PLANETARY SCIENCE

A glimpse of martian plumbing

Numerous long, wall-like ridges can be observed in the Valles Marineris region of Mars. They probably represent fault zones cemented by water-deposited minerals and are indicative of ancient groundwater flow.

Jonathan D. A. Clarke
is at the Mars Society Australia, PO Box 327, Clifton Hill, Victoria 3068, Australia.
e-mail: jon.clarke@bigpond.com

The reams of data transmitted back from an armada of Mars probes makes it easy to overlook the fact that the picture we have of the planet is, almost exclusively, only skin deep. Even where robot rovers have carried out some field investigations, our understanding of the detailed three-dimensional geological architecture of Mars is limited. Until the time when humans walk on the Red Planet, geologists interested in understanding the subsurface processes and the role of liquid water on Mars[1,2] must make do with proxies. On page 181 of this issue[3], Allan Treiman describes long ridges from the Valles Marineris region of Mars that, by analogy with fault/fracture zones on Earth cemented by water-deposited minerals, probably indicate ancient flow of groundwater through fault systems on Mars.

Clues for the presence of liquid water on Mars abound: satellite observations of the planet's surface indicate an important role of water in carving martian landforms[1], observations by the *Opportunity* rover have provided detailed field evidence for aqueous sedimentary processes[4,5], and minerals deposited by hydrothermal fluids in martian meteorites have revealed how water can alter crustal rocks[6]. Additional insights on liquid water flow on Mars can be gleaned from haloes — zones showing bleaching and colouration around faults/fractures, which result from aqueous alteration[7].

Treiman adds important insights on liquid water flow on Mars from fault-trace ridges — traces of faults on the surface of Mars that are now preserved as ridges owing to cementation. The parallel sets of fault-trace ridges described in this study are hundreds of kilometres long and are associated with the tectonic extension in the Valles Marineris, which is a system of deep canyons on Mars stretching over 3,000 km (Fig, 1). Individual fault-trace ridges vary in length from a few kilometres to 70 km and can manifest themselves as vertical walls of more than 7 km in height. The width of the fault-trace ridges can be estimated from alteration haloes around them that are on the order of several hundred metres. The age of these fault-trace ridges is probably Hesperian, that is, from between 3.8 and 1.8 billion years ago.

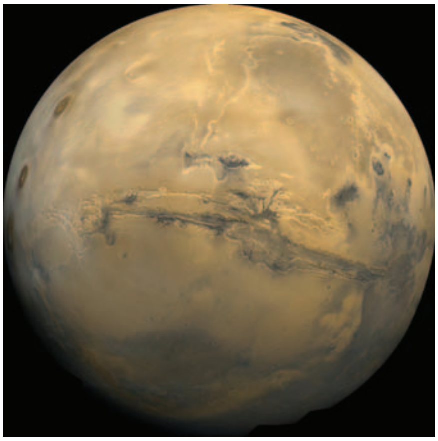

Figure 1 Viking image mosaic of the Meridiani Planum. This >3,000-km-long and 8-km-deep canyon system on Mars extends in an east–west direction. Features including the cementation of fault systems within the Valles Marineris as observed by Treiman[3] reveal a period of extensive water activity in the Martian crust. This has major implications for surface and subsurface evolution, life and suitable habitats.

These observations have far-reaching implications for our understanding of processes on and beneath the martian surface during the Hesperian period. The erosion-resistant and bleached haloes around the fault-trace ridges suggest extensive interactions of water and rock involving both mineral dissolution and deposition along the length and depth of the groundwater flow system. By extrapolation, this also implies lateral transport of dissolved solutes over a minimum of tens of kilometres.

Such large-scale systems of groundwater flow suggest that permafrost was rare or absent at Mars' equator during the Hesperian period, confirming models of relative warm and wet martian palaeoclimates. This finding is consistent with the presence of extensive early-Hesperian groundwater discharge complexes and open water at Meridiani Planum, as inferred from observations by the *Opportunity* rover[4,5]. But how such a warm Hesperian Mars can be reconciled with evidence from some martian meteorites of little or no alteration over several billion years[8] remains a challenge for planetary scientists.

Treiman points out that widespread water in fault systems would be important for martian tectonics because of its role in lubricating faults. If the pressure of water within the faults exceeded the ambient pressure exerted by the overlying rocks locally, the presence of water would facilitate hydraulic fracturing and greatly increase the porosity and permeability of the fault zones. The value of understanding this process for our knowledge of the structural evolution of the planet's crust would surely repay investigation.

There has been considerable interest in the possibility of subsurface zones on Mars that are hospitable to life. Treiman's conclusions about widespread liquid water and water–rock reactions along fault systems during the Hesperian period[6] indicate that potentially hospitable zones with liquid water and energy sources were present across large areas and over significant depths. Determining whether these zones were inhabited by microorganisms, as is probably the case with some terrestrial fault-related vein systems such as those at Arkaroola in South Australia[9], will require detailed on-site exploration.

Fault-trace ridges are attractive targets for future space missions. They could provide detailed information on tectonic and fluid histories, groundwater dynamics and composition, and the temperatures and pressures under which various mineral phases were deposited or altered. They would also be ideal places to look for chemical signatures of and textural evidence for subsurface organisms.

To fully extract such information is well beyond the capabilities of any planned or conceptual rover, and would require samples to be returned to Earth where they could be analysed in detail. However, even sampling the fault-trace ridges *in situ* would be challenging, perhaps too challenging for an unmanned rover, not least because of their steep slopes.

More speculatively, many terrestrial counterparts of the structural and groundwater systems responsible for fault-trace ridges are highlymineralized and host major ore deposits, such as Mount Isa and Broken Hill in Australia, Sullivan in Canada, and Lubin in Poland, to name a few. Perhaps, sometime in the future, martian explorers may target fault-trace ridges for exploration because of their resource potential to support possible settlements.

References

1. Carr, M. H. *Water on Mars*. (Oxford Univ. Press, USA, 1996).
2. Kargel, J. S. *Mars — A Warmer, Wetter Planet* (Springer, 2004).
3. Treiman. A. H. *Nature Geosci.* **1,** 181–183, (2008).
4. McLennan, S. M. *et al. Earth Planet. Sci. Lett* **240,** 95–121 (2005).
5. Grotzinger, J. P. *et al. Earth Planet. Sci. Lett.* **240,** 11–72 (2005).
6. Bridges, J. C. *et al.* in *Chronology and Evolution of Mars* (eds Kallenback, R., Geiss, J. & Hartmann, W.) 365–392 (Kluwer, Amsterdam, (2001).
7. Okubo, C. H. & McEwen, A. *Science* **315,** 983–985 (2007).
8. Shuster, D. L. & Benjamin P. W. *Science* **309,** 594–597 (2005).
9. Bons, R. D. & Montenari, M. *J. Struct. Geol.* **27,** 231–248 (2005).

GLACIOLOGY

The last stampede of a glacial lake

Lakes dammed by ice will commonly spill in catastrophic outbursts. Lake Agassiz-Ojibway, at the margin of the Laurentide ice sheet, burst 8,470 years ago in a subglacial flood whose marks have been scratched into the seafloor of Hudson Bay.

Martin Jakobsson

is in the Department of Geology and Geochemistry, Stockholm University, 106 91 Stockholm, Sweden.
e-mail: martin.jakobsson@geo.su.se

Ice-dammed lakes were common features during glacial periods in the Pleistocene epoch (1.8 million years to ~10,000 years ago). Because the dams were created by the melting and disintegrating of ice sheets, all of these lakes were eventually prone to catastrophic flooding. The giant Lake Agassiz-Ojibway — first discovered in the last decades of the nineteenth century[1] — was one such water body. At the end of the last deglaciation, the lake was trapped behind the southern margin of the Laurentide Ice Sheet. On the basis of multibeam maps of the Hudson Bay seafloor, Lajeunesse and St-Onge[2] suggest on page 184 of this issue that the outburst flood first made its way underneath, rather than over or through the ice dam.

A subglacial flooding scenario has previously been suggested as the most likely termination of Lake Agassiz-Ojibway on the basis of hydraulic modelling[3]. It was concluded that the freshwater outburst could have been on the order of 5 million cubic metres per second, flowing for a period of about six months. The multibeam bathymetric images obtained by Lajeunesse and St-Onge provide observational support for this scenario. Their maps of Hudson Bay delineate sandwaves, curved and arc-shaped iceberg scours, and eroded channels: traces of an outburst event

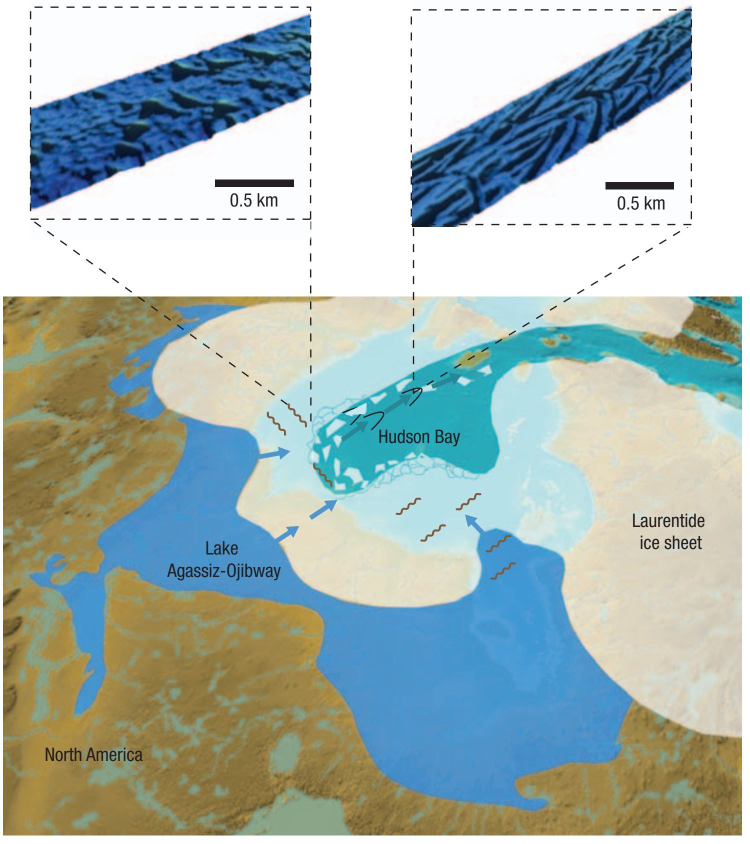

Figure 1 Reconstruction of the Lake Agassiz-Ojibway outburst flood. As water pressure in the immense lake reached a critical limit, the natural dam formed by the margin of the Laurentide ice sheet was lifted up. Rapid floodwaters forced their way beneath the ice sheet to reach Tyrell sea — the precursor of today's Hudson Bay — resulting in the formation of sandwaves (left inset) on the seafloor. The ice sheet margin further north of the northern terminus of the lake began disintegrating in response to the flooding, and icebergs in this region cut characteristic arc-shaped scours on to the seafloor (right inset). Multibeam data for insets courtesy of the Ocean Mapping Group (University of New Brunswick).