massive stars. Accurately measured neutron star masses all fall near 1.4 $M_\odot$, the two in the neutron star binary PSR1913+16 being the most accurately measured[8]: 1.444 ± 0.01 $M_\odot$ and 1.384 ± 0.01 $M_\odot$. The mass of 4U0900−40 is quoted[9] as 1.85 ± 0.3 $M_\odot$, but the error is large and this mass could well be less than 1.5 $M_\odot$. Very soft equations of state stabilize masses only less than 1.5 $M_\odot$. Maybe none are larger than this because the EOS is indeed soft and they cannot be stabilized.

In 'laboratory' physics, the EOS, expressed as the compression modulus K_0 of nuclear matter, has been determined chiefly from the 'breathing' vibrational mode of ^{208}Pb. From this state, K_0 is determined[10] to be 210 ± 30 MeV, which is very stiff compared to the value (K_0 = 120 MeV) used by Prakash *et al.* in their soft-EOS calculation[5] for neutron stars. But correcting for quantum effects and allowing for the finite size of the nucleus ^{208}Pb, I find[11] that for infinite nuclear matter $K_0(\infty) \lesssim 2/3\ K_0(^{208}\mathrm{Pb}) \lesssim 140$ MeV. Even lower values seem to be required[12] to fulfil a sum rule for interactions developed by Landau.

Thus observations do not yet distinguish decisively between the two 'camps' — the stiff and the soft — of those studying the nuclear EOS. But the observation of a pulsar with a period of less than 1.55 milliseconds would negate the argument[1] of Friedman *et al.* in favour of a stiff EOS; or the discovery of a neutron star more massive than 1.5 $M_\odot$ would destroy my argument for a very soft EOS.

Many-body calculations for supranuclear densities predict a rather stiff EOS, with K_0 < 210 MeV. But it seems that the masses of the scalar and vector mesons — the carriers of the nuclear interaction — decrease with increasing nuclear density. Until recently, these masses were assumed to be constant. Introducing such density-dependent meson masses changes the calculations drastically, permitting a substantial, but as yet uncertain, softening of the EOS. □

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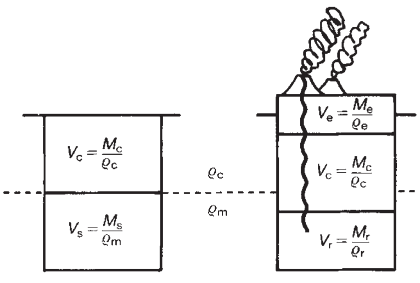
Martian geology

Making a big impression

Michael H. Carr

Tharsis bulge, discovered on Mars in the early 1970s, is about 8,000 km across, 10 km high at its centre and covers over a quarter of the planet's surface. It clearly has played a significant part in the evolution of the planet. Most of the volcanic activity on Mars, including some of the largest shield volcanoes in the Solar System, has been concentrated there: huge equatorial canyons start at the centre of the bulge and extend down the eastern flank, and most of the large flood features of the planet are around its periphery. The bulge is also at the centre of a vast radial fracture system that affects half the planet. How did the bulge form and how has it sustained itself throughout martian history? A.A. Finnerty *et al.* now suggest (*J. geophys. Res.* **93**, 10225–10235; 1988) that changes of density that resulted from vertical transport of volcanic magmas caused the bulge.



Tharsis bulge could be the result of volume changes resulting from volcanic activity. (V, volume; M, mass; and ϱ, density. Subscripts: c, crust; m, mantle; s, source; e, erupted; and r, residual.) Eruptions remove mass M_e of rock from the mantle, building a block of new material on the surface. The combined volume of the residual and erupted rock is greater than that of the source rock, so the surface becomes raised. (After Finnerty *et al.*)

Theories about the origin of the Tharsis bulge can be classified as either 'uplift' or 'constructional' models. The first class suggest that the martian lithosphere in the Tharsis region has been subject to uplift from below. The uplift can result from isostatic forces attempting to compensate for density anomalies in the mantle and crust, or from dynamic processes such as mantle convection (Wise, D.U., Golombek, M.P. & McGill, G.E. *Icarus* **38**, 456–472; 1979). Constructional models suggest that the bulge is due largely to near-surface accumulation of volcanics (Solomon, S.C. & Head, J.W. *J. geophys. Res.* **87**, 9755–9774; 1982). The new model proposed by Finnerty *et al.* is a variant of these models, in the sense that the bulge is caused by accumulation of near-surface volcanics. Uplift of the surface occurs only insofar as the near-surface volcanics are intruded below the surface rather than extruded onto it.

There is a large gravity anomaly associated with the Tharsis bulge which N.H. Sleep and R.J. Phillips (*Geophys. Res. Lett.* **6**, 803–806; 1979) showed could have formed isostatically, without the introduction or loss of material from the Tharsis region. They suggested that the gravity field could be explained if anomalously high near-surface densities were compensated by anomalously low mantle densities that extend to depths of at least 300 km. The petrologic model proposed by Finnerty *et al.* is consistent with the isostatic gravity model. The authors suggest that the Tharsis bulge is the result of large-scale volcanism. The model requires no lateral transport of material, only vertical transport of magmas from their source regions, deep within the mantle, towards the surface (see figure).

Volcanism would result in extraction of iron-rich basaltic melts from the mantle, leaving it enriched in magnesium, and hence anomalously buoyant. Deposition of the iron-rich magmas on or near the surface would leave the near-surface materials anomalously dense. Finnerty *et al.* use previous experimental data to estimate the range of mantle densities expected, and the densities expected of the extracted magmas and resulting volcanic rocks. They estimate that 30–50 per cent of the source region was partially melted to build Tharsis, the fraction being a function of the densities of the various crust and upper-mantle components, and conclude that the lithosphere under Tharsis must be at least 300 km thick.

The model is ingenious but still leaves several unanswered questions. Such a lithospheric thickness contrasts markedly with that estimated (20–30 km) from the flexing of the lithosphere under local loads (Comer, R.P., Solomon, S.C. & Head, J.W. *Rev. Geophys.* **23**, 61–92; 1985). What triggered the massive volcanism in Tharsis? Why was the process so sustained in Tharsis, while most of the rest of the planet was left almost unaffected? Fortunately, the theory could soon be tested, for Mars Observer, to be launched in 1992, will greatly improve our knowledge of the planet's gravity and topograpy, and will also reveal something of the chemistry and mineralogy of the near-surface rocks, about which Finnerty *et al.* make specific predictions. □

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