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Jour. Research U.S. Geol. Survey
Vol. 4, No. 5, Sept.–Oct. 1976, p. 505–510

FRACTURING AND SUBSIDENCE OF THE LAND SURFACE CAUSED BY THE WITHDRAWAL OF GROUND WATER IN THE MILFORD AREA, UTAH

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Prepared in cooperation with the Utah Department of Natural Resources

Abstract.—Fracturing and subsidence of the land surface in the Milford area of Utah have resulted from the decline of water levels due to pumping in unconsolidated deposits of Quaternary age. To the writers' knowledge, these are the first such effects of ground-water withdrawal reported in Utah.

The fracturing is in an area about 1 mile (1.6 km) wide and 11 miles (18 km) long near Milford, in an unsaturated clay-silt zone (locally peaty at top) in the upper part of the principal ground-water reservoir. The fractures range in length from several feet to more than 100 feet (30 m), and their maximum measured depth in 1972 was 4 feet (1.2 m).

Land subsidence in the Milford area is demonstrated by three lines of evidence: (1) collapse structures, (2) well casings that protrude higher above the land surface than when first placed in the borehole, and (3) lower elevations at National Ocean Survey (formerly U.S. Coast and Geodetic Survey) bench marks in 1970 than in 1908. This evidence shows that land subsidence in the Milford area is of two types, each having a different origin. One type has a near-surface origin in the clay-silt zone in the upper part of the principal ground-water reservoir, and the other is in the lower artesian aquifers of the principal ground-water reservoir. The amount of observed subsidence ranges from 0.05 foot (0.015 m) at the bench mark at Read to about 6 feet (1.8 m) at collapse structures in the Hay Springs area.

The withdrawal of ground water from wells has caused fracturing and subsidence of the land surface in a part of the Milford area, Utah. To the writers' knowledge, these are the first such effects resulting from ground-water withdrawal reported in Utah.

The Milford area is in southwestern Utah. The town of Milford, approximately in the center of the area, is about 200 miles (322 km) southwest of Salt Lake City (fig. 1).

The area is in the Basin and Range physiographic province and consists of a valley that is almost entirely bounded by elongate subparallel mountains. The altitude of the valley bottom ranges from about 4,850 to 5,500 feet (1,478 to 1,676 m), and the valley was occupied during Pleistocene time by Lake Bonneville to the altitude of about 5,120 feet (1,561 m). Erosional and depositional features of this lake are still preserved.

The mountains consist of sedimentary rocks of Paleozoic, Mesozoic, and Tertiary age, igneous rocks of Tertiary and Quaternary age, and metamorphic rocks of Precambrian age. Most of the valley is underlain by unconsolidated Quaternary materials.

The Quaternary deposits compose the principal ground-water reservoir of the Milford area (Mower and Cordova, 1974). This reservoir is the source of nearly all the water withdrawn from wells and is the locus of the fracturing and subsidence of the land surface. The thickness of the reservoir ranges from 0 to about 840 feet (256 m) but is generally less than 500 feet (152 m).

DESCRIPTION OF FRACTURING

The fracturing is in an area about 1 mile (1.6 km) wide and 11 miles (18 km) long, extending mostly southwest of Milford (fig. 1). The fracturing has developed in the upper part of the principal ground-water reservoir in an unsaturated clay-silt zone which is peaty at top in the Hay Springs area. The clay-silt zone ranges in thickness from about 3 feet (1 m) to about 40 feet (12 m) but most commonly ranges from 15 to 25 feet (5 to 8 m). The largest fractures are in Tadpole Springs and Hay Springs areas (fig. 1), both of which are now dry. The photographs in figures 2 and 3 show examples of the fracturing.

The maximum measured depth of the fractures in 1972 was 4 feet (1.2 m); however, the total depth could not be measured because of bridging or partial filling. Although the total depth of the fractures could not be determined, they possibly extend to the bottom of the unsaturated clay-silt zone.

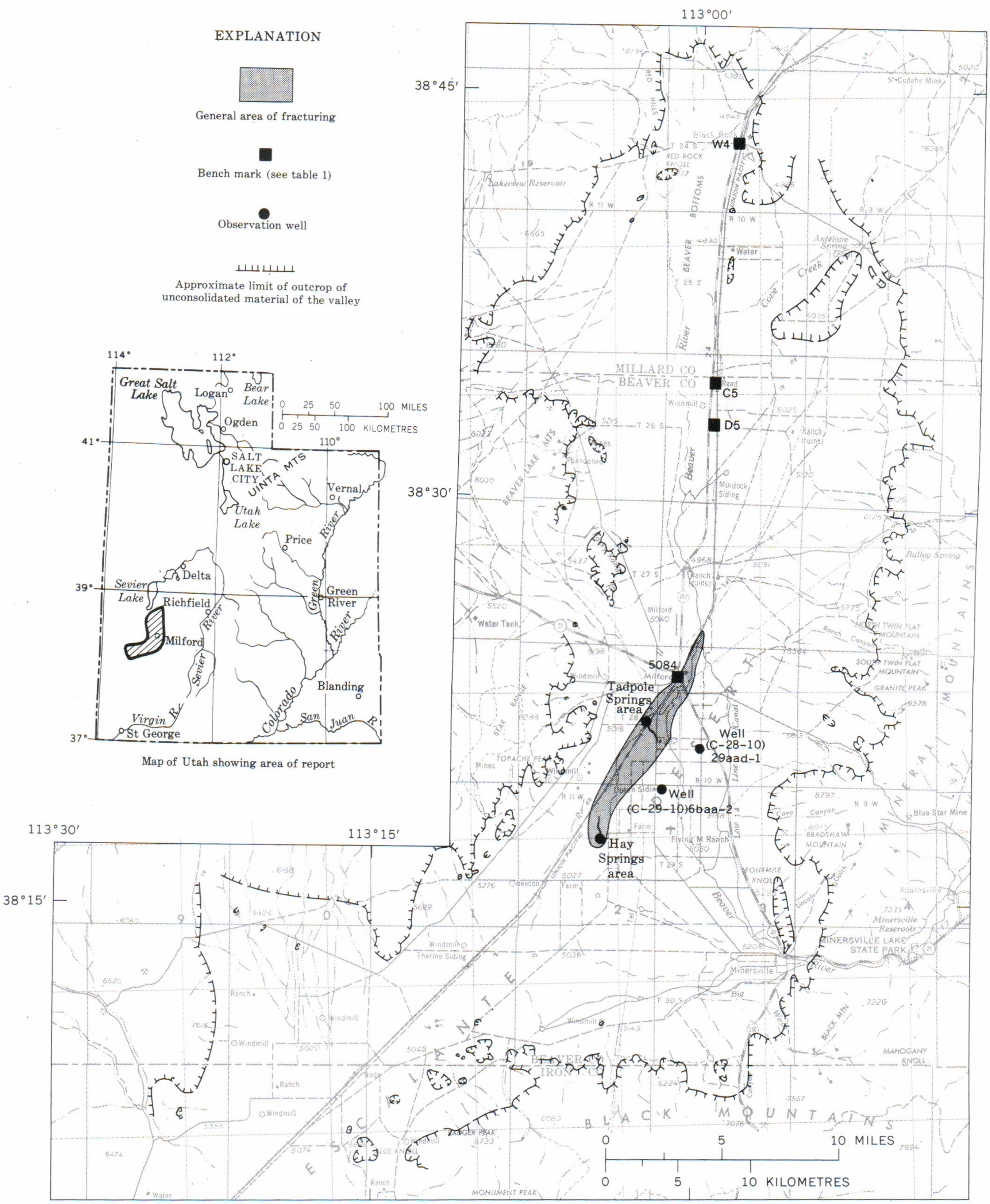

Figure 1.—Location of the Milford area, approximate limit of outcrop of unconsolidated materials of the valley, and selected information pertaining to fracturing and subsidence of the land surface.

FIGURE 2.—Linear fracturing in the SW¼SW¼NE¼ sec. 24, T. 28 S., R. 11 W., in the Tadpole Springs area. The stick at upper right is 4 feet (1.2 m) long. Photographed October 5, 1972.

The fractures are generally linear, but some are elliptical; they range in length from several feet to more than 100 feet (30 m). Linear fractures that intersect form polygons similar to those formed in drying mud. Most polygons range in longest diameter from about 3 feet (1 m) to about 40 feet (12 m).

DESCRIPTION OF LAND SUBSIDENCE

Land subsidence in the Milford area is demonstrated by three lines of evidence: (1) collapse structures, (2) well casings that protrude higher above the land surface than when first placed in the borehole, and (3) lower elevations in 1970 than in 1908 at bench marks of the National Ocean Survey (formerly U.S. Coast and Geodetic Survey). The evidence suggests that land subsidence in the Milford area is of two types, each having a different origin. One type has a near-surface origin in the clay-silt zone in the upper part of the principal ground-water reservoir, and the other is in the lower artesian aquifers of the principal ground-water reservoir. In this report the former type is referred to as near-surface subsidence and the latter type as deep-seated subsidence.

The collapse structures (see fig. 3, bottom photograph) include small grabens and elliptical sinks bounded by normal faults. These structures are in the areas of the Tadpole and Hay Springs and also in the SE¼ sec. 7 and the west half of sec. 18, T. 28 S., R. 10 W. The maximum amount of subsidence by collapse structures in the Hay Springs area is about 6 feet (1.8 m) and about 2 feet (0.6 m) in the other areas.

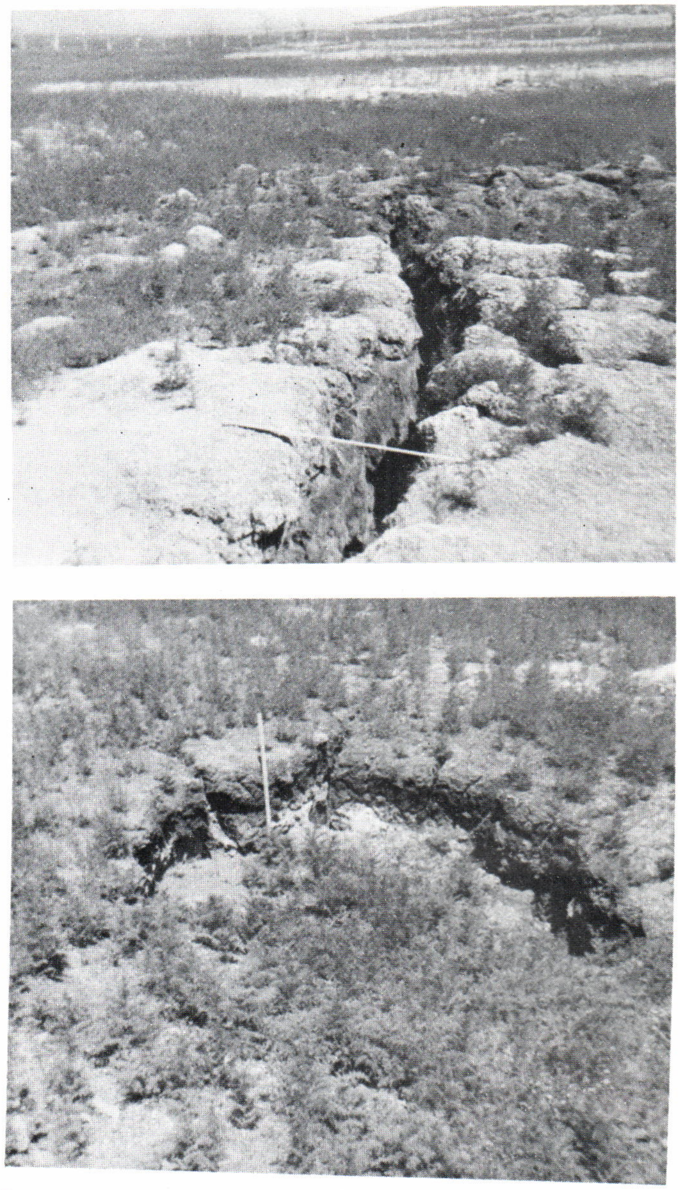

FIGURE 3.—Linear (top) and elliptical (bottom) fracturing and land subsidence of near-surface origin (collapse structure) in the NE¼NE¼NE¼ sec. 15, T. 29 S., R. 11 W., in the Hay Springs area. Metre stick is scale. Photographed May 16, 1973.

Casings of at least two wells in the most heavily pumped part of the valley protrude higher above the land surface than when they were installed. A result of land subsidence is shown in figure 4. Well (C-29-10)6baa-2 was drilled in 1953; therefore, the subsidence of at least 0.33 foot (0.10 m) at the well occurred during the period of heavy pumping that began in 1950 (fig. 5). Subsidence at a second well (C-28-10)29aad-1, for which the drilling date is un-

FIGURE 4.—A result of land subsidence at pumped well (C–29–10)6baa–2. Discharge pipe between standpipe and well is displaced vertically 0.33 foot (0.10 m) at flexible connection. Photographed October 5, 1972.

known, amounts to at least 0.1 foot (0.03 m), based on evidence similar to that at well (C–29–10)6baa–2.

Comparative surface-elevation data by the National Ocean Survey are available for the area from Milford northward to Black Rock. (See fig. 1 and table 1.) A comparison of elevations determined in 1908 and 1970 shows a maximum subsidence of 0.415 foot (0.126 m) at Milford. Although comparative elevation data are not available south of Milford, the displacement of the discharge pipe of well (C–29–10)6baa–2 (fig. 4) indicates at least 0.33 foot (0.10 m) of subsidence.

TABLE 1.—*Elevations at selected bench marks for 1908 and 1970*

[Bench mark: Designations are those of the National Ocean Survey; see figure 1 for locations. Elevation: First-order leveling by the National Ocean Survey; the elevation of bench mark W4 was considered as constant for this evaluation of changes; elevations, in feet, are based on the sea-level datum of 1929]

Bench mark	1908 elevation	1970 elevation	Difference
W4	4852.963	4852.963	0.000
C5	4883.825	4883.773	—.052
D5	4905.896	4905.759	—.137
5084	4956.690	4956.275	—.415

CAUSES OF FRACTURING AND SUBSIDENCE

Fractures and near-surface subsidence

Fractures and near-surface subsidence were caused by the dewatering of part or all of the clay-silt zone after pumping of ground water from aquifers beneath the zone had lowered the potentiometric surface. Prior to about 1950, the potentiometric surface was near or above the land surface in the area of fracturing, and the clay-silt zone was saturated by ground water. After lowering of the potentiometric surface, at least the upper part of the clay-silt zone was no longer saturated. The clay-silt and peaty materials dried, and contraction, fracturing, and subsidence resulted during the processing of drying. Fracturing of the land surface due to ground-water withdrawal has been reported in States other than Utah; for example, see

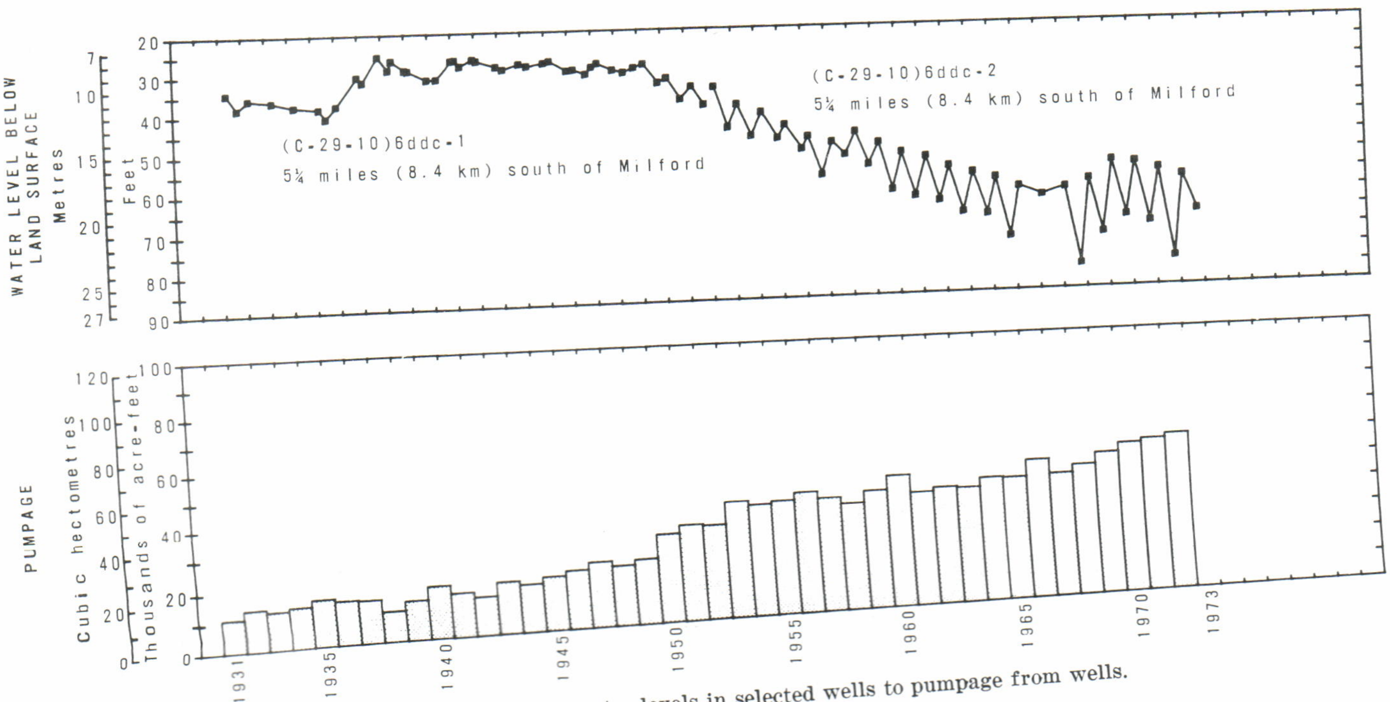

FIGURE 5.—Relation of water levels in selected wells to pumpage from wells.

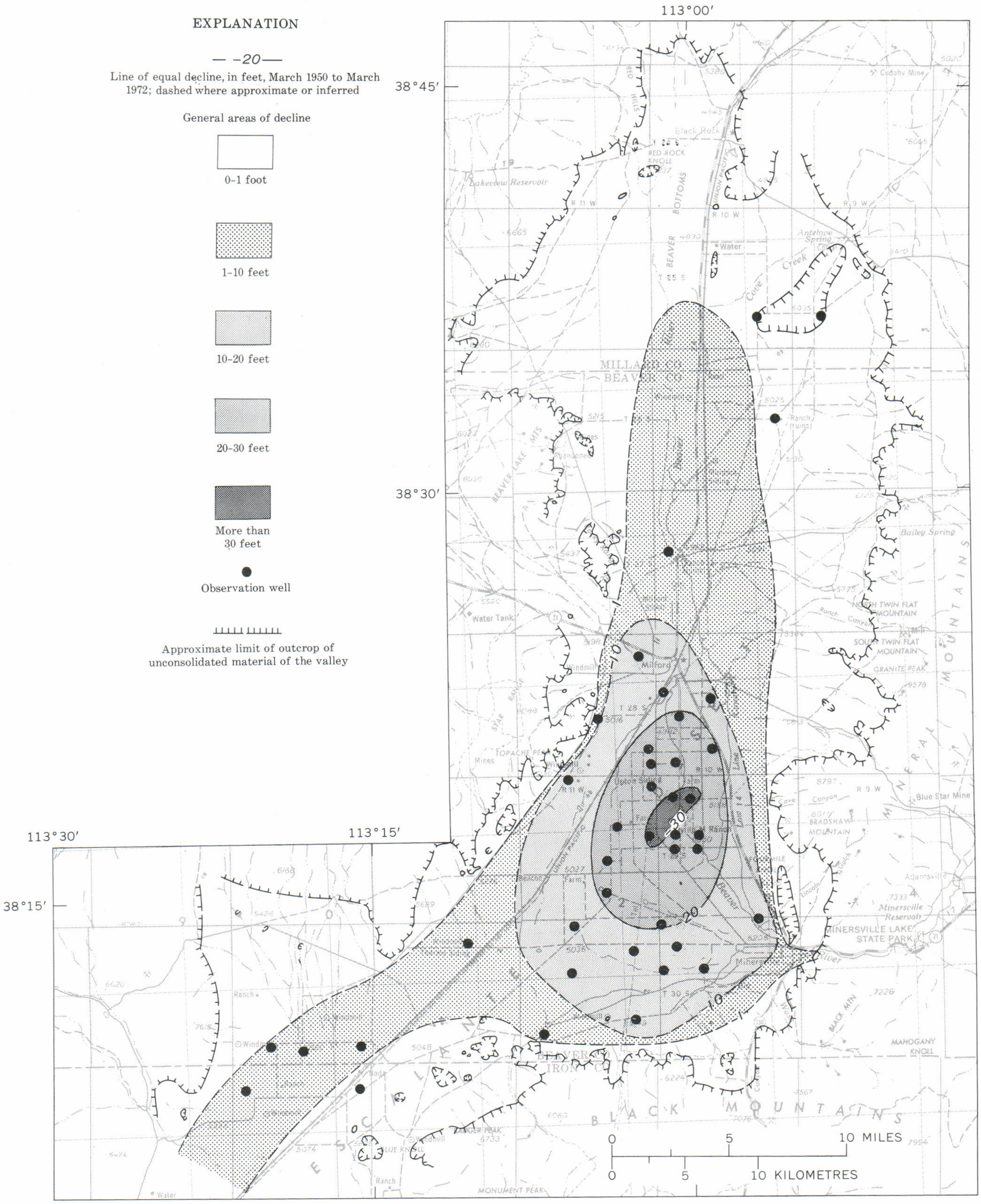

Figure 6.—Decline of the potentiometric surface of the principal ground-water reservoir from March 1950 to March 1972.

Robinson and Peterson (1962) for a description of earth fissures in southern Arizona.

The following evidence supports the concept that the development of the fracturing is comparatively recent and coincided with the withdrawal of ground water by wells: (1) fractures are commonly little eroded and the walls have the appearance of being freshly broken, (2) vegetation has not grown in the fractures, (3) fracturing has developed locally in previously cultivated fields, and (4) the fracturing could not have occurred if the surface area was saturated, as it was prior to about 1946 when, according to local residents, the Tadpole and Hay Springs areas virtually ceased discharging ground water.

Where peat is the dominant material, as in the Hay Springs area, the fracturing is the result of differential subsidence that occurred after the lowering of the water table. Subsidence of the peat results mainly from one or a combination of the following processes: (1) oxidation due to action of aerobic bacteria above the water table (for example, see Weir, 1950); (2) sinking or compacting of the peat after the buoying interstitial water is removed (W. E. McKinzie, U.S. Soil Conserv. Serv., oral commun., 1975). Peaty areas which have subsided are known in several other States. For example, subsidence of the Sacramento–San Joaquin Delta of California has exceeded 8 feet (2.4 m) (Weir, 1950, p. 46); the main reason for the subsidence is concluded to be oxidation.

The subsidence outside the Hay Springs area does not have an exact parallel in other States. After excluding piping and gypsum solution because of negative field evidence, it is tentatively concluded that an organic soil zone of high porosity and weak structural strength is buried by a relatively thin surficial mineral soil; the organic soil zone is tabular or perhaps lenticular in geometry. Also, removal of the interstitial water in effect weakened the support of the overlying surficial zone so that subsidence occurred.

Deep-seated subsidence

Deep-seated subsidence was caused by reduction of artesian pressure by pumping from the artesian aquifers of the principal ground-water reservoir, resulting in an increase of the grain-to-grain pressure of the aquifer materials. Therefore, the aquifers compacted or shrank in volume, and the land surface subsided. (See Poland and Davis, 1969, for a detailed discussion of the causes and effects of land subsidence due to fluid withdrawal.)

Withdrawal from the ground-water reservoir began in the Milford area in the early 1900's (about 1914 for irrigation) and increased gradually until 1950. Since 1950 the annual rate of withdrawal for the entire area (mainly for irrigation) has increased markedly (fig. 5). Coinciding with the increased withdrawal rate was a fairly steady decline of water levels in most of the valley. The decline of the potentiometric surface from March 1960 to March 1972 is shown in figure 6.

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