Planetary science and meteoritics

Differential motion in the Earth's core *(May 2000)*

Periodically the Earth's magnetic field flips, so that its direction reverses. The signals of geomagnetic field reversals occur in well-dated continental lavas, and a chronology derived from them is key to understanding the more continuous magnetic signature preserved in surveys running at right angles to oceanic ridge systems. They presented to Earth scientists the now familiar patterns of magnetic 'stripes' of normal and reversed polarity running parallel to the ridges, which characterise oceanic lithosphere. The 'stripes' permit the dating of the ocean floor, which increases more or less systematically away from the ridges in both directions. That pointed unerringly to the formation of oceans by sea-floor spreading, and underpins the theory of plate tectonics. That is a fine example of deduction from, in many respects, fortuitous information of an empirical kind, and has kept Earth scientists extremely busy since Vine and Matthews figured-out its significance in the 1960s.

Why these magnetic upheavals take place has proved to be a tough nut to crack. Not long after Earth scientists began to speak of little else, theoretical geophysicists proposed that somehow the Earth contained a self-sustaining dynamo prone to inverting its magnetic effects. The only conceivable source was the almost certainly iron-rich core, with an outer liquid shell and a solid inner core, proven by analysis of seismic waves travelling through the Earth's central parts. Motion within the core also moves electrons, thereby simulating current flow, and from Maxwell's law there must be a related magnetic field that would shift as the motion changed. The liquid outer core is clearly the part that undergoes the most complex motion, partly as a consequence of rotation, and partly because of heat transfer. Ideas on the nature of that motion have developed over the last 3 decades, importantly through analysis of the drift of the magnetic field itself. The key feature however, is that the mantle and outer and inner core are mechanically decoupled, at least partly, by the outer core's fluidity. Discovering how the solid inner core moves is clearly important for more realistic models of the self-exciting dynamo.

John Vidale and co-workers form the University of California, Los Angeles and the Lawrence Livermore National Laboratory show how they re-analysed 30 year old records of seismic wave arrivals from Soviet nuclear tests to 'image' inner-core motion from the scattering of these signals (Vidale, J.E. *et al*. 2000. Slow differential rotation of the Earth's inner core indicated by temporal changes in scattering. *Nature*, v. **405**, p 445-448; doi: 10.1038/35013039) - one of very few useful outcomes of the Cold War, and hopefully one that will never be repeated! Their results are not definitive, but suggest that the inner core rotates on a different axis from that of the Earth as a whole.

A 'treasure map' for asteroids *(June 2000)*

Not only geologists are waking up to the influence that stray asteroids and comets have had on geological and biological evolution, but so too are politicians. Despite the minuscule chances of a sizeable body hitting the Earth within our lifetime, the devastation would be awesome. Insurance actuaries have calculated the risk from such rare events, taking into account the number of likely deaths in the same way as for airline disasters. You or I are more likely to perish in the aftermath of an asteroid or comet strike than from botulism or a fireworks accident, and the risk is comparable with that of intercontinental flying. Governments are beginning to find money to support systematic mapping of bodies that may pose a threat; not a lot, but sufficient to spot bad news and refine the risks.

On June 22, a French-US team released a first assessment of the near-Earth objects (NEOs) that pose the biggest threat; those more than 1 kilometre in diameter (Bottke, W.F. *et al*., 2000. Understanding the distribution of near-Earth asteroids. *Science*, **288**, p. 2190-2194; DOI: 10.1126/science.288.5474.2190). They estimate about 900 big asteroids in orbits that will pass eventually within a few moon distances of us. "Sometime in the future, one of these objects could conceivably run into the Earth," warns astronomy researcher William Bottke at Cornell University. "One kilometer (about .6 of a mile) in size is thought to be a magic number, because it has been estimated that these asteroids are capable of wreaking global devastation if they hit the Earth." Much smaller objects caused the celebrated Meteor Crater in Arizona (20 000 years ago) and the Tunguska explosion (1905), and seem to pose the greatest hazard, being undetectable at present.

NASA'a Jet Propulsion Laboratory freely provides copious information about NEOs at its Center for Near-Earth object Studies (CNEOS)

First signs of liquid water on Mars? *(June 2000)*

If Mars is ever to visited by astronauts, and for there to be any chance of finding living things there, water close to the surface is vital. Not surprisingly, the search for Martian water, albeit not in a network of canals, is becoming a thriving cottage industry. The last week of June 2000 saw a leaked report from research using images from the Mars Global Surveyor spacecraft, publicised in *New Scientist* and *Science* for that week (Malin, M.C. & Edgett, K.S. 2000. Evidence for recent groundwater seepage and surface runoff on Mars. *Science*, v. **288**, p. 2330-2335; DOI: 10.1126/science.288.5475.2330). *Some* of these showed extremely sharp systems of V-shaped gullies on steep sides of valleys and craters. Several workers claim that they were cut by running water in the recent past. That they are young features is clear, because they are not blurred by dust blown across the Martian surface by it nightmarish winds, and none are cut by craters. How water might have flowed freely a short time ago is not too clear. The Martian surface is well below freezing point for most of the time (average temperature -50°C).

The explanation given by the researchers is that a layer of frozen pore water a few hundred metres below the surface can melt because of built up of pressure. Where the layer meet the surface in valleys cut through it, the pore water remains frozen, and acts as a dam. When this becomes breached, water simply squirts out to form the peculiar runnels seen at more then 150 sites. Several of the gullies lie below signs of collapse on the slopes above, suggesting that water release has removed support for debris on the steep slopes.

There a number of reasons to take these accounts with a pinch of salt. Sure, increased pressure depresses the melting point of water, but at -50°C it would have to be pretty high. In permafrost areas on Earth, waterlogged soil freezes from the top down in winter, thereby trapping the last dregs of water. This becomes pressurised, to remain liquid in a supercooled state. If it breaks out it does not flow, but forms ice almost instantly. As well as forming the famous pingoes (ice cored mounds) of Arctic alluvial plains, this phenomenon almost caused a bizarre disaster during one of the Yukon gold rushes. High-pressure water jetted into a public bath house - the warmth of the building had created a trough of melt water directly beneath - and filled the entire edifice with ice. Fortunately, this happened at night and no prospector was encased. Much the same would probably happen to any such water escape on Mars, unless it was preternaturally warm. Such was the case for the truly huge and unmistakable water-cut valleys on Mars. But they formed far back in Martian history, perhaps as a result of energy introduced by large impacts.

Martian channels on steep slopes that may have been incised by flowing water. (Credit: NASA, Mars Orbiter Camera)

It is tempting to look to other explanations for the gullies. Very dry sand flows down the lee slopes of dunes, often to form runnels with collapse features above them. Perhaps some attention to the physics of dry sand - Mars is a sandy and silty place - under near-airless conditions and suitably reduced gravity, might offer an alternative explanation.

Even more optimistic is the notion that Mars once has seas, based on the discovery of various salts in an Egyptian meteorite that approximate the blend of dissolved ions in Earthly seawater (New Scientist, 1 July 2000, In Brief). The evidence that the class to which this meteorite belongs comes from Mars rests on comparison of its noble-gas content with the extremely imprecise measurements or Mars' air by the Viking mission in the 1970s. Why the chemistry of Martian 'seas', or any of its water for that matter should bear comparison with that for waters derived from a planet with both weather and highly evolved continents seems to demand an explanation. Oh well, no doubt we will get answers when astronauts do get there - it is not inconceivable that all the papers suggesting it is important to go have some relation to NASA's decades long fight for funds to do that.

See also: Kerr. R.A. 2000. Making a splash with a hint of Mars water. *Science*, v. **288**, p. 2295-2297)

Earth's earliest events *(July 2000)*

The Earth has a core made of alloyed iron, nickel and sulphur. Much evidence points to the core having formed very early in our planet's history, probably in its first 100 million years. Core formation explains the depletion in iron of mantle rocks and magmas derived from them, compared with iron's abundance in the cosmos. Because some rarer elements have a 10 000 times greater tendency to partition into melts containing metallic iron than into silicates, such siderophile ('iron-loving') metals are also highly depleted in the outer Earth. That is one of the reasons why gold and the platinum-group elements (PGEs) are so rare and highly prized at the Earth's surface. In fact, such noble metals are a lot more abundant in the crust than the presence of a metallic core could have allowed; they should be at vanishingly low abundances.

One solution to this paradox is that the 'extra' gold and PGEs arrived after core-formation had finished, the agency of delivery being continual bombardment by meteoritic debris in the first half billion years of the Solar System's history. The other is that somehow, the affinity of such metals for iron drops off at extremely high pressures. German, Canadian and Australian geochemists (Holzheid, A. *et al*., 2000. Evidence for a late chondritic veneer in the Earth's mantle from high-pressure partitioning of palladium and platinum. *Nature*, v. **406**, p. 396-399; doi: 10.1038/35019050) have shown experimentally that such a decrease doesn't occur, at least in the outermost 500 km of the Earth. This points strongly to impacts having seeded the upper mantle with noble metals, and therefore, perhaps, with lots more besides. This re-opens the old controversy between homo- and heterogeneous accretion of the Earth, tempered by the fact that more common siderophile metals, such as nickel and cobalt do not show mantle abundances that are in disequilibrium with core formation. The distinction is not trivial, for much of Earth's evolution has been driven by its internal composition, most especially its content of radioactive isotopes and water.

The Moon seems to have formed as a result of a gigantic impact of a Mars-sized body with the early Earth. Since the Moon has neither a core nor its full cosmic complement of iron, such a catastrophic beginning (effectively 'Year Zero' for the geochemistry of both bodies) must have taken place after core formation in the Earth. Because lunar rocks are so little changed by later events, its age is known with considerable accuracy - the Lunar Highlands are about 4450 million years old. It would be interesting to compare gold and PGE abundances between Earth and its Moon, for that might reveal the period during which bombardment delivered siderophile elements. Up to 3.8 billion years ago, both bodies received lots of visitors, culminating in a bout of huge impacts between 4.0 and 3.8 billion years ago that formed the huge lunar craters, that early astronomers termed *maria* or 'seas

Atmosphere linked to Earth's rotation: The mystery of Chandler Wobble *(August 2000)*

One of the annoying features of the Earth as a planet is that it engages in a kind of Saint Vitus' dance. The best known of its gyrations are those involving variations in the eccentricity of its orbit, and the tilt and precession of its axis of rotation. These follow from the gravitational influences of massive planets elsewhere in the Solar System, and are implicated in the modulation of climatic change through the last 2.5 Ma by the Milankovich Effect. Rather less well-known, and even more aggravating are far more rapid, but geometrically quite small deviations from good behaviour. One of these is the habit of the spin axis to wander around the geographic poles within a circle roughly 3 to 6 metres across. It does this every 14 months. It takes a certain degree of dedication to chart such a tiny planetary tic. Chandler Wobble is the single claim to fame of its eponymous discoverer. Seth Carlo Chandler Jr, an American businessman and amateur astronomer, discovered the quirk in 1891 by observing stars with a degree of single-mindedness that might have put a lesser mortal on the couch. He set out to verify the famous Swiss mathematician Leonhard Euler's prediction that the Earth *ought* to wobble every year, and he did.

So minuscule is Chandler Wobble, that keeping it going is something of a vexing problem, for a single jostle's effect ought to fade away in a few years. There are innumerable ways of nudging the Earth, and deciding which is sufficiently regular and just right to maintain the wobble is no easy task. Following in the great tradition of Seth Chandler, Richard Gross of the Jet Propulsion Laboratory compared Wobbling between 1985 and 1996 with the continual but inconstant motions of atmosphere and oceans, as simulated by super-computer modelling of climate. The forces of winds and currents are simply insufficient to induce the Wobble, but variations in atmospheric and deep-water pressure, together with their positional shifts are, in the manner of Goldilocks and the little bear's porridge, just about right. Because changes in water depth are wind-driven (as for instance with the wandering hump in the Pacific's surface, linked with El Niño), 'weather' is the ultimate driving force for Chandler Wobble.

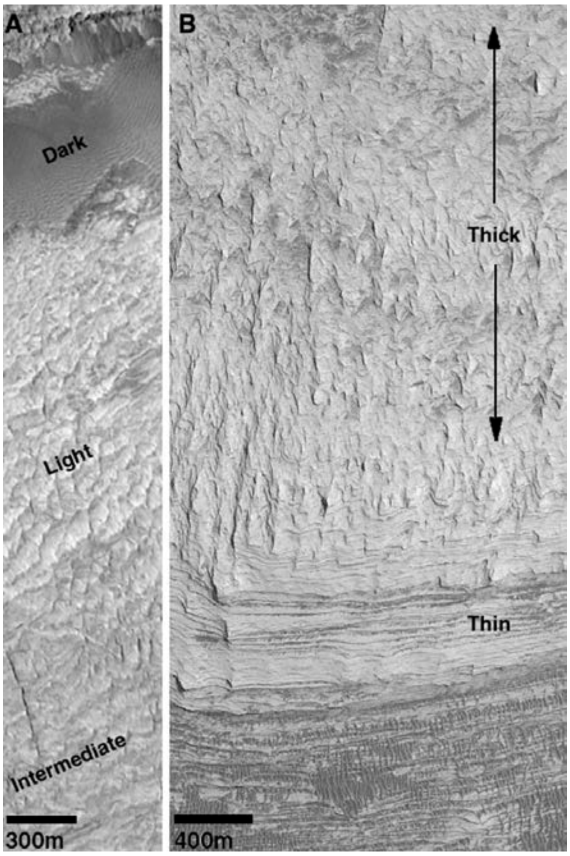
Why devote time to this picayune curiosity? The answer is to chart more accurately the position of distant spacecraft; not easy when the measuring platform is behaving like a Womble.

Source: Kerr, R.A. 2000. Atmosphere drives earth's tipsiness. *Science*, **v. 289**, p. 710; DOI: 10.1126/science.289.5480.710.

More evidence for water on early Mars? *(December 2000)*

The Mars Orbiter Camera aboard the Mars Global Surveyor spacecraft is one of those little irritations that irks Earth-oriented remote sensers. It captures pictures with resolutions as fine (1.5 m) as those from "spies in the sky" of a decade back, and the best commercially available imaging systems in orbit around our home world (they cost between US$16 to 44 per km^2). Nor surprisingly, geologists interpreting features of the Martian surface are having a heyday (there is no damned cloud or atmospheric haze either, and it's the dry season all the time!)

Nearly every report focuses on water, either that supposed to have flowed after recent (most unlikely) melting of ice in the upper veneer of Martian "soil", and the episode of catastrophic melting early in Mars' history that cut huge valleys. The latest shows abundant topographic features that speak of layer-cake sediments (Malin, M.C. and Edgett, K.S. 2000. Sedimentary rocks of early Mars. *Science*, v. **290**, p. 1927-1937; DOI: 10.1126/science.290.5498.1927). Even unconformities and exhumed channel-like features show up, and some of the deposits partly fill ancient impact craters. While aeolian and volcanic processes, and those associated with impacts might all form sediments – it is certain that all these processes have operated on Mars – to conclude that some of the sediments might be waterlain is not so easily assumed. Malin and Edgett are cautious, for there is no definitive sign that the Martian sediments are waterlain – but some <u>might</u> have been.



Varying bedding thickness in sedimentary rocks on Mars (Credit: Malin & Edgett, 2000: Fig. 3)

Having just returned from a technical meeting with people working for humanitarian relief agencies, and heard of their needs for remote-sensing data that should show up habitations clearly enough to estimate numbers of people affected by disasters, I did not read this paper with any great relish. NASA's determination to convince itself that indeed water lies waiting to be tapped on the "Red Planet" by the first staffed mission there sits uneasily with the fact that the best part of a billion people on Earth have neither enough nor much with a safely drinkable quality. It’s a pity that there isn’t an “Earth Orbiter Camera” that would serve their needs rather than those of a few earnest astronauts and some ambitious bureaucrats.