How Faulting Keeps the Crust Strong

Townend & Zoback

Prithvi Thakur

Paper discussion

Key Points

- Intraplate crust: critically stressed, hydrostatic pore pressure, high permeability.
- Observed friction coefficient = 0.6-1.0. The theoretical friction coefficient for brittle rocks is 0.6.
- Laboratory measurements show upto four orders of magnitude lower permeability than in-site borehole measurements.
- Critically stressed rocks are hydraulically conductive.

Key Points

- Characteristic diffusion rate for fluid transport in the upper 1-10km is 10-1000 yr.
- Intraplate crust is able to sustain higher differential stresses than would be possible if bulk permeability were sufficiently low to sustain fluid pressures higher than hydrostatic.

Methods

- Borehole in-situ stress meassurements and laboratory measurements.
- Maximum depth of 9.1 km.
- Measurements of in-situ stress, fluid pressure, permeability.

Discussion

TABLE 1. LOCATIONS EXHIBITING NEAR-HYDROSTATIC FLUID PRESSURE AT DEPTHS OF SEVERAL KILOMETERS

Well location	Regime	Depth (km)	Observation	Source	Evidence for critical stress
Cornwall HDR, England	SS	2.5	DST	Pine et al. (1983)	Stress magnitudes; induced seismicity
Fenton Hill HDR, New Mexico	N, SS	3.0	SWC	Barton et al. (1988)	Stress magnitudes
Dixie Valley, Nevada	N	2–3, 5–7	DST, SG	Hickman et al. (1997)	Stress magnitudes; prehistoric fault offsets
Cajon Pass, California	SS	3.5	DST	Coyle and Zoback (1988)	Stress magnitudes; breakout rotations
Soultz HDR, France	N, SS	5.0	DST	Baumgärtner et al. (1998)	Stress magnitudes; induced seismicity
Siljan, Sweden	SS	7.0	DST	Lund and Zoback (1999)	Stress magnitudes
KTB, Germany	SS	9.1	DST, SWC	Huenges et al. (1997) Zoback and Harjes (1997)	Stress magnitudes; induced seismicity
Kola, Russia	?R	12.2	SWC	Borevsky et al. (1987)	N.A.

Note: HDR—hot dry rock; KTB—Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland (German Continental Deep Drilling Program); SS—strike-slip faulting regime; N—normal faulting regime; R—reverse faulting regime; DST—drill stem test; SWC—static water column; SG—silica geothermometry; N.A.—not available.

Discussion

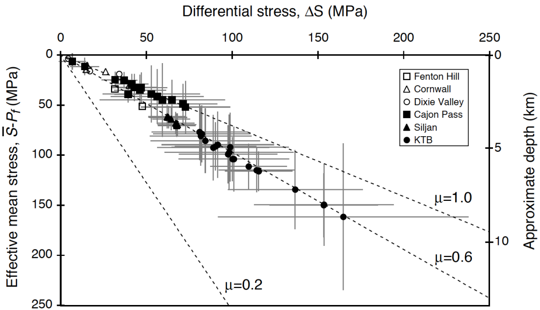


Figure 1. Dependence of differential stress, ΔS, on effective mean stress, $\overline{S} - P_f$, at six locations where deep stress measurements have been made. Dashed lines illustrate relationships predicted using Coulomb frictional-failure theory for various coefficients of friction, μ. References: Fenton Hill—Barton et al. (1988); Cornwall—Pine et al. (1983), Batchelor and Pine (1986); Dixie Valley—Hickman et al. (1997); Cajon Pass—Zoback and Healy (1992); Siljan—Lund and Zoback (1999); KTB (German Continental Deep Drilling Program)—Brudy et al. (1997).

Discussion

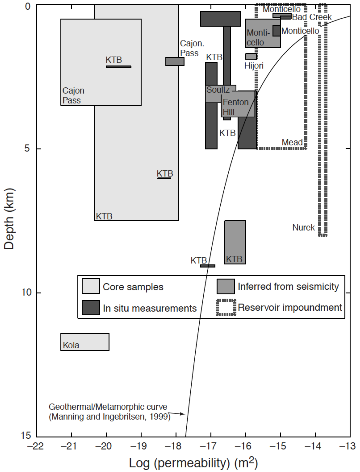
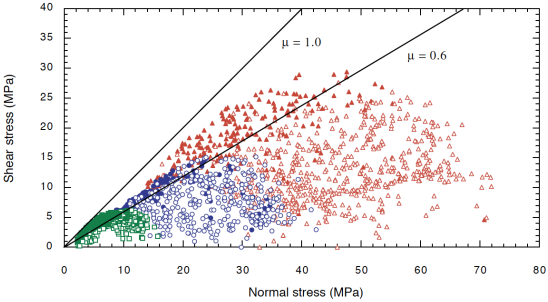


Figure 2. Deep crustal permeability data acquired from core samples, in situ hydraulic tests, and induced seismicity. References: core samples—Huenges et al. (1997), Lockner et al. (1991), Morrow and Byerlee (1988, 1992), Morrow et al. (1994); in situ measurements—Coyle and Zoback (1988), Huenges et al. (1997); seismicity data—Sasaki (1998), Shapiro et al. (1997, 1999), Zoback and Hickman (1982); reservoir impoundment data—Roeloffs (1988), Talwani et al. (1999); geothermal/metamorphic curve—Manning and Ingebritsen (1999). KTB—German Continental Deep Drilling Program.

Discussion

Figure 3. Shear and normal stresses on fractures identified with borehole imaging techniques in Cajon Pass (triangles), Long Valley (circles), and Nevada Test Site (squares) boreholes. Filled symbols represent hydraulically conductive fractures and faults, and open symbols represent nonconductive fractures. Original data are from Barton et al. (1995).



Discussion

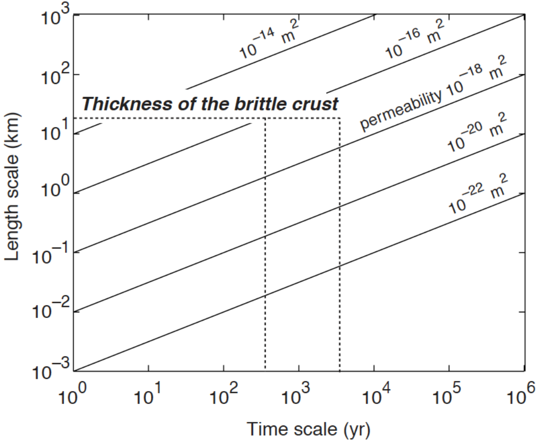


Figure 4. Length and time scales for diffusive fluid flow in rock masses of different permeabilities.

Questions and Discussions

- The depth measurements are shallow, we can talk about induced seismicity but what about tectonic faults?
- High permeability would imply what in terms of pore pressure?
- What is the relation between differential stress and fluid pressure?
- Characteristic length scale of faulting?