levels in the wells are measured continuously, and the data are recorded on a data logger located in the extensometer building. The period during which subsidence occurs at a reduced rate corresponds to the winter and spring months, September 1990 to April 1991 (fig. 11) when water levels at the site stabilized or rose; this period of stability is attributed to reduced pumping from the South Track well field during the winter months.

LAND-SURFACE PROFILES

Areal variation of land subsidence at Edwards AFB is shown by changes in surface profiles of transects A, B, and C (fig. 12). Transect A is oriented north-south; transect B is oriented east-west. Transect C is on Rogers Lake; bench marks for this transect are located off the lake so calculations of changes of the lakebed elevation are estimates.

Transects A and B (figs. 13 and 14) show that the area of greatest subsidence is near the southern part of the base. Land subsidence along transect A occurs north of Hospital Road between bench marks E1140 and G1140, and south of Hospital Road between bench marks G1155 and 106-116 (fig. 12). The presence of two subsidence areas bordering Hospital Road indicates that this low ridge may act as a separation between land-surface deformation to the north and south. Transect A also shows that subsidence along the western edge of Rogers Lake extends about 8 mi south of Hospital Road. The pattern of land subsidence on transects A and B (figs. 13 and 14) shows that land subsidence probably occurred at the south end of Rogers Lake. Subsidence is apparent along all of transect B (figs. 12 and 14) as indicated by changes in elevation between bench mark N487, which is near Sierra Highway, and bench mark 3MDC.

A profile of transect C on Rogers lakebed is shown in figure 15. The lowest point shown on this profile, elevation 2,267.8 ft, is about 11,000 ft north of bench mark 4RLB. The elevation of the lakebed near this low point may show the effects of land subsidence, because nearby bench marks along the south edge of Rogers lakebed J1155, K1155, L1155, M1155, and N1155 (fig. 6) all show 1 or more feet of land subsidence during 1961-91 (table 2). Because about 3 ft of lakebed subsidence occurred near bench marks M1155 and L1155 at the south end of the lakebed and 0.2 ft near bench mark R1140 at the north end (fig. 6), the slope of the entire lakebed probably is affected by various amounts of change in slope, with the southern part the most affected. Any change in lakebed slope represents an increase in the potential for lakebed erosion caused by wind-induced movement of water during periods of lakebed flooding. Increases in lakebed slope typically result in greater hydraulic shear stresses and increased erosion during periods of lakebed flooding that causes greater lengths and densities of existing drainage channels (number of channels in a given area) and formation of new drainage channels, which collectively are called desert flowers (fig. 16).

RATES OF LAND SUBSIDENCE

Estimates of land-subsidence rates are best obtained from a comparison of elevations measured at one bench mark for a period of years. The relative stability of bench marks can be identified by comparing repeated, adjusted elevations; those showing little change are considered to be more stable. Differences in measured elevation of bench marks less than about 0.2 ft are not considered reliable indications of land subsidence (Blodgett and others, 1990).

Land subsidence of 3.2 and 3.3 ft at bench marks M1155 and P1155, respectively (fig. 6), near the South Track well field are the maximum determined on the base to date and were determined by comparing surveys made in 1961 and 1989 (table 1). Bench mark F1147 near Rosamond was used as the stable reference for all surveys.

The average rate of land subsidence at bench mark M1155 was 0.109 ft/yr between 1961-89 (fig. 17). The average rates of land subsidence at most other bench marks in the study are less than that of bench mark M1155 (fig. 6). Variation in these subsidence rates is related to the variable effects of ground-water pumping at different locations on the base and lithologic variation in the substrata.

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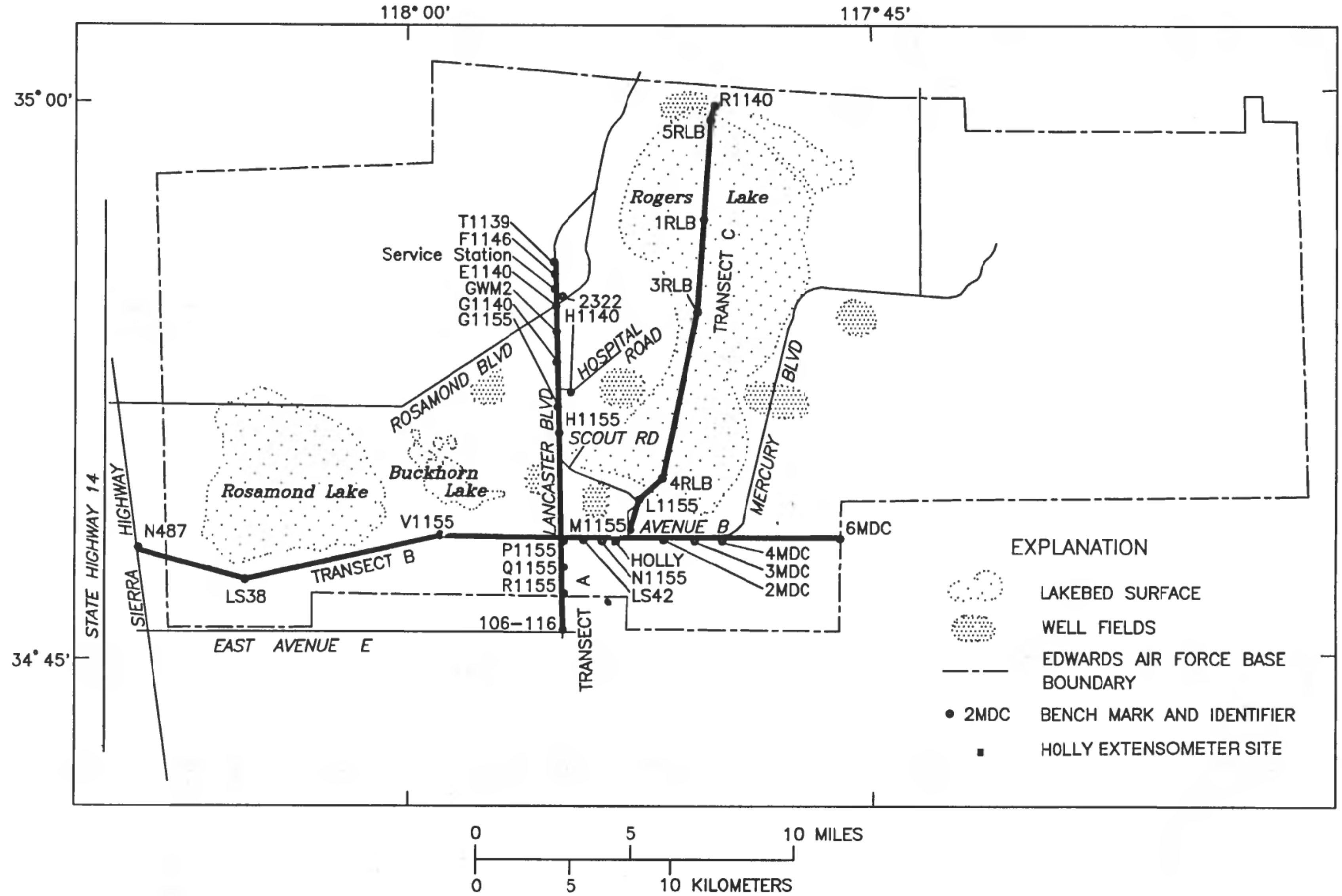

Figure 12. Location of land-surface survey transects A,B, and C.

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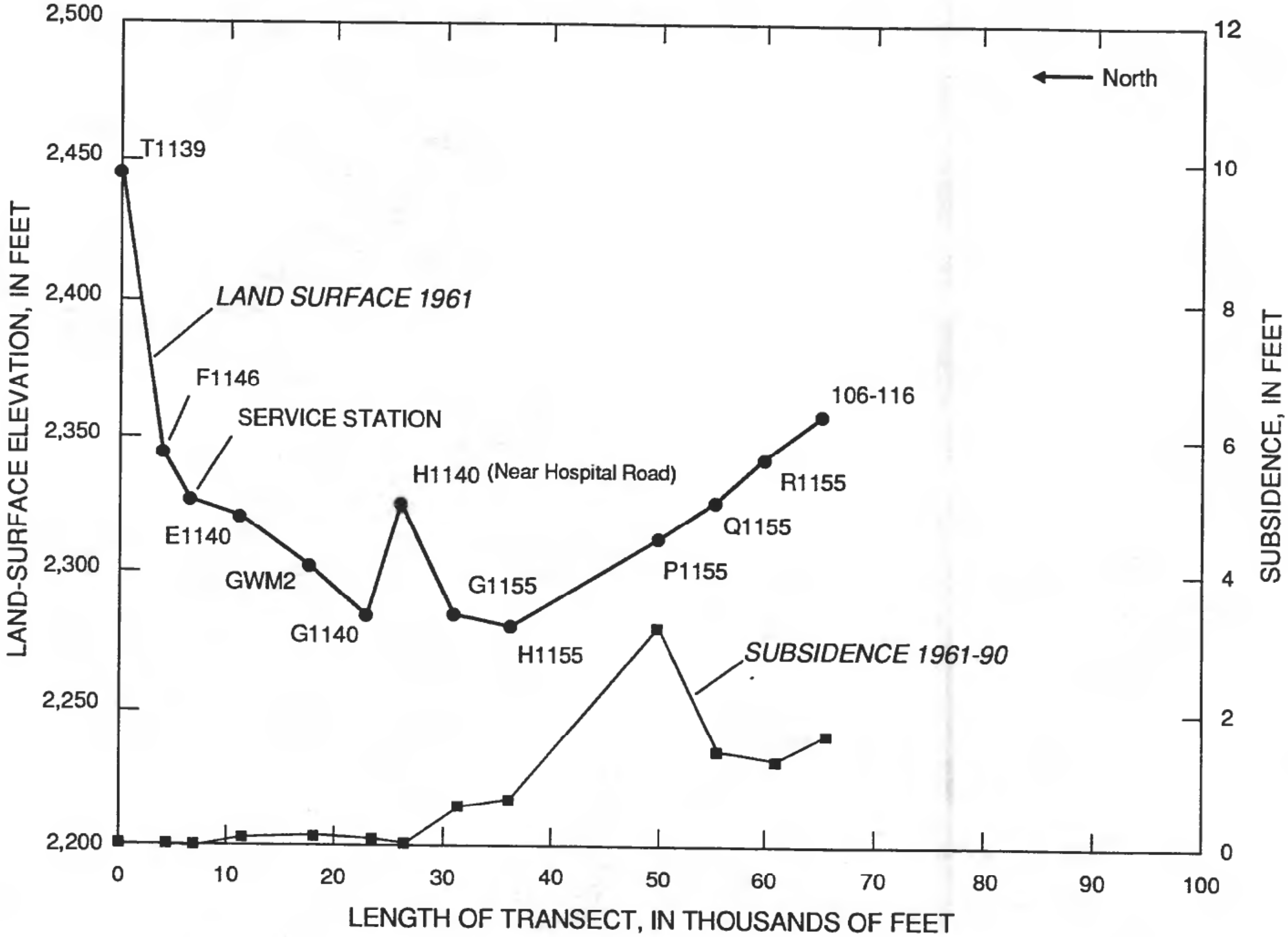

Figure 13. Land-surface elevation, transect A, Lancaster Boulevard.

LAND SUBSIDENCE AND ASSOCIATED PROBLEMS AFFECTING LAND USE

Land subsidence caused by ground-water pumping is a progressive phenomenon that occurs during a period of years. Several well fields are located along the margins of Rogers Lake (fig. 5). The amount and areal extent of land subsidence and associated land-use problems on Rogers lakebed are related to the lowering of ground-water levels and lithologic variations in the substrata. The effect of land subsidence on certain land-use practices may not be a cause for concern. In other instances, however, such as increased urbanization, the effects of land subsidence may be significant. Several land-use problems, caused by continuing land subsidence at Edwards AFB, have been noted. These include

- Failure of well casings caused by compression stresses developed during compaction of the aquifer system.
- Damage to fluid-transport systems, such as underground water, sewer, and petroleum lines.

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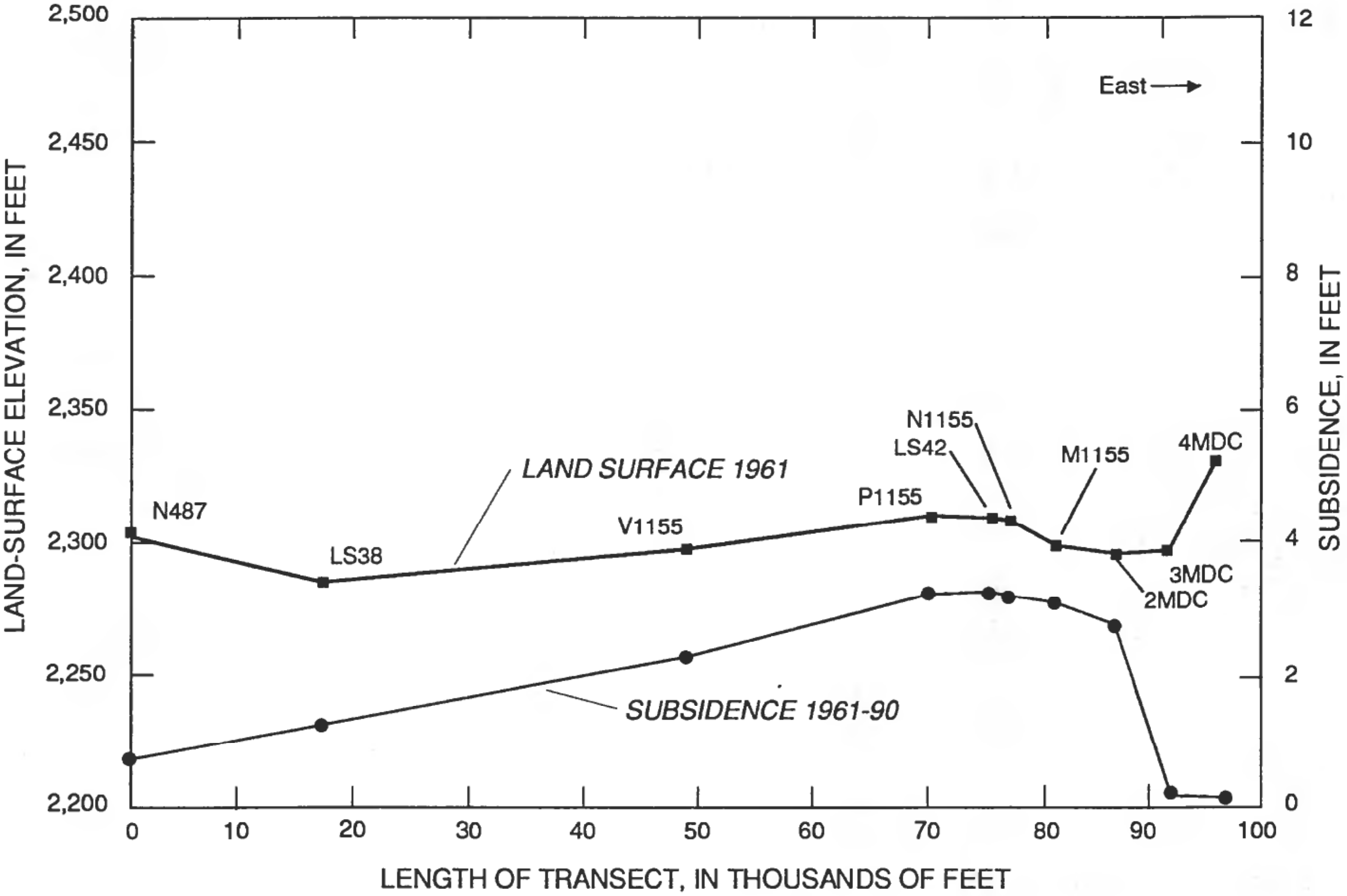

Figure 14. Land-surface elevation, transect B, Avenue B.

- Erosion of drainage channels and formation of new drainage channels (waterways) on the lakebed caused by changes in elevation and gradient of the lakebed and wind-induced movement of the ponded water (fig. 16).

- Increase in areas subject to flooding as a result of land subsidence.

- Development of cracks, fissures, sinklike depressions, and soft spots (loss of load-bearing capacity) on the lakebed that affect the use of runways.

- Rapid drainage of water on the lakebed into fissures and sinklike depressions. The Air Force has observed that during lakebed flooding in 1983 much of the water on the lakebed drained into fissures and sinklike depressions within 24 hours of 1 inch of precipitation (Phillip Brady, U.S. Air Force, written commun., 1991). Water on the lakebed contains suspended sediment that is scoured from the beds and banks of channels tributary to Rogers Lake. In addition, water on the lakebed contains suspended sediment caused by lakebed erosion when the water mass is moved by the wind. Inflow of the lakebed water into

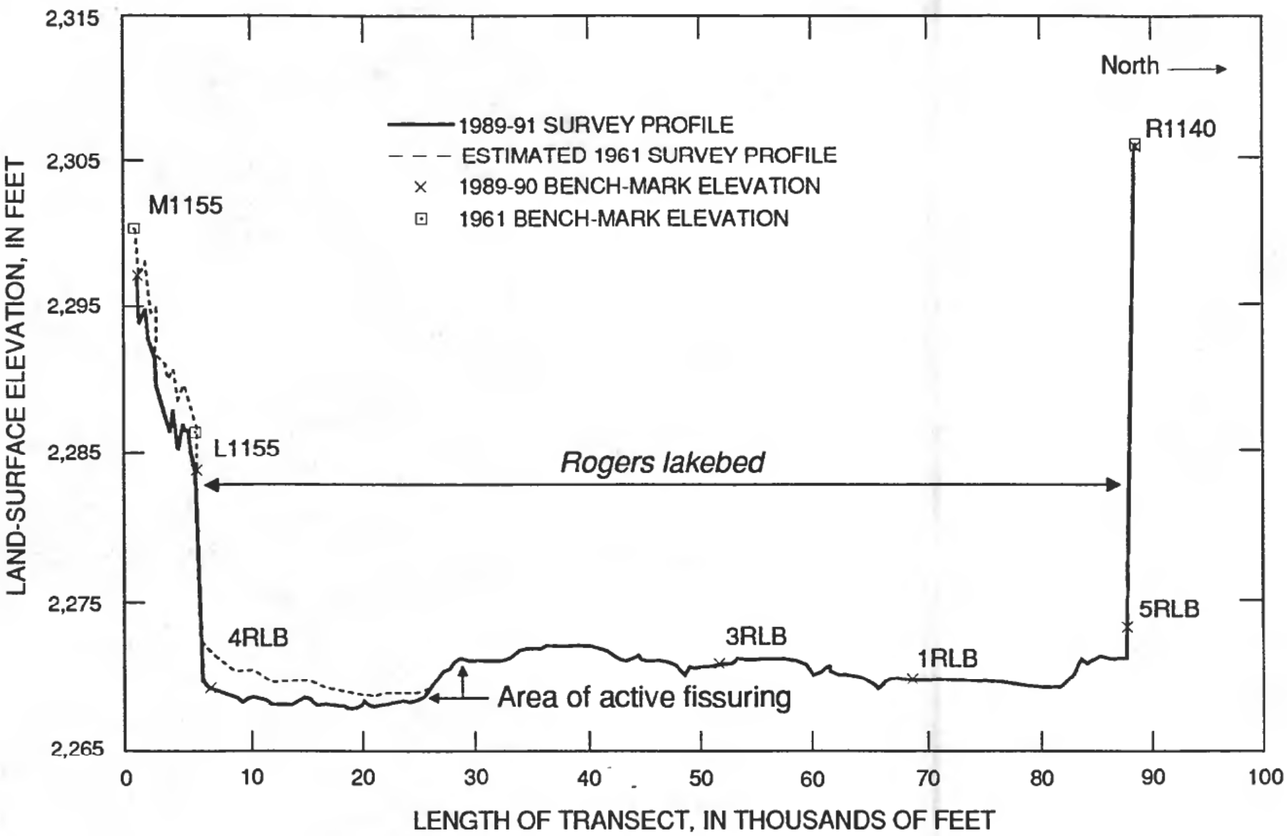

Figure 15. Land-surface elevation, transect C, Rogers lakebed.

fissures and sinklike depressions tends therefore to reduce the quantity of water that is moved by wind on the lakebed and is available to fill surface irregularities by deposition on the lakebed. Formation of gullies and channels along the sides of the fissures is an additional detrimental effect caused by drainage of surface water (fig. 18). Erosion during subsequent periods of lakebed flooding cause these gullies and channels to enlarge and deepen. Slumping (shear failure), erosion along the sides of the fissures, and, as reported by Schumann and others (1986), rapid piping along the strike of the fissure also cause the fissures to enlarge during periods of flooding.

FISSURING

The geology, mineralogy, and hydrology of selected dry lakebeds (playas) in the Western United States have been studied by numerous investigators (Neal, 1965, 1968; Motts and Carpenter, 1970), but the characteristics of these lakebeds are not well understood. Playa surfaces, which are large, flat expanses of desert, are valued for their use as long runways when testing aircraft and for use as emergency landing sites. Dry lakebeds within closed valley basins are geologically unique because the inflow consists of surface and ground water, with no surface outlet and, therefore, the lakebeds are areas of deposition for all suspended sediments and chemical constituents of the water.

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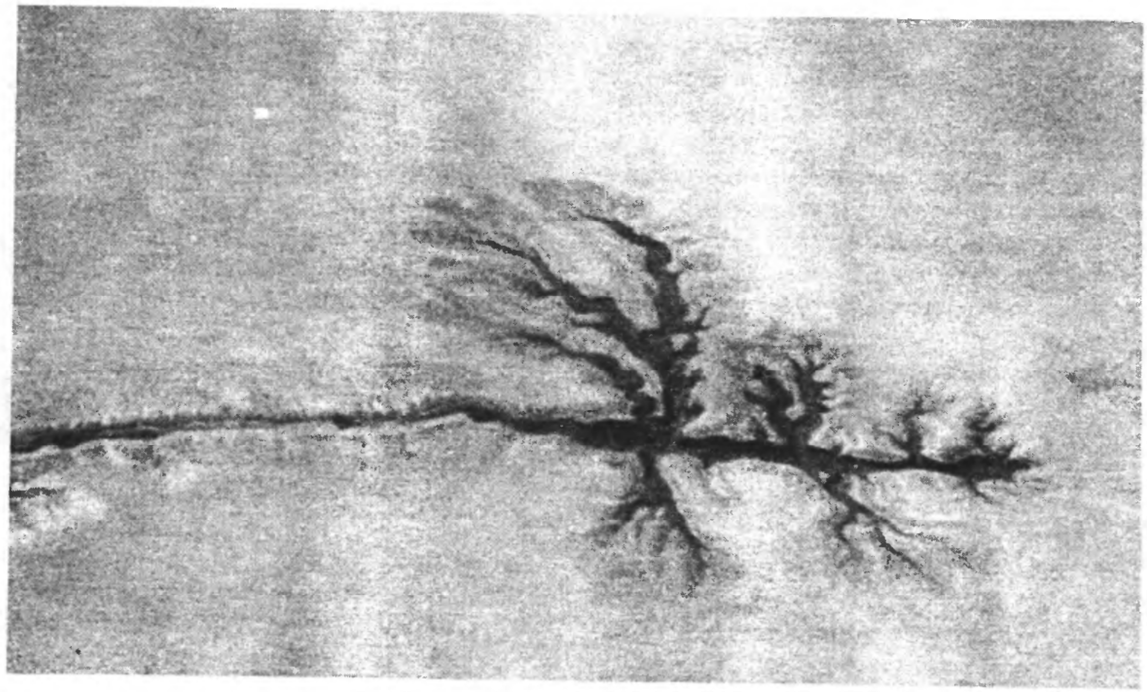

Figure 16. Drainage channels (collectively called desert flowers) caused by erosion during flooding of Rogers lakebed. Photographed August 1989.

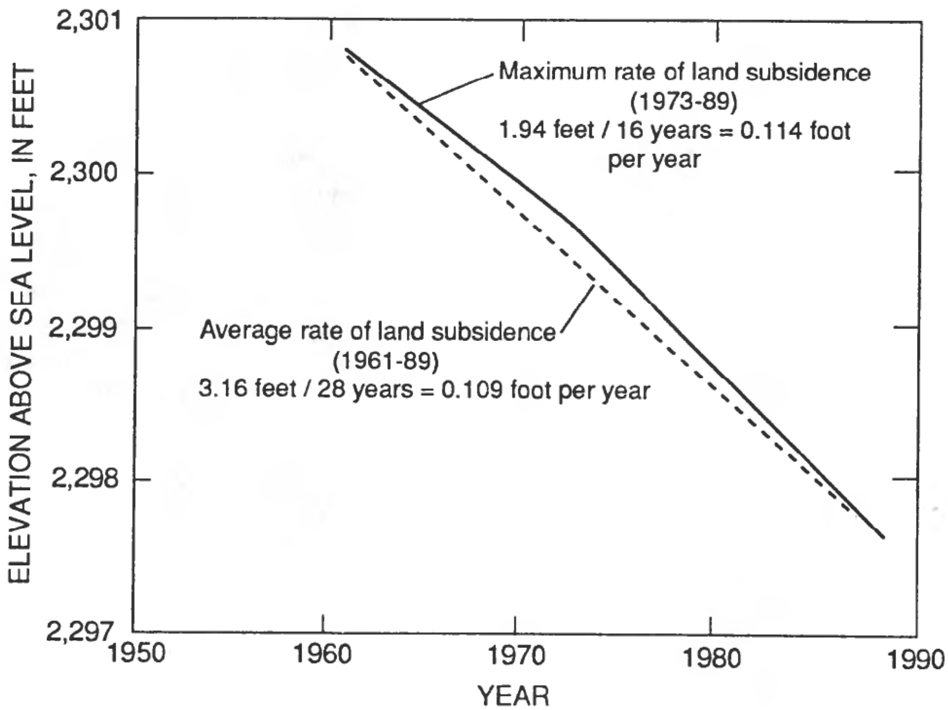

Figure 17. Land subsidence at bench mark M1155 near South Track well field, 1961-89.

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Figure 18. Erosion of Rogers lakebed caused by movement of ponded water to fissure opening, March 1991.

Figure 19. Small sinklike depression on Rogers lakebed showing small (cobblestone size) flat, sun-baked polygons on depression wall. The polygons are formed during moisture loss by evaporation. Photographed August 1988.

Dry lakebeds usually have smooth, hard, flat surfaces. Some have small (cobblestone size) polygons or large (giant) desiccation polygons (figs. 19 and 20). The small polygons range from 1 to 4 inches across; the giant polygons may exceed 300 ft (Neal, 1965).

Giant desiccation polygons are formed by the orthogonal intersection of giant mud cracks, which commonly are as much as 3 ft wide and 3 ft deep (Neal, 1965). Orthogonal polygons result from volume change in a uniform horizontal mass with one surface exposed (Neal, 1968). These features are described as giant polygons to distinguish them from small polygons, which have shallow, surface cracks. Giant polygons on dry lakebeds evidently are caused by three factors: (1) intense evaporation at and below the land surface, (2) lowered ground-water levels, and (3) changes in size or location of polygons following precipitation. The surface features of fissures, which are caused by land subsidence and appear as large cracks on the soil surface, can be more than 9 mi long (Schumann and others, 1986). Because of the location and size of the various types of fissures found on the lakebed, repairs often must be made to the lakebed to keep the runways operable.

The relation of surface deformation and land subsidence caused by ground-water pumping was noted previously (Feth, 1961; Poland, 1984, p. 6-7). Excessive ground-water pumping and depletion of the aquifer can cause compaction of the unconsolidated alluvium resulting in surface deformation and fissuring, as has been noted in Antelope Valley.

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