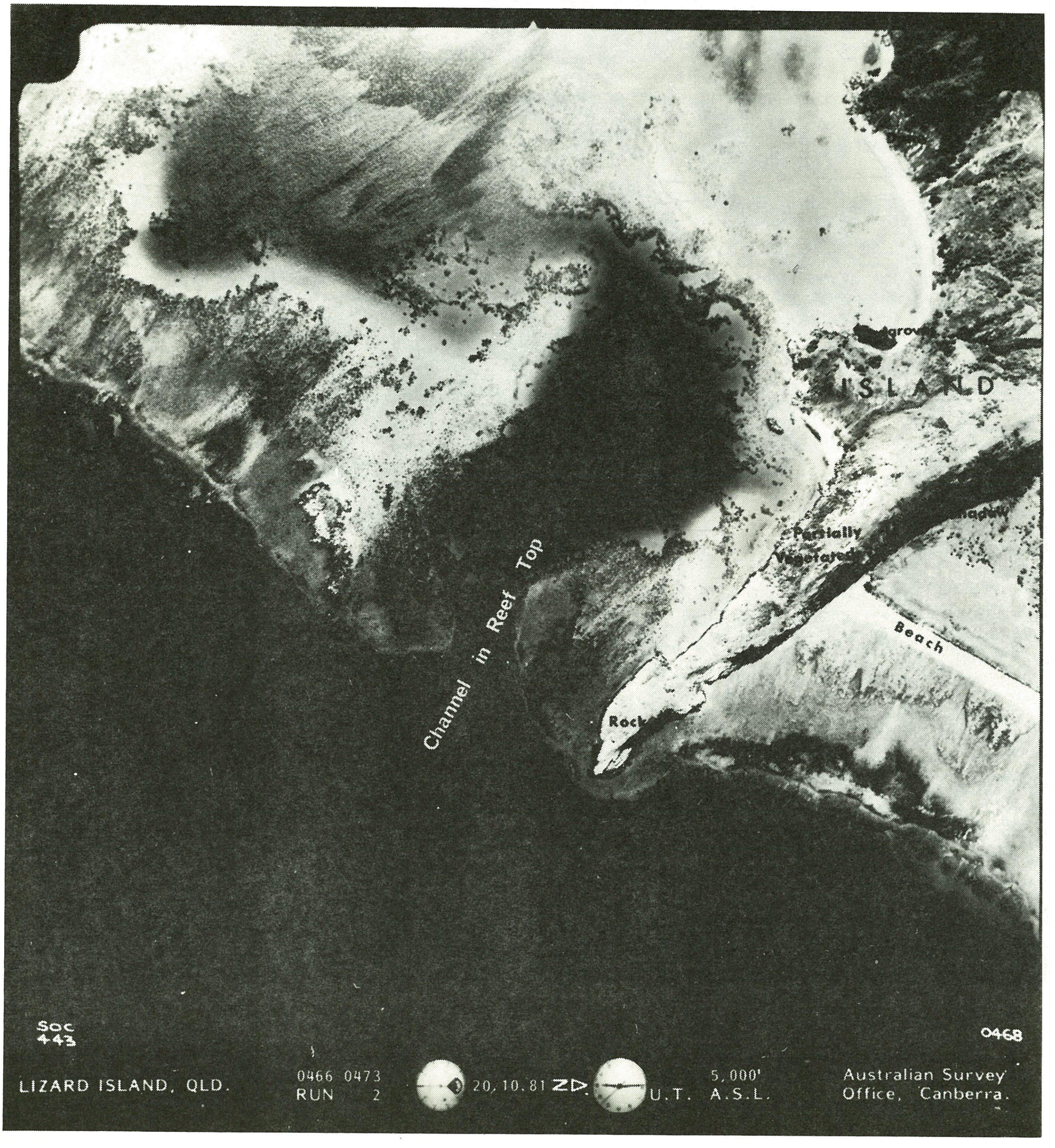

Plate 4. Fitzroy Reef, Capricorn-Bunker Group. Photograph reproduced with permission from the Australian Survey Office.

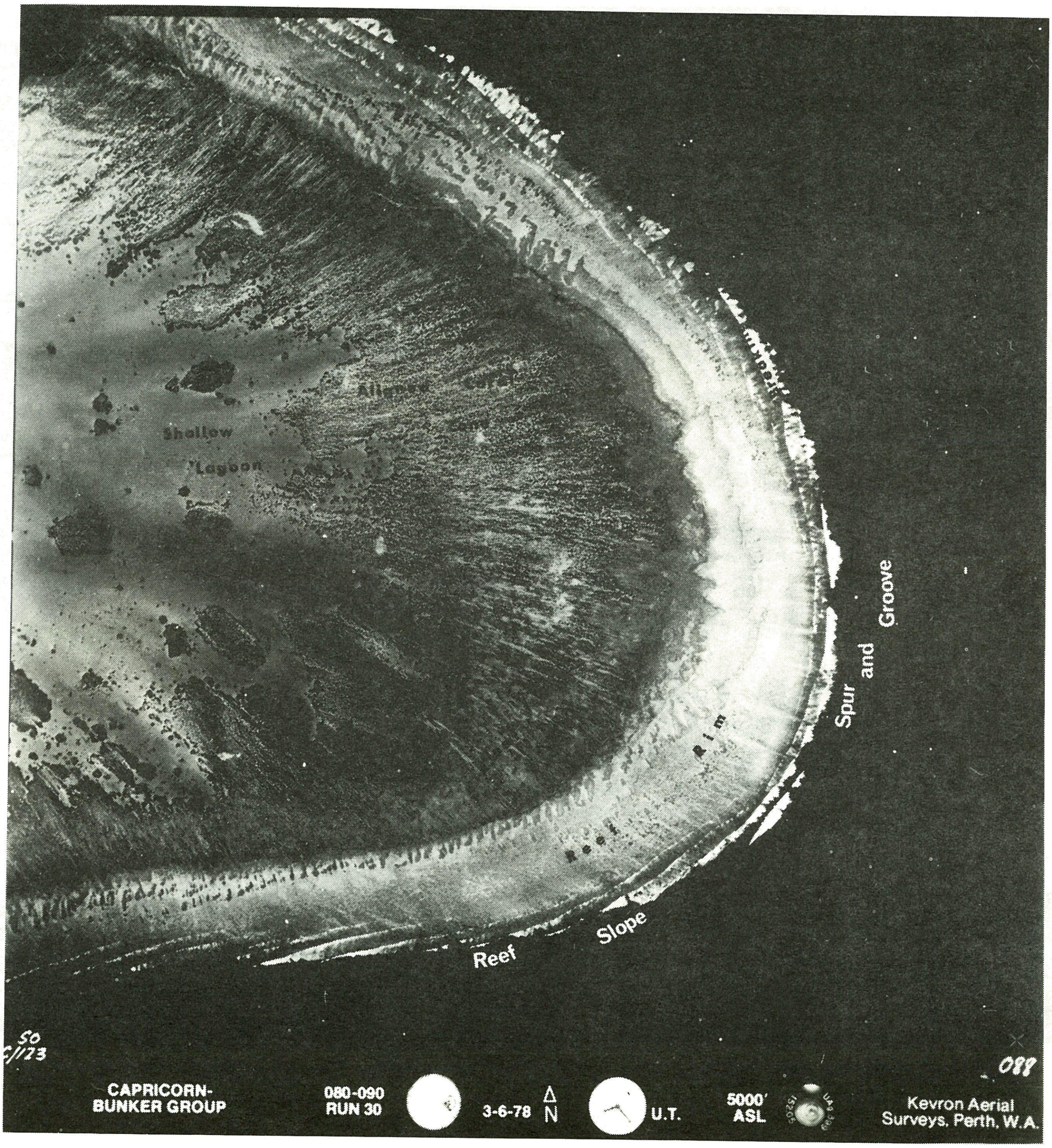

Plate 5. One Tree Reef, Capricorn-Bunker Group. Photograph reproduced with permission from the Australian Survey Office.

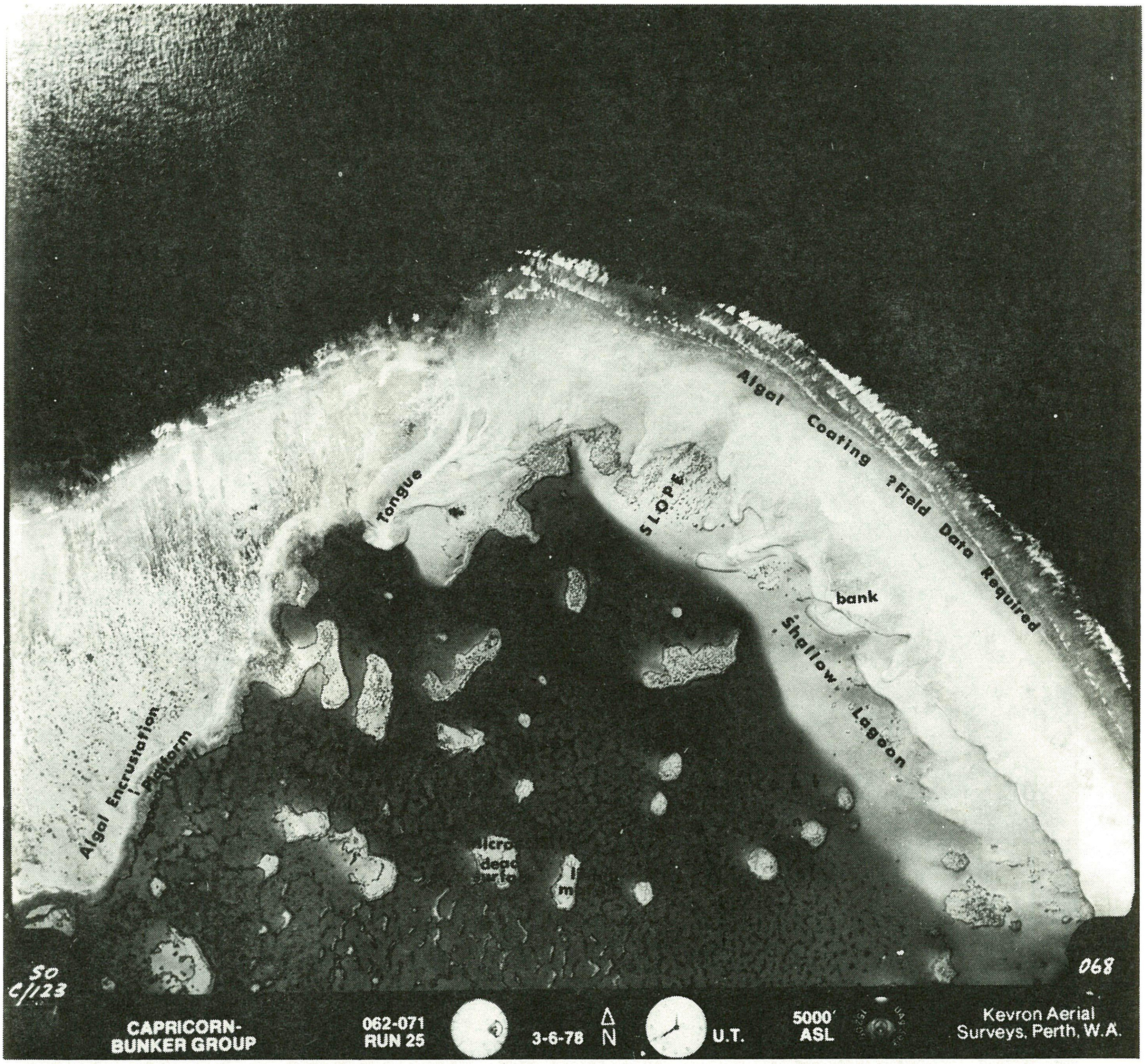

Plate 6. Frame 093; Run 10; 086-094; 18/10/78; 15 000 ft ASL. Photograph reproduced with permission from the Australian Survey Office.

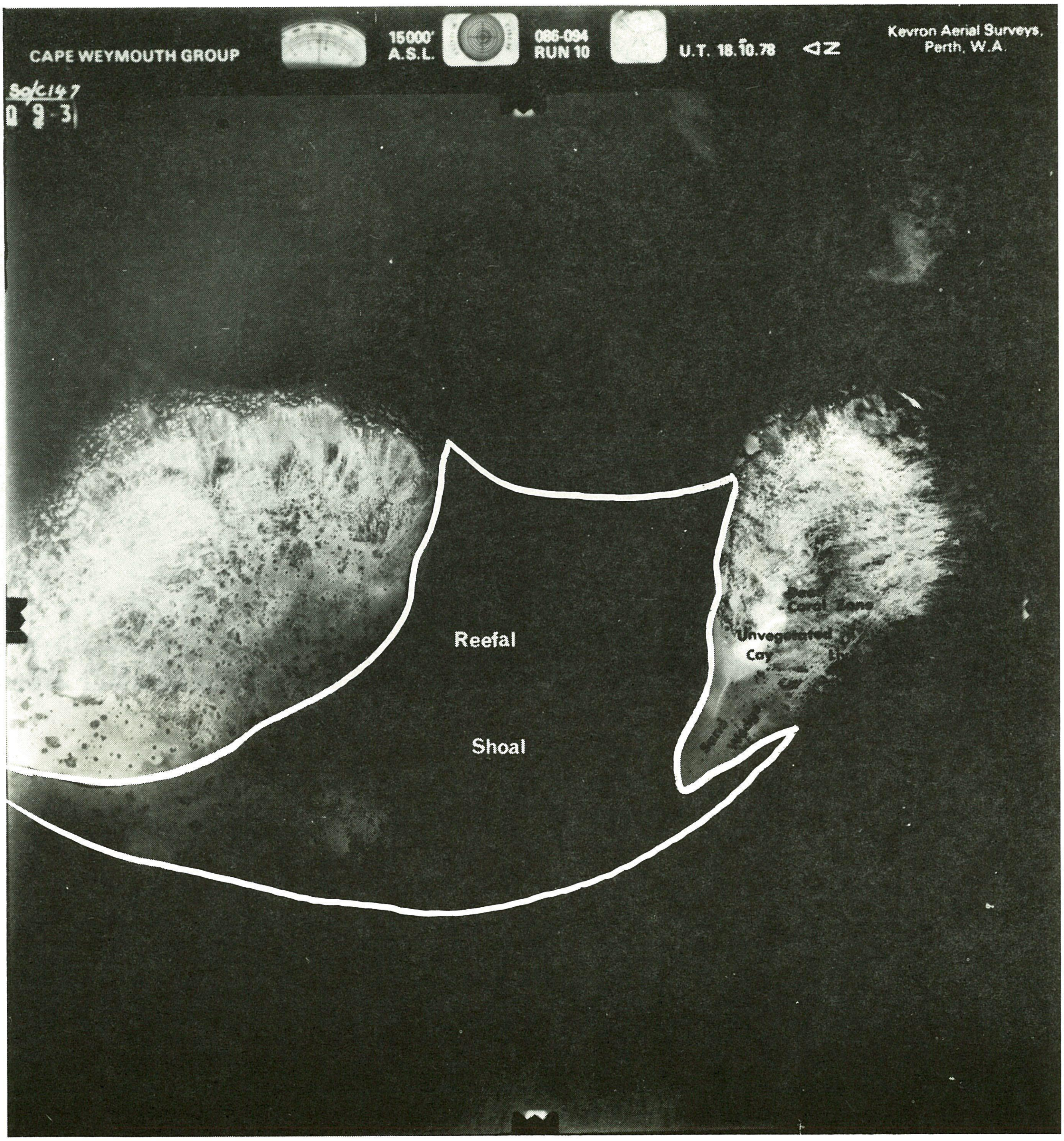

Plate 7. Northern reefs. Photograph reproduced with permission from P.J. Isdale.