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Earth fissures of the Mimbres Basin, southwestern New Mexico

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Introduction

Large earth fissures—long, narrow, eroded extensional cracks—exist in the Mimbres Basin of southwestern New Mexico. Similar earth fissures have been described for numerous areas in the southwestern United States, including but not limited to the Fremont, San Jacinto, and San Joaquin Valleys of California (Holzer, 1984; Ireland et al., 1984; Pampeyan et al., 1988), western Arizona (Lister and Secrest, 1985), south-central Arizona (Holzer, 1984; Péwé et al., 1987), southeastern Arizona (Holzer, 1984), western Nevada (Bell and Hoffard, 1990), Las Vegas, Nevada (Holzer, 1984), Animas Valley of New Mexico (Lang, 1943), and San Agustin Plains of New Mexico (Neal and Motts, 1975). Both human-induced and natural causes produce the stress necessary to fissure the earth in these areas.

The study area encompasses 12 townships (approximately 432 sq mi) of the Mimbres Basin, a closed drainage basin in southwestern New Mexico (Fig. 1). Located south of Deming, the study area is bounded by the Little Florida and Florida Mountains on the east, the Tres Hermanas Mountains on the south, and Red Mountain and Snake Hills on the west. Interstate 10, US–180, and NM–11, 26, 331, 332, 377, 418, 490, and 549 provide vehicle access to the area.

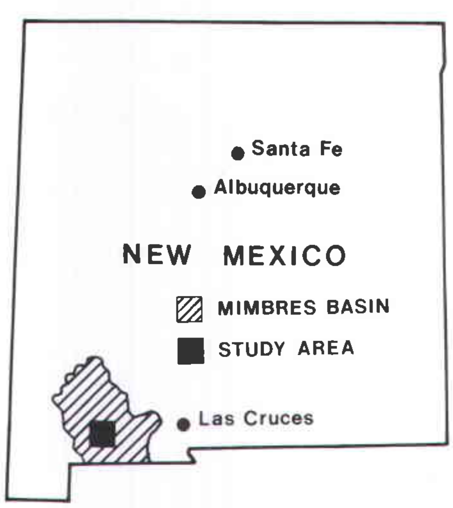

FIGURE 1—Mimbres Basin and study area.

Associations related to formation of the Mimbres Basin earth fissures are based on integrating fissure data with water-level and land-subsidence data. Particular attention is given to documenting earth fissures, total water-level decline, and land subsidence. This study is the first to address earth fissures and land subsidence of the Mimbres Basin.

Geology

The geology of the study area is highly varied (Fig. 2). Rock types range from Cambrian plutonic rocks to basin-fill alluvium of Recent age. Basin and Range normal faults inferred in the area from gravity data include the Treasure Mountain fault zone, the West Florida fault zone, the Snake Hills fault zone, and the Seventy-six fault zone (Seager, in press). A northwest- to west-trending Laramide reverse fault zone is exposed in the Florida Mountains.

According to Clemons (1986), most of the study area was covered by Eocene to early Miocene volcanic rocks before the onset of Basin and Range deformation. As structural basins formed along normal faults, the volcanic rocks exposed in adjacent uplifts provided most of the source material for the basin-fill alluvium. Interpretation of cuttings from four deep (>4,000 ft) wildcat oil and gas exploration wells located near Deming indicates that the boundary between bedrock and overlying basin-fill alluvium is at the top of the consolidated Miocene–Oligocene volcanic sequence (Clemons, 1986). Overlying this sequence is late Tertiary to Holocene basin-fill alluvium. Basin-fill alluvium can be distinguished from the volcanic sequence because drill cuttings of the former generally contain a greater percentage of well-rounded grains (Clemons, 1986).

The thickness of basin-fill alluvium is probably greatest in the half-graben east and northeast of Deming and in the graben between the Snake Hills and Seventy-six fault zones and decreases toward the surrounding mountains. In the Deming area, Clemons (1986) suggests that the thickness of basin-fill alluvium ranges from 3,160 to 4,225 ft. Based on interpretations of complete Bouguer anomalies, the maximum thickness of basin-fill sediments inferred by Seager (in press) in the graben between the Snake Hills and Seventy-six fault zones is about 3,500 ft.

The basin-fill alluvium consists of irregular lenses of gravel, sand, silt, and clay. Individual beds or lenses vary greatly in thickness and lateral extent (Darton, 1916); sorting and rounding in these sediments are also irregular (Doty, 1959). The basin-fill alluvium can be separated further into upper and lower units.

In general, the lower unit is composed of sediments extending from 4,000 ft above sea level down to bedrock. This unit is finer grained than the overlying upper unit and consists primarily of reddish clays. Hawley (written comm. 1988) indicates that sediments of the lower unit represent alluvial-fan and playa deposits that are middle Pleistocene or older.

The upper unit extends from 4,000 ft above sea level to the present land surface. According to Hawley (written comm.

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1988) much of the upper unit is composed of admixtures of gravel, sand, silt, and clay and represents fan-delta or splay sedimentation by the Mimbres River and its distributaries in the late Quaternary (Qa and Qb in Fig. 2). Braided channels of ancient Mimbres distributaries in uppermost basin fill have been mapped in detail by Seager (in press). For additional information on the geology of this area and surrounding mountains, the reader can refer to the literature of Darton (1916, 1917), Balk (1962), Corbitt (1971), Clemons and Brown (1983), Clemons and Mack (1988), Matheney et al. (1988), Clemons (1982, 1984, 1985, 1986, in press), and Seager (in press).

Hydrology

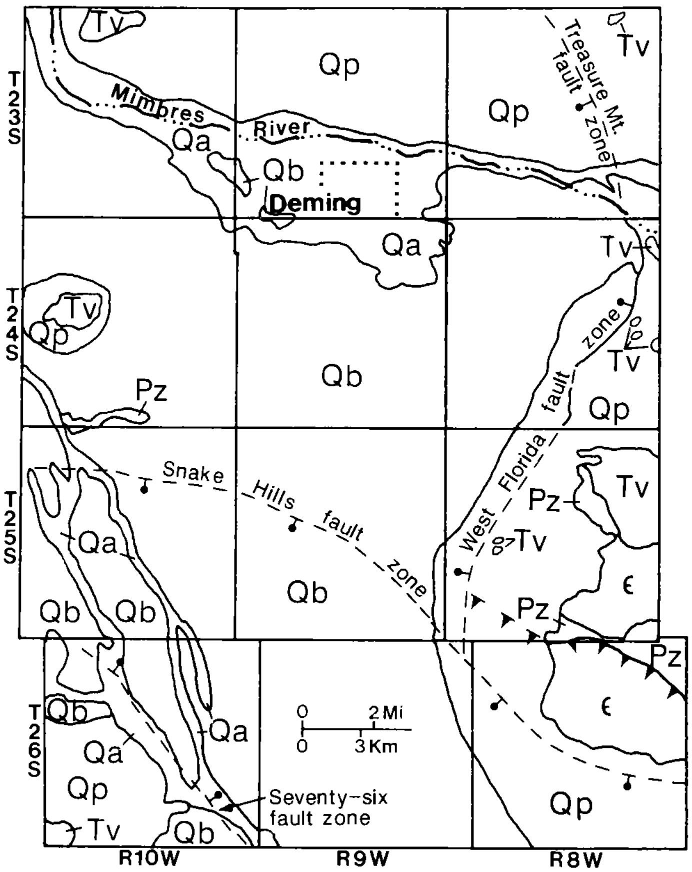
The major aquifer in the study area is the upper basin-fill unit. Thickness of sand and gravel deposits in this unit generally varies between 40 and 50 ft though in many places the thickness is much less, ranging from 5 to 18 ft (Darton, 1916). Determination of the lateral extent of water-bearing strata is very difficult because of the wide spacing of water wells and the lenticular nature of the water-bearing sand and gravel.

The aquifer in the unconsolidated basin-fill alluvium is generally unconfined (phreatic aquifer) although some local confinement and artesian conditions have been described previously (Darton 1915, 1916; White, 1930; Theis, 1939). The transmissivity of the alluvial aquifer varies from 14,000 to 190,000 gal/day/ft, and specific capacity of wells developed in this unit ranges from 0.5 to 106 gal/min/ft of drawdown (McLean, 1977). The range of these aquifer characteristics may be correlated with the lenticular character of the alternating clayey and sandy beds of the basin-fill alluvial deposits.

The aquifer is recharged primarily by runoff from the Black Range, Mimbres Mountains, and Cooke's Range and, to a lesser extent, from the Florida Mountains (White, 1930; Doty, 1959). This recharge is mainly in the form of seepage from the Mimbres River and San Vincente arroyo (Doty, 1959). The recharge by rainfall on the basin floor is greater in areas where sands are exposed, and much less where relatively thick deposits of generally impermeable clay pond and hold water at the surface. The contribution to ground water from sources outside the Mimbres Basin is uncertain at present.

Most ground water in the study area is used for domestic consumption, livestock watering, municipal and industrial supplies, and irrigation. Initial pumping of ground water began in 1908 when a large number of homesteaders settled in Luna County (Fiedler, 1928). As the population grew, the amount of irrigated acreage increased, and the demand for ground water also increased (Doty, 1959). Darton (1916) estimated ground water used about that time was no more than 10,000 acre-ft per yr. Wilson (1986) estimated the groundwater withdrawal and depletion in 1985 at 106,825 and 50,563 acre-ft, respectively.

Water levels in the area began to decline in 1913 and continue to decline. Numerous researchers, such as Darton (1915, 1916), Fiedler (1928), White (1930, 1932), Theis (1939), Conover and Akin (1942), Doty (1959), and McLean (1977) have documented the amount and extent of water-level declines during specific time inter-



Qa - Quaternary axial river and basin-floor arroyo deposits
Qb - Quaternary basin-floor deposits and fluvial fan deposits of Mimbres River
Qp - Quaternary piedmont-slope deposits
Tv - Tertiary volcanics and volcaniclastics
Pz - Paleozoic sedimentary rocks
€ - Cambrian igneous and metamorphic rocks
- Normal fault, ball and bar on downthrown side, dashed where inferred
- Reverse fault, barbs on upthrown side, dashed where inferred

FIGURE 2—Generalized geologic map of the study area (modified from Clemons, in press; Seager, in press).

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vals. McLean (1977) produced the most recent and comprehensive maps showing the decline of water levels for various periods from 1910 to 1970. Most apparent in McLean's maps is a circular to elliptical cone of depression that expanded in areal extent from 1910 to 1970. Also evident is the fact that the rate of ground-water decline has increased through time, and the cone of depression has migrated somewhat southward. The increased rate and southward migration are probably the result of increased development of irrigated land and increased pumpage associated with this development.

Earth fissures

Earth fissures occur in 13 discrete locations in the Mimbres Basin (Fig. 3, Table 1). Their locations and dates of appearance were determined through interviews conducted with local residents and through use of high-resolution aerial photographs. The latter included 1954 (1:54,000 scale) Army Map Service photographs, and 1977, 1984, and 1989 (1:20,000 scale) United States Soil Conservation Service photographs. Fissures located by the above methods were field checked in 1988.

Earth fissures in the area have two patterns (Table 1): 1) orthogonal to polygonal and 2) curvilinear. An orthogonal to polygonal pattern consists of a series of fissures interconnected to form triple junctions (Fig. 4). Individual polygons ☞

TABLE 1—Earth fissures of the Mimbres Basin shown in Figure 3. **PLSS**, Public Land Survey System.

Location number	Location (PLSS)	Date fissures first appeared	Land use	Fissure type
1	W½NW¼ sec. 31 T25S R9W	June 1982	subdivided rangeland	intersecting curvilinear
2	E½NE¼ sec. 32 T25S R9W	June 1982 and October 1984	rangeland	curvilinear
3	NE¼ sec. 6 T25S R9W	mid-1950's	subdivided rangeland	orthogonal-polygonal
4	S½SW¼ sec. 11 T25S R9W	early 1970's	subdivided rangeland	curvilinear
5	E½ sec. 10 T25S R9W	post-1954 pre-1984	subdivided rangeland	curvilinear
6	central ¼ sec. 27 T25S R9W	post-1954 pre-1984	rangeland	curvilinear
7	SW¼ sec. 20 T25S R9W	post-1954 pre-1984	rangeland	curvilinear
8	S½ sec. 31 T24S R9W	mid-1950's	rangeland	orthogonal-polygonal
9	NW¼ sec. 30 T24S R9W	post-1954 pre-1984	subdivided rangeland	orthogonal-polygonal
10	NW¼ sec. 18 T25S R9W	post-1954 pre-1984	rangeland	intersecting curvilinear
11	S½ NW¼ sec. 26 T24S R9W	post-1954 pre-1984	subdivided rangeland	intersecting curvilinear
12	NW¼NW¼ sec. 26 T23S R8W	post-1954 pre-1984	rangeland	curvilinear
13	SW¼ sec. 23 T25S R9W	post-1954 pre-1977	rangeland	curvilinear

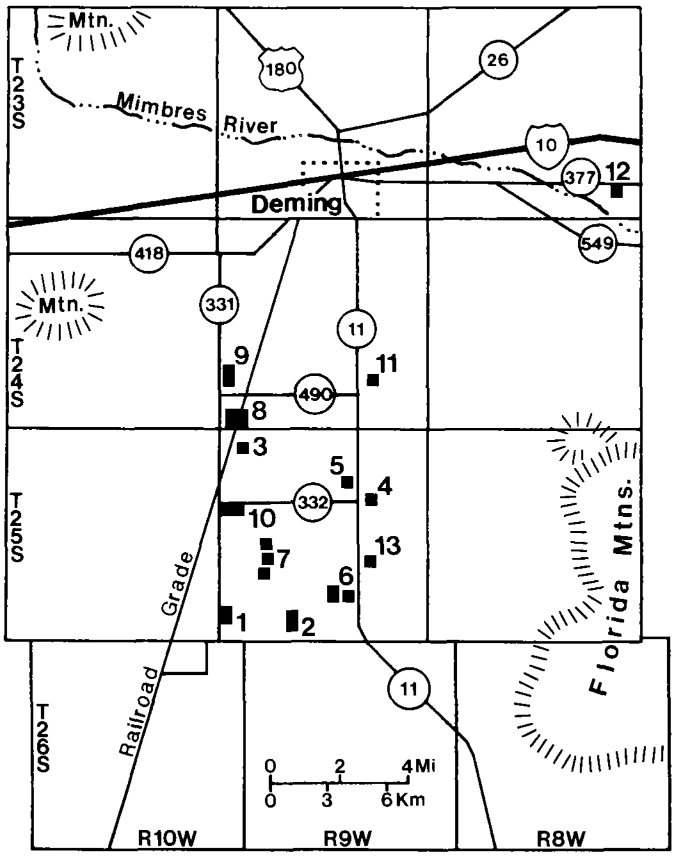

FIGURE 3—Earth fissures of the Mimbres Basin.

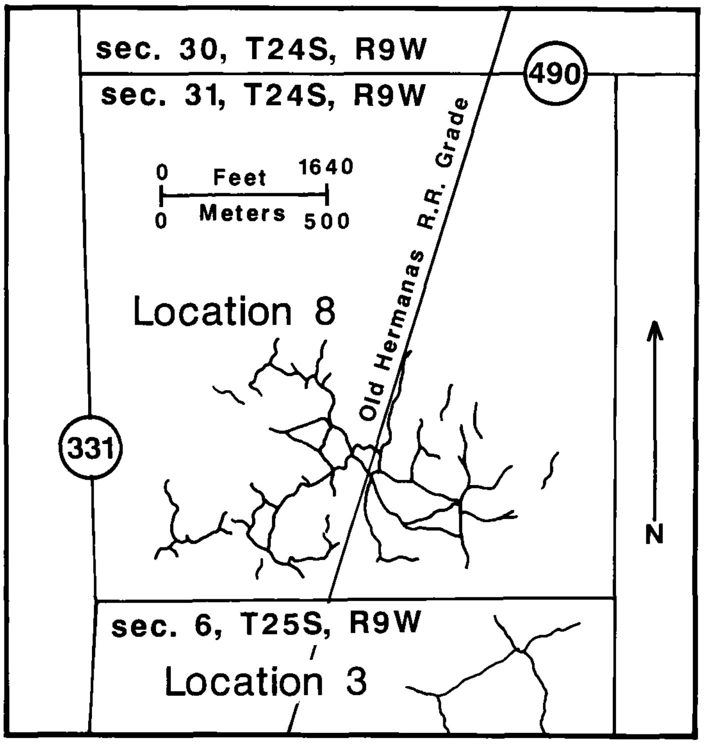

FIGURE 4—Fissures at location 3 and location 8 mapped from a 1984 aerial photograph.

range from 98 to 1,200 ft across. Curvilinear fissures are arcuate and exist isolated from each other in six of their nine areas of occurrence; their lengths range from 50 to 2,015 ft.

Measurable fissure depths range from less than 1 ft to 42 ft. These measurements are conservative and represent the limit to which a weighted tape can be lowered into the fissures. Depth measurements are actually measurements of surface features (e.g., potholes, hairline cracks, and surface depressions) rather than measurements of total fissure depth. Field evidence indicates that the near-surface void space of surface features is generated by transport of shallow soils to greater fissure depths. Holzer (1984) suggests that the near-surface void space is a measure of the total void space created during the formation of an extensional crack. Based on the observed size of surface features and the amount of material transported to greater depths, the actual depths of fissures are probably at least one order of magnitude greater than measured depths. Widths, on the other hand, are often exaggerated by erosional processes; they range from incipient hairline cracks at many locations to a maximum of 32 ft at location 8.

The appearance of aligned potholes at the surface at many fissure locations, and the fact that no vertical offset was observed along fissures, indicate that fissures initially form as extensional cracks in the subsurface. These extensional cracks create preferred pathways for infiltrating water, which in turn promotes enlargement of the cracks through subsurface piping erosion. Once large voids are created in the subsurface, soil above the voids can no longer support itself and eventually collapses, typically forming aligned potholes at the surface. Erosion through tributary gullying, slumping, and subsurface piping continues to enlarge many potholes. Potholes generally become larger along the trend of fissures and eventually may interconnect, completely opening fissures to the surface (Fig. 5). As erosion at the surface and concomitant deposition within the fissures proceeds, the width of fissures generally increases, whereas the apparent depth decreases. Many of the fissures appear to be almost completely filled with slump and runoff material. These fissures are marked on the surface by curvilinear surface depressions.

Additional conspicuous characteristics of the earth fissures are: 1) almost without exception, fissures occur in areas where the land surface is currently undisturbed by cultivation, typically forming either between or immediately adjacent to cultivated fields; 2) most curvilinear fissures trend north–south; and 3) fissures are generally narrower and shallower across roads compared to those in adjacent undisturbed land. The reader can refer to Contaldo (1989) for a more detailed description and map of each fissure location.

Water-level declines, fissures, and land subsidence

The contours in Fig. 6 show total water-level decline from 1910 to 1987. Conspicuous is a circular to elliptical cone of depression that is elongated north–south. An area of about 340 sq mi has been affected by water-level declines. The maximum decline from 1910 to 1987 in the Deming area is slightly greater than 110 ft; the average rate of decline in the area of greatest depletion is 1.5 ft per yr.

A comparison of the location of earth fissures (Fig. 3) to the areas of water-level decline (Fig. 6) reveals that the two are spatially associated. The majority of fissures, including those at locations 2 through 11 and location 13, occur near the apex of the cone of depression in an area where the water level has declined at least 70 ft. Earth fissures at location 1 and location 12 are also in the cone of depression where the water level has declined about 60 ft and 35 ft, respectively.

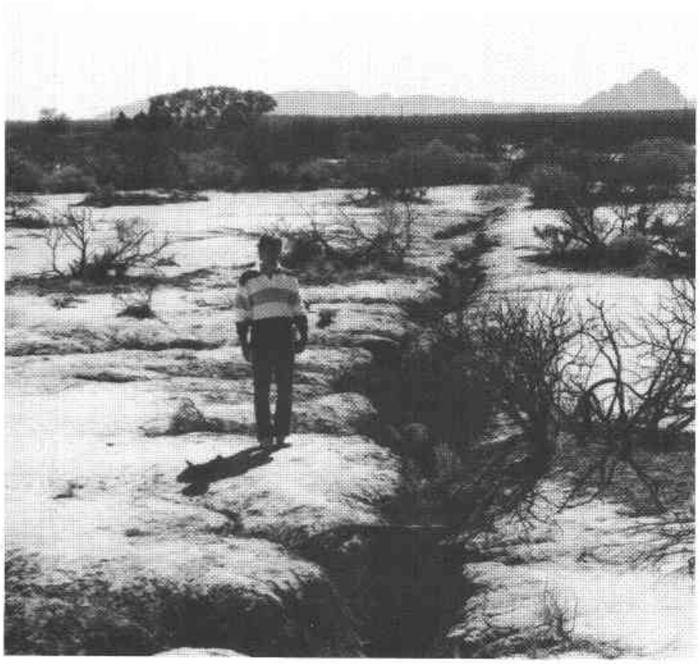

FIGURE 5—This fissure at location 8 is well defined at the surface and displays tributary gullying on left (north). Photograph was taken in April 1988.

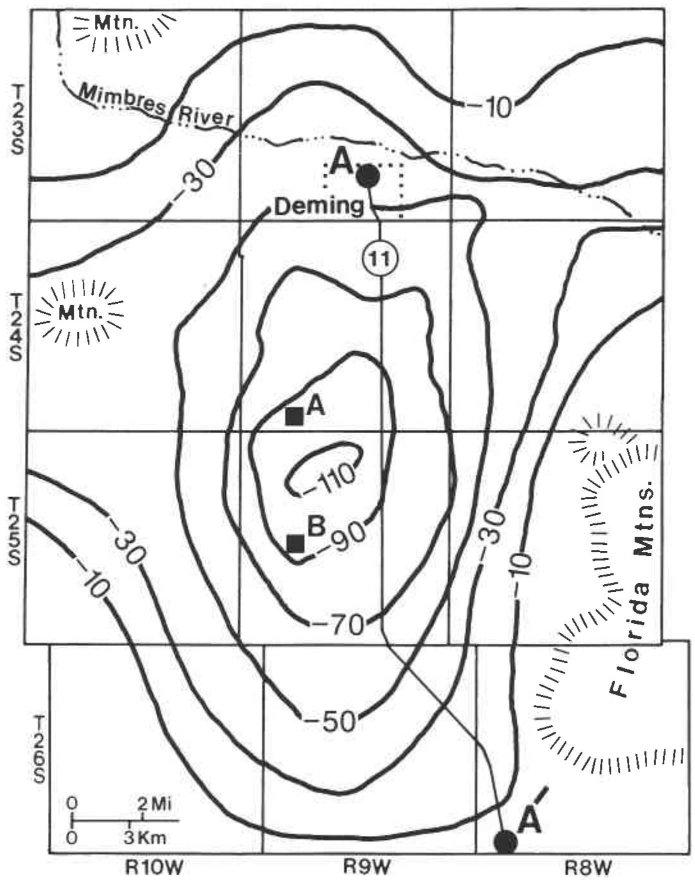

FIGURE 6—Total water-level decline from 1910 to 1987 indicated by contours (in feet). Data source: McLean (1977) and New Mexico State Engineer Office in Deming. **A**, **B**, protruding water wells.

Earth fissures are temporally associated with water-level declines. The first known earth fissures in the Mimbres Basin appeared at the surface during the mid-1950s, and others appeared as recently as October 1984 (Table 1). Analysis of water-level decline maps provided by McLean (1977) reveals that the ground-water level had declined as much as 45 ft by the mid-1950s. Relatively precise dates on the first appearance of fissures at locations 1 through 4 and location 8 indicate that these fissures, which are nearest the apex of the cone of depression, are older than those found farther from the apex. Fissures at locations 3 and 8 first appeared in the mid-1950s and are nearest to the apex. Fissures at location 4 first appeared in the early 1970s and are located farther from the apex than fissures at locations 3 and 8. Fissures at locations 1 and 2 are located even farther from the apex and first appeared between June 1982 and October 1984. Because the more recent fissures are located farther from the cone of depression apex, the fissures appear to be spatially and temporally associated with the expanding cone of depression.

Fig. 7 shows the amount of land subsidence in the study area along line A–A' in Fig. 6, based on leveling data obtained by the National Geodetic Survey. The original leveling line, line L4486, which is along NM-11 (line A–A'), was first surveyed in 1935. Each benchmark along this leveling line is assumed stable and is used as the datum; benchmarks along the line are spaced less than 1 mi apart. Unfortunately, leveling line L4486 has never been releveled. Only certain benchmarks along this line were resurveyed when surveys were conducted along other leveling lines. Benchmarks A134, Z133, Y133, and X133 along leveling line L14850 were resurveyed in 1953. Based on unadjusted leveling data, a minor amount of land subsidence (<3 in.) occurred in the area between 1935 and 1953. Benchmark A134 along leveling line L24557 was resurveyed in 1980. Analysis of elevation data from this benchmark indicates that subsidence increased greatly from 1953 to 1980.

Additional indirect evidence for determining the amount of land subsidence during certain time periods was obtained from two protruding water wells (A and B in Figs. 6 and 7). At both wells, the top of the surface casings, the pumps, and the concrete slabs supporting the pumps stand farther from the ground surface than when the wells were first completed.

Water well A was completed in April 1958 to a total depth of 400 ft. According to Paul Smith (pers. comm. 1985), a local well driller who installed the well, the base of the concrete slab that supports the pump for this well originally was flush with the ground surface. Over a period of years, the discharge pipe connected to the pump continued to bend, resulting in damage to the flow valve connected to the discharge pipe. Measurements taken from the ground surface to the base of the concrete slab in April 1988 indicate that the land surface had subsided 13.5 inches since 1958 (Figs. 7 and 8).

Water well B was completed in April 1953; the total depth is unknown. Similar in construction to protruding well A, the base of the concrete slab that supports the pump of well B was flush with the ground surface when it was installed. Measurements taken from the ground surface to the base of the concrete slab in April 1988 indicate that the land surface had subsided 14.1 inches since 1953 (Fig. 7).

Analysis of total water-level decline from 1910 to 1987 (Fig. 7) suggests a cause and effect relationship between water-level decline and land subsidence. The amount of subsidence, determined from benchmarks along leveling line L14850, increases as the amount of water-level decline increases. Maximum subsidence, determined by measurements at protruding water-wells A and B, has occurred near the apex of the cone of depression where the ground-water level has declined at least 90 ft (Fig. 6). ☞

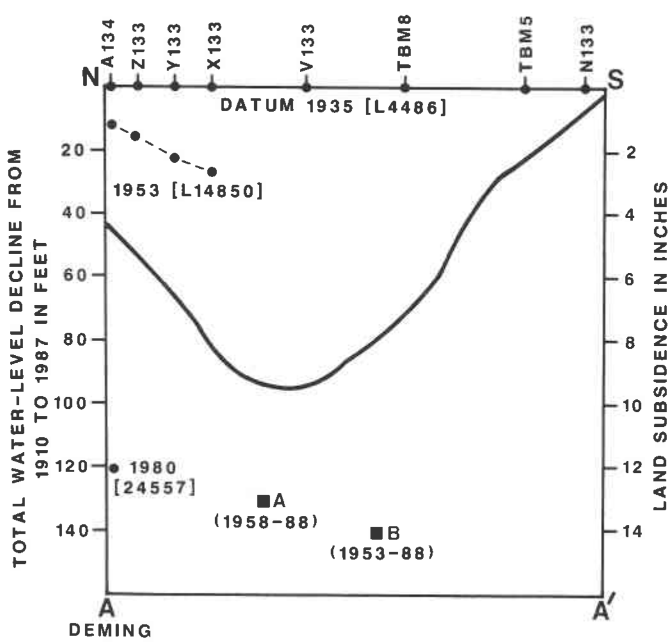

FIGURE 7—Total water-level decline from 1910 to 1987 (solid line) and land subsidence (dashed line) along line A–A' in Fig. 6. Benchmark designations are provided at top of diagram. Leveling line designations are shown in brackets. Protruding water wells A and B are shown by squares. Benchmark data points are shown by circles.

FIGURE 8—Photograph showing protruding water well A. Original land surface is indicated by arrow. Photograph was taken in April 1988.

In summary, most earth fissures occur in the area of greatest water-level decline. Analysis of leveling-line and protruding water-well data indicates that land subsidence is greatest in the area of greatest water-level decline. This evidence suggests that the earth fissures are spatially and temporally associated with water-level declines and land subsidence.

Environmental problems related to fissuring and subsidence

Problems related to the earth fissures of the Mimbres Basin include: damage to roads, water wells, and earthen stock tanks; abandonment of irrigated land; and various safety hazards. Sixteen instances of road damage have been documented. Much of the soil material used to patch the fissured roads is eventually lost through piping processes, making road repair repetitive. Cattle have reportedly fallen into earth fissures, and the hazard to off-road vehicles and passengers is equally great. The use of fissures as waste-disposal sites poses a serious threat of ground-water contamination.

Future structural damage is possible. This is based upon the assumption that long-term water-level declines and the processes responsible for the formation of the earth fissures will continue. Fissures may directly damage buildings, roads, water wells, and other agricultural structures, and even without ground failure, compaction subsidence in and of itself may cause damage to structures that are large in area or height. Aqueducts, storm drains, water mains, and sewer mains that depend on gravity flow may reverse flow, and in extreme cases, rupture. The possibility of gas-line rupture and leaks also exists.

Conclusions

The spatial and temporal association of water-level decline with earth fissure formation in the Mimbres Basin suggests a cause and effect relationship. Although existing land subsidence data are limited, analysis of the data presented suggests that land subsidence is a manifestation of ground-water depletion. The fissures are therefore suspected to be a result of land subsidence caused by compaction of unconsolidated sediments. The compaction may be due to increased effective stresses as a result of water-level decline, either as the result of decrease in hydrostatic (pore) pressure in a confined aquifer or dewatering of an unconfined aquifer.

The United States Geological Survey is presently involved in studying land subsidence in this area utilizing the Global Positioning System (GPS). The New Mexico Bureau of Mines and Mineral Resources recently conducted seismic reflection and gravity surveys to characterize the distribution of alluvial units and their physical properties. Information obtained from these studies will provide greater insights into the mechanisms responsible for the initiation, development, and propagation of earth fissures in the Mimbres Basin.

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