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Case histories of stress measurements across faults and varying lithologies

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In the course of a 35-year experience with in situ stress measurements, I have observed significant decouplings in stress magnitudes and directions at several locations affected by changes in lithology or by fault crossing. Near Bowmanville, Ontario, hydraulic fracturing (HF) measurements in a 300-m-deep borehole yielded consistent results within the Ordovician limestone between 50 and 220 m depth, with the minimum and maximum horizontal stresses (σ_h and σ_H) and the σ_H direction averaging 9 MPa, 13.5 MPa, and N70ºE, respectively. However in the deeper 80 m of the hole, 4 tests run in Precambrian gneiss revealed a dramatic change of stress regime with σ_h and σ_H averaging 11 MPa and 18 MPa, respectively, and σ_H direction shifting to N23ºE. At Niagara Falls, Ontario, minor differences in stress magnitudes but substantial rotations in stress directions were discovered from HF tests in \the Whirlpool sandstone and the underlying Queenston shale, within the shallow depth range of 90 to 125 m. From sandstone to shale σ_h changed from 4 MPa to 5 MPa, σ_H from 9.5 MPa to 8 MPa, and σ_H direction from N58ºE to N32ºE. A similar condition in which the principal horizontal stresses were less differential in shale than in sandstone, reflecting perhaps the ductility of the former, was found in central Arkansas, where the horizontal principal stresses in the Hartshorne sandstone at a depth of 55 m were 5 MPa and 8 MPa, while in the Atoka shale at 118-131 m they were 3.5 MPa and 5.5 MPa. In this case stress directions were relatively unchanged between the two formations.

A different type of stress decoupling was found in the Underground Research Laboratory near Pinawa, Manitoba, where six HF stress measurement campaigns were conducted in the Lac-du-Bonnet granite above and below a gently dipping fracture zone (also referred to as a reverse fault) at about 275 m depth. Here the relatively uniform linear increase in principal stresses with depth between 50 and 275 m came to

an abrupt stop in the fault zone, below which both the stress magnitudes and their increase with depth differed. Moreover, the average σ_H direction jumped spectacularly from N66ºE above the zone to N66ºW below it.

Finally, a strange stress-depth profile was registered at Reydarfjordur, Iceland. Here HF stress measurements conducted independently by two groups in the top 600 m of a scientific borehole in a sequence of lava flows and basalt dykes, showed consistent linearly increasing principal stresses with depth between 50 and 300 m, indicating a reverse faulting regime. Between 300 m and 400 m, however, the two horizontal stresses increased with depth at a much faster rate, followed by an equally rapid decrease between 400 m and 500 m such that below that depth the stress regime became one favoring normal faulting. This surprising stress-depth behavior has never been explained satisfactorily.