# Ocean Digest

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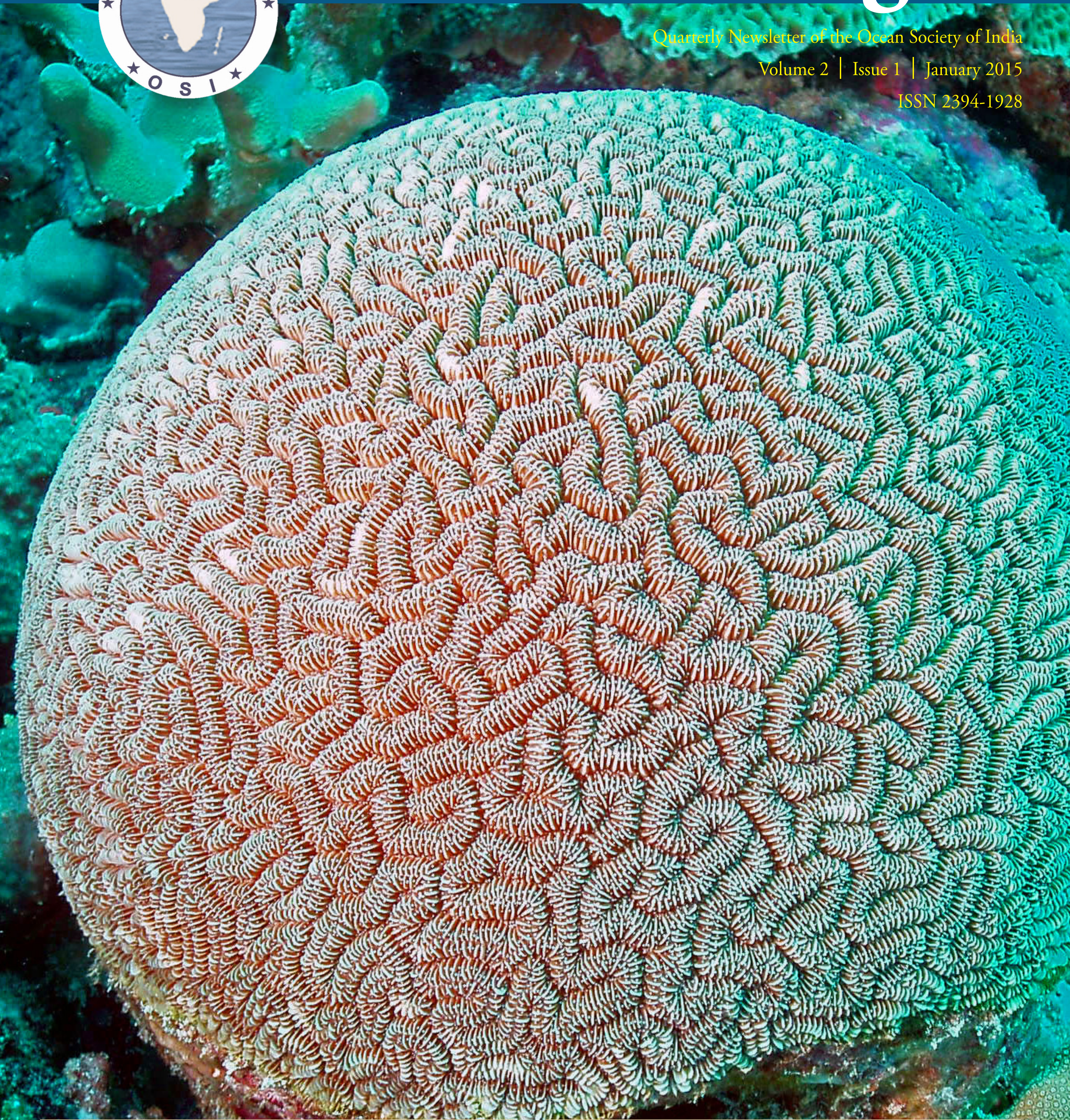
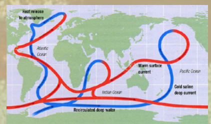


Journey to the Centre of the Indian Ocean - Effects of Climate Change



Climate Change and the Oceans

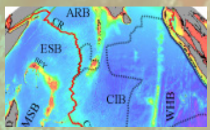
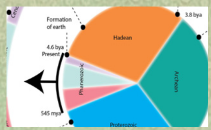


Plate tectonic reconstruction of India and Madagascar closing through the Mascarene Basin



A Brief History of Earth

# Central Indian Ocean - Effects of Climate Change

Invited Article

Prof. **Charles Sheppard** is a Professor at University of Warwick, UK, and Chairman of the Chagos Conservation Trust. He had dedicated nearly 40 years of research in developing the world's largest marine reserve, the Chagos Archipelago.

### Where and what is Chagos?

The British Indian Ocean Territory (BIOT) lies at the southern end of the chain of atolls extending south from India, to about 7 degrees South. The area is geographically known as the Chagos archipelago, and has five islanded atolls, surrounded by numerous submerged or awash atolls and banks (Fig. 1). The archipelago's central feature is the 150 by 100 km Great Chagos Bank, the World's largest atoll in terms of area. This is mostly submerged, but it has eight islands on its western and northern rim. The submerged structures of the archipelago are some of the most notable features of this central Indian Ocean region. The whole Territory out to the 200nM boundary covers about 640,000 km$^2$, and it is the largest no-take marine reserve in the world. Five chapters in Sheppard 2013 summarise the >200 scientific papers that we have produced about the islands and reefs of this area, mostly on work done since the late 1990s, but with useful earlier accounts that help us to identify changes that are taking place over time.

The reefs and islands are a haven for marine wildlife and for seabirds, mainly, I suspect, because most of the area is uninhabited. Its reefs have become strikingly different – better in every respect – from those in much of this ocean (Fig. 2). But recently, reef health in the Chagos islands is showing signs of stress too, this time from climate change. This is examined here from several angles: changes in coral cover, water temperature, sea level rise and island erosion, all aspects of research that we continue to conduct. This is a round-up of results to date on these aspects of increasingly rapid change.

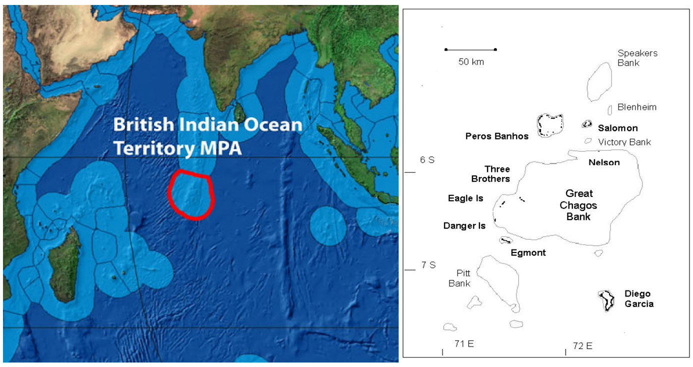



Figure 1. Left: Boundary (in red) of the British Indian Ocean Territory, measuring over 900 km across. Right: the Chagos Archipelago, whose submerged atolls and scattered islands of the Great Chagos Bank are all located in the centre of the Territory. Atolls and islands are in bold font, some larger submerged atolls are named in normal font. These spread over approximately 150 km.

### Coral cover

Coral cover is one widely used and simple indication of coral reef health. In some cases it is overly simple because it ignores coral diversity, calcareous algal growth, and other key factors, but it has many uses. Figure 3 shows the averaged coral cover on ocean facing Chagos atolls, with time. Coral cover was high several decades ago, then collapsed following the 1998 El Niňo as happened on most reefs in this ocean. Then, cover grew relatively very rapidly. Survivors produced huge numbers of juveniles, fish biomass and grazing remained high (there is almost no reef fishing in the Marine Protected Area), no blooming of algae to outcompete the corals for space and no pollution, so these reefs increasingly stood apart as an example of what coral reefs could be and once were.

Fig. 2. Coral reefs on Chagos atolls offer spectacular views of steep slopes that descend to a kilometre deep or more.

But there has been another marked reduction very recently. There have been more warm years and more widespread coral bleaching since 1998, but although warming is likely to have been the cause to some degree there is another factor which, let us hope, would perhaps be a more benign cause. That is, following the widespread recruitment of millions of table corals onto the bare space created after the massive coral mortality of 1998, these tables have all reached a large

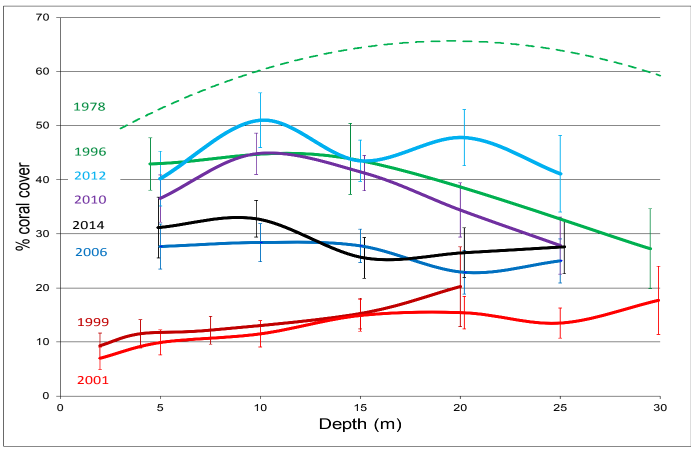



Fig. 3. Averaged coral cover on ocean facing reef slopes. The collapse after the 1998 warming event is clear, then slow recovery, then a further reduction up to 2014 (black line).

Fig. 4. A patch of table corals in 2014, one on the left being dead over most of its surface and the others mostly living.

size more or less at the same time. Figure 4 shows a small cluster of tables, all still standing but some are dead, some partly dead and some still living. The tables of this and similar species grow by 10-20 cm each year, then they age, topple, and die. It may well be that a natural old age of so many tables all at the same time (augmented we think by disease too), is partly or even mainly the cause of the decline in cover in this case. Before the 1998 wipe-out, such corals were all of widely different ages, big and small, but in the last decade millions grew up together, all having started growth in 2000 - 2002. Their simultaneous senescence might be the cause of the present drop in coral cover (let us hope it is).

For a time, these dead tables might produce more sand as they become eroded and ground down, but this source of island building material is unlikely to last long. This, as in many things, is an under-researched area of Chagos reefs that now we need to address, if only because continued existence of the islands depends to a large degree on it.

**Sea temperature rise**

Sea temperature rise has had the most profound effects of all environmental factors. We have deployed several temperature loggers all around the archipelago since early 2006. These are placed at 5, 15 and 25 m depths, on ocean facing and lagoon reefs. They record sea water temperature at intervals of 2 hours. On most expeditions we locate and collect them, download their data and, depending on their battery state, either put them back for another year or replace them (Fig. 5). We lose some, but we find most! Funding issues mean that some series we have had to discontinue. Other series have gaps where we have been able to restart them after a couple of years. We sometimes add a new site if other lines of research suggest it would be a useful addition, and we have abandoned at least one when weather repeatedly meant we could not collect them. We have four series that go back to the beginning in 2006, which are some of the most valuable,

Fig. 5. A temperature logger being replaced. It is placed inside a plastic pipe to prevent it being chewed by parrotfish.

though all are yielding useful results.

We found quite soon that the ocean facing reefs exhibit unexpected and important features, namely that every year, usually near the time that water should be warmest (which is Feb-March) there are sustained plunges in water temperature – something we don't properly understand but which might be due to region-wide internal waves (Fig. 6). Basically, the deep ocean thermocline rises closer to the surface, and this cooling may have a lot to do with the better survival or recovery of corals from heat-induced warming that we see here, when compared with other regions of the coral world where recovery commonly has not happened at all.

While these massive plunges in water temperature of over 10°C mask any longer term small trend, they are mostly not apparent in lagoons (which is what we would anticipate from internal waves). In lagoons, there is much smaller annual variation, and an overall rise is apparent in all cases, even over the relatively short period since early 2006. Data

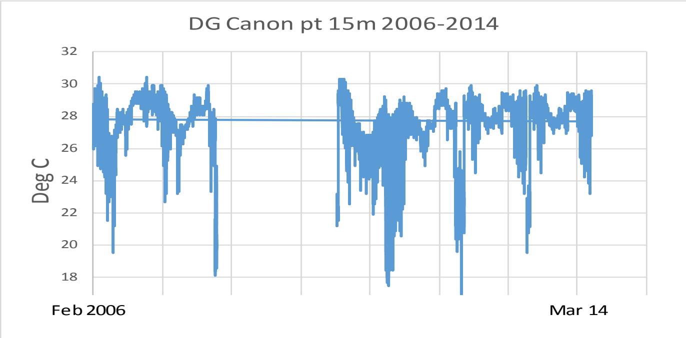



Fig. 6. The plunges in temperature at Cannon Point, Diego Garcia atoll. Water temperature can fall from about 30 to 18°C (Sheppard 2009).

from Peros Banhos lagoon at 15 m depth is shown in Figure 7. The trend is rising, showing a mean increase since 2006 of as much as 0.3°C. (Note the y-axis of this graph is not the same as in the previous figure for an ocean facing reef – it is much less variable.)

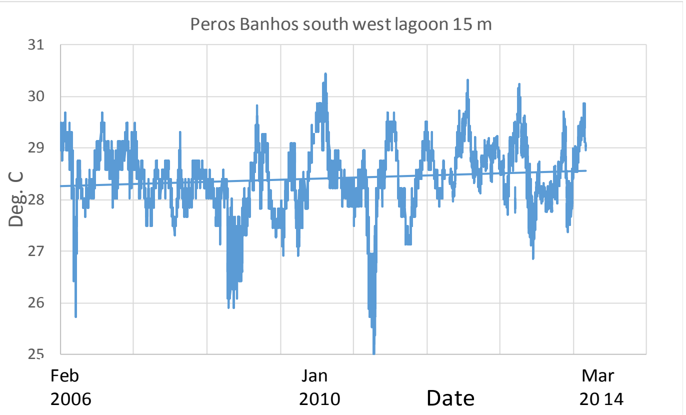



Fig. 7. Temperature at 15 m depth on a coral knoll in SW Peros Banhos lagoon.

It was warming water that killed 90% of the Chagos reef corals (and those of much of the Indian Ocean) in 1998. We do not know what the lethal temperatures are exactly for these lagoonal corals, nor how much acclimation to warmer water might exist here. We do know that on the seaward side, the 1998 warming pulse that killed 90% of corals was about 29.5°C. Today, we can see that the warmest pulses now approach 31°C. In Diego Garcia where I have looked every year for over a decade, we have seen several episodes of coral bleaching (caused by warm water) since coral started to recover after 1998, though this has apparently not been sufficient to cause further widespread coral death.

But, effects are patchy over this large archipelago, and not everywhere responds in the same way at the same time. In 2013, deeper water corals in Salomon lagoon were almost all killed, and from around mid-February of that year our data shows that there was a period of over two months where temperature at 5 m depth was mostly well over 29.5 ° C, and indeed it was over 30.5°C, approaching 31 degrees for a significant length of time, in early March. We saw the effect this had on the corals (Fig. 8). We had unfortunately lost the deeper water temperature logger for that site, though another has now been secured.

Temperature stress is not simple to explain. There are around 300 species of corals, all with different shapes, depth preferences and different capacity to resist or adapt to warming. Corals should not be taken as being just one group: like trees, where pine trees, teak and hundreds more each have different tolerances to environmental factors. But the temperature trend is upwards in Chagos lagoons, and they lack the probable respite from the unusual and prolonged plunges in temperature seen on the ocean facing reefs.

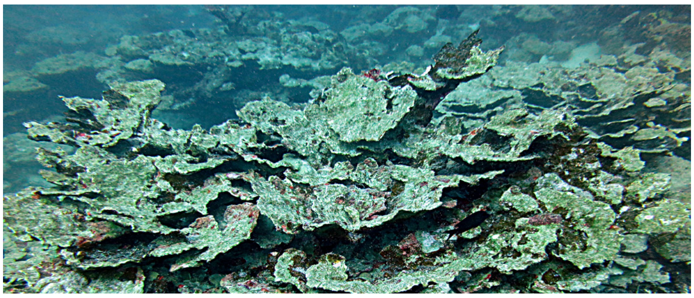


Fig. 8. Dead leafy corals in deeper water in Salomon atolls. Photo taken at the end of Feb 2013.

## Sea level rise

The world now knows there is sea level rise. Climate change deniers do still exist, and indeed commentaries saying there is no significant sea level rise (even temperature rise until recently) can still be found on several climate change deniers' web sites where they are enthusiastically promulgated. I have seen much misused Chagos interpretations on such sites in fact.

There are two important components to sea level rise: overall oceanic levels that now can be measured by satellite (and are termed "eustatic"), added to which are local land movements. The sum of both will be detected by tide gauges, one of which (part of a global network) is located in Diego Garcia.

Figure 9 shows the data for two runs of sea level that

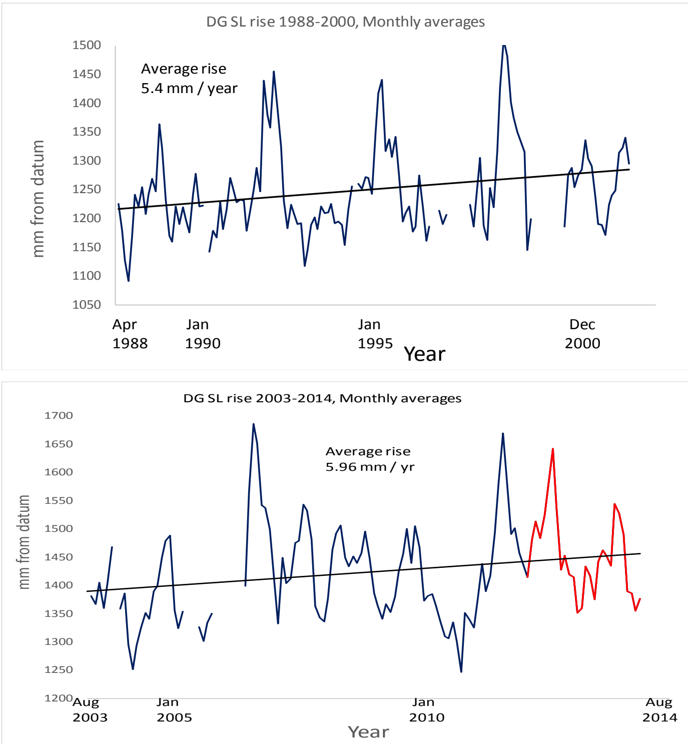



Fig. 9. Sea level in Diego Garcia lagoon. The data is 'research grade', except for the red, recent segment in the most recent two years, which is 'fast' grade. (In fact the red line continues back to 2003 but all points lie exactly underneath the blue line.)

exist in Diego Garcia. Sea level is rising, no doubt about that, and is rising significantly. Anyone can plot this on Excel. The raw data is daily (you can get hourly data too in fact) but for various reasons, including averaging out tidal differences, accounting for 'auto-correlation' and other technical details, I have chosen to average out for calendar months. In one month there are two neap-spring cycles and about 60 tides altogether, so plotting by average calendar month provides a pretty reasonable and widely used averaging out.

From 1988, sea level in Diego Garcia rose on average 5.4 mm per year, while in 2003 to 2012 it rose about 5.8 mm per year. The rate seems to be accelerating. All the simple straight line fits are highly significant statistically, and is similar to many sites all around the tropical world. It is, of course, highly significant to islanders throughout the tropical world too, as well as being increasingly expensive to try and combat!

**Island erosion**

These are low lying islands built by coral, so what will happen as a result of sea level rise and rising temperature that kills the reef building corals more frequently? We cannot be sure, but island erosion is occurring in several places. Earlier in 2014 some of us (led by distinguished US reef geologists) published in Science a short rebuttal of some ill-considered and over simplified results that asserted that the growth of coral islands can keep up with the rise in sea level. We showed that the average rise in reef growth around the world over thousands of years was only around 3.5 mm per year. We also made the point that this growth rate assumes good, healthy coral growth, but, as shown above, warming is now seriously effecting coral growth here by causing sporadic episodes of mortality. This average of 3.5 mm is derived from results ranging from 0.6 to 7.9 mm per year. We do not know (because we have never measured) where Chagos reefs lie in this range, but, given warming which is damaging coral

Fig. 10. Sharks on the grass. An area in Diego Garcia atoll where the sea now regularly floods over 100 m inland on many high spring tides. There have been dozens of occasions in the last decade when high tides have inundated areas of the island.

growth, and the measured sea level rise approaching 6 mm per year today, it is unsurprising that we see several substantial areas of shoreline flooding (Fig. 10), which has led to attrition in many places too.

One further point is important here, namely the profiles of most Chagos islands. Most of these islands have raised rims and depressions in the middle, meaning that sea level rise may show no significant erosion of coastline for a while, until the rim breaches. This is very important as this means that rates of inundation of the islands will be non-linear with respect to sea level rise, not affecting erosion at all at first, followed by disproportionate flooding. Where shoreline defence is done, in the inhabited atoll Diego Garcia, it is becoming extremely expensive, using rocks imported from Asia or Mauritius that are much harder than the soft Chagos limestone.

**Other climate change factors**

Other climate change factors affecting reefs include an increase in acidity of the water as atmospheric $CO_2$ continues to rise, much of which dissolves in sea water. We have never measured this in Chagos, but it is known from major and recent studies (such as at Hawaii and the Great Barrier Reef) that this may even be as important as warming. In brief, rising acidification reduces calcification, a factor critical to coral and reef growth. Chagos atolls are protected by massive calcareous algal ridges and spur systems, natural, major wave breaks protecting the shorelines. Problems here could turn out to be most critical of all.

Diseases are another factor that may be increasing in Chagos. Diseases are certainly very noticeable there now, though low. Unfortunately there is evidence that they increase with rising stress from, for example, rising temperature. This is one aspect on which we are carrying out more research.

**The overall picture**

Reefs depend on fairly constant and constrained physical characteristics of the oceans. Despite the above, Chagos reefs are probably the most healthy overall that we can see anywhere, probably because they have not been subjected to direct impacts for nearly half a century. They are certainly the largest expanse of reefs still in excellent condition in the Indian Ocean, possibly the world in several respects. They are correspondingly important therefore. But it seems that changing climate factors are catching up with it. Ignoring this would be foolish, and we need to wake up to the problem far more than we have done so far.

What can we do about global reef deterioration? Another article is needed to do that subject justice, but there is one powerful school of 'management' which we must resist strongly. I call it the MAWBID school (Might As Well Because It's Doomed), which is something we see in many areas of conservation (fisheries is a good example relevant to Chagos). It is seen especially where there is conflict between those who wish to exploit a resource and the greater good. We must avoid such fatalistic syndromes.

Caution, science and application of sense now can buy 20-30 years more life for these reefs. Few places have reefs as resilient or as 'good' as those in Chagos. Many world records have been found here: the abundance of coconut crabs, biomass of reef fishes, the total lack of marine introduced

Fig. 11. Without fishing or disturbance, Chagos reefs have the highest known fish biomass so far recorded.

species, the least polluted seas so far known in the world, and others. Chagos is increasingly being used as a global reference site in a world which sees rising human demands on declining natural resources. The example it sets and information it gives can be used by those countless people who are trying to restore their own damaged reefs and who otherwise would have a poorer idea of what to aim for. It is well worth treating Chagos with great care to ensure it remains in this state, for there is almost nowhere else left in the Indian Ocean like it. 'Management' of reefs or islands is a misleading though popular hubris anyway: we like to think we can manage a reef but we cannot even manage some small parts or species of a reef. What we can manage is human activity and our impact upon them, which is quite different! If we do that effectively then we know that a reef and its components can rebound with greater resilience than if it has been damaged. With good governance we should be able to sustain Chagos reefs in the condition that we all would like to see maintained, for ever, with rich corals, huge biomass of fish that never learned to avoid people (Fig. 11) – a reservoir for the future.

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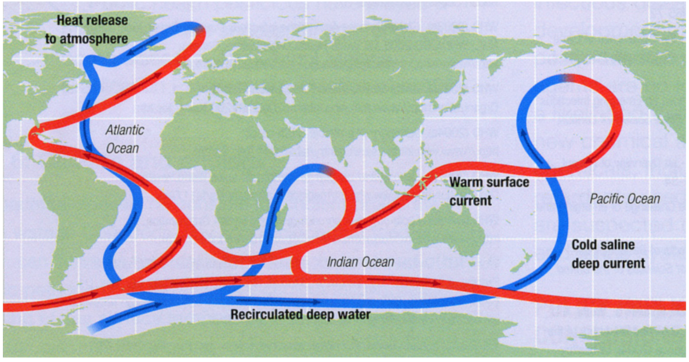
All underwater photos by Anne Sheppard. The cover image is of a brain coral, *Ctenella chagius*, from the Chagos Archipelago. During the day, the brain corals' tentacles are retracted into the valleys where they are protected, and during the night they extend them to catch food.

# Climate change and the Oceans

## Review

Heat transport by oceans is an important component of climate change. The ocean stores heat before it is released to the atmosphere. Thermohaline circulation moves a massive current of water around the globe, from northern oceans to southern oceans, and back again. Currents slowly turn over water in the entire ocean, from top to bottom. This is also known as conveyor belt, moving warm surface waters downward and forcing cold, nutrient-rich waters upward. The Gulf Stream and the North Atlantic Current carry warm salty water to Greenland Seas from equatorial region. Due to strong cool Arctic winds cools transported water and causes for increasing its density. This water then sinks, feeding deepwater currents. Starting off the Greenland coast, the newly created deepwater slowly drifts south along the western margin of the Atlantic basin. It then crosses the equator and mixes with the deepwater currents circling Antarctica and also spreads to Indian and Pacific Oceans where it mixes with warmer water and resurfaces. The Southern Ocean plays a critical role in driving, modifying and regulating global climate change. The Antarctic Peninsula has shown some of the most rapid rises in atmospheric and oceanic temperature in the world, with an associated retreat of the majority of glaciers (Reid et al. 2009). Changes in thermoheline circulation/Conveyor belt are vital for climate change.

Recent study by Woodard et al. (2013) suggested that the ocean circulation plays important role in regulating Earth's climate. Based on ocean sediment core samples it has been found that the major cooling of Earth and continental ice build-up in the Northern Hemisphere 2.7 million years ago (e.g., Maslin et al. 1996). At the same time major volume expansion in the northern hemisphere glaciers and substantial fall in sea levels affected the ocean conveyor system even though there was no major change in carbon dioxide concentration in the atmosphere (Woodard et al. 2013). This deep ocean circulation changes were associated




Schematic global oceanic thermohaline circulation. Blue lines are deep coldwater flow; red lines are warmer surface flow. Source: IPCC

with high-latitude processes that altered the temperature/ salinity of deep water mass. Woodard et al. (2013) found that before the intensification of northern hemisphere glaciers, the North Pacific deep waters were substantially colder (4°C) and probably fresher than the North Atlantic Deep Water. Based on analysis of reconstructed bottom water temperature they suggested that at ~2.73 million years ago the Atlantic-Pacific temperature gradient was reduced to <1°C, suggesting the initiation of stronger heat transfer from the North Atlantic to the deep Pacific. The authors have attributed the enhanced interhemispheric heat and salt transport to increased glaciation of Antarctica and, which caused global climate change at that time by contributing to the intensification of northern hemisphere glaciers. Thus ocean can play critical role in climate change.

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*Review compiled by* Jasti Chowdary and Anant Parekh, IITM

# A Brief History of Earth

## History

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According to the current scientific consensus, universe formed 15 bya (billion years ago), which is 1500 Crore years ago, in the so-called "big bang hypothesis." Sun and the solar system including Earth formed 4.567 bya, which is 456 Crore years ago. According to Vedas, age of earth is 1.97 billion years (precisely 197,29,49,116 years, in year 2015), which is much closer to the current understanding rather than 6019 years, as calculated by 17th Century Vice Chancellor of University of Cambridge, John Lightfoot [1]. Soon after the earth formed, a giant Mars-sized body "Theia" collided with our planet in so-called "giant impact hypothesis" (4 bya) ejecting a huge mass of earth to the space, that resulted in a giant crater on this planet, which would soon turn out to be the Pacific Ocean, and ejected mass became moon [2].

Evolutionary history of Earth is gauged by evolutionary or geologic time scale (Fig. 1). The scale is divided into four major eons (each eon is 1 billion years or more); Hadean, Archean, Proterozoic and Phanerozoic. Earliest eon is Hadean, which begun with the formation of the earth and lasted till about 3.8 bya. Early molten earth was cooled down, and precipitation resulted in the formation of oceans. It is thought that during this period the first RNA (Ribonucleic Acid) molecules formed, that later turned out to be self-replicating (able to make copies of itself) to form the so-called "RNA World.". About 3.9 bya earth and moon was pounded with heavy bombardment by meteorites (lunar cataclysm) -that resulted in craters in moon as we can see today on the lunar surface and numerous craters (almost 20,000 of them!) on our planet.

Archean eon began 3.8 bya and lasted till 2.5 bya. Life originated (abiogenesis) around 3.8 -3.4 bya, with first organisms believed to be chemoautotrophic bacteria- that fix carbon dioxide with energy derived from oxidization of inorganic chemicals. During this eon, the earth was a bacterial world- when the first cells evolved to prokaryotes, and first cyanobacteria formed through endosymbiosis of one bacteria with another. Cyanobacteria started the photosynthesis, resulting in enrichment of oxygen in the atmosphere, evolution of aerobic bacteria, and the formation of the Ozone layer. Cyanobacterial biofilms formed in rocky intertidal habitats, and these turned out to be "stromatolites"- some of the oldest fossils.

Proterozoic eon began 2.5 bya with a major global glaciation event called Huronian. As the temperature rose, glaciers melted and first eukaryotes (green algae) appeared around 1.8 bya, colonial eukaryotes appeared 1.2 bya, dinoflagellates (1.1 bya) and protozoa 750 mya (million years ago). Second global glaciation (snowball earth) happened around 630 mya that would soon melt, when some of the complex multicellular eukaryotes of "Ediacaran" evolved around 580 mya. Soon, the most magnificent event in the history of life on planet would begin, the so-called "Cambrian explosion", when most of the diversity of life on oceans formed, that included fungi, ctenophora (comb jellies), porifera (sponges), crustaceans (marine arthropods), and mollusks. This event was so profound that evolutionary biologists group entire history of the earth till this time as "pre-Cambrian" [3].

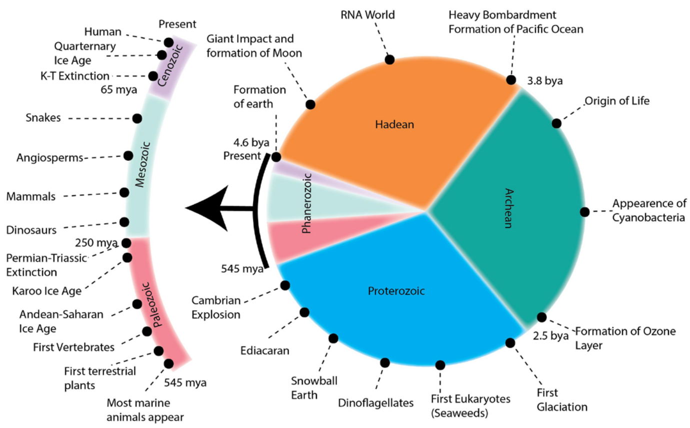


Fig. 1. Evolutionary time scale. *Source*: Felix Bast © 2014 Creative Commons Attribution-ShareAlike 2.5 India License.

The current eon Phanerozoic began 545 mya (5.4 Crore years ago). Because of the excellent fossil evidence, this eon is divided into three era (each era is around 150 million years or more); Paleozoic, Mesozoic and Cenozoic. Each era is in turn divided into periods, each period into epochs, and each epoch into ages; for the sake of brevity only up to the era is introduced in this manuscript. Paleozoic era began 545 mya and lasted till 250 mya. It was during Paleozoic era that oceanic biodiversity vastly expanded to have first chordates, echinoderms (that include starfish), forams and radiolarians (protists) around 535 mya. Terrestrial plants formed from intertidal seaweeds around 530 mya. First vertebrate animals (jawless fishes) appeared 485 mya. A minor ice age called Andean-Saharan occurred around 450 mya. In ocean, great diversification of animal phyla continued resulting in ray-finned fishes and crabs. In land, ferns, gymnosperms, beetles, crabs, scorpions, amphibians, reptiles, scorpions, etc. appear. However, a glaciation event (Karoo Ice Age), that would soon transcend to a major extinction event that happened around 250 mya, Permian-Triassic extinction, wipes out around 90% of marine life, marking the end of Paleozoic era.

Mesozoic era began 250 mya and lasted till 68 mya. It was during this era that the first dinosaurs (225 mya), mammals (215 mya), angiosperms (130 mya), snakes and ants (80 mya) appeared. The supercontinent Pangaea was later split into Laurasia and Gondwana (200 mya). The name Gondwana is derived from Sanskrit "Gondavana"-Forest of Gonds, which is located in Central-Northern India. Laurasia split to Laurentia (present day North America) and Eurasia, forming Northern Atlantic Ocean (100 mya). South Atlantic Ocean and Indian Ocean formed when supercontinent Gondwana split into present day continents of Antartica and Africa (100 mya). Indian subcontinent began north-eastward drift after breaking away from Africa (75 mya) and collided with Eurasia plate (50 mya) resulting in the formation of Alpine Orogeny (mountain ranges including Alps and Himalayas). Australia broke away from East Antarctica around 80 mya.

The current era Cenozoic began 65 mya with a mass extinction event called K-T (cretaceous-tertiary) that wiped out all of the dinosaurs. Modern birds, whales, rodents, and rabbits appeared around 55 mya. Soon bats (52 mya), butterflies (40 mya), pigs and cats (30 mya), deers (25 mya), giraffes (20 mya), mammoths (15 mya) and wolves (10 mya) would appear. South America broke away from West Antarctica (30 mya). Laccadives formed around 36 mya and Andaman & Nicobar Islands formed around 26 mya. Japan broke away from Eurasian plate and started moving eastward (15 mya), that opened up Sea of Japan. First hominin (common ancestor for humans and chimpanzees) appeared around 6.5 mya. Isthmus of Panama formed around 3 mya that separated Atlantic and Pacific Oceans. Last ice age (Quaternary glaciation) occurred around 2.5 mya. Our genus Homo appeared around 2 mya, and modern humans (Homo sapiens) around 200,000 years ago in Africa. Humans would soon start expanding, first from Africa to Eurasia (60,000 years ago), subsequently to Australia through South-East Asian Land Bridges (45,000 years ago) and later to Americas through Bering Land Bridge (12,000 years ago) –that is now Bering Strait between Eastern Russia and Western Alaska [4]. As per a number of reports, the Earth is currently moving towards the sixth major extinction event caused exclusively by the human impact on environment, abbreviated as HIPPO (Habitat destruction, Invasive species, Pollution, Human Over-Population and Overharvesting). The scientific consensus is that the climate change is in large part caused by human activities and is largely irreversible. Solar luminosity will be augmented by 10% in about 1 billion years, that will result in evaporation of oceans to cause "moist greenhouse" effect, increasing the surface temperature by several fold. By then the entire life on earth will either become extinct, or we will colonize another suitable planet. The earth's ultimate fate would be absorption into the red giant sun- in about 7 billion years.

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## Plate tectonic reconstruction of India and Madagascar closing through the Mascarene Basin

### Student Article

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The Indian Ocean (Fig. 1) was created by fragmentation and dispersal of a continental assemblage, Gondwanaland. In this context, the western continental margin of India and the adjacent ocean basins were evolved by rifting and subsequent drifting of India first from Madagascar, creating the Mascarene Basin, and then from Seychelles, creating the conjugate Arabian and Eastern Somali basins. Since the hydrocarbon occurrence in passive continental margins is closely associated with its spatio-temporal evolution, plate tectonic reconstructions of these margins and adjacent oceanic basins are found to be very useful to provide important constraints on conceptual evolution of hydrocarbons.

The plate tectonic reconstruction of western continental margin of India with its conjugate region of Madagascar has been directly addressed or indirectly depicted in a number of earlier studies. However the proposed relative configurations of India with Madagascar in their pre-drift tectonic scenario vary in different models. The formation of Indian Ocean is associated with Indian Plate (IND), African Plate (AFR) and Antarctic Plate (ANT) to cite the major plates (Fig. 1). Therefore, the India-Madagascar (IND-MAD) reconstruction can be achieved by considering different plate circuits - either by considering movement of IND directly to AFR (closing the Arabian, Eastern Somali and Mascarene basins) or by a combination of movements of IND to ANT (closing Central Indian and Crozet basins) and then IND-ANT

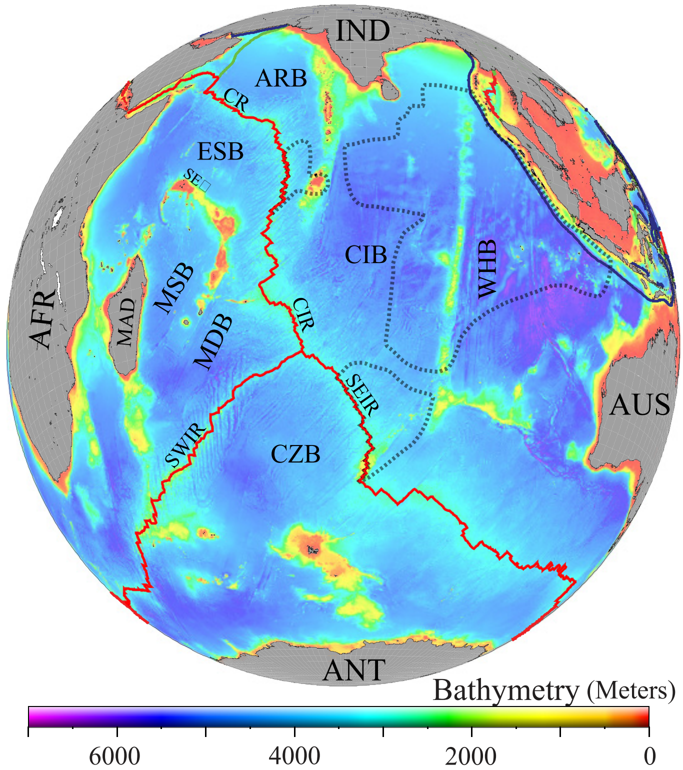


Fig. 1. Bathymetry of the Indian Ocean along with the plate boundaries. Thick lines with red/blue/green colours for divergent/convergent/transform boundaries and dotted black lines for zone of deformation in the Central Indian Basin. CR: Carlsberg Ridge; CIR: Central Indian Ridge; SWIR: Southwest Indian Ridge; SEIR: Southeast Indian Ridge; ARB: Arabian Basin; ESB: Eastern Somali Basin; MSB: Mascarene Basin; MDB: Madagascar Basin; CZB:Crozet Basin; CIB: Central Indian Basin; WHB: Wharton Basin; SEY: Seychelles Plateau

to AFR (closing the Southwest Indian Ridge). The absence of detailed magnetic anomaly information from Mascarene Basin forced all those studies to follow the IND-ANT-AFR circuit to obtain India-Madagascar reconstruction models in their pre-drift scenario (e.g. Fig. 2a). Since those models were not accounted for the deformation in the Central Indian Basin, subsequent studies (e.g. Fig. 2b) applied a correction for reflecting this deformation in the India-Madagascar configuration. However, since the detailed understanding on the deformation still remains vague, the models created based on IND-ANT-AFR circuit needs improvement.

Recently, Eagles and Wibisono (2013) published magnetic anomaly picks and rotation parameters for different ages of the Mascarene Basin from its initiation to cessation of spreading (between ~ 88 Ma to 61 Ma). These information enabled to obtain a better-constrained IND-MAD juxtaposition model through direct IND-AFR (more specifically, India-Seychelles-Madagascar) circuit. This was achieved first by closing the conjugate Arabian and Eastern Somali basins for 61 Ma using rotation parameters of Royer et al. (2002) to bring India attached to the northern flank of the Mascarene Basin and then to obtain India-Madagascar pre-drift juxtaposition by closing the Mascarene Basin from 61 Ma to 88 Ma. Following this circuit could avoid the effect of the Central Indian Basin deformation, since all these rotation parameters were computed from conjugate magnetic anomaly picks from the oceanic crust unaffected by that deformation. The present model (Fig. 2c) also matches well with IND-MADclose-fit reconstructions of Yatheesh et al. (2006) or Müller et al. (2008), where the Alleppey-Trivandrum Terrace Complex was depicted as conjugate of a bathymetric notch in the Northern Madagascar Ridge. However, compared to those models, the present model shows considerably more gap between India and Madagascar. This gap suggests possibility of a wider continental rift zone between India and Madagascar that might have later fragmented to form smaller continental blocks of Laccadive Plateau, Seychelles Plateau and Laxmi Ridge.

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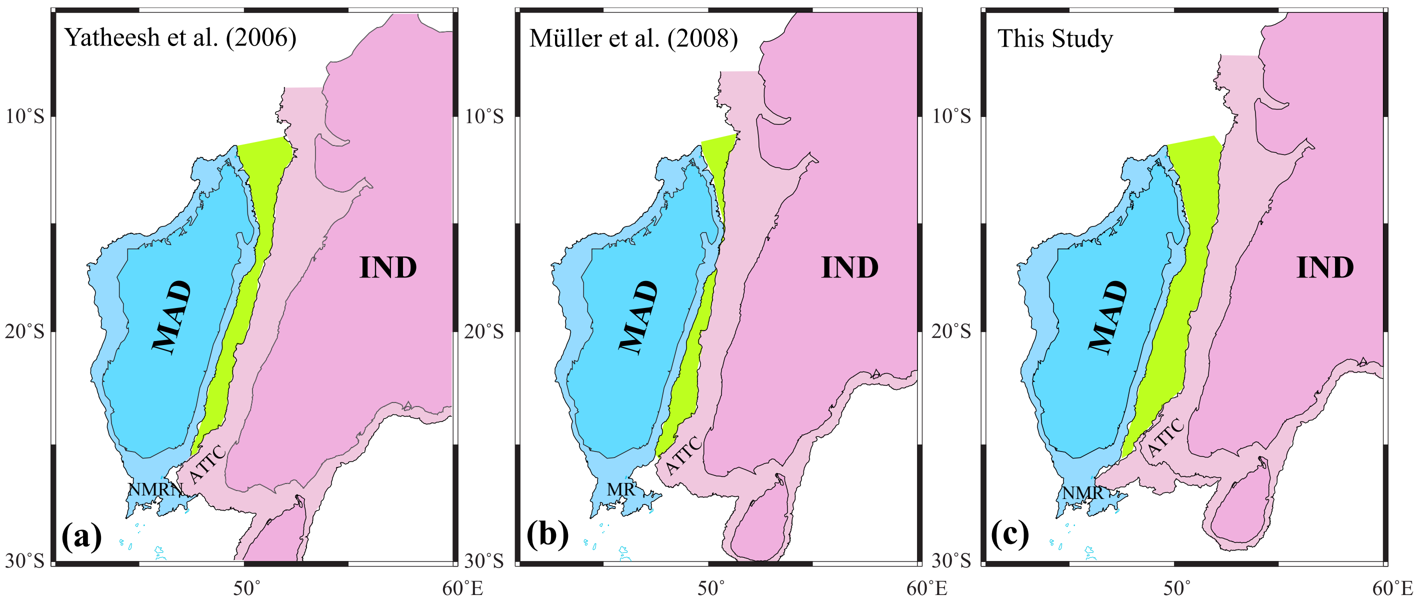


Fig. 2. India-Madagascar juxtaposition models based on [a] Yatheesh et al. (2006); [b] Müller et al. (2008); [c] Present study. The green shaded region represents the possible continental rift zone between India and Madagascar. ATTC: Alleppey-Trivandrum Terrace Complex; NMR: Northern Madagascar Ridge.

# Infinity: Mystery of Mathematics

## Contributed Article

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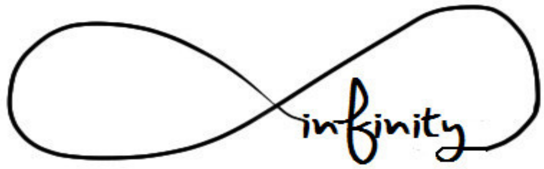
Sometime between 5th and 6th centuries B.C., the Greeks discovered infinity. The concept was so overwhelming, so bizarre, so contrary to every human intuition, that it confounded the philosophers and mathematicians who discovered it, causing pain and insanity. Of course from the time people began to think about the world they lived in, questions about infinity arose. There were questions about time. Did the world come into existence at a particular instant or had it always existed? Would the world go on forever or will there be a finite end? Then there were questions about space. What happens if one keeps on travelling in a particular direction? Would one reach the end of the world or could one travel forever? Again above the earth one could see moon, planets, sun and stars, but was this space finite or does it go on forever? These questions are very fundamental and must have troubled thinkers long before recorded history. There were more subtle questions about infinity, which were also asked at a stage when people began to think deeply about the world. What happens if one cuts a piece of wood into two pieces, then again cuts one of the pieces into two and continues to do this. Could one do this forever? We begin our account of infinity with the fifth-century philosopher Zeno of Elea. The early Greeks had come across the problem of infinity at an early stage in their development of mathematics and science. In their study of matter they realized the fundamental question: "Can one continue to divide matter into smaller and smaller pieces or will one reach a tiny piece which cannot be divided further". Pythagoras (569 – 500 B.C.) had argued that "all is number" and his universe was made up of finite natural numbers. Then there were Atomists who believed that matter was composed of an infinite number of indivisibles. Of course these paradoxes arise from the infinite. Aristotle did not seem to have fully appreciated the significance of Zeno's arguments but the infinite did worry him nevertheless. He introduced an idea, which dominated thinking for two thousand years and is still a persuasive argument to some people today. Aristotle argued against the actual infinite and, in its place, he considered the potential infinite. His idea was that we can never conceive of the natural numbers as a whole. However they are potentially infinite in the sense that given any finite collection we can always find a larger finite collection. It was an attempt to bring infinity, as well as zero, into the number system. Of course it does not work since if it were introduced then 0 times infinity must be equal to every number n, so all numbers are equal. Thomas Aquinas, the Christian theologian and philosopher, used the fact that there was not a number to represent infinity as an argument against the existence of the actual infinite. The concept of infinity has tantalized and sometimes troubled mankind. To a mathematician, the word 'infinity' means many different things depending on their context. There are many kinds of infinity. At the end of 19th century, the mathematician Georg Cantor devised a system for comparing infinities. For example; the infinity of integers is smaller than the infinity of real numbers. In fact, for any infinity you can name, there is another infinite quantity that's infinitely bigger.

The symbol, ∞, which we use today for representing infinity was first used and given by an English mathematician John Wallis who used it in "De Sectionibus Conicis" in 1655 and again in "Arithmetica Infinitorum" in 1656. John Wallis (1616-1703) was one of the most original and accomplished English mathematician of his time. He chose this symbol to represent the fact that one could traverse the curve represented by this symbol infinitely often. Infinity symbol,




∞, is also sometimes called "Lazy Eight", evoking the image of "8" lying on its side. Romans used the infinity symbol to represent 1000, a BIG number to them. The word infinity comes from the Latin word 'infinitas'. Infinity refers to different concepts in theology, philosophy, mathematics and everyday life. The earliest known documented knowledge of infinity was presented in ancient India in 'Yujur Veda' (1200-400 BC), which states "if you remove a part from infinity or add a part to infinity, still what remains is infinity". The Jaina mathematical text 'Surya Prajnapati' (400 BC), classifies infinite into 'Nearly Infinite', 'Truly Infinite' and 'Infinitely Infinite'. The Jaina was the first to discard the idea that all infinities were identical or same. They recognized different types of infinities. In common parlance, infinity is often used in a hyperbolic sense. For example: "The movie was infinitely boring, but we had to wait forever for tickets". Mathematics considers infinity as the useful concept of a process with no end. The terms infinity and infinite have a variety of related meanings in mathematics. The adjective finite means having an end, so infinity may be used to refer something having no end. In mathematics, the infinity symbol ∞ means boundlessly large but not necessarily uncountable. In 1600s Galileo proposed that infinity should obey a different arithmetic than finite numbers. Few concepts in mathematics are more fascinating, tantalizing and confounding than infinity. The concept of infinity has tantalized and sometimes troubled mankind. Infinity is neither a fiction nor a figment of imagination. It is a part of reality, or a positive quantity or measurement, but it is too large to accommodate a count of dimension in it. In the state of infinity, there is no beginning, no mid-point, no end-point and no point of reference. However unlike infinity which is a reality, zero is an abstract or imaginary quantity because in reality zero does not exist and is an abstract assumption. Infinity as a real physical thing is still often treated with skepticism. The definite nature of infinity is very much an unresolved mystery in both physics and mathematics.

Newton (1643 – 1727) rejected indivisibles in favour of his fluxion, which was a measure of the instantaneous variation of a quantity. Of course, the infinite was not avoided by him since he still had to consider infinitely small increments. Newton's fluxions produced wonderful mathematical results but many were wary of his use of infinitely small increments. Newton believed that space is in fact infinite and not merely indefinitely large. He claimed that such infinity could be understood; particularly using geometrical arguments, but it could not be conceived. The problem of whether space and time are infinitely divisible continued to trouble mathematicians and scientists. Little progress was being made on the question of the actual infinite. The same arguments kept on appearing without any definite progress towards a better understanding. Perhaps one of the most significant events in the development of the concept of infinity was Bernard Bolzano's "Paradoxes of the Infinite" which was published in 1840. He argued that the infinite does exist and his argument involves the idea of a set, which he defined for the first time as "A collection where the order of its parts is irrelevant and where nothing essential is changed if only the order is changed". Why does defining a set make the actual infinite a reality? Once one thinks of integers as a set then there is a single entity that must be actually infinite. Aristotle looked at the integers from the point of view that one can find arbitrarily large finite subsets. But once one has the set concept then these are seen as subsets of the set of integers which must itself be actually infinite. At this stage the mathematical study of infinity moved into set theory. Infinity as a physical thing is still often treated with skepticism.

Infinity is neither big nor huge nor tremendously large. Infinity is simply endless. Infinity is the idea of something that has no end. Infinity does not grow. Infinity has been treated with a mixture of fascination and awe. Infinity is more than simply the largest ever number, and even this simple description has caused problems for mathematicians throughout the ages. From the ancient Greeks to Newton, from Newton to present-day mathematicians, infinity has posed both practical and conceptual problems. Philosophers and mathematicians have gone mad contemplating its nature and complexity. The definite nature of infinity is very much an unresolved mystery in both physics and mathematics, but there are a few tolerated infinities such as black holes. Some author has described infinity as a floorless room without walls and ceiling. Desire to quantify the magnitude of infinity has always been triggering the imaginations and intelligence of mathematicians and scientists. Numerical representation of infinity is one of the profound unsolved problems and mysteries of computational mathematics. No other concept has ever moved so profoundly the spirit of man; no other idea has so fruitfully stimulated his intellect and no other concept stands in greater need of clarification than that of infinity. The concept of infinity has been a subject of speculation throughout history of mankind.

# News and Views

## Recent Updates

**Extreme oxygen loss in oceans as a result of global warming**
Seafloor sediment cores reveal abrupt, extensive loss of oxygen in the ocean when ice sheets melted roughly 10,000-17,000 years. The study suggests similar changes observed in today's climate change scenario [Read more]

**Iceland rising due to melting glaciers**
Earth's crust under Iceland is rising as global warming melts the island's great ice caps [Read more]

**Warming seas invites sea-slug population shifts**
Researchers have tracked the Hopkins' Rose nudibranch, a bright pink sea-slug farther north of their typical ranges. This may signal a much larger shift in ocean climate and a strong forthcoming El Niño. The pink nudibranchs have not appeared so far north or in such high numbers since the strong El Niño events--periods of warmer-than-usual ocean water and heavy rains--of 1998 and 1983. Without an official El Niño on record for 2015, scientists note that the recent sea slug bloom may mirror a much larger climate shift that occurred in the eastern Pacific Ocean nearly four decades ago. [Read more]

**El Niño turn into El-Limbo**
El Nino 2014/15 created a lot of hype in April 2014, but the chances of a fully developed El Niño occurring is now just 50 to 60 percent, down from 65 percent last month. Interestingly, if El Niño does finally emerge in the next few weeks neutral conditions are most likely to be back by March. [Read more]

**Small volcanic eruptions partly explain 'warming hiatus'**
It is known that volcanoes cool the atmosphere because of sulfur dioxide release during eruptions. Susan Solomon's publication in the journal Science in 2011 recognized that an upward trend in volcanic activity might also be implicated in the warming hiatus. The paper relied on a combination of ground, air and satellite measurements, indicating that a series of small 21st-century volcanic eruptions deflected substantially more solar radiation than previously estimated. [Read more]

**Magnificent blue glow of Hong Kong seas are disturbing**
Fluorescent blue patches of water glimmering off Hong Kong's seashore are potentially toxic according to marine biologists. The glow is created by a single-celled organism called Noctiluca scintillans, nicknamed Sea Sparkle. Noctiluca can eventually magnify the accumulation of algae toxins in the food chain and hence harmful to marine life. [Read more]

**La Niña Events May Spike with Climate Change**
Increased land warming due to climate change coupled with more frequent extreme El Nino events will mean extreme La Niña could occur every 13 years, rather than the 23 years previously seen. This might lead to increase in devastating weather events with profound socio-economic consequences. [Read more]

**The world is warming faster**
Arctic ice cap thinning by more than 50 meters since 2012 has been captured by satellite imageries, which is about one-sixth of its original thickness and is now flowing 25 times faster. Rising ocean temperature in the recent years might have been a trigger for ice cap thinning. About a one-third of the global sea level rise is due to melting ice caps and glaciers. [Read more]

*Compiled by* Chaitri Roy, IITM

# Negotiations News from Lima

## Spotlight

Another round of UNFCCC negotiations held in Lima (Peru) during 1-14 December 2014, the 20th Conference of Parties noted 'with grave concern' the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with having a likely chance of holding the increase in global average temperature below 2°C or 1.5°C above pre-industrial levels. It decided that the Ad Hoc Working Group on the Durban Platform for Enhanced Action, a subsidiary body, will intensify its work, with a view to making available a negotiating text for a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties before May 2015.

Needless to say, the stakes for a developing country such as India are high. An interesting article from the Climate Policy Research, an Indian think-tank, deliberates upon the options for us [url: Indian Express]. Meanwhile, the joint India-USA statement on climate change cooperation has been also reported by the newsroom of the UNFCCC [url: UNFCC NewsRoom]

- Ashok Karumuri, Univ. Hyderabad

# Conferences

## Upcoming Events

- OSICON 2015, the 4th biennial conference organized by the Ocean Society of India will be held during 22-24 Mar 2015 at NIO, Goa. url: http://www.oceansociety.in

  OSI encourages active participation by students and research scholars in large numbers and there will be prizes for the best papers from among them. Limited Travel support may be available for students.

  Receipt of abstracts: 05 Feb 2015

  Acceptance of abstracts and intimation: 15 Feb 2015

- Asia Oceania Geosciences Society (AOGS) 2015 Conference will be held during 2-7 Aug 2015 at at Singapore. url: http://www.asiaoceania.org/aogs2015/

Send your correspondence and contributions to:

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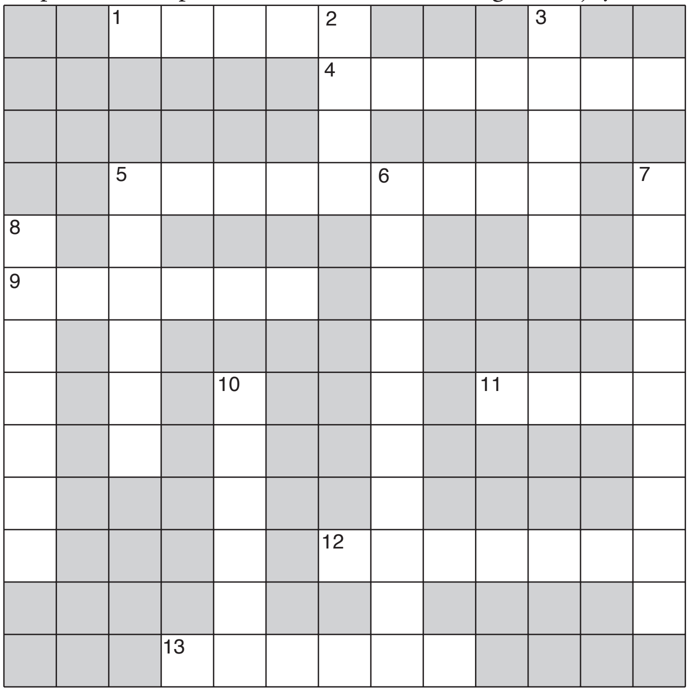
# Crossword

The clues for the Earth Science Crossword can be traced to the present and previous issues of Ocean Digest. Enjoy.




**ACROSS**

1. This planet takes the longest time for a full rotation
4. Granite falls under this category of rock types
5. These mountain ranges were formed when the Indian plate collided with the Eurasian landmass
9. The 90°E ridge is the part of this ocean
11. Recent UN Climate Negotiations were held at
12. The universe formed about __ billion years ago
13. The line that connects areas of equal air pressure

**DOWN**

2. Upper layer of the Earth's crust made of rocks rich in silicates and aluminium minerals
3. A clastic, predominantly silt-sized sediment, which is formed by the accumulation of wind-blown dust
5. During October 2014, the Indian subcontinent contfronted this cyclone from the Bay of Bengal
6. This continent has the highest average elevation
7. The Indian landmass drifted from Madagascar, creating the __ basin
8. Intensity of an Earthquake is measured in this scale
10. The wide, open ocean engulfed which between the Eurasian and Gondwana continents was known as

Keys to the Crossword in October 2014 issue:
ACROSS 4. thermohaline 6. sonar 8. pangaega 10. himadri 12. rossby 13. elnino 14. hygrometer DOWN 1. suez 2. atacama 3. chlorophyll 5. kepler 7. pacific 9. isro 11. dipole

*Compiled by* Bhupendra B. Singh and Roxy Mathew Koll

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