about 10 km (ref. 8), supporting their inference.

One of the most interesting results of the survey is that the high-angle faults appear to extend, in an approximately planar geometry, to the base of the crust and possibly into the uppermost mantle. Earthquakes at mid-ocean ridges have centroid depths consistent with faulting of the entire crustal column[8], but only along ridges spreading at half-rates of 20 mm per year or less. The spreading half-rate at which the crust of the MCS survey was generated, however, was about 80 mm per year[9]. Ridges spreading at such fast rates are characterized by only small-magnitude earthquakes confined to the uppermost few kilometres of the near-axis crust[10]. Bull and Scrutton speculate that the deepest imaged portions of the faults in their survey may not have originated at the ridge axis but instead formed by downward extension of upper crustal faults during the recent episode of lithosphere compression. Reverse-faulting earthquakes in the central Indian Ocean basin have centroid depths of 20–40 km (ref. 6), suggesting that slip on these faults nucleates in the strong layer of the upper mantle and that these fault structures may extend much deeper than even the best current images indicate.

In a related MCS profiling study, White *et al.*[2] report a variety of non-horizontal reflectors within the Mesozoic crust of the western north Atlantic near the Blake Spur fracture zone. In a profile following the direction of spreading, they have imaged a number of planar reflectors. The most prominent are within the lower crust, but some appear to cut through the entire crustal column. Dip angles are 20–40°, with two-thirds of the lower crustal reflectors dipping eastward towards the ridge. Along an orthogonal isochron line, planar low-angle reflectors were also imaged (see figure). Dip angles are 10–30°, with southward dips most common.

Although a single set of obliquely trending structures is a possible interpretation, limited data from profiles at other azimuths in the same region lead White *et al.* to conclude that the profiles in the spreading and isochron directions are generally imaging two different sets of structures. They interpret the structures imaged in the 'spreading direction' profile as normal faults formed near the ridge axis. The dip angles of the reflectors are somewhat less than the dip angles indicated by the mechanisms of ridge axis earthquakes[8], but the difference could be attributed to a general steepening of the faults in the upper crust, as is seen for some of the reflectors[2], or to rotation of fault-bounded crustal blocks outwards from the seismically active zone of the median valley. There is, too, the possibility that some of the reflectors, particularly those terminating in the middle to upper crust, may be relics of ridge-axis magmatic processes[2].

White *et al.* interpret the planar structures observed along isochron lines as thrust or reverse faults. Lithospheric thermal stress models do predict compressive stress in young oceanic crust[11], but near-ridge earthquakes with compressive mechanisms appear to occur on reverse faults[12] with dip angles steeper than the 10–30° seen for planar reflectors along isochrons[2]. This discrepancy may only be apparent, however, as a large fraction of the reverse-faulting earthquakes in young oceanic lithosphere occurs on fault planes oblique to an isochron[12], so that the true dip angles of fault surfaces imaged along isochrons may be significantly larger than those inferred from the MCS profiles.

An unresolved issue is why the imaged structures are such prominent reflectors of seismic energy. A distinct contrast in seismic velocity or density is implied. The presence of fluids in the fault zones has been suggested as an explanation for the structures in the Central Indian Ocean Basin[1]; frictional heating and fault-controlled hydrothermal circulation may contribute to localized, anomalously high heat flow in the region[5]. But such an explanation does not obviously apply to the structures imaged in the crust of the western Atlantic. Perhaps mineralization during an earlier episode of hydrothermal circulation has left a permanent difference in physical properties compared with those of the surrounding crust. Measurements of the physical properties of rocks from fault zones in ophiolites may help to resolve this question. □

Sean C. Solomon is in the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.

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Still standing after the earthquake

David Graham

A truck escapes untouched on the lower roadway of the Nimitz freeway in Oakland, California, following the Loma Prieta earthquake of 17 October 1989. In the 1.4-km-long section of the freeway that collapsed in the earthquake, only the segment shown survived; the lower roadway here is supported by three pillars at each end instead of the usual two. On page 853, an analysis of aftershock recordings sheds some light on the failure of the Nimitz freeway; it seems that the presence of three-pillar supports strengthened the segment sufficiently to prevent its collapse.