Geology

A new data source for *in situ* stress field orientations

from Mark D. Zoback

THE lack of reliable data that has hampered attempts to understand the nature and origin of stresses in the Earth's crust may soon be made good by a new method for studying the orientation of horizontal stresses. Easy to use wellbore logging instruments make it possible to determine the direction of stress-induced wellbore spalling which, for reasons explained below, takes place preferentially around the wellbore at the azimuth of the least horizontal stress. The method is now beginning to be widely used (see *Nature* 305, 619; 1983) and may well yield a wealth of data in a few short years.

Three main types of stress field indicators have been used in the past, but each type has distinct and well known problems. Earthquake focal plane mechanisms have been most commonly employed but, unfortunately, even well-constrained focal mechanisms for a given earthquake yield P- and T- axes which only approximate the principal stress directions. The determination of principal stress orientations can be improved by using a family of mechanisms from different faults in a given area, but available cases for such analyses are rare.

In situ stress measurements have also been widely used as stress-field indicators. Although shallow measurements are relatively inexpensive and easy to make, it now seems clear that reliable tectonic stress directions often must be taken from measurements made at depths of 50–100 m or more. Thus, strain relief stress measurements in mines (when the measurements can be made far enough away from the mine cavity) or hydraulic fracturing stress measurements in wells or boreholes are required.

Finally, geologic features such as dike and cinder-cone alignments, and fault-slip (slickenside) data on young scarps can also yield data on the orientation of the stress field. Well-exposed and sufficiently young (usually less than a few million years old) volcanic features cannot, however, be found in most regions of interest. Fault slip data have the same type of uncertainty as focal plane mechanisms, but again adequate data sets for a family of faults are rare.

It was noticed almost twenty years ago at the Nevada Test Site that wellbore elongation seemed to be controlled by the *in situ* stress field. The nature of this phenomena, however, is only now coming to light, largely through the work of two Canadian scientists; Ian Gough and Sebastian Bell (see *Nature* 305, 619; 1983). They showed that in several oil fields the well-

bore elongated in the direction of the least compressive stress as indicated by other stress field data in the region. These elongated sections of wellbores are often called breakouts in the petroleum industry. My colleagues and I at the US Geological Survey have recently substantiated the correlation suggested by Bell and Gough by showing that breakout and hydraulic fracturing data from the same well give the same stress field orientation at several different sites.

The devices that are now being used to study stress-induced wellbore elongation are four-arm oriented calipers and acoustic borehole televiwers. The caliper data are more exciting because information is already available for many wells and logs are commercially available in new wells. There are three problems with the breakout data yielded by the calipers, however.

First, the caliper only provides the minimum and maximum well diameter and no detailed information on the shape of the hole. Second, the caliper's low sensitivity means that many small breakouts may be

missed. Third, because of rotational torque on the caliper from the logging cable, a bias in the data can occur if the caliper arm does not stay centered in the breakout as the caliper is pulled up the hole.

The acoustic televiwer is a sophisticated ultrasonic scanning device which can be used to determine accurately the cross-sectional shape of wellbores. Although it does not have any of the disadvantages of the calipers, televiwer data are often difficult to obtain.

It appears that the origin of the breakouts is related to a compressive shear failure process because the breakouts form where the compressive circumferential stress concentration around the well is highest. As this point is located at right angles to the direction of maximum horizontal compression, the wellbore elongates in the direction of the least principal stress. Although the formation of breakouts has been addressed with limited theoretical and laboratory studies, a great deal more effort is still needed. With sufficient understanding, however, it may even be possible someday to estimate the magnitude of *in situ* stress from accurate measures of breakout size and shape. □

Mark D. Zoback is in the US Geological Survey, Office of Earthquakes, Volcanoes and Engineering, 345 Middlefield Road, Menlo Park, California 94025.

Meteoritics

New isotopic evidence of early Solar System processes

from Mark H. Thieme

METEORITES possess the most pristine record of the early Solar System, since other planetary objects, like the Earth and Moon, have undergone secondary events that have erased the primordial record. Cosmochemists are particularly interested in meteoritic isotopic distributions, since they indicate the nuclear and chemical events associated with their own history and, presumably that of the Solar System at large.

In the latest issue of *Nature*, Lewis *et al.* have reported some striking new measurements for the isotopes of nitrogen in the carbonaceous chondrites Allende and Murchison. The reported measurements are of special significance, because of their apparent correlation with documented isotopic anomalies in neon, xenon and carbon and, hence, may be of utility in resolving their astrophysical origin. The peculiar reported isotopic signatures may, in fact, represent a mixture of a "normal" Solar System material and a component of material with an origin outside the Solar System.

Nitrogen possesses two stable isotopes, ^{15}N and ^{14}N , with natural abundances 0.36 and 99.64 per cent respectively. By convention, isotope geochemists report isotopic anomalies in the delta (δ) notation, where δ ^{15}N refers to the $^{15}\text{N}/^{14}\text{N}$ ratio in a sample with respect to the same ratio in a standard; for nitrogen this is air. The δ ^{15}N is simply the proportional difference between a sample and air, expressed in parts per thousand, or per mil (‰). A positive delta is referred to as being heavy (^{15}N enriched) and negative as light, or ^{14}N enriched. On Earth, nitrogen isotopic compositions range from a δ ^{15}N of approximately -10‰ for natural gas to about +20‰ for nitrogen in mid-ocean ridge basalts. Lewis *et al.* report a nitrogen component in the Allende meteorite with a δ ^{15}N of -326‰, the largest ^{14}N enrichment ever observed. Even more impressive are the results from Murchison. Through chemical isolation of exceedingly rare components, they have shown the presence of several nitrogen components which range in δ ^{15}N from -272‰ to +153‰.