Neotectonic joints: Discussion and reply

Discussion

ADRIAN E. SCHEIDEGGER *Section of Geophysics, Technical University, Vienna, Austria*

In their paper on "neotectonic joints," Hancock and Engelder (1989) started from the assumption that such joints are "extension fractures" which are formed parallel to the maximum neotectonic compression.

By using such an assumption, Hancock and Engelder ignore two simple, ubiquitous facts: (1) vertical surface joints occur in *conjugate* sets, and (2) they *transect* grains, inclusions, pebbles (in conglomerates), and concretions.

It is simply mechanically impossible that *two* conjugate sets of extension joints occur in a neotectonic stress field: the latter has only *one* maximum compressional stress. It is also mechanically impossible that extension joints *transect* harder inclusions in an otherwise more friable matrix: extension joints would go *around* such inclusions.

Regarding the fact that neotectonic joints occur in conjugate sets, this writer has collected much evidence (Scheidegger, 1985) and similarly so with regard to the fact that the joints transect inclusions (see photographs in Scheidegger, 1985).

The interpretation of these facts is still somewhat of an enigma (Scheidegger, 1978). The most likely guess is that the joints are shearing fractures or represent shear planes in the (triaxial) stress field. This interpretation is now also supported by recent *laboratory* evidence by others (for example, the results of compression tests by Santarelli and Brown, 1989). Implicitly, it also is contained in the work of Hancock and Engelder (1989) themselves. If one compares the direction of the *in situ* maximum compression determinations in northern France (marked by I and F in Fig. 2 of Hancock and Engelder, 1989) with the joint orientations given for that area, there is a discrepancy of 30°–40°. This corresponds exactly to the shear fracture theory.

The joint orientations presented by Hancock and Engelder (1989) should therefore be reinterpreted in the light of the above comments.

REFERENCES CITED

Hancock, P. L., and Engelder, T., 1989, Neotectonic joints: Geological Society of America Bulletin, v. 101, p. 1197–1208.

Santarelli, F. J., and Brown, E. T., 1989, Failure of three sedimentary rocks in triaxial and hollow cylinder compression tests: International Journal of Rock Mechanics, Mining Sciences, and Geomechanics Abstracts, v. 26, no. 5, p. 401–413.

Scheidegger, A. E., 1978, The enigma of jointing: Rivista Italiana de Geofisica e Scienze Affini, v. 5, p. 1–4.

——— 1985, The significance of surface joints: Geophysical Surveys, v. 70, p. 259–271.

MANUSCRIPT RECEIVED BY THE SOCIETY JANUARY 2, 1990
MANUSCRIPT ACCEPTED AUGUST 7, 1990

Reply

P. L. HANCOCK *Department of Geology, University of Bristol, Wills Memorial Building, Queen's Road, Bristol BS8 1RJ, United Kingdom*
T. ENGELDER *Department of Geosciences, Pennsylvania State University, University Park, Pennsylvania 16802*

Despite welcoming this opportunity to reply to Scheidegger's comments about our (Hancock and Engelder, 1989) interpretation of shallow-formed neotectonic joints, we wish to emphasize that some of his general points repeat arguments that he advanced (Scheidegger, 1982), in a comment on Engelder's (1982a) hypothesis that some joints in the Appalachian Plateau are related to the contemporary stress field. In a reply, Engelder (1982b) answered Scheidegger's alternative explanations by listing field criteria for distinguishing between joints (generally mode I cracks) and shear fractures. In this response, we address Scheidegger's criticisms in the order that he presents them.

The article discussed appeared in the *Bulletin*, v. 101, p. 1197–1208.

(1) It is not true that we "started from the assumption that such joints are 'extension fractures' which are formed parallel to the maximum neotectonic compression." First, field evidence requires no such assumption. Second, we describe a few of the studied joints as belonging to either conjugate sets of hybrid-shear fractures or joint spectra, the latter comprising a continuum of extension and hybrid-shear fractures (Hancock and Engelder, 1989, Figs. 5 and 6).

(2) Although joints investigated by Scheidegger in other regions may belong to conjugate sets, we emphasize that the systematic joints surveyed by us belong mainly to single sets; the only exceptions are the conjugate sets referred to above. Nonsystematic cross-joints abut and link systematic joints in single sets and are generally at right angles to them (see Hancock and Engelder, 1989, Figs. 5, 6, and 7). Because they are younger than the

systematic neotectonic joints and enclose angles of 90° with them, they do not define conjugate systems. An implication of Scheidegger's comments is that we make a case for our study areas containing conjugate extension joints; we made no such case.

(3) It would be inappropriate for us to repeat here all seven of the observations presented by Engelder (1982b) that are criteria for distinguishing between shear fractures and mode I cracks. We emphasize, however, that joints transect grains in the host rock despite evidence (for example, calcite growth fibers, no shear offset) for their initiation as mode I cracks.

(4) Although Scheidegger guesses that many joints elsewhere are shear fractures, we have not found field evidence supporting this interpretation in our study areas. Our field evidence favors the formation of most of the joints as mode I cracks, or axial splitting cracks, propagated perpendicular to the minimum principal stress axis. Only on conjugate fractures is it possible that there was a potential component of shear in addition to dilation.

(5) It is curious that the work of Santarelli and Brown (1989) is cited as supporting evidence for the shear-fracture hypothesis. Santarelli and Brown showed that at low confining pressures failure by axial splitting occurred in the rocks they tested. Axial splitting cracks propagate in the direction of the maximum compressive stress and are therefore difficult to distinguish from other joints. Furthermore, Santarelli and Brown (1989) showed that the differential stress required for generating shear fractures far exceeds differential stresses commonly found in the crust (Evans and others, 1989). Because the crust is pervaded by faults and joints, crustal stress appears to be governed by friction on these existing faults and joints (Brace and Kohlstedt, 1980). With local exceptions, crustal stress is unlikely to climb to the level necessary to fracture intact rocks throughout large regions.

(6) Scheidegger claims that there is a 30°–40° mismatch between the average strike of neotectonic joints in northern France (Hancock and Engelder, 1989, Fig. 2) and the direction of contemporary greatest horizontal compression determined from *in situ* measurements and earthquake focal mechanisms. We point out that stress can vary in orientation with depth (Becker and others, 1987). Hence, there is no *a priori* reason for the exact correlation of the near-surface stress and that determined at depth. Likewise, earthquake focal mechanisms poorly constrain the orientation of principal stresses (McKenzie, 1969).

Although a stress orientation mismatch occurs in the Calais area (about 180 km north of Paris), the strikes of neotectonic joints along the north coast of France are (a) identical to those in southeast England, where they are normal to numerous borehole breakout elongation directions, and (b) subparallel to the direction of greatest horizontal stress both south and northeast of Paris. Thus we do not accept that the local mismatch near Calais is of regional significance and, furthermore, it does not follow that such mismatches, even if of significance, should be interpreted as indicating the origin of a fracture set by shear. An equally probable explanation is that there has been a rotation of the horizontal axes of the stress field since the initiation of the fractures. Indeed, this is likely to be the case as a consequence of neotectonic joints forming only when there is a thin cover, and being available for inspection only after denudation. The time gap between joint propagation and exposure is unknown but is unlikely to be less than, say, a few thousands of years. That is, there is sufficient time available for small rotations of the stress field to occur. The data reported by us from the Appalachian Plateau, southeast England and northeast France, and the Pennsylvanian sector of the Valley and Ridge province suggest that in most settings such rotations do not generally exceed about 10°.

REFERENCES CITED

Becker, A., Bluming, P., and Muller, W. H., 1987, Recent stress field and neotectonics in the eastern Jura Mountains, Switzerland: Tectonophysics, v. 135, p. 277–288.

Brace, W. F., and Kohlstedt, D. L., 1980, Limits on lithospheric stress imposed by laboratory experiments: Journal of Geophysical Research, v. 85, p. 6248–6252.

Engelder, T., 1982a, Is there a genetic relationship between selected regional joints and contemporary stress within the lithosphere of North America?: Tectonics, v. 1, p. 161–171.

——1982b, Reply to Scheidegger's Comment on 'Is there a genetic relationship between selected regional joints and contemporary stress within the lithosphere of North America?' by T. Engelder: Tectonics, v. 1, p. 465–470.

Evans, K., Engelder, T., and Plumb, R. A., 1989, Appalachian stress study 1: A detailed description of in situ stress variations in Devonian shales of the Appalachian Plateau: Journal of Geophysical Research, v. 94, p. 1729–1754.

Hancock, P. L., and Engelder, T., 1989, Neotectonic joints: Geological Society of America Bulletin, v. 101, p. 1197–1208.

McKenzie, D. P., 1969, The relation between fault plane solutions for earthquakes and the directions of the principal stresses: Seismological Society of America Bulletin, v. 59, p. 591–601.

Scheidegger, A. E., 1982, Comment on 'Is there a genetic relationship between selected regional joints and contemporary stress within the lithosphere of North America?' by T. Engelder: Tectonics, v. 1, p. 463–464.

MANUSCRIPT RECEIVED BY THE SOCIETY MAY 18, 1990
MANUSCRIPT ACCEPTED AUGUST 7, 1990