Allen Coral Atlas
Mapping Class Definitions

Global Geomorphic and Global Benthic Map Class Descriptors

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Global Map Classes

The Allen Coral Atlas has two mapped levels – one that displays **global geomorphic zones** and another for **global benthic zones** commonly associated with shallow water tropical coral reefs.

The following guide explores both sets of map classes.

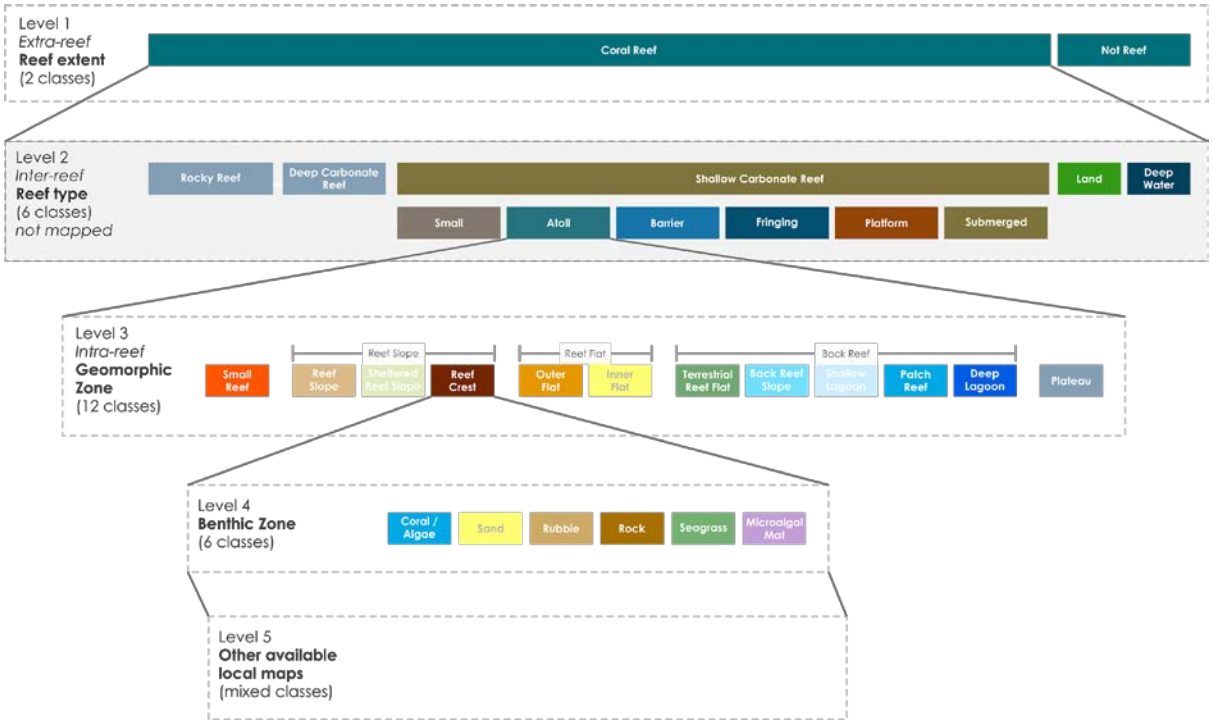

Figure 1. Typology for the Allen Coral Atlas map classes. Level 1 is a reef extent outline, distinguishing "reef" and "not reef". Level 2, Reef Type, is not displayed currently. Level 3 shows the 12 Global Geomorphic Classes that mapped based on pixel metrics and depth, slope and exposure attributes. Level 4 shows the six Global Benthic Classes. Level 5 integrates existing historic local scale reef maps that are not part of the Allen Coral Atlas mapping project.

Global Geomorphic Map classes

Class and colour		Definition
Reef Slope	219, 186, 136	Reef Slope is a submerged, sloping area extending seaward from the Reef Crest (or Flat) towards the shelf break. Windward facing, or any direction if no dominant prevailing wind or current exists.
Sheltered Reef Slope	255, 235, 190	Sheltered Reef Slope is any submerged, sloping area extending into Deep Water but protected from strong directional prevailing wind or current, either by land or by opposing reef structures.
Reef Crest	115, 38, 0	Reef Crest is a zone marking the boundary between the Flat and the Reef Slope, generally shallow and characterised by highest wave energy absorbance.
Outer Reef Flat	230, 152, 0	Adjacent to the seaward edge of the reef, Outer Reef Flat is a level (near horizontal), broad and shallow platform that displays strong wave-driven zonation.
Inner Reef Flat	225, 225, 0	Inner Reef Flat is a low energy, sediment-dominated, horizontal to gently sloping platform behind the Outer Reef Flat.
Terrestrial Reef Flat	112, 168, 0	Terrestrial Reef Flat is a broad, flat, shallow to semi-exposed area fringing reef found directly attached to land at one side, and subject to freshwater run-off, nutrients and sediment.
Back Reef Slope	115, 223, 255	Back Reef Slope is a complex, interior - often gently sloping - reef zone occurring behind the Reef Flat. Of variable depth (but deeper than Reef Flat and more sloped), it is sheltered, sediment-dominated and often punctuated by coral outcrops.
Deep Lagoon	0, 92, 230	Deep Lagoon is any sheltered broad body of water, fully to semi-enclosed by reef, with a variable depth (but deeper than 5 m approx. and shallower than surrounding ocean) and a soft bottom dominated by reef-derived sediment.
Shallow Lagoon	204, 237, 255	Shallow Lagoon is any fully to semi-enclosed, sheltered, flat-bottomed sediment-dominated lagoon area, shallower than 5 m approx.
Plateau	132, 159, 181	Plateau is any deeper submerged (> 5 m approx), hard-bottomed, horizontal to gently sloping (angle shallower than 10 ° approx), seaward facing reef platform.
Patch Reef	0, 169, 230	Patch Reef is any small, detached to semi-detached lagoonal coral outcrop arising from sandy bottomed area.
Small Reef	255, 85, 0	Small Reef refers to any detached (stand-alone) reef, surrounded by Deep Water and too small (generally less than approx.. 1 sq km) to show a central depression and/or other clear geomorphic zonation (e.g. crest, flat, backreef) besides a Reef Slope.

Table 1. Allen Coral Atlas global geomorphic map classes, with the colour codes currently adopted. Short definitions can also be found listed here.

Global geomorphic zones and features.

There are twelve geomorphic classes in the Allen Coral Atlas - nine zones and three features.

While coral reefs display immense variability in shape and size, most can be classified into different "zones" dictated by reef geomorphology - underlying geological structural features - primarily characterised by differences in **depth**, **slope** and **exposure** (see Supplementary section). Planet satellite-derived bathymetry and slope angle, and wave data, give us an insight into major structural classes such as lagoons or reef slopes. When these data are examined in combination with the colour, brightness levels and texture produced by pixels that help provide information on the substrate, geomorphic classes can be mapped

The twelve reef geomorphic zones and features mapped by the Allen Coral Atlas are known to be fairly consistent across different biogeographic regions, and zones are often associated with regionally distinct ecological assemblages of benthic animals and plants. This is because the settlement and growth of benthic reef species – especially corals – is often determined by physical factors like light availability and water movement, which co-vary with depth, slope and exposure. For example, Reef Slope is often associated with diverse and abundant coral species, whereas Lagoons tend to be sand-dominated.

While individual reefs vary enormously in shape and size, ecologists and geologists have largely agreed that reefs feature three major geomorphic elements – a reef slope, a reef flat and a back reef area – although subdivisions and complexities around these, and natural variation means there is always an exception to every rule.

Reef Slope - *Terumbu depan - Pendiente arrecifal frontal*

Definition. Reef Slope is a submerged, sloping area extending seaward from the reef crest (or reef flat) towards the shelf break. Windward facing, or any direction if no dominant prevailing wind or current exists.

Reef Slope explainer. Deep, sloping and exposed, **Reef Slope** (also sometimes known as Fore Reef, or Reef Front) has long been a classical term for the submerged seaward-sloping part of the reef [10]. Ecologists and geoscientists almost all agree that Reef Slope is one of the three major geomorphic elements of a coral reef, along with Reef Crest and Back Reef [1-6]. Reef Slopes are always subtidal, seaward-facing (opening up into open sea or ocean, facing away from land or lagoons) [2, 7] and sloping (to various degrees: atolls have straighter, steeper profiles, barriers tend to be subdivided into bumps or "terraces", and fringing reef profiles are gentler [8-11]).

This sloping characteristic means Reef Slope zones are subject to gradients of both light and water movement, resulting in strong depth-driven patterns of coral community zonation [9]. Being seaward-facing means they are characterised by high wave exposure [7]. Reef Slopes are often divided into sub-zones by scientists, primarily based on a) depth and natural breaks in slope (e.g. Fore Reef / Reef Front / Shelf Break) b) slope angle (e.g., Wall / Terrace / Spur and Groove) and c) the level of exposure (e.g. Leeward or Sheltered / Windward or Exposed) - three attributes directly linked to their three main defining characteristics). In the Allen Coral Atlas, Reef Slope encompasses most of these terms (but see Sheltered Reef Slope and Plateau).

Sheltered Reef Slope - *Terumbu depan terlindung - Arrecifes delanteros protegidos*

Definition. Sheltered Reef Slope is any submerged sloping area extending into Deep Water, protected from strong directional prevailing wind or current, either by land or by opposing reef structures.

Sheltered Reef Slope explainer. Sheltered Reef Slope is any Reef Slope (submerged, sloping area extending into Deep Water) that is protected either by an island, continental land (i.e. Florida Keys) or by opposing reef structures - from strong directional prevailing currents. Geomorphologists frequently sub-divide Reef Slope based on relative exposure: e.g. from leeward vs windward to up to six types of breaker zones defined by Geister (1977). The reason why this Sheltered Reef Slope is distinct from Reef Slope in the Allen Coral Atlas is that exposure can greatly influence profile shape (e.g. geomorphology) as well as the benthic communities growing in the zone [10]. In the Allen Coral Atlas, where exposure is not pronounced, or prevailing wind direction fluctuates throughout the year, slopes will be classed as Reef Slope rather than Sheltered Reef Slope.

Reef Crest - *Igir terumbu - Cresta arrecifal*

Definition. Reef Crest is a zone marking the boundary between the Reef Flat and the Reef Slope, generally shallow and characterised by highest wave energy absorbance.

Reef Crest explainer. The Reef Crest is the break point at which a sharply defined edge divides the shallower reef platform from a more steeply shelving reef front [12]. It is arguably the most defining feature of any reef – as other geomorphic zones tend to be arranged in parallel to the crest [3]. Two characteristics of Reef Crest zones are that they represent a demarcation point separating the Reef Slope from the Reef Flat [1, 5, 8], and are "an area of maximum wave shoaling", i.e. a zone that absorbs the greatest wave energy, playing a key role in coastal defence [5]. Reef Crest zones dissipate >85% of the incoming ocean wave energy and 70% of the swell energy (Ferrario et al. 2014; Lowe et al. 2005). Darwin also recognised them as an area of maximal carbonate accretion – this is the "growing point" of most reefs. Reef Crest zones are often described as the shallowest and often emergent part of the reef [5]: on atolls, for example, they can appear "flattened" [13] or "flat-topped" [2]. However in under different circumstances, the Reef Crest can be deeper and *"gently sloping"* [12], curving at the boundary between horizontal reef flat and vertical slope. This is common on fringing reefs, where Reef Crest development is linked to sea level: here the demarcation point between flat and slope may be submerged, deeper than the reef flat, and gently curving, representing a less sharply defined transition. Some younger fringing reef types lack a clear Reef Crest altogether, despite the presence of a crest being one of the oft-cited defining elements of a fringing reef [1].

Outer Reef Flat - *Rataan terumbu luar - Arrecife plano exterior*

Definition. Adjacent to the seaward edge of the reef, Outer Reef Flat is a levelled (near horizontal) and generally shallow, broad and shallow carbonate platform, which displays distinct wave-driven zonation.

Outer Reef Flat explainer. Extending inwards from the seaward edge of the reef, Outer Reef Flats are characterised by broad (hundreds of meters wide), level surfaces and a shallow

depth (generally no deeper than a few centimetres to a few meters [12] [14], and in some regions – particularly the Pacific - they can be intertidal). The shallow and flat characteristics of this zone are a consequence of its geological development: upward growth of reefs is halted by the sea surface and so a growing reef platform can only really expand outwards.

With one edge located parallel to the seaward edge of reef, Outer Reef Flat zones are typically distinguished from Inner Reef Flats by their depth (shallower); slope angle (flatter, but may slope gently down towards Inner Reef Flat); exposure (more high energy waves and more likely to experience emersion); benthos (harder, and more corals and coralline algae in the case of coral-dominated flats or larger pieces of scattered debris on rubble-dominated flats), and clear zonation (e.g., more clear cut zones, with coral cover and or rubble size diminishing away from the seaward edge). Although the Outer Reef Flat receives some protection from the neighbouring Reef Crest (absorbing >85% of incoming wave energy), the first 150 m of Outer Reef Flat will dissipate 65% of the remaining wave energy and reduce wave height by a further 43% [15]. Zonation is particularly distinct [9], due to wave energy being the single driver (being flat means a relatively uniform exposure to light) and belt-like sub-zones (e.g., algal rim, cor-algal flat and coral windrows) are often detectable in aerial images of Outer Reef Flats as coloured bands [16]. Features such as deeper pockets (troughs or moats) where corals persist, scattered microatolls, "feo" (undercut mushroom shaped rocks remnant from where sea level has fallen) and stranded fossil ridges can punctuate Outer Reef Flat zones.

Inner Reef Flat - *Rataan terumbu dalam - Arrecife plano interior*

Definition. Inner Reef Flat is a low energy, sediment-dominated horizontal and generally shallow to gently sloping platform behind the Outer Reef Flat.

Inner Reef Flat explainer. Inner Reef Flat lies behind (inwards of) the Outer Reef Flat (or Reef Crest if no Outer Reef Flat exists), and shares many geomorphic features in terms of being shallow, horizontal and broad. The leeward "sand zone" of a reef flat, Inner Reef Flats are depositional systems dominated by sediment and distinguished from Outer Reef Flat by depth (may be slightly deeper), slope (still flat but with a greater downward sloping gradient), exposure (low energy leading to calmer conditions and more sand) and benthos (softer substrates). In terms of its benthos, it can be distinguished from coral-dominated outer reef flats by a relative paucity of living coral and algae, and from rubble-dominated outer reef flats by smaller rubble pieces. Zonation is also generally less pronounced than on Outer Reef Flats, with material stratified across wide inner reef flats. Where Inner Reef Flat meets Shallow Lagoon, it can be distinguished by its lower sand content and more features, such as rubble pieces (if neighbouring a rubble-dominated outer reef flat) or unfused coral windrows grading into coral patches and sand flats if neighbouring a coral-dominated reef flay.

Additional Inner Reef Flat features include a low cover and diversity of corals due to the harsh conditions and limited opportunity for upward growth [9], which means they are often described as "barren" [12]. Reef Flat descriptions also frequently reference the presence of rubble, describing flats as "strewn with detritus", and "littered with coral sand and storm tossed shine or blocks of reef limestone brought in from outer margin" [17].

Terrestrial Reef Flat - *Rataan terumbu terrestrial - Arrecife plano terrestre*

Definition. Terrestrial Reef Flat is a broad, flat, shallow semi-exposed area of fringing reef found directly attached to land at one side, and subject to freshwater runoff, nutrients and sediment.

Terrestrial Reef Flat explainer. Terrestrial Reef Flats are broad, shallow and flat semi-exposed areas, the span the distance between the shoreline intertidal zone and the Reef Crest of a continental fringing reef. Landward of a fringing reef crest it may extend directly to the shoreline or drop into a Shallow Lagoon [13]. Due to its proximity to large land masses, this zone is subject to freshwater run-off, nutrients, sediment and is often turbid, muddy or algal dominated zone.

Back Reef Slope - *Lereng terumbu belakang - Pendiente de arrecife posterior*

Definition. Back Reef Slope is a complex interior - often gently sloping - reef zone occurring behind the reef flat. Of variable depth, it is sheltered, sediment-dominated and often punctuated by coral outcrops.

Back Reef Slope explainer. Back Reef is a widely used term*, but in this instance Back Reef Slope refers to the transitional landward gently sloping area that links the Reef Flat and Lagoon areas [14]. It is an interior-reef zone (i.e. always found behind the Reef Crest or flat) and characteristically sheltered. Being a low energy area means the Back Reef Slope zone (like all Back Reef areas - including lagoons and reef flats) is a largely depositional environment, receiving debris swept landwards from the crest and front – from rubble strewn across reef flats, to sand sheets and mud deposits into lagoons [2, 3] – meaning this sloping area will generally be sediment-dominated. Back Reef Slopes are variable in slope angle and depth, but often are punctuated by coral outcrops, particularly deeper ones.

**Back Reef vs Back Reef Slope.* The term "Back Reef" is widely adopted among scientists, and the third of the three classic geomorphic reef zones. Differences exist in how this zone is defined, particularly in terms of the geomorphic zones it incorporates. This generally depends on whether it is defined functionally (e.g. seen as a purely depositional environment, in which case it includes the Back Reef Slope and Lagoon but *not* the productive Reef Flat) or whether it is defined in respect to positioning (e.g. everything landward of the Reef Crest – including Lagoon and Reef Flat vs just the Back Reef Slope). From a geological perspective, the Back Reef is also seen as a transitional stage in a reefs life: the end point will be infilling [3].

Deep Lagoon - *Laguna dalam - Laguna profunda*

Definition. Lagoon is any sheltered broad body of water semi-enclosed by reef, with a variable depth (but deeper than 5 m (approx.) and shallower than surrounding ocean) and a soft bottom dominated by sediment.

Lagoon explainer. Lagoons are sheltered internal water bodies protected from wave energy by a reef crest by which it is semi-enclosed, resulting in a calm and stable environment [13]. Lagoon depths are variable: while 10 m [1, 18] and 5 m (Fairbridge 1950) are suggested

depth thresholds for distinguishing a "true" Lagoon (a defining feature of barrier reefs and atolls only) from shallower water bodies (e.g. associated with fringing reefs and platforms) atoll lagoon floors are typically 20-36 m [19] and can reach >70 m [20]. Here, we set a threshold of 5 m for lagoon depth, but as a rule, lagoon depth is always shallower than the neighbouring water bodies on the reef's seaward side [13]. Lagoons tend to be broad in width although width and shape can be variable depending on reef type (e.g., atoll lagoons more round, barrier lagoons elongated).

Lagoons are always highly depositional environments, receiving near-continuous supply of calcium carbonate bioeroded from reef flats, crests and slopes. This means lagoon floors are largely soft bottomed, dominated by sediment of biological origin, and constantly infilling [20]. Enclosure to semi-enclosure within a bordering reef construction limits water exchange with the sea creating a relatively calm environment, typified by low currents [4]), long residence times (up to 12 days), and seawater supersaturated with calcium carbonate [20] which can promote coral growth [12]. As a result, lagoons often feature beds of coral (see Patch Reef). While floor level remains constant, many lagoons develop small knolls (non-living coral heads and pinnacles) as well as deep sinkholes caused by karst solution effects.

Shallow Lagoon - Laguna dangkal - Laguna somera

Definition. Shallow lagoon is any sheltered, shallow (shallower than 5 m approx), flat-bottomed sediment-dominated lagoon-like area.

Shallow Lagoon explainer. Shallow Lagoon zones in the Allen Coral Atlas are distinguished mainly by their depth (no deeper than 5 m), but they also tend to be soft bottomed, feature fewer coral patches than true lagoons, and are sand-dominated. Unlike the Deep Lagoon class, which describes true lagoons, Shallow Lagoon classes are too shallow to technically be lagoons, although they share many features. The type of sediment in a Shallow Lagoon is typically foraminiferal dominated sediment, which differs from the *Halimeda*-derived sediment in deeper atoll lagoons [20].

Technically, true lagoons (Deep Lagoons) by definition are associated with barriers and atolls only [17], but not platform reefs, fringing reefs or other reef types, while Shallow Lagoons can be found anywhere. A threshold used to distinguish barrier reefs from fringing reefs in the literature is that the lagoon depth needs to exceed 10 m [1, 18]. However, this implies that fringing reefs can be associated with lagoon-like water bodies, with a depth <10m. There are exceptions to this rule where true lagoons become very shallow; Lighthouse Reef in Belize has a 120 sq m sandy lagoon, 2-6 m deep.

Plateau - *Dataran tinggi - Meseta de arrecife*

Definition: Plateau is any submerged (deeper than approx. 6 m), hard-bottomed, horizontal to gently sloping (angle less than 10 ° approx), seaward facing reef platform.

Plateau explainer. Including submerged offshore platforms, banks and shoals, and the terraces associated with flatter Reef Slopes, the "Plateau" map class refers to any submerged carbonate reef feature beyond 6 m depth, and is a feature rather than a geomorphic zone. As

well as being submerged, other characteristics are that Plateaus are largely horizontal (angle < 10 °), and is always found adjacent to deeper water (seaward facing) - in some cases it may be a standalone reef. Other features of this class are that the majority of the reef structure does not reach the surface, it can not be subdivided into other geomorphic zones, and is made of hard substrate. Some of the world's largest reef structures – for example the 12,642 sq km Great Chagos Bank, and Cay Sal, the Bahamas third largest bank - are entirely submerged [8]. The "Plateau" map class refers exclusively to coral reefs - these reef features can be formed by other, non-scleractinian sources: *Halimeda* can also form submerged banks and biohermal structures [8].

Patch Reef - *Terumbu serpihan - Parche arrecifal*

Definition. Patch Reef is any small, detached to semi-detached lagoonal coral outcrop arising from a sandy-bottomed area.

Patch Reef explainer. A feature rather than geomorphic one, Patch Reefs are isolated reef outcroppings found in sheltered and sandy areas (e.g. Deep Lagoon, Shallow Lagoon, Back Reef Slope) that may develop in close proximity to each other but are often physically separated by sandy lagoon floor. Patch Reefs are generally arranged independently of the broader geomorphic organisation of a reef (e.g. along a structural axis relative to contours of shore or shelf edge) and to some degree detached from other reef structures: [5, 13], although their ability to aggregate and grow together into networks suggests "isolation" is not necessarily a characteristic that is easy to define. Patch Reefs will tend to have a high ratio of vertical relief to planar reef "with a vertical relief of one meter or more in relation to the surrounding seafloor" [13].

Patch Reefs are incredibly diverse in terms of size, distribution, shape and coalescence, meaning the term can be interpreted widely. A multitude of terms exist to describe different types of Patch Reefs – based on their distribution (e.g. "dense" or "diffuse" [5]); morphology ("single", "coalesced", "linear" and "reticulate" [21]); connectedness ("individual" or "aggregated"); size (defined by whether outcrops are large enough to be distinguished or too close together or small to be mapped independently [13]); location of the Patch Reef (splitting "shelf patch", "lagoon patch" and "intra seas patch" from "coastal/fringing patch" [22]), and relative depth (emergent "patches", submerged "knolls" and deep water "pinnacles" [12]. For the purposes of the Allen Coral Atlas, only Patch Reefs large enough to be confidently detected are mapped (typically this size threshold is 5-10 the 5 m pixel resolution) and large Patch Reefs (e.g., highly reticulated Patch Reefs, if broad enough, or Farus) will sometimes be zoned into geomorphic classes rather than as a Patch Reef.

Small Reef - *Terumbu karang kecil - Arrecifes pequeños*

Definition. Small Reef refers to any detached (stand-alone) reef, surrounded by deep water and too small (generally ≲ 1 sq km) to exhibit a central depression and/or other clear geomorphic zonation (e.g. crest, flat, back reef) besides a Reef Slope.

Small Reef explainer. Size is the main defining feature of a Small Reef: spatially independent reef outcrops too small to lack the large defining features that would enable them to be

confidently classified as either an atoll, fringing, barrier or platform, and too shallow to be a submerged reef, are classed as "Small Reefs" by the Allen Coral Atlas. As well as being too "small" and "featureless" to be classed as a Reef Type (Hopley suggests small reefs can be "shelf reefs <1 km2 growing off antecedent platforms"), Small Reefs are generally rounded or ovoid in shape [23], spatially independent (i.e. not a geomorphic sub-feature of a reef type, or connected to any other reef – this map class excludes lagoonal patch reefs and features like faros, that have developed inside of larger reef structures), and largely featureless (e.g. lacking in strong geomorphic zonation - besides a reef slope - that would allow the sub-zones to be mapped). This is because in order to develop a lagoon and therefore strong zonation, platform reefs generally need to be at least 1 km across: since any reef flat >0.5 km in width is capable of causing rapid infilling and transition to a planar "platform" reef.

Small Reefs will include coral knolls and pinnacles, and submerged reef platforms and banks < 1km across. In the first ever attempted global coral atlas, Darwin's 1843 map of coral reef distribution, Darwin identified fringing reefs (in red), atolls (dark blue) and barrier reefs (pale blue), but commented that "there are many scattered reefs, of small size, represented in the chart by mere dots, which rise out of deep water: these cannot be arranged under either of the three classes".

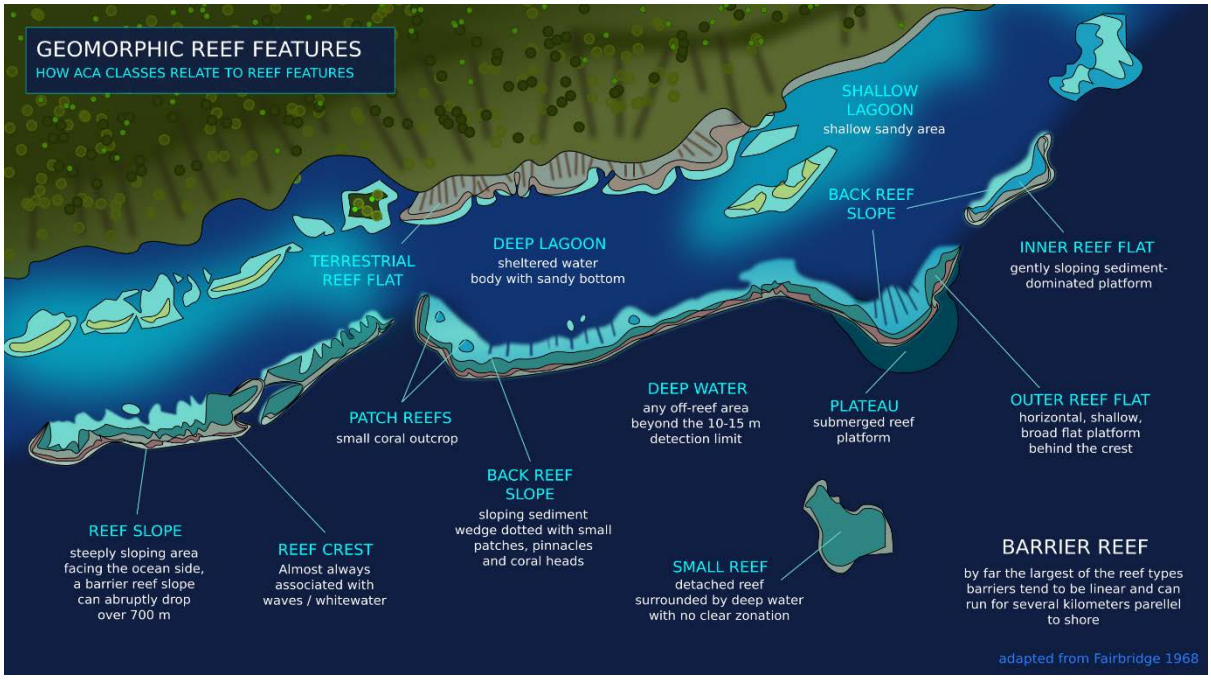

Figure 2. Diagram showing where major geomorphic reef features appear when viewed from above, as seen from above in a typical barrier reef.

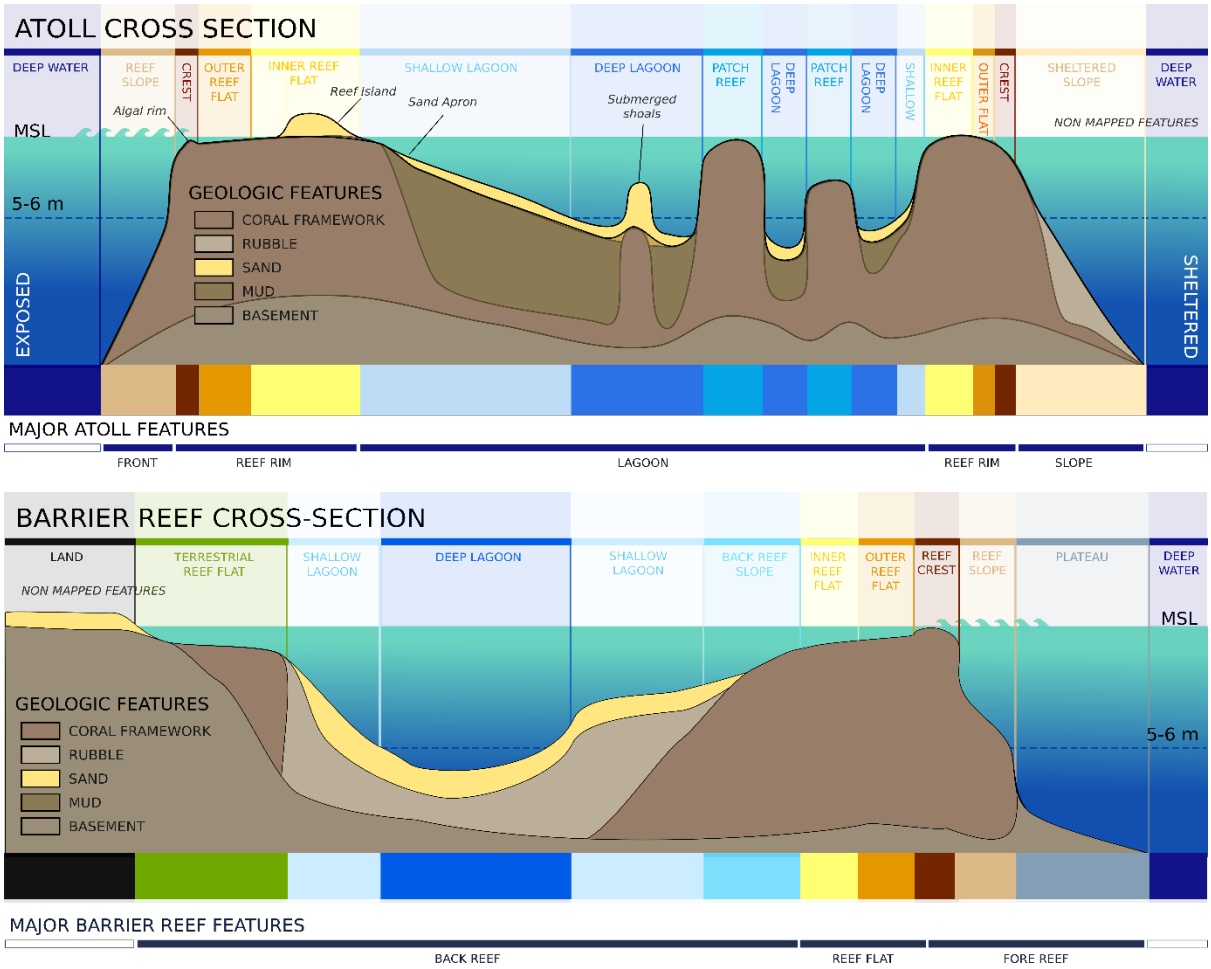

Figure 3. Cross section through a 'typical' coral reef showing how geomorphic map classes might be arranged across a) an atoll and b) a barrier reef cross-section

Global Benthic Map classes

Class and colour		Definition
Coral / Algae	0, 169, 230	**Coral / Algae** is any hardbottom area supporting living coral and/or algae.
Seagrass	115, 178, 115	**Seagrass** is any habitat where seagrass is the dominant biota.
Microalgal Mats	194, 158, 215	**Microalgal Mats** are any visible accumulations of microscopic algae in sandy sediments.
Sand	255, 255, 155	**Sand** is any soft-bottom area dominated by fine unconsolidated sediments.
Rubble	205, 170, 102	**Rubble** is any habitat featuring loose, rough fragments of broken reef material.
Rock	168, 112, 0	**Rock** is any exposed area of hard bare substrate, with uncommon to scarce corals and fleshy macroalgae.

Table 2. Allen Coral Atlas global benthic map classes, along with RGB colour codes for the current colours. Definitions can also be found listed here.

Global Benthic Classes.

There are six benthic classes in the Allen Coral Atlas.

Benthic map classes characterise different bottom types - especially communities of living organisms attached to the reef (benthos) - but also sediments and underlying substrate, describing the local ecology. Benthic zones can be characterised in different ways, for example based on dominance of a particular species (e.g. "Acropora zone"), absence of species (e.g. "no coral zone"), presence of characteristic or differential species (e.g. parrotfish zone), characteristic growth forms (e.g. plating coral zone), or using multivariate techniques to describe the full complement of organisms [9].

Remote sensing is still fundamentally unable to distinguish some of the key measures that ecologists prefer to assess reef health – cover of living coral, cover of dead coral, cover of bleached corals and functional forms of algae [24], but broad classes like Coral / Algae and Rubble can still be very useful. For the Allen Coral Atlas, Planet Dove-derived spectral reflectance data provides some information about benthic composition, while bathymetry maps, slope angle and wave data (used to differentiate geomorphic zones) can be useful as surrogates for aspects of the physical environment (light availability, temperature, wave exposure) that determine most coral reef ecological partitioning. Underlying reef structure also helps determine gradients in light (depth and turbidity) and water movement (waves and currents) known to be the main drivers of benthic zonation on reefs [9]. This means global geomorphic maps can help influence benthic map classes.

Coral / Algae - *Karang / Alga - Corales / Algas*

Definition. Coral / Algae is any hardbottom area supporting living coral and/or algae.

Coral / Algae explainer. The Coral / Algae mapping class describes a habitat characterised by a hard underlying framework (usually coral-derived limestone framework, but may be non-carbonate) with a benthic covering of coral (including soft coral) and/or seaweeds (including macroalgae and turf algae). Coral / Algae class is generally the most topographically complex class (sand, seagrass, rubble and rock comparatively flat), supports the greatest amount of animal diversity and biomass, and most commonly associated with Reef Slope, Sheltered Reef slope, Patch Reefs and Outer Reef Flat classes.

Why "Coral / Algae"? The photosynthetic nature of both corals and seaweeds mean they are spectrally similar making them challenging to distinguish clearly though remote sensing [25]. The epilithic algal turf or film that quickly covers coral framework creates the same problem, meaning dead coral matrix cannot be reliably distinguished either, because of the speed at which it becomes covered.

How much "Coral / Algae"? The "Coral / Algae" habitat class will have a cover of coral or algae of at least 1%, normally more than 5% and sometimes exceeding 40%, but does not necessarily have a dominance of any of these groups over non-living substrate. With average coral cover 10-20% globally, most reef habitats - even those supporting extensive coral growth - are unlikely to be quantitatively dominated by coral [5]). However, Mumby and Harborne [5] point out that "*describing reefs with the highest coral cover as algal-dominated may be politically unacceptable and confuse interpretation*" suggesting that systematic accuracy should be sacrificed to aid intuitive acceptance of a scheme.

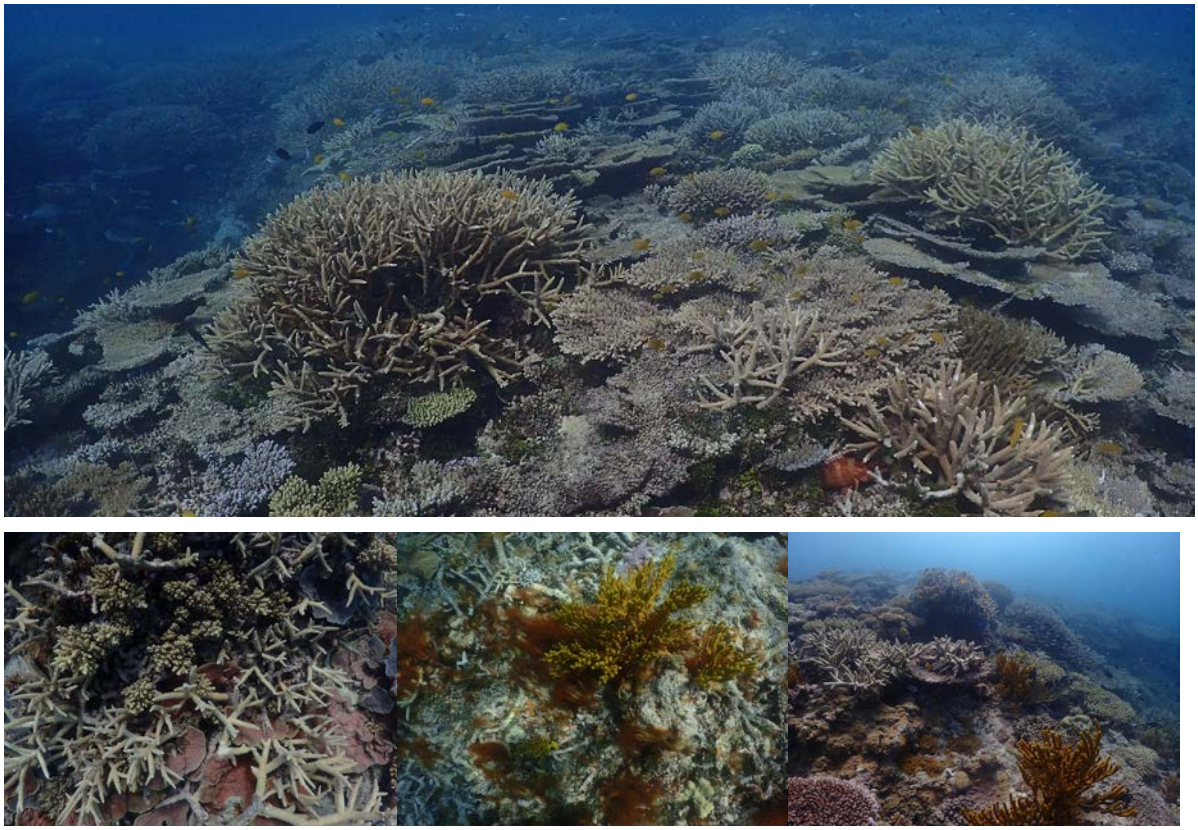

Figure 4. Example of what Coral / Algae class might look like

Seagrass - *Padang - Seibadales*

Definition. Seagrass is any habitat where seagrass is the dominant biota.

Seagrass explainer. The Seagrass map class describes a soft-bottomed habitat dominated by any single species of seagrass from the order Alismatales (e.g. *Syringodium sp., Thalassia sp*., and *Halophila sp.*) or any combination of species [13]. Seagrasses can form extensive beds, called meadows, which shelter abundant diverse species (epiphytes, small invertebrates and juvenile fish), support herbivory (e.g. of turtles and dugongs) and play an important role in trapping sediment, as well as biogeochemical cycling. This class also includes sparser or more spatially restricted seagrasses, as long as it is the dominant biota, and/or has a total cover >10%. Seagrass habitats are most commonly associated with Shallow Lagoons and Back Reef Slope.

Microalgal Mats - *Ganggang mikro bentik - Lechos de microalgas bénticas*

Definition. Microalgal Mats are visible accumulations of microscopic algae in sandy sediments

Microalgal Mats explainer. The Microalgal Mat class describes microscopic communities - abundant and spatially extensive enough to be visible as mats - growing on or in the top few centimetres of shallow, sandy sediments. The benthic microalgae that comprise these mats, also known as microphytobenthos, are primarily diatoms, but include cyanobacteria, chlorophytes, and other microscopic organisms that grow on sand, silts and muds in both marine and freshwater habitats. In shallow, sandy and sheltered reef areas, such as the leeside of islands and in lagoons, benthic microalgae aggregate into mats which can be geographically extensive (up to several kilometers), and penetrate up to 15cm into the

sediment (although most biomass occurs in the upper centimetres). Benthic microalgal mats are productive habitats that play important roles in sediment stabilisation, trophodynamics and biogeochemical cycling [26]. They may promote benthic recovery by rapidly re-oxygenating the sediment surface. These habitats are most often associated with Shallow Lagoons.

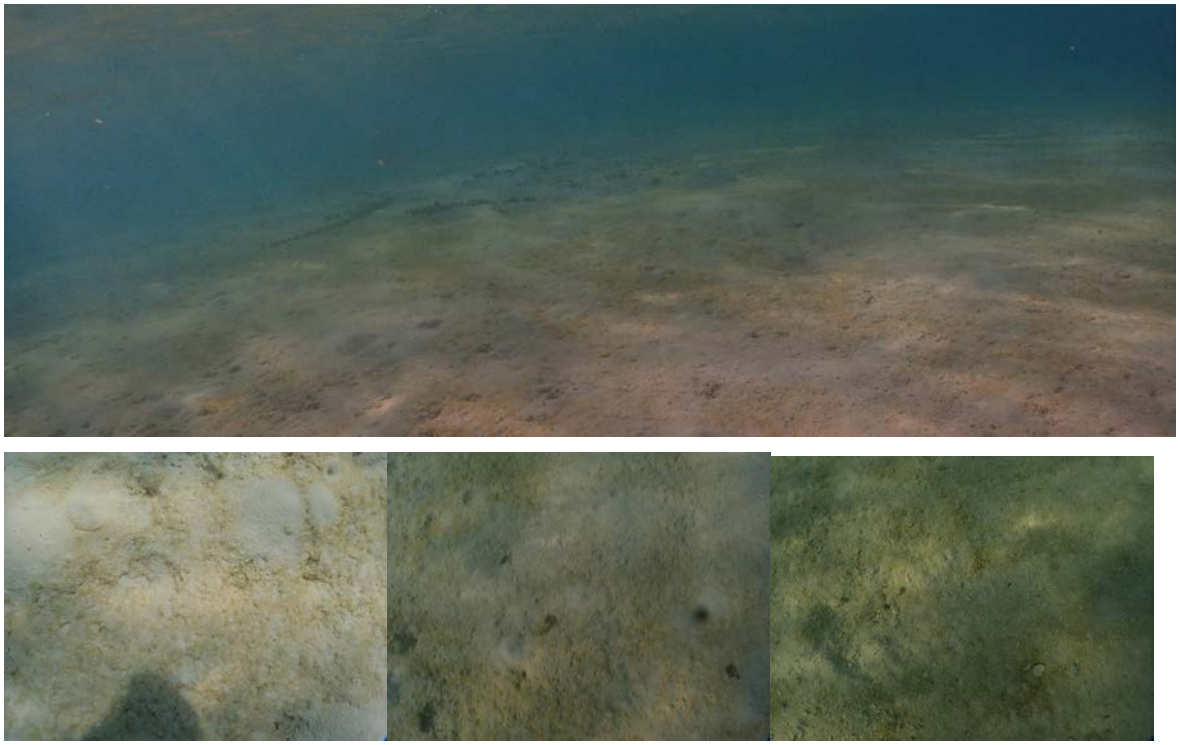

Figure 5. Example of what Microalgal Mat class might look like

Sand - *Pasir - Arena*

Definition. Sand includes any soft-bottom area dominated by fine unconsolidated sediments.

Sand explainer. The Sand class describes soft-bottomed reef areas where fine unconsolidated granular material (finer than coral rubble but coarser than muds) dominate, thickly obscuring any underlying bedrock. Sparse algae, scattered rocks or small, isolated coral heads may also occur in the Sand class, but these features do not exceed 10% of the area [13]. Most reef-associated sands are largely comprised of aragonite (50-80%) and magnesium calcite [3], although the source of the grain (including corals, coralline algae, molluscs, benthic foraminifers and Halimeda, among others) and the grain size will vary and often shows strong cross reef zonation, driven by biogeographic and hydrodynamic factors [3]. Sand class is associated with back reef zones such as Inner Reef Flat, Back Reef Slopes and Lagoon classes in particular, where it can occupy 80% [3].

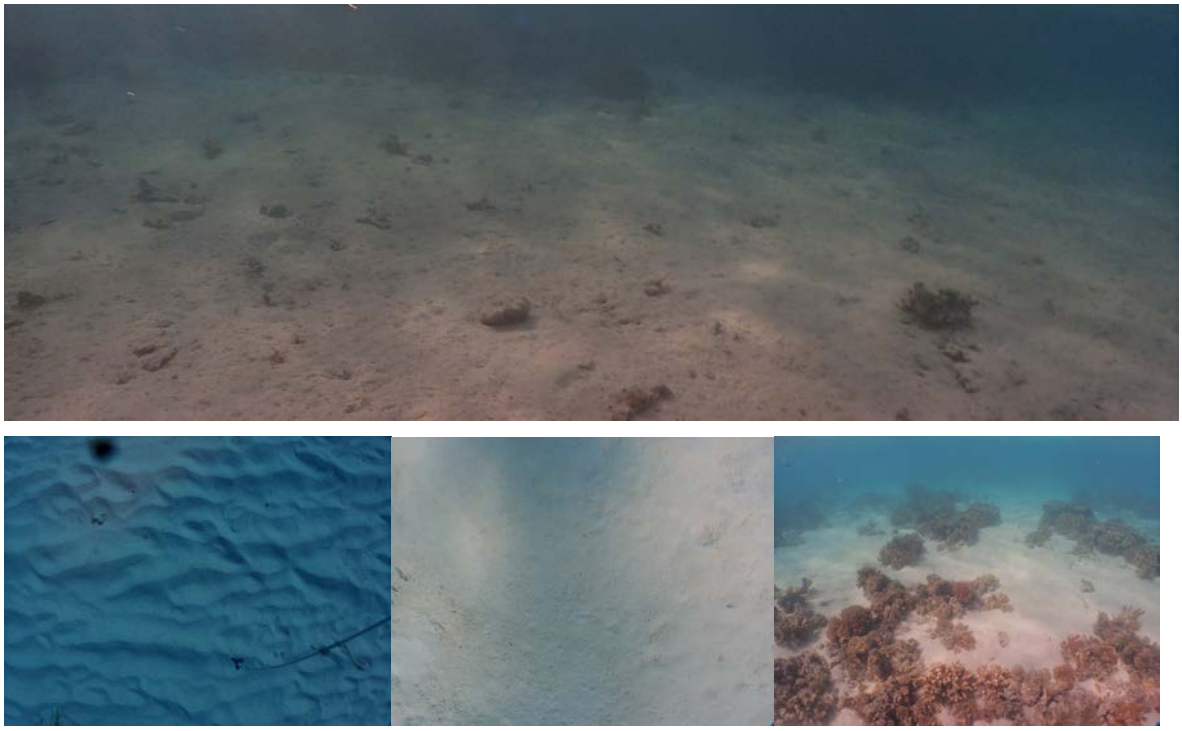

Figure 6. Example of what Sand class might look like

Rubble - *Pecahan karang - Grava de arrecifes*

Definition. Rubble is any habitat featuring loose, rough fragments of broken reef material.

Rubble explainer. The Rubble map class describes any area featuring loose, cylindrical to irregularly shaped fragments of bedrock or clasts of corals, bivalves and coralline algae [3]. Rubble pieces - while themselves are non-living - can be heavily encrusted by foraminifers, bryozoans or coralline algae, and contain boring organisms. This important habitat often occurs landward of well-developed reef formations in the Reef Crest, Back Reef or Reef Flat zones, and may be associated with some fringing reefs, and also rubble-dominated reef flats (Thornborough & Davies).

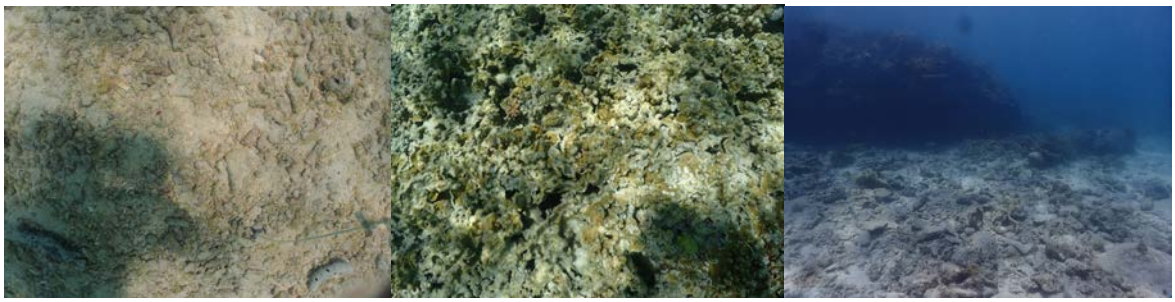

Figure 7. Example of what Rubble class might look like

Rock - *Batuan - Roca*

Definition. Rock is any exposed hardbottom area with uncommon to scarce corals and fleshy macroalgae.

Rock explainer. The Rock class (also commonly known as “bedrock” or “pavement”) describes any habitat dominated by “exposed areas of hard bare substratum without visible corallite structure” [5]. This habitat often has a near horizontal, pavement-like appearance and is usually associated with areas of high energy (e.g. reef crests) where the cover of living organisms is low (< 10%) - although it may have high coverage of crustose coralline algae. The class encompasses limestone reef matrix, but also underlying non-reefal bedrock and “beach rock” - areas of coral sand cemented together which are difficult to distinguish in this dataset.

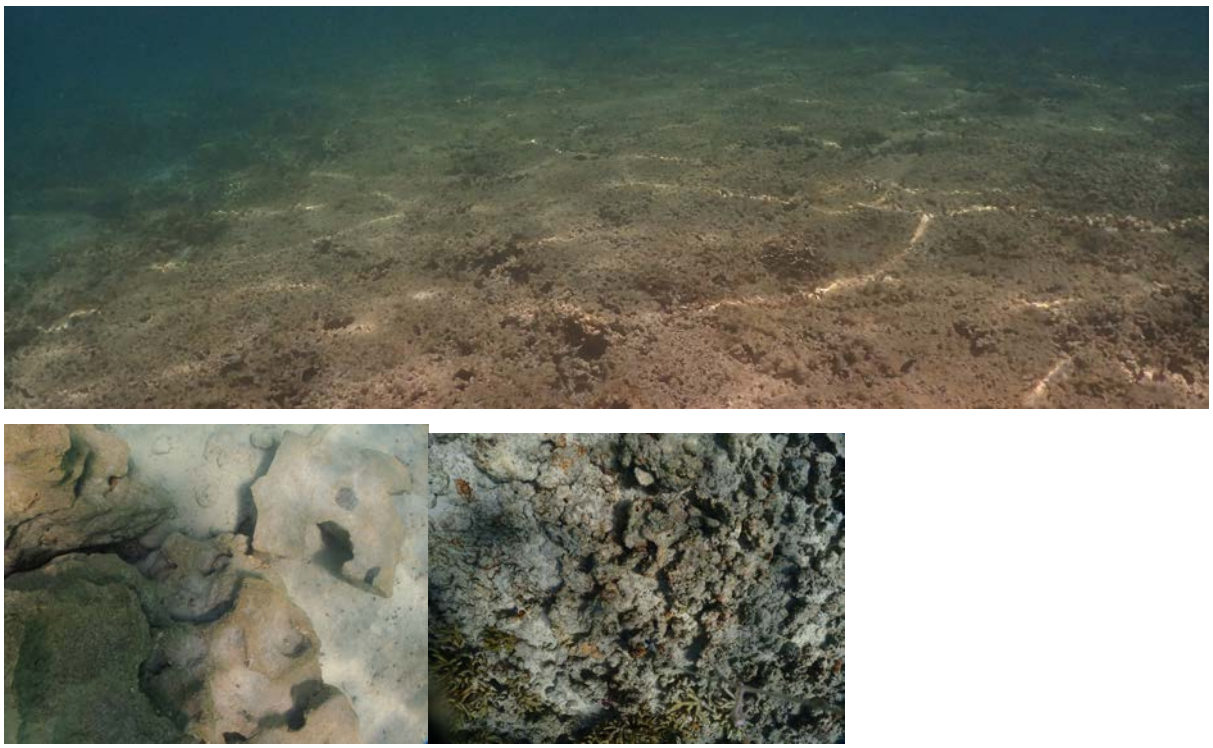

Figure 8. Example of what Rock class might look like

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