EARTH FISSURES AND LAND SUBSIDEN

by Michael K. Larson and Troy L. Péwé

INTRODUCTION

Earth fissures—long, narrow, eroded tension cracks associated with land subsidence caused by ground-water withdrawal—have formed during the past 50 years in alluvial basins of southern and south-central Arizona (Leonard, 1929; Schumann, 1974; Laney, Raymond, and Winikka, C.W., 1978; Peirce, 1979; Jachens and Holzer, 1982). Until recently, the fissure hazard has been confined to outlying agricultural areas. In January 1980 a 400-foot-long fissure opened in Paradise Valley at a residential construction site of northeast Phoenix. This fissure is the first known occurrence in a densely populated, non-agricultural area of the state, and the first in the city of Phoenix.

Land subsidence and earth fissures pose serious problems for urban areas, with the potential for widespread damage to manmade structures. Well failure is a dramatic manifestation of subsidence as the casing collapses or the well head protrudes above the ground. Canals designed for gravity flow may overflow as a result of local sags and gradient reversals. Water and sewer mains that also depend on gravity flow may reverse flow or clog, and in extreme cases rupture, because of altered gradients. Subsidence may also necessitate new designs of storm drainage systems, and expensive, repeated levelings of benchmarks, resulting in obsolete surveying data. Fissures may directly damage buildings, roads, and other architectural structures. However, even without ground failure, differential subsidence in and of itself may cause damage to structures large in area or height.

Our recently completed study (Péwé and Larson, 1982) outlines in detail the problems of ground-water withdrawal, land subsidence, and earth fissuring in northeast Phoenix (Figure 1). The research consisted of a detailed gravity survey supplemented by geologic mapping, precise, repeated land surveying, and interpretation of well records. The city of Phoenix Engineering Department has provided logistical support, partial funding for the project, and has published the final report.

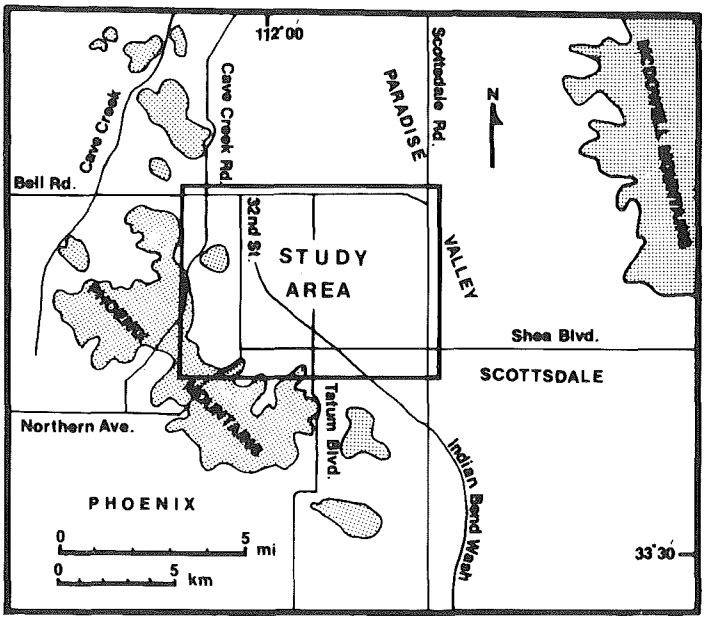

Figure 1. Map of Paradise Valley with study area outlined.

THE PHOENIX FISSURE

The fissure at 40th Street and Lupine Avenue opened 400 feet in an east-west direction, marked by hairline cracks, small open holes, and a linear opening 15 feet long, and as much as 8 feet deep and 15 inches wide (Figure 2). No vertical offset was observed; the fissure appeared to be an example of a tensional break. The crack appeared after locally heavy rains on the weekend of January 19, 1980. Such fissures have been commonly reported after rain showers or application of irrigation water, apparently because the cracks first open below the surface, only to be eroded later by downward percolation of the surface water. At the 40th Street construction site, the overlying soil cover had been scraped off, exposing the subterranean crack, and the collecting of rainwater in a retention basin eroded the large main cavity. The temporary halting of construction, modification of plans, hiring of consultants, and other expenses incurred as a result of the fissure are estimated by the owners of the subdivision to have cost them approximately $500,000.

HISTORY OF GROUNDWATER DEVELOPMENT AND LAND SUBSIDENCE

Water levels remained nearly constant in the study area prior to about 1950, generally within 250 feet of the surface. Increased pumpage in relatively unproductive aquifers has caused rapid water-level decline, particularly in two areas where ground-water has dropped more than 300 feet from its original level. These "cones of depression" are centered halfway between Greenway and Bell Roads at 44th Street and near 56th Street and Thunderbird Road. Withdrawals of ground water are many times the natural recharge rate, and this overdraft has resulted in depletion of thin aquifers peripheral to the mountains, and loss of supply to shallow wells. More wells will certainly become dry as pumping in the area continues.

Since the mid-50s, water levels have declined, resulting in current water depths of more than 500 feet. Subsidence apparently began about a decade later in the vicinity of 52nd Street and Thunderbird Road after water levels declined from 100 feet to 150 feet. Since 1970 the subsidence bowl has increased in size at an average rate of two square miles per year, with early expansion predominantly in a westerly direction, and more recent expansion toward the north and east.

As of March 1982, the maximum subsidence measured was 3.44 feet at 56th Street and Thunderbird Road (Figure 3), near the center of the southern cone of water-level depression. At the assumed center of the subsidence area (or subsidence "bowl") 0.5 miles to the southwest (Figure 3), there is indirect evidence from topographic and land survey data for as much as 5 feet of subsidence. Harmon (1982) noted that the subsidence rate has increased to the south, particularly at 56th Street and Cactus

CE HAZARDS IN NORTHEAST PHOENIX

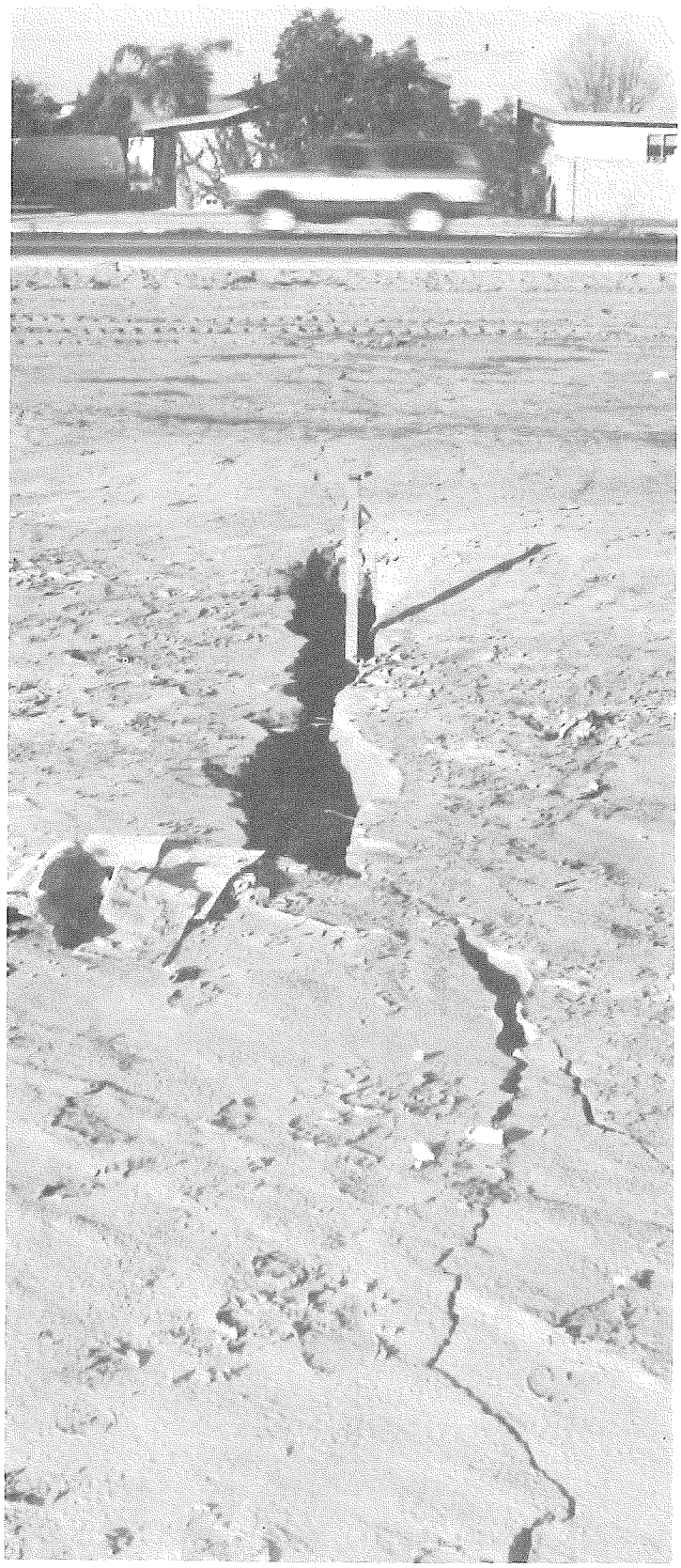

Figure 2. Earth crack in construction area at Lupine Avenue and 40th Street, Phoenix, Arizona. View is west toward 40th Street. Photo by Troy L. Péwé, No. 4484, January 27, 1980.

Road, and Tatum Boulevard and Cholla Street, where the ground is subsiding 4-5 inches per year. This occurrence may represent a southward shift in the center of the subsidence bowl.

The growth of the subsidence bowl suggests that it will expand farther, particularly toward the north and east; subsidence has been measured to the east in the city of Scottsdale. The extent of land subsidence to the south into the town of Paradise Valley, however, is not known. There is insufficent data on compaction and material properties of the subsurface to fully evaluate the potential of future land subsidence in northeast Phoenix; however, given known thicknesses of alluvium and present subsidence rates near the center of the subsidence bowl, more than 9 feet of land subsidence is possible if this area is completely dewatered.

The apparent lack of significant subsidence near the northern cone of depression of water levels may be due to the slow draining of the 200-foot-thick clay layer. Greater subsidence in this area will probably occur as water levels reach the base of the clay unit.

SUBSURFACE CONDITIONS

Well-drilling records and gravity data provide the basis for a depth to bedrock map (Figure 4). The map shows the relationship of past and potential land subsidence and earth fissuring to the buried bedrock topography.

The underground bedrock slopes gently toward the northeast from the Phoenix Mountains. The inner part of this area is buried less than 500 feet, and extends at least 2.5 miles into the Paradise Valley basin, with a series of hills and ridges with relief of 100-300 feet (Figure 4). The buried bedrock features follow the same NE-SW direction as the foliation and topographic expression in the adjacent Phoenix Mountains. One can visualize the buried bedrock topography as that which would exist if the present Papago Park (three miles SE of the Phoenix Mountains) were buried beneath 300-500 feet of silt, sand, and gravel.

Bordering the inner surface, is an outer, more deeply buried, low-relief topography, sloping gently northeastward at a depth of 500-1,000 feet. A major NW-SE basin and range fault separates this gently sloping surface from thick deposits of consolidated sediments.

The subsurface geologic conditions control patterns of water-level decline and land subsidence. Maximum subsidence and water-level decline have been on the deeper outer surface; whereas minimal subsidence and little or no water has been obtained from wells drilled on the shallow buried inner surface. Subsidence generally increases wherever the thickness of alluvium increases.

Gravity data indicate that a small bedrock hill underlies the fissure at a depth of about 150 feet, with at least 100 feet of relief (Figure 5C). Differential compaction induced by dewatering of sediments across this buried knoll was sufficient to cause ground failure. Continued differential subsidence has been measured (April 1981 to April 1982) along 40th Street between Shea Boulevard and Cactus Road, with as much as 0.17 feet of subsidence south of the fissure (Figure 5B). The striking similarity between the

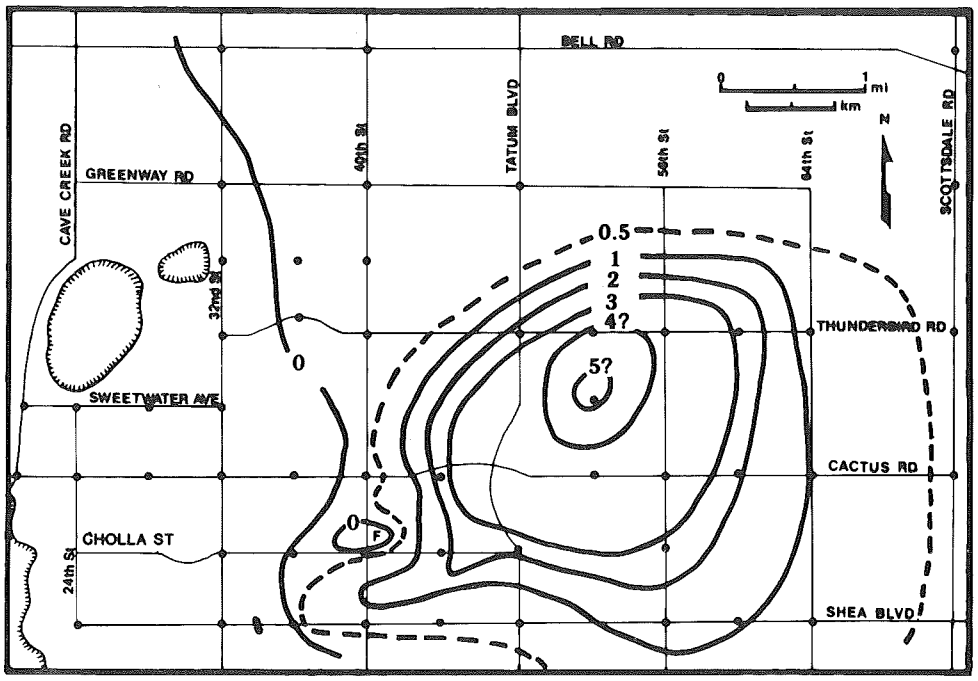

Figure 3. Land subsidence (in feet), northeast Phoenix from 1962-1982. "F" indicates location of fissure. Dots indicate locations of city benchmarks.

subsidence curve and an interpreted depth-to-bedrock profile along 40th Street supports the argument that fissuring is associated with the crests of buried hills. On the basis of the subsidence profile, theoretical calculations and computer modeling by Michael Larson (Figure 5A) and Dr. Donal Ragan at Arizona State University Department of Geology indicate that the stress in the sediments over the inferred buried hill was sufficient to crack the ground surface in 1980.

Measured differential subsidence and calculated horizontal strain strongly suggest a reopening of the entire fissure. Continued displacement is indicated by small cracks that have lengthened and become more numerous in the newly constructed paved road and concrete wall across the original fissure trace. On the basis of detailed gravity traverses, a future westward extension of the fissure is probable, with less than 600 feet of eastward extension possible. Several fissures subparallel to the original could form in the vicinity of 40th Street and Lupine Avenue.

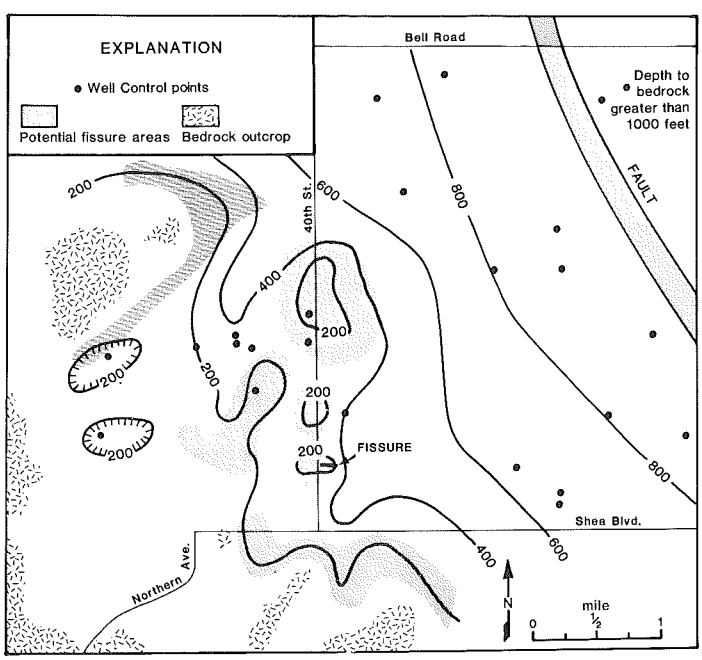

Figure 4. Estimated depth to bedrock (in feet) and potential fissure areas, northeast Phoenix. Contour interval 200 feet.

The history of fissured basins in southern Arizona bears ample evidence that the initial fissure is later followed by complex patterns of multiple fissuring. In northeast Phoenix, future fissuring may be localized in three geological settings: 1) buried bedrock topographic highs, 2) at the hinge line of subsiding areas controlled by bedrock depth, and 3) buried fault scarps. Gravity data suggest there are several buried hills between 30th and 42nd Streets, with a high probability of fissuring, particularly near those hills directly north of the fissure (Figure 4). Another area of potential fissuring is near the hinge line of subsidence between Shea Boulevard and the Phoenix Mountains east of 34th Street. Differential subsidence and fissuring are also possible across an inferred buried basin and range fault scarp in the eastern part of the study area; however, because most water-level decline and land subsidence has occurred on the upthrown rather than the downthrown fault block, fissuring seems less likely in this area at the present time.

CONCLUSIONS

Studies such as that of the northeast Phoenix area permit a better understanding of earth fissures and land subsidence phenomena. Hydrogeological and geophysical methods are now available to delimit specific areas where there is a high potential for problems due to fissuring and land subsidence. Many of these methods have been applied to the northeast Phoenix study, but as land subsidence and water-level decline continue, ongoing monitoring is necessary in order to anticipate future problems.

Similar studies could prove timely elsewhere in south central Arizona, because of the widespread distribution of ground-water development in similar geologic settings. Cooperation of city, state, and federal governments and

public education is essential if problems associated with water-level decline, land subsidence, and earth fissures are to be resolved.

For a copy of the report, make checks payable for $25.00 ($26.00 if mailed) to the City of Phoenix. Requests are taken by David Harmon, Assistant City Engineer, City of Phoenix Engineering Department, 125 East Washington St., Phoenix, AZ 85004.

CITED REFERENCES

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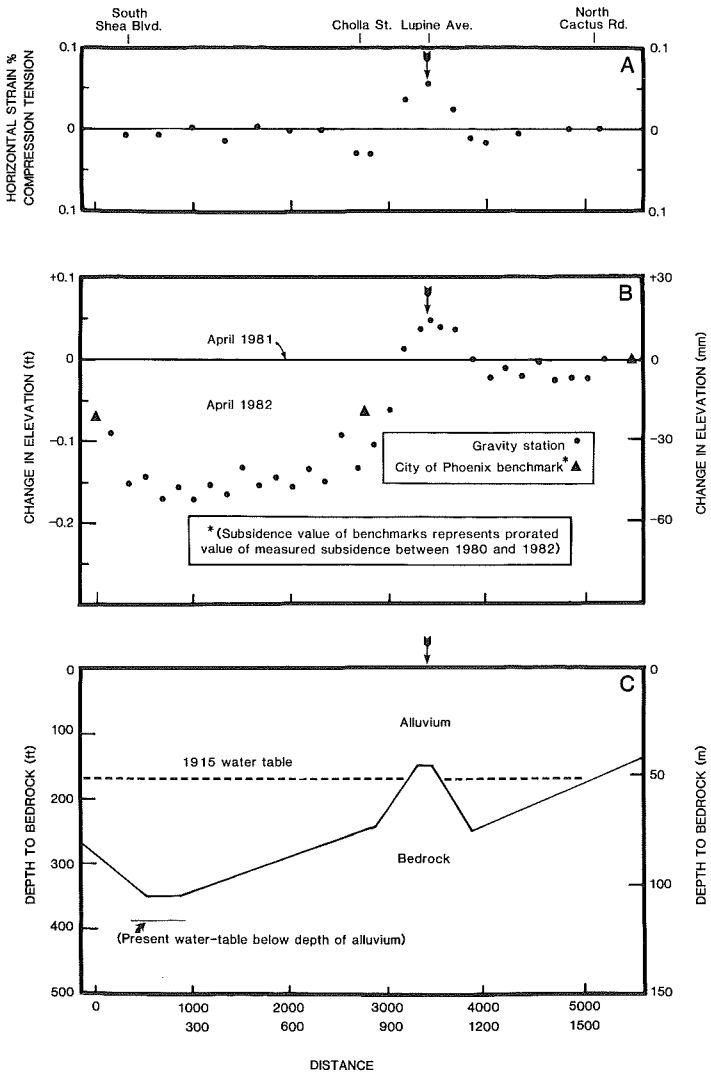

Figure 5. Surface strain, land subsidence, and depth to bedrock, 40th Street from Shea Boulevard to Cactus Road.

5A. Computed horizontal surface strain (1980) at time of fissuring.

5B. Land subsidence from April 1981 to April 1982.

5C. Interpreted depth to bedrock based on gravity data.

KRAKATAU—A Geologic Cataclysm

One hundred years ago, on August 27, 1883, the island of Krakatau exploded; then, after several days, it disappeared into the Sunda Strait near Java and Sumatra. A volcano, dormant for 203 years, had erupted, causing the two-mile-long island to collapse into the sea. All that remained after the explosion was a caldera or basin, five miles wide and more than 700 feet deep.

The volcanic blast, equal to 100-150 megatons of explosives, was heard 3,000 miles away. Seismic waves traveled several times around the earth in both directions. Four cubic miles of ash and pumice was spewed into the atmosphere (about 60 times the ejecta produced by Mount St. Helens during the early 1980s). Two islands adjacent to Krakatau were covered by 45 feet of ash and pumice, then overlain by 180 feet of lava. The heavier fallout ash blanketed 180,000 square miles; the airborne ash drifted in the stratosphere for many months, causing vivid sky scapes around the world. A sulfate/dust layer remained in the atmosphere for over five years, combining with ozone and precipitation to create a 'greenhouse' effect. As a result, a portion of solar heat was prevented from reaching the surface of the earth, and lower average surface temperatures occurred.

Loss of life from the eruption and the accompanying tsunami (the great sea wave that destroyed 300 villages and thousands of ships) is estimated to have been between 36,000 and 100,000 people.

Just as the mythical Phoenix arose from its own ashes, Anak Krakatau (child of Krakatau) first emerged as a new cone in 1927, and has since produced 30 small eruptions. Anak Krakatau is one of 500 known active volcanoes in the world today. Three of the six worst volcanic disasters in the world since the beginning of the 16th century have occurred in Indonesia (Kelut in 1586, Tambora in 1815, and Krakatau in 1883). In order of the most active volcanic history, Indonesia ranks first, Japan, second, and the United States, third.

ANNOUNCEMENT

Daniel N. Miller, Jr., resigned from his position as Assistant Secretary for Energy and Minerals at the Department of the Interior at the end of May 1983. He had occupied that position since May 1981.

In his capacity as Assistant Secretary, Miller headed up the U.S. Geological Survey, the U.S. Bureau of Mines, the Office of Surface Mining, and most recently, the Minerals Management Service.

Prior to joining Secretary Watt's team, Miller served 12 years as State Geologist of Wyoming and Director of the Wyoming Geological Survey. He also spent 11 years as Senior Exploration Geologist in the petroleum industry.

Miller will reside in Coeur d'Alene, Idaho, where he will establish a consulting service.