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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EARTH FISSURES AND LOCALIZED DIFFERENTIAL SUBSIDENCE

by

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Abstract

Long tension cracks caused by declines of ground-water level at four sites in Arizona, California, and Nevada occur at points of maximum, convex-upward curvature in subsidence profiles based on relevelings of closely-spaced bench marks aligned perpendicular to the cracks. We conclude the cracks are caused by horizontal strains associated with the differential subsidence.

Earth fissures, long tension cracks with negligible vertical offset (Holzer, 1977), are caused by declining ground-water levels in at least eight areas in the western United States and Mexico. Although several mechanisms have been proposed to explain the source of the tension causing these fissures, none have been corroborated by geodetic measurements. In this report, we describe geodetic data which reveal that linear fissures at four sites in Arizona, California, and Nevada are coincident with zones of localized differential subsidence. At all four sites, the fissures occur at points of maximum, convex-upward curvature. Because horizontal strains are inferred to be a maximum at these points, we conclude that differential subsidence, probably caused by differential compaction, is the mechanism that caused the earth fissures. Horizontal extension across the fissures was measured at all sites but the one in Nevada where no horizontal measurements were made.

The earth fissures investigated are in areas of land subsidence caused by man-induced compaction of unconsolidated alluvium. Closely-spaced bench marks were set in lines perpendicular to each fissure and were precisely leveled, except where noted, to First-Order, Class I, standards as defined by the National Geodetic Survey (Federal Geodetic Control Committee, 1974). Such leveling has a nominal accuracy of 1.5 mm $\sqrt{K}$, where K is the distance in kilometers between marks. Changes of elevation with time at each fissure were computed based on relevelings to these same standards.

Fissures at sites 1 and 2 are 61 km southeast of Phoenix, Arizona, in the northern part of the Picacho basin. An area of more than 1200 km^2 underlain by unconsolidated alluvium within this basin has subsided more than 30 cm (Jachens and Holzer, 1979) in response to water-level declines that locally have exceeded 100 m. Earth fissures are widespread (Laney and others, 1978). No bench marks with long-term histories of releveling are available, however, to evaluate subsidence near fissures at sites 1 and 2. Both fissures investigated began to form sometime between January 1970 and November 1975, based on aerial surveys. By November 1975, the ends of the fissure at site 1 had formed but had not yet joined to form a single continuous fissure. In May 1976, a pair of bench marks, 30 m apart across the projection of the segments, was set in the gap between the segments with vertical and horizontal positions determined relative to each other. Subsequently, between February and October 1977, a fissure connecting the two segments occurred between the two bench marks. At site 2, a similar pair of bench marks was set in May 1976 on the projection of the western end of another fissure. By October 1976, the western end of this fissure had extended between the two marks. At both sites, closely-spaced bench marks were set in April 1978 along the lines defined by the pairs of bench marks. These lines run in both directions from the fissures with each line reaching stable crystalline bedrock on one end. Based on releveling of the lines in March 1979, both fissures are at points of maximum, convex-upward curvature in the subsidence profiles (figs. 1A and 1B). Horizontal extension at sites 1 and 2, based on each pair of bench marks spanning the fissures, of 12 and 29 mm, respectively, was measured from May 1976 to March 1979 by precise chaining, accurate to ±1 mm (figs. 2A and 2B). The horizontal extension was measured at the point of maximum curvature in the subsidence profiles. At both sites, except at site 2 for the time period bounding the formation of the earth fissure, the extension appears to have occurred by a creeping motion, at least at the frequency of our measurements. Relative movement of the land surface across the fissures during this time period was dominantly horizontal and not vertical as shown by results from relevelings of the bench-mark pairs (figs. 2A and 2B). Leveling before April 1978 was with a Philadelphia rod and theodolite, accurate to ±1.5 mm.

Site 3 is in the northwestern part of the subsiding area in Las Vegas Valley, Nevada. Within the valley, water levels have locally declined more than 50 m (Harrill, 1976) and the land has locally subsided approximately one meter (Holzer, 1978a). Many earth fissures have been mapped (Patt and Maxey, 1978). Approximately 2 km south of the site, 66 cm of subsidence was measured from 1963 to 1973. The date of formation of the fissure at site 3 is unknown. Fissures were not reported in this area by Mindling (1971); however, many fissures north of, but along the trend of, the fissures at site 3 were observed by Holzer in February 1976. Based on these observations, garbage in the fissures, and the condition of the fissures, we speculate that they are not more than ten years old. The bench marks at site 3 were set and leveled by the Nevada Highway Department as part of a network in April 1978. Although their leveling did not conform to First-Order, Class I Standards, the procedures used and the shortness of the segment considered here indicate that the results probably are comparable to results from procedures adhering to First-Order standards. The line was releveled in March 1979 by the U.S. Geological Survey to First-Order standards, and the resulting changes in elevation are shown in Figure 1C. Because of the great distance to a bench mark demonstrably unaffected by ground-water withdrawal, the changes were computed relative to an arbitrary datum. The fissures clearly correlate with the part of the subsidence profile where its curvature is greatest and is convex upward. Horizontal control was not available to evaluate horizontal displacements over this same time period.

The fissure in California, site 4, is along a segment of the Garlock fault in Fremont Valley, California, where man-induced water-level declines of more than 80 m have occurred (Koehler, 1977). Ground failure is extensive within the area of Fremont Valley affected by water-level declines. Although leveling data are sparse, more than 30 cm of land subsidence within the valley can be documented. That at least some, if not all, of the subsidence is caused by man-induced compaction of sediments rather than tectonism is indicated by protruding water-well casings within the valley. Additional arguments for a nontectonic origin of surface displacements in Fremont Valley were summarized by Clark and others (1978). The fissure investigated formed between 1971 and 1975 (M. M. Clark, oral commun., 1979). A closely-spaced line of bench marks was set and leveled in April 1978. As at site 3, level surveys did not extend to a demonstrably stable bench mark, so that changes of elevation are relative and not absolute. Two relevelings of the line show that the fissure occurs at the point of maximum, convex-upward curvature in the subsidence profile (fig. 1D). Computed horizontal strains at site 4 (fig. 1D), based on repeated measurements with an electronic distance meter, suggest that horizontal extension is occurring at the point of maximum, convex-upward curvature. Rebound from September 1978 to January 1979 provides further evidence that the surface displacements are related to declines of ground-water level rather than tectonism. The rebound correlates with large water-level recoveries observed on that side of the Garlock fault. Riley (1969) documented elastic response of aquifers to water-level recoveries, and the magnitude of the response observed here is consistent with such a mechanism.

In summary, earth fissures at four sites in Arizona, California, and Nevada are associated with zones of localized differential subsidence. Because the fissures occur near the point of maximum, convex-upward curvature in the profiles, we conclude that the earth fissures were caused by horizontal strains induced by the differential subsidence, a process that has been documented by Lee and Shen (1969). At the two sites in Arizona and the site in California, horizontal extension across the fissures was measured. Although not documented here, we believe the most likely cause of the differential subsidence is differential compaction controlled by either pre-existing faults or different thicknesses of unconsolidated alluvium (e.g. see Holzer, 1978b; and the discussion of sites 4 and 5 in Jachens and Holzer (1979) which correspond to sites 1 and 2 in the present report, respectively). Recognition that these four different sets of earth fissures are associated with zones of localized differential subsidence indicates a method, based on precise vertical control surveys of closely-spaced bench marks, by which locations of potential earth fissures can be identified in areas with declining ground-water levels. Such surveys easily could be conducted near planned or existing major engineered structures as well as within urban areas where earth fissures are a potential hazard. The results presented here, obtained after only one year of monitoring, indicate that evaluations could be made after relatively short time periods.

Whether this conclusion can be extended to all fissures in alluvium remains to be demonstrated. The fissures investigated here are linear to curvilinear; fissures forming polygonal patterns were not included in this study. Such fissures are believed to form in response to soil moisture changes (Neal and others, 1968), and it is not clear to us that differential subsidence across these fissures would occur before failure.

References

Clark, M. M., Buchanan-Banks, J. M., and Holzer, T. L., 1978, Creep along parts of the Garlock fault: possible relation to decline in ground-water levels: Geological Society of America Abstracts with Programs, v. 10, no. 3, p. 100.

Federal Geodetic Control Committee, 1974, Classification standards of accuracy, and general specifications of geodetic control surveys: U.S. Department of Commerce National Ocean Survey, Rockville, Maryland, 12 p.

Harrill, J. R., 1976, Pumping and ground-water storage depletion in Las Vegas Valley, Nevada, 1955-74: Nevada Water Resources Bulletin No. 44, 69 p.

Holzer, T. L., 1977, Ground failure in areas of subsidence due to ground-water decline in the United States in Land Subsidence: International Association of Hydrological Sciences, pub. no. 121, p. 423-433.

_______1978a, Documentation of potential for surface faulting related to ground-water withdrawal in Las Vegas Valley, Nevada: U.S. Geological Survey Open-File Report 78-79, 10 p., Denver, Colorado.

_______1978b, Results and interpretation of exploratory drilling near the Picacho fault, south-central Arizona: U.S. Geological Survey Open-File Report 78-1016, 17 p., Denver, Colorado.

Jachens, R. C., and Holzer, T. L., 1979, Geophysical investigations of ground failure related to ground-water withdrawal--Picacho basin, Arizona: Ground Water in press .

Koehler, J. H., 1977, Ground water in the Koehn Lake Area, Kern County, California: U.S. Geological Survey Water-Resources Investigations 77-66, 24 p.

Laney, R. L., Raymond, R. H., and Winikka, C. C., 1978, Maps showing water-level declines, land subsidence, and earth fissures in south-central Arizona: U.S. Geological Survey, Water-Resources Investigations 78-83.

Lee, K. L., and Shen, C. K., 1969, Horizontal movements related to subsidence: American Society of Civil Engineers Journal of Soil Mechanics and Foundation Division, v. 94, no. SM6, p. 140-166.

Mindling, A. L., 1971, A summary of data relating to land subsidence in Las Vegas Valley: Center for Water Resources Research, Desert Research Institute, Reno, Nevada, 55 p.

Neal, J. T., Langer, A. M., and Kerr, P. F., 1968, Giant desiccation polygons of Great Basin playas: Bulletin Geological Society of America, v. 79, p. 69-90.

Patt, R. O., and Maxey, G. B., 1978, Mapping of earth fissures in Las Vegas Valley, Nevada: University of Nevada Water Resources Center, pub. no. 41051, 19 p.

Riley, F. S., 1969, Analysis of borehole extensometer data from central California _in_ Land Subsidence: International Association Hydrological Sciences, pub. no. 89, p. 423-431.

Figure Captions

Figure 1. Profiles of changes of elevation on level lines perpendicular to earth fissures (Subsidence is positive). A. Site 1, Picacho basin, Arizona; B. Site 2, Picacho basin, Arizona; C. Site 3, Las Vegas Valley, Nevada; and D. Site 4, Fremont Valley, California. Horizontal strains at site 4 were computed from measured changes in horizontal position of bench marks from April 13 to September 14, 1978 (Extension is positve).

Figure 2. Relative horizontal and vertical displacements of pairs of bench marks ± 15 m from fissures at sites 1 and 2, Picacho basin, Arizona. Displacement of basinward bench mark relative to bench mark closest to crystalline bedrock is shown (Extension and subsidence are positive).

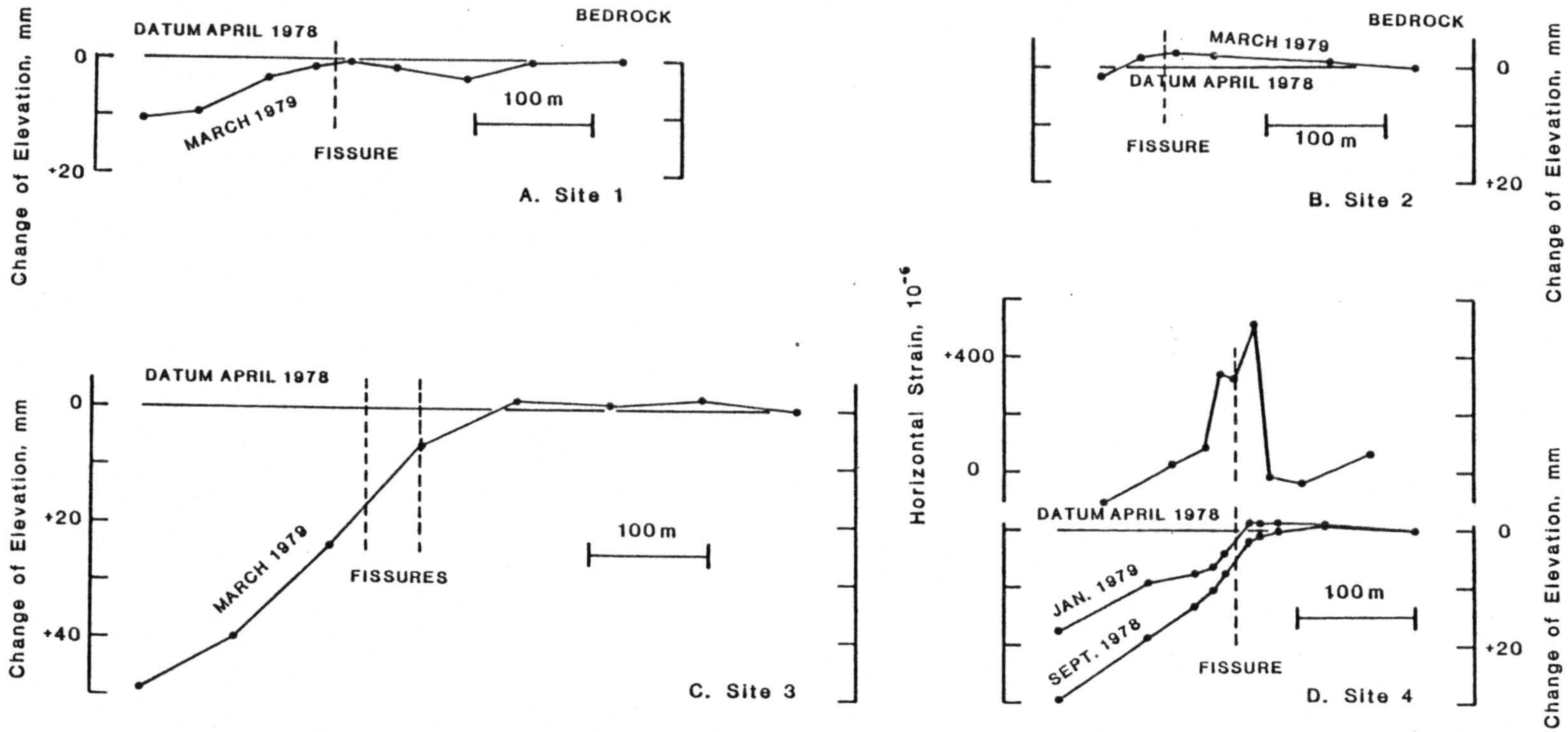
Change of Elevation, mm
0
+20
DATUM APRIL 1978
MARCH 1979
FISSURE
BEDROCK
100 m
A. Site 1
BEDROCK
MARCH 1979
DATUM APRIL 1978
FISSURE
100 m
0
+20
B. Site 2
Change of Elevation, mm
Change of Elevation, mm
0
+20
+40
DATUM APRIL 1978
MARCH 1979
FISSURES
100 m
C. Site 3
Horizontal Strain, 10^{-6}
+400
0
DATUM APRIL 1978
JAN. 1979
SEPT. 1978
FISSURE
100 m
0
+20
D. Site 4
Change of Elevation, mm

Figure 1

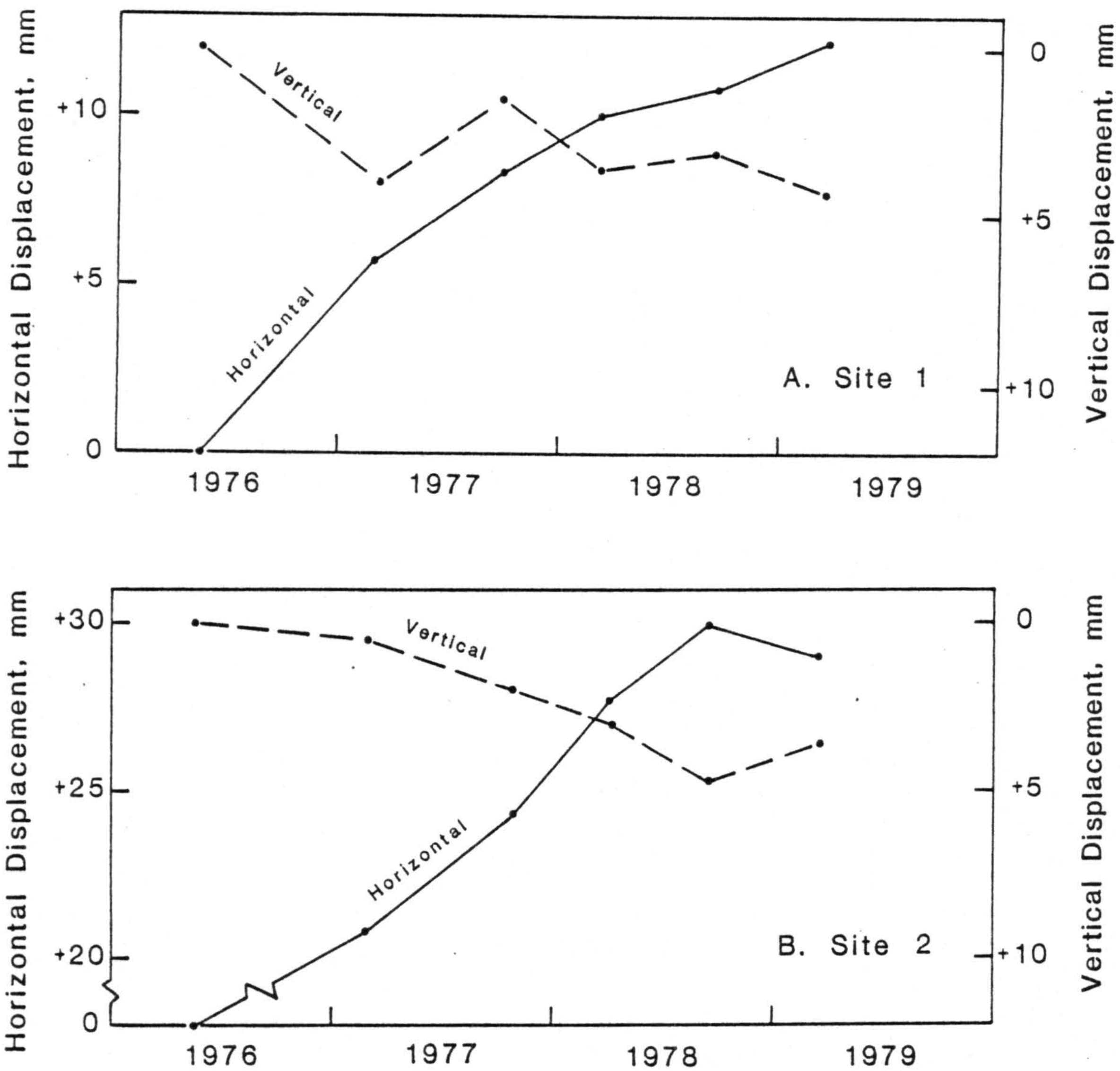
Horizontal Displacement, mm
+10
+5
0
Vertical
Horizontal
A. Site 1
Vertical Displacement, mm
0
+5
+10
1976
1977
1978
1979
Horizontal Displacement, mm
+30
+25
+20
0
Vertical
Horizontal
B. Site 2
Vertical Displacement, mm
0
+5
+10
1976
1977
1978
1979

Figure 2