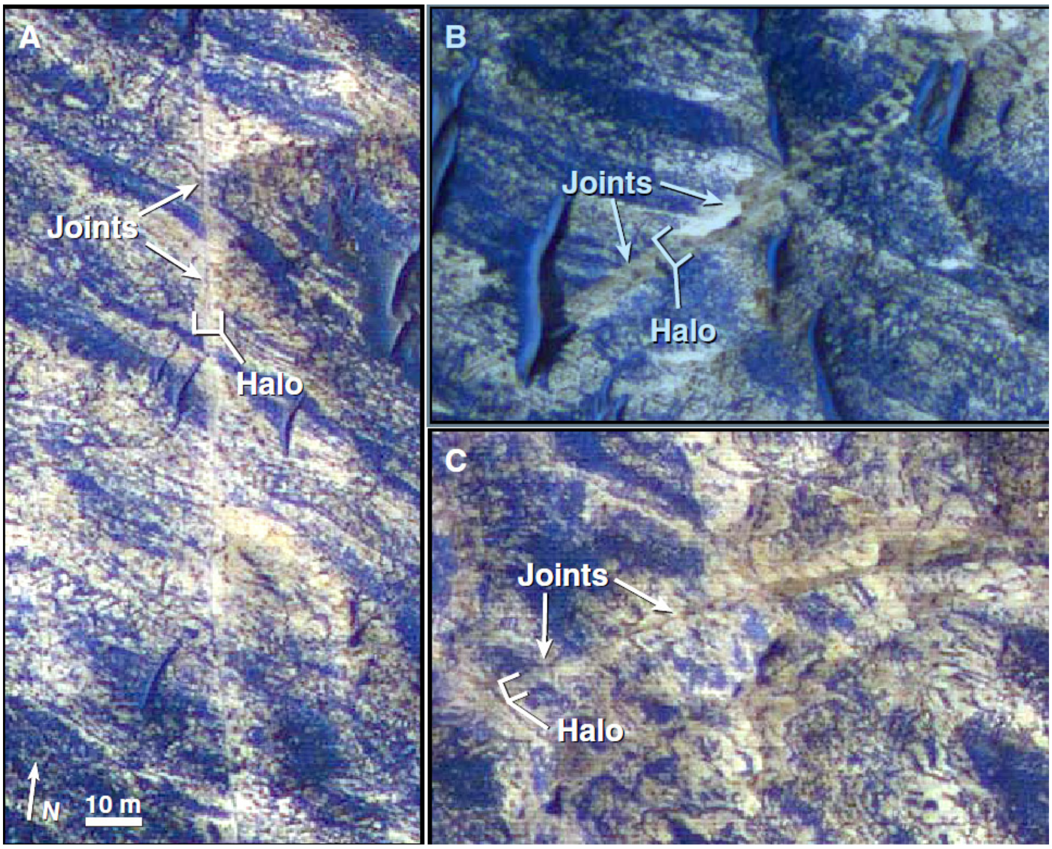
Remote sensing

Is Mars a better place to do geology? (*February 2007*)

The various imaging instruments that peer down on the Martian surface from NASA and ESA orbiters have provided a wealth of information about the planet and its evolution. The sophistication of the instruments far surpasses anything available for the Earth at low- or no cost. The multi-and hyperspectral approach that helps identify and map a range of minerals using their distinct spectral features in the reflected and thermally emitted parts of the spectrum was pioneered by tests of concept aimed at terrestrial rocks. Several astonishing discoveries on Mars stem from that most traditional of photogeological tools, the stereoscopic potential of image-pairs taken from slightly different angles. Mars is cloud free with a very thin atmosphere and no sign of life: the ideal place to conduct geological remote sensing, and good luck to those who like looking at alien worlds. One thing that gives them a decided edge over Earthward looking image interpreters is the spatial resolution and broad coverage that has been deployed on Mars and made available at virtually no cost to investigators.



HiRISE image (note the resolution suggested by the scale bar) of the Martian surface showing joints and halos thought to be due to fluid flow along fractures (Credit: Okubo and McEwan 2007; Fig 2)

For terrestrial geologists, unless they have vast funds for aerial campaigns over big areas, resolution is limited to the order of 15-30 m for the reflected region and 90 m for multispectral thermal data. The joint US-Japanese ASTER mission produces data for both spectral regions in 14 wavebands, with the bonus of 15 m stereopairs of very-near infrared images(a one-off). The old workhorse, the Landsat Thematic Mapper conked out over a year ago, and its replacement is uncertain. That was to be little different from its predecessor and with limited geological potential. Hyperspectral reflected data (of the order of 200 bands covering the 0.4 to 2.4 μm range) from orbit is restricted to a few tiny experimental swaths (about 7.5 km wide) from NASA's experimental Hyperion system.

The High Resolution Imaging Science Experiment aboard the Mars Reconnaissance Orbiter has a resolution as fine as 26 cm, two orders of magnitude better than Landsat and equivalent to aerial images from a few thousand metres above the surface. Because of this superb performance, intricate details of Martian features emerge from the HiRISE images (see Okubo, C.H and McEwan, A.S. 2007. Fracture-controlled paleo-fluid flow in Candor Chasma, Mars. *Science*, v. **315**, p. 983-985; DOI: 10.1126/science.1136855). Although 65 cm resolution of the Earth is available in images from the commercial Quickbird satellite, they come at enormous cost for areas as large as those being analysed on Mars. As any user of Google Earth knows, you can spot your own car in the driveway on the outdated Quickbird and Ikonos images obtained by Google for increasingly wide areas. But they are natural colour only – not very useful in geological remote sensing. The perspective Google Earth views, which could substitute for the 'Swiss hammer' (binoculars), are limited to 90 m terrain resolution by the SRTM elevation data being used to generate them. Stereoscopic Quickbird and Ikonos images can provide elevation data with a one-metre resolution, rivalling those freely available for the Martian surface.

The technology is available to bring routine geological remote sensing of the Earth to the standard of what is on offer from Mars, with the difference that it would be of enormous use in addressing all manner of human problems and opportunities (and a great deal of unresolved geology). Such standards are available to mining and petroleum companies (and a favoured few in UN agencies). And they have long been available to the intelligence community, at resolutions down to about 15 cm (and perhaps better if the 'twinkling' effect of atmospheric turbulence can be digitally removed). For many years the US government refused to deploy high-resolution public-domain imaging systems in orbit, because it would cause 'diplomatic difficulties' with governments of some countries who might object to being imaged, or might 'give away' secrets of the devices being used. Once the private sector saw a profit in taking pictures from space, both arguments disappeared overnight (there is a proviso of a US national-interest override). Despite all the technical advances, very few can afford to look in detail at issues that carry little potential profit, such as finding and managing groundwater resources or monitoring geohazards in the detail necessary for risk assessment.

Ice age mass deficit over Canada deduced from gravity data (*July 2007*)

The gravitational potential field over the Earth's surface changes according to variations in mass beneath it. Among the best-known causes is the depression of low-density continental lithosphere into the asthenosphere as a result of loading by ice sheets during glacial maxima. Once glacial ice cover has melted away the surface once covered by it rises to restore the isostatic balance. There is also post-glacial subsidence beyond the former ice-margins, where displaced asthenosphere had produced broad surface bulging when ice sheets were at their thickest. However, both are very sluggish processes that continue more than 7 ka after the bulk of ice had melted from the Northern Hemisphere: Northern Britain still rises whereas those parts south of the ice front at the last glacial maximum subside to form a drowned coastline.

Mapping the height of raised beaches around the Baltic gave a clue to where Pleistocene ice sheets were at their thickest in Scandinavia. The largest ice sheet was that which spread out from the Canadian Shield, and there are few surface clues to where it was thickest and most elevated. One of the objectives of the Gravity Recovery and Climate Experiment (GRACE) has been to map the gravity anomalies remaining from the last glacial maximum. GRACE comprises two satellites launched in 2002, gravitational potential being measured from very accurate GPS and radar measurements of the distance between the two platforms.

Four years worth of GRACE data shows the free-air gravity anomaly – difference between measured and theoretical gravity – trends over Canada (Tamisiea, M.E. *et al*. 2007. GRACE gravity data constrain ancient ice geometries and continental dynamics over Laurentia. *Science*, v. **316**, p. 881-883; DOI: 10.1126/science.1137157). Large mass deficits occur beneath the Canadian Shield west of Hudson's Bay and to the east below NE Quebec. They are the likely sites of ice-sheet 'summits' where most snow accumulated to become ice, and from which ice flowed outwards. Interestingly, a multi-domed ice sheet was the first to be proposed in the early 20th century, but was replaced a single-dome model, so ideas have come full circle. The longer GRACE gathers data, the better the resolution of gravitational fields, so more detail will be added over time. Maybe it will become possible to model the course of post 18 ka melting, throwing some light on likely directions for loss of meltwater to the boreal oceans (see *The Younger Dryas and the Flood* Climate etc June 2006).

An unfortunate mistake for refugees (*September 2007*)

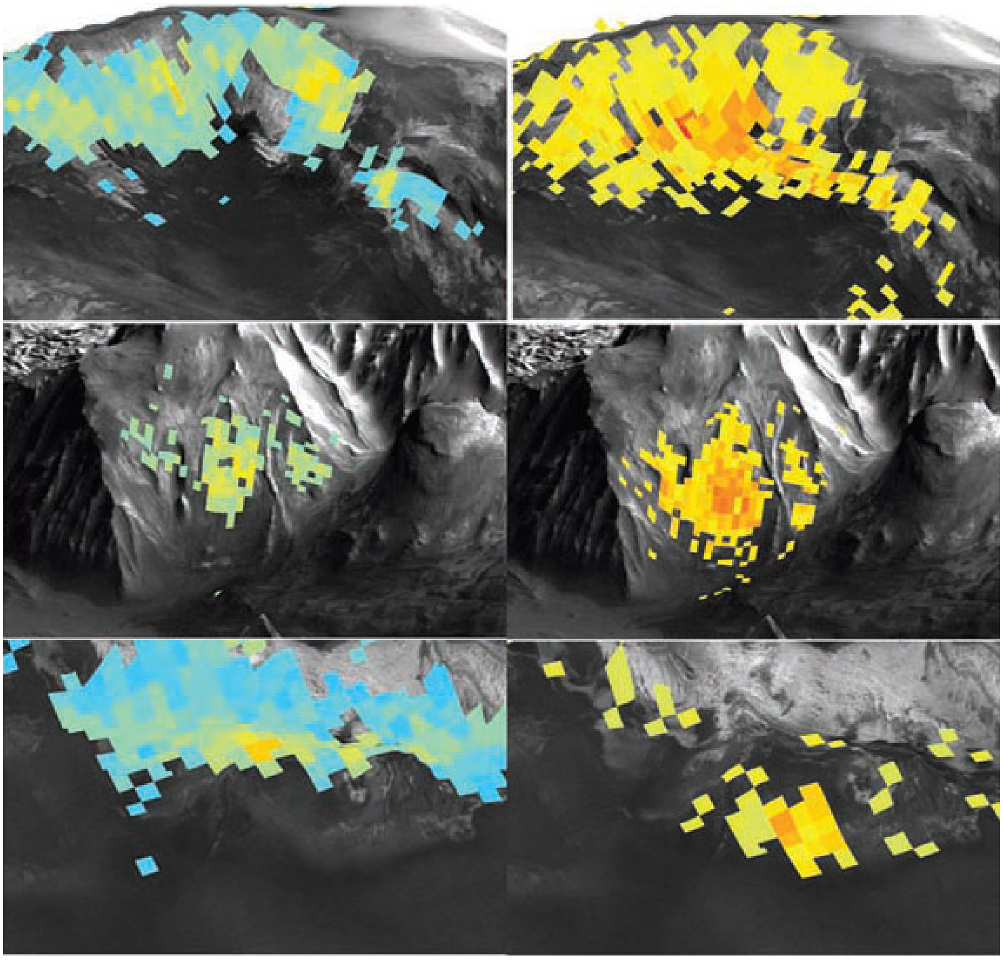
April 2007 saw the announcement of an initiative to drill a 'Thousand Wells for Darfur' by the University of Boston, USA and the government of Sudan. This was based on Boston remote senser, Farouk el Baz having claimed that his team had 'discovered' signs of a large former lake in northwestern Sudan that may have drained its waters into underlying sandstone deposits to create a huge reservoir of groundwater. This attractive idea stemmed from interpretation of satellite image data, including that produced by radar illumination, which gives some subsurface information (down to a few metres at most) if surface materials are very dry. The media in Africa and the rest of the world over-egged the somewhat breathless scientific briefing, to the extent that some readers began to believe that a lake had somehow migrated underground and may yet have fish in it, as well as presenting a possibly vast freshwater resource.

In fact the lake-bed sediments had been discovered in 1985 and mapped in the 1990s. More to the point, the sandstone aquifer is the Nubian Sandstone that extends through Libya, Chad, northern Sudan and southern Egypt, and is thins out at its southern margin where the lake once existed. It transmits its groundwater northwards and feeds a number of oases. Since the lake evaporated as climate changed in the eastern Sahara, any water that entered the aquifer would probably have been highly saline. Finally, it is far from the real area of need where hundreds of thousands of people have been driven from their homes in western Darfur.

See: Butler, D. 2007. Darfur lake is a 'mirage'. *Nature*, v. **448**, p. 394-395; DOI: 10.1038/448394a.

Mapping iron minerals – on Mars (*November 2007*)

For geological remote sensers, Mars is the ideal planet; it has virtually no atmosphere. That has four definite advantages: no 'proper' geologists are likely to go there for at least several generations, and those that do will not stay long; solar radiation of all wavelengths can illuminate the Martian surface; unlike the Moon, there seems to be a wide diversity of Martian rocks, though not so many as here; there is no vegetation to obscure bare rocks and soils. The Earth's atmosphere, especially its content of water vapour, oxygen and ozone, carbon dioxide and a few other gases, absorbs many wavelength regions of the radiation spectrum thereby ruling-out several opportunities to explore the mineral diversity of terrestrial rocks from their spectra. There are, however, sufficient atmospheric 'windows' to do some useful mineral mapping, especially in the 1.5-2.5 μm region for minerals containing Al-OH, Mg-OH and C-O bonds (e.g. clays, phyllosilicates and carbonates) and in the visible and very-near infrared (0.4-1.5 μm) for various kinds of iron-bearing minerals.



Images showing distribution of iron sulfates (left) and oxides (right) on the Martian surface, draped over a perspective view of the topography (Credit: Bibring *et al*.; Fig. 3)

The remote sensing 'works' has been put into Mars Orbit; for the reflected and thermally emitted regions. The latter, divided into several narrow wavebands, has enabled assessment of a number of rock forming silicates on Mars and is also available for Earth (given vegetation-poor surfaces) from the US-Japan ASTER instrument. ESA's Mars Express carries the Observatoire pour la Minéralogie, l'Eau, les Glaces, at l'Activité (OMEGA), whose coverage of the short-wave end of electromagnetic radiation by 350 narrow bands can match spectra reflected from rocks and soils with those measured under laboratory conditions for several hundred important minerals. It has been used to systematically map the occurrence of iron oxides and sulfates in Martian surface (Bibring, J-P. and 11 others 2007. Coupled ferric oxides and sulfates on the Martian surface. *Science*, v. **317**, p. 1206-1210; DOI: 10.1126/science.1144174). This interests Mars-focused geologists because of the evidence for hematite nodules and iron sulfates found by the Mars Exploration Rover, Opportunity; likely signs of hydrous alteration of iron silicates by acid waters.

On Earth these minerals, along with iron hydroxides, are the main colouring agents of sedimentary rocks, soils and the weathered surfaces of igneous and metamorphic rocks. Being able to map them here, using orbital remote sensing, would be extremely useful in many geoscience fields. The odd thing is that suitable wavelength bands have never been carried over the Earth by operational remote sensing systems, except in the crudest form of the 80 m resolution Multispectral Scanner data aboard the first five Landsat platforms. In November 2000 NASA launched the experimental Earth Observing-1 satellite (EO-1) carrying the only orbiting hyperspectral imaging system (Hyperion) similar but inferior to OMEGA, and a simpler 9-band system that did deploy three wavebands capable of discriminating iron minerals. This Advanced Land Imager (ALI) was intended to provide information to guide the choice of bands to deploy on the follow-on for the workhorse Landsat Thematic Mapper. (The latest TM has broken down). EO-1 is still up and running, but scientists have to pay handsomely for data gathering, and few parts of the Earth have been covered, unlike with the ASTER system. After due consideration, NASA and the US Geological Survey decided not to deploy bands specifically sensitive to iron minerals in the next TM-like instrument, which will be the same as its predecessors, to all intents and purposes.

How serious the USGS is about systematic geological mapping of the Earth has yet to be divined… In the 21st century the geology of more than half the land surface has still not been mapped at scales better than 1:250 000, mostly in Africa and other economically disadvantaged regions. Just how privileged H.G. Wells's Martians might be can be judged from the 21 September 2007 issue of *Science*, which devotes 14 pages to high-resolution mapping of Mars by the Mars Reconnaissance Orbiter.