The north–south martian divide

Peter Gierasch

Some of the differences between the northern and southern hemispheres of Mars may stem from asymmetry in the planet's atmospheric circulation, and the resulting distribution of water and dust.

Mars is an asymmetrical planet. Its northern hemisphere is relatively smooth and free of craters, with a large, permanent ice-cap that is mainly composed of water. The southern polar cap is smaller and contains carbon dioxide, and the surrounding terrain is heavily cratered (Fig. 1). Hemispheric dichotomies are not unusual in the Solar System. The Moon, for example, has extensive lava plains on the side facing the Earth and is heavily cratered on the other side. Unlike the Moon, however, Mars has an atmosphere that can transport dust and water vapour around the planet. So one might expect that, over the long term, mixing would lead to a balanced distribution of polar ice. But this is not what we see.

On page 298 of this issue[1], Richardson and Wilson propose that atmospheric transport of water and dust, rather than tending to redistribute material uniformly, in fact acts as a pump across the martian equator and contributes to the north–south asymmetry in ice coverage. It may also produce an imbalance in the distribution of surface dust deposits, although the absence of depth measurements of the deposits means that this possibility remains speculative. Mars has no ocean, and therefore the atmosphere is the only medium for transportation on the planet. So Richardson and Wilson's suggestion is important.

Mars has an elliptical orbit around the Sun; its eccentricity is 0.093 (0 indicates a perfectly circular orbit). The axis of rotation is tilted away from the normal by 25.1°. So Mars has seasons similar to the Earth's, but they are exaggerated and more asymmetrical. At present, summer in the martian southern hemisphere occurs near perihelion — that part of its orbit when the planet is closest to the Sun. At this point, Mars is about 20% closer to the Sun than it is during the northern hemisphere summer.

Thus, one possible cause of the asymmetry is that southern hemisphere summers are much warmer than northern hemisphere summers. Another possibility lies in the fact that the terrain in the southern hemisphere is on average higher than that in the north. But study of these factors has produced no widely accepted explanation for the asymmetries in water distribution, and the observations remain puzzling[2–4]. For example, a thermal explanation for the paucity of water ice in the south might at first appear promising because of the warm southern summers. But this factor is at least partly offset by the shorter duration of the southern summer as a result of Mars's rapid orbital motion near perihelion. Furthermore, subtle factors, such as the reflectivity of dusty ice to sunlight, can also have strong effects[2,3].

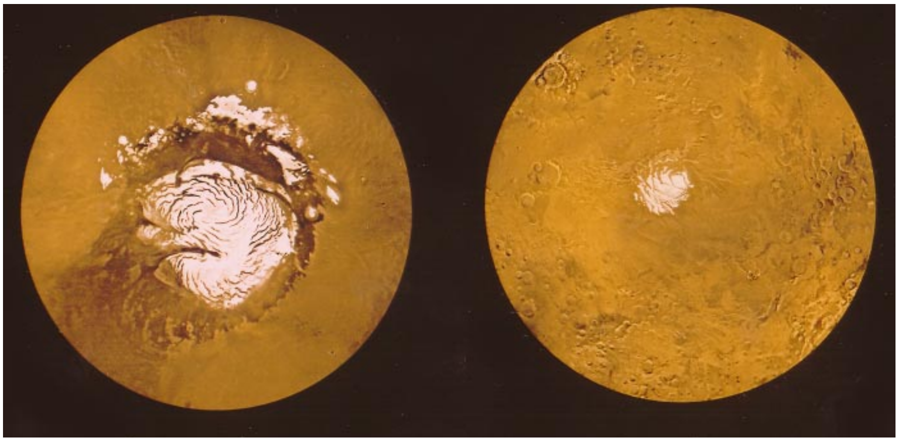

Figure 1 **Mars, north and south. The extensive northern polar cap (left) is composed of water, and the surrounding terrain is relatively smooth. The southern cap is smaller, and is thought to contain both water and carbon dioxide. Cratering in the southern hemisphere is comparatively heavy. These pictures are projections of images taken by the NASA Viking Orbiter spacecraft, and show each hemisphere from 65° latitude to the poles.**

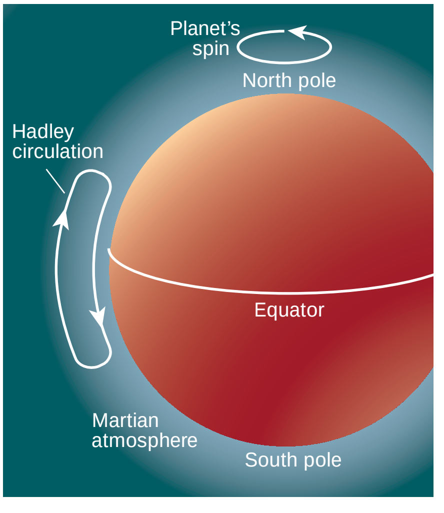

Figure 2 **A cross-equator Hadley circulation during summer in the southern hemisphere on Mars. The flow changes direction during summer in the northern hemisphere, but Richardson and Wilson[1] propose that because the terrain in the planet's southern hemisphere tends to be higher than that of the northern hemisphere, the southern summer circulation dominates. The asymmetric flow, on an annual average, is northward at high altitudes in the atmosphere, and southward lower down — perhaps explaining certain inter-hemispheric differences on Mars.**

Richardson and Wilson[1] present a new idea to explain how the atmosphere might cause the north–south asymmetry on Mars. Using a set of numerical circulation experiments, they show that, on average during the year, the atmosphere circulates across the equator with northward flow at high levels in the atmosphere and southward flow at low levels. This circulation — known as a Hadley circulation (Fig. 2) — is produced by heating at the latitude on a planet where the noon Sun is directly overhead.

The annual average Hadley circulation on the Earth was originally viewed as a major component of the general circulation of the atmosphere, with air rising at the Equator and sinking towards the poles. More recently it has been realized that the strongest Hadley circulations occur at the solstices, when the Sun is at a maximum distance from the Equator[5]. At mid- and high latitudes, Hadley circulations are strongly inhibited by Coriolis forces, which result from the Earth's rotation. These forces turn the flow at right angles to its original path, rather than allowing it to move directly down the pressure gradient. Coriolis forces vanish at the Equator. So the strongest Hadley circulation occurs across the Equator at solstices, when the gradient of solar heating between the two hemispheres is largest.

On Mars, the Hadley circulation at the solstices is stronger than that on the Earth and spans a much wider range of latitude, reaching beyond 50° N at the southern hemisphere summer solstice[6]. The mass of the martian atmosphere (per unit area) is only about 1.3% that of the Earth's, and is composed primarily of carbon dioxide, a strong absorber of infrared radiation. Consequently, the martian atmosphere responds strongly to temperature gradients created by solar radiation.

In the new simulations[1], the cause of the north–south asymmetry in the Hadley circulation is the difference in the height of the terrain in the two martian hemispheres. This elevation gradient across the planet's equator remains fixed, of course, whereas the parameters relating to its orbit and spin vary and perhaps cancel out hemispheric differences over time. The origin of the difference in elevation, which averages about 5 km (ref. 7), is unknown. One hypothesis is that, early in martian history, global-scale convective movement of the planet's mantle — the layer beneath the surface layer, or crust — pulled crustal material towards the south, thickening the crust there[8]. Another is that a large impact removed crustal material from the northern hemisphere[9].

Richardson and Wilson suggest two mechanisms that might be driving the atmospheric flow, but do not claim to have fully analysed its origin. One idea is that the warm surface, which is at relatively high elevations in the southern hemisphere, heats the atmosphere up at elevations where it would be cool if the surface were not elevated. Since the surface in the northern hemisphere is not elevated, this leads to a temperature gradient from north to south. Another possible explanation is that the upward slope of the warm surface from north to south across the martian equator favours rising atmospheric movement during the southern solstice over sinking movement during the northern solstice. But whatever the detailed mechanism, Richardson and Wilson's numerical experiments, which they performed with and without incorporating the difference in terrain height between the two hemispheres, convincingly show that this difference is the cause of the annual mean circulation.

Trace constituents of the atmosphere, such as water, dust and possibly certain gases, generally occur in a concentration gradient with height. So a cross-equator Hadley circulation can have a strong effect on transport between the hemispheres by acting as a pump. In the case of water, Richardson and Wilson argue that its concentration will generally be highest in the warm summer hemisphere, where its vapour pressure is highest, and therefore that it will be most abundant in the upper part of the cross-equator circulation, flowing from summer towards winter hemispheres. So this bias could stabilize the water ice-cap in the northern hemisphere.

Understanding climate dynamics is a complicated and tricky business, especially on a planet where the buried geological record of climatic effects is beyond our reach. Nonetheless, Richardson and Wilson have pointed out a new constraint on the interplay between the surface of Mars and its atmosphere, one that should help us to understand the planet much better. ■

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Neurobiology

Ready to unlearn

Shigeru Kitazawa

After rabbits learn to associate a tone with a small shock near the eye, they blink when they hear the tone. Learning requires activation of nerve fibres known as climbing fibres. Inhibition of these fibres leads to 'unlearning'.

Many of us were taught about Pavlov's classic experiments in school: when a dog is repeatedly fed after a neutral tone is sounded, the animal soon learns to salivate when it hears the tone. There are, of course, other pavlovian responses, and one that is commonly used in laboratory studies is the 'eye-blink' response. A brief shock near the eye causes 'innate', defensive blinking. When a brief tone is repeatedly paired with the shock, the tone comes to elicit a 'conditioned' blinking response that begins just before and peaks at around the time that the shock would be expected.

Just as important as learning an association like this, however, is forgetting it when necessary. So, if the tone is sounded without a shock, the rate and amplitude of blinking gradually decrease until the tone no longer evokes a response. This process is known as extinction and, on page 330 of this issue, Medina *et al.*[1] reveal how it comes about.

Several brain regions, which are either within or connected to the cerebellum, are required to learn the conditioned eye-blink response[2–4] (Fig. 1). A shock elicits defensive blinking by setting off electrical impulses through simple neuronal circuits (known as reflex arcs) in the brain stem. By contrast, a tone causes conditioned blinking by sequentially activating the pons, mossy fibres and interpositus nucleus, among other parts of the brain.

Before the conditioned response has been 'acquired', impulses set off by the tone are blocked at the interpositus nucleus by so-called Purkinje cells. When the tone and shock are combined, electrical impulses are conveyed in parallel to the Purkinje cells, the tone by way of mossy fibres, granule cells and parallel fibres, and the shock via the inferior olive and climbing fibres. The joint activation of parallel fibres and climbing fibres induces long-term depression — which is thought to involve long-lasting molecular changes — of the connections (synapses) between the parallel fibres and Purkinje cells[4]. This reduces the activity of the Purkinje cells. So, when the tone and shock are repeatedly paired, the activity of the Purkinje cells is progressively reduced, and so too is the inhibition of the interpositus nucleus by the Purkinje cells. This means that the tone can now act via the interpositus nucleus to evoke conditioned blinking.

Medina *et al.*[1] now reveal that extinction, which is no less important than acquisition, is not a passive process of 'forgetting', but rather an active 'unlearning' process that is driven by inhibition of climbing fibres. After training rabbits to blink in response to a tone, the authors infused various different fluids into the inferior olive. As a control they used artificial cerebrospinal fluid; the conditioned response gradually disappeared in 60 to 70 'tone-alone' trials — as it did when no fluids were infused. But when Medina *et al.* used picrotoxin, which blocks the inhibitory neurotransmitter GABA, the rabbits continued to blink even after 100 tone-alone trials. So blocking inhibitory inputs to the inferior olive prevents extinction. In contrast, blocking excitatory inputs to the inferior olive induced extinction even in the presence of both tone and shock[1]. These results suggest that inhibition of the inferior olive, and