in tumour formation and growth but high in those related to sex and reproduction[5]. It is surprising, then, that Ross *et al.*[1] predict that a full 10% of protein-coding genes on the X produce 'cancer-testis antigens', a class of genes normally expressed mostly in the testis but whose activity is increased in testicular cancers, melanomas and other cancers.

These proteins are key targets for the development of cancer vaccines, as they are usually seen by the immune system only when they occur in tumours, and their expression is linked to the same mechanisms at work in X inactivation. As we know little about their normal function[6], tailoring treatments will require a much better understanding of the role of the X in cancer. Given the prediction[7] that genes on the X can benefit males even at the expense of females, as the detrimental effect would be masked in females, it may be that the genes encoding cancer-testis antigens convey some selective advantage to males, allowing some of the gene family to expand independently in both humans and mice[1].

What about the sequences between the genes? The X chromosome is very rich in repeats (56% compared with a 45% average for the whole genome), and 14 gaps remain in the estimated 1.5-million base-pair sequence — despite the intensity of the sequencing effort[1]. But it's not just any repeats that matter. A whopping 29% of the chromosome consists of DNA repeats known as 'long interspersed nuclear elements' (LINEs), thought to be 'selfish' bits of DNA that jump around the genome. The main LINE constituents concerned are members of the L1 family and, in theory[8], L1 repeats may serve as 'booster elements' for the X-inactivation signal, which emanates from around the middle of the chromosome with the transcription of *XIST* and spreads down the chromosome arms.

In support of this theory, the sequence shows almost no L1 elements in the *XIST* locus itself, but high concentrations on either side. L1 sequences are more common in the older areas of the chromosome, with more genes subject to inactivation, and less frequent in the newer areas, where more genes escape[1,2]. So it is possible that more genes may become subject to inactivation over time, as still-active L1 elements invade in higher numbers.

The exact mechanism for L1 involvement is not known: is this 'junk DNA' crucial in shaping the X, or merely the footprint left behind as the process progresses? Mice and cows do not show similar patterns of LINE elements on their Xs, or of any other known repeat element that might fit the bill, yet they have many similar features of X-chromosome inactivation. Factors involved in inactivating the X are modifications to the DNA and proteins in the chromosome, and formation of a complex with *XIST* RNA and presumably associated proteins. Intensive research is aimed at finding out how these modifications might have evolved, and how they now establish and maintain the inactivated state.

Like the rest of the human genome, the primary sequence of this chromosome is an advanced starting point for exploring the mysteries of evolution and development. Geneticists eagerly await genomic sequences from non-placental mammals, such as the platypus and opossum, so as to reconstruct earlier, proto-X chromosomes. As the rock band U2 would say, the X moves in mysterious ways, and we've just been given a preview. ■

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1. Ross, M. T. *et al. Nature* **434,** 325–337 (2005).
2. Carrel, L. & Willard, H. F. *Nature* **434,** 400–404 (2005).
3. Skalestky, H. *et al. Nature* **423,** 825–837 (2003).
4. Lahn, B. T. & Page, D. C. *Science* **286,** 964–967 (1999).
5. Kohn, M. *et al. Trends Genet.* **20,** 598–603 (2004).
6. Spatz, A. *et al. Nature Rev. Cancer* **4,** 617–629 (2004).
7. Rice, W. R. *Evolution* **38,** 735–742 (1984).
8. Lyon, M. F. *Cytogenet. Cell Genet.* **80,** 133–137 (1998).

Planetary science

Picturing a recently active Mars

Victor R. Baker

Discoveries made with the High Resolution Stereo Camera on the Mars Express orbiter show that, as recently as a few million years ago, the surface of Mars was being shaped by flowing water, lava and ice.

Spectacular ground-based images and chemical analyses of ancient sedimentary rock formations[1] leave no doubt that Mars had a watery ancient past. These discoveries by NASA's Mars Exploration Rover Mission apply to the Noachian epoch of Mars history — the first several hundred million years of the Solar System, when the impact rate of meteors and comets was much higher than in the past 3–4 billion years[2]. Image interpretation has long been key to revolutionary changes in the scientific understanding of Mars. Three papers in this issue[3–5] add to that tradition, but also add to the new evidence that Mars has been active in the geologically recent past.

The first vidicon camera images and atmospheric data from the Mariner fly-bys of the 1960s led to the view that the planet had been continuously cold and dry[6]. Thinking changed radically during the 1970s, when pictures of higher resolution and global coverage, taken from the Mariner 9 and Viking orbiters, revealed river-valley networks and huge channels carved by cataclysmic floods[7]. Nevertheless, in the theoretical syntheses that followed during the 1980s and 1990s, any active hydrological cycling was generally limited to the Noachian epoch. This MIDDEN hypothesis ('Mars is continuously dead and dry, except in the Noachian') prevailed for two post-Viking decades, during which there were no further pictures at increased resolution. Advocates of the MIDDEN hypothesis have variously argued that Mars is poorly endowed with water, that it is inefficient at releasing water to its surface, or that most of its water was lost to space.

In the 1980s, NASA planned a Mars geoscience and climatology orbiter, but many scientists wanted its payload to be limited to non-imaging experiments. Some even proclaimed that imaging science was an oxymoron, and that the only use of pictures was for public relations. Thus, a high-resolution stereo camera system was rejected for what eventually became the Mars Observer spacecraft. The miniature, non-stereo, high-resolution Mars Observer Camera (MOC) was eventually added to its payload, but Mars Observer was lost in 1993, and MOC did not arrive at Mars until the Mars Global Surveyor mission of the late 1990s.

Despite being limited to non-stereo coverage of very small areas, the phenomenally high resolution of the MOC images contributed to notable discoveries. These discoveries included very recent, globally dispersed hillslopes, with gullies created by water[8], as well as associated lava flows and large channels carved by cataclysmic flooding[9]. All of these were less than about ten million years old[10], as indicated by the densities of impact craters measured from the high-resolution images. These features and many others[11] were clearly anomalous in regard to the prevailing MIDDEN hypothesis.

The High Resolution Stereo Camera (HRSC) carried by the European Space Agency's Mars Express Mission is the direct descendant of the camera that was rejected by NASA for the original Mars Observer. Although slightly lower than MOC in resolution, HRSC produces colour and stereo images in the broad areal context necessary for the fully effective application of geological analyses (Fig. 1). Initial results from the camera[12] identified two major anomalies in regard to the MIDDEN hypothesis. First, crater counts for calderas on five major volcanoes show that there has been episodically active volcanism during the past 20% of martian history, up to only two million years ago; second, glacial activity occurred in the equatorial regions of Mars, at the base of

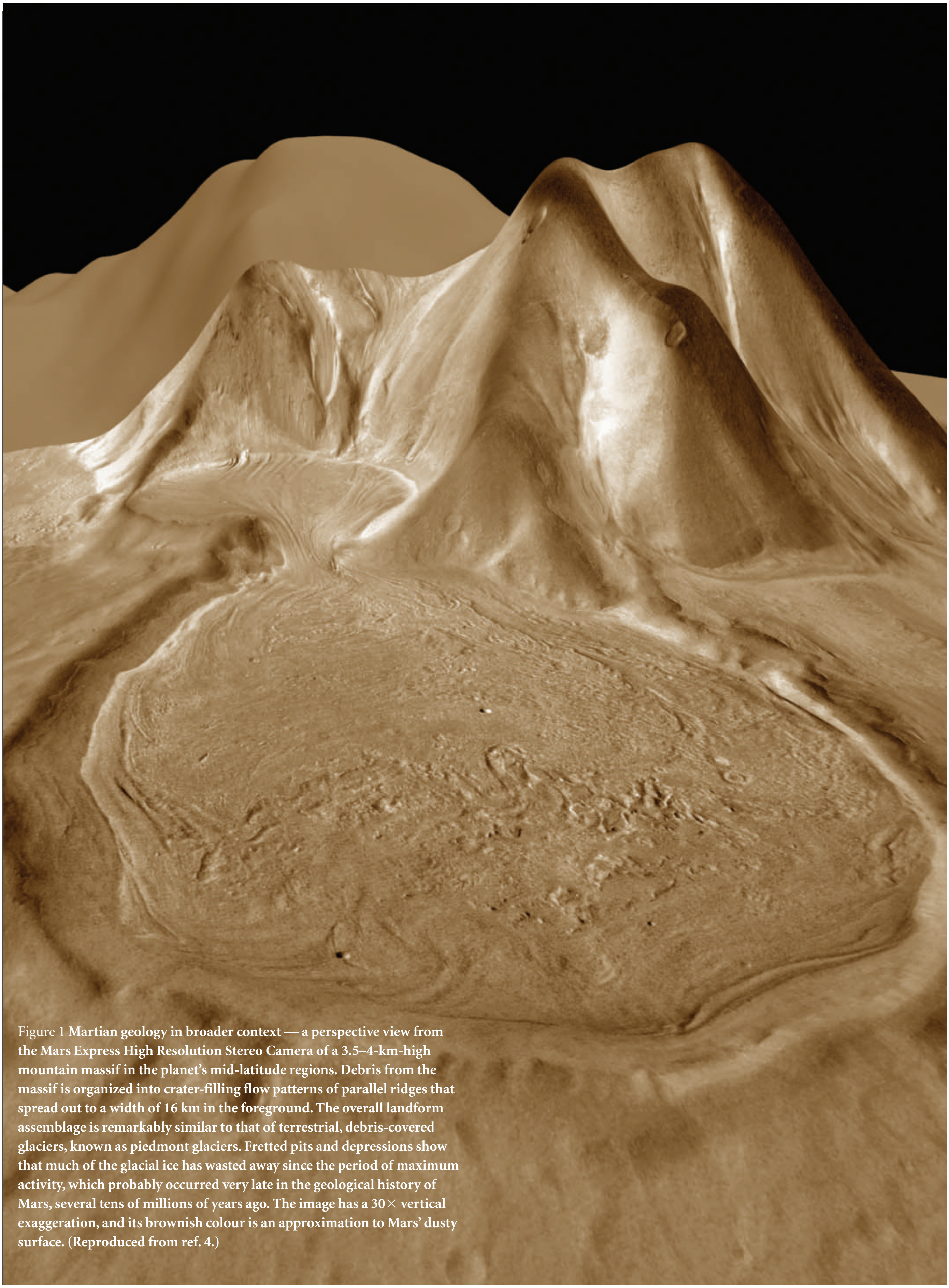

Figure 1 **Martian geology in broader context — a perspective view from the Mars Express High Resolution Stereo Camera of a 3.5–4-km-high mountain massif in the planet's mid-latitude regions. Debris from the massif is organized into crater-filling flow patterns of parallel ridges that spread out to a width of 16 km in the foreground. The overall landform assemblage is remarkably similar to that of terrestrial, debris-covered glaciers, known as piedmont glaciers. Fretted pits and depressions show that much of the glacial ice has wasted away since the period of maximum activity, which probably occurred very late in the geological history of Mars, several tens of millions of years ago. The image has a 30× vertical exaggeration, and its brownish colour is an approximation to Mars' dusty surface. (Reproduced from ref. 4.)**

the Olympus Mons escarpment, as recently as four million years ago.

The three papers in this issue use HRSC data to provide an overwhelming case for new thinking about recent geological activity on Mars. On page 356, Hauber *et al.*[3] document that explosive eruptions, about 350 million years ago, created depressions on the flank of the volcano Hecates Tholus. As recently as five million years ago, glacial deposits were laid down on the floors of these depressions.

Head *et al.*[4] (page 346) use HRSC data to reanalyse controversial landforms that had been recognized as possibly glacial from Viking data. Combined with data from the Mars Global Surveyor, the new images (Fig. 1) show that the landforms are indeed evidence for geologically recent and recurring glacial activity at what are now tropical and mid-latitude regions on Mars. This glaciation may be a response to recent changes in the incidence of sunlight induced by variations in obliquity of the planet's spin axis[13]. Glaciers form by the net accumulation of snow and its metamorphosis to ice during an Earth-like hydrological cycle.

Early evidence from Viking data for relatively young Mars glaciation[14], plus other indications of young flowing[15] and 'ponded' water activity[16], led to a hypothesis in 1991, considered outrageous at the time[17], that Mars had been episodically active in a hydrological sense for geologically short intervals of post-Noachian time. In the 1991 hypothesis[18], martian climate change is triggered by the outburst of volcanic gases and cataclysmic flood water, with the water ponding in huge seas that subsequently evaporated.

Murray *et al.*[5] (page 352) present striking evidence for just such an event, resulting in a frozen water body approximately the size of Earth's North Sea. The inundation was generated within the past five million years because of cataclysmic flooding that accompanied volcanic eruptions from the fracture system associated with two long and narrow depressions known as Cerberus Fossae. Flood water was probably conveyed to the sea via the Athabasca Valles channel system at peak flows of about ten million cubic metres per second[9]. This may be a smaller version of what happened when much larger channels delivered peak flows of hundreds of millions of cubic metres per second to indundations on the northern plains of Mars during much earlier periods of post-Noachian martian history[18].

What happened to all the water that induced the past, short-term hydrological cycling on Mars? The evidence from HRSC for recent aqueous activity suggests that the water is still present, as ice on the ground and water deep beneath the surface. In early May, Mars Express will deploy its Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), which should be able to detect subsurface water and ice to depths of several kilometres. Evidence from the latest pictures indicates that the water will surely be there. ■

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1. Squyres, S. W. *et al. Science* **306,** 1709–1714 (2004).
2. Neukum, G., Ivanov, B. A. & Hartmann, W. K. *Space Sci. Rev.* **96,** 55–86 (2001).
3. Hauber, E. *et al. Nature* **434,** 356–361 (2005).
4. Head, J. W. *et al. Nature* **434,** 346–351 (2005).
5. Murray, J. B. *et al. Nature* **434,** 352–356 (2005).
6. Leighton, R. B. & Murray, B. C. *Science* **153,** 136–144 (1966).
7. Baker, V. R. *The Channels of Mars* (Univ. Texas Press, Austin, 1982).
8. Malin, M. C. & Edgett, K. S. *Science* **288,** 2330–2335 (2000).
9. Burr, D. M., Grier, J. A., McEwen, A. S. & Keszthelyi, L. P. *Icarus* **159,** 53–71 (2002).
10. Berman, D. C. & Hartmann, W. K. *Icarus* **159,** 1–17 (2002).
11. Baker, V. R. *Nature* **412,** 228–236 (2001).
12. Neukum, G. *et al. Nature* **432,** 971–979 (2004).
13. Head, J. W. *et al. Nature* **426,** 792–802 (2003).
14. Kargel, J. S. & Strom, R. S. *Geology* **20,** 3–7 (1992).
15. Gulick, V. C. & Baker, V. R. *Nature* **341,** 514–516 (1989).
16. Parker, T. J., Saunders, R. S. & Schneeberger, D. M. *Icarus* **82,** 111–145 (1989).
17. Kerr, R. A. *Science* **259,** 910–911 (1993).
18. Baker, V. R. *et al. Nature* **352,** 589–594 (1991).

Evolution

Deep-sea spiral fantasies

John Gage

Pictures of strange, gelatinous deep-sea worms have intrigued zoologists, as they hinted at the solution to an evolutionary puzzle. But does the first specimen to be obtained in good condition back the theories up?

Zoologists dream of connecting up the evolutionary pathways among the ragbag of phyla that have been placed together in the super-phylum Deuterostomia[1]. This super-phylum includes the chordates — back-boned animals such as ourselves — and the hemichordates ('half chordates'), which are mostly small, bottom-living marine organisms. Hemichordates arguably possess two chordate features: gill slits and a hollow, dorsal nerve cord. But in other ways, the two main hemichordate classes — the microscopic, tube-dwelling 'pterobranchs', which feed on suspended particles, and the much larger, mud-swallowing 'acorn' worms (the enteropneusts) — differ considerably from each other in lifestyle and anatomy. A reassessment of the evolutionary histories of the pterobranchs and enteropneusts is now prompted by

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Figure 1 **Worm turns — the first photograph, taken in 1962, of an abyssal enteropneust worm lying on the sea bed near the eastern wall of the Kermadec Trench in the southwestern Pacific. The worm's body ends shortly past the first bend, where the faecal coil begins. (Reproduced from ref. 4.)**