for long periods. And, although MAPCs seem to have normal chromosomes, it is important to establish that the pathways governing cell proliferation are unperturbed. Otherwise, short-term gains might fall prey to long-term complications.

The work of Kim *et al.*[1] and Jiang *et al.*[2] will not resolve the debate over embryonic versus adult stem cells. Rather, it underscores the need for research in this area to continue unfettered by political concerns. Only then will the public have a chance to get what it deserves: novel, validated and safe treatments for intractable diseases. ■

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Planetary science

An older face for Mars

Sean C. Solomon

Mars has a north–south divide in the age of its surface, as judged by the density of impact craters. Altimetry data, which by inference provide a subsurface view of the planet, reveal that the divide is only skin deep.

A surprising finding from the exploration of Mars by orbiting spacecraft in the 1970s was that the southern and northern hemispheres have very different surfaces. The density of impact craters seen in images taken by Mariner 9 and Viking Orbiter indicated that the surface of the topographically high southern hemisphere is old enough to have preserved the effects of the early, heavy impact bombardment of the inner Solar System (known from lunar studies to have occurred before about 3.7 billion years ago). The surface of the northern hemisphere, in contrast, was revealed to be generally lower in elevation, to consist of smooth plains, and to contain a far lower density of impact features — implying a surface age hundreds of millions to billions of years younger.

A new view of this striking hemispherical contrast, the Martian 'crustal dichotomy', has come from an analysis of observations collected by the Mars Global Surveyor spacecraft, which has been in Martian orbit since 1997. From subtle signatures in topography measured by the Mars Orbiter Laser Altimeter Experiment[1], Frey and others[2] have identified a large population of nearly buried impact structures in both hemispheres that were not evident in the spacecraft images. More importantly, the areal density of these features, together with those previously mapped, indicates that the northern hemisphere has a buried surface that is essentially as old as the surface of the southern uplands.

Frey and colleagues[2] took the following approach in their search for buried impact features. From regional altimetric maps, in which different colours were assigned to narrow intervals of elevation from a global gridded data set, the group catalogued all roughly circular, localized depressions. They identified such depressions as candidate impact features if concentric segments of contours collectively totalled at least 180° of arc, and if the preserved relief exceeded 50 m — a figure much larger than the altimetry accuracy[1] of about a metre. Many of the features so catalogued had been identified as impact craters from orbiter images. As shown in Fig. 1, however, many others had not. In particular, Frey *et al.* counted 644 potential impact features greater than 50 km in diameter in the northern lowlands, many more than the 90 such features discernible from Viking Orbiter images. A strong argument that most, if not all, of the newly identified features are largely buried impact craters is that their areal density as a function of their diameter has the same form as the distribution for known impact structures. The southern highlands also contain buried impact craters newly recognized by this method, but they do not increase the total population of impact structures by as large a factor as in the north.

Frey and colleagues' main conclusion is that the geologically younger units constituting the uppermost crust of the northern hemisphere are a relatively thin veneer of material that incompletely masks an underlying ancient surface. There were a few previous clues that this was so. Careful photogeological mapping led to the suggestion[3] that underlying the deposits in the Utopia

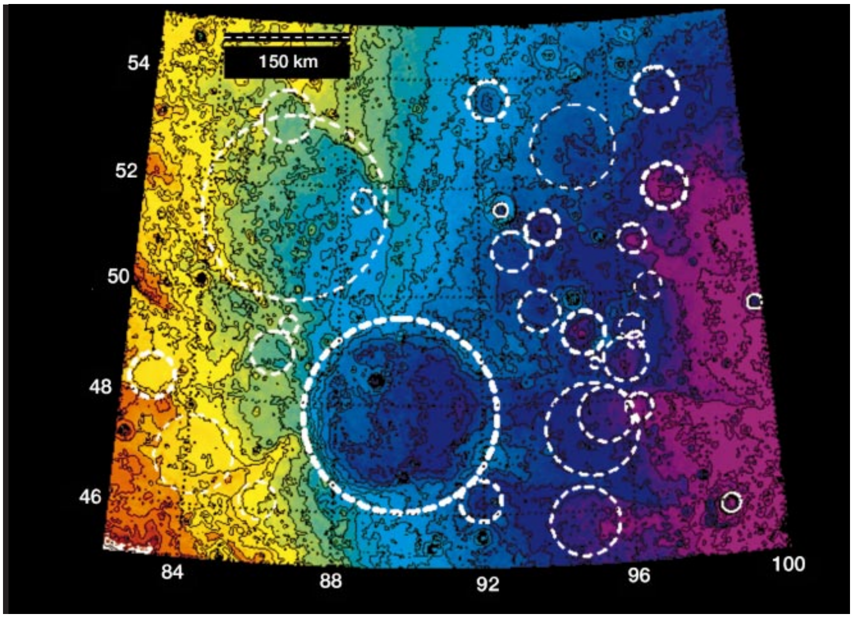

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Figure 1 **Partly buried impact craters, identified by Frey *et al.*[2], in the northern lowlands of Mars. The part of the planet shown is near the Utopia region. Elevation is colour-coded, with purple grading through blue and green to yellow, orange and red as height increases (orthographic projection, 50-m contour interval). Craters greater than 15 km in diameter visible in the earlier Viking Orbiter images are circled by solid lines. The many more craters discernible only from their topographic signatures are shown by thick dashed lines; thinner dashed lines denote less confident identifications.**

region of the northern plains is a 3,300-km impact basin, a feature so large that it must date from the early heavy bombardment. That hypothesis was strengthened by the discovery of a broad depression, the outline of which coincides with that of the buried basin[4], and by a large, positive, gravity anomaly having a magnitude consistent with the nearly complete infilling of an ancient impact depression by younger sedimentary and volcanic material[5]. But the work of Frey *et al.* extends the mapped area of ancient surface to nearly the entire northern lowlands and quantifies the density of impact features.

The crustal dichotomy, then, might be the most ancient structural feature preserved on the Martian surface. If so, there are several implications for our understanding of the geological and geophysical evolution of the planet. The northern lowlands must have exerted a primary influence on the flow direction of surface and subsurface water on Mars for the entire duration of preserved geological history[6], and much of the material making up the veneer overlying the ancient northern surface probably consists of sediments. The high density of newly detected large impact structures within the Utopia basin — whose original depth might have been comparable to the nearly 10-km relief of Hellas, a partly filled basin of similar diameter in the south — implies that much of the resurfacing of the northern hemisphere occurred during the period of early impact bombardment. The incomplete burial of impact craters allows the thickness of the younger northern-plains units to be estimated at typically 1–2 km, but that figure could exceed 5 km in a few areas near major volcanic centres where no older craters can be seen[2]. The difference in elevation between the north and the south requires a generally thinner crust in the north[5]. Because lateral flow of lower crust would tend to reduce such variations if the temperature at the base of the crust exceeded about half the local melting temperature[5,7], preservation of the dichotomy implies that the lower crust cooled rapidly after early crustal formation — perhaps as a result of deep hydrothermal circulation[8].

A question, first raised when the crustal dichotomy was discovered, remains. What caused it? Suggestions have ranged from removal of crust in the northern hemisphere by one or more large impacts, to hemispherical differences in crustal addition or internal recycling by dynamical processes in the underlying mantle. None has proved fully persuasive[9]. At the least, however, the demonstration that the crust in both hemispheres formed very early in the history of Mars adds a fresh requirement for any successful explanation of this longstanding mystery. ■

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Embryology

Fluid flow and broken symmetry

Claudio D. Stern

The asymmetries between the right- and left-hand sides of the body are initiated at an early stage of development. Two groups provide welcome news of progress in revealing the mechanism concerned and its generality.

How an embryo first distinguishes its left from its right side has baffled embryologists for a long time. The rotational beating of cilia — hair-like structures attached to individual cells — is known to be essential for the process. But cilia have been seen only in mouse embryos, and it has remained unclear whether their movement could really generate the necessary molecular asymmetries. Papers by Essner *et al.*[1] and Nonaka *et al.*[2] (pages 37 and 96 of this issue) set our understanding on a much firmer footing in both respects.

Despite its superficial appearance of bilateral symmetry, the vertebrate body plan is asymmetric in several respects, most obviously in the position of internal organs such as the heart and parts of the gut. Left–right asymmetry first arises in the embryo at around the stage — the gastrula — when the three major cell layers of ectoderm, mesoderm and endoderm are first laid down. But until recently we knew virtually nothing about the molecular mechanisms responsible.

The turning point came in 1995 when four genes (*Sonic hedgehog*, *Nodal*, *HNF3β* and the *Activin-receptor IIA*) were identified as being expressed on one or the other side of the chick embryo at the gastrula stage, and their activities were implicated in heart turning[3]. However, subsequent work revealed that only one of these, *Nodal*, is expressed asymmetrically in all vertebrates. Shortly afterwards it was discovered that a mouse mutant, called *iv* and characterized by random positioning of internal organs, carries a mutation that inactivates left–right dynein (LRD), a protein required for the beating of cilia[4]. Researchers then looked for cilia in the mouse gastrula and found that the 'node', a critical organizing structure in the midline of the early embryo, does indeed possess short cilia protruding from its cells, which beat in an anticlockwise circular motion and generate a leftwards flow of fluid that is strong enough to displace solid particles to the left[5,6]. But again, the cilia could be found only in the mouse. Could different vertebrates have evolved different ways of establishing asymmetry? And could the beating of cilia really be sufficient to generate molecular asymmetry by removing a 'morphogen' signal from one side of the embryo and enriching it on the other?

The papers by Essner *et al.*[1] and Nonaka *et al.*[2] answer both questions. Essner *et al.* reveal that cilia, as well as LRD, are indeed present in all the major vertebrate groups at appropriate stages and locations to generate left–right asymmetry. Nonaka *et al.* show that a flow of fluid in the reverse direction to that generated by cilia can randomize embryonic asymmetry — and that artificially induced fluid flow is enough to control the position of the internal organs in *iv* mutant mice.

The idea that the circular beating of tiny cilia could be enough to generate a biologically meaningful molecular gradient within a large, relatively open fluid space seemed rather unlikely when it was first proposed[5]. Nonaka and colleagues have designed an ingenious mechanical device to demonstrate that it is indeed possible to control the distribution of molecules by regulating the direction of fluid flow around embryonic cells. The experimental design was similar to one described nearly 20 years ago[7]. There, it was demonstrated that gentle flow applied to a wounded sheet of cells in culture restricted healing growth of the wound to the downstream side of the flow, as if it were controlled by the local distribution of a growth factor. The study by Nonaka *et al.* now reveals a likely role for this mechanism *in vivo*. It highlights the significance of biomechanical phenomena in generating biological pattern, an idea that has hitherto been broadly dismissed.

In contrast, the finding[1] that cilia and LRD are associated with the node or its equivalent structures in all major vertebrate groups is reassuring. Developmental biologists generally choose one 'model' organism or another according to the experimental advantages it offers, with the underlying assumption that the basic principles should