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).

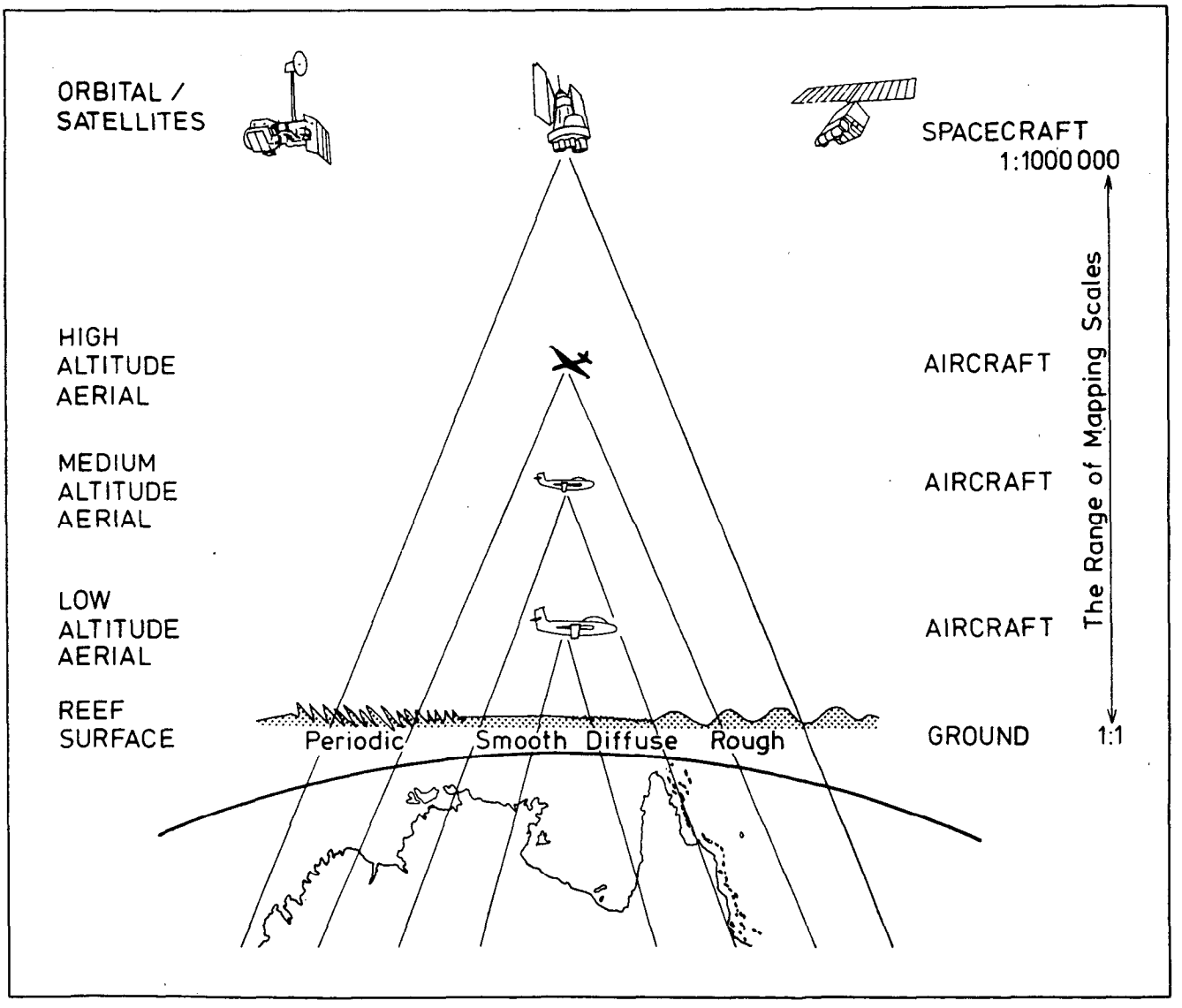
4.1.1 Hierarchical component

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
Systematic Recording System	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	32613N 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	32613NN 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.	