DEFORMATION ACROSS AND NEAR EARTH FISSURES: MEASUREMENT TECHNIQUES AND RESULTS

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Deformation across and near earth fissures is complex and requires varied and extensive instrumentation to determine depth and type of active fissure movement (see Haneberg and Friesen abstract for related discussion of deformation measurements near an earth fissure in New Mexico). Measurements that augment one another include measurements on several different scales, continuous measurements and seasonal repeated surveys (table 1), and combined vertical, horizontal, and tilt measurements.

Table 1. Methods of measurement of horizontal strain.

Method	Approximate range or span, in meters	Approximate resolution	
		Millimeters	Microstrain
Differential Global Positioning System	>30,000	5	2
Electronic distance measurement	>16,000	1	2
Tape extensometry	30	.3	10
Invar-wire extensometer	>30	.001	.03
Pyrex tube and dial gage	3	.0001	.3
Quartz tube and transducer	3	.00001	.003

Precise leveling has a resolution of 0.1 to 0.2 mm or 0.1 microradian for double-run lines as much as 1 km long. Biaxial tiltmeters with AC voltage output for continuous recording have a resolution of 0.1 microradian. Most measured fissure movement has been less than the measurement error for differential Global-Positioning-System (GPS) surveys. Thus, GPS alone is generally inadequate for monitoring fissure movement. However, GPS serves exceptionally well for establishing a fixed frame of reference from which to make the finer measurements.

Three elastic models that explain fissure development and movement are (1) bending of a plate or beam above a horizontal discontinuity in compressibility (Lee and Shen, 1969), (2) dislocation theory representing a fault or tensile crack (Okada, 1985; Holzer and others, 1979; Carpenter, 1993), and (3) upward propagation of tensile strain in response to draping of a material over a horizontal discontinuity in compressibility (Haneberg, 1992; see Haneberg abstract). These three mechanisms probably act together at all earth fissures and are here grouped in the term *generalized differential compaction*. In each case, the horizontal discontinuity can be an edge of a bedrock bench, a mountain-bounding fault, a bedrock high, or a facies change; and, the driving force is differential compaction caused by increased effective stress, which is in turn caused by aquifer-system hydraulic-head decline. The inherent assumption in dislocation modeling is that the differential compaction is concentrated along specific planes such as preexisting faults.

A study was done near Picacho in south-central Arizona from 1980 to 1984 to test hypotheses of earth-fissure movement associated with hydraulic-head fluctuation (see Pool #1 abstract for related landsubsidence information for the Picacho Basin, Arizona). Vertical and horizontal displacements were monitored along a single survey line normal to the Picacho earth fissure, while ground-water levels were monitored in shallow and deep piezometers set in each of two test holes on opposite sides of the fissure (fig. 1) and used to compute the aquifer-system hydraulic head. The survey line extends from a bedrock outcrop (fixed reference frame) in the Picacho Mountains on the east, past an observation well near the fissure, to a point 1,422 m to the west. The survey line consists of nine closely spaced monuments (G-O) for tape extensometry and leveling near the fissure and eight widely spaced monuments for electronic distance measurements and leveling elsewhere along the line. From May 1980 to May 1984, the western, downthrown side of the fissure subsided 167 mm and moved 18 mm westward into the basin. Concurrently, the eastern, relatively upthrown side subsided 147 mm and moved 14 mm westward. Thus, the fissure itself translated toward the center of the basin. Dislocation modeling of deformation along the survey line near the fissure suggests that dip-slip movement occurred along a vertical fault surface that extends from the land surface to a depth of about 300 m.

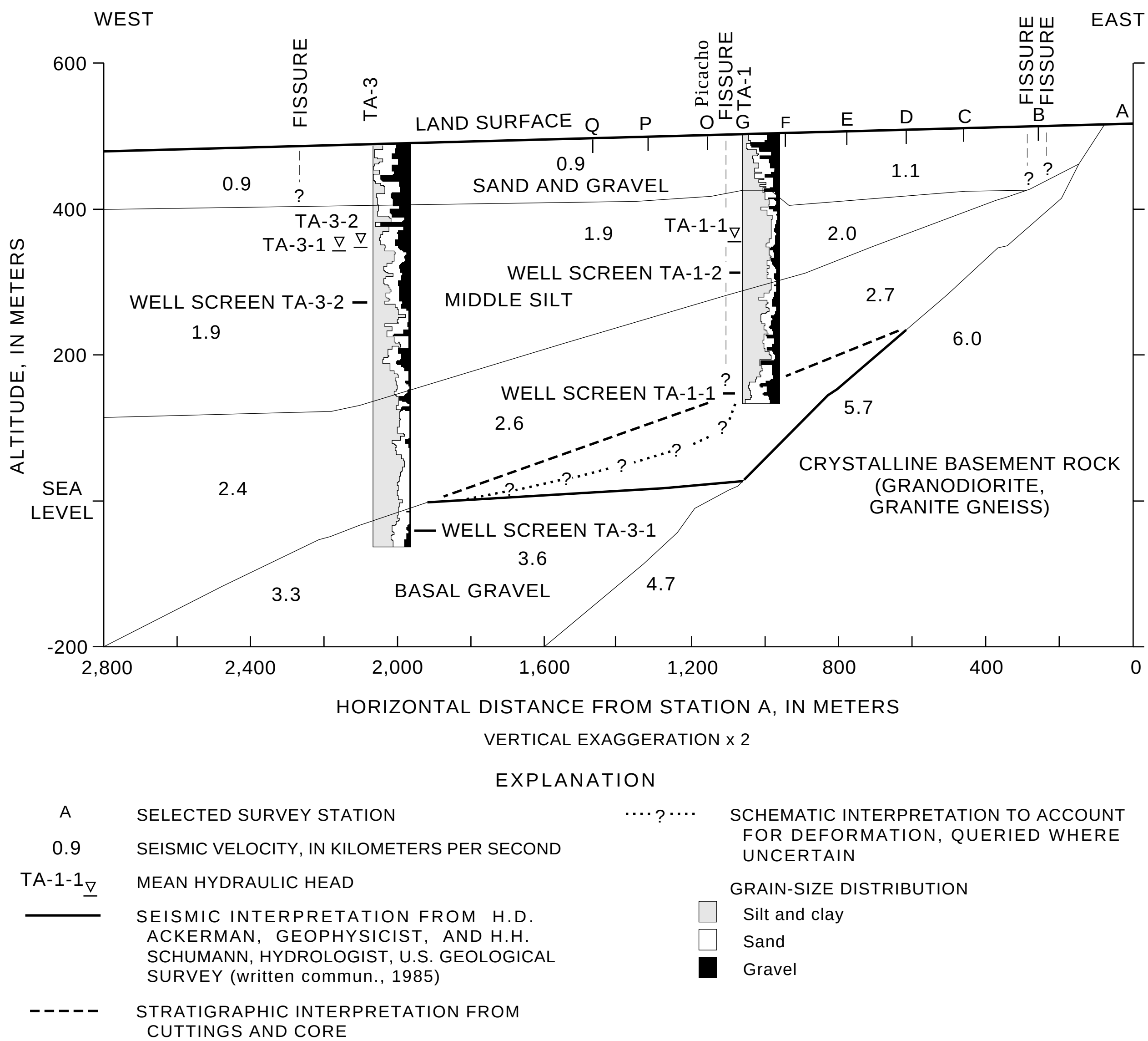

Figure 1. Geologic section constructed from seismic refraction profile and grain-size distribution for test holes TA-1 and TA-3 near Picacho earth fissure.

Continuous measurements were made of horizontal movement across the fissure using a buried invar-wire horizontal extensometer, while ground-water-level fluctuations were continuously monitored in four piezometers nested in two observation wells (fig. 1). Opening and closing movements of the fissure were smooth and were correlated with aquifer-system hydraulic-head decline and recovery, respectively, measured in the nearby piezometers and with aquifer-system compaction and hydraulic-head fluctuation at Eloy, Arizona, 12 km west in the central part of the basin (see Haneberg and Friesen abstract for related finding for an earth fissure in the Mimbres Basin, New Mexico). Pearson correlation coefficients between the hydraulic-head fluctuations measured in the deeper piezometers, TA-1-1 and TA-3-1, and horizontal movement ranged from 0.913 to 0.925, indicating that differential compaction in the deeper alluvium is the driving force for fissure movement at the study site (fig. 2). The hypothesis of horizontal seepage stresses is not supported at the study site because of the low correlation between fissure movement and horizontal head gradients such as between TA-1-1 and TA-3-1. Correlograms of hydraulic-head decline as ordinate and horizontal strain as abscissa for TA-1-1 and TA-3-1 exhibit hysteresis loops for annual cycles of water-level fluctuation as well as near-vertical excursions for shorter cycles of pumping and recovery, indicating the usefulness of a viscoelastic model such as a Kelvin substance for deformation associated with aquifer-system compaction.

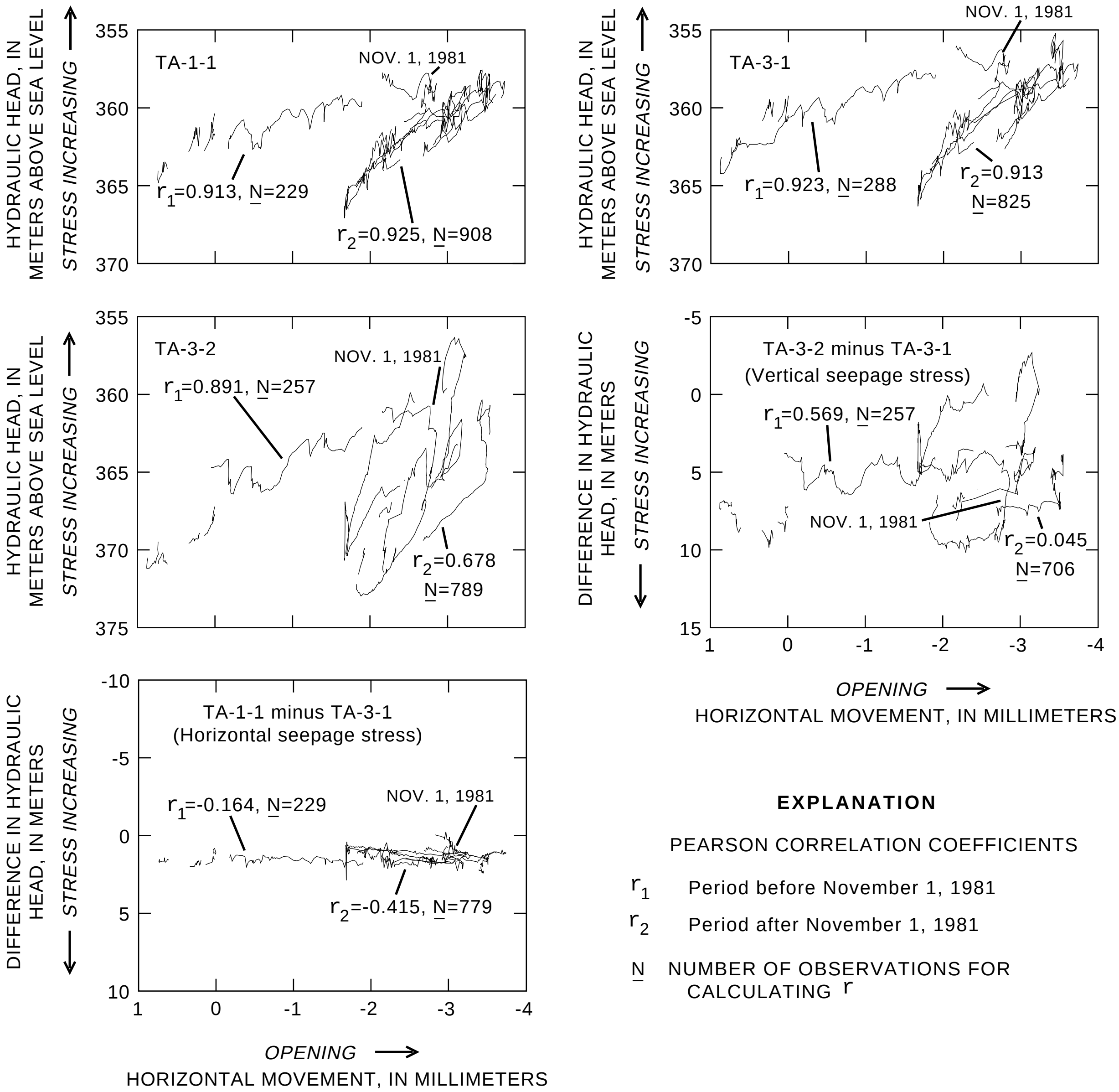

Figure 2. Correlation of horizontal movement with hydraulic-head fluctuations measured in piezometers near the Picacho earth fissure.