Planetary science and meteoritics

Carbon dioxide and Martian channels (*January 2003*)

Despite the evidence from the neutron detector on Mars Odyssey for the possible existence of subsurface water on Mars (see *Water on Mars*, August 2002) not everyone accepts that minor rills and channels on its surface are due to periodic melting of buried water ice (see *Water on Mars*, July 2000). Two small pieces in *New Scientist* contest that view. In a letter, Wytse Sikkema of Shell likens them to features carved by turbidity flows (suspensions of solid particles in a fluid, such as avalanches, ash flows and submarine turbidity currents) which they resemble more than stream channels (Sikkema, W. 2003. Rivers of Dust. *New Scientist*, 18 January 2003, p. 24). Sikkema suggests that the supposed ocean-like basins on the Red Planet are filled with dusts carried by such flows. Support for such a mechanism emerges from observations of gullying in progress during Mars' late spring near the poles, when temperatures were too low for liquid water to exist. Nick Hoffman of the University of Melbourne, suggests that the active gullying that he observed on successive Mars Global Surveyor images involves rapid vaporisation of CO_2 snow and ice to lubricate dust avalanches (Nowack, R. 2003. Ravines hint at gas avalanches on Mars. *New Scientist*, 18 January 2003, p. 14-15). Hoffman also considers that massive release of gas by boiling of buried CO_2 liquid could have carved the much larger valley systems on Mars by massive flows of dust-gas mixtures. If he is correct, there is no reason to consider Mars either as a haven for early life or one for intrepid astronauts. Britain's Beagle 2 probe and two unnamed NASA Mars rovers, due for launch this year, should resolve the issue, but if water is not confirmed, there will be huge disappointment for both teams involved with those missions.

Chromium isotopes and Archaean impacts (*March 2003*)

Up to the late 1990s, and even today, many geologists have been slow to accept that the Earth's evolution has been substantially affected by impacts of extraterrestrial bodies. In hindsight, this stubborn scepticism seems perverse. The discovery of impact-induced melt spherules in the Late Triassic sediments of SW England (see *Britain's own impact* December 2002) went almost unnoticed. However, there is still an entrenched view that nothing really *big* (i.e. on the scale of the lunar maria and ringed basins) ever happened on Earth. When similar spherule beds were reported from the Early Archaean greenstone belts in Australia and South Africa in 1986, and deduced to have formed by an impact, the authors were pounced on by those who thought they could plausibly explain the very odd rocks by unremarkable, Earthly processes. How satisfied Donald Lowe and Gary Byerly, of Stanford and Louisiana State Universities must be to find their view now proven beyond doubt, and to share in publishing the evidence. The proof comes from isotopic studies of three spherule beds in the 3200 Ma-old Barberton greenstone belt in South Africa (Kyte, F.T. *et al*. 2003. Early Archean spherule beds: Chromium isotopes confirm origin through multiple impacts of projectiles of carbonaceous chondrite type. *Geology*, v. **31**, p. 283-286; doi:10.1130/0091-7613(2003)031<0283:EASBCI>2.0.CO;2).

Chromium isotopes in the rocks are so unearthly, that explaining them requires that they contain up to 60% of extraterrestrial material, probably from carbonaceous chondrite impactors. Compared with the global spherule-bearing and iridium-rich K/T boundary layer (3 mm thick on average), that is the ejecta from the Chicxulub impact, the Barberton beds are much thicker (10-20 cm). The authors estimate that, if the Barberton layers are globally representative, the impactor responsible for their formation could have been 50 to 300 times more massive than that which terminated the Mesozoic Era. Besides that, three such layers formed within 20 Ma, and that suggests bombardment flux more than ten times that late in Earth evolution.

Triggering core formation at the microscopic level (*March 2003*)

Since Francis Birch's discovery in the 1950's that the Earth's excessive density compared with exposed rocks could be explained by a metallic, iron rich core, whose presence was detected by studies of seismic waves, there have been many explanations for core formation. Some regarded the process as a slow accumulation of iron-rich melt as it sank from the mantle, others that it formed during Earth's initial accretion from the iron-rich parents of metallic meteorites. Lead and tungsten isotope studies indicate clearly that the core formed very early in Earth's evolution, taking as little as 30 Ma. However, for such a vast mass to have quickly segregated from the rest of the Earth poses awesome mechanical problems. Alloys of iron, nickel and sulphur do have much lower melting temperatures than silicate minerals, and planetary accretion releases gravitational potential energy. That serves to heat up a growing planet, but core-forming materials would melt long before the dominant silicates that envelop them, if indeed mantle materials did melt substantially. So, at the centimetre scale of rocks, a melt fraction, however dense, would have to migrate and accumulate in globules with sufficient gravitational potential to sink through the viscous early mantle. The boundaries of pores in which melts form are critical.

If the angles between silicate facets and melt-filled pores are large, tiny amounts of molten metal cannot become interconnected and migrate, unless the silicates begin to melt too or are actively deformed. Since coexisting silicate and metal melts are not supported by geochemical evidence and deep planetary interiors are probably static, the fact that the interfacial angles of crystalline minerals are high poses quite a problem. Geochemists at the University of Yokohama in Japan have performed complex experiments at high pressure and temperatures to simulate likely conditions during planetary accretion (Yoshino, T. *et al*. 2003. Core formation in planetesimals triggered by permeable flow. *Nature*, v. **422**, p. 154-157; DOI: 10.1038/nature01459 ·). They discovered that if metallic melts account for more than 5% by volume of the accreting body, then this melt can percolate through the solid rock, because the angles separating melt and solid fall below the critical value of 60º.

The implication is that even quite small planetesimals (>30 km radius) can quickly develop metallic cores, using energy released by the decay of short-lived isotopes that were plentiful early in Solar System history. This is borne out by studies of metallic meteorites Of course, the immense gravitational energy released by accretion of larger planetary bodies would result in the same differentiation, but if they formed by accumulation of smaller differentiated bodies there is no need to postulate within-planet processes on the microscopic scale. The core would be "pre-manufactured", only requiring blending of many smaller cores of accreting planetesimals

See also: Minarik, B. 2003. The core of planet formation. *Nature*, v. **422**, p. 126-127; doi: 10.1038/422126a.

Potassium in the core (*May 2003*)

It might seem impossible for planetary cores dominated by iron-nickel alloys to contain any source of heat generation. The main three elements (uranium, thorium and potassium) with long-lived radioactive isotopes and sufficient abundance to produce substantial heat energy are all highly concentrated in the Earth's crust. That is because they are incompatible with the minerals in mantle rocks, and so readily enter magmas that contribute to continental growth. However, the only natural materials that bear any resemblance to geoscientists' notions of core materials, metallic meteorites, contain abundant sulphur. Theoretically, potassium can enter sulphide minerals. So, since as long ago as the 1970s there has been debate about whether motion in the core was driven entirely by residual heat from Earth's accretion and the formation of the core, or that it contained its own heat source in the form of ^{40}K. If the first was true, then the self-exciting dynamo responsible for the Earth's magnetic field has been running down over geological time, because heat is transferred across the core-mantle boundary, eventually to reach the surface by convection. The existence of a solid inner core might result from such cooling, though its formation would release latent heat of crystallization and prolong inner motion. However, some calculations suggest that core motion and so geomagnetism ought to have vanished long ago, through loss of core heat to the surface. Substantial potassium in the core would demand considerable revision of ideas about the bulk evolution of the Earth, and other rocky planets. Experiments to prove that iron-sulphur alloys can contain abundant potassium have had a chequered history.

Research at the University of Minnesota and the Carnegie Institute of Washington has discovered why there were such ambiguous results (Murthy, V.R. *et al*, 2003. Experimental evidence that potassium is a substantial radioactive heat source in planetary cores. *Nature*, v. **423**, p. 163-165; DOI: 10.1038/nature01560). The problem was in the preparation of samples for analysis. Rama Murthy and colleagues found that the oils used in polishing samples for electron-microprobe analysis actually leach potassium from the sulphides in them, nearly all disappearing in a few days of contact. With great care, they repeated experiments on mixtures of metallic iron, iron sulphide and potassium bearing glass held at high temperature under pressures between 5 and 10 % of those experienced in the core. Their results show that potassium can indeed enter core materials with high sulphur contents. The higher the temperature the more gets in, and their most extreme run saw almost 4 % K in the quenched sulphide. Plan are afoot to discover if uranium and thorium might also be in core materials.

Incidentally, in the week that the film *The Matrix: Reloaded* was premiered in the USA, a proposal to send a probe to the core-mantle boundary also appeared (Stephenson, D.J. 2003. Mission to Earth's core – a modest proposal. *Nature*, v. **423**, p. 239; doi: 10.1038/423239a). David Stephenson, of the California Institute of Technology, builds on the notion of the "China Syndrome", in which meltdown of the core of a nuclear reactor would lead to superdense molten uranium melting its way through the mantle. In his proposal, ruggedized instruments in a capsule the size of a grapefruit would make the journey, along with about 10 million tons of molten iron, by propagating a large crack started by a 10 Mt nuclear explosion. Data is to be transmitted by modulated acoustic signals in the kHz range. The article helps to demonstrate the delays in publication, even in a prestigious weekly journal; it should have appeared 6 weeks earlier.

Divine intervention? (*June 2003*)

Christianity had a hard time in its first four centuries as a faith, especially at the centre of the Roman Empire. Persecution of Christians ended abruptly with the conversion of Emperor Constantine in 312 AD. Legend has it that, while faced with the double problem of northern barbarian hordes at the gates of Rome and dissident Christians within, Constantine saw a vision in the sky while preparing to take on the invaders. Immediately converting to Christianity, he saw off the hordes, albeit temporarily, and the rest, as they say, is history. One version of the legend, from the Sirente region of Central Italy, tells of a new star that came nearer and nearer to disappear behind the mountains, with a blaze of light from horizon to horizon and ground shaking. Unsurprisingly, impact theorists latched onto this because of its similarity to what probably happens when a substantial meteorite strikes the Earth. Geologists from Sweden have discovered a small crater field in the Sirente area, that consists of a 125 m wide, circular lake with a raised and deformed lip, and several lesser craters dotted around it. Preliminary dating gives an age of 412$\pm$ 40 years. Although this date is a century later than Constantine's conversion, contamination with later material might have reduced the actual age. If the link does prove to be substantial, the Sirente impact will rank with other catastrophes that literally made history, such as the filling of the Black Sea which has been argued to be the inspiration for the Biblical Flood and the Epic of Gilgamesh, and the explosive volcanism of Santorini that wiped out Minoan civilisation on Crete and may well be recorded apocryphally in the Old Testament as well as in the legend of Atlantis.

Source: Chandler, D.L. 2003. Crater find backs falling star legend. *New Scientist*, 21 June 2003, p. 13.

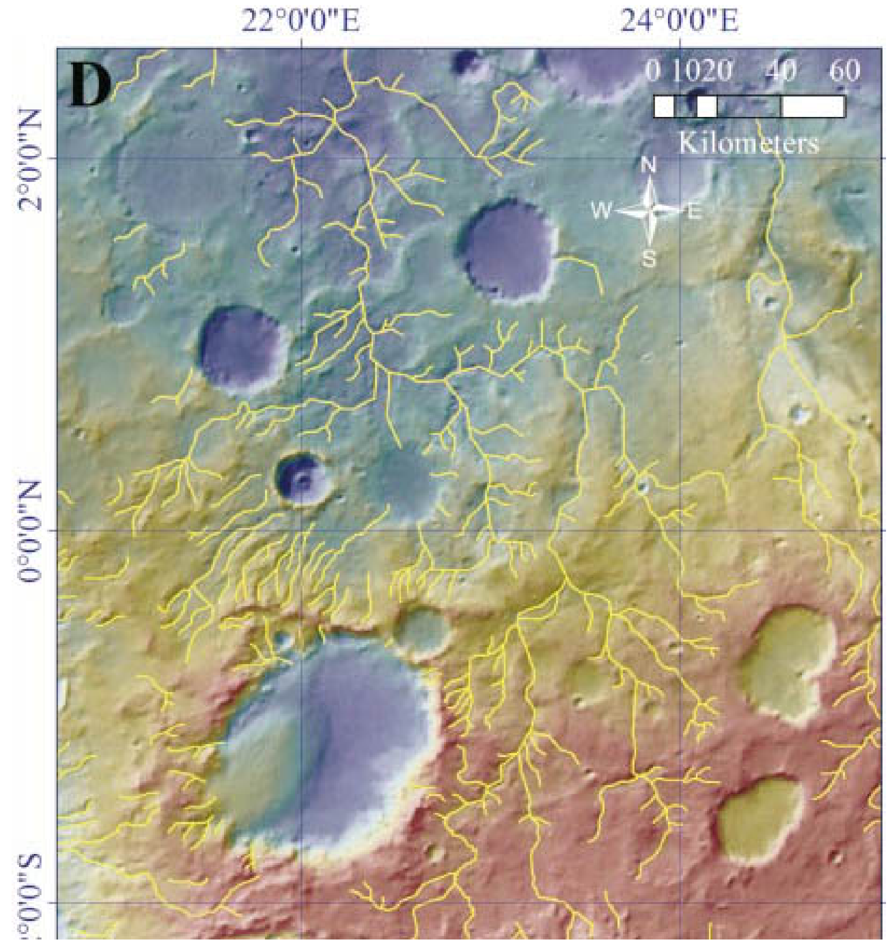
The glaciers of Mars (*July 2003*)

The world has been agog these last few years as evidence has mounted to suggest that Mars still has abundant water buried beneath its dusty surface, in the form of permafrost. Early in its history there are many signs of vast floods that carved huge meandering canyons and may have filled basins with moderately long-lived seas. Yet Mars has probably always been pretty cold, as it is now, and the most likely form that surface water would have taken is in glaciers; that is, if there was ever sufficient atmospheric water to precipitate snow. As on Earth, the likeliest places to look are in mountainous regions, and Mars is not lacking in very high places. By far the largest, and indeed they are the highest mountains in the Solar System, are the shield volcanoes of the Tharsis Rise, topping out around 18 km above the Martian version of the geoid. The volcanoes have gnarled surfaces, which until recently have been regarded by most as the result of volcano-related processes. Imaging of the Martian surface has stepped up several notches in resolution in recent years, and details of the small-scale features of the volcanoes are very clear.

Peculiar landforms on Arsia Mons, Mars that Head & Marchant 2003 ascribe to glacial processes

Above all else, they resemble aspects of the nearest analogue to Martian conditions on Earth – the Dry Valleys of Antarctica. Although the Dry Valleys are now largely free of ice sheets, they show many features of former glaciation, perhaps extending back 30 Ma to the Oligocene. Their frigidity has ensured that any glaciers there were frozen to the surface, rather than having zones of incipient melting at their bases. Such cold-based glaciers move sluggishly, and produce peculiar features. Among these are moraines produced by sublimation rather than melting of the ice – they evidence no reworking by melt water – and rock glaciers that are also products of sublimation and sometimes rest on relics of former glaciers. Probable examples of both occur on the flanks of the Tharsis volcanoes, together with weird track-like assemblies of concentric ridges, which are likely to have formed on the flanks of ablating glaciers as they reached a standstill and then retreated. (Head, J.W. & Marchant, D.R. 2003. Cold-based mountain glaciers on Mars: Western Arsia Mons. *Geology*, v. **31**, p. 641-644; DOI: 10.1130/0091-7613(2003)031<0641:CMGOMW>2.0.CO;2). Interestingly, the relationship of the glacial features to impact craters suggests that glaciation took place during the period since about 1.8 billion years ago (the Amazonian phase of Mars' history) when bombardment had slackened to almost terrestrial rates and liquid water was unable to form on the red planet. Of course, glaciers do not have to be made of water ice, and there is still a possibility that at such immense altitudes any glaciers might have been made of solid carbon dioxide. Head and Marchant speculate that some of the features might still sit upon relics of the glaciers. It could be a bit of a disappointment if future explorers of Mars landed there expecting a water supply.

Case for Martian rainfall strengthens (*September 2003*)

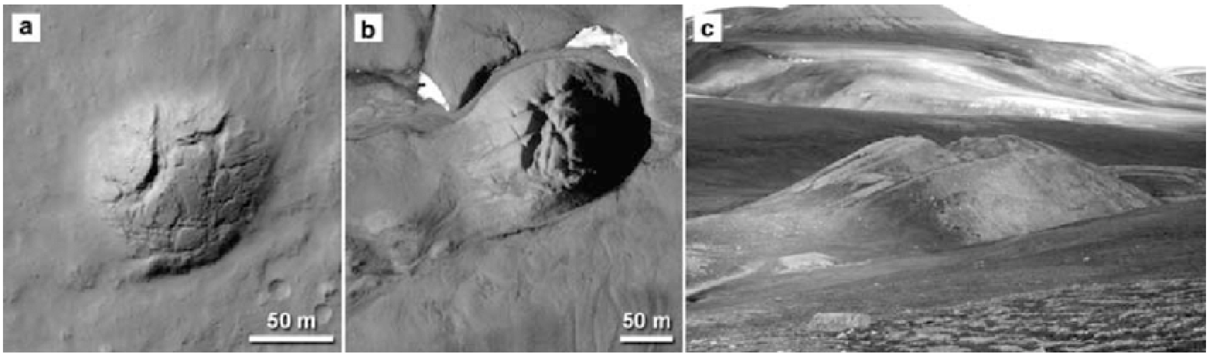


Traces of stream-like channels On Mars (Credit: Hynek & Phillips 2003; Fig. 1D)

"Everyone knows" about the huge valley systems on Mars, which through their relationships to other aspects of the planet's features are thought to have formed catastrophically early in its history. The high-resolution Mars Global Surveyor images and altimetry bring a new perspective to fluvial features (Hynek, B.M. & Phillips, R.J. 2003. New data reveal mature, integrated drainage systems on Mars indicative of past precipitation. *Geology*, v. **31**, p. 757-760; DOI: 10.1130/G19607.1). The authors, from Washington University in St Louis USA, show depressions extracted from the altimetry data by simulation of the paths likely to be taken by rain water falling on the surface. In some areas, the depressions link up in dendritic networks very like those that occur on the Earth's surface. Previous data only picked up disconnected valleys. The newly outlined valleys are V-shaped, unlike the U-shaped systems that developed on Mars probably by sapping as groundwater emerged, either slowly or catastrophically. Such profiles are good evidence for surface run-off, and that can only indicate precipitation, either of rain, or as a result of melting snow. Only 11000 kilometres of valley segments can be identified, and are probably relics of a larger ancient system that later events have masked. Some however, reach to the rims of large craters and seem to post date them. Probably, the events that carved these systems occurred in Mars' early history.

Recent snowfall on Mars (*December 2003*)

Evidence from the neutron detector on Mars Odyssey suggested the possible existence of subsurface water on Mars (see *Water on Mars*, August 2002). I reluctantly succumbed to all the hype about what is implied by that, the more so when reports came in of dendritic drainages revealed by high-resolution elevation data (see *Case for Martian rainfall strengthens* above). In planetary exploration, including remote sensing of the Earth's surface features, progressive improvement in resolution generally reveals novelty. The Mars Orbiter Camera, deployed by the Mars Global Surveyor mission has a resolution from 15 down to 2 metres. For the Earth, you can get 15 m images freely from the ASTER programme, but to match the 2 m images would be very costly. Given a broadband or better connection you can download the lot for Mars (http://pds-imaging.jpl.nasa.gov/atlas/). It is this resource that scientists from Brown and Boston Universities in the USA and the Kharkov National University of the Ukraine have used to reveal the latest paradigm buster from the Red Planet (Head, J.W. *et al*. 2003. Recent ice ages on Mars. *Nature*, v. **426**, p. 797-802; DOI: 10.1038/nature02114).



Fractured mound on Mars (a) a pingo on Spitsbergen (B&C) (Credit: Hauber *et al. 2011*)

James Head and his colleagues focused on the smooth terrains, or mantles, which drape over older deposits above 30º latitude on both Martian hemispheres, especially where water had been indicated by the Mars Odyssey neutron detector. They were looking for signs of what on Earth would be regarded as periglacial features, formed by the growth and melting of subsurface ice. They found lots, including signs of flowing ice-bound debris, but they do not show them in the Article, which deals with the implications of their findings. An important conclusion is that at least some of the mantle may have formed by what could be described as very dirty snow – a mixture of ice and wind blown dust.

Judging the age of the deposits directly depends on the standard stratigraphic method for all planets other than the Earth and Moon, their relationship to signs of impacts. There are very few fresh craters in the mantle, but many that have been "blurred" by it. Head *et al*. suggest that the mantle dates to at most 10 Ma. They resort to modelling climate shifts on Mars from its orbital and rotational history. Its rotational axis undergoes the greatest obliquity shifts of any planet, from about 15 to 35º over a 124,000-year cycle (unlike Earth's tilt, which slowly rocks through a range of only 4 degrees thanks to the stabilising tuggings of our large Moon). At high obliquity, the polar caps probably evaporate. loading the atmosphere with water vapour, so unlike the Earth it is global warming that induces low-latitude ice accumulation. It is this modelling that encouraged the authors to suggest an ice age between 2 million and 400 thousand years ago.