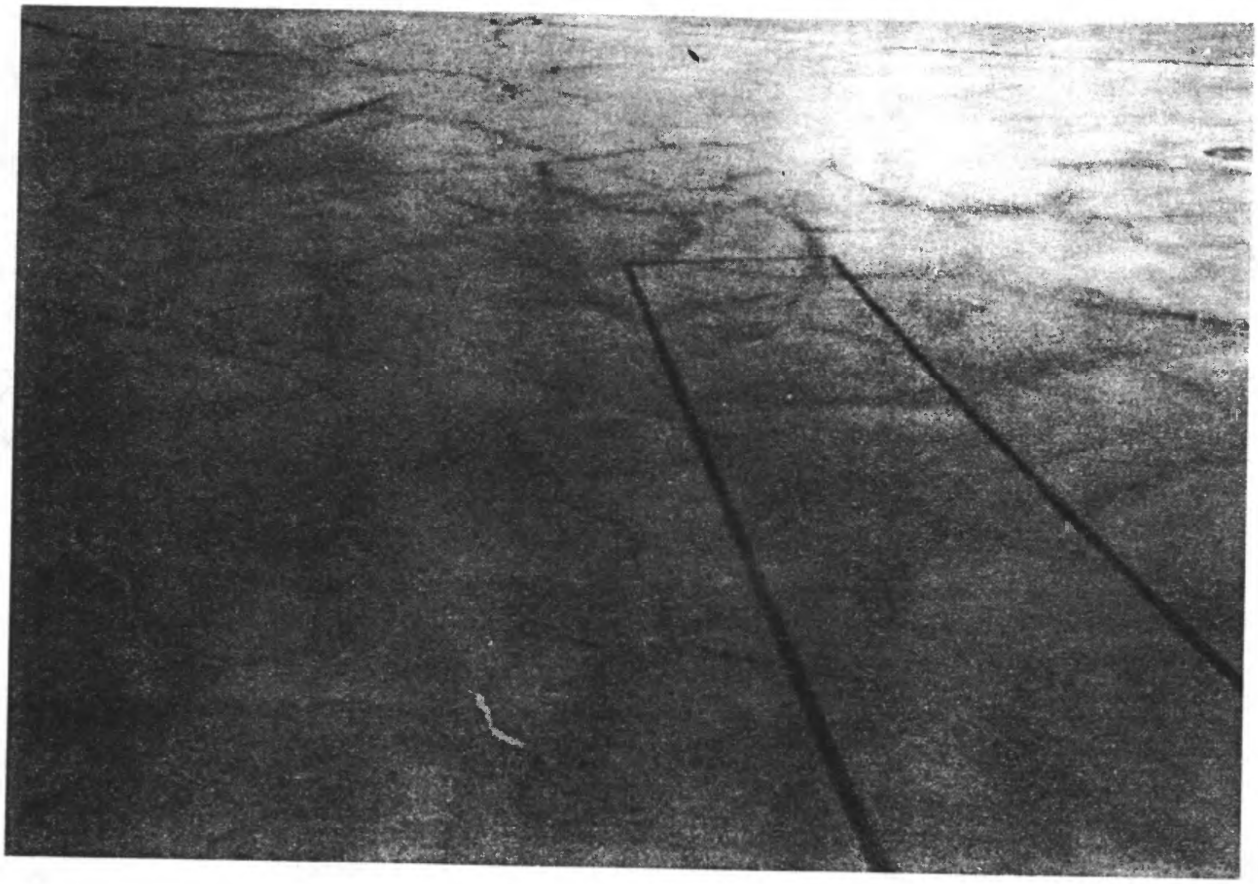

Figure 20. Aerial view of Rogers lakebed showing giant desiccation polygon cracks. Width of runway is about 330 feet. Photograph courtesy of U.S. Department of the Air Force, 1983.

Because fissures may extend to the water table, there is potential for direct surface-water access to the aquifer and possible contamination by toxic materials.

Factors that are associated with earth fissures and surface faults induced by ground-water depletion, as noted at Edwards AFB, include the following:

- Fissures generally form in a zone of tensile stress that extends to the water table. However, seismic refraction techniques have measured fissures deeper than the water table at Rogers lakebed (Neal and others, 1968). Fissure cracks may show only as a hairline crack on the land surface.
- The location of fissures may be affected by the location of subsurface bedrock or consolidated alluvium ridges that act as hinge points for deformation of the land surface. Fissures generally form in the alluvium near the edges of the areas subject to ground-water depletion (Schumann and others, 1986).
- Fissures generally occur near the part of the subsidence profile where the land surface has the greatest convex curvature upward. This phenomenon has been observed on Rogers lakebed (fig. 21).
- Fissures tend to intersect and form linear fissure systems.

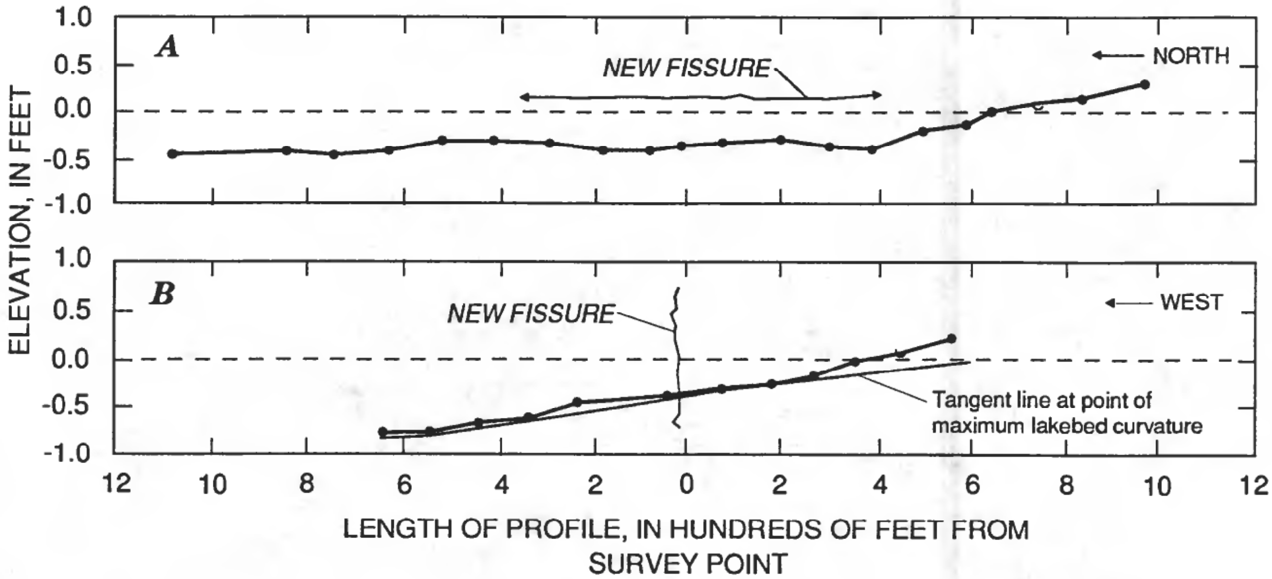

Figure 21. Land-surface profile at new fissure on Rogers lakebed. *A,* Longitudinal profile of land surface parallel to fissure. *B,* Cross profile of land surface at survey point.

- Fissures may first appear as narrow cracks (less than 0.1 ft wide) or as an alignment of shallow holes or sinklike depressions.
- New fissures have nearly vertical sides and exhibit no evidence of lateral or vertical offset.
- Fissures form on the periphery of the area of subsidence and transect natural drainage patterns. Many capture large volumes of surface runoff. The fissures then enlarge by slumping, eroding, or piping along the strike of the fissure.

Fissures on the lakebed that were large enough to be of concern to Air Force operations were first noted about 1988. Fissures that formed prior to 1988 were obliterated when the lakebed flooded, such as in March 1983. More recently, however, new and larger fissures on the lakebed have been noted by Air Force personnel with increasing frequency. This apparent increase in the rate of fissure formation may be caused by increased ground-water pumping related to drought conditions in the area during 1984-91. In January 1991, following a period of lakebed flooding, the largest fissure observed to date was discovered on the lakebed (figs. 2 and 5). This fissure is greater than 12 ft in depth and acts as a vertical conduit to the subsurface for water ponded on the lakebed.

SINKLIKE DEPRESSIONS

Sinklike depressions on the land surface that range in size from 0.5 ft to several feet in diameter and from a few inches to 6 ft in depth (figs. 22 and 23) have been found at several Edwards AFB locations. Sinklike depressions were defined by H.H. Schumann (U.S. Geological Survey, written commun., 1991), who noted a series of holes and depressions in association with earth fissures in southern Arizona. Some of the depressions have nearly vertical sides and form along trends of earth fissures that may not yet be expressed at the land surface. Sinklike depressions observed by Schumann are similar to the localized holes and depressions observed at Edwards AFB (figs. 19 and 22), with underground voids enlarged as a result of vertical and lateral movement of water or piping. The definition of these sinklike depressions differs from that for sinkholes given by Bates and Jackson (1984, p. 470), in which a sinkhole is a "circular depression in a karst area. Its drainage is subterranean, its size measured in meters or tens of meters, and it is commonly funnel-shaped." For sinkholes and sinklike depressions, the physical process of vertical erosion during movement of surface water into an underground void is believed to be similar. The distinction is that the definition of sinkholes applies to karst (limestone) areas, whereas sinklike depressions occur in other areas.

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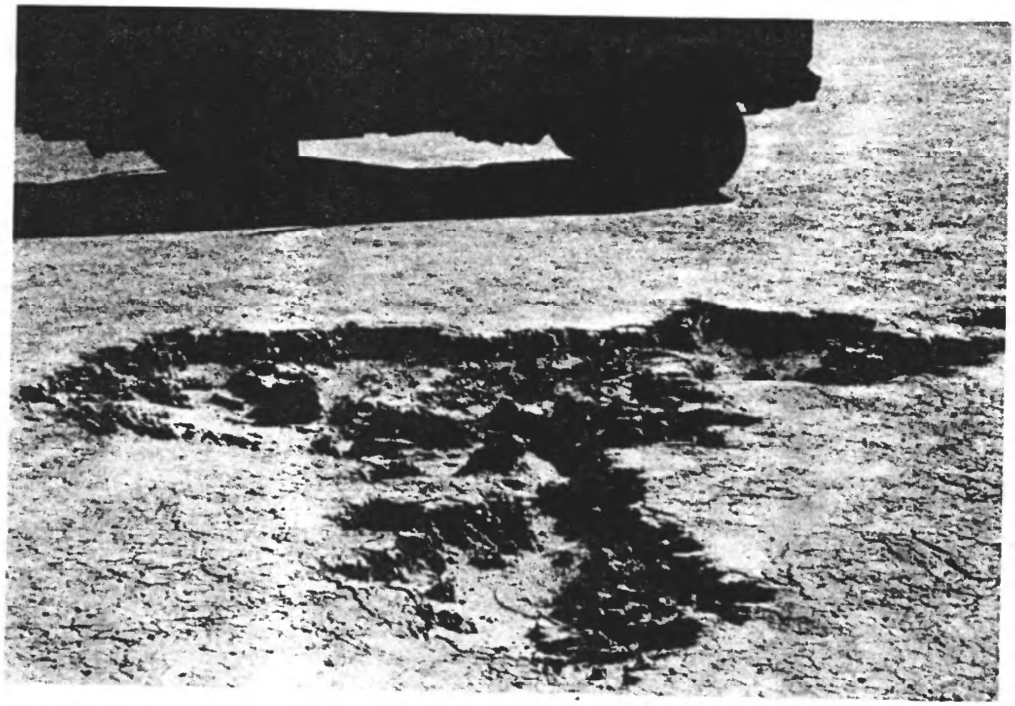

Figure 22. Expanding sinklike depression on Rogers lakebed caused by erosion during periods of lakebed flooding. Photographed June 1990.

The occurrence of sinklike depressions at Edwards AFB (fig. 22) is related to land subsidence, declining ground-water levels, and formation of giant polygons. Because all these elements are present, enlargement of older sinklike depressions and formation of new depressions are considered progressive. The rate at which new sinklike depressions form is dependent on many factors, including lakebed flooding from precipitation on the lakebed, inflow from tributaries to the lake, movement of bodies of surface water on the lakebed, and ground-water pumping that, in turn, affects the rate of subsurface (aquifer) water-level decline.

LAKEBED EROSION

Rogers lakebed is virtually flat, with a change in elevation from the north to south of only 5 ft in a distance of 11 mi. During periods of lakebed flooding, as in March 1983 and March 1984, drainage channels formed by erosion on the lakebed (fig. 23). These channels are affected by variable amounts of inflow, timing of floods, sediment transport from tributaries, force of prevailing winds that tend to move the water west to east, and local undulations of the lakebed surface.

Erosion on dry lakebeds and subsequent formation of drainage channels, collectively called desert flowers (area A on fig. 23), were first noted by Motts and Carpenter (1970). In some locations, such as Rogers lakebed, the channels forming the dendritic channel pattern adjacent to the main channel were as deep as 0.3 ft on the lakebed surface. Erosion of channels on the lakebed generally continues after each period of flooding and now covers an extensive part of the lakebed (fig. 23). Many drainage channels are several feet wide and several feet deep. The development of the channels on the lakebed is affected by the slope of the lakebed and also by the presence of fissures or erosion depressions, which serve as outlets for the flow.

Continued land subsidence on Rogers lakebed will affect the slope of the lakebed (fig. 15) and development of surface channels. For example, the changing and presently steeper lakebed slope between bench marks 3RLB and 4RLB (fig. 15), affects the geomorphic characteristics of natural drainage on the lakebed. As the slope increases, the lakebed is increasingly incised with drainage channels (figs. 16 and 23). The channel network density increases in the downstream direction, with lakebed channels larger in areas A and B than in area C because the

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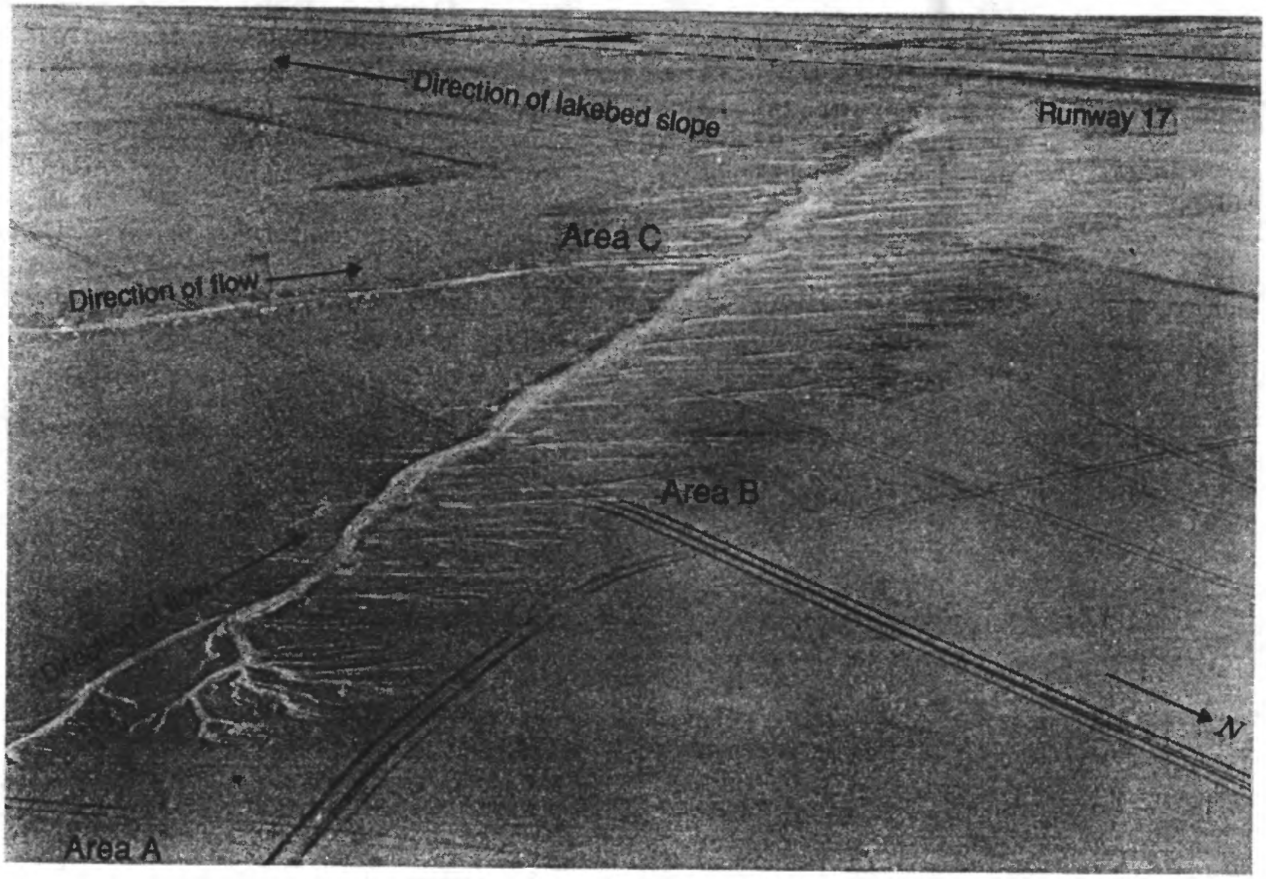

Figure 23. Oblique aerial photograph of Rogers lakebed east of South Base well field. A typical network of drainage channels (collectively call desert flowers) is shown at area A. Erosion in areas B and C is a result of land subsidence, which causes an increase in lakebed slope from north to south (right to left on photograph). Photograph courtesy of U.S. Department of the Air Force, August 1990.

lakebed slope plus channel slope is greater in areas A and B than in area C. The length of the drainage channels is a function of the lakebed slope, with the length increasing from area A toward areas B and C. A detrimental feature of this type of erosion and channel formation is that the presence of water on the lakebed, either from direct rainfall or flooding by tributaries, will extend the channel erosion and sediment transport processes toward low points on the lakebed.

SUMMARY

To document current land subsidence at Edwards Air Force Base and vicinity, a vertical-control network with 41 bench marks was surveyed using the Global Positioning System (GPS). Four bench marks that were unaffected by subsidence and with known geoidal heights were used in adjusting the GPS surveys to sea-level datum. Accuracy of the ellipsoidal height for the surveyed area, based on North American Datum 1983 and relative to sea level, is about 0.1 foot. Differential levels to third-order standards of accuracy were surveyed for 65 bench marks in 1989-91 to determine the areal distribution of subsidence. Measured land subsidence ranged from 3.3 feet along the southern edge of Edwards Air Force Base to about 0.3 foot on the northern edge. Near the southern edge of Rogers lakebed, the land has subsided more than 2 feet between 1961 and 1989. The average rate of land subsidence near the south end of Rogers lakebed is about 0.1 foot per year. A gradual decline of ground-water levels, more than 90 feet at some wells since 1947, is associated with the land subsidence.

The formation of fissures and sinklike depressions and the formation of drainage channels, which are caused by erosion of Rogers lakebed during periods of flooding, also are associated with the occurrence of land subsidence. The development of fissures on the lakebed are a major concern because they may extend to the water table, allowing direct access for contamination by toxic materials. In addition, existing sinklike depressions, fissures, and cracks may not be detected until the load capacity of the overlying soil is unexpectedly exceeded when aircraft or space shuttles land or take off from the lakebed. Changes in lakebed slope and continued land subsidence contribute to the formation of new drainage channels on the lakebed. These channels, which increase in size and density following periods of precipitation or lakebed flooding, often cross runways resulting in a need for extensive repairs.

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U.S. DEPARTMENT OF THE INTERIOR
Geological Survey, Room W-2233
2800 Cottage Way, Federal Building
Sacramento, CA 95825

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