CORAL TAXONOMY, CORAL BLEACHING, SCUBA DIVING AND INTERTIDAL AND UNDERWATER CORAL TRANSPLANTATION

Key words: ENSO, Global warming, Hazards, Reef building

INTRODUCTION

Corals belong to the Phylum Cnidaria, Class Anthozoa. These consist of anemone-like animals (anemones, disk anemones, tube anemones, zoanthids, and corals) of a similar body structure called a polyp: a ring of tentacles surrounding a mouth, which is the only opening to the body cavity, or coelenteron.

Corals are marine animals in class Anthozoa of phylum Cnidaria typically living in compact colonies of many identical individual "polyps". The group includes the important reef builders that inhabit tropical oceans and secrete calcium carbonate to form a hard skeleton.

A coral "head" is a colony of myriad genetically identical polyps. Each polyp is a spineless animal typically only a few millimeters in diameter and a few centimeters in length. A set of tentacles surround a central mouth opening. An exoskeleton is excreted near the base. Over many generations, the colony thus creates a large skeleton that is characteristic of the species. Individual heads grow by asexual reproduction of polyps. Corals also breed sexually by spawning: polyps of the same species release gametes simultaneously over a period of one to several nights around a full moon.

Although corals can catch small fish and plankton, using stinging cells on their tentacles, most corals obtain the majority of their energy and nutrients from photosynthetic unicellular algae called zooxanthellae that live within the coral's tissue. Such corals require sunlight and grow in clear, shallow water, typically at depths shallower than 60 metres (200 ft). Corals can be major contributors to the physical structure of the coral reefs that develop in tropical and subtropical waters, such as the enormous Great Barrier Reef off the coast of Queensland, Australia. Other corals do not have associated algae and can live in much deeper water, with the cold-water genus *Lophelia* surviving as deep as 3,000 metres (9,800 ft). Examples live on the Darwin Mounds located north-west of Cape Wrath, Scotland. Corals have also been found off the coast of the U.S. in Washington State and the Aleutian Islands in Alaska.

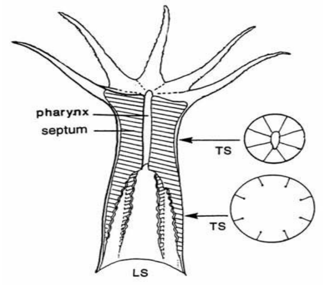

Fig – 23.1

Fig – 23.2 - Coral polyps inside a colony

Most corals seen on a coral reef are colonial, consisting of many polyps growing together to form a colony. 'Coral' is a term that encompasses a diverse array of these anemone-like animals, the most common of these being **stony corals** and **soft corals**.

Stony coral or **true coral** is an organism in the order Scleractinia. Organisms in this order get their name from their skeletons, which are composed of hardened calcium carbonate which can cause the coral to feel like stone. While a coral is alive, the skeleton is covered in a soft layer of living material, but after corals die, their hardened skeletons are clearly visible. Organisms in this order can be divided into two groups: colonial and solitary. Colonial stony coral forms colonies which develop into the fantastic forms many people associate with coral reefs. Solitary stony corals do not live together in colonies, and many of them are also free-floating.

In the case of a colony of stony coral, the hard skeleton is created by numerous individuals known as polyps, which work together to build the skeleton. Corals can grow asexually by budding, a process which splits the polyps into copies of themselves, and colonies can also grow by fusing with neighboring colonies. Stony coral is also capable of sexual reproduction, which is usually accomplished by releasing eggs and sperm into the ocean, where gametes can form when eggs and sperm come into contact with each other. In the case of stony coral which grows into colonies, the gametes can start new colonies.

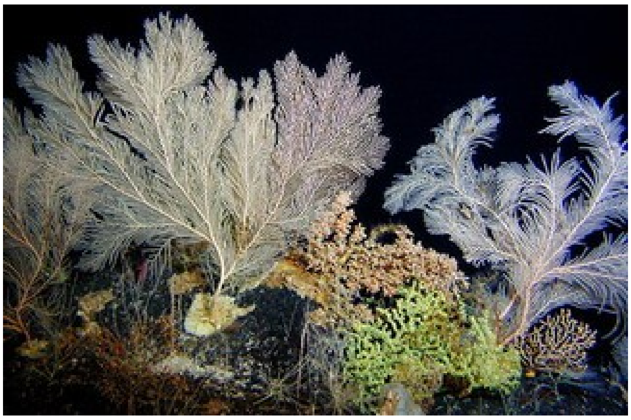

Fig – 23.3

Stony corals can also be divided into **zooxanthellate** and **non-zooxanthellate** corals. **Zooxanthellate** corals form symbiotic relationships with algae which live inside the coral skeleton, providing energy for the colony. **Non-zooxanthellate** corals, as you might imagine, do not rely on algae for food. In both cases, the polyps also supply their own food, using specialized structures known as sweeper tentacles to grab prey as it drifts by on the current.

A number of basic shapes of stony coral can be observed in the ocean, including branching corals, pillar corals, table corals, elkhorn corals, encrusting corals, massive corals, massive corals, and foliase corals, which form interconnected whorls and plates of material. All stony coral species adhere to a rocky or hard substrate, and once a coral is established, it can be extremely difficult to dislodge.

Stony corals, such as brain corals, belonging to the Order Scleractinia, secrete an external skeleton of calcium carbonate (limestone). **Brain coral** is a common name given to corals in the family Faviidae so called due to their generally spheroid shape and grooved surface which resembles an animal brain. Each head of coral is formed by a colony of genetically identical polyps which secrete a hard skeleton of calcium carbonate; this makes them important coral reef builders like other stony corals in the order Scleractinia.

Brain corals are found in shallow warm-water coral reefs in all the world's oceans. They are part of the phylum Cnidaria, in a class called Anthozoa or "sea flowers." The life span of the largest brain corals is 900 years. Colonies can grow as large as 6 or more feet (1.8 m) high. Brain corals extend their tentacles to catch food at night. During the day, the brain corals use their tentacles for protection by wrapping them over the grooves on their surface. The surface is hard and offers good protection against fish or hurricanes. Branching corals, such as staghorn corals, grow more rapidly, but those are more vulnerable to storm damage.

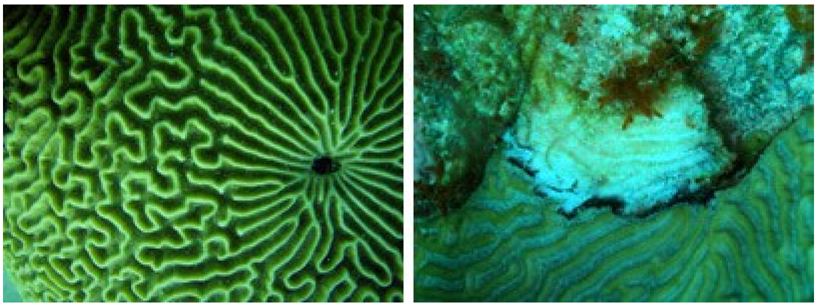

Fig – 23.4- Live brain coral (left) and white skeleton of brain coral revealed after damage by black band disease.

Like other genera of corals, brain corals feed on small drifting animals and also receive nutrients provided by the algae which live within their tissues. The behavior of one of the most common genera, Favia, is semi-aggressive; it will sting other corals with its extended sweeper tentacles during the night.The genus and species has not been defined through the scientific classification segment.

Soft corals, belonging to the Order Alcyonacea, do not have large external skeletons, although most have small internal spicules of calcium carbonate instead. The gorgonians (e.g. sea fans, sea rods and sea plumes), which are most common in the Caribbean, also gain support from internal proteinaceous rods of gorgonin.

Fig – 23.5

Soft corals, typified by their internal fleshy skeletons, are the most appropriate varieties of stinging animals for the marine aquarist graduating from fish to invertebrate to full-blown-reef enthusiast. Many of these are tolerant toward aquarium conditions, relatively inexpensive, and more easily cared for than the small or large polyped true or stony corals.

Beyond the above considerations is one that should be important to every conscientious aquarist; the removal of soft corals from the worlds reefs is less destructive to the environment than chipping away, otherwise removing calcareous corals. Their recruitment (growth and replacement) rates are far greater, they're not principal prey species, and little used as habitat by other reef creatures.

Classification: Taxonomy, Relation with Other Groups:

The soft corals are members of the stinging-celled animals, Phylum Cnidaria, formerly Coelenterata; a group that includes the anemones, jellyfishes, hydroids, sea-pens, the true corals and other coral-named groups.

Cnidarians are tissue-grade life characterized by having just two germ layers (ecto- and endoderm), stinging-cells, and principal radial symmetry. Other salient characteristics; they have a single body cavity (the coelenteron) that is sac-like, with one opening that serves as both an mouth and an anus; lack a central nervous system (have simple nerve nets), no head or gas exchange, excretory or circulatory systems.

The phylum Cnidaria is separated into three Classes roughly by the principal form (bell-shaped free-living medusoid, or attached polypoid) they take as life stages.

- Class Scyphozoa, the jellyfishes, are mainly medusoids.
- Class Hydrozoa, the hydroids and hydromedusae, display alternation of generations with asexual benthic polyps alternating with sexual planktonic medusae.
- Class Anthozoa, sea anemones, corals, sea pens; have no medusoid stage. They are further subdivided into two subclasses.

- Subclass Hexacorallia (=Zoantharia), sea anemones and true corals (Order Scleractinia), have tentacles and mesenteries (internal body divisions) in multiples of six ("hex"), 0,1,2 siphonoglyphs (slot-like mouth/anus openings).

- Subclass Octocorallia (=Alcyonaria), the octocorals called soft, blue, organ-pipe corals, sea fans, sea pansies. Colonial polypoids, with eight-numbered mesenteries and hollow tentacles (pinnately, i.e. side-branched like a bird's feather), one siphonoglyph. A few orders of note to aquarists:

    - Order Gorgonacea, sea fans, sea whips. Non-living central structure with living "rind" covering.

    - Order Pennatulacea, sea pens, sea pansies.

    - Order Heliporacea, blue "coral"

    - Order Stolonifera, red organ-pipe "coral" (*Tubipora*)

The Order Alcyonacea, the soft corals, are made up of either encrusting or erect colonies, mostly fleshy and flexible with a bizarre assortment of internal structural elements called sclerites, rendering shape and structure.

Briefly, we can see that it is not only the lack of external hard, stony, calcareous skeletons that the "true" corals (Order Scleractinia, Subclass Hexacorallia) from the soft fleshy or leathery corals, the Alcyonacea and their relatives; but major elements of body plan and symmetry (tentacular and body segmentation number, mouth-anus openings).

Natural Range

Soft corals are found worldwide, more in tropical than temperate reefs, mainly in mid-depths of 5-30 meters. Abundance on reefs in the Indo-Pacific and Red Sea is often conspicuous compared with stands of colonies in the Caribbean, Hawaii and elsewhere.

Principal Forms in the Hobby

First the general disclaimer regarding classifying difficult-to-discern life forms. The alcyonaceans that we call soft corals are really told apart only by microscopic examination of the aforementioned calcareous particles (sclerites). Therefore we will detail them more generically, as in by family and most commonly available genera.

Family Nephtheidae; Carnation, Tree, Colt Soft Corals, the genera Capnella, Dendronephthya, Nephthea, Scleronephthya, Cladiella, Lemnalia and more are known to all divers and other appreciators of tropical marine environments. They are the gorgeous warm colored (red, pink, yellow) and purplish cotton-candy looking creatures attached to reefs. Know that these colorful, branched-tree animals inflate and shrink regularly in rhythm with feeding and metabolite flushing, and that many species are difficult to care for.

Fig – 23.6 -Nephthea sp. in captivity and in Australia's Great Barrier Reef.

Family Alcyoniidae, the mushroom, ridged and lobed leather or toadstool corals, Lobophytum, Alcyonium, Cladiella, Sarcophyton, Sinularia With their almost unreal rubbery appearance with tentacles retracted, hardly recognizable as living, yet alone as stinging-celled animals. Mainly yellow, brown to grayish in overall uniform color. Amongst all the animals called corals, the leathers are the toughest for aquarium use; getting by on higher nutrient levels/lower water quality, and less stringent turbulence and lighting conditions.

Fig – 23.7 - A Sinularia in Nuka Hiva, Marquesas

Family Xeniidae, the pulsing and not Xenia, Stereosoma, Anthelia, Efflatournaria with their very fine wafting colonies of long feathery tentacled polyps pulsing and waving rhythmically. White, brown to bluish in coloration.

Fig – 23.8 - A Xenia sp. in Australia and Anthelia glauca in the Red Sea

Family Nidaliidae, some of these soft corals are superficially very similar to gorgonians (sea fans). Though quite common in the wild (Indo-Pacific) the gorgonian-like ones (genera Chironephthya, Siphonogorgia) are almost impossible to keep in captivity. Lacking zooxanthellae Nidaliids must be fed on suspensions of small zooplankton. Other genera that more resemble Nephtheids (Agaricoidea, Nidalla, Pieterfaurea) are of use to aquarists, though not as easily kept as the more hardy members of that family.

Fig – 23.9 - A Siphonogorgia with retracted polyps in a typical setting off Heron Island, Australia's Great Barrier Reef

Coral bleaching

Bleaching, or the paling of zooxanthellate invertebrates, occurs when (i) the densities of zooxanthellae decline and / or (ii) the concentration of photosynthetic pigments within the zooxanthellae fall (Kleppel et al. 1989). Most reef-building corals normally contain around 1-5 x 10^6 zooxanthellae cm^{-2} of live surface tissue and 2-10 pg of chlorophyll a per zooxanthella. When corals bleach they commonly lose 60-90% of their zooxanthellae and each zooxanthella may lose 50-80% of its photosynthetic pigments (Glynn 1996). The pale appearance of bleached scleractinian corals and hydrocorals is due to the cnidarian's calcareous skeleton showing through the translucent tissues (that are nearly devoid of pigmented zooxanthellae). Under stress, corals may expel their zooxanthellae, which leads to a lighter or completely white appearance, hence the term "bleached". Once bleaching begins, it tends to continue even without continuing stress. If the coral colony survives the stress period, zooxanthellae often require weeks to months to return to normal density. The new residents may be of a different species. Some species of zooxanthellae and corals are more resistant to stress than other species.

If the stress-causing bleaching is not too severe and if it decreases in time, the affected corals usually regain their symbiotic algae within several weeks or a few months. If zooxanthellae loss is prolonged, i.e. if the stress continues and depleted zooxanthellae populations do not recover, the coral host eventually dies.

Three hypotheses have been advanced to explain the cellular mechanism of bleaching, and all are based on extreme sea temperatures as one of the causative factors. High temperature and irradiance stressors have been implicated in the disruption of enzyme systems in zooxanthellae that offer protection against oxygen toxicity. Photosynthesis pathways in zooxanthallae are impaired at temperatures above 30 degrees C, this effect could activate the disassociation of coral / algal symbiosis. Low- or high-temperature shocks results in zooxanthellae low as a result of cell adhesion dysfunction. This involves the detachment of cnidarian endodermal cells with their zooxanthellae and the eventual expulsion of both cell types.

It has been hypothesized that bleaching is an adaptive mechanism which allows the coral to be repopulated with a different type of zooxanthellae, possibly conferring greater stress resistance. Different strains of zooxanthellae exist both between and within different species of coral hosts, and the different strains of algae show varied physiological responses to both temperature and irradiance exposure. The coral / algal association may have the scope to adapt within a coral's lifetime. Such adaptations could be either genetic or phenotypic.

Fig – 23.10 - Unbleached (left) and bleached (right) coral

Causes of coral bleaching:

Ecological causes of coral bleaching

As coral reef bleaching is a general response to stress, it can be induced by a variety of factors, alone or in combination. It is therefore difficult to unequivocally identify the causes for bleaching events. The following stressors have been implicated in coral reef bleaching events.

- **Temperature**

  Coral species live within a relatively narrow temperature margin, and anomalously low and high sea temperatures can induce coral bleaching. Bleaching events occur during sudden temperature drops accompanying intense upwelling episodes, (-3 degrees C to –5 degrees C for 5-10 days), seasonal cold-air outbreaks. Bleaching is much more frequently reported from elevated se water temperature. A small positive anomaly of 1-2 degrees C for 5-10 weeks during the summer season will usually induce bleaching.

- **Solar Irradiance**

  Bleaching during the summer months, during seasonal temperature and irradiance maxima often occurs disproportionately in shallow-living corals and on the exposed summits of colonies. Solar radiation has been suspected to play a role in coral bleaching. Both photosyntheticaly active radiation (PAR, 400-700nm) and ultraviolet radiation (UVR, 280-400nm) have been implicated in bleaching.

- **Subaerial Exposure**

Sudden exposure of reef flat corals to the atmosphere during events such as extreme low tides, ENSO-related sea level drops or tectonic uplift can potentially induce bleaching. The consequent exposure to high or low temperatures, increased solar radiation, desiccation, and sea water dilution by heavy rains could all play a role in zooxanthellae loss, but could also very well lead to coral death.

- **Sedimentation**

  Relatively few instances of coral bleaching have been linked solely to sediment. It is possible, but has not been demonstrated, that sediment loading could make zooxanthellate species more likely to bleach.

- **Fresh Water Dilution**

  Rapid dilution of reef waters from storm-generated precipitation and runoff has been demonstrated to cause coral reef bleaching. Generally, such bleaching events are rare and confined to relatively small, nearshore areas.

- **Inorganic Nutrients**

  Rather than causing coral reef bleaching, an increase in ambient elemental nutrient concentrations (e.g. ammonia and nitrate) actually increases zooxanthellae densities 2-3 times. Although eutrophication is not directly involved in zooxanthellae loss, it could cause secondary adverse affects such as lowering of coral resistance and greater susceptibility to diseases.

- **Xenobiotics**

  Zooxanthellae loss occurs during exposure of coral to elevated concentrations of various chemical contaminants, such as Cu, herbicides and oil. Because high concentrations of xenobiotics are required to induce zooxanthellae loss, bleaching from such sources is usually extremely localized and / or transitory .

- **Epizootics**

  Pathogen induced bleaching is different from other sorts of bleaching. Most coral diseases cause patchy or whole colony death and sloughing of soft tissues, resulting in a white skeleton (not to be confused with bleached corals). A few pathogens have been identified the cause translucent white tissues, a protozoan.

Factors that influence the outcome of a bleaching event include stress-resistance which reduces bleaching, tolerance to the absence of zooxanthellae, and how quickly new coral grows to replace the dead. Due to the patchy nature of bleaching, local climatic conditions such as shade or a stream of cooler water can reduce bleaching incidence. Coral and zooxanthellae health and genetics also influence bleaching.

Spatial and temporal range of coral reef bleaching

Mass coral moralities in coral reef ecosystems have been reported in all major reef provinces since the 1870s. The frequency and scale of bleaching disturbances has increased dramatically since the late 70's. This is possibly due to more observers and a greater interest in reporting in recent years. More than 60 coral reef bleaching events out of 105 mass coral moralities were reported between 1979-1990, compared with only three bleaching events among 63 mass coral moralities recorded during the preceding 103 years.

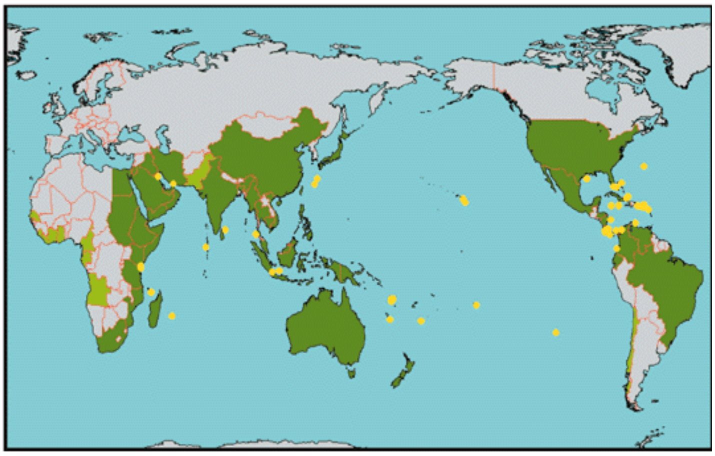

Fig – 23.11 - Regions where major coral reef bleaching events have taken place during the past 15 years.Yellow spots indicate major bleaching events.

Nearly all of the world's major coral reef regions (Caribbean/ western Atlantic, eastern Pacific, central and western Pacific, Indian Ocean, Arabian Gulf, Red Sea) experienced some degree of coral bleaching and mortality during the 1980s.

Prior to the 1980s, most mass coral moralities were related to non-thermal disturbances such as storms, aerial exposures during extreme low tides, and Acanthaster outbreaks. Coral bleaching accompanied some of the mortality events prior to the 1980s during periods of elevated sea water temperature, but these disturbances were geographically isolated and restricted to particular reefs zones. In contrast, many of the coral bleaching events observed in the 1980s occurred over large geographic regions and at all depths. Most of the coral reef bleaching events of the 1980s occurred during years of large-scale ENSO activity.

Global change and reef bleaching

Of the causing stressors of coral reef bleaching, many are related to local environmental degradation and reef overexploitation. Of the stressors mentioned above, only sea water temperature and solar irradiance have possible global factors driving changes and extremes. Global warming, along with ENSO events, change sea water temperatures. Ozone depletion increases the amount of UVR reaching the Earth's surface, and possibly causing coral bleaching events.

Increased sea temperatures and solar radiation (especially UV radiation), either separately or in combination, have received consideration as plausible large-scale stressors. In most instances, wherever coral reef bleaching was reported, it occurred during the summer season or near the end of a protracted warming period.

Coral bleaching was reported to have occurred during periods of low wind velocity, clear skies, calm seas and low turbidity, when conditions favor localized heating and high penetration of short wave length (UV) radiation. Also less oxygen is held by water at higher temperatures. Potentially stressful high sea temperatures and UV radiation flux could conceivably cause coral reef bleaching on a global scale with suspected greenhouse warming and the thinning of the ozone layer.

As reef building corals live near their upper thermal tolerance limits, small increases in sea temperature (.5 –1.5 degrees C) over several weeks or large increases (3-4 degrees C) over a few days will lead to coral dysfunction and death. Anomalously high sea temperatures have often been reported in the Caribbean-wide series of bleaching events that occurred during 1986-88, leading to hypothesis that global warming was having an effect on the coral reefs in this region.

Solar ultraviolet radiation is potentially harmful to reef corals and their symbiotic. UV radiation can readily penetrate clear sea water, and reef –building corals contain UV-absorbing compounds capable of blocking potentially damaging UV radiation. These compounds are produced in response to ambient UV levels and the concentration in corals is usually an inverse function of depth, but it is not known if bleaching responses are related to variations in UV flux that exceed the protective capacity of UV-absorbing compounds. There is a possible interaction between temperature and UV, with temperature significantly reducing zooxanthelae densities and also the concentration of UV absorbing compounds in a reef zooanthid, thus potentially increasing the exposure of the symbionts to the direct effects of UV radiation.

If a global warming trend impacts on shallow tropical and subtropical seas, we may expect an increase in the frequency, severity and scale of coral reef bleaching. Coral mortality could exceed 95% regionally with species extirpation and extinctions. A conservative temperature increase of 1-2 degrees C would cause regions between 20-30 degrees N to experience sustained warming that falls within the lethal limits of most reef-building coral species. In conjunction with sea temperature rise would be a sea level rise, and it has been suggested that sea level rise would suppress coral growth or kill many corals through drowning or lower light levels. Some coral populations and their endosymbiotic zooxanthellae may be able to adapt to the extreme conditions predicted during global climate change. Refuges in benign habitats, such as deep, sunlit reef substrates, oceanic shoals and relatively high latitude locations, might exist, but widespread coral mortality and reef decline would be expected in shallow reef zones in most low latitude. Even if significant sea warming and elevated irradiance levels do not occur, coral reef degradation from anthropogenic pollution and overexploitation will still continue, a result of unrelenting human population growth.

SCUBA DIVING

Fig – 23.12

Scuba diving ("scuba" originally being an acronym for Self Contained Underwater Breathing Apparatus, although now widely considered a word in its own right) is a form of underwater diving in which a diver uses a scuba set to breathe underwater for recreation, commercial or industrial reasons.

Unlike early diving, which relied exclusively on air pumped from the surface, scuba divers carry their own source of breathing gas (usually compressed air), allowing them greater freedom than with an air line. Both surface supplied and scuba diving allow divers to stay underwater significantly longer than with breath-holding techniques as used in snorkelling and free-diving.

According to the purpose of the dive, a diver usually moves underwater by swim fins attached to his feet, but external propulsion can come from an underwater vehicle, or a sled pulled from the surface.

History:

The first commercially successful scuba sets were the Aqualung open-circuit units developed by Emile Gagnan and Jacques-Yves Cousteau, in which compressed gas (usually air) is inhaled from a tank and then exhaled into the water, and the descendants of these systems are still the most popular units today. The open circuit systems were developed after Cousteau had a number of incidents of oxygen toxicity using a rebreather system, in which exhaled air is reprocessed to remove carbon dioxide. Modern versions of rebreather systems (both semi-closed circuit and closed circuit) are still available today, and form the second main type of scuba unit, most commonly used for technical diving, such as deep diving.

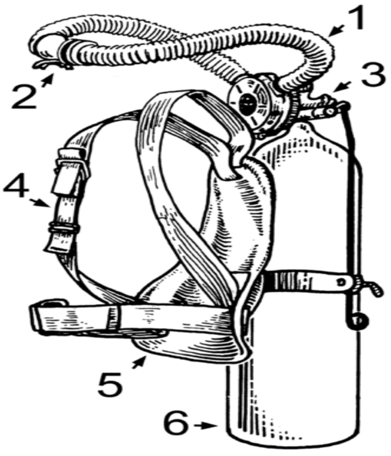

Fig – 23.13 - Original Aqualung SCUBA set

1. Hose
2. Mouthpiece
3. Valve
4. Harness
5. Backplate
6. Tank

Types of Diving:

Scuba diving may be performed for a number of reasons, both personal and professional. Most people begin though recreational diving, which is performed purely for enjoyment and has a number of distinct technical disciplines to increase interest underwater, such as cave diving, wreck diving, ice diving and deep diving.

Divers may be employed professionally to perform tasks underwater. Most of these commercial divers are employed to perform tasks related to the running of a business involving deep water, including civil engineering tasks such as in oil exploration, underwater welding or offshore construction. Commercial divers may also be employed to perform tasks specifically related to marine activities, such as naval diving, including the repair and inspection of boats and ships, salvage of wrecks or underwater fishing, like spear fishing.

Other specialist areas of diving include military diving, with a long history of military frogmen in various roles. They can perform roles including direct combat, infiltration behind enemy lines, placing mines or using a manned torpedo, bomb disposal or engineering operations. In civilian operations, many police forces operate police diving teams to perform search and recovery or search and rescue operations and to assist with the detection of crime which may involve bodies of water. In some cases diver rescue teams may also be part of a fire department or lifeguard unit.

Lastly, there are professional divers involved with the water itself, such as underwater photography or underwater filming divers, who set out to document the underwater world, or scientific diving, including marine biology and underwater archaeology. Reasons for diving may include:

Type of diving	**Classification**
aquarium maintenance in large public aquariums	commercial, scientific
boat and ship inspection, cleaning and maintenance	commercial, naval
cave diving	technical, recreational
civil engineering in harbors, water supply, and drainage systems	commercial
crude oil industry and other offshore construction and maintenance	commercial
demolition and salvage of ship wrecks	commercial, naval
diver training for reward	professional
fish farm maintenance	commercial
fishing, e.g. for abalones, crabs, lobsters, pearls, scallops, sea crayfish, sponges	commercial
frogman, manned torpedo	military
harbor clearance and maintenance	commercial, military
media diving: making television programs, etc.	professional
mine clearance and bomb disposal, disposing of unexploded ordnance	military, naval
pleasure, leisure, sport	recreational
underwater photography	professional, recreational
policing: diving to investigate or arrest unauthorized	police diving, military,

divers	naval
search and recovery diving	commercial
search and rescue diving	police
spear fishing	professional (occasionally), recreational
stealthy infiltration	military
marine biology	scientific, recreational
underwater tourism	recreational
underwater archaeology (shipwrecks; harbors, and buildings)	scientific, recreational
underwater welding	commercial

Breathing Underwater:

Water normally contains dissolved oxygen from which fish and other aquatic animals extract all their required oxygen as the water flows past their gills. Humans lack gills and do not otherwise have the capacity to breathe underwater unaided by external devices. Although the feasibility of filling and artificially ventilating the lungs with a dedicated liquid (Liquid breathing) has been established for some time, the size and complexity of the equipment allows only for medical applications with current technology.

Early diving experimenters quickly discovered it is not enough simply to supply air in order to breathe comfortably underwater. As one descends, in addition to the normal atmospheric pressure, water exerts increasing pressure on the chest and lungs—approximately 1 bar or 14.7 psi for every 33 feet or 10 meters of depth—so the pressure of the inhaled breath must almost exactly counter the surrounding or ambient pressure to inflate the lungs. It generally becomes difficult to breathe through a tube past three feet under the water.

By always providing the breathing gas at ambient pressure, modern demand valve regulators ensure the diver can inhale and exhale naturally and virtually effortlessly, regardless of depth. Because the diver's nose and eyes are covered by a diving mask; the diver cannot breathe in through the nose, except when wearing a full face diving mask. However, inhaling from a regulator's mouthpiece becomes second nature very quickly.

Open-circuit:

The most commonly used scuba set today is the "single-hose" open circuit 2-stage diving regulator, coupled to a single pressurized gas cylinder, with the first stage on the cylinder and the second stage at the mouthpiece. This arrangement differs from Emile Gagnan's and Jacques Cousteau's original 1942 "twin-hose" design, known as the Aqua-lung, in which the cylinder's pressure was reduced to ambient pressure in one or two or three stages which were all on the cylinder. The "single-hose" system has significant advantages over the original system.

In the "single-hose" two-stage design, the first stage regulator reduces the cylinder pressure of about 200 bar (3000 psi) to an intermediate level of about 10 bar (145 psi) The second stage demand valve regulator, connected via a low pressure hose to the first stage, delivers the breathing gas at the correct ambient pressure to the diver's mouth and lungs. The diver's exhaled gases are exhausted directly to the environment as waste. The first stage typically has at least one outlet delivering breathing gas at unreduced tank pressure. This is connected to the diver's pressure gauge or computer, in order to show how much breathing gas remains.

Rebreather:

Less common are closed and semi-closed rebreathers, which unlike open-circuit sets that vent off all exhaled gases, reprocess each exhaled breath for re-use by removing the carbon dioxide buildup and replacing the oxygen used by the diver.

Rebreathers release few or no gas bubbles into the water, and use much less oxygen per hour because exhaled oxygen is recovered; this has advantages for research, military, photography, and other applications. The first modern rebreather was the MK-19 that was developed at S-Tron by Ralph Osterhout that was the first electronic system. Rebreathers are more complex and more expensive than sport open-circuit scuba, and need special training and maintenance to be safely used.

Because the nitrogen in the system is kept to a minimum, decompressing is much less complicated than traditional open-circuit scuba systems and, as a result, divers can stay down longer. Because rebreathers produce very few bubbles, they do not disturb marine life or make a diver’s presence known; this is useful for underwater photography, and for covert work.

Gas mixtures:

For some diving, gas mixtures other than normal atmospheric air (21% oxygen, 78% nitrogen, 1% trace gases) can be used, so long as the diver is properly trained in their use. The most commonly used mixture is Enriched Air Nitrox, which is air with extra oxygen, often with 32% or 36% oxygen, and thus less nitrogen, reducing the likelihood of decompression sickness. The reduced nitrogen may also allow for no or less decompression stop times and a shorter surface interval between dives. A common misconception is that nitrox can reduce narcosis, but research has shown that oxygen is also narcotic.

Several other common gas mixtures are in use, and all need specialized training. The increased oxygen levels in nitrox help fend off decompression sickness, however below the maximum operating depth of the mixture, the increased partial pressure of oxygen can lead to oxygen toxicity. To displace nitrogen without the increased oxygen concentration, other diluents can be used, often helium, when the resultant mixture is called trimix.

In cases of technical dives, some of the cylinders may contain different gas mixture for each phase of the dive, typically designated as Travel, Bottom, and Decompression. These different gas mixtures may be used to extend bottom time, reduce inert gas narcotic effects, and reduce decompression times.

HAZARDS AND DANGERS

Injuries due to changes in air pressure:

Divers must avoid injuries caused by changes in air pressure. The weight of the water column above the diver causes an increase in air pressure in any compressible material (wetsuit, lungs, sinus) in proportion to depth, in the same way that atmospheric air causes a pressure of 101.3

kPa (14.7 pounds-force per square inch) at sea level. Pressure injuries are called barotrauma and can be quite painful, in severe cases causing a ruptured eardrum or damage to the sinuses. To avoid them, the diver equalizes the pressure in all air spaces with the surrounding water pressure when changing depth. The middle ear and sinus are equalized using one or more of several techniques, which is referred to as clearing the ears. The mask is equalized by periodically exhaling through the nose. If a drysuit is worn, it too must be equalized by inflation and deflation, similar to a buoyancy compensator.

If properly equalized, the sinus passages can stand the increased pressure of the water with no problems. However, congestion due to cold, flu or allergies may impair the ability to equalize the pressure. This may result in permanent damage to the eardrum. Although there are many dangers involved in scuba diving, divers can decrease the dangers through proper training and education. Open-water certification programs highlight diving physiology, safe diving practices, and diving hazards.

Effects of breathing high pressure gas:

- **Decompression sickness**

  The diver must avoid the formation of gas bubbles in the body, called decompression sickness or 'the bends', by releasing the water pressure on the body slowly at the end of the dive and allowing gases trapped in the bloodstream to gradually break solution and leave the body, called "off-gassing." This is done by making safety stops or decompression stops and ascending slowly using dive computers or decompression tables for guidance. Decompression sickness must be treated promptly, typically in a recompression chamber. Administering enriched-oxygen breathing gas or pure oxygen to a decompression sickness stricken diver on the surface is a good form of first aid for decompression sickness, although fatality or permanent disability may still occur.

- **Nitrogen narcosis**
  Nitrogen narcosis or inert gas narcosis is a reversible alteration in consciousness producing a state similar to alcohol intoxication in divers who breathe high pressure gas at depth. The mechanism is similar to that of nitrous oxide, or "laughing gas," administered as anesthesia. Being "narced" can impair judgment and make diving very dangerous. Narcosis starts to affect some divers at 66 feet (20 meters). At 66 feet (20 m), Narcosis manifests itself as slight giddiness. The effects increase drastically with the increase in depth. Almost all divers are able to notice the effects by 132 feet (40 meters). At these depths divers may feel euphoria, anxiety, loss of coordination and lack of concentration. At extreme depths, hallucinogenic reaction and tunnel vision can occur. Jacques Cousteau famously described it as the "rapture of the deep". Nitrogen narcosis occurs quickly and the symptoms typically disappear during the ascent, so that divers often fail to realize they were ever affected. It affects individual divers at varying depths and conditions, and can even vary from dive to dive under identical conditions. However, diving with trimix or heliox dramatically reduces the effects of inert gas narcosis.

- **Oxygen toxicity**

Oxygen toxicity occurs when oxygen in the body exceeds a safe "partial pressure" (PPO2). In extreme cases it affects the central nervous system and causes a seizure, which can result in the diver spitting out his regulator and drowning. Oxygen toxicity is preventable provided one never exceeds the established maximum depth of a given breathing gas. For deep dives, (generally past 180 feet / 55 meters) "hypoxic blends" containing a lower percentage of oxygen than atmospheric air are used.

- **Refraction and underwater vision**

  Water has a higher refractive index than air; it's similar to that of the cornea of the eye. Light entering the cornea from water is hardly refracted at all, leaving only the eye's crystalline lens to focus light. This leads to very severe hypermetropia. People with severe myopia, therefore, can see better underwater without a mask than normal-sighted people.

  Diving masks and diving helmets and fullface masks solve this problem by creating an air space in front of the diver's eyes. The refraction error created by the water is mostly corrected as the light travels from water to air through a flat lens, except that objects appear approximately 34% bigger and 25% closer in salt water than they actually are. Therefore total field-of-view is significantly reduced and eye-hand coordination must be adjusted.

- **Controlling buoyancy underwater**

  To dive safely, divers need to be able to control their rate of descent and ascent in the water. Ignoring other forces such as water currents and swimming, the diver's overall buoyancy determines whether he ascends or descends. Equipment such as the diving weighting systems, diving suits (Wet, Dry & Semi-dry suits are used depending on the water temperature) and buoyancy compensators can be used to adjust the overall buoyancy. When divers want to remain at constant depth, they try to achieve neutral buoyancy. This minimizes gas consumption caused by swimming to maintain depth.

  The downward force on the diver is the weight of the diver and his equipment minus the weight of the same volume of the liquid that he is immersed in; if the result is negative, that force is upwards. Diving weighting systems can be used to reduce the diver's weight and cause an ascent in an emergency. Diving suits, mostly being made of compressible materials, shrink as the diver descends, and expand as the diver ascends, creating unwanted buoyancy changes. The diver can inject air into some diving suits to counteract this effect and squeeze. Buoyancy compensators allow easy and fine adjustments in the diver's overall volume and therefore buoyancy. For open circuit divers, changes in the diver's lung volume can be used to adjust buoyancy.

- **Avoiding losing body heat**

  Water conducts heat from the diver 25 times better than air, which can lead to hypothermia even in mild water temperatures. Symptoms of hypothermia include impaired judgment and dexterity, which can quickly become deadly in an aquatic environment. In all but the warmest waters, divers need the thermal insulation provided by wetsuits or drysuits.

In the case of a wetsuit, the suit is designed to minimize heat loss. Wetsuits are generally made of neoprene that has small gas cells, generally nitrogen, trapped in it during the manufacturing process. The poor thermal conductivity of this expanded cell neoprene means that wetsuits reduce loss of body heat by conduction to the surrounding water. The neoprene in this case acts as an insulator.The second way in which wetsuits reduce heat loss is to trap a thin layer of water between the diver's skin and the insulating suit itself. Body heat then heats the trapped water. Provided the wetsuit is reasonably well-sealed at all openings (neck, wrists, legs), this reduces water flow over the surface of the skin, reducing loss of body heat by convection, and therefore keeps the diver warm (this is the principle employed in the use of a "Semi-Dry")

In the case of a drysuit, it does exactly that: keeps a diver dry. The suit is sealed so that frigid water cannot penetrate the suit. Drysuit undergarments are often worn under a drysuit as well, and help to keep layers of air inside the suit for better thermal insulation. Some divers carry an extra gas bottle dedicated to filling the dry suit. Usually this bottle contains argon gas, because of its better insulation as compared with air.

- **Avoiding skin cuts and grazes**

  Diving suits also help prevent the diver's skin being damaged by rough or sharp underwater objects, marine animals or coral.

- **Diving longer and deeper safely**

  There are a number of techniques to increase the diver's ability to dive deeper and longer:

  i. **Technical diving** – diving deeper than 40 metres (130 ft), using mixed gases, and/or entering overhead environments (caves or wrecks)
  ii. **Surface supplied diving** – use of umbilical gas supply and diving helmets.
  iii. **Saturation diving** – long-term use of underwater habitats under pressure and a gradual release of pressure over several days in a decompression chamber at the end of a dive.

INTERTIDAL AND UNDERWATER CORAL TRANSPLANTATION

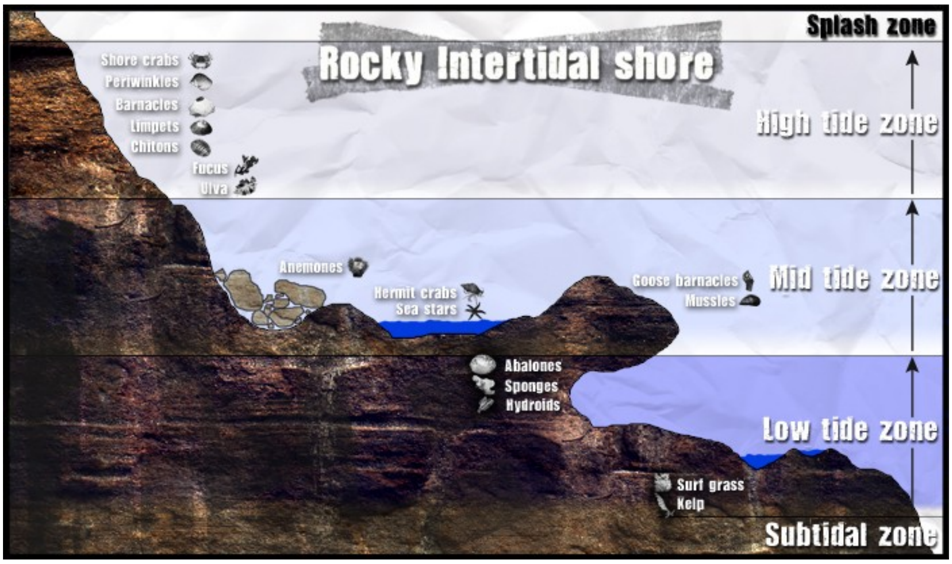

Fig – 23.14

Damage to the coral reef systems worldwide, particularly in developing and underdeveloped countries, is particularly alarming in recent decades. Blast fishing and other destructive fishing practices have been responsible for annihilating most of nature's coral cover resulting in lower fishery productivity and marine biodiversity. Efforts in the past had been focused on developing artificial coral reefs with little or no appreciable results. In most instances, the artificial coral reefs developed simply became effective aggregating devices for important fish species artificially raising the observed fishery catch yet not really restoring the damaged environment.

Coral reef deterioration, caused by natural and/or anthropogenic factors, has been widely reported worldwide over the last two decades. Because of the slow natural recovery of reefs and their high economic potential, reconstruction efforts of various kinds and on a wide range of scales have been proposed and efforts have been made to facilitate reef redevelopment (Craik et.al., 1990; Rinkevich 1995; Guzman 1999).

Various transplantation methods have been attempted with the goal of restoring coral cover to reefs. Much of the restoration efforts to date have been focused on responding to acute episodes of damage; in particular the repair of reefs subsequent to ship groundings. Most of these efforts are located in high-energy reef front areas, using expensive methods, and requiring hundreds of hours underwater to secure dislodged coral colonies. Apparently little consideration has been given to the fact that the high-energy environments most often affected are normally dominated by stable sediment-free substrata where natural recruitment and recovery processes are most active, potentially making restoration efforts in thesehabitats unnecessary. The overall positive impact of expensive coral reef restoration projects has recently been questioned (Harriott and Fisk, 1988b; Hatcher et al., 1989; Maragos, 1992; Edwards and Clark, 1998; Birkeland, 1999; Challenger, 1999). Rather than abandoning the work, Maragos (1992) suggested that less costly methods should be developed. A recent reevaluation (Edwards and Clark, 1998), detailed the conditions where transplantation was most appropriate, and concluded that transplantation should be viewed as a tool of last resort, for use only where natural recruitment and recovery processes are failing. We concur with these sentiments.

Simple, low-tech methods of coral transplantation have been investigated for restoring coral cover to damaged lower-energy reefs, using unattached coral fragments to mimic and accelerate asexual fragment-driven reef recovery processes (Guzman, 1991,1993; Lindahl, 1998; Fox et al., 1999; Bowden-Kerby, 1997, 2001a,b). Transplanting corals into lower energy areas precludes the necessity of securing coral transplants, considerably lowering cost and effort. A high survival rate for unattached coral transplants has been demonstrated for such sheltered areas (Maragos, 1974; Harriot and Fisk, 1988a; Guzman, 1991,1993; Lindahl, 1998; Bowden-Kerby 2001a,b), particularly for rubble environments and for larger fragment sizes.

Transplanting corals directly onto sand has also been done successfully (Bowden-Kerby, 1997; 2001b), establishing that entirely new patch reefs can be created on barren sand-flat "deserts", providing for increased fish habitat. This patch reef creation process is modelled on the natural process of coral colonization of sand dominated reef areas (Bowden-Kerby 2001b), whereby storm currents sweep detached coral colonies into sandy back reef environments where larval recruitment is not possible, but where conditions for coral growth are ideal. The key factor in coral survival on sand is the large size of coral colonies, as small fragments always perish (Bowden-Kerby 2001b).

Coral transplantation in the past suffered from serious difficulties such as:

a) Coral transplants are swept away by tidal currents
b) Substrates used are not calcium bicarbonate-based which are not conducive to the growth of the transplants
c) Even if calcium bicarbonate substrates are used, they are often too light that the transplants are damaged by tidal currents as well.

The basic problem then was to develop a substrate that will hopefully address all these concerns.

Relying on natural recruitment is one possible approach (Edwards & Clark 1998), but several limitations have been reported. First, the rate of natural recruitment of corals is often so highly variable that the process can take up to several years, especially in species broadcasting their gametes (Wallace 1985; Gleason 1996; Connell et al. 1997). Species releasing larvae (i.e., planulae) have high settlement rates in some areas, but more often than not they often settle near parents and show only limited range of dispersal (Harrison and Wallace 1990). Substantial spatial variations with respect to recruitment have also been reported in many studies (Dunstan & Johnson 1998; Hughes et al. 1999); thus, many suitable habitats are too often bare due to the absence of natural recruitment. Further, coral recruits, settling on monitored surfaces, are often low in species diversity, which means a damaged reef may require a considerably long time to regain its original diversity. Another disadvantage is that recruits in nature usually suffer from high mortality and slow growth rates (Sato 1985). For example, in southern Taiwan, less than 5% of coral recruits reportedly survived 22 months, and some of those that did were still below 1 cm in diameter (Soong, unpublished data). Moreover, some destruction renders the bottom of the sea into an unconsolidated substrate that inhibits successful recruitment of corals.

As a second approach, the transplantation of whole coral colonies has been undertaken in area of small-scale destruction where hard substrate is still available (Maragos 1974; Hudson & Diaz 1988; Munoz-Chagin 1997). Aside from providing new colonies to the receiving sites, this procedure may also increase local recruitment as in the case when transplants are gravid (Richmond & Hunter 1990). The fixation of colonies is critical in this kind of operation, but unfortunately it too often necessitates high costs (Kaly 1995). An adequate source of live corals is also a prerequisite so that enough raw materials for transplantation can be supplied without damaging the communities of the donor sites. For obvious reasons this approach can only be realistically applied in cases of certain small-scale reconstruction.

A third approach, the transplantation of coral fragments, is also feasible (Alcala et al. 1982; Oren & Benayahu 1997; Guzman 1999). Because corals are modular organisms, small pieces of corals have the capability of growing in the same way as whole colonies (Connell 1973; Birkeland et al. 1979). The growth of corals from fragments is, in fact, an important natural process, at least in some branching species (Highsmith 1982; Wallace 1985). The natural fragments first anchor and secure themselves in the crivices, more or less by chance, then continue to attach themselves to the substrate by regeneration and extension of soft tissues and skeleton. A new coral colony may start by this asexual means, and there is evidence suggesting that fragmentation is adaptive in some species (Brazeau & Lasker 1992; Fong & Lirman 1995). In artificial transplantation, exactly how to best arrange fragments, which are of course much smaller in size than whole colonies, is critical to their survival and growth rates. Because sedimentation often causes mortality and inhibits coral growth (Yap & Gomez 1985; Nagelkerken et al. 2000), keeping fragments above the bottom can reduce the likelihood of their being covered with silt. Placing a coral nursery structure in shallow waters may facilitate coral growth on account of the higher light intensities; nevertheless, the risk of the structures being easily damaged by strong wave actions is greatly increased (Plucer-Rosari & Randall 1987).

Strategically, it is imperative to consider all options available at the particular site being considered for reconstruction. Because no single method stands out as suitable for all situations and purposes, critical evaluations must be made before human intervention is taken.

Source:
http://nptel.ac.in/courses/120108002/23