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APPLICATION OF ENTROPY-RATIO MAPS TO SURFICIAL REEF FACIES, GREAT BARRIER REEF

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Entropy-ratio maps enable mapping of surficial facies of coral reefs at any chosen resolution. A ternary classification uses detritus, framework encrustation, and pavement as end-members, and is subdivided on the degree of mixing of these. The classification is sensitive to all reef environments, particularly to zonation across reef flats. It can also be superimposed on other classifications. An example is given of its use in the Great Barrier Reef.

Introduction

This paper describes an entropy-ratio classification of surficial facies and demonstrates its application to the mapping of coral reefs. Field procedures and techniques are outlined.

In reef studies there is a diversity of disciplinary interests, each with its own concepts and information to be presented in maps. Within each discipline there is a range of possible classifications that can be used to categorise data, from purely descriptive to totally genetic, and qualitative or quantitative in approach. Any one classification, however, is likely to be too specific to be extendable to other disciplines or to describe interdisciplinary relationships. One way of overcoming this problem is to superimpose the different classifications. Classifications may be general or specific, but if they have a well-defined quantitative basis they will be of much more value. There is also a need, particularly in reef studies, to standardise data- categorising procedures within disciplines, to ensure comparability of data and, thereby, the identification of reef variation both on local and regional scales (Stoddart, 1969). Entropy-ratio classification provides just such a standardised quantitative basis and entropy-ratio maps are ideally suited for interdisciplinary studies.

An entropy-ratio map is a facies map based on the degree of mixing of three end members of a given stratigraphic unit and that indicates by map pattern the nature of the lithologic 'mixture' through which a given end member is approached (Bates & Jackson, 1980; Forgotson, 1960).

In a Bureau of Mineral Resources' (BMR) reconnaissance study, an entropy-ratio classification has been developed for comparison of surficial reef cover, and used to produce maps of Wheeler, Viper, and East Stanley Reefs in the Great Barrier Reef (BMR, 1982). Geologically, the nature and distribution of surface facies of reefs can be extrapolated for interpretation of the subsurface, using Walther's law (Friedman & Sanders, 1978), and the entropy-facies classification can be modified for use on the subsurface sequence. However, the classification and maps discussed here refer only to the surficial sediments (uppermost 5 cm, approximately).

Concept and method

Surficial facies are defined in a ternary system using framework encrustation, pavement, and detritus as end members (Fig. 1).

Framework encrustation (F) encompasses all the substrate-bound hard skeletons of sessile organisms that construct open interlocking frameworks. The skeletal material itself, therefore, controls the morphology of the surface. The most significant organisms on present-day coral reefs are corals and coralline algae (Fig. 2a), and, to a lesser extent, substrate-bound pelecypods.

Pavement (P) is a cemented or bound surface with no active framework encrustation (Fig. 2b) and, arbitrarily, less than 5 cm of detrital cover. It is commonly a relatively flat eroded

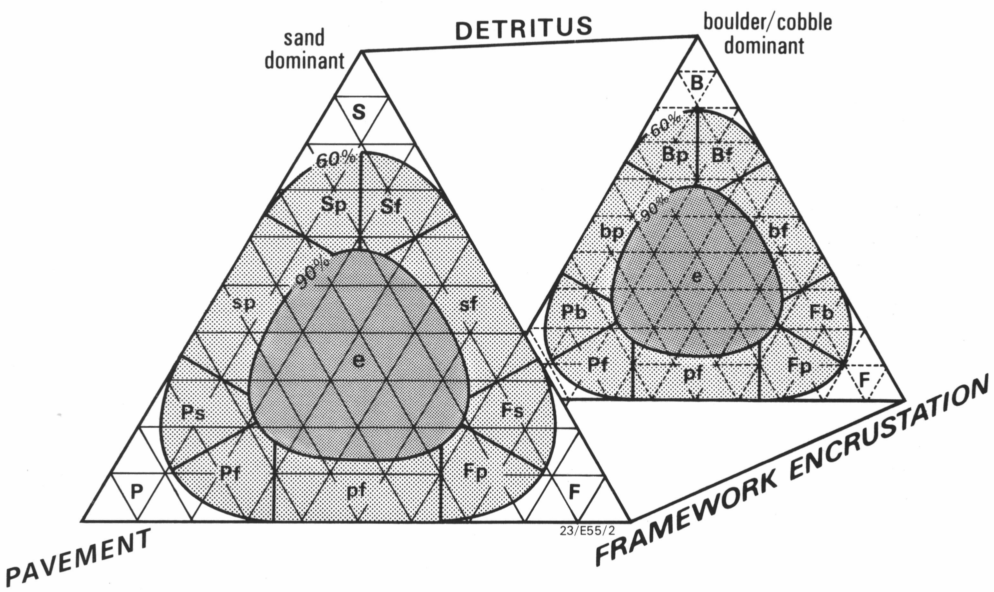
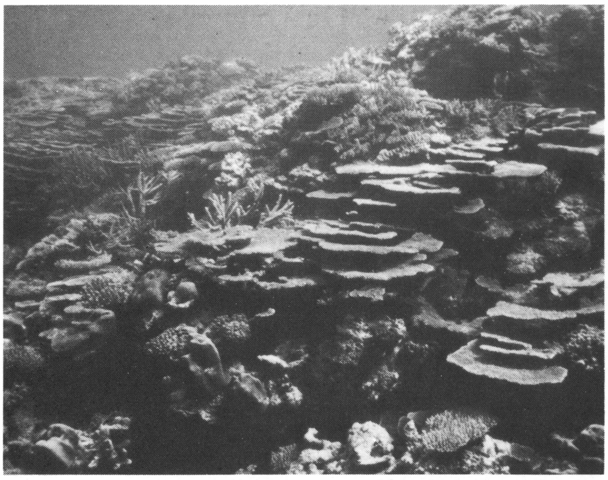
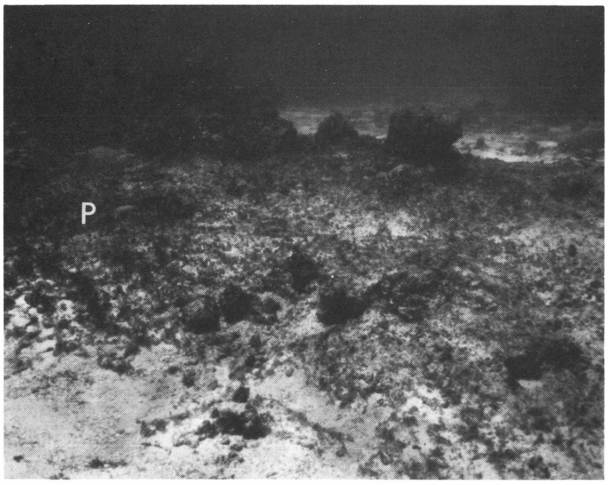


Figure 1. Classification of surficial cover facies.



a



b

c

Figure 2.
A–Total framework encrustation of the windward reef crest at the change of slope from vertical wall to shallow subtidal ramp. There is extensive cover of overlapping platy and branching forms of *Acropora* at moderate depth, and more compact coral forms at the shallowest subtidal level. Viper Reef, (2 m at low water). B–Slightly raised pavement (P) interspersed with areas of detritus (light tones in foreground and background). Small bombies of framework encrustation rise off the pavement, which has low, scattered soft algal tufts. Viper Reef (1.5 m at low water). C–Profusely bioturbated sands with mounds of callianassid origin. Scattered patches of filamentous algae cover older sediment surfaces between mounds. Viper Reef (15 m at low water).

surface exposing indurated sediment and relict reef framework. It may also be hummocky and smooth, pitted, or potholed. Exposed pavement is commonly colonised by endolithic and epilithic soft algae, which give it a dark grey-green to brown-green appearance. Lighter-toned areas probably indicate grazing of the algae or abrasion by sediment.

Detritus is unconsolidated sediment (Fig. 2c), on most reefs almost exclusively calcium carbonate. It comprises reworked debris of disarticulated skeletons, whole tests of foraminifera, and material eroded from framework encrustation, pavement, or existing detritus. Detritus is subdivided on the relative abundance of fine and coarse components into sand-dominant (S) and boulder/cobble-dominant (B) categories, giving two parallel ternary systems. The sand-dominant group has a predominance of particles less than 1 ø *f*2 mm diameter), compared to the boulder/cobble-dominant field with particles predominantly above –6 ø (64 mm diameter).

The three substrate types, framework encrustation, pavement, and detritus, are invariably intermixed in most reef environments and, depending on the mapping scale used, cannot always be separated. The ternary fields are, therefore, subdivided into levels of relative entropy, which express the degree of mixing of the substrate types. (Relative entropy as defined by Pelto (1954) is the ratio of actual entropy to the maximum entropy which could be obtained with the same set of components.) With a limit of 60 per cent relative entropy, three fields are defined adjoining end members at the apices of the ternary system (Fig. 1). A field of maximum relative entropy is defined within the 90 per cent contour. Between the 60 per cent and 90 per cent contours of relative entropy, an intermediate zone is subdivided into 9 fields that are most easily distinguished from reconnaissance observations. With the subdivision of detritus into sand-dominant and boulder/cobble-dominant categories, parallel ternary classifications are produced. The maximum-entropy zones of the two classifications are undivided, and the total number of facies is 20 (Fig. 1).

In some circumstances, this degree of subdivision may be cumbersome for communication or comprehension. In these cases the number of classes in the 60–90 per cent relative entropy field can be reduced from 9 to 3 in each ternary system by grouping the intermediate classes: Sf + sf + Fs → SF; Sp + sp + Ps → SP; Pf + pf + Fp → PF. The number of classes in the whole classification is thus reduced to 10. In this paper, however, all 20 classes have been used, to demonstrate the maximum resolution.

Mapping methodology

Preliminary airphoto interpretation is used to map zonal trends. Control sites are then selected on traverses across these zones for assessment by SCUBA divers. The control sites are circular and of a size appropriate for the map scale and resolution required. For 1:10 000 maps, areas of 50 m diameter have generally been used, except where photopatterns indicated smaller but distinct facies zones. Details are recorded on underwater slateboards (Figs. 2c, 4) and later transferred to a magnetic tape file for processing. Additional information is acquired from dive traverses on the reef margin slopes.

The main limitation to photo-interpretation is the decreasing resolution with increasing water depth (Fig. 3), because light penetration is dependent on water clarity, surface texture, and sun angle. Bathymetric profiles offer a limited extension to interpretation for depths that preclude SCUBA surveys. Ideally, submersible traverses or side-scan sonar techniques have greatest potential in these deeper zones.

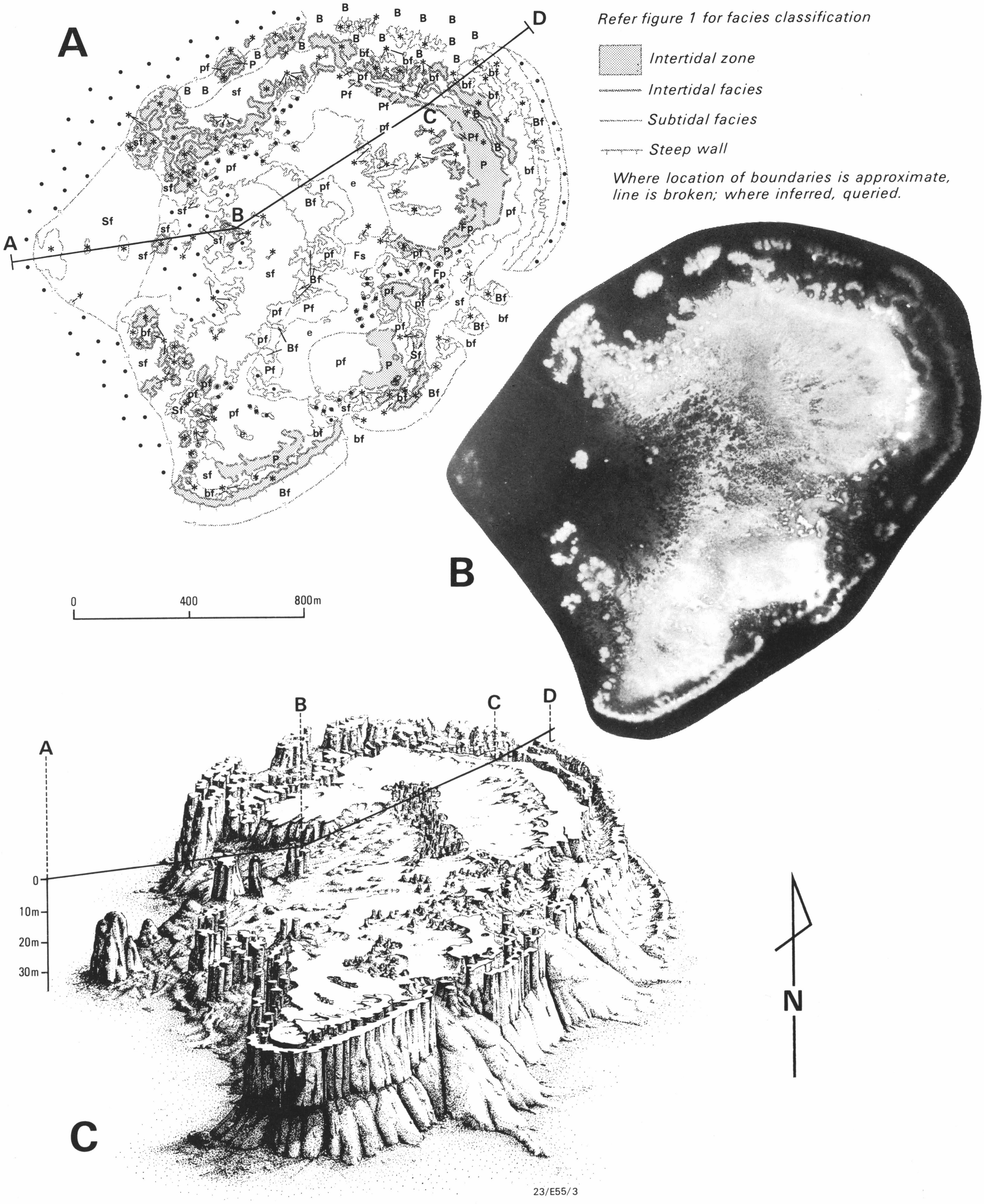


Figure 3.
A–Surficial facies map of Viper Reef, using classification in Figure 1 (from BMR, 1982). Comparison of the facies distribution with airphoto features shows the transtional nature of facies on gentle slopes and more distinct boundaries on steeper slopes. B–Aerial photograph of Viper Reef. C–Three dimensional view of Viper Reef, demonstrating bathymetric features of the reef (from BMR, 1982). The contrast between the steep-walled windward margin and the gently sloping leeward sediment wedge is a feature common to many reefs in this region.

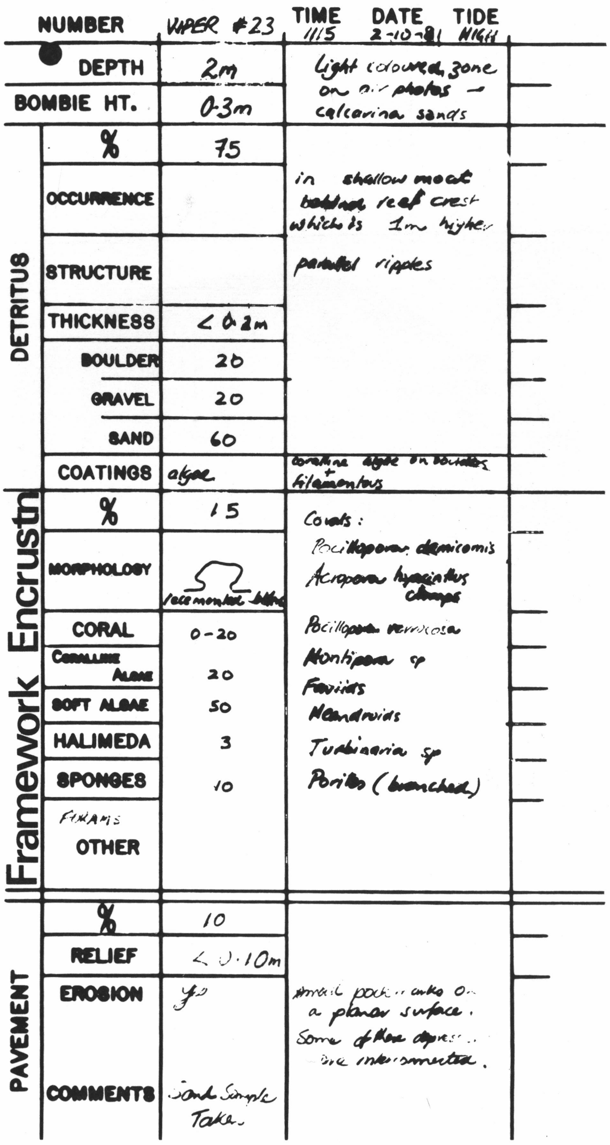


Figure 4. Data inventory on slateboard used for each dive-control site.
In addition to percentage cover of surficial types, descriptive elements including coral species are recorded for later compilation of species distribution.

End-member percentage abundance at each control site is plotted on the ternary system to determine the entropy-based facies type. The resolution of end-member distribution varies with map scale. Entropy levels are proportionally higher at smaller map scales. It has been found that, at any scale, resolution of mapping decreases with increasing water depth. Depending on the proposed usage of the map, resolution may be either standardised over the whole map, which requires acceptance of the lowest level of resolution, or be kept at various levels to preserve detailed information in shallower environments.

If the maps are printed in four colours, one for each detrital type and the other end members, the other facies are represented by intermediate colours (BMR, 1982). Where surficial facies are not superimposed on detailed bathymetry, tidal zones can be differentiated with different line weights on or between facies boundaries. Supratidal (above highest astronomical tide), intertidal, and subtidal (below low-water datum) zones are differentiated in Figure 3a.

Viper Reef

Located at 18°52′30″S, 148°08′45″E, on the edge of the continental shelf, east-northeast of Townsville in the central Great Barrier Reef, Viper Reef is about 2 km long and roughly curved about an east-northeast axis (Fig. 3a, b). The south-eastern arm of the reef front is longer and more continuous than the northern front. The windward (east to southeast) main reef front (Fig. 2a) and the outer ridges (Fig. 5) are separated by deep, steep-sided moats with detrital floors (Fig. 3c) and are completely covered by framework encrustation. Leeward (west) of the reef front is a flat pavement zone (Figs. 3a, 5), which delineates the shallowest windward zone. This pavement is partly covered by low-relief shoals of boulder/cobble detritus. Further leeward, this pavement, which is at first variably encrusted with framework, slopes gently westward, through transitional detrital facies, to more framework encrustation interspersed with boulder/cobble detritus and then to a high-entropy reef flat. At depths greater than 5 m, the floor becomes predominantly sand (Figs. 2c, 3a). This example demonstrates that in areas of subdued relief the boundaries of most surficial facies are diffuse. Facies boundaries are sharper in areas of higher relief, where they generally coincide with breaks in slope at the base of steep walls (Fig. 3a, c).

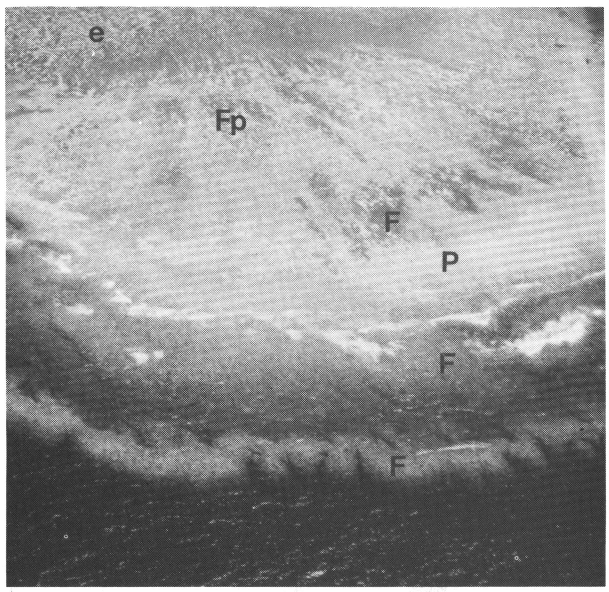


Figure 5. Oblique aerial view of Viper Reef from the windward side, showing distinct outer ridges (F), moats, main reef crest (F), pavement (P) and transition (Fp) to increasing entropy (e) on the reef flat.

Discussion

The correlation of mixtures of substrate types with entropy zones gives a classification that can categorise both variation of the reef surface and the relative dominance of substrate types.

The surface of Viper Reef has been effectively classified by 13 of the possible 20 classes (Fig. 3a). Using the simplified classification, only 8 classes would be needed. Other reefs from the same region as Viper Reef show different substrate variation and facies proportions. For example, Wheeler Reef (BMR, 1982) is classified with 12 of the possible 20 classes, including one not present on Viper Reef. East Stanley Reef (BMR, 1982) requires 15 classes, including two not on either Viper or Wheeler Reefs. Between these three reefs in one province, there is significant variation of substrate type and distribution that is not solely related to geomorphology. With a broader comparison of reefs, this variation would undoubtedly be greater.

Many zonation schemes, mostly based on geomorphology, have been applied to the description and mapping of reefs, and various disciplinary schemes have used a mixture of unrelated terms (e.g. Adey, 1975; Goreau, 1959; Hopley, 1982; Longman, 1981; Maxwell, 1968). These zone classifications offer easily comprehended generalisations for particular scales and, in some cases, specific provinces. However, their application to consistent quantitative mapping is very limited.

An additional problem with geomorphological categories is their lack of standardisation. Geomorphological nomenclature in the Great Barrier Reef has been extremely varied, and a generally accepted standardisation is yet to be resolved (Kuchler, in press, a). Without standardisation of terms there is little scope for meaningful comparative analysis of reefs beyond that of the nomenclature itself!

In contrast, the entropy-based classification has three distinct advantages in addition to its internal consistency.

1) It is applicable over a large range of scales, as it can accommodate different levels of resolution. LANDSAT imagery is presently being assessed for its applicability to regional mapping of the Great Barrier Reef (Jupp & others, 1981; Kuchler, in press, b), and the simplified entropy classification with only 10 classes has been successfully applied to this imagery by using an additional parameter, water depth, to allow correlation of substrate type with LANDSAT spectral classes.

2) Because of its simplicity and the minimal subjectivity in differentiating end members, the classification can be used for local, regional, or worldwide comparisons. It is the practicality of such standardisation that Stoddart (1969) saw as essential for comparing reef studies and the recognition of variations at local and regional scales. Comparison of gross sedimentological and ecological factors is possible with surficial facies, regardless of the details of biotic elements in the reef community.

3) It can also be applied to the subsurface and to ancient reefs, where the biota and communities were quite different. For this application, sampling needs to be modified to accommodate differences in preservation of pavement, a two- dimensional feature, and detritus and framework encrustation, which are preserved as three-dimensional bodies. From the geological viewpoint, it offers a practicable descriptive and genetic basis for comparison of surficial facies with those preserved in the subsurface. Classifications with morphological criteria are limited in that they can only be applied to the subsurface if the reef structure and its over-all relief are known or if morphological features are first interpreted in the context of specific substrate associations.

Conclusions

An entropy classification of surficial facies, using framework encrustation, pavement, and detritus as end members, can be used for mapping coral reefs at all scales and degrees of resolution, and for comparisons between reefs. Facies derived from this classification can be superimposed on bathymetric, biological, morphological, and other classifications, offering a powerful and objective approach for communicating the character and complexity of reef surfaces.

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