Week 4: Microbiology & Geology: Subsurface bacteria & mineral deposits
*****Answers to Questions due 10/11/06*****

Article #1 of 2:

Science gets hot under the crust

Book Review by Paul Davies: February 1999 Source: http://physicsweb.org/articles/review/12/2/1

Book: The Deep Hot Biosphere by Thomas Gold. 1998 Copernicus 225pp

On page 38 of this provocative book, Thomas Gold describes how he began "nosing around in the field of petroleum geology" only after establishing himself as an esteemed astronomer and physicist, and having been elected as a member of several prestigious learned societies. He would not recommend a scientist of lesser standing, "however brilliant", to propose the sort of radical theories summarized here. For Gold's thesis amounts to a total revision of much of the Earth sciences. If he is right, the consequences could be dramatic, not only for science, but also for economics and politics.

At the heart of the theory is the problem of the origin of hydrocarbons in the Earth's crust. Conventional wisdom has it that oil and coal are remnants of ancient surface life that became buried and subjected to extremes of temperature and pressure. **Gold maintains that these deposits are not fossil fuels** in the normal sense, but the products of primordial hydrocarbons dating from the time of the Earth's formation. He claims that over the aeons the volatile gases migrate towards the surface through cracks in the crust, and either leak into the atmosphere as methane, become trapped in sub-surface gas fields, or are robbed of their hydrogen to become oil, tar or carbonaceous material like coal. In other words, these substances are formed from the bottom up, rather than the top down. It follows that there must be reserves of fuel vastly in excess of the quantities that the gas and petroleum industry estimates.

When Gold proposed this theory in the early 1980s, few scientists took him seriously. However, he did persuade the Swedish State Power Board to drill into a slab of granite fractured by an ancient meteor impact. Since oil is supposed to be found only in sedimentary rocks, it was a good test of Gold's theory. If gas is coming up from deep in the Earth, it might be expected to accumulate beneath the dense granite cap, and migrate slowly up through any fissures, perhaps turning into oil or tar. In the event, the prospectors did strike oil - about 12 tons of it. This was not enough to make the well commercially successful, but it did confirm that Gold was on to something.

It was not the Swedish oil that proved the most significant discovery though. Mixed in with the sludge at the bottom of the well, at a depth of over 6 km, was a large quantity of magnetite - a reduced form of iron oxide often associated with bacterial activity. After further investigation, Gold announced to the world that life exists not only on the surface of our planet but, in microbial form, deep inside the crust too.

The claim that the biosphere extends far underground was, if anything, even more heretical than the theory of upwelling hydrocarbons. At the time it was greeted with widespread scepticism. But I, for one, immediately found the basic idea plausible. As it happened, within a few years other researchers also obtained evidence for deep-living microbes, not only beneath the land, but also under the sea bed. Soon, microbes were being extracted from deep bore holes and cultured in the laboratory. Today there is no doubt that the underworld teems with life, as Gold asserted all along, although the precise extent of this subterranean realm remains uncertain.

Many of the deepest dwelling organisms are "hyperthermophiles" thriving at temperatures in excess of 90 °C, and in some cases these resemble the microbes that inhabit the regions around volcanic ocean vents. Gene sequencing suggests that these heat-loving sub-surface organisms are genetic hangovers - living fossils that occupy the oldest and deepest branches of the tree of life. **The implication, with which Gold concurs, is that life began inside the Earth, and migrated to the surface only at a later stage**, when the intense cosmic bombardment that accompanied the formation of the planets abated.

For Gold, the existence of the deep hot biosphere provides clear confirmation of his theory of upwelling hydrocarbons, which he believes provide the primary energy source for sub-surface life. Other researchers disagree. They accept that life exists below ground, but they think that either the microbes make a living from organic products indirectly related to surface life, or else they combine hydrogen and carbon dioxide directly into biomass.

Whichever explanation is correct, Earth scientists are slowly coming round to the view that **life has played a major role in shaping the geology of our planet**, including the formation of large-scale mineral deposits such as iron, zinc and even gold. Conventionally it is assumed that water is the key solvent involved, but Gold suggests that hydrocarbons suffusing the crust offer a more efficacious medium. As microbes strip out the hydrogen, so minerals are precipitated. He presents some evidence for the association of oil and gas deposits with metal ores.

Article #2 of 2: Bacteria and ore-formation

Goldbugs

The Economist , Jul 19th 2001

Gold mines may owe their origins to microbes

MEDIEVAL alchemists found, in the end, that they could not create gold. Modern geochemists have a similar problem. They find it hard to understand how natural gold deposits form. There is much handwaving about gold-rich fluids from deep in the earth, and chemical precipitation, but the physics does not add up. The answer may be that what is happening is not geochemical at all, but biochemical. And a casual experiment by a bacteriologist may hold the key.

Derek Lovley, of the University of Massachusetts, Amherst, has been studying “metal-eating” bacteria for two decades. These bacteria make their living by converting (or “reducing”) the dissolved ions of metallic elements from one electrical state to another. This reduction releases energy, which the bacteria extract for their own purposes.

Unsurprisingly, such bacteria tend to prefer common metals such as iron and manganese for lunch, though some species are able to subsist on such exotica as uranium. A few months ago, though, as “a bit of a lark”, Dr Lovley decided to put some of his bacteria into a solution of gold chloride. He was fully prepared for nothing to happen, as gold compounds are generally toxic to bacteria. Instead, the test tube containing the solution turned a beautiful shade of purple, the color of metallic gold when it is dispersed very finely in water.

Bacteria are already known to be involved in the formation of an iron ore called limonite, and Dr Lovley has argued that they are also involved in the creation of certain ores of uranium. His jokey experiment, reported in the July issue of *Applied and Environmental Microbiology*, opens up the possibility that gold deposits, too, may have a bacterial origin, with the microbes acting as the agent that concentrates gold from sources such as volcanic springs into a form that people can mine.

Dr Lovley has some support among geologists. According to Francis Chapelle, of the US Geological Survey’s branch in South Carolina, his hypothesis would neatly explain the origin of some of that state’s gold deposits. The rocks of the Carolina slate belt, including the Haile gold mine, contain the metal in an unusual form: rather than appearing in veins and nuggets, it is finely disseminated in a layer of sedimentary rock.

The sediments that form the Carolina slates were once a seabed through which volcanic fluids flowed. According to Dr Chapelle, metal-reducing micro-organisms may have extracted gold ions from these fluids, reduced them, and dropped the waste (ie, metallic gold) as a powdery precipitate in the sediments. How that relates to the more traditional deposits of gold in veins and nuggets remains to be seen, although the fact that several species of Dr Lovley's gold-eating bacteria prefer high temperatures suggests they might survive well in the hot environments mineral veins are thought to form in.

Dr Chapelle also suspects that Dr Lovley's discovery may have a bearing on the origin of the vast Witwatersrand goldfield in South Africa, whose mines produce about one-third of the world's supply. Like South Carolina, Witwatersrand has an area of gold that is found not in igneous rocks but in a thin sheet, sandwiched among sediments. Perhaps the Boer war was actually triggered by arguments over bacterial excreta.

Questions (due Wednesday, Oct. 11th)

1. What reduced form of iron oxide was found deep underground in Thomas Gold's unlikely oil well, suggesting the presence of microbial life at great depth?

2. What type of scientific analysis suggests that deep earth hyperthermophiles are "living fossils", representing the earliest forms of life on earth?

3. What color is a fine suspension of metallic gold in water?

4. What may bacteria have done to gold ions to produce metallic gold deposits in sedimentary rock?

If you are intrigued by Thomas Gold's argument for deep-earth gas and the deep hot biosphere, read the book reviewed above, or check out his scientific journal article in PNAS (Proceedings of the National Academy of Sciences):
http://www.pubmedcentral.gov/pagerender.fcgi?artid=49434&pageindex=1#page