Impact of Evaporite Dissolution and Collapse on Highways and Other Cultural Features in the Texas Panhandle and Eastern New Mexico

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Cover drawing: Cover is artist's conception of a typical sinkhole on the Rolling Plains of the Texas Panhandle. Although not documented in this report, livestock and farm machinery have reportedly fallen into similar holes. Drawing by Judy P. Culwell.

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ABSTRACT

Geological investigations in the Texas Panhandle and eastern New Mexico indicate that regional subsurface dissolution of Permian evaporites has occurred and is an ongoing process. Evidence of removal of large volumes of evaporites (mainly halite) and collapse of overlying beds is demonstrated by cross sections constructed from gamma-ray logs.

Surface manifestation of subsurface dissolution and collapse is clearly shown in Hall County, Texas, where over 400 sinkholes and undrained depressions have been identified from aerial photographs. Sinkhole diameters up to approximately 100 m (300 ft) and depths to 15 m (50 ft) have been observed. Eleven active northeast- and southwest-trending fractures and faults have been recognized, some of which are demonstrated as patched sections of highways.

Formation of collapse features and faults that damage highways is a recognized problem in the region. Stock tanks and large reservoirs are also affected to a lesser degree. Dissolution and collapse pose difficult problems for geologists, highway engineers, and maintenance crews. Areas of active subsurface dissolution have been identified, but development of collapse features and faults at the surface generally follows no predictable pattern. The history of, and potential for, evaporite dissolution should be investigated in each area before construction of highways, reservoirs, and stock tanks. Areas with high densities of collapse features, fractures, and faults should be avoided when possible.

INTRODUCTION

Thick sequences of Permian evaporites that are both highly soluble (halite) and moderately soluble (anhydrite and gypsum) constitute a significant part of the sedimentary fill in the Permian Basin of the southwestern United States. Geologists at the Bureau of Economic Geology, The University of Texas at Austin, have been studying evaporite dissolution in the Texas Panhandle since 1977 as part of a comprehensive analysis of Permian salt as a potential repository for isolation of nuclear wastes. As part of this study, Gustavson and others (1980b) have determined that pre-Holocene and Holocene dissolution of Permian bedded salts of the Palo Duro, Dalhart, and Anadarko Basins is a major factor in the development of the Texas Panhandle landscape. Sinkholes, collapse depressions, fractures, and faults are common surface manifestations of subsurface dissolution.

This process of dissolution and collapse directly affects highways that traverse parts of the Texas Panhandle and eastern New Mexico. This first became evident to us when investigating the faults along FM 2639 in Hall County, Texas. Further investigations employing questionnaires and field work confirm highway damage due to subsidence and faulting over the zone of salt dissolution. Large reservoirs and stock tanks are also affected to a lesser degree.

Highways occupy only a small part of the total land surface in the Texas Panhandle and eastern New Mexico. The number of collapse features and faults observed near and on highway right-of-ways suggests that they are widespread in fenced, privately owned land not traversed by highways. Thus, the phenomena described in this paper are only a small fraction of the total number in the region.

Major physiographic features in the study area include the Northern and Southern High Plains surfaces (Llano Estacado), the Caprock Escarpment, and the Rolling Plains and Pecos Plains to the east and west, respectively (fig. 1). The High Plains is divided into north and south sections by the valley of the Canadian River, termed the Canadian Breaks. The High Plains surface is developed on the late Tertiary Ogallala Formation, the remnants of a large alluvial plain that originated in the Sangre de Cristo Mountains and Pedernal Hills in New Mexico and spread eastward across the Texas Panhandle (Seni, 1980). The Ogallala Formation is now overlain in most areas by eolian cover sand. The High Plains surface and underlying Ogallala Formation and Dockum Group are truncated by the Caprock Escarpment, an erosional scarp which in Texas has retreated since Tertiary time westward to its present position. A similar escarpment, the southern part of which is known as the Mescalero Ridge, forms the western rim of the High Plains in eastern New Mexico. The Caprock Escarpment is supported by massive caliche zones within the uppermost part of the Ogallala Formation and to some extent by indurated sandstones in the upper part of the Triassic Dockum Group. Vertical relief on the escarpment locally exceeds 300 m (1,000 ft). East of the Caprock Escarpment lies the Rolling Plains, a gently rolling surface developed on structurally disturbed Permian red beds. The Pecos River Plains lies west of the Caprock Escarpment in New Mexico, and the Edwards Plateau merges with the High Plains surface to the south.

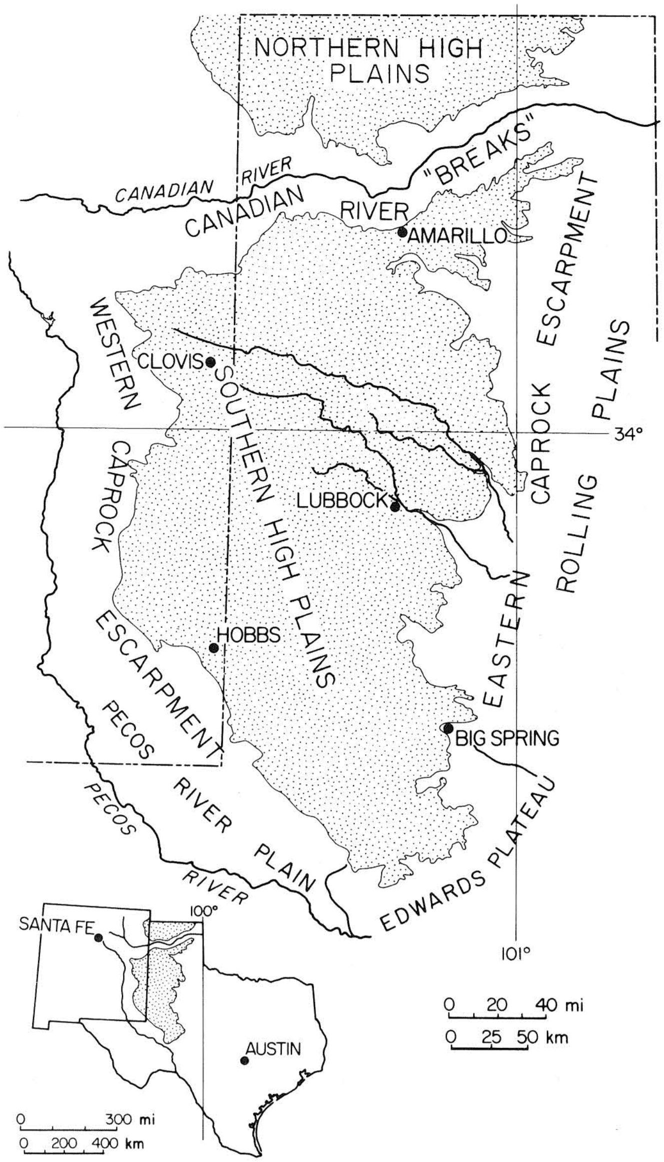

Figure 1. Physiographic units of the Texas Panhandle and eastern New Mexico (from Gustavson and others, 1980b).

GEOLOGIC SETTING

Major tectonic elements of the Texas Panhandle, eastern New Mexico, and western Oklahoma (fig. 2) have been discussed elsewhere by Nicholson (1960) and Johnson (1976). These elements, the Palo Duro, Dalhart, and Anadarko Basins, the Amarillo-Wichita uplifts, Matador Arch, and Oldham Nose, were tectonically active from late Mississippian to mid-Permian time. Fault displacements since the late Permian have been identified, but the total extent of post-Permian displacements is unknown (A. Goldstein, personal communication, 1980).

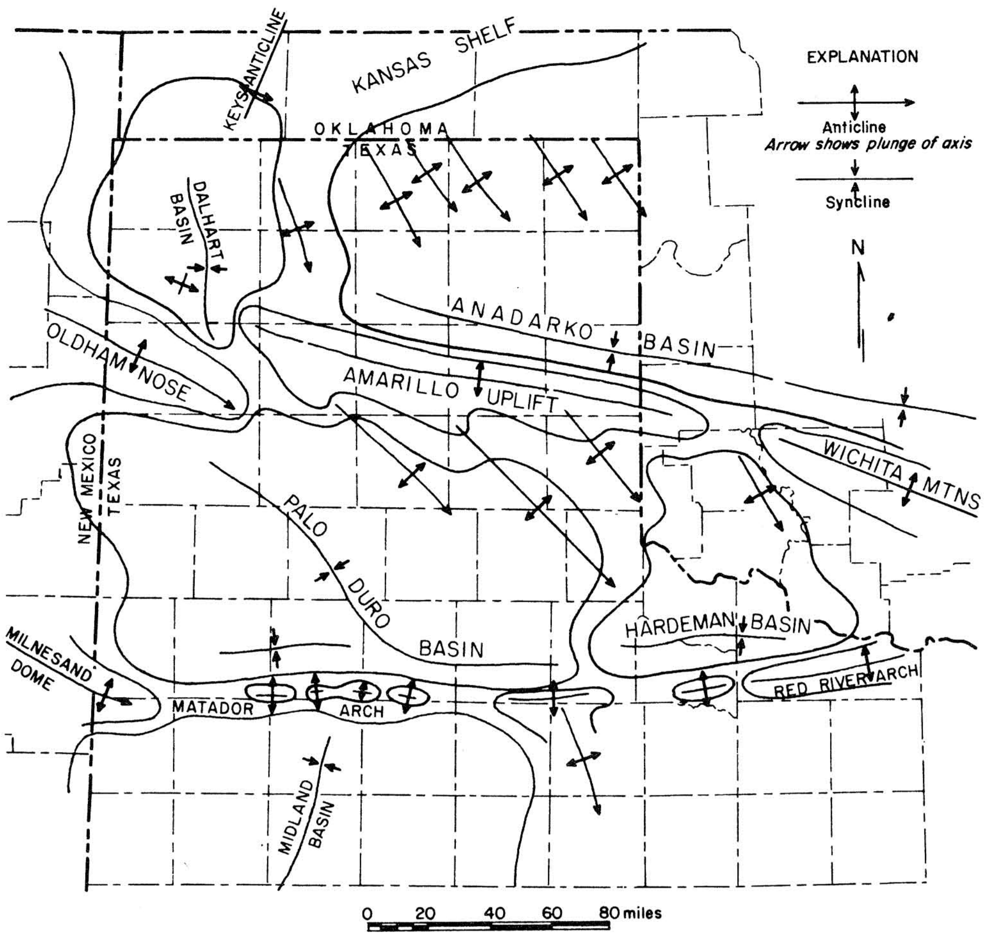

Figure 2. Major structural elements of the Texas Panhandle (after Nicholson, 1960).

Salt, gypsum, anhydrite, mudstone, sandstone, dolomite, and limestone make up the Permian strata in the Palo Duro, Anadarko, and Dalhart Basins (Dutton and others, 1979). Apart from areas of dissolution, evaporites constitute 50 to 75 percent of the Upper Permian section in the basins (M. Presley, personal communication, 1980). This percentage of evaporites decreases toward basin margins because of increased terrigenous sediment and extensive evaporite dissolution. In the Panhandle, evaporite and associated carbonate rocks display facies that grade from supratidal environments in the north to subtidal environments in the south. From north to south, lithofacies include upper sabkha salts, lower sabkha anhydrites, supratidal to subtidal dolomites, and subtidal carbonates. Red beds occur as sheets of basin-edge mudstones and fine-grained sandstones that intertongue basinward with dolomite-evaporites (Dutton and others, 1979).

There are seven salt-bearing units within the Anadarko, Dalhart, and Palo Duro Basins. These are the Salado, Seven Rivers, upper and lower San Andres, Glorieta, and upper and lower Clear Fork Formations, which lie at depths between 150 and 757 m (500 and 2,500 ft). Stratigraphic names of some of these units change from basin to basin (fig. 3). Except for the lower Clear Fork Formation, all of the salt units are undergoing regional dissolution. Stratigraphically higher (shallower) salt beds are dissolved progressively farther toward the center of the Palo Duro Basin (fig. 4). Relatively fresh, undersaturated ground water migrating down to the salt beds is the agent of dissolution; thus, the shallowest salt beds have been the most affected by the dissolution process. Anhydrite, hydrated to gypsum near the land surface, is also undergoing dissolution, but apparently gypsum dissolution occurs only at or near the surface (Gustavson and others, 1980b).

PREVIOUS WORK

Subsurface dissolution of Permian bedded salt has been recognized since Johnson (1901) first suggested that this process accounts for the structure of the Meade Basin in southwestern Kansas. Lee (1923) and Morgan (1941) suggested that the present course of the Pecos River in eastern New Mexico is a result of the interconnection of solution troughs along that course. Fiedler and Nye (1933) described solution phenomena in the Roswell Artesian Basin. Adams (1963), Jordan and Vosberg (1963), Brown (1967), Hills (1968), Bachman and Johnson (1973), and Johnson (1976) have all attributed the thinning of subsurface evaporite sequences to the dissolution process.

Surface manifestations of subsurface dissolution have been described in eastern New Mexico and the Texas Panhandle. Kelley (1972) and Sweeting (1972) discussed the geologic setting of Santa Rosa, New Mexico, a city that occurs in a large collapse sink. Jones (1973) reported several depressions in the Los Medanos area of southeast New Mexico, including the San Simon Swale, Nash Draw, and Clayton Basin. He attributed these depressions to the dissolution of salt, gypsum, and anhydrite in the subsurface. Vine (1976) described breccia pipes caused by salt dissolution in the same region. Anderson (1978) documented geomorphic features such as domes, sinkholes, and depressions in southeastern New Mexico, and attributed them to dissolution of salt and other soluble minerals within the (Upper Permian) Ochoan Series.

In the Texas Panhandle, dissolution of Permian salt beds within the Palo Duro, Dalhart, and Anadarko Basins has been discussed by Johnson (1976), Dutton and others (1979), Gustavson and Finley (1979), and Gustavson and others (1978, 1979, 1980a, 1980b, 1980c). Karst features attributed mainly to gypsum dissolution have been studied by Miotke (1969), Smith (1969), and Baker (1977).

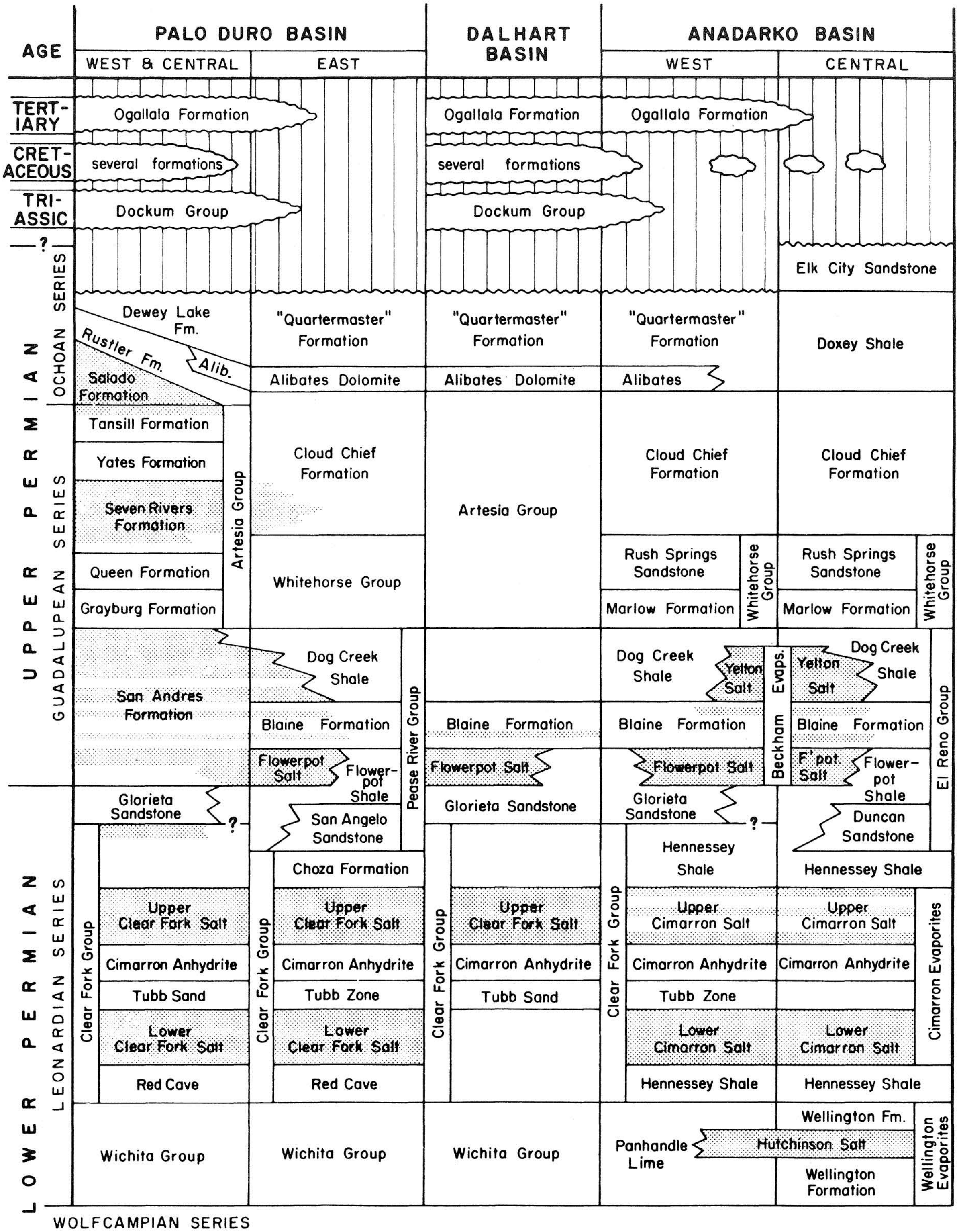

Figure 3. Stratigraphic nomenclature of Permian and younger strata in the Texas Panhandle and western Oklahoma. Principal salt units are shown in gray. Modified from data in Fay (1965), Jordan and Vosburg (1963), McKee and others (1967a, b), and Tait and others (1962) (from Johnson, 1976).

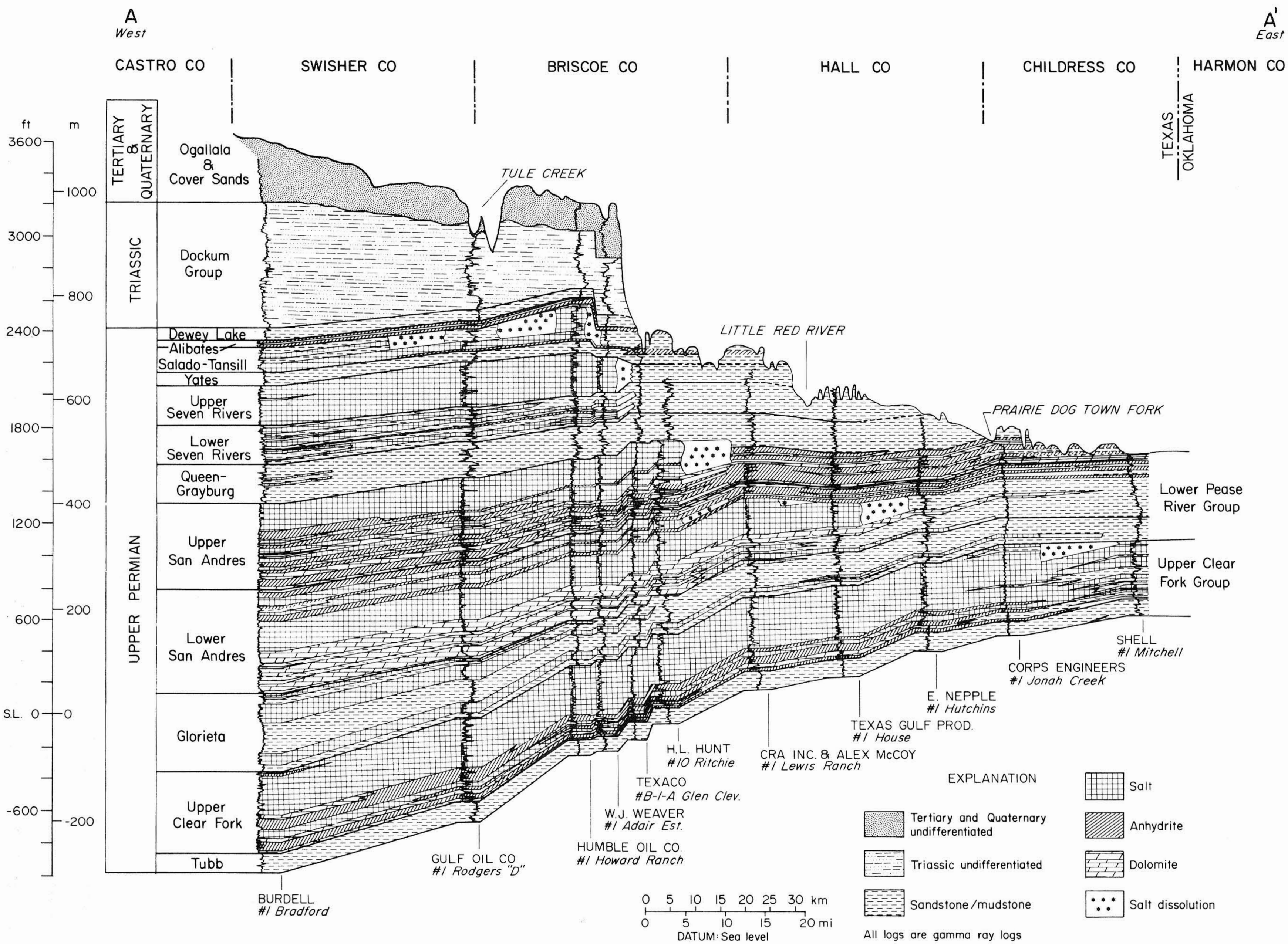

Figure 4. Zones of salt dissolution and stratigraphic units as interpreted from gamma-ray logs. Cross section extends from Castro County in Texas eastward into Oklahoma. Line of section is shown in figure 6. From Gustavson and others (1980a).

SURFACE DISSOLUTION FEATURES AND EFFECTS

Extensive Holocene karstification related to evaporite dissolution has been documented in Hall County, Texas, by Gustavson and others (1980a), who used several vintages of aerial photography to identify over 400 total sinkholes and collapse depressions and 11 faults or fractures. Thirty-six sinkholes and two depressions formed between 1940 and 1979 within a 307 km^2 (120 mi^2) test area. This area was selected for study because of the availability of aerial photography taken during that time period. These sinkholes are generally circular to oval in plan view, and may be 100 m (330 ft) in diameter and 15 m (50 ft) deep. Sinkholes have vertical walls when formed (fig. 5), but by mass wasting and slope processes the vertical walls degrade to form a more stable, gentler slope. The stabilizing process is somewhat accelerated if the sinkhole is filled with water. Collapse depressions are broad, shallow, internally drained depressions that, in contrast to sinkholes, have no steep vertical sides and are generally larger and more oval in plan view. Lengths up to 2.4 km (1.5 mi) have been observed in the study area. Fractures and faults resulting from dissolution are recognized from aerial photographs as offsets in highways (faults) and as open fractures in cultivated fields. All fractures and faults identified in Hall County trend between N 25° E and N 50° E.

To determine the extent of collapse features, fractures, and faults in other areas of the Panhandle region, a questionnaire was sent to each county Soil Conservation Service (SCS) and Agricultural Stabilization and Conservation Service (ASCS) office in the Texas Panhandle and eastern New Mexico. Conversations with representatives of these agencies in Hall County, Texas, revealed their thorough knowledge of sinkholes, collapse depressions, fractures, and faults in that county. We hoped that in other counties these agencies would also be familiar with such features. Of 54 counties canvassed in the study region, representatives of 98 percent of the counties returned at least one response. Representatives of 70 percent of the counties returned two responses. In 37 percent of the reporting counties, SCS and ASCS agents knew of sinkholes, collapse depressions, fractures, and faults.

Effect on Highways

For those counties in which collapse features, fractures, and faults were recognized by SCS and ASCS personnel (37 percent of total counties), additional questionnaires were sent to representatives of the Texas Department of Highways and Public Transportation and the New Mexico State Highway Department. The purpose of

Figure 5. Sinkhole located near U.S. Highway 287, 6.4 km (4 mi) northwest of Estelline in Hall County, Texas. The feature is approximately 10.6 m (35 ft) wide and 7.5 m (25 ft) deep.

the second questionnaire was to determine if the development of collapse features, fractures, and faults was a recognized problem among those who construct and maintain highways. Results of that questionnaire, shown diagrammatically in figure 6, demonstrate that such features are recognized by highway personnel in 38 percent of those counties that responded positively to the first questionnaire sent to SCS and ASCS personnel. Although highways cover only a small part of the total area, highway personnel recognized that collapse features, fractures, and faults pose a significant problem in maintaining the structural integrity of the highways. Counties in which highway personnel reported such features all lie within the zone of active salt dissolution (fig. 6) and within outcrop belts of gypsum beds of the Permian Blaine Formation (see Barnes, 1967, 1968).

Areas in Texas were subsequently field checked with representatives of the Texas Department of Highways and Public Transportation. Areas in New Mexico were not field checked because of limited positive responses to the questionnaire. Field checking verified several sites where sinkholes, collapse depressions, and faults have affected highways (fig. 7).

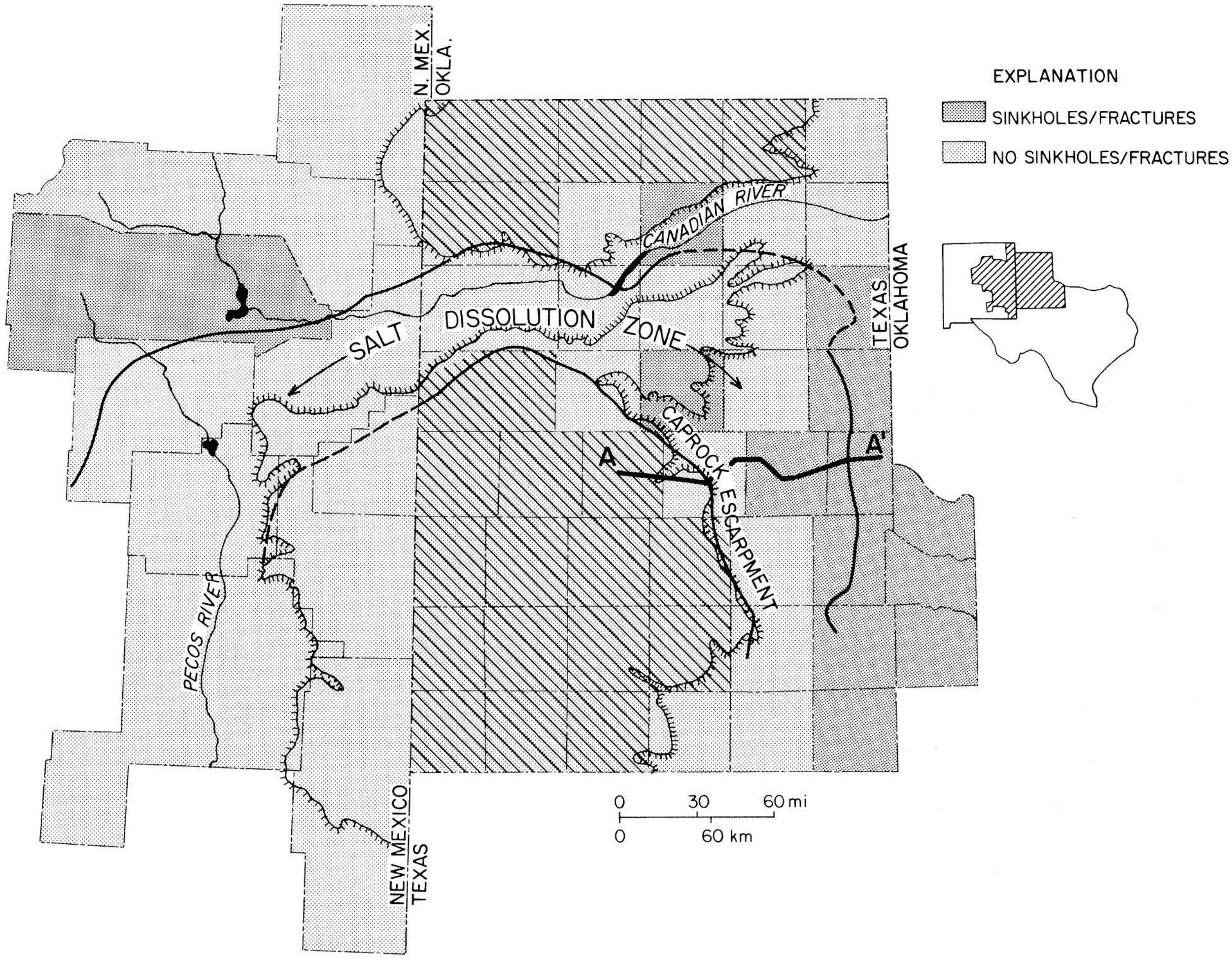

Figure 6. Distribution of collapse features, fractures, and faults that affect highways in the Texas Panhandle and eastern New Mexico, as recognized by highway personnel responding to the second questionnaire. Hachured areas are those counties whose SCS and ASCS representatives did not recognize collapse features, fractures, and faults in the first questionnaire. Correspondingly, these counties were not sent the second questionnaire dealing solely with impacts of collapse features on highways. Salt dissolution lines in Texas after Gustavson and others (1980a) and salt limits in New Mexico after Foster and others (1972). Line of section A-A' refers to figure 4.

In July 1979, in the northern part of the study area, a sinkhole formed beneath part of U.S. Highway 83 just north of the Interstate 40 overpass in Shamrock, Texas (fig. 7; site 2). The sinkhole opened to a depth of 2.4 m (8 ft) and a diameter of 3.0 to 3.6 m (10 to 12 ft). City water and sewer lines were damaged and part of the northbound lane of U.S. Highway 83 was closed. Gypsum beds of the Blaine Formation are exposed in roadcuts throughout the area, but whether gypsum dissolution is the sole cause of this sinkhole is not known.

A possible collapse depression occurs approximately 4 km (2.5 mi) west of Shamrock on Interstate 40 (fig. 7; site 3). At the point where Interstate 40 passes over Finley Creek, the pavement is depressed about 5 cm (2 inches) over a distance of

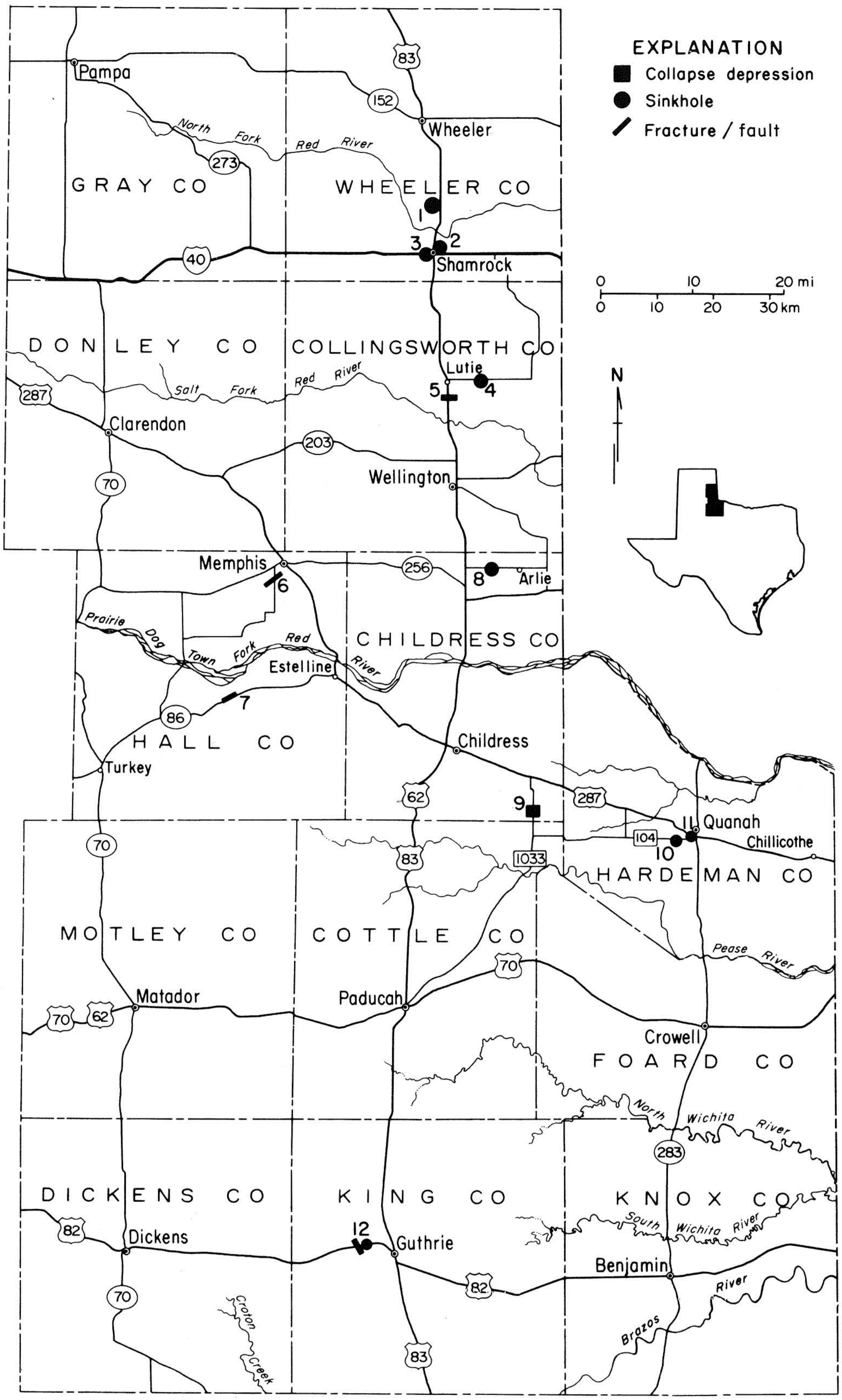

Figure 7. Locations of collapse features, fractures, and faults that affect highways within the study area.

Figure 8. View south along FM 1033 in Childress County showing collapse depression. The depression affects most of the northbound lane and extends into the borrow ditch. Different shades of road patches at this site attest to the history of subsidence.

approximately 9.1 m (30 ft), and the swale has developed since the highway was built in June 1968. Evidence of previous subsidence at this site is shown by the badly faulted old road (formerly U.S. Route 66), which now parallels Interstate 40 on the south. The old faulted road and the depressed sections of Interstate 40 are generally aligned in a northeasterly direction. A sinkhole measuring 3.3 m (10 ft) in diameter occurs in a roadcut immediately west of this site, which further confirms that the processes of dissolution and collapse are active in this area.

In the central part of the study area, a small collapse depression was identified on FM 1033 south of Kirkland, Texas, 1.6 km (1.0 mi) north of the Childress-Cottle county line (fig. 7; site 9). Diameter of the feature is about 6 m (20 ft); about half of the depression affects the pavement surface. Several generations of road patches attest to the fact that collapse has occurred over several years. Repairs to this section of the highway have been made regularly since 1966. Within the collapse depression, a smaller sinkhole in the highway borrow ditch collapses periodically and must be filled (fig. 8). The effect on the highway itself, however, is mainly from the collapse depression.

Figure 9. Sinkhole in the borrow ditch adjacent to FM 1034 west of Arlie, Texas. The sinkhole is approximately 0.9 m (3 ft) deep and 1.2 m (4 ft) wide. Sinkholes of this type are common along highways in the Texas Panhandle.

A small-scale drilling operation was initiated at this site near Kirkland to determine the depth of subsidence and whether this feature was due to shallow gypsum dissolution. Drilling indicated that the center of the sinkhole contained moist, silty clay (highway fill) to a depth of 4.5 m (15 ft), at which point Permian bedrock was encountered. The second hole about 6 m (20 ft) away contained about 2.7 m (9 ft) of dry, sandy alluvial sediment overlying Permian bedrock. From the depth of fill in the center of the sinkhole, it appears that a minimum of 1.8 m (6 ft) and maximum of 4.5 m (15 ft) of total subsidence has occurred. More significant is the fact that no gypsum was encountered in either hole. This suggests that shallow gypsum dissolution is not responsible for this feature, at least not in the vicinity of the boreholes. The collapse depression occurs in strata that are stratigraphically below a major gypsum unit (McQueen Gypsum Bed) of the Blaine Formation (Barnes, 1968). Dissolution of deeper gypsum or salt is probably the cause of this karst feature.

Numerous smaller sinkholes, commonly called "gyp sinks" by highway personnel, are recognized in borrow ditches throughout the study area (fig. 7; sites 1, 4, 8, 10, 11, and 12). Many sinkholes exist in outcropping gypsum bedrock (fig. 9). Somewhat larger sinkholes in gypsum bedrock occur along Texas Highway 114/U.S. Highway 82, 4.8 km (3 mi) west of Guthrie, Texas (fig. 7; site 12). Two holes with depths between 5.2 and 6.4 m (17 and 21 ft) have developed there within the last 10 years. A third sinkhole began as a very small hole in the borrow ditch and eventually expanded under the highway along a N 30° W trend. Subsidence was sufficiently rapid to require repairs at least twice a week for the first year and a half after collapse began. A linear trend like that displayed by this sinkhole is unusual. In this case the trend may actually comprise a much larger sinkhole that collapsed first where the surface was not supported by highway pavement.

Another major impact of dissolution and collapse on highways is faulting. The best example of faulting occurs along FM 2639, 19 km (12 mi) west of Estelline in Hall County, Texas (fig. 7; site 7). Here, six faults trending N 25° E to N 50° E were recognized by displacement along the faults measuring from 1 to 4 cm (0.4 to 1.6 inches). Although only a few inches wide when formed, the fault plane (fig. 10) was 1.5 m (5 ft) deep. Repairs have been necessary on the road about three times per year since the fault appeared in 1979. Similar faults have been recognized near Memphis, Texas (fig. 7; site 6), and 9.6 km (6 mi) south of Lutie, Texas (fig. 7; site 5). The Lutie fault plane was nearly 0.9 m (3 ft) deep and the fault trace trended almost east to west across the northbound lane of U.S. Highway 83. It has since been filled and has not recurred.

Although natural evaporite dissolution contributes most to collapse and faulting, failure may be aggravated by highway construction practices and highway traffic. Pre-road weaknesses caused by salt and anhydrite/gypsum dissolution may be aggravated by use of heavy construction machinery and construction of borrow ditch systems. Borrow ditches may concentrate water along preexisting fractures in near-surface gypsum and promote further evaporite dissolution. Subsequent vehicular traffic may cause further fracturing of gypsum and compaction of the unconsolidated roadbed fill and alluvium filling irregularities on the gypsum surface. All these processes contribute to continuing subsidence in the immediate vicinity of the highway. However, in investigating individual cases of collapse, human impact is difficult to separate from natural processes of evaporite dissolution and collapse.

Engineering Problems

In addition to highway construction and maintenance problems, other engineering problems resulting from evaporite dissolution were noted during construction projects

Figure 10. Fault trending northeast across FM 2639 in Hall County. Left side of fault is depressed approximately 3 to 4 cm (1.5 to 1.8 inches) relative to the right side. Fault extends into the cultivated field.

in the Texas Panhandle and eastern New Mexico. Eck and Redfield (1963) and Bock and Crane (1963) identified 27 collapse chimneys during excavations for Sanford Dam on Lake Meredith, 64 km (40 mi) northeast of Amarillo, Texas. Collapse chimneys generally are circular to elliptical in cross section and are typically filled with slumped and brecciated sediments from the overlying Triassic Dockum Group, Ogallala Formation, or Canadian River terraces. The largest collapse chimney exposed at the Sanford Dam site is approximately 305 m (1,000 ft) in diameter. Origin of chimneys is attributed to collapse due to regional dissolution of Permian bedded salts (Gustavson and others, 1980b).

Eck and Redfield (1965) considered the problem of reservoir leakage through collapse chimneys to be a serious geologic problem. Pressure tests within the chimneys and adjacent formations indicated low permeability, and examination of drill cores also indicated that most fractures were filled with silty clay and gypsum. No mention was made of the possible impacts of future evaporite dissolution and surface collapse at the dam site. McDowell (1972) and Spiegel (1972) investigated structurally disturbed Permian strata at the Los Esteros Dam site, north of Santa Rosa, New Mexico, which is within the zone of active salt dissolution.

It would be prudent to assess the potential impacts of evaporite dissolution and subsequent collapse of overlying strata during the planning of large reservoirs and other projects in the two-state region. Clearly, development of large sinkholes similar to the collapse chimneys at Sanford Dam could have a catastrophic effect on a dam structure. Placement of a large reservoir over zones of active dissolution might initiate further dissolution, possibly by rerouting ground-water flow across the soluble beds or by adding more fresh, undersaturated ground water to the system.

Although no problems associated with salt dissolution have been reported for large reservoirs, gypsum dissolution is a problem where gypsum rock crops out on the floor of the reservoir. A classic example of this is McMillan Reservoir on the Pecos River north of Carlsbad, New Mexico (Esmiol, 1957). Since its construction in 1893, the dam has continually cracked, subsided, and lost water along underground channels (Brune, 1965). To alleviate these conditions, as well as to solve the problem of sedimentation that has occurred behind the dam since construction, the Brantley Reservoir has been proposed to replace the original reservoir (Redfield, 1967). Although the sedimentation problem may be solved by the new structure, recent preliminary hydrogeochemical studies by the U.S. Geological Survey indicate that the bed of the reservoir will still contain a high percentage of gypsum and that dissolution of gypsum will add significantly to the downstream solute load of the Pecos River (H. Claassen, personal communication, 1979).

Brune (1965) has noted that along the outcrop of the Blaine gypsum in Childress, Cottle, and King Counties (see Barnes, 1967; 1968, for outcrop location) in the Texas Panhandle an unusually large number of stock tanks (farm ponds) lose large amounts of water because of fractures and sinkholes in surface and near-surface gypsum. Stock tank failure also occurs in Collingsworth and Stonewall Counties, according to ASCS and SCS representatives. The Soil Conservation Service now requires preliminary coring at proposed stock tank sites to determine local extent of gypsum, and subsequent construction of either a positive cutoff to bedrock or a mud blanket on the bottom of the reservoir to help prevent water loss (Brune, 1965).

Evaporite dissolution related to human activity (such as solution mining) is not well documented in Texas or New Mexico but it does occur. On July 25, 1978, a sinkhole opened near an abandoned brine well owned by Phillips Petroleum Corporation in the vicinity of Borger, Hutchison County, Texas (Borger News-Herald, 1978). The hole grew to 33 m (100 ft) in diameter directly adjacent to a Phillips Petroleum Corporation tankfarm. The site is about 45.5 m (150 ft) from U.S. Highway 270. Collapse of a large sinkhole near Wink in Winkler County, Texas, in June 1980 probably resulted from salt dissolution caused by natural and human activities in the region (Baumgardner and others, 1980).

RESPONSE TO THE PROBLEM

The process of evaporite dissolution and subsequent collapse poses certain difficulties for geologists, highway engineers, and maintenance crews. Areas of active subsurface evaporite dissolution have been identified, but development of collapse features and faults at the surface in those areas generally follows no predictable pattern. The trend of faults caused by dissolution along FM 2639 in Hall County is, however, consistent with the lineament trend analyses in the region (Dutton and others, 1979).

In any case, attempts to control or prevent damage to highways and other structures over the long term have been ineffective. Sinkholes, collapse depressions, and faults are dealt with on a regular basis with short-term remedial measures. Sinkholes in borrow ditches are generally filled with sand or similar fill material. Depressions in an asphalt pavement are filled with asphalt mix, bladed with a road grader, and rolled out. On rigid concrete pavements such as Interstate 40, holes are drilled through the pavement surface and grout (normally soil and cement mixed into a slurry) is forced through tubes under the depressed part of the highway until the pavement is forced upward to its original level. This process is commonly known as "mud-jacking." Faults in the pavement are generally treated by filling with sand or other fill and patching with asphalt mix. Smaller tension cracks or faults may be mitigated to some degree by the use of a more expensive rubberized asphalt, which would allow the pavement to stretch before cracking.

SUMMARY

Dissolution of Permian evaporites and collapse of overlying strata are major processes that alter the landscape in parts of the Texas Panhandle and eastern New Mexico. Sinkholes, collapse depressions, fractures, and faults are the common surface expressions of these phenomena. These features were first recognized in Hall County, Texas. Responses to questionnaires sent to representatives of the Soil Conservation Service and Agricultural Stabilization and Conservation Service in the region indicate that at least 37 percent of the counties in the Texas Panhandle and eastern New Mexico contain similar features.

Evaporite dissolution has a significant effect on highways, reservoirs, and stock tanks. Highways have sustained the most reported damage to date, with several sections of roads having been patched or filled on a regular basis because of faulting or subsidence. Collapse chimneys, which were identified during excavations for the Sanford Dam, are evidence of past evaporite dissolution. Small stock tanks frequently lose water to fractures and solution cavities within surface and near-surface gypsum beds.

Long-term methods to predict and thus mitigate the effects of collapse have been unsuccessful. The problem, however, is of large scope and potential impact. We suggest that in future construction of highways, reservoirs, stock tanks, and other structures, care should be taken to investigate the history of, and potential for, evaporite dissolution beneath the construction site. Areas with high densities of collapse features, fractures, and faults should be avoided when possible.

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