GEOPHYSICAL WELL-LOG ANALYSIS IN CHARACTERIZING THE HYDROLOGY OF CRYSTALLINE ROCKS OF THE CANADIAN SHIELD

by

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ABSTRACT

A full suite of geophysical logs, including nuclear, electric, acoustic transit-time, acoustic waveform, and acoustic televiewer logs, and high-resolution flowmeter measurements have been used to investigate the lithologic and hydrologic properties of three igneous plutons located on the southern margin of the Canadian shield. Geophysical logs were used to identify lithologic boundaries, determine the properties of unfractured granitic or gabbroic rocks, interpret and calibrate the results of surface geophysical surveys, and characterize permeable fracture zones that could serve as conduits for fluid migration. Nuclear and acoustic transit-time logs provided good quantitative correlation with changes in lithology. Electric logs yielded consistent qualitative correlations, with lower resistivities associated with more mafic lithologies. Lithologic contacts indentified on logs generally confirmed the results of surface electromagnetic, seismic, and gravity surveys. All major fracture zones intersected by boreholes were clearly indicated by the geophysical logs. Electric, epithermal-neutron, and acoustic transit-time logs gave the most consistent indications of fracturing, but the lithologic responses associated with some thin mafic intrusions were difficult to distinguish from possible fractures, and some steeply-dipping fractures were not indicated by conventional acoustic transit-time logs. Electric and neutron log response is attributed to the effect of clay minearl alteration products in the vicinity of fractures. This alteration may be indirectly related to permebaility, but no direct relationship between resistivity or neutron attenuation and permeability appears to exist. Tube-wave attenuation determined from acoustic waveform logs was related to the transmissivity of equivalent infinite, plane fractures; these results agree qualitatively, and possibly quantitatively with packer isolation and injection tests if the combined effects of differing scales of investigation and borehole enlargements in fracture zones are taken into account. Tube-wave attenuation in waveform logs also compares well with the permeability distributions determined from tube-wave generation in vertical seismic profiles.

Comparison of conventional geophysical logs, acoustic televiewer images of the borehole wall, and fracture frequency distributions measured on core samples indicates that many fractures are completely sealed and have no effect on log response, whereas many more apparently sealed fractures have been slightly opened during drilling, and do provide some log response. High resolution flowmeter meaurements of natural flow in boreholes and comparison of packer isolation tests with log data indicate that a relatively few individual fractures often provide a large proportion of fracture zone transmissivity in the immediate vicinity of the borehole, and that the orientation of these fractures may not coincide with fracture zone orientation. These results indicate that the scale problem in relating borehole logs to regional configuration of fracture flow systems may be the most important consideration in the appplication of geophysical well logging to the characterization of ground water flow in crystalline rock bodies.

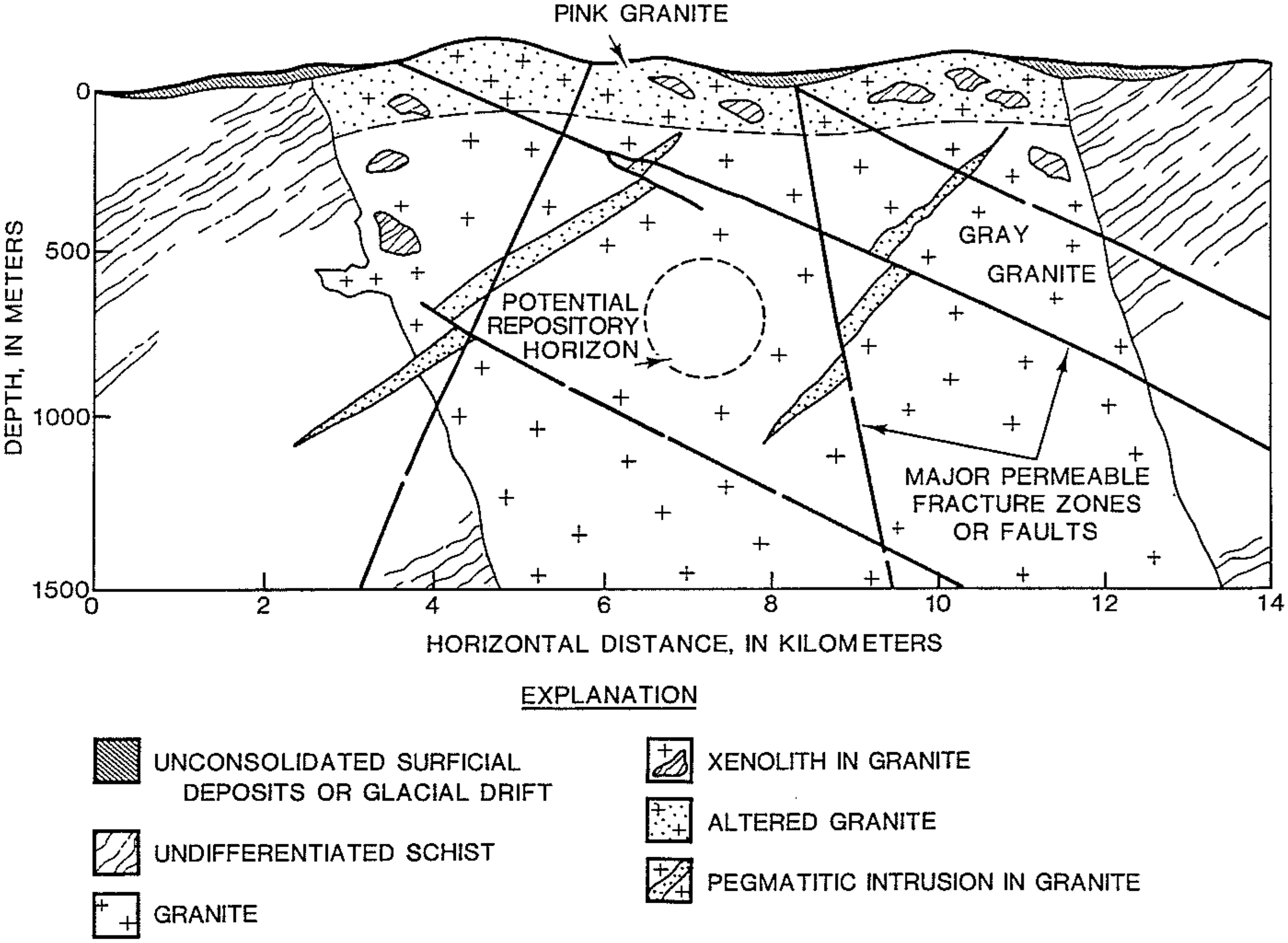

Figure 1: Idealized cross-section of fractured granitic intrusion in the Canadian shield, illustrating major fracture zones, depth of weathering, contact with country rock, and xenoliths; individual and isolated fractures not shown.

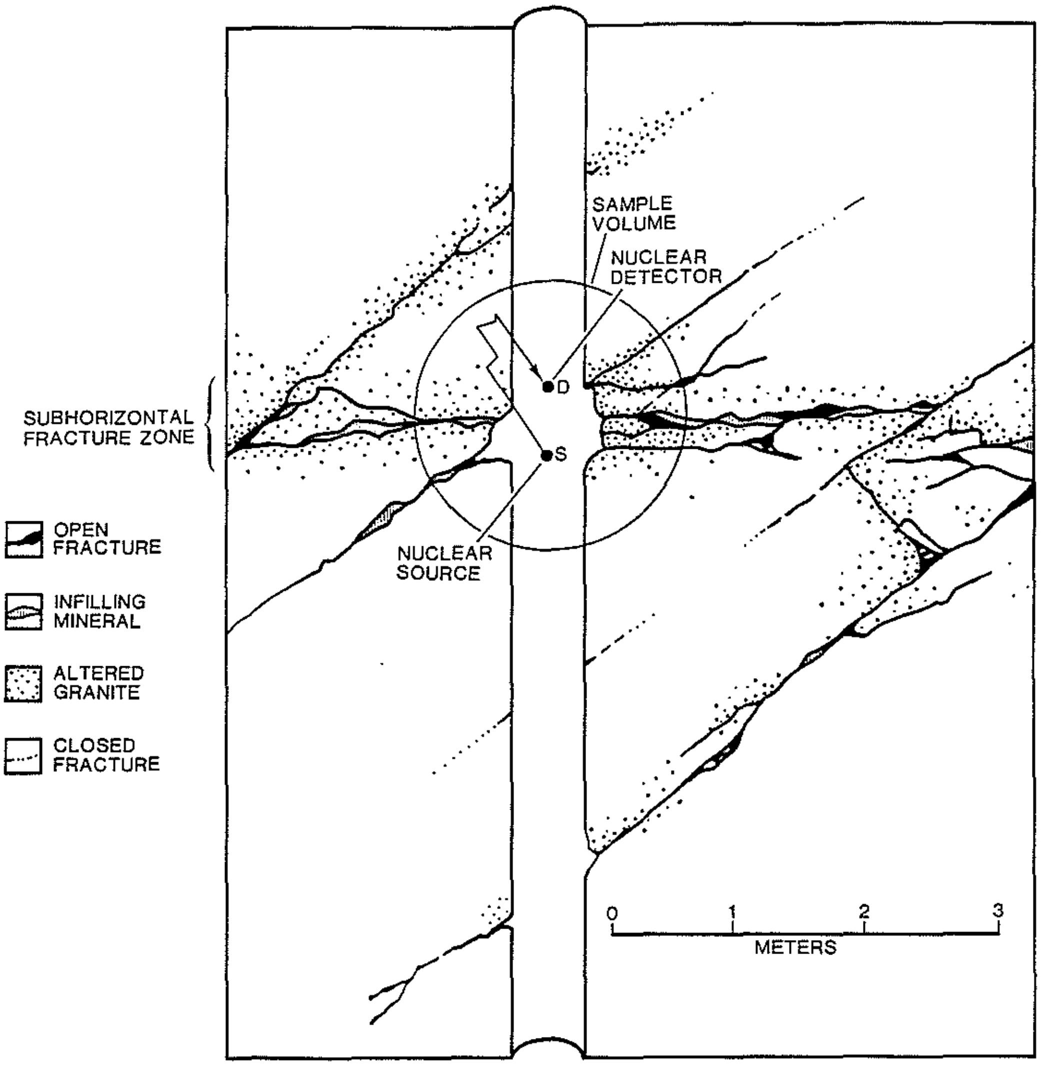

Figure 2: Illustration of typical fracture zone showing alteration of granite, infilling minerals, fracture interconnections, damage to fractures at the borehole wall, and contribution of fracture zone to geophysical sampling volume.

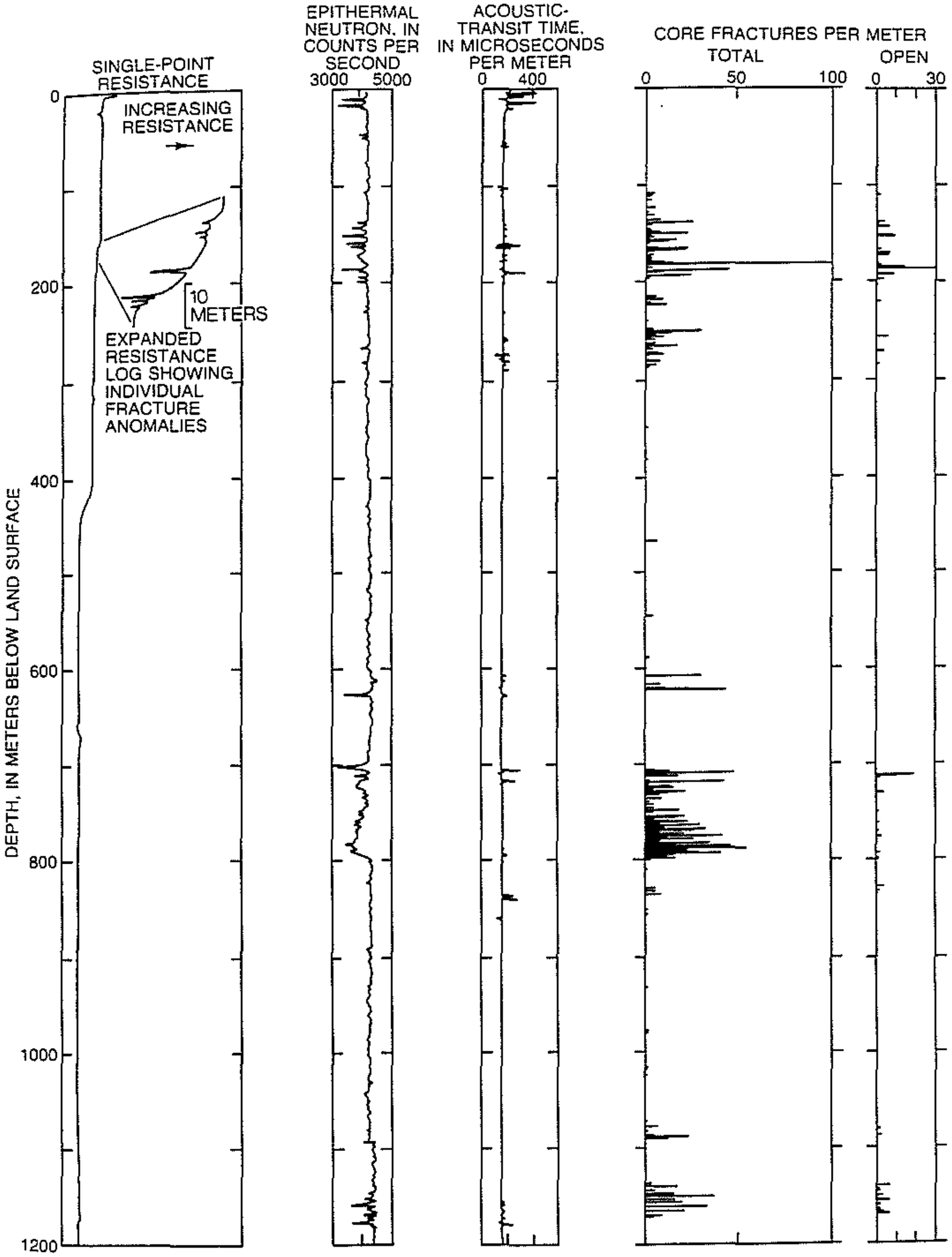

Figure 3: Comparison of geophysical logs to incidence of open and sealed fracture in orientated core for borehole with nearly complete core recovery.

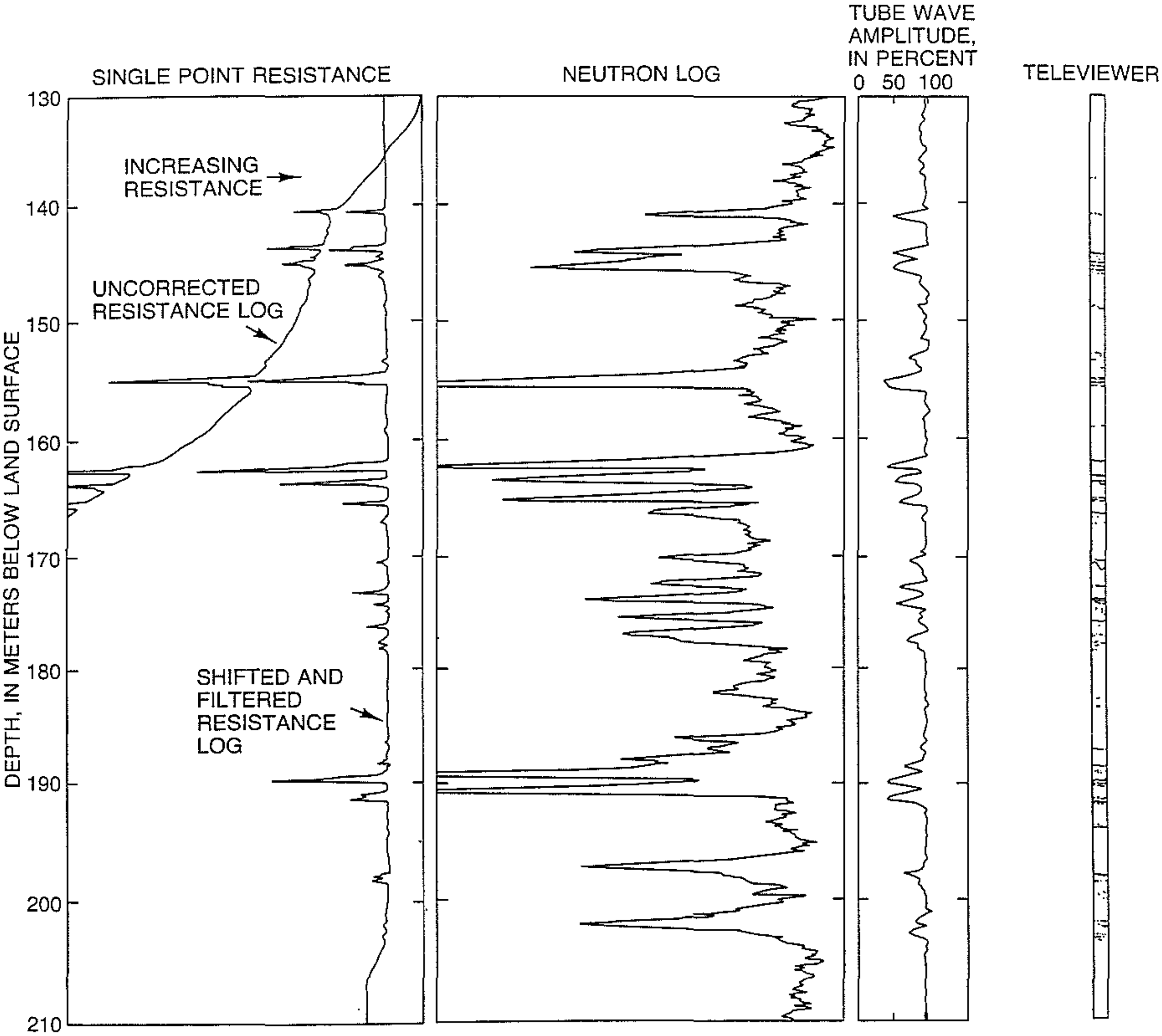

Figure 4: Differential single point and epithermal neutron (uncompensated) logs compared to fracture incidence indicated on televiewer log.

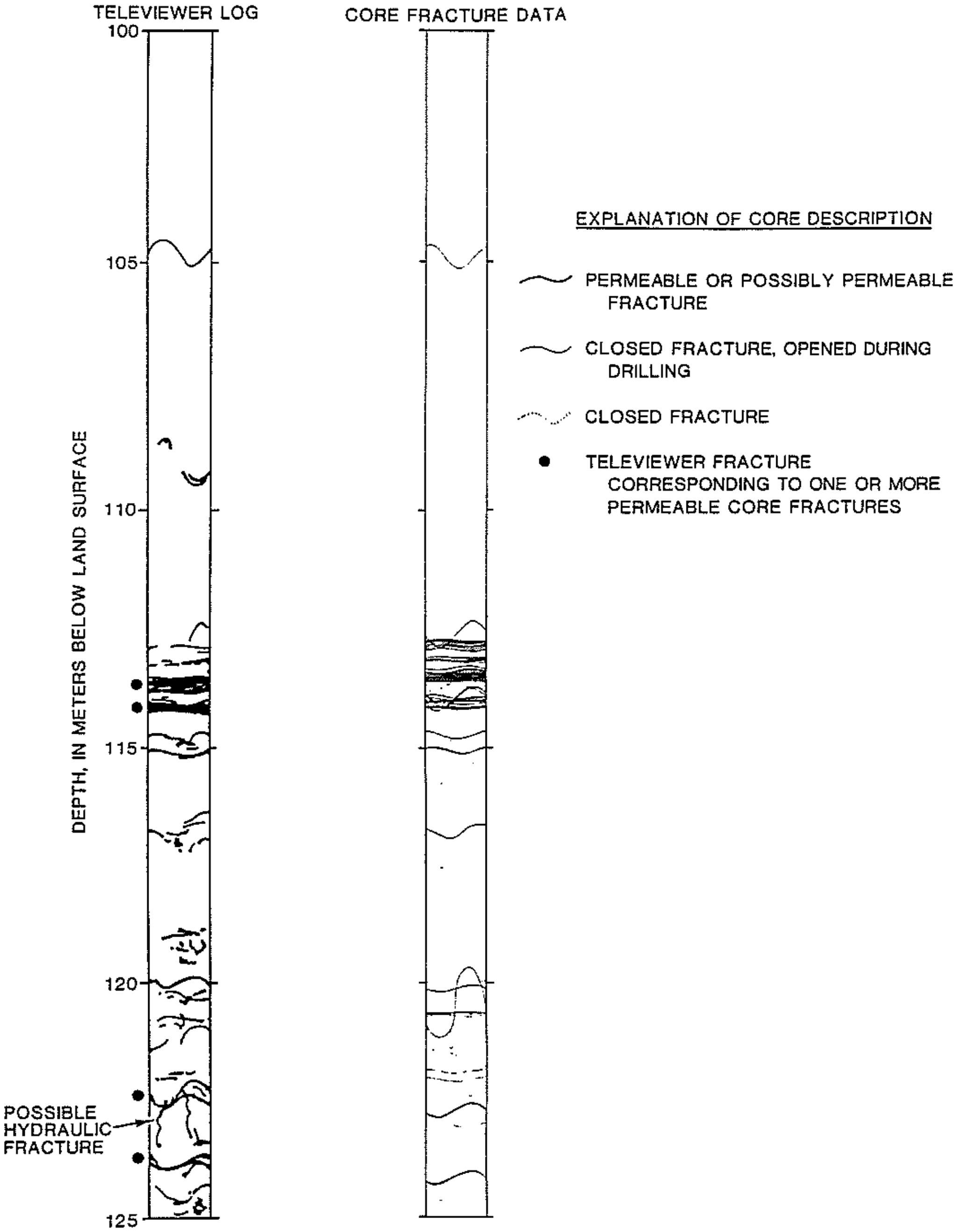

Figure 5: Comparison of acoustic televiewer log with orientated core fracture data (plotted in televiewer log format).

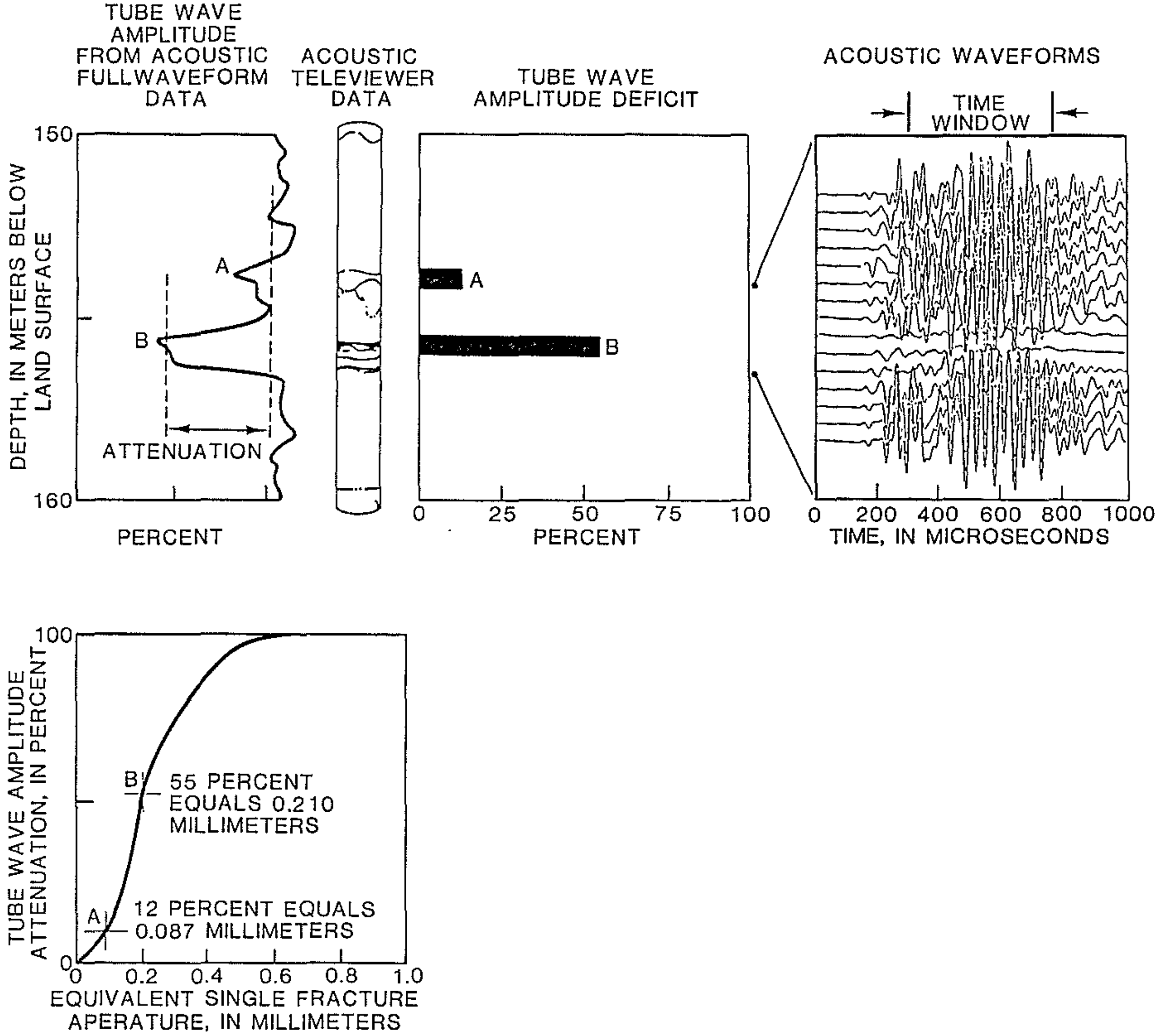

Figure 6: Estimating fracture permeability using tube-wave attenuation.

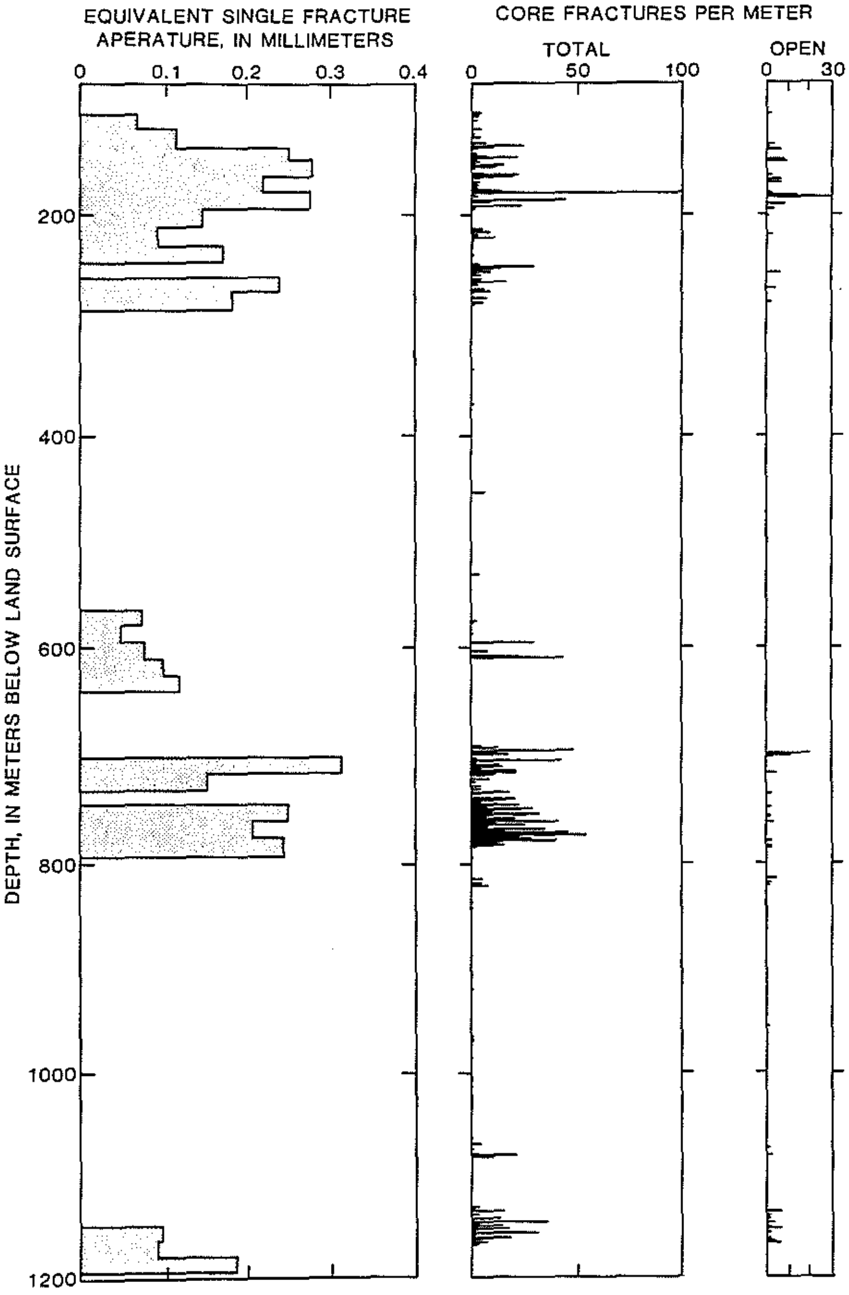

Figure 7: Estimated hydraulic aperture of equivalent single infinite fracture from tube-wave attenuation compared to frequency of open and closed fractures in core (waveforms obtained with 34 kHz source).

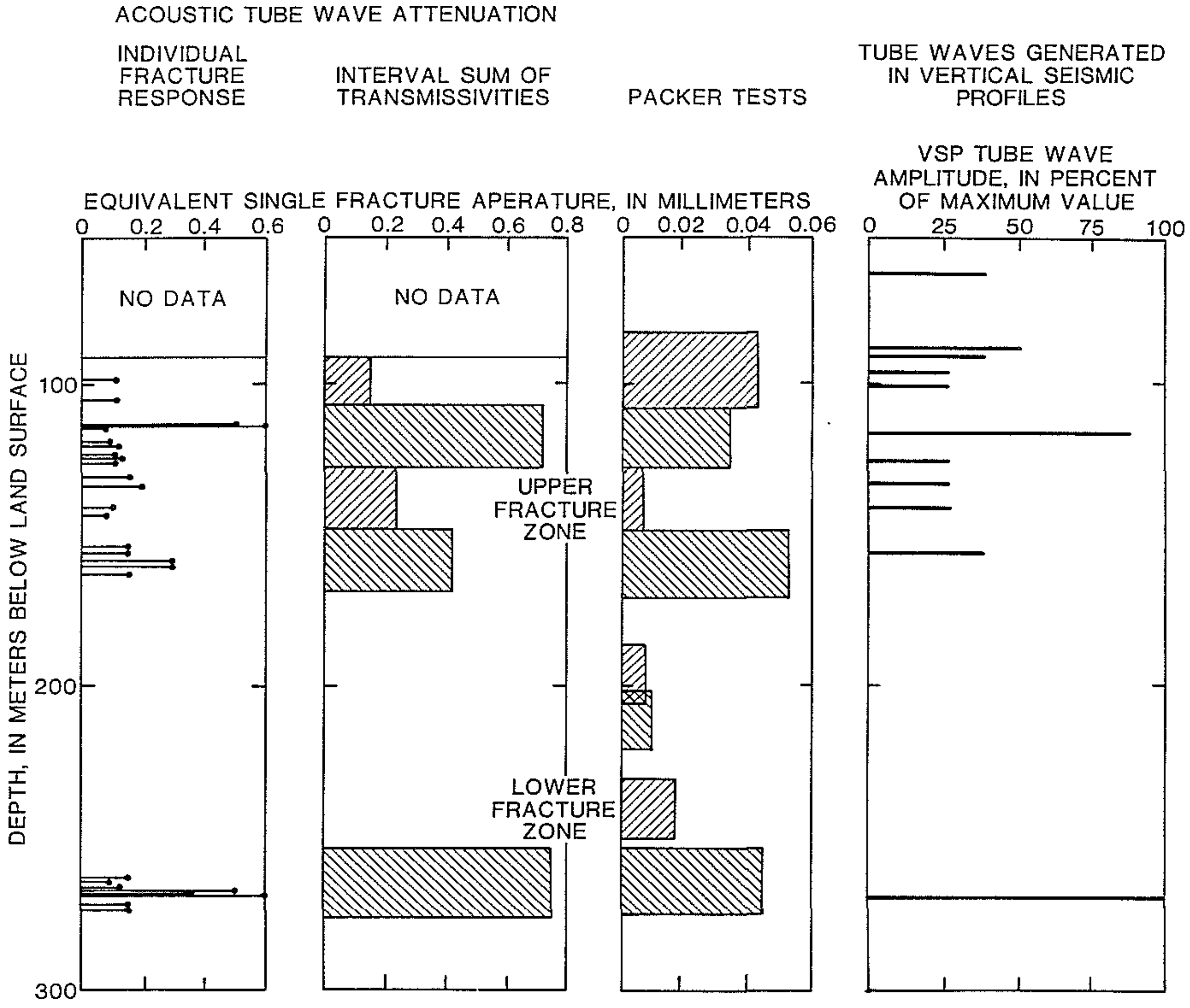

Figure 8: Comparison of fracture permeability given in equivalent single fracture aperture with packer tests and VSP tube wave data (waveform logs obtained with 34 kHz source).

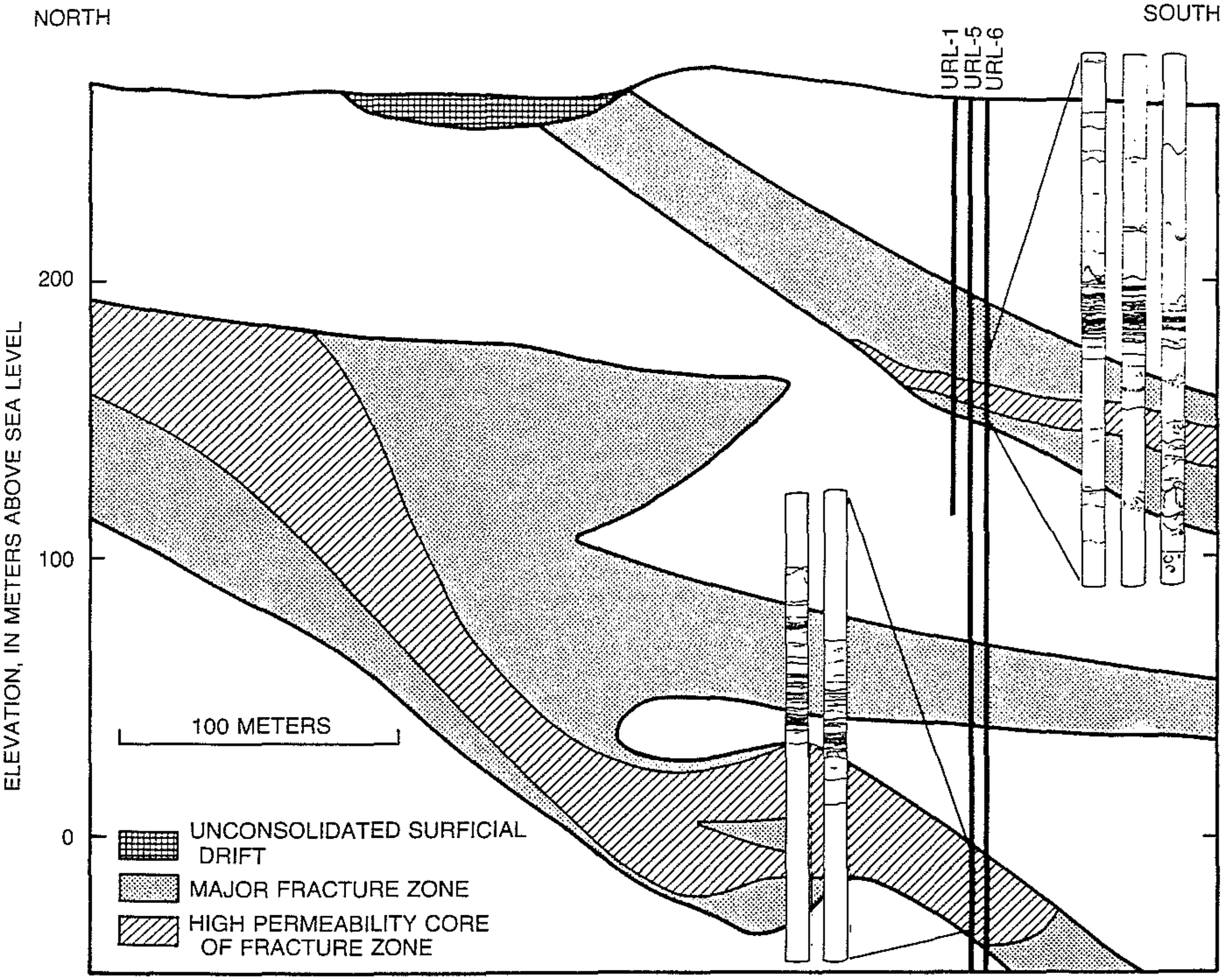

Figure 9: Geologic cross-section showing variability of fracture zones.

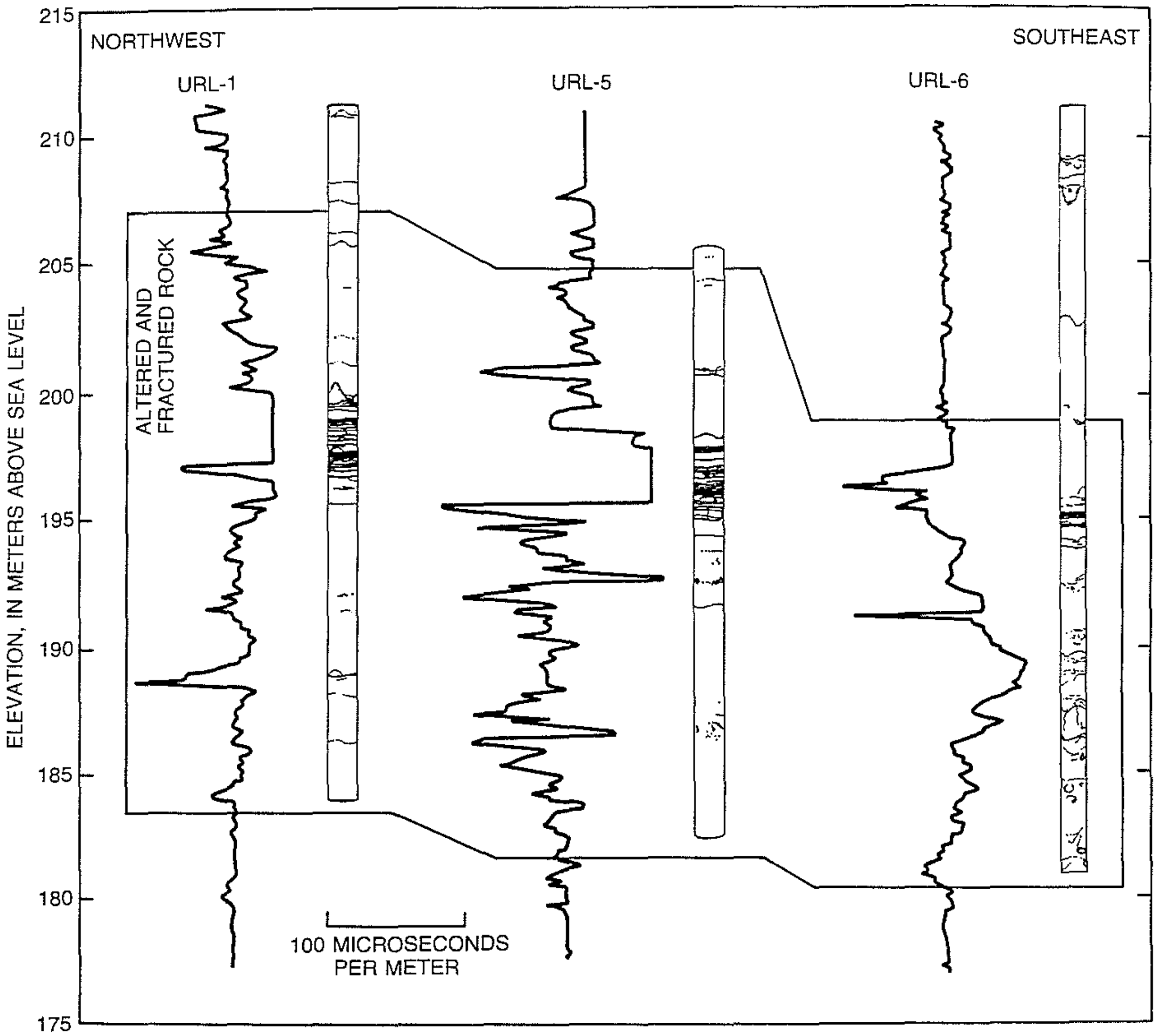

Figure 10: Acoustic logs indicating the extent of alteration and fractures along three adjacent boreholes penetrating the same fracture zone; there are approximately 50 m between boreholes in the plane of Figure 9.

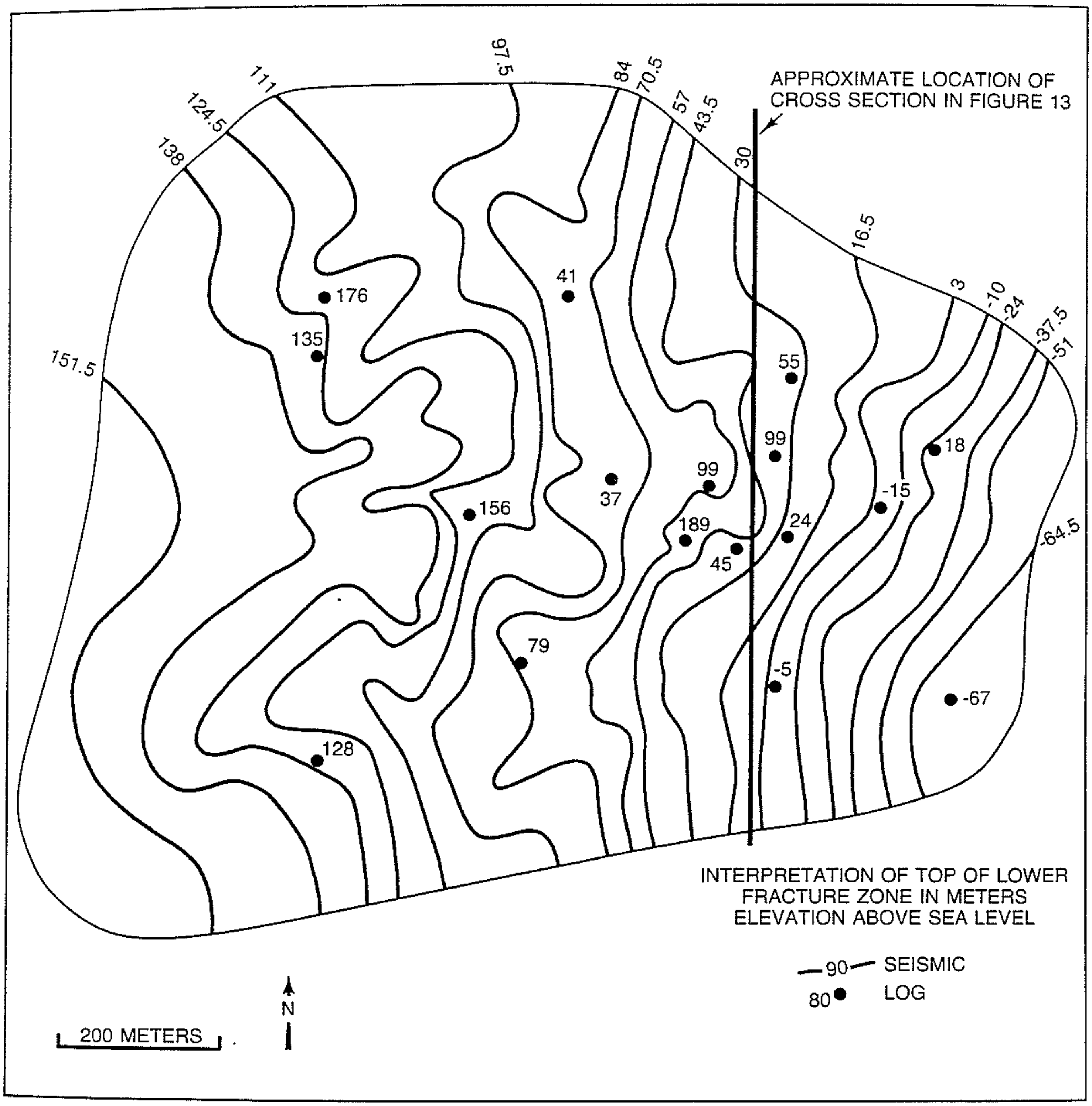

Figure 11: Comparison of the top of the lowermost fracture zone in Figure 9 as interpretted form surface seismic reflections and geophysical logs.

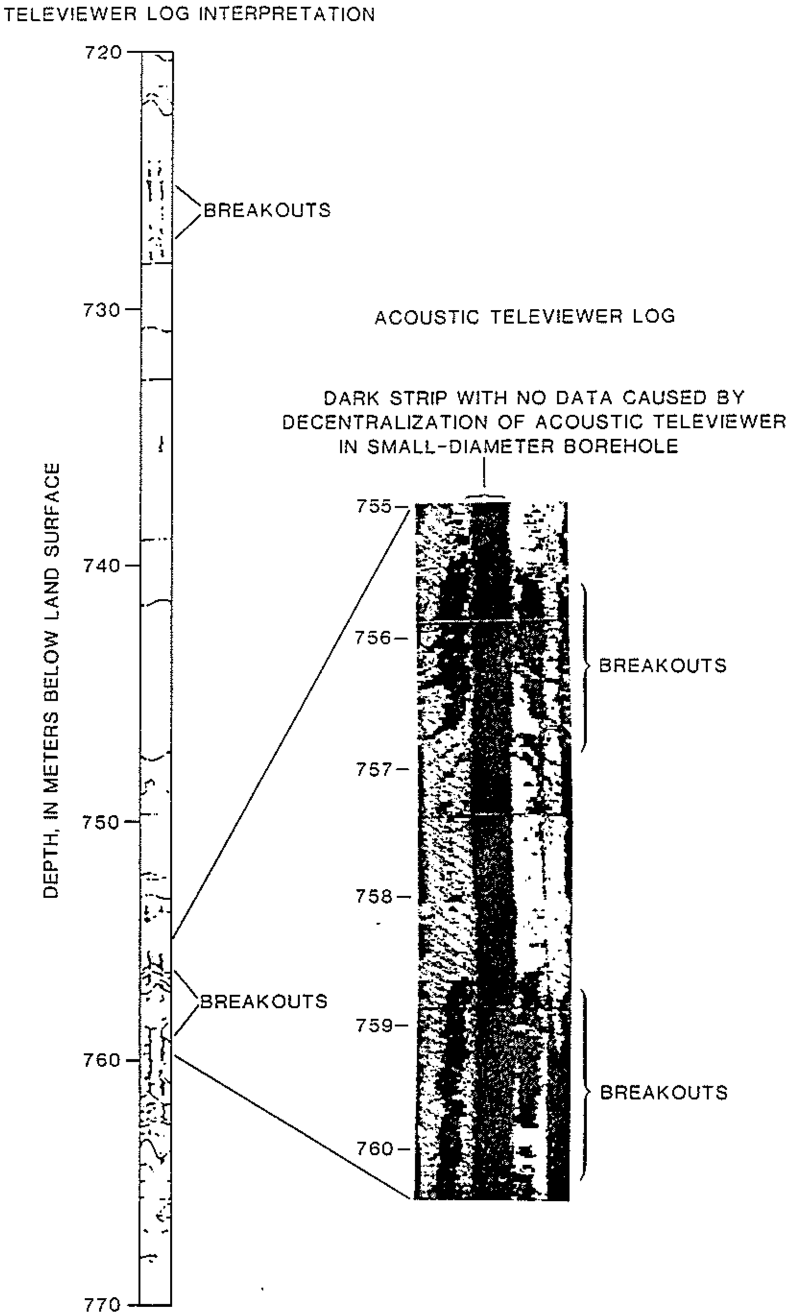

Figure 12: Televiewer log indicating stress concentration and reorientation wsithin fracture zone because borehole wall breakouts are limited to a single deep fracture zone; fracture distribution along the complete borehole is indicated in Figure 7.