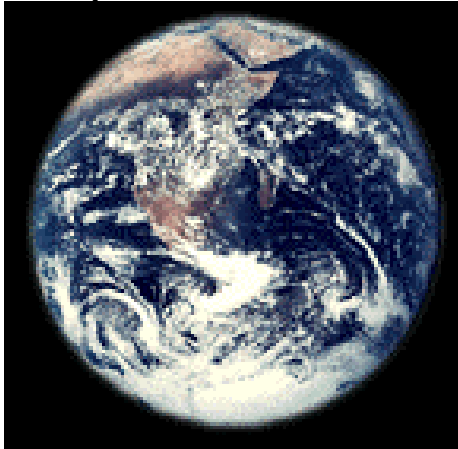


AIR: THE GREAT, THE LARGE and the small.
accompanies Air Lecture 1.

P.B.Rhines 4 ii 2003



readings this week: McNeill Ch. 3 Lovins,
Natural Capitalism Ch.12 ('Climate')

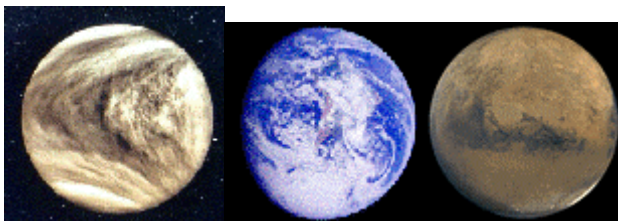
Energy in natural systems. In energy lectures we gave you some of the basic scientific ideas to work with: at the level of atoms and molecules, where physicists start their work. Power and energy, forms of energy, movement (transmission) of energy, transformations from one kind to another...heat to electricity and back. These were ideas about small things, electrons in wires, atoms flying around expressing 'heat'. We were looking at energy in human-built systems: cars, motors, heating. Now we want to look at the natural systems that support life, for which energy ideas are also a guiding principle.

The mother of (almost) all energy. Above all the problems of energy on Earth there was one thing hovering: the sun. We didn't spend much time talking about the sun, 150 million kilometers away, only its spectrum of colors that arrive here and give us most of our energy...fossil, solar, hydro-, wind-: most except nuclear, geothermal and tidal ('moon-power'). But I did emphasize that the sun is a star, and as gravity fights to control its outward flow of energy, the sun and other stars contract in size and become brighter and hotter. As they use up their 'fuel' they will one day collapse into a supernova, a last explosion. In the sun, pairs of hydrogen atoms, the most abundant element in the Universe, collapse into helium atoms. In doing so they give off enormous energy: this is nuclear fusion, which we are trying to imitate here on Earth. The total power output of the sun is about 10^{27} watts. Being so far away we intercept a small fraction of this, about 2×10^{17} watts. Recall the 'quad', a unit of energy (10^{18} Joules), which the world uses about 400 of each year. Putting this together, the sun's energy arrives at the top of our atmosphere at a rate about 14,000 times larger than our fossil fuel use.[#] "This ratio makes the amount of fossil fuels being consumed sound insignificant. In fact, though this burning turns roughly 6 ½ billion tons a year of carbon—carbon that was fixed by photosynthesis in ancient swamps over tens of millions of years, then locked deep underground as coal, oil and natural gas__into carbon dioxide."[#] This math is pretty simple: that's about 1 ton of carbon per person on Earth, each year.

In a similar fashion I will talk about air at three scales: the Great, the Large and the Small. The *first* of these is the greatest vision of the environment one can imagine, the whole Earth as an almost-living being. The *second* is the large-scale properties of the circulation of the atmosphere, it's role as a natural heat engine, and the problem of human-induced global warming. The *third* is the small-scale behavior of the atmosphere, particular the layer just above the ground which we breathe and pollute, and hope for winds to arrive to clean us up. The quality of indoor air is a serious part of the third scale, as we spend much of our lives indoors.

Time and space both have 'scales'. We have large-scale air properties like the high- and low-pressure systems that define our weather, some 1000s of km across. We have small-scale properties like the ozone concentration near I-5 in Seattle. Corresponding to these are time-scales. The time-scale of a stormy weather system may be ½ day or so, which may be the time it takes to pass overhead, or the time it takes to 'build' and 'decay'. The time-scale of an air-pollution pattern in a city may be an hour, as rush-hour traffic builds it up or winds blow it away. At the other end of the scale, the 'Great' scales of Earth's evolution involve many length-scales, and some very long time-scales. Evolution of animals takes millions of years, as does the weathering of rocks and building of mountains (there is a picture book called 'Orders of Magnitude', worth looking at in this regard).

AIR: THE GREAT. James Lovelock** is a 'geophysicologist'@ who lives and works in rural southwest England. His environmentalism is of a different kind. Trained as a chemist, he designed instruments for NASA's first Mars landings, to see if signs of life could be found (by looking for trace chemicals given off from a stimulated pan of Marsian soil). His instrument designs were popular enough that he could support his research without grants or university employment. This search for life on Mars was thought by many to be a failure (life was not found!) It led him to wonder why Mars was lifeless and Earth was not. The following remarks draw on his books and the website below ++, \$\$.



Venus

Earth

Mars

not to scale

Lovelock seized on the simple observation that carbon dioxide (CO₂) makes up about 370 ppm of Earth's atmosphere (0.03%) while the atmospheres of Venus and Mars are about 95% CO₂. These three neighbors have much in common yet Mars and Venus seem to be dead planets. Earth, with 77% nitrogen and 21% oxygen is living, and Lovelock focused the idea that it is life on Earth that *makes* the air and water and perhaps even rocks, what they are. A system of chemical reactions often ends of in some kind of equilibrium if it is isolated for long enough, with fixed amounts of the various chemicals. Mars and Venus seem to be in this state, yet Earth is far from being in chemical equilibrium. Now,

the chemical balances of even a dead planet are complicated, depending for example on the exchange of interior and surface rocks and sediments through convection...plate tectonics. But I see these as relatively small details when compared with the effects of life.

Earth's odd chemistry began sometime deep in the past, perhaps 3 billion years ago (the Earth is thought to be about 4.5 billion years old, as an identifiable planet), when something like bacteria and the phytoplankton of the ocean began to use solar power to strip carbon off the rich carbon dioxide atmosphere, use it and give off 'waste' oxygen. This changed the thin atmosphere, increasing its oxygen content and driving its carbon dioxide level down toward its present concentration, about 280 parts per million (0.028%) of air. Along with water vapor, methane, ozone and a few other trace gases, carbon dioxide is known as a 'greenhouse gas', whether it is natural or human-produced.

The greenhouse-gas 'blanket'. In building solar cookers, we have actually been making scale models of the Earth. The trapping of incoming visible sunlight in a box occurs because the box tries to radiate, not like a mirror which would bounce back the sunlight, but as a warm radiator sending out long-wavelength, invisible, infra-red (IR) radiation ('heat waves' instead of 'light waves'). This IR radiation is easily trapped by a plastic window whereas the visible light passed through it.

It is a remarkable property of the greenhouse gases that they act like the plastic window, and trap heat on Earth (see the solar radiation curve in the Energy experiment handout). They literally blanket the Earth. Any living creature or plant that trades oxygen for carbon dioxide, one way or the other, will alter this blanket. They may in fact have such a strong effect that the air temperature may change greatly. At present levels of carbon dioxide (360 parts per million) the Earth's surface is about 33⁰C (that's 59⁰F) warmer than if there were no atmosphere. The moon is cold! Though temperature on an air-less planet swings wildly from day to night. Venus, by contrast is hot, an overheated greenhouse with an atmosphere that is dominantly (roughly 95%) carbon dioxide.

Once one changes the makeup of air with just small amounts of greenhouse gases, another dominant force on Earth is modified and energized: the huge store of water. The warmer air-blanket holds more water—in gaseous form, evaporated from the oceans. Water not only is the most potent greenhouse gas but also shapes the solid Earth through rainfall, erosion, and the dynamics of the oceans that cover 70% of its surface. The case is building up, according to Lovelock, that *the evolution of life on Earth and air and water and probably rocks and landforms happened together, cooperatively.*

Lovelock's neighbor in England, William Golding, author of *Lord of the Flies*, suggested he call this idea *Gaia*, after the Greek goddess 'who drew the living Earth from chaos'. Gaia is probably the grandest scientific idea that we have on Earth. Darwin's evolution of species, an earlier grand scientific idea, tries to answer the question:

'Why are we here?'

Yet to me, Gaia tries to answer the question:

‘Why is Earth as it is, green and blue, with white clouds, deep seas, towering snowcapped mountains, with generally pleasant temperatures, teeming with oxygen and carbon cycling life of all sizes and forms?’

It closes the circle: I see that Darwin’s evolution of spiders, bananas and humans owes much to ‘the environment’ yet the environment seems always to be in the shadows of Darwin’s world, and relatively fixed; sort of like wallpaper. ‘Environmental change’ is a source of the small mutations that give advantage, pushing evolution of creatures, making creatures who do things more effectively: sense, forage, run or fly or crawl or swim, compete or hide, and interact, some or all done better than the next guy. But Gaia, the grand, and all the lesser corners of environmental science, are putting the structure and influence of the environment fully in the picture. *We begin to see that environment becomes an active part of evolution.* Quotes from Lovelock’s Gaia:

- "The name of the living planet, Gaia, is not a synonym for the biosphere - that part of the Earth where living things are seen normally to exist. Still less is Gaia the same as the biota, which is simply the collection of all individual living organisms. The biota and the biosphere taken together form a part but not all of Gaia. Just as the shell is part of the snail, so the rocks, the air, and the oceans are part of Gaia. Gaia, as we shall see, has continuity with the past back to the origins of life, and in the future as long as life persists. Gaia, as a total planetary being, has properties that are not necessarily discernable by just knowing individual species or populations of organisms living together ... **Specifically, the Gaia hypothesis says that the temperature, oxidation, state, acidity, and certain aspects of the rocks and waters are kept constant, and that this homeostasis is maintained by active feedback processes operated automatically and unconsciously by the biota.**"
- "You may find it hard to swallow the notion that anything as large and apparently inanimate as the Earth is alive. Surely, you may say, the Earth is almost wholly rock, and nearly all incandescent with heat. The difficulty can be lessened if you let **the image of a giant redwood tree** enter your mind. The tree undoubtedly is alive, yet 99% of it is dead. The great tree is an ancient spire of dead wood, made of lignin and cellulose by the ancestors of the thin layer of living cells which constitute its bark. How like the Earth, and more so when we realize that many of the atoms of the rocks far down into the magma were once part of the ancestral life of which we all have come."
- The quotation above complements that of the physicist Richard Feynmann, our ‘poster quote’ for this course: “The world looks so different after learning science. For example, trees are made of air, primarily. When they are burned, they go back to air, and in the flaming heat is released the flaming heat of the sun

which was bound in to convert the air into tree. And in the ash is the small remnant of the part which did not come from air, that came from the solid Earth, instead. These are beautiful things, and the content of science is wonderfully full of them. They are inspiring and they can be used to inspire others.”

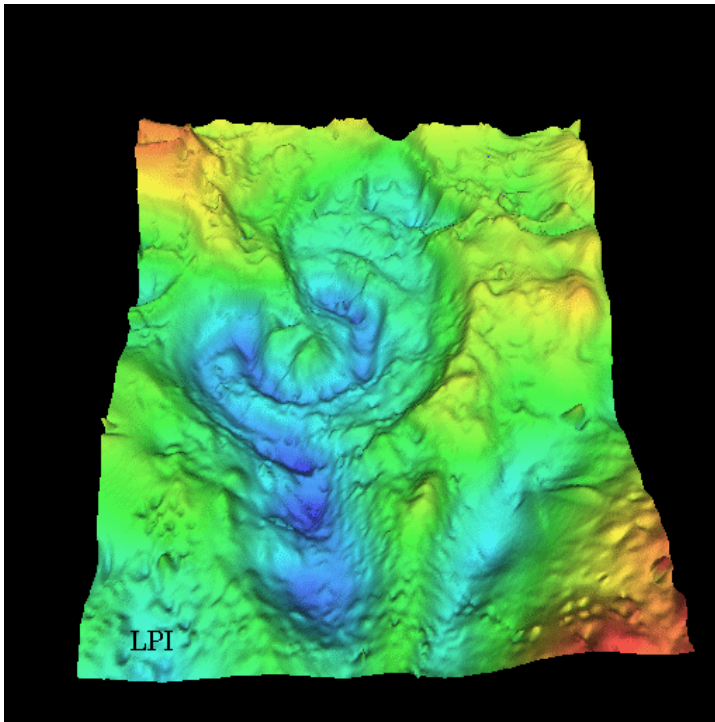
To pursue the question of evolution of living things, one good interpreter is Richard Dawkins; interpreters of Gaia are becoming numerous ++ too, but beware of New Age philosophies about Gaia that can forget the science altogether. Gaia does have deep spiritual, esthetic, artistic implications (how could it not?). But it shows how science, rather than mysticism, can be a source of these ‘non-scientific’ implications.

The Earth as a living organism. The word I used above, ‘cooperatively’ to describe evolution of life, air, water and rocks, should perhaps be replaced by ‘interactively’, for then there is little doubt about its truth. Lovelock argues further that the Earth acts as a living organism, regulating its atmosphere and its acceptance of sun’s radiation so as to be ‘comfortable’. He has been criticized for going too far in the direction of New Age philosophy, in arguing that Gaia has consciously done this, implying that the many separate parts of the Earth’s ecosystems are somehow working together as if they had a communicating central nervous system. Lovelock seems to waver on this point. Richard Dawkins, cited above, doesn’t believe it, nor do many scientists. There are other forces at work besides biology (notably, plate tectonics...continental drift...that does much to shape the solid Earth and affect its chemistry). We are on thin ice as simple scientists, wondering when something as active and dynamic as the Earth is ‘alive’. Perhaps, as I suspect, it is the internet that *is* the final central nervous system for our planet. Together with our new range of environmental sensors (satellites, deep-sea autonomous instruments...) which give us ‘eyes’, perhaps we are unconsciously building Gaia as a global organism. ‘Life’ is not easy to define with certainty.

BIG environmental events. Lovelock and Darwin are usually looking backward, but they have given us formulas to help predict the future. A few important points Like the weather itself, evolution of plants and animals (and rocks) is very unpredictable and subject to some poorly known influences. Take the dinosaurs, who lived for more than 100M years successfully. They disappeared rather suddenly (in the greater scheme of things) at the end of the Cretaceous period, about 65M years ago. Until relatively recently there were many theories about why they vanished from Earth; particularly that ‘their bodies outgrew their brains’, or that climate change somehow did them in. But in fact, there is much evidence that an asteroid collided with Earth, and caused such disruption that the dinosaurs, and *a majority (perhaps 70%) of all species of animal on Earth* died. Sharks survived. Alligators survived. We don’t know why.

This remarkable discovery in 1980 came when two physicists named Luis and Walter Alvarez, father and son, saw peculiar layers of rock in a road cutting in Italy. Below a certain level, older layers were rich with fossils of marine plankton. Above that level, were almost none. That ‘certain level’ happened to contain lots of iridium, a rare, heavy metallic element that is rich in extra-terrestrial bodies like asteroids. At sites with dinosaur fossils, a similar picture emerged (though there was argument for some years

about ‘how quickly’ the dinosaurs disappeared). In 1960 geologists exploring the Yucatan Peninsula in Mexico discovered ring-like layers beneath the surface that looked like an impact feature...sort of a frozen wave radiating out from a center. It defines an 80-mile crater in Chicxulub. In the last few years, this feature has been dated and seems to have been *the* asteroid event. Ocean ‘tsunamis’.. sometimes called tidal waves... at this time left mud deposits widely round the Caribbean, and stone transformed into small glass spheres which signal a horrendous impact event.



The crater at Chicxulub Mexico that may be the impact of the asteroid.

There have been many asteroid impacts on Earth, including one at the *beginning* of the dinosaur era which Walter Alvarez thinks may have helped dinosaurs become a dominant species.

Time-scales. We come back to the time it takes for the environment and creatures living it, to change. Asteroids impact Earth every 100 M years (very roughly...no predictions here), but are sudden. They reset the entire environment. Lovelock’s favorite examples of Earth evolution are way out there, 100s of millions of years and longer. It is the time-scale of the changing sun, its gradually increasing brightness. Darwin’s animal and plant evolution is at the time-scale of millions of years (though Steven Gould’s variant on Darwin’s evolution process has quicker events followed by long periods without change). We and McNeill have spoken of cultural or social evolution that humans are particularly good at, which can occur overnight. So, in studying Earth, Air and Water...and human contexts, we have to keep in mind the great sweep of ‘deep time’, those millions of years, as well as the here-and-now events that reshape the

environment daily. Global warming, human population growth and technological change are compelling events with short time-scales.

We want to come to grips with the flow of the atmosphere, the air-conditioning that creates the geography of life on Earth, and work toward understanding what was in your most recent breath: that is what we shall do next.

References:

Lovins, A., 1999, *Natural Capitalism*, Little,Brown Co., Boston, p.234. Note, in the metric world 1 ton (or tonne or metric ton) is 1000 kg... (that's 2200 lbs, a bit more than the English ton, 2000 lbs).

&& Dawkins, Richard, 1986: *The Blind Watchmaker: Why the Evidence of Evolution Reveals a Universe Without Design*. Penguin Books Ltd

@ to quote James Hutton (1727-1797), an early geologist who believed that rocks and mountains were part of an constantly changing, active landscape, transforming rock types through heat, pressure, erosion and chemical reactions.

** Lovelock, James, 1979. *Gaia: a new look at life on Earth*. Reissued 2000 with new preface. Oxford Univ. Press.

“ “ 1988. *The Ages of Gaia: A biography of our living Earth*

“ “ 2001. *Homage to Gaia: the life of an independent scientist*. Oxford Univ Press

++ http://www.magna.com.au/~prfbrown/gaia_jim.html

<http://www.lancs.ac.uk/users/philosophy/mave/guide/gaiath~1.htm>

\$\$ I find myself encountering the web (as perhaps you have) with uncertainty: I have my own ideas and interpretations about this topic, and so do the web sources. How do I let you know which ideas are mine? The classic academic method is to reference every statement that is borrowed from elsewhere but this leads to a pretty jerky essay. Instead, here I have broadly referenced the web and books, and then write with the famous personal pronouns, “I” and “me” and “we” to show you what I think. I recommend that you try this, while avoiding writing something that reads like a diary.

<http://www.nature.com/nsu/020513/020513-11.html>

There are some wild websites about the end of the dinosaurs, e.g. <http://www-geology.ucdavis.edu/~GEL3/SHORTCH18.html>