CLASSIFICATION OF EMERGENT REEF SURFACES

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Anyone who has attempted serious bibliographic work on "coral reefs" (sensu latissimo), or on islands, or on coastal zone features, has likely had a feeling of being overwhelmed by the sheer amount of published (and unpublished) information that has accumulated. The realization inevitably leads to analytical attempts to break the mass down into more manageable fragments or "fields". These are normally arranged into classifications of one sort or another. The nature of such analyses and classifications ordinarily is determined by and reflects the particular interests and biases of those who make them.

Sometimes, in any area of knowledge, one finds that a more or less satisfactory scheme already exists, and can be accepted and used or modified. Most often, because of differences in purposes or objectives of one's investigation, available schemes are not entirely appropriate and must be modified to suit new requirements, or new schemes must be worked out. This may be true at any level in the hierarchy of the classification of knowledge.

The present attempt resulted from an essay on the present state of knowledge of the floras and vegetation of emergent reef surfaces--the terrestrial plant cover of relatively recent emergent reefs.

Rough or vague arrangements of information on these may be found in almost any consideration of the vegetation of islands, or of a single island or group, less frequently in floristic works. These schemes usually assume a knowledge or familiarity with "the obvious" and often use undefined general units or local folk terms and concepts. They are often more or less satisfactory for the immediate area concerned, but become less os or unsatisfactory when extended, generalized, or adapted to other regions. The scheme here presented evolved because none of the familiar ones was broad enough, precise enough, or exactly served to facilitate understanding of the botany of emergent reef surfaces.

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Even the term "emergent reef surface" presents difficulties. Obviously it means the surface of a reef that is above high tide level. But what about fossil reefs? In a sense, all even slightly emergent reefs, even elevated beach-rock, are fossil reefs. How far back should one go geologically? Ideally, emergent reef surfaces should be surfaces that have never been buried by massive sedimentary deposits or by volcanic ejecta--either ash or lava--though they may bear accumulations of sand, gravel, boulders or other reef-derived material. They are calcareous in composition except for small amounts of pumice or other water-borne or wind-borne substances. This means that the plant cover of these surfaces derives from successful plant colonizations over the period since the emergence of the reefs, by lowering of sea-level, tectonic uplift, or accumulation of water-carried calcareous material (bars, spits, or storm ridges).

This definition of emergent reef surfaces excludes most geologically old or ancient reefs, as their exposed surfaces have mostly been formed by erosion of overlying non-reef material. Usually their limestones are of quite different character than those of the more recent reefs that have never been buried. Their floras bear little or no relation to the strand flora or enriched strand flora of modern emergent reefs. In general, fossil reefs of Quaternary to Recent age provide emergent reef surfaces. Some are classed as Plio-Pleistocene, and in rare instances as Miocene (e.g. the Barrigada Limestone of Guam, and limestones on Mangaia, Cook Islands). Of course, there has been more or less chemical erosion, and even abrasion, on all or most such surfaces.

The following scheme will provide a basis or framework for correlation of the plant species and vegetation with appropriate variations in the emergent reef habitat. It is arranged in outline form, but with sufficient descriptive comment to make the distinctions and relationships clear. The principal basis of the classification is topographic and locational, but these factors are strongly correlated with degree or lack of induration, and degree of chemical erosion and consequent roughness or ruggedness of the surface. Almost all of the units listed show differing facies in areas of greater or less rainfall. Solution of the limestone and consequent change or degradation of the surface may be more active in areas of greater rainfall, as may the effects of plant roots and humus. Different burrowing animals may affect the surfaces in different ways, and their distribution may be influenced by the climate. The rainfall factor strongly influences the vegetation and flora directly, and the more abundant soil formation in wet areas produces perceptible effects on the reef surface. Salt spray, too, affects the nature of the erosion of coral limestone, in a way not fully understood, at least by me. This will be described at an appropriate place in the classification.

(1) A convenient primary subdivision of emergent reef surfaces is into (1.1) <u>oceanic</u>, that is, formed on or around islands which have never had any connection or close proximity to continental or major island land-masses, vs. (1.2) <u>continental</u>, formed on the shores of continental

or large island land-masses. These categories are appropriate for biological purposes, because of the differences in complexity of oceanic vs. continental biotas (see 1.2 below).

(2) Oceanic emergent reefs are either (2.1) atolls and table reefs, not closely associated with non-calcareous islands, or (2.2) fringing and barrier reefs, formed around higher, usually volcanic islands.

(3) Atolls and table reef surfaces are either essentially at (3.1) sea-level or (3.2) relatively uplifted.

(4) Essentially sea-level reefs may be of (4.1) loose, unconsolidated material, sand, gravel or boulders, or of (4.2) indurated such material or in-place reef structure; either kind may bear temporary local accumulations of loose sand (dunes) or gravel storm-ridges which may reach over 3 m, rarely considerably more.

(4.1) Unlithified reef surfaces, including sand cays, islets and bars, are loose accumulations of sand-size or larger foraminiferal tests and fragments or entire skeletons of other calcareous animals and plants. In areas where the ocean is generally only slightly or moderately turbulent there may be, especially on lagoon margins, deposits of precipitated or triturated silt-size material. This material is usually blown away by wind but may be held by algal crusts or evaporite salt crusts. Cays of loose material tend to be changed frequently by storms and wave action, at least until they become well-stabilized by vegetation or their margins become protected by intertidal beach-rock formation.

(4.2) Lithified atoll islets and table reefs have at least parts of their surface of a cemented reef-conglomerate or a lime-sandstone platform, or of bedded atoll phosphate rock (Jemo soil). There is little agreement as to the circumstances under which such lithification takes place, but the physiography frequently suggests that it happened during previously higher post-glacial sea-levels of 2 or 3.5 m above present. The phosphatic lithification is associated with present or past Pisonia grandis forests and roosting or nesting of sea-birds. Lithified surfaces on these very low islands are usually flat, but older ones may be rough or pitted by chemical erosion.

(5) Elevated reefs may be either (5.1) slightly raised (4-8 m) or (5.2) substantially more so, and almost always at least mostly indurated, but often with some perched loose material, storm- or wind-deposited. Surfaces may be either relatively flat, or dissected; older strongly elevated reefs may be eroded into (5.3) karst topography, but karsts also may be cut into much older limestones of other than reef origin. This distribution may not be easy to establish.

(5.1) Slightly elevated atolls and table reefs. Usually partly of sand or gravel, but at least with a core or an extensive platform of conglomerate or "reef-rock" that extends locally to more than 4 m elevation. The lithified surface is flat and covered by loose deposits, or bare and either a flat "pavement" (platin) or a pitted, pinnacled,

or intricately dissected or eroded into a sharp "fretwork" (champignon), or less so (pavé). These parenthetical terms are Creole, used in the Western Indian Ocean islands, especially Aldabra. A Polynesian term for dissected slightly elevated surfaces is feo. Caribbean terms for sharply dissected surfaces are "dog-tooth" and "iron-shore". The very sharply and finely dissected or "fretwork" facies of this surface seems associated in someway with proximity to salt-water, perhaps exposure to salt spray. Simply pinnacled facies may be found more inland, out of reach of heavy spray. How sea-water, which is said to be super-saturated with calcium carbonate, can cause or accentuate chemical erosion of limestone is not clear. Long-term experimental work on this problem would be desirable.

(5.2) Elevated flat-topped reefs (10-200 m or more) not closely associated with high islands or continental shores are not numerous, and the surfaces of most of them have been destroyed or completely altered by phosphate-mining. On Nauru, for example, an artificial mini-karst or deeply (to 10 m) pitted-pinnacled new surface has been produced. Natural pinnacled surfaces exist on Henderson Island, nearly undisturbed. On Henderson, also, are relatively smooth surfaces of loose material or soil. Such islands are generally surrounded by cliffs, with or without a narrow flat coastal strip or shelf at or just above sea-level at base. The cliffs may be vertical or very steep, with, in places, ledges or caves. They may be undercut, intertidally.

(5.3) True karsts are a third sort, more often near larger islands (or on continental shelves). They are very rugged, with sharp peaks and ridges, steep rough slopes, and are often deeply undercut at base. Without careful geological observation it is not always certain whether they are cut in elevated reefs or in ancient limestones of other than reef origin. Good examples are the southern islands of the Palau group (except Angaur and Peliliu) and the Lau Group of Fiji (possibly continental rather than oceanic).

(2.2) Reefs around high islands. The difference between these and those listed above is important biologically because of the enrichment of the biota due to the proximity to the more diverse biota of the high islands. As with the reefs not associated with high islands, those in this category may be divided into (6.1) essentially sea-level and (6.2) significantly elevated above sea-level.

(6.1) Sea-level-fringing and barrier reef emergent surfaces are similar in most ways to those of atoll islets. The islets on barrier reefs are, in fact, scarcely distinguishable from those of atolls except for the proximity of a high island. Emergent fringing reefs may present a smooth, abraded surface, or a variously pitted one. Non-calcareous earth may wash or blow down onto the fringing reef surface, making possible the growth of more species of plants.

(6.2) Elevated reefs surrounding high islands may be (7.1) slightly elevated or (7.2) strongly elevated, as are those in open sea.

(7.1) Slightly elevated reefs, either barrier reef islets or fringing reefs. These present a series of surface features similar to those described above for slightly elevated atolls and table reefs (see 5.1).

(7.2) Elevated reefs - peripheral and terraces on slopes. These are frequently deeply dissected, sometimes labryrinthine. The "makatea" surrounding some South Pacific islands (e.g. Austral Islands) is an example.

(1.2) Continental reefs, lining coasts of continents and continental islands, comprise a series of categories parallel to that outlined above for oceanic island reefs but, by their geographic positions, carrying richer floras and more complex vegetation. Descriptions of such categories need not be repeated here. Continental reef surfaces are numerous in the Caribbean and western Pacific regions.

The above scheme is summarized in the accompanying diagram.

In a review of this paper the suggestion was made that the classification here proposed be related to previous classifications of the same phenomena. The literature on reef-classification is enormous and I am familiar with much, but by no means all, of it. By far the greater part of it concerns submerged reef features and the processes that produce them, the preoccupation of most students of coral reefs. Emerged features are mentioned incidentally, or in relation to such features as soils, geology, geomorphology, and land ecology. Descriptions usually apply to specific examples--atolls, islands, or localities. Many of the descriptive terms, and the phenomena referred to, are of wider occurrence or application, and are useful for general descriptive purposes while others are too limited or specific to be generally applicable. Many of the terms and features used or described in the present attempt are from one or more such papers, but nowhere have I seen a comprehensive description or classification of emergent reef surface phenomena. The one that comes closest is in the sections on Terrain and on Islets, as well as scattered through the text, of my volume on Military Geography of the Northern Marshall Islands (1956). This includes and describes many of the surfaces treated in the present paper, and furnishes much of its substance. However, it is limited to the surfaces found on the sea-level atolls of the Northern Marshall Islands and is not organized into a classification. It does not provide the inclusive array of emergent reef surfaces that exist and is not thoroughly applicable to all known atolls and barrier reef islets. Elevated surfaces are not treated at all.

I have read and been impressed by Stoddart's pungent discussion of the confused state of reef terminology in Coral Reef Research Methods (Stoddart and Johannes, 1978). I hope I have not contributed further to the confusion he described. It is noticeable that, after this pertinent discussion, the volume does not offer a terminology which would help avoid the difficulties pointed out, nor does it include any attempt toward a classification or orientation in the kinds of reefs or reef surfaces.

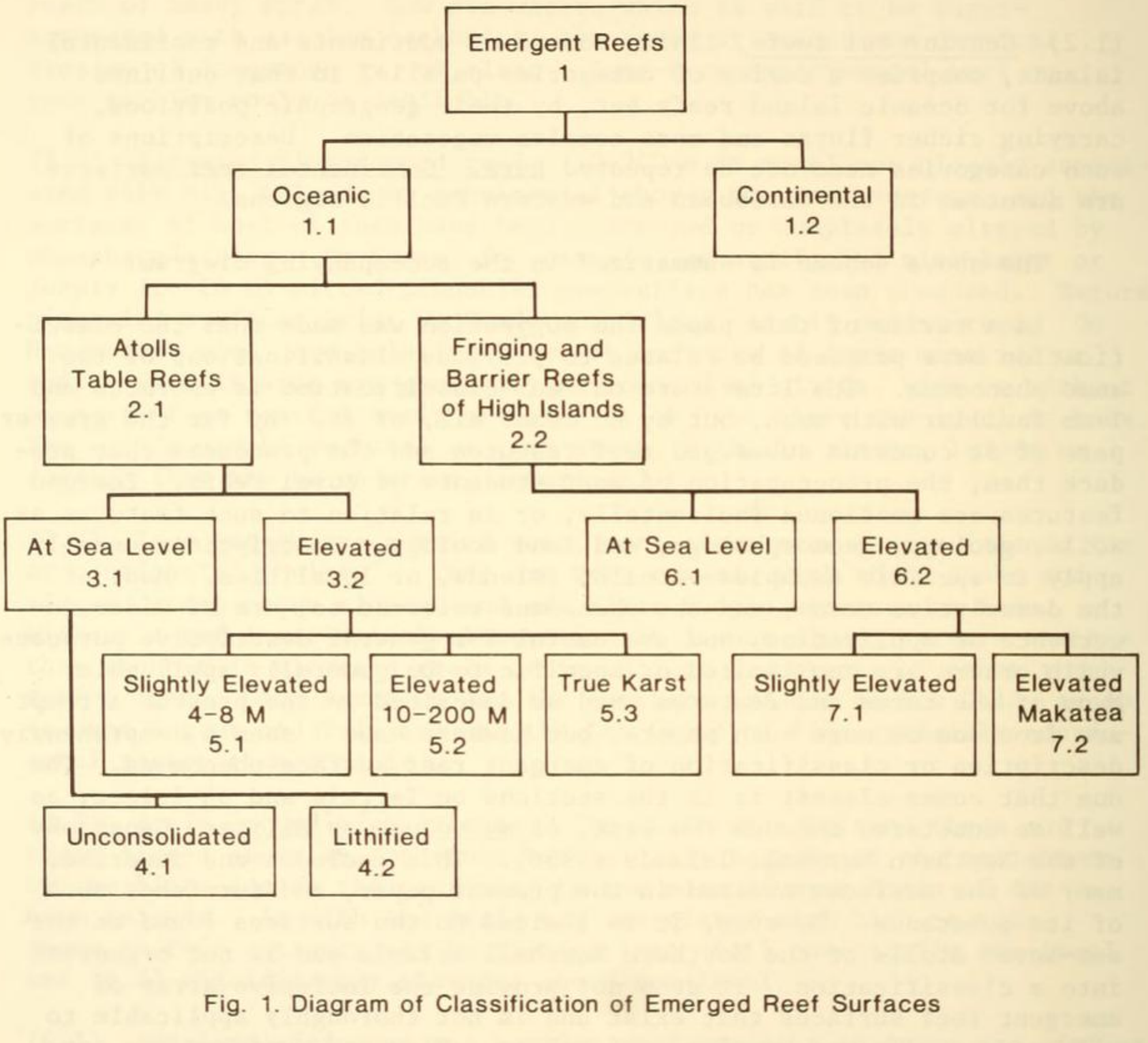

Fig. 1. Diagram of Classification of Emerged Reef Surfaces

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