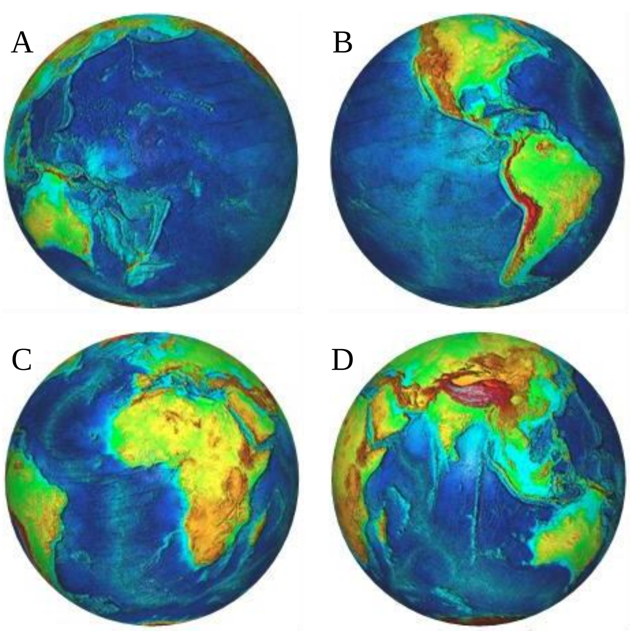
Earth – the 'Blue' Planet

Earth, the "3rd Rock from the Sun", is also called the "Blue" planet and the "Lonely" planet. All these epithets relate, directly or indirectly, to oceans — the huge water-filled basins that cover almost three-quarters of the Earth's surface.

1.1 From seven Seas to five oceans

The advances in space exploration and satellite imagery (Fig 1.1) have vastly enhanced not only our knowledge of our neighborhood in space but also of the Earth's surface itself. At the first level of approximation, they clearly show that the oceans cover most of Earth's surface. Notice how all the four views of Earth in Fig 1.2, taken



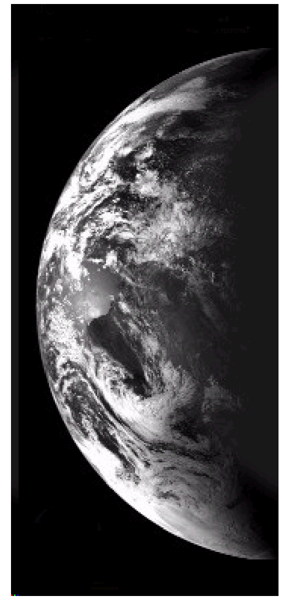


Fig. 1.1: Above satellite image is from NASA's Apollo missions (http://www.nasa.gov) that shows Africa, South Atlantic and Indian Ocean while the image alongside is from the recent Indian lunar probe Chandrayaan-1 (http://www.isro.org) that shows Australia.

at 90° intervals centered at the equator, reveal this dominance in the Earth's surface relief. We do live on a water planet, after all!

This fact, that the Earth is truly a water planet, hardly had to await the advent of the space age and satellite technology, however. While most of of our early ancestors may well have migrated, and spread all the world over, from out of the Olduvai gorge in Kenya, the early inhabitants of the South Pacific and even South and Central Americas did traverse vast stretches of open, and often treacherous oceans. But today's global out-look is a novelty. Recall the 'Seven Seas' refrain, for instance. From ancient Greeks down to the medieval Europe, though, these comprised (Fig 1.3) the Mediterranean, Adriatic, Black, Caspian, Red and Arabian seas and the Persian Gulf. To the Arab sailors of those days, on the other hand, these seven seas comprised today's Persian Gulf, Gulf of Khambhat, Bay of Bengal, Strait of Malacca, Singapore Strait, Gulf of Thai-land and the South China Sea. Whatever be the sanctity of the number 7, its relevance to oceanic realm has clearly depended on the seas that these sailors frequented the most.

Fig 1.2: Four views of surface relief globe, centered at the equator and at (A) 180°W, (B) 90° W, (C) 0° and (D) 90°E (based on the satellite data; source: NGDC/NOAA).

Modern science and technology have established that the ‘World Ocean’ is really a single continuous expanse of well-mixed water, i.e., the names of these oceans and seas have been purely matters of convention, not as if any boundaries separate them. Thus, in lieu of the ‘Seven Seas’ adage, the International Hydrographic Organization (IHO: http://www.iho-ohi.org) divides the ocean world into five major oceans and seas (Table 1.1).

Table 1.1: Some statistics about the oceans

	Area (million km^2)	Mean depth (km)	Volume (million km^3)*
Pacific Ocean	155.6	4.03	707.6
Atlantic Ocean	76.8	3.93	323.6
Indian Ocean	68.6	3.96	291.0
Southern Ocean	20.3	4.0-5.0	
Arctic Sea	14.1	1.21	
All oceans and seas	361.0	3.80	1371.8

* Note: At 4ºC temperature, when pure water (H_2O) has its maximum density, 1 km^3 of water equals 10^{12} kg or 264.2 billion U.S. gallons

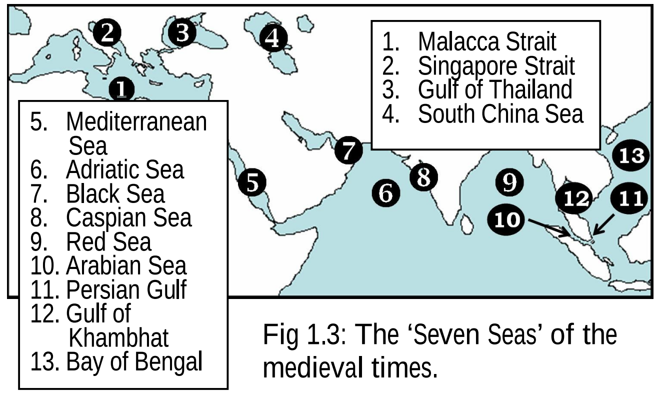
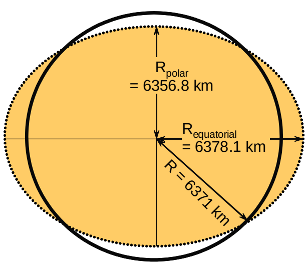


Fig 1.3: The ‘Seven Seas’ of the medieval times.

Pacific Ocean, the largest of them, is shown in Fig 1.2A and 1.2B. It covers almost a third of the Earth’s total surface area of about 510 million km^2 (Box 1.1) and is larger than the Atlantic (Fig 1.2C) and Indian (Fig 1.2D) oceans combined (Table 1.1). Indeed, as the Earth views in Fig 1.2A and 1.2B show, if we are to identify the so-called Eastern and Western hemispheres now, we would identify them as the Pacific and the rest! Other volumes of water also exist, e.g., Mediterranean and Caribbean seas, for instance, but they only add up to another 40 million km^2.

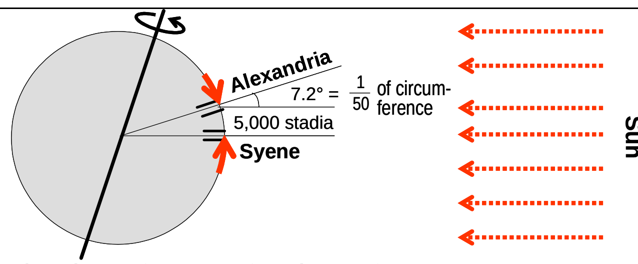
Box 1.1: Measuring Earth’s Dimensions



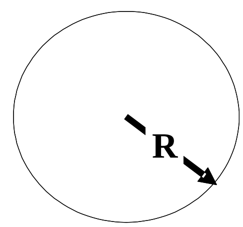
The early Greek and Hindu philosophers believed the Earth to be spherical but we now know that polar radius (6356.8 m) is 21 km smaller than the equatorial radius (6378.1 m). This too is an approximation, as the north polar radius is about 40 m larger than the south polar radius. The radius of a sphere having the same volume as the Earth is 6371 km.

Does this 21 km difference between equatorial and polar radii, or a flattening of about 1 part in 300, really matter? Trivial as it may sound, it indeed plays a major role in our atmospheric and oceanic circulations.

Eratosthenes was the first to estimate the Earth’s circumference, in 230 B.C. He found that at local noon on the summer solstice, Sun appeared at the zenith, directly overhead, in the ancient Egyptian city of Syene (modern Aswan) on the Topic of Cancer but at Alexandria, 5000 stadia to the north, Sun’s elevation was 1/50th of great circle south of zenith. Sun is so far from the Earth that he correctly assumed its rays falling on Earth to be parallel. He thus estimated Earth’s circumference as 50×5000 stradia, or 700 stradia per degree. As 1 stradion is 157.5 to 185 m, depending on whether we use the Greek or the Egyptian measure, this yields the estimate for Earth’s circumference as 39,690 to 46,620 km.



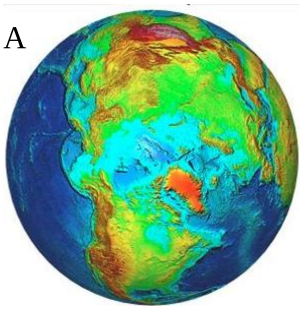
The circumference of a circle of radius R is $2\pi R$. Thus, with $2\pi R$ = 39,690 km and $\pi = 3.14$, R = $(39690/2\pi)$ km = 6320 km, and R = 7423.6 km if the circumference $2\pi R$ is 46620 km



A significant improvement over these estimates had to await over a millennium, however, when the 11th century Persian scholar al-Biruni devised a trigonometry-based strategy to estimate Earth’s radius as 6340 km, a value within 5% of the 6,371 km value that we now know to be the correct estimate!

The geometric simplicity of a perfectly spherical Earth model also allows us to easily estimate its surface area which, for a body of radius R is $4\pi R^2$. Thus, setting R = 6371 km, Earth’s surface area can be estimated as

$$4\pi R^2 = 4\times3.14\times(6{,}371\text{ km})^2 = 12.56\times40.59\times10^6\text{ km}^2 = 509.8\times10^6\text{ km}^2$$



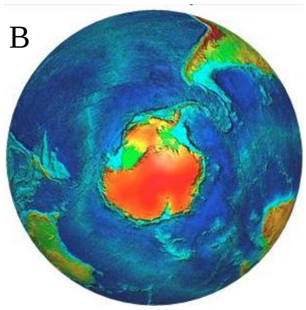
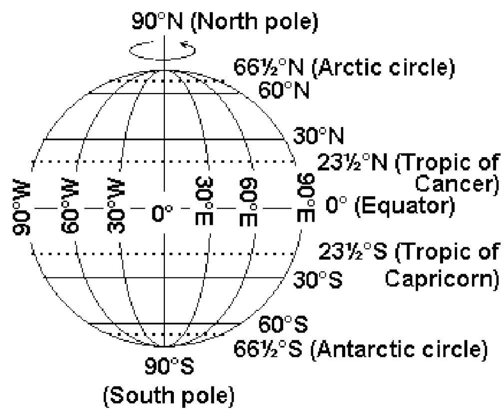


Fig 1.4: These satellite data-based views of Earth's surface relief centered about the North (A) and South (B) poles correspond to the Arctic Sea (left) and Southern or Circum-Antarctic Ocean (right), respectively.

The two other oceans in the IHO list of five are Southern Ocean and the Arctic Sea (soon to be an ocean, anyway, in the likely scenario of continued global warming that will melt all existing polar ice). Of them, the Arctic Sea (Fig 1.4A) covers an area of 14.1 million km^2 and Southern Ocean, whose 20.4 million km^2 surface area comprises the waters surrounding Antarctica and enclosed by the Antarctic Circle (i.e., 63½°S latitude), includes the southernmost waters of the Pacific, Atlantic and Indian oceans. It thus combines the waters of most of the oceans.

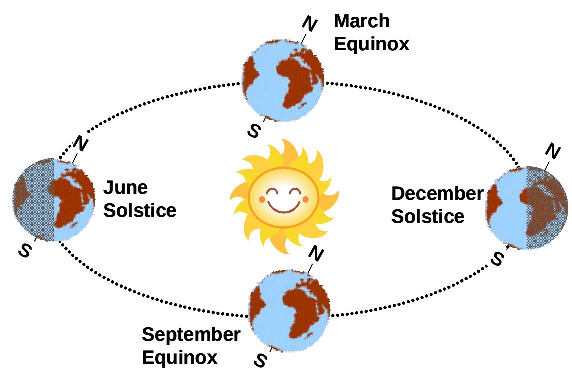
Box 1.2: Latitudes and Longitudes

Latitudes and longitudes are the coordinates that we use to locate any point on the earth's spherical surface. Of these, latitudes are the imaginary lines that run parallel to equator, whose latitude is 0º, and North and South poles, are 90ºN and 90ºS latitudes, respectively. The latitude circles have different circumferences, therefore. Equator is the great circle with the same circumference as the Earth (actually larger, thanks to Earth's equatorial bulge), the two polar latitudes are single points, and the intermediate latitudes circles get progressively smaller from equator to the poles.



Besides equator and the two poles, four other latitudes have proper names: Tropic of Cancer (23½º N) and Tropic of Capricorn (23½ºS) define the two limits of the tropics, while the Arctic (66½ºN) and Antarctic (66½ºS) circles define the outer limits of the two polar regions. Incidentally, it is Antarctic circle that defines the limit of the Southern Ocean.

Why these 23½º differences from the equator and the poles? The answer lies in the Earth's 23½º tilt to the spin axis. Thus, as the Earth orbits about the Sun in its nearly elliptical orbit, North pole is tilted towards the Sun and northern hemisphere receives most sunlight on June solstice*, and the opposite occurs on December solstice. Tropics receive sunlight all year round, and lack seasons therefore, whereas Northern hemisphere has summer when it is winter in the Southern hemisphere, and vice versa.



Latitudes are also the measures of absolute distance on Earth, with 1º of latitude = 60 nautical miles, i.e., each 1' of latitude is a nautical mile (= 1.15 statute miles or 1.85 km).

Longitudes are imaginary lines that join the two poles and are therefore farthest from one another at the equator. Starting with 0º longitude called Greenwich meridian that passes through Greenwich in London, U.K., basically for historic reasons, we thus have 360º of longitudes, 180º going east and 180º going west. "International Date Line" is where they meet.

Longitudes help us measure time. Since Earth completes one spin every 24 hours, 1º of longitude = 4 minutes of time (= 24 hours/360º). Consider the coordinates of New York, NY (40.8ºN:73.8ºW) and Los Angeles, CA (33.9ºN:118.2ºW), for instance. The approximately 45º of longitude difference between these two cities clearly explains why New York is 3 hours ahead of Los Angeles.

* In northern hemisphere, summer or June solstice is the longest day of the year when Sun is directly above Tropic of Cancer, and winter or December solstice is the shortest day of the year when Sun is directly above Tropic of Capricorn. The con-verse is true of the southern hemisphere, i.e., winter solstice there when northern hemi-sphere has summer solstice, and vice versa. Note that equator has the maximum tilt, in either case. The vernal (March) and Autumnal (September) equinoxes occur when Sun is directly above the equator.

How do we distinguish Southern Ocean from all the other oceans, then? Latitudes are imaginary lines, after all, so that identifying the 63½°S latitude as its boundary is not a workable proposition. But a unique characteristic of these waters creates an interesting physical reality.

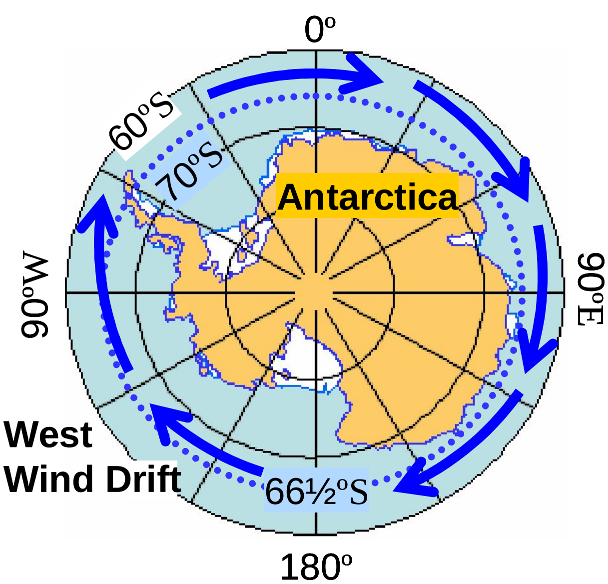


Fig. 1.5: The Antarctic Circumpolar Current or "West Wind Drift" moves perpetually eastward — chasing and joining itself, and at 21,000 km in length — it is the world's longest ocean current, transporting about 130 million m^3 of water per second, i.e., 100 times the flow of all the rivers combined.

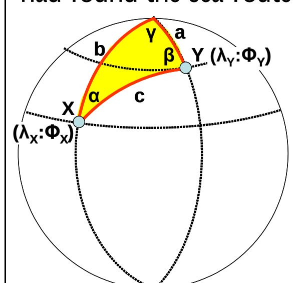
Note in Fig. 1.5 how waters surrounding Antarctica are the only waters whose flow can actually circumscribe the Earth, across all the longitudes, unhindered by any land. That ocean current, powered by the Earth's rotation, is cold and sluggish but nonetheless real, and is called the West Wind Drift (or Antarctic circum-polar circulation). At about 21,000 km in length, this is the world's longest ocean current, compared to Gulf Stream (the ocean current that, first discovered and mapped by Benjamin Franklin, carries the warm tropical waters from the Gulf of Mexico to Europe).

This not only gives the Southern Ocean its own distinct geographic identity but is also the reason why Penguin forgot to fly! After all, the constant lateral flow of this current means that the organic debris stays in the Sunlit surface waters instead of settling down in the deep and dark bottom of the ocean where little Sunlight, if at all, can ever reach. The nutrients so critically needed for photosynthesis then become available, together with Sunlight, water and the carbon dioxide that is dissolved aplenty in these cold waters. Thus, by ensuring the availability of nutrients in the sunlit surface waters, West Wind Drift makes these circum-Antarctic waters amongst the biologically most productive on the Earth. With so much of food available right there, no wonder penguin never felt the urge to fly around in the search for food!

Perhaps no single fact emphasizes the importance of knowing the dimensions of the Earth and its oceans more than the mistake that great voyager, Christopher Columbus, made. Had he correctly estimated the distance that he had traveled, he would have known that he had not reached the Orient, his stated objective (Box 1.3). This is despite his correct premise that sailing west on a spherical Earth promised an alternate route from Europe to the East, assuming, as he did, that no land stood in the way!

Box 1.3: How and why Columbus went wrong?

Modern European settlements of the Americas were heralded by the 3-months long voyage of Christopher Columbus in 1492. But, inspite of his three trans-Atlantic voyages, he died believing that he had found the sea-route to the Orient!



Why and how did he go so wrong? Most plausibly because he had estimated the distance poorly.

To understand this, note that the angular distance 'c' of any two points X and Y, with latitudes λ_X and λ_Y, respectively, and longitudes φ_X and φ_Y, is given by the cosine law of spherical trigonometry as

$$\cos c = \cos a \cos b + \sin a \sin b \cos \gamma$$
$$= \sin \lambda_X \sin \lambda_Y + \cos \lambda_X \cos \lambda_Y \cos (\varphi_X - \varphi_Y)$$

On the spherical Earth of radius R, this great arc or straight line distance is Rc, where c is in radians. To estimate his target distance, then, all Columbus had to do was to plug in the coordinates of his starting point, say Canary Islands (28.0°N:15.5°W), and end point, say Japan (36.0°N:138.0°E), in this equation. It works out to 12,384 km, whereas Columbus had assumed it to be about 4,400 km!

1.2 Two Peculiarities of the World Ocean

Two peculiarities characterize the world ocean — geographic and geological.

The fact that the oceans cover more than double the proportion of the Earth's surface area than the land does clearly emphasizes the need to understand the oceans, and how they have Formed, in order for us to be able to understand our habitat. Two peculiarities of the oceans need to be noted at this juncture, therefore — geographically, the asymmetric distribution of land and oceans between the southern and northern hemispheres, and, geologically, the subtle but significant differences between the rocks that make up the land and those that form the ocean basins.

As for the first of these two issues, Fig 1.5 shows the distribution of land and oceans in different latitudes. Note how most of the land lies in the northern hemisphere, with ocean in the middle (Fig. 1.4A) and most of the ocean lies in the southern hemisphere, with land in the middle (Fig. 1.4B). With a little over 70% of the Earth's surface that the oceans cover, they do dominate both the hemispheres, though. It is just that, in terms of proportions, oceans cover 60.7% of the northern hemisphere, and land 39.3%, whereas southern hemisphere is 80.9% oceans and 19.1% land. The proportion of oceans to land is 3:2 in the northern hemisphere, therefore, but rises to 4:1 in southern hemisphere.

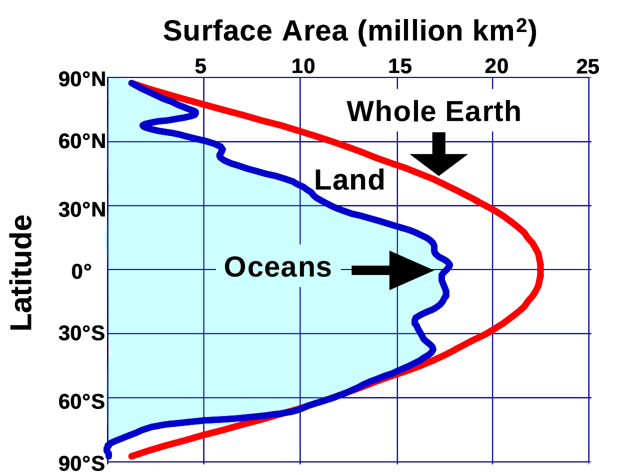


Fig 1.5: Earth's hemispherically asymmetric distribution of oceans and land.

Is this a big deal? Most certainly, particularly in terms of the way hydrological cycle functions. More on this later, however, when we will discuss hydrological cycle and atmospheric circulation, and learn how climate change has already started impacting our habitat.

The second issue raised above, that significant geological dissimilarities exist between the oceans and the land, rests on a simple finding. Ocean basins are depressions on the Earth's surface, of course, and the land is an upraised region. The question then is if these height and depth differences are systematic enough to really matter and carry any underlying geological significance.

Consider the distribution of heights and depths on the Earth's surface. Note how, in Fig 1.6 which graphs these heights and depths relative to mean sea level (MSL), these topographic (i.e.,

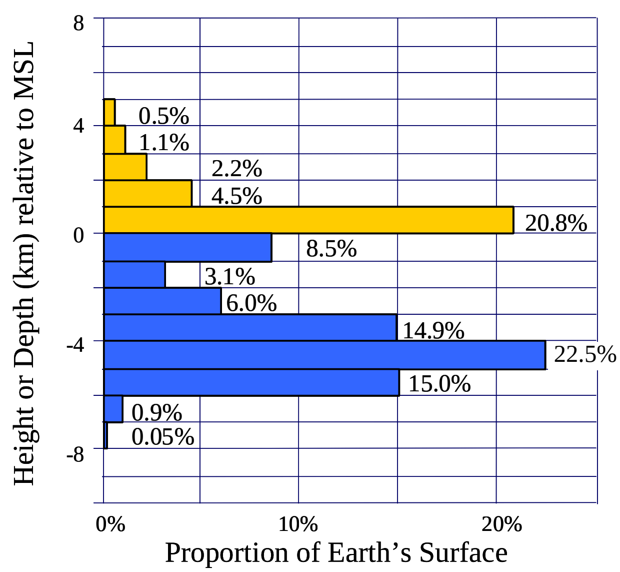


Fig 1.6: The land heights and ocean depths show a bimodal or two peaked distribution.

On land, above the MSL) and bathymetric (i.e., on the ocean floor, below the MSL) undulations display a two-peaked distribution: one of these peaks at 0-1 km heights above the MSL (20.8% of the Earth's surface), and the other peaks at 4-5 km depths below the MSL (22.5% of Earth's surface).

There is no reason, of course, why we should expect a single-peaked (or the typical Gaussian) distribution here. Indeed, had that been the case, we could have simply argued that the distribution of land heights and ocean depths is random. Fig 1.6 suggests that such an argument may not work here.

This bimodal distribution reflects the simple geophysical reality that the rocks that make the ocean floor are distinctly different from the ones that form the continental basement. The ocean floor is made up of basalts and basalt is typically a volcanic rock (Box 1.4), with a density of 2.9 gm/cm^3 (= 2,900 kg/m^3) whereas continental basement comprises granites (density = 2.67 gm/cm^3 or 2,670 kg/m^3). Compared to the relatively iron (Fe) and magnesium (Mg) rich basalts that carry about 50% silica (SiO_2), granites are richer in silica and potassium (K) but poorer in Fe and Mg.

Box 1.4: Basalt Volcanism*

Basalts are dark colored rocks that typically form from volcanic activity. They commonly carry 38-53% silica (SiO_2) and 5-15% iron (Fe), calcium (Ca) and magnesium (Mg), although some Lunar samples have up to 20% FeO contents. Our familiar volcanic activities in Hawaii, Alaska and Cascades in the U.S., or Mount Fuji, Pinatubo and Krakatau in Asia, Iceland, Pompeii, Vesuvius etc. in Europe, or Popocatepetl in central Mexico, to name a few, are not the most typical examples of volcanic activity on Earth, however. They show majestic eruptions, often with giant chimneys of smoke and ash, spewing forth in violent episodes. But the 360 million km^2 of our basaltic ocean floor has mostly formed through gentle but continuous squeezing out of lava in the central valleys of the submarine ridges.


This NPS photo by Katja Chudoba shows how basaltic lava flows like a river out of the crust made up of hardened basalts.

* Try http://ads.harvard.edu/books/bvtp/toc.html to access the best treatise on this subject, "Basalt Volcanism on the Terrestrial Planets", published by NASA's Lunar and Planetary Institute and stored in SAO/NASA Astrophysics Data System (ADS) at Harvard University.

The question that therefore arises is this – if the ocean-floor has indeed been created by volcanic activity, as the evidence of basaltic floor clearly suggests, then how is it that the same basalt volcanism that ordinarily creates lofty mountains through giant explosive outbursts of episodic volcanism has created such huge depressions as ocean basins?

The reason why this happens is because the sea-floor forms by the successive filling and widening by the lava of the crack or fissure at the axis of a submarine ridge. As successive eruptions along the same fissure make the fissure wider and wider, with activity limited to the center and the older now solidified basalts being pushed farther and farther, it is easy to visualize this as the same process that is now occurring at the East African Rift Valley started creating the Red Sea about 10 Ma* ago and the Atlantic Ocean about 180 Ma ago. Fig 1.7 shows one such event "caught-in-the-act", the January 1998 eruption at Axial volcano in the Pacific, about 500 km off-shore the Oregon coast.

Fig. 1.7: This video-clip of a January 1998 eruption at Axial volcano, about 500 km off-shore from Oregon coast, was shot by a NOAA research team and shows an approximately 1.5m crack with lava welling up in the bottom. Source:
http://www.pmel.noaa.gov/vents/geology/video_nemo00.html

Their presence as huge water-filled basins is not the only distinction between the oceans and the land. Rather, they would appear distinct even if there was not a drop of water anywhere around.

* Ma is short for mega aeons or million years, Ga is likewise short for giga aeons or billion years.

This is precisely the reason why we identify the oceans on our Moon (Fig 1.8) as well, even though the discovery of water there has as yet eluded us.

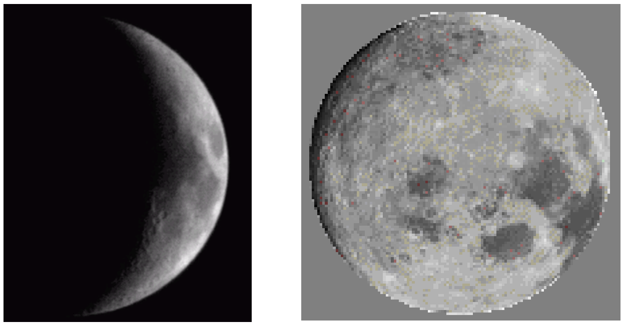


Fig 1.8: The image on the right is whole-Moon view from NASA's Apollo-17 mission (http://www.NASA.gov) to moon and that on the left is from India's October 2008 mission to moon, Chandrayaan-1 (http://www.isro.org).

Note the familiar light and dark patches on these satellite pictures ─ they are called terrae or highlands and maria (plural of mare, Latin for seas) regions, respectively. Maria are basalt-filled and heavily cratered depressions. Their likely similarity to Earth's oceans on stops here, however, for the simple reason that Moon has as yet proven to be dry. Lunar highlands are raised regions on the other hand, much like the Earth's continents, and largely comprise anorthosite. Much like granites, and unlike basalts, this is a silica-rich acidic rock that forms from slow-cooling at depths.

This geological difference is precisely the reason why land is up-raised and the ocean floor is depressed. Earth has a layered structure (Fig 1.9), with a 3,500 km thick metallic core, the outer 2,250 km of which is fluid and the inner 1,250 km solid, mantled by a rocky* mantle and crust. This outer most layer, the crust, is 30-35 km thick beneath the continents, and 50-70 km thick beneath the mountains like Himalayas, Andes and Alps, but barely 10-15 km thick beneath the oceans.

Note that the crust is not only the thinnest and

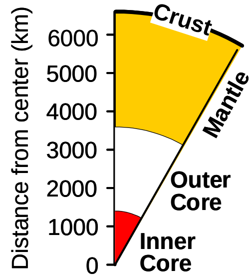
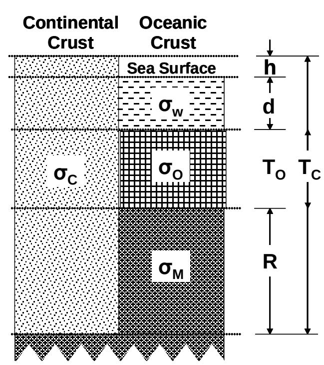


Fig 1.9: Earth is a multi-layered body the outermost layer of which, the crust, is 30-35 km thick beneath the continents but 10-15 km thick beneath the oceans and 50-70 km thick beneath the mountain belts like the Himalayas and the Alps.

the outermost layer of the Earth, it is the lightest layer as well. As the whole-Earth density (~5.52 gm/ cm^3) is about double the crustal density of ~2.75 gm/cm^3, density must increase with depth inside the Earth, perhaps reflecting compaction. But this also suggests that the lighter crust is floating over the denser mantle. In that case, analogous to how we only see the tip of an iceberg as the rest remains submerged, the taller a mountain is the deeper its root extend into the mantle. This is the concept of isostasy (Box 1.5).

Box 1.5: Mountains have "roots"

The fact that the oceanic crust is much heavier than the continental crust makes it appreciably thinner as well. Theoretical basis for this lies in the concept of isostasy, that for mass distribution inside the Earth to be in dynamic equilibrium, lateral inhomogeneities must disappear at a certain depth.



Compare the oceanic crust of thickness T_O and density σ_O (=2.95 g/cm^3) with continental crust of thickness T_C and density σ_C (= 2.7 g/cm^3) and average continental height h = 1 km and average ocean depth d = 4 km. For unit columns of these two crustal segments, then, these lateral mass inhomogeneities will exert same pressure at depth if

$$T_C\sigma_C = h\sigma_{air} + d\sigma_{water} + T_O\sigma_O + R\sigma_{mantle}$$

where R, the "root" of the continental crust into the mantle, mirrors its rise on the surface. For simplicity, if we assume that $(\sigma_O - \sigma_C) = (\sigma_{mantle} - \sigma_O) = 0.25$ g/cm^3 then, for $T_C = (h+d+T_O+R)$, the above equation yields R = 14 km and T_C = 29 km for T_O = 10 km. Likewise, for h = 8 km as would be the case for the Himalayas, these numbers yield R = 52 km and T_C = 64 km for T_O = 10 km.

Clearly, the greater the height above the sea level surface, the deeper the crust extends into the mantle!

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* Presence of silicon (Si), specifically silica (SiO_2), is what makes the mantle and the crust, indeed the Earth itself, "rocky". Silicon comprises only 0.083% of the composition of the universe but 15.6% of that of the Earth.

1.3 Oceans explain why Earth is called the "Blue" and "Lonely" planet

Now that we know how chemistry and geology have conspired to make the Earth a "rock", let us examine if oceans are indeed what have turned the Earth into a "Blue" and "Lonely" planet.

Take the color "blue". It is not that 'why is Earth called the blue planet' is a difficult question to answer. We could simply say that Earth seems blue because oceans cover two-thirds to three-quarters of the planet. But that would be true if water was blue, which is not really the case, nor does it make sense to claim that the Earth looks blue because oceans reflect the blue sky. At best, that only deflects the question to our having to answer as to why the sky is blue, specifically, as to why the clearer the sky is the bluer it appears!

Indeed, the Earth does seem blue when viewed from the outer space (e.g., Fig 1.1), except for the white patches of polar ice caps and the cloud cover. But global warming would someday melt the polar ice, judging from the observed thinning of the Arctic (Fig 1.10), and that should only add to the Earth's existing bluish tint.

Interestingly, the scattering of light is the real reason why this is so. Light travels in waves and the part of the electromagnetic spectrum known as 'visible light' (Fig 1.11) has wavelengths that range from 380 nm (violet) to 750 nm (red). The corresponding frequencies are 790 to 400 THz.

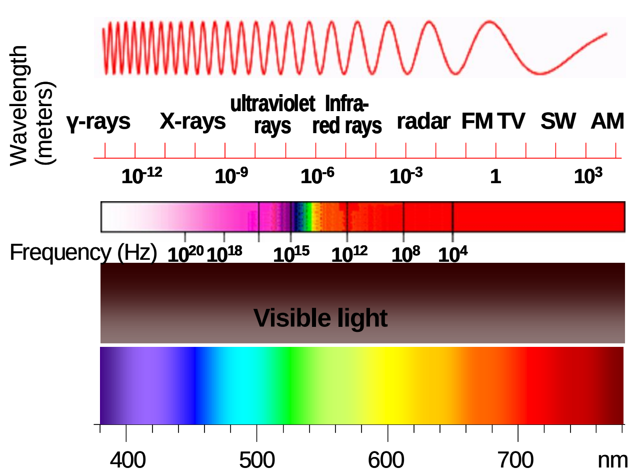
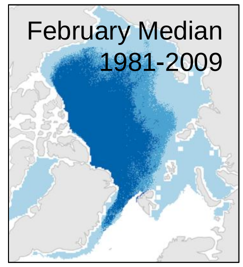


Fig 1.11: Visible light occupies a very narrow segment of the electromagnetic spectrum.



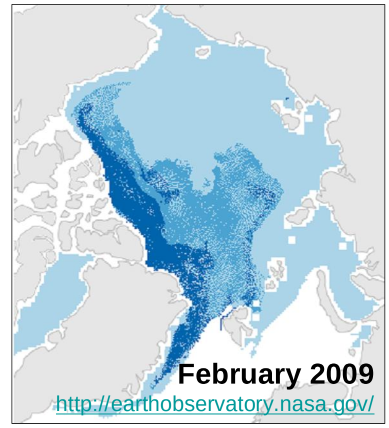
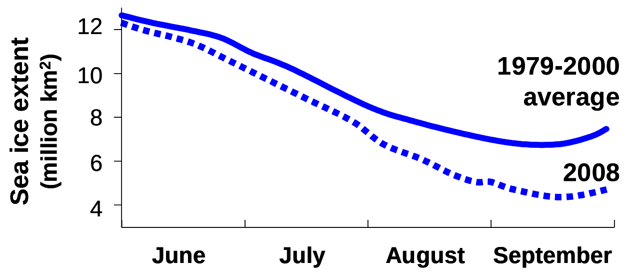


Fig 1.10: The winter maximum (end Feb to mid-March) ice covering in Arctic is increasingly younger and thinner. Here, ice >2 years old is dark blue, ice 1-2 years old is medium blue, and ice <1 year old is light blue. In 1987, 57% of the ice was ≥5 years, almost a quarter of that ≥9 years. The retreat of Arctic sea ice has become a very well documented pheno-mena (see below). It hit its lowest in September, 2008, when the area at least 15% covered by ice dropped to 4.5 million km^2.



Source: http://earthobservatory.nasa.gov/IOTD/

This is the range that the typical human eye can respond to. Scattering then explains where the seven colors of rainbow (Box 1.6) come from.

Box 1.6: Seven colors of the rainbow

If you are familiar with the following experiment then you already know that white is made up of seven colors. If not, try out this simple experiment.

- Start with these seven colors: violet, indigo, blue, green, yellow, orange and red.
- Cut a cardboard disk, say 4 inches diameter, mark seven equal seg-ments in it and color each using the above scheme, in exactly the above sequence.
- Puncture a hole at the center of this disk, say by using a golf pencil, and push the pencil through this hole at least one-half the way.
- If you now spin the disk using this pencil, you will notice that the disk turns grayish white to white, depending on how fast the disk spins, even though white is not one of the color you have used here.

Box 1.7:

What Was God Thinking? Science Can't Tell

By Eric Cornell

This article by the physicist and Nobel Laureate Eric Cornell appeared in November 6, 2005 issue of the Time magazine and is being reproduced here in the hope that it will clarify, particularly in the minds of the freshman science students to whom this book is primarily addressed, that the so-called conflict between science and religion should not really exist.

Scientists, this is a call to action. But also one to inaction. Why am I the messenger? Because my years of scientific research have made me a renowned expert on my topic: God. Just kidding. You'll soon see what I mean. Let me pose you a question, not about God but about the heavens: "Why is the sky blue?" I offer two answers: (1) The sky is blue because of the wavelength dependence of Rayleigh scattering; (2) The sky is blue because blue is the color God wants it to be.

My scientific research has been in areas connected to optical phenomena, and I can tell you a lot about the Rayleigh-scattering answer. Neither I nor any other scientist, however, has anything scientific to say about answer No. 2, the God answer. Not to say that the God answer is unscientific, just that the methods of science don't speak to that answer.

Before we understood Rayleigh scattering, there was no scientifically satisfactory explanation for the sky's blueness. The idea that the sky is blue because God wants it to be blue existed before scientists came to understand Rayleigh scattering, and it continues to exist today, not in the least undermined by our advance in scientific understanding. The religious explanation has been supplemented — but not supplanted — by advances in scientific knowledge. We now may, if we care to, think of Rayleigh scattering as the method God has chosen to implement his color scheme.

Right now there is a federal trial under way in Dover, Pa., over a school policy requiring teachers to tell students about "intelligent design" before teaching evolution. The central idea of intelligent design is that nature is the way it is because God wants it to be that way. This is not an assertion that can be tested in a scientific way, but studied in the right context, it is an interesting notion. As a theological idea, intelligent design is exciting. Listen: If nature is the way it is because God wants it to be that way, then, by looking at nature, one can learn what it is that God wants! The microscope and the telescope are no longer merely scientific instruments; they are windows into the mind of God.

But as exciting as intelligent design is in theology, it is a boring idea in science. Science isn't about knowing the mind of God; it's about understanding nature and the reasons for things. The thrill is that our ignorance exceeds our knowledge; the exciting part is what we don't understand yet. If you want to recruit the future generation of scientists, you don't draw a box around all our scientific understanding to date and say, "Everything outside this box we can explain only by invoking God's will." Back in 1855, no one told the future Lord Rayleigh that the scientific reason for the sky's blueness is that God wants it that way. Or if someone did tell him that, we can all be happy that the youth was plucky enough to ignore them. For science, intelligent design is a dead-end idea.

My call to action for scientists is, Work to ensure that the intelligent-design hypothesis is taught where it can contribute to the vitality of a field (as it could perhaps in theology class) and not taught in science class, where it would suck the excitement out of one of humankind's great ongoing adventures.

Now for my call to inaction: most scientists will concede that as powerful as science is, it can teach us nothing about values, ethics, morals or, for that matter, God. Don't go about pretending otherwise! For example, science can try to predict how human activity may change the climate, but science can't tell us whether those changes would be good or bad.

Should scientists, as humans, make judgments on ethics, morals, values and religion? Absolutely. Should we act on these judgments, in an effort to do good? You bet. Should we make use of the goodwill we may have accumulated through our scientific achievements to help us do good? Why not? Just don't claim that your science tells you "what is good" ... or "what is God."

Act: fight to keep intelligent design out of science classrooms! Don't act: don't say science disproves intelligent design. Stick with the plainest truth: science says nothing about intelligent design, and intelligent design brings nothing to science, and should be taught in theology, not science classes.

My value judgment is that further progress in science will be good for humanity. My argument here is offered in the spirit of trying to preserve science from its foes — but also from its friends.

The red end of the spectrum of visible light has long wavelength, and therefore low frequency, whereas the blue end has shorter wavelength and higher frequency. As nitrogen and oxygen that together comprise 99% of Earth's atmosphere and match blue light's wavelength in size, they scatter the blue part of direct Sunlight, whereas red light gets past them without getting scattered. Sky thus looks blue when we see more of the scattered blue light than the red light that reaches us unscattered.

Blue is also the color that is absorbed least by water, and the other colors are absorbed first. The short wavelength and high frequency of blue light enable this end of the spectrum to penetrate deeper. The quieter the waters are the deeper the light can travel and bluer they therefore appear.

The "photic zone" extends deep, to 100-150 m, in the "blue" waters of relatively quiet open ocean whereas the shallow but turbulent coastal waters appear pale (Fig 1.12) and wave activity gives it a white color, much as the spinning disk of Box 1.6 does. The greenish hue of the coastal waters that gives the color "sea green" its name, has a completely different source, however — photo-synthesis by phytoplanktons. The organic debris that become nutrients for photosynthesis remain in the shallow but sunlit ocean-bottom here, so making nutrients available in these sunlit waters.

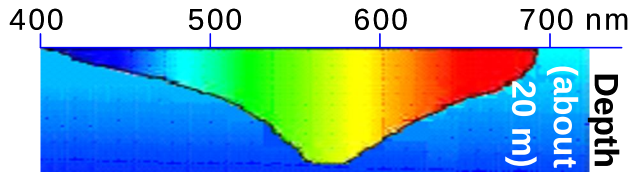
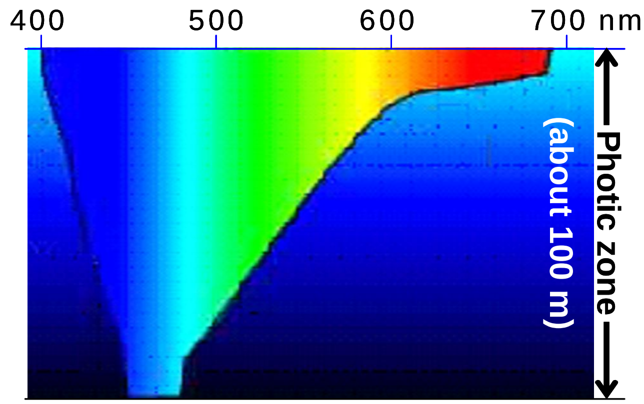


Fig 1.12: The coastal waters (above) are shallow, often turbulent, and generally have high biological productivity. The result is that they seldom show the brilliant blue color of the open ocean (below) that is also very quiet and therefore has poor biological productivity.



To complete this discussion about ocean colors, we should also mention NASA's SeaWiFS (Sea-viewing Wide Field-of-view Sensor) ocean color project. It uses satellite imagery to map the ex-change between atmosphere and ocean and examine their effect on biological activity, mainly phytoplankton production (Fig 1.13). These microscopic creatures — a teaspoon of sea water can contain up to a million of them — conduct most of the photosynthesis on Earth.

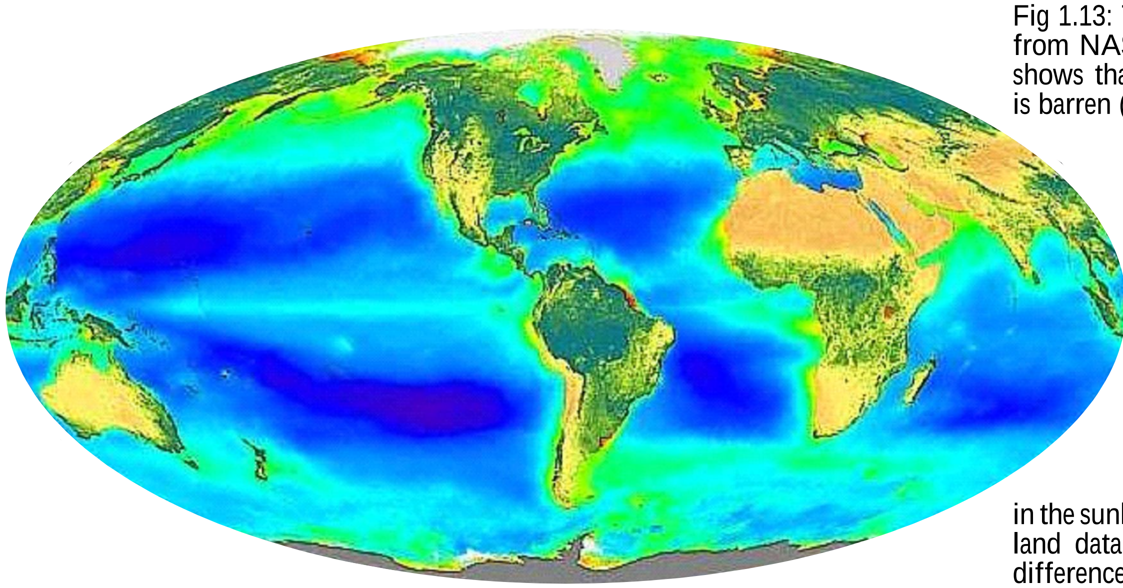
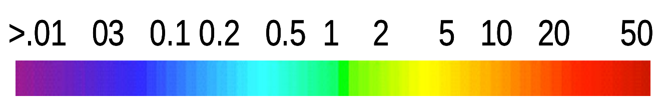


Fig 1.13: This ocean color map from NASA's SeaWiFS project shows that much of the ocean is barren (purple and blue) but coastal waters have high biological productivity everywhere (shown by the color green here). The cold polar waters too have high biological productivity, particularly because intense wave activity here ensures that nutrients — the decomposing organic detritus — is available in the sunlit surface waters. The land data here are normalized differences.



mg/m^3 (Chlorophyll a concentration over the oceans)

Source: http://oceancolor.gsfc.nasa.gov/SeaWiFS/

Oceans are also the reason why Earth is called the "lonely" planet. They hold most of the water on Earth and it is hard to imagine that the life as we know it can exist without water. From what we know, life on Earth is all about carbohydrate synthesis ─ this is done by the autotrophs or the primary producers like plants on land and phyto-planktons in the oceans (photosynthesis is the dominant form here) ─ and consumption, as we, the members of the animal kingdom, do by way of oxidation, i.e.,

Photosynthesis:	$CO_2 + H_2O + \hbar\nu$ + nutrients $\rightarrow CH_2O + O_2\uparrow$
Consumption or Oxidation:	$CH_2O + O_2 \rightarrow$ Energy $+ H_2O + CO_2\uparrow$

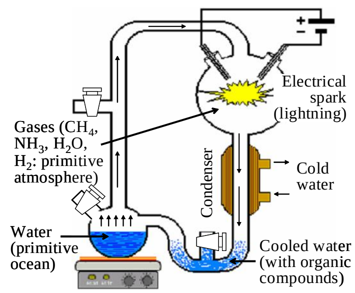
Here CH_2O, with one carbon atom for each water molecule, is the simplest form of a carbohydrate and $\hbar\nu$ denotes sunlight. Hence the importance of water, and of the oceans. The questions as to how this organic synthesis by autotrophy began from its inorganic precursors, where, and when, have as yet eluded simple answers however, even if we assume that the life we are familiar with is the only possible form of life, and that CH_2O is its only plausible signature.

The first of these questions was partly answered by the Urey-Miller experiment (Box 1.8) which demonstrated that organic compounds could well have been created out of the inorganic materials. In this experiment, a mixture of methane (CH_4), ammonia (NH_3), Hydrogen gas (H_2) and water vapor (H_2O), to simulate the version of Earth's primitive atmosphere was introduced into a 5-liter flask and energized by an electrical discharge apparatus to represent lightning. Water vapor here was produced by heating water in a lower flask to mimic the evaporation of ocean by Sunlight. The product was allowed to condense and collected in a trap from which it could return to this lower flask. After about a week of operation, a dark brown scum had collected in the lower flask and was found to contain several types of amino acids ─ the building blocks of life ─ together with sugars, tars etc.

While this may well have happened sometime in the early stages of Earth's history, it provides no

Box 1.8: The Urey-Miller Experiment

Perhaps the most successful experimental demonstration that right conditions can facilitate evolution from inorganic to the organic was that conducted by Miller and Urey* in the 1950s. Designed to examine if organic compounds could have formed from the inorganic materials under the primitive earth-like conditions, this experiment sparked a mix of methane, ammonia, water vapor and hydrogen gas. The presence of organic compounds, including amino acids, in the resulting cooled water clearly raised the possibility that conditions in the primitive earth could well have produced the building blocks of life.



*Stanley L. Miller & Harold C. Urey: 'Organic Compound Synthesis on the Primitive Earth', *Science* vol. 130, p. 245 (July 1959).

reason to preclude the possibility that life may have evolved under similar conditions elsewhere. What if those early seeds of life got transplanted on the Earth and then bloomed here when the conditions were ripe, say immediately after the appearance of the earliest oceans? Comets could then hold the keys to life[1], as recent discoveries of hydrocarbon molecules (NASA's 2004 Stardust Mission to Comet Wild 2) and mixture of organic and clay particles (NASA's 2005 Deep Impact mission to Comet Temple 1) suggest.

This leads us to the evidences of the earliest life on Earth. Impact cratering data from Mercury, Moon and Mars suggest a 3.9-4 Ga event of intense cometary bombardment, just as life was trying to gain a foothold on the Earth. There is no reason why this event spared the Earth. But the recent finding[2] of abnormally low inorganic carbon isotope C-13, and the very high content of lighter C-12 isotope in diamonds/graphites embedded inside 4.25-4.4 Ga old zircons found in

1. W.M. Napier, J.T. Wickramasinghe & N.C. Wickramasinghe: 'The Origin of life in comets', *International Journal of Astrobiology*, vol. 6, pp. 321-323
2. A.A. Nemchin, M.J. Whitehouse, M.Menneken, T. Geisler, R.T. Pidgeon & S.A. Wilde: 'A light carbon reservoir recorded in zircon-hosted diamond from the Jack Hills', Nature, vol. 454, pp. 92-95 (2008).

Jack Hills, western Australia, suggests that life on Earth may have predated this event. In the alternative, we could seek some as yet unknown inorganic source for this light carbon, particularly as some meteorites too display similar chemical signatures.

Such extraterrestrial interventions in the biotic record are well documented and have often raised intense but inconclusive debates. Perhaps the most celebrated of them is the debate on whether one or several simultaneous meteorite impacts or massive flood basalt volcanism caused the sudden extinction of dinosaurs ~65 Ma ago.

Deeper as these issues are, of immediate interest to us is the fact that marine studies have already debunked some of our earlier myths including, most notably, the idea that the life on Earth owes everything to Sun. But Alvin's (the submerseble research vehicle) 1991 discovery of freshly barbecued worms on the ~2.4 km deep Darwin Rise (Fig 1.14) suggests that autotrophy in this aphotic environment involves chemosynthesis by the sulfur-eating bacteria!

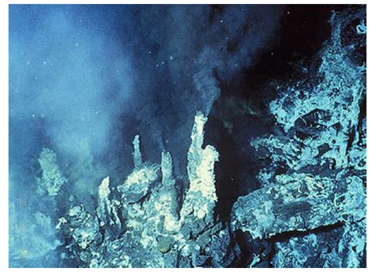


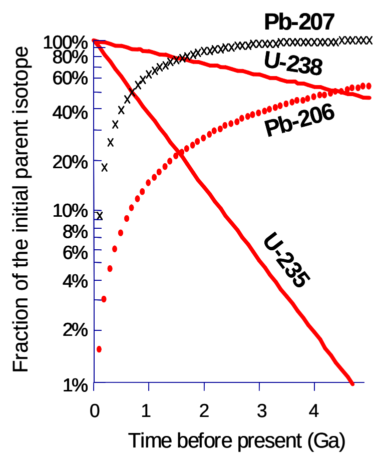
Fig 1.14: The 1991 discovery of vent communities at 2.4 km deep Darwin Rise, where no life was expected, revealed chemosynthesis as the main form of autotrophy.

To conclude this chapter, let us address a concern that readers often have with the enormity of geological time, viz., how do we date the events that occurred million and billion of years ago. Box 1.9 therefore introduces radiometric dating, the tool that helps geologists accomplish this task.

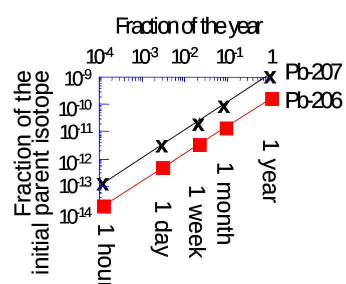
Box 1.9: Dating the geological past

Geological time is enormous and geological processes sluggish. Radioactive dating provides the most reliable way to date the events in geological past, therefore. The simplest way to understand this is as follows. Consider the Uranium-Lead radioactive decay. Uranium (U) has 92 electrons in orbit about its nucleus, and 92 protons are packed in the nucleus. Lead (Pb), on the other hand, has 82 electrons in orbit about its nucleus that has as many protons. But U has two isotopes, U-238 with 146 neutrons in its nucleus and U-235 with 143 neutrons in its nucleus, of which U-238 decays to the lead isotope Pb-206 and U-235 to the lead isotope Pb-207. These two lead isotopes are essentially radiogenic, i.e., they have no other origin, U-235 sheds 10 electrons, 10 protons and 18 neutrons to produce its daughter isotope Pb-207. Likewise, the radioactive parent isotope U-238 expels 10 electrons, 10 protons and 22 neutrons to produce its daughter isotope Pb-206. These decays occur in a series of steps, through α- (or helium nuclei) and β- (electron-emission) decays, γ-radiation, electron-capture etc., with half-lives $t_{½}$ (i.e., the time taken for the parent isotope to decay to one-half of its initial quantity) of 4.47Ga for U-238/Pb-206 decay and 704 Ma for the U-235/Pb-207 decay.

Clearly, if the Earth evolved about 4.5 Ga ago then we should now have almost equal quantities of U-238 and Pb-206. As this period corresponds to 6.4 half-lives for U-235, this also means that we should now have $1/2^{6.4}$ = 1/84.5 or 1.2% of the original amount of U-235, the rest = (1–1/84.5) = 98.8% of it having already decayed to Pb-207. Besides, if we start with equal amounts of U-235 and U-238 then, ~4.5 Ga later, most of the uranium in nature should be U-238 and most of the lead Pb-207. This is indeed true. Just look up the atomic weights of U and Pb in Periodic Table of Elements, for instance.



How can we measure such time scales, one may well ask, and the answer is "linearize", as these two graphs show for our two U-Pb decay series. The time scale in the above graph is huge but is quite manageable in the graph alongside. Note the perfectly linear plots of production rates for the daughter isotopes Pb-206 and Pb-207 when we logarithmically scale the horizontal and vertical axes.



This is because, for decay constant $\lambda = (1/t_{½})\ \ln(2)$, the amount N(t) of parent isotope remaining after time t is

$$N(t) = N_0 \exp(-\lambda t)$$

where N_0 is its initial quantity, so that the relative quantity of the daughter isotope is $D(t)/N_0 = 1 - \exp(-\lambda t)$.