the palaeomagnetic method: a rock's remanent magnetism is a fossil compass that tracks the ancient magnetic field, recording movements of continents, sea floor and tectonic plates. To account for the magnetization of the Vredefort crater, some other magnetizing mechanism must have been at work during the meteorite impact.

Carporzen *et al.*[5] suggest that highly charged plasmas produced in the impact created magnetic fields that lasted only a matter of minutes, but which were as much as 1,000 times stronger than Earth's magnetic field. The plasma currents that created the transitory fields would have varied on a scale of centimetres and are proposed to be the cause of the strong but randomly directed bedrock magnetizations. The magnetite that carries the bedrock magnetization is confined to planar deformation features in shocked quartz grains. The magnetic carrier certainly formed as a direct result of the shock: unshocked but otherwise similar rocks lack this magnetite. The orientation of the magnetite grains in the quartz cannot explain the random directions of magnetization — any external field in a constant direction would produce a distribution of magnetic vectors over a half-sphere, not over 360° as observed. The field itself must have had a random orientation, and remanent magnetization[6] of the magnetite that crystallized during the brief existence of that field is responsible for the bedrock magnetization.

Supporting evidence comes from rocks that melted during the impact, which were also analysed by Carporzen *et al.*[5]. Unlike the shocked but unmelted bedrocks, these 'dyke' and 'vein' samples cooled for days before their magnetization became permanently fixed. By this time, the plasma fields had long vanished and the melt rocks acquired thermal remanent magnetizations as they cooled in Earth's field. Their magnetizations are much weaker than those of the surrounding bedrocks, but they are all in the same direction.

In drawing analogies between the Vredefort crater and giant impact basins on Mars, we must bear in mind the differences in scale, and in the types of rocks involved. Earth's continental crust, where most impact craters are preserved, tends to be granitic, rich in aluminium and silicon but poorer in magnesium and iron. The crust of the martian highlands is more basaltic[7], similar to the composition of Hawaii, Iceland and the ocean floor. These rocks contain much more iron, and abundant iron-bearing magnetic minerals can form during cooling without the intervention of shock. The meteorite that formed the Vredefort crater was probably 10–20 km in diameter, but to produce a cavity 1,000 km wide, as Argyre initially was, requires an impacting body closer to 100 km in size. Shock-wave pressures are correspondingly larger and their effects are felt at greater depths.

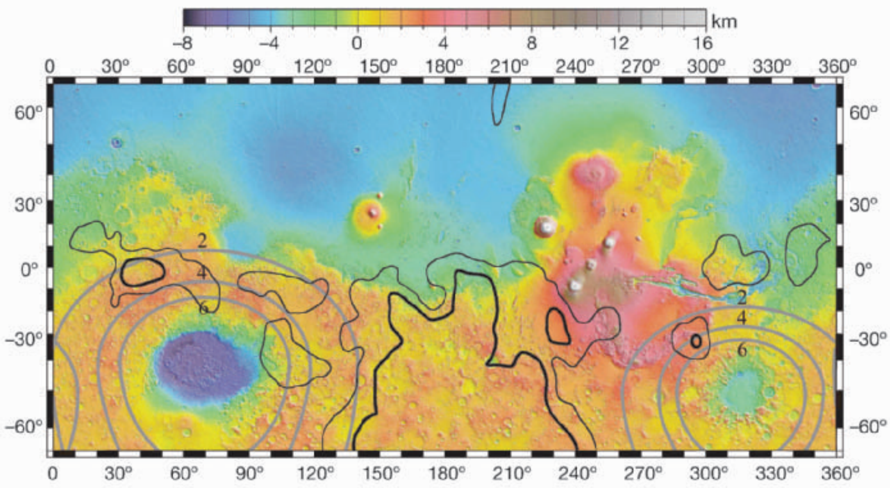

Figure 1 **Magnetic lows over the Hellas (left) and Argyre impact basins on Mars. Superimposed on the topography are the peak shock pressures, in gigapascals, estimated to have been produced by the impact. The light and heavy magnetic-field contour lines are for 20 and 40 nanotesla, respectively, and were measured by the Mars Global Surveyor at about 400 km altitude. (Reproduced from ref. 3 with permission from the authors and the American Geophysical Union.)**

The strongest magnetic fields measured by the Mars Global Surveyor require at least the upper 30 km of the crust to be magnetized[8,9]. At these depths, shock and thermal blanketing would cause demagnetization of rocks that are already coherently magnetized — in addition to the new but randomly directed magnetization that plasma fields would create in crystallizing minerals. At the surface, the spatial coherence of bedrock magnetizations could be tested using an outcrop magnetometer on a future rover mission to Hellas or Argyre. It is noteworthy that some lunar rocks returned by the Apollo missions had strong and stable magnetizations whose directions varied by 60–120° between adjacent subsamples[10] — these are a possible extraterrestrial example of the suggested magnetization mechanism at Vredefort. ■

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Sensory physiology

Brainless eyes

Rüdiger Wehner

The visual equipment of box jellyfish includes eight optically advanced eyes that operate with only a rudimentary nervous system. As they produce blurred images, their function remains an open question.

According to conventional wisdom, information-processing in visual systems is a hierarchical process[1]. It starts at the level of the receptor layer, the retina, where raw sensory data are taken up from the outside world, and continues by transferring this information to increasingly higher centres in the brain. During this upstream process, exactly those features are extracted from the retinal response patterns that enable the animal to cope successfully with its ecological world.

The findings that Nilsson *et al.* describe on page 201 of this issue[2] run counter to this view. A lowly animal inhabiting the tropical seas — a box jellyfish, or cubomedusa (Fig. 1) — is equipped with eight surprisingly sophisticated lens eyes of the camera-type, but there is no common brain behind them. In nearly every respect, these lens eyes resemble those of animals such as fish and cephalopods, but the 'central nervous system' behind the eyes consists only of a diffuse nerve net accompanied by a marginal nerve ring[3].

Nilsson and colleagues' anatomical,

Figure 1 **Eye see — but what? A box jellyfish of the genus *Chironex*. The species studied by Nilsson *et al.*[2] was *Tripedalia cystophora*, which can be bred from polyps in the lab.**

optical (microinterferometrical) and modelling studies reveal two phenomena. The first is amazing, and the second peculiar. Amazingly, the tiny spherical lenses, which are only a tenth of a millimetre wide, are able to form sharp images, which are free of spherical aberration. This is due to a refractive index gradient within the lens — exactly as one would expect from optical theory, and exactly as is found in the much larger spherical lenses of fish and cephalopods[4]. Peculiarly, however, the focal plane of each jellyfish lens, and hence the sharp image formed by the lens, lies far behind the retina. This underfocusing leads to a blurred image, and thus to a loss of the fine visual detail that the lens is able to provide.

So why should evolution have produced highly sophisticated optics that have only poor resolution? Isn't higher resolution always better, irrespective of the visual function to be fulfilled? Obviously not. Cubomedusae are strong, agile swimmers and active predators[3] living in near-shore habitats such as mangroves[5]. But how they are visually guided within these cluttered environments has remained elusive. Here we face the problem of what could be dubbed 'reversed neurobiology', analogous to the case of 'reversed genetics'[6], in which the genes are known but their functions are not. We know what kind of visual cues the eyes of jellyfish are best at extracting, but not the visual tasks that the animals have to accomplish.

In insects, there are two examples in which the degradation of spatial resolution is a design feature of a particular visual subsystem known to serve a specific function. One is course stabilization, which involves horizon detectors that are built into small, single-lens eyes, the ocelli[7]. The other is skylight navigation, which is based on patterns of

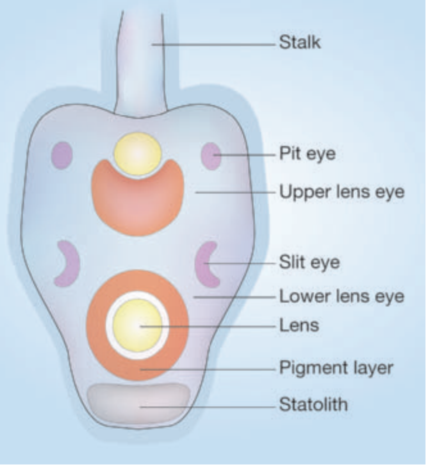

Figure 2 **The rhopalium (sensory club) of a box jellyfish. In each of the four rhopalia located at the corners of the jellyfish's cube-shaped body there are two lens eyes[2] and four pigment-pit eyes (two upper pit eyes and two lower slit eyes). Each rhopalium hangs by a stalk from the rim of the medusa. The function of the crystalline concretion called the statolith might be to ensure that the rhopalium, and thus the eyes, are always oriented in the same way, irrespective of how the body of the medusa is tilted. (Diagram based on ref. 11.)**

polarized light and mediated by a small, specialized part of the insect compound eyes[8]. But what are the jellyfish's eyes designed for?

This question is even more compelling, as Nilsson *et al.*[2] find that the photoreceptors of the jellyfish eyes possess wide and often complex (for example, asymmetrically shaped) receptive fields. In mammals, for instance, such complex receptive fields result from multi-level processing and hence are confined to higher cortical centres in the brain[9]. But in jellyfish they are generated by the optics of the lens and the position of the photoreceptors within the retina. This extreme case of peripheral filtering again hints at a very particular task that these eyes must accomplish. It is further corroborated by the observation that, in each of the animal's four sensory clubs (or rhopalia), there are not only the two types of lens eye studied by Nilsson *et al.* — one looking upwards, the other horizontally — but also two other (simpler) types of eye (Fig. 2). Within these batteries of eyes, which exhibit quite some diversity of optical design, each type of eye could be specifically adapted to a particular aspect of the animal's lifestyle.

Nilsson and co-workers[2] provide us with one of the most dramatic examples that vision is not a general-purpose sense. Box jellyfish evidently have different eyes for different tasks, and have delegated such tasks, which are usually accomplished by neural processing, to the optics of the eyes. Furthermore, as the outputs of the eyes are channelled directly into the pacemakers for the swimming movements, and as these pacemakers are also located in the sensory clubs[10], visuomotor processing occurs at an extremely peripheral level. Specialization of eyes for particular tasks and peripheral coding seem to go hand in hand — during the course of evolution, box jellyfish have clearly not had the need to feed the information provided by their total of 24 eyes into a central processing unit, or brain. ■

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Granular media

Information propagation

Stefan Luding

The transmission of force through granular matter such as sand is a crucial consideration in certain applications. The behaviour observed depends on the particle interactions as well as on the length scale involved.

How is information propagated through granular matter? This is an essential question for researchers investigating the stability of buildings, silos and slopes — particularly for predicting failure and avalanches. Does propagation occur through specific ('easy') paths or along a wide front? Is the mechanism similar to that of sound- or light-wave propagation? Is it elastic, or entirely different?

Goldenberg and Goldhirsch[1] provide answers to these questions on page 188 of this issue. Their numerical simulations show that, for short distances, forces in granular systems propagate much like waves, but that at longer distances an applied force causes an elastic-like deformation. Furthermore, the regime of wave-like behaviour becomes