Waste Isolation Pilot Plant

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Development of the Wink Sink in west Texas due to salt dissolution and collapse

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ABSTRACT

The Wink Sink, in Winkler County, Texas, is a collapse feature that formed in June 1980 when an underground dissolution cavity migrated upward by successive roof failures until it breached the land surface. The original cavity developed in the Permian Salado Formation salt beds more than 400 m (1,300 ft) below ground level. Natural dissolution of salt occurred in the vicinity of the Wink Sink in several episodes that began as early as Salado time and recurred in later Permian, Triassic, and Cenozoic times. Although natural dissolution occurred in the past below the Wink Sink, it appears likely that the dissolution cavity and resultant collapse described in this report were influenced by petroleum-production activity in the immediate area. Drilling, completion, and plugging procedures used on an abandoned oil well at the site of the sink appear to have created a conduit that enabled water to circulate down the borehole and dissolve the salt. When the dissolution cavity became large enough, the roof failed and the overlying rocks collapsed into the cavity. Similar collapse features exist where underground salt beds have been intentionally dissolved during solution mining or accidentally dissolved as a result of petroleum-production activity.

Introduction

The Wink Sink, located 3.2 km (2 miles) north of the town of Wink in Winkler County, Texas (Figure 1), formed on June 3, 1980, and within 24 hours it had expanded to a maximum width of 110 m (360 ft) (Baumgardner et al., 1982). Two days later, the maximum depth of the sinkhole was 34 m (110 ft) and the volume was estimated at about 159,000 cubic m (5.6 million cubic ft). The collapse occurred near the middle of Hendrick Field, a giant oilfield that has been operating since 1926; one abandoned oil well was incorporated within the sink itself, and a second oil well was plugged and abandoned because of its proximity to the sinkhole. There appears to be no doubt that the Wink Sink resulted from an underground dissolution cavity that migrated upward by successive roof failures, thereby producing a collapse chimney filled with brecciated rock (Baumgardner et al., 1982). The dissolution cavity had developed in salt beds of the Permian Salado Formation, which is about 260 m (850 ft) thick and lies about 400 to 655 m (1,300 to 2,150 ft) beneath the Wink Sink. Natural dissolution of salt beds in the Salado Formation in Winkler County and other areas of West Texas and New Mexico is well known, but the dissolution and collapse associated with the Wink Sink apparently resulted from, or at least was accelerated by, oilfield activity in the immediate vicinity of the sink. Whether the dissolution is due to natural causes or oilfield activity, there are four distinct requirements for salt dissolution to occur (Johnson, 1981): (1) a deposit of salt through which water can flow, (2) a supply of water unsaturated with respect to NaCl, (3) an outlet whereby the resulting brine can escape, and (4) energy (such as hydrostatic head or density gradient) to cause the flow of water through the system.

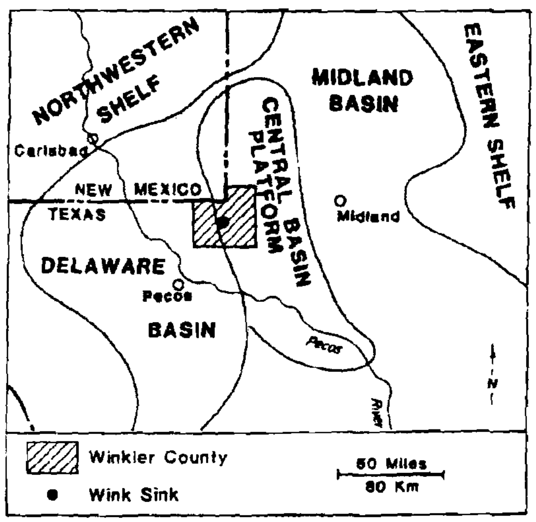

Figure 1: Map of west Texas and southeast New Mexico showing major geologic provinces and location of Wink Sink in Winkler County.

Previous reports on the Wink Sink include widely distributed articles by Baumgardner et al. (1980, 1982) and a limited-distribution government document by Johnson (1986). The current report is a summary of data presented by Johnson (1986).

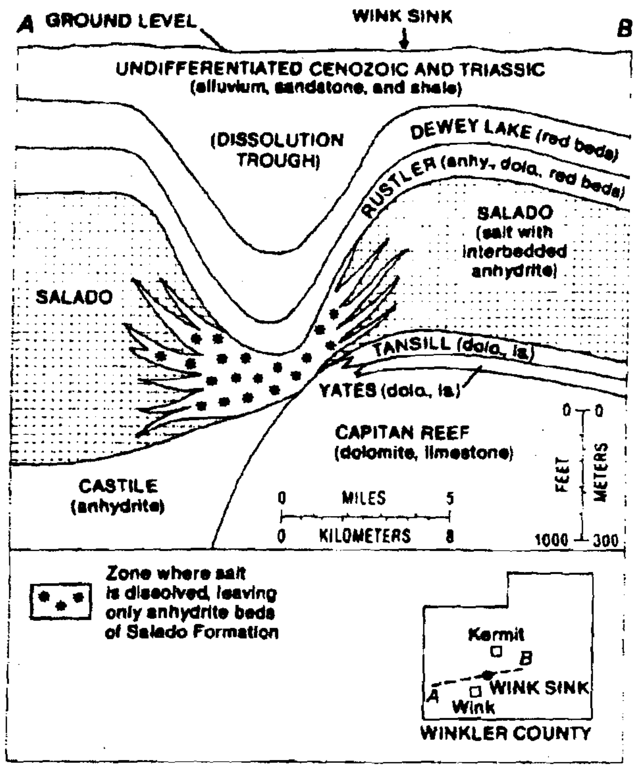

Figure 2: Schematic east-west cross section in Winkler County showing natural dissolution of Salado Formation salts on the eastern edge of the Delaware Basin (modified from Baumgardner et al., 1982). All strata below the "Undifferentiated Cenozoic and Triassic" are Permian in age.

Geologic History and Stratigraphy

Winkler County is located astride the boundary between the Delaware Basin on the west and the Central Basin Platform on the east (Figure 1). These major structural provinces are both part of the greater Permian Basin of West Texas and southeast New Mexico and are characterized by different sequences of Permian-age strata. The provinces are separated by the Capitan Reef, a massive limestone and dolomite reef that fringed the Delaware Basin during Guadalupian time when different suites of sediment were deposited on either side of the reef.

Rock units of principal concern in the vicinity of the Wink Sink are all of sedimentary origin and are of Permian, Triassic, or Cenozoic age (Figure 2). The Capitan Reef, the oldest Permian unit of interest, is a massive sequence of limestone and dolomite about 457 to 610 m (1,500 to 2,000 ft) thick and 13 to 16 km (8 to 10 miles) wide in western Winkler County (Garza and Wesselman, 1959). Carbonate rocks in the Capitan typically have a high porosity and permeability. The Capitan grades eastward into contemporaneous back-reef carbonates and clastics of the Artesia Group; the two uppermost formations of the Artesia (the Yates and Tansill Formations) are present above the Capitan beneath the Wink Sink.

The Yates Formation consists of light-gray, white, and flesh-colored dolomite and limestone with some interbeds of fine-grained gray sandstone and shale (Ackers et al., 1930). The Yates is about 85 m (280 ft) thick in the vicinity of the Wink Sink (Baumgardner et al., 1982). Porosity occurs in the form of irregular solution cavities as large as 5 cm (2 in) in diameter, and also as interstitial voids in the granular rocks. Solution cavities lined with calcite are commonly found in the oil-producing horizons.

The overlying Tansill Formation consists mainly of dolomite and limestone, interbedded with dolomitic shales, and a persistent bed of anhydrite that overlies the dolomitic sequence (Ackers et al., 1930; Baumgardner et al., 1982). The Tansill Formation is about 50 m (160 ft) thick beneath the Wink Sink, and the anhydrite in the upper part of the Tansill is generally 9 to 15 m (30 to 50 ft) thick. The top of the formation is at the base of the lowest salt unit in the Salado Formation (Baumgardner et al., 1982).

The Salado Formation is a thick sequence of interbedded salt (halite) and anhydrite. The formation is about 260 m (850 ft) thick beneath the Wink Sink, but it is as much as 400 m (1,300 ft) thick just to the east and only about 180 m (600 ft) thick just to the west (Figure 2). Individual Salado anhydrite units in the area typically are 3 to 15 m (10 to 50 ft) thick, whereas the intervening salt units commonly are 3 to 30 m (10 to 100 ft) thick. Variations in thickness of the Salado Formation and of the individual salt units are largely due to dissolution of one or more of the salt units during Salado and post-Salado times. Dissolution of the salts in the Salado has been noted several times in earlier literature (Ackers et al., 1930; Maley and Huffington, 1953; Anderson and Kirkland, 1980), and, most recently, Baumgardner et al. (1982) and Johnson (1986) have shown that dissolution has occurred in each of the Salado salt units in the vicinity of the Wink Sink.

Overlying the Salado is the Rustler Formation, which consists of interbedded anhydrite, dolomite, limestone, shale (or mudstone), and sandstone (Ackers et al., 1930; Baumgardner et al., 1982). The Rustler is about 82 m (270 ft) thick beneath the sink, but locally it is as much as 95 m (310 ft) thick where it apparently thickens due to dissolution and collapse of underlying Salado salt units prior to or during Rustler deposition. The Dewey Lake Formation consists of interbedded red-brown shale, sandy shale, and siltstone overlying the Rustler (Ackers et al., 1930; Baumgardner et al., 1982). The thickness of Dewey Lake strata in the area ranges from about 110 to 146 m (360 to 480 ft), and is about 137 m (450 ft) beneath the Wink Sink. The local sharp increase in thickness of the Dewey Lake indicates the likelihood that some of the dissolution of salt in the Salado occurred prior to or during Dewey Lake deposition.

Unconformably above the Dewey Lake Formation lies a sequence of Triassic shales and sandstones overlain by unconsolidated Cenozoic clastics; these strata are not readily differentiable in the area, and thus have been referred to as "undifferentiated Cenozoic and Triassic" strata (Figure 2). This undifferentiated sequence increases in thickness markedly across the area from about 120 m (400 ft) on the east to as much as 457 m (1,500 ft) in the dissolution trough west of Wink Sink (Figure 2). The abrupt thickening of these strata in the same area where the Salado salts reach minimum thickness supports the interpretation of salt dissolution and concurrent (or subsequent) basin filling during Triassic and Cenozoic times.

Natural dissolution of salt beds of the Salado Formation in western Winkler County began during Late Permian time and still may be going on today (Baumgardner et al., 1982). Abnormal thinning and thickening of individual salt units in the Salado, as well as local thickening of each of the overlying formations of Permian, Triassic, and Cenozoic age, indicate that this process of dissolution and subsidence has occurred intermittently in the Wink area and began even before the end of Salado deposition (Johnson, 1986).

Petroleum Activity in the Hendrick Field

The Hendrick Field, which includes the location of the Wink Sink (Figure 3), is one of the giant oilfields of Texas. More than 1,400 wells have been drilled in the field since its discovery in 1926, and these wells have yielded a cumulative total of about 40.55 million cubic m (255 million barrels) of oil (one metric ton of crude oil equals 1.166 cubic m). Drilling activity and oil production were phenomenally high in the first few years after the discovery well was drilled, but by the early 1930s, the activity was reduced greatly and has continued to decline to a relatively low level today. One of the major problems in the Hendrick Field since its beginnings is the great volume of oifield brine that has been produced along with the oil and has required disposal.

Several articles were published during the early boom period of the Hendrick Field (Vance, 1928; Bignell, 1929, 1930; Ackers et al., 1930; Heithecker, 1932; Carpenter and Hill, 1936), and these documents provide valuable insight into the methods of drilling, well completion, oil production, brine production, and brine disposal used in the field.

Production in the Hendrick Field has been predominantly oil, with small amounts of natural gas. Most of the oil has come from the Yates Formation, although some is produced from the overlying Tansill Formation. Initial daily production of individual wells, based on short-time gages, ranged from 48 to 15,583 cubic m (300 to 98,000 barrels) of oil per day, and pilot-tube measurements of natural-gas production on some wells indicated as much as 2 million cubic m (70 million cubic ft) per day. Most wells were drilled only 201 m (660 ft) from neighboring wells, with spacing throughout the field typically being one well per 4 or 8 hectares (10 or 20 acres) (Figure 4). In parts of the field explosives were used to fracture the producing zones and thereby increase production of some of the wells with low yields (Vance, 1928).

Many crooked boreholes were drilled in the early years of development of the Hendrick Field (Carpenter and Hill, 1936). As a result, the lower part of some boreholes is shifted a hundred meters (several hundred feet) or more laterally away from the surface location. In surveys of some of the boreholes, it was found that the deflection of the holes at various depths was as much as 20 to 40 degrees from the vertical. In some of these boreholes where the deviation was excessive, such as in the Hendrick well 10-A at the Wink Sink, explosives were used to fracture the rock and allow realignment of the hole.

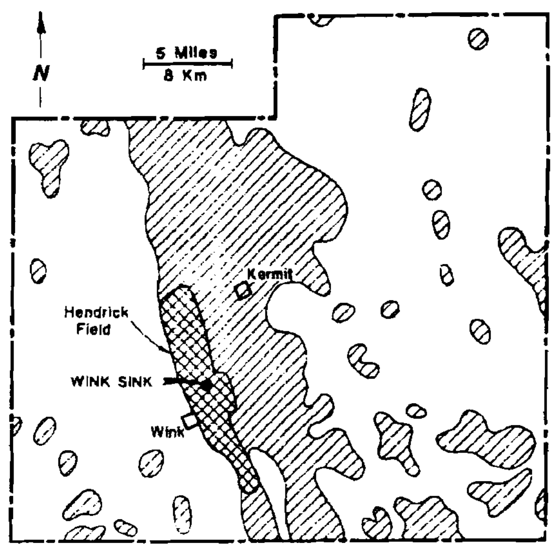

Figure 3: Winkler County, Texas, showing oil- and gas-producing areas (diagonal lines) and location of Hendrick Field and Wink Sink.

Oilfield Brines in the Hendrick Field

Production and disposal of oilfield brines has been a serious problem in the Hendrick Field since shortly after the field was discovered. The vugs and fractures within the Tansill and Yates carbonate reservoirs yield saline formation waters along with the oil, and, in most cases, large amounts of brine were produced shortly after completion of an oil well. The brines generally contain from 5,000 to 48,000 parts per million dissolved solids. Water production ranged from about 95,400 to 139,000 cubic m (600,000 to 875,000 barrels) per day in the 1930s, and the water-oil ratio for the producing wells increased from about 16 to 1 in 1930 to as much as 50 to 1 in 1934 (Carpenter and Hill, 1936).

Although no accurate totals are available, it is clear that a tremendous quantity of water has been produced in the Hendrick Field. By assuming an average production of 135,000 cubic m (850,000 barrels) of water per day from 1929 through 1957 (Garza and Wesselman, 1959) and an average of 47,700 cubic m (300,000 barrels) per day from 1958 through 1982 (Johnson, 1986), it is herein estimated that the cumulative production of water has amounted to about 1.86 billion cubic m (11.7 billion barrels, or 1.5 million acre-feet).

The principal means for handling the great quantity of water produced with oil in the Hendrick Field consisted of disposal in unlined, natural and artificial earthen "evaporation" pits (Heithecker, 1932). In some places, dynamite was used to blast caliche or other hard rock units present in the floor of a pit. It was realized from the outset that most of the water disposed of in the earthen pits was in fact lost through seepage into the ground (Heithecker, 1932). The ground surface in most parts of the Hendrick Field consists of loose sand, and this covers the unconsolidated sand, gravel, silt, and clay in the Cenozoic alluvium. Therefore, waters (including oilfield brines) were able to percolate down easily through the porous and permeable surface materials to reach and recharge the ground water.

No public records have been kept of the location of these earthen pits, the period of their use, or the quantity of wastewater that was discarded into individual pits or into all pits combined. However, a series of aerial photographs taken in 1942, 1946, 1954, and 1968 show the location of a great many natural and artificial earthen pits that were used intermittently or continuously for disposal of water. By stereoscopic study of these photographs, I have established that nearly 50 separate areas, ranging in size from 0.4 to 12 hectares (1 to 30 acres), were used at one time or another as disposal pits in the vicinity of the Wink Sink (Figure 5). In fact, the largest pit, located in the northeast quarter of section 34, is just 300 m (1,000 ft) south-southeast of the Wink Sink; portions of this pit

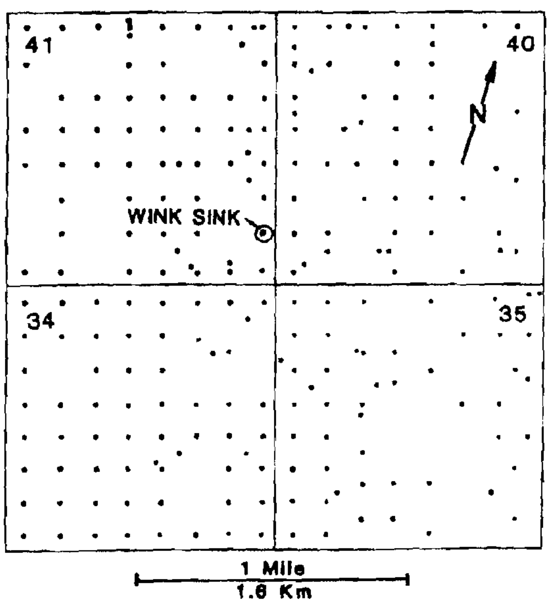

Figure 4: Location of the 227 petroleum tests and other boreholes drilled near Wink Sink in sections 34, 35, 40, and 41 of Block B-5, Public School Land Survey, Winkler County.

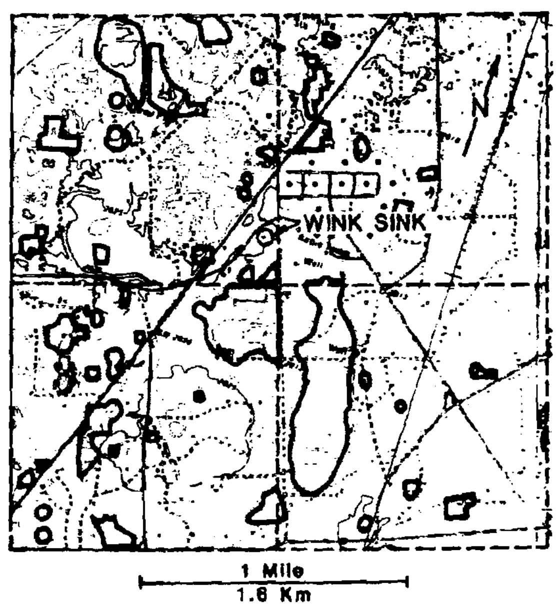

Figure 5: Map showing location of earthern ponds and pits (heavy lines) used for disposal of oilfield brines in four-section area surrounding the Wink Sink in Winkler County.

have been used continuously from 1942 through 1968, and the pit may have been put in use as early as the early 1930s. Several smaller pits, located in the southeast quarter of section 41 (Figure 5), are even closer to the Wink Sink, but have been in use for shorter periods of time.

Within the Hendrick Field the shallow, fresh-water aquifers have been recharged substantially by leakage of wastewater from the disposal pits (Garza and Wesselman, 1959). Great volumes of water have seeped down through permeable, sandy soil in the central part of the field, including the location of the Wink Sink, creating a large ground-water mound that in 1956 extended about 13 km (8 miles) north-south and 6.5 km (4 miles) east-west (Garza and Wesselman, 1959). It appears that the water table in the mound may have been raised some 15 to 30 m (50 to 100 ft) by that time. In 1956 the water table at the site of the Wink Sink was about 9 m (30 ft) below ground level.

History of Hendrick Well 10-A

An abandoned oil well, the Hendrick well 10-A, is located within the circumference of the Wink Sink. The sink apparently did not breach the surface at the location of the borehole, but reportedly appeared to one side of the borehole (Baumgardner et al., 1982). As the sink enlarged by slumping and caving of the sides, the surface casing of the well apparently was incorporated in the slump material, although no eyewitnesses reported sighting the surface casing. The following discussion on the history of the Hendrick well 10-A is modified slightly from an original discussion by Baumgardner et al. (1982) based largely on data filed with the Texas Railroad Commission.

Republic Production Company began drilling the Hendrick well 10-A on June 29, 1928, and completed it on October 25, 1928. The driller's log and the borehole representation (Figure 6) show drilling, casing, and plugging procedures reported to the Texas Railroad Commission during the life of the well. The well was drilled with rotary tools to the top of "brown lime of the Tansill Formation" at a depth of 668 m (2,193 ft), and cable tools were used to complete the well in the Yates Formation at a depth of 778 m (2,552 ft). Initial daily production from the well was estimated to be 159 cubic m (1,000 barrels) of oil and 636 cubic m (4,000 barrels) of water. The casing program consisted first of setting surface pipe, 39.4 cm (15.5 in) in diameter, at a depth of 122 m (400 ft) and cementing it with 300 sacks of cement. Second, 25.4-cm (10-in) casing was set at a depth of 669 m (2,196 ft) and cemented with 800 sacks of cement. Finally, casing 21 cm (8.25 in) in diameter was set at a depth of 744 m (2,440 ft) but was not cemented. No casing was set below 744 m (2,440 ft). The Hendrick well 10-A was a crooked borehole that deviated too much from the vertical; it was straightened at a depth of 701 m (2,300 ft) by exploding 151 liters (160 quarts) of nitroglycerine in the borehole.

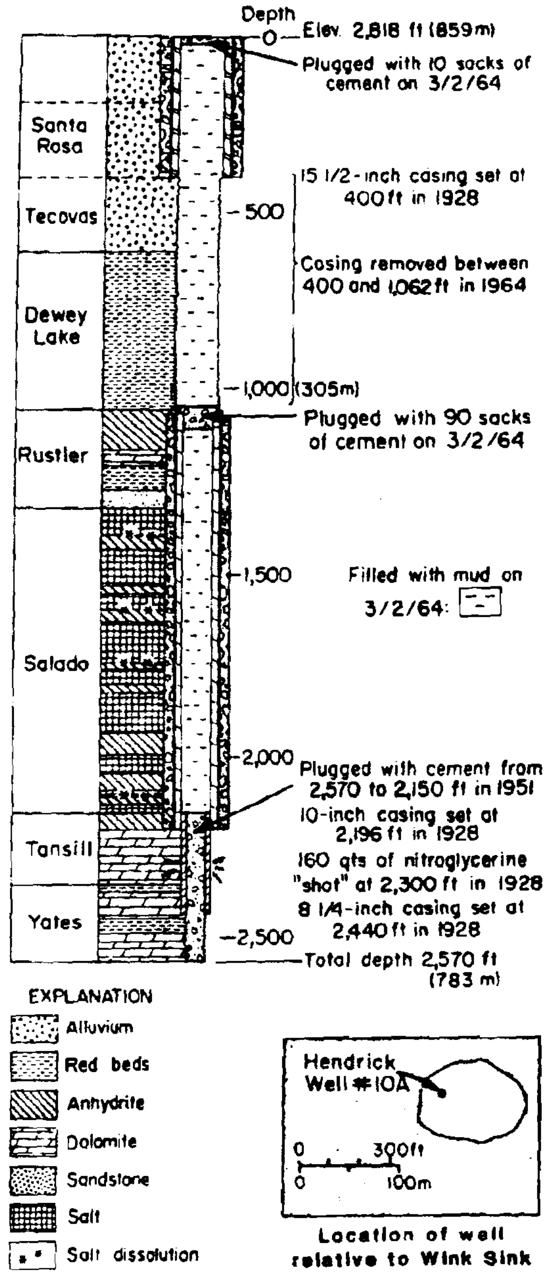

Figure 6: Stratigraphic section of Hendrick well 10-A, section 41, Block B-5, Public School Land Survey, Winkler County, Texas (modified from Baumgardner et al., 1982).

The Republic Production Company later deepened the well to 783 m (2,570 ft) in January 1930. They then filed an application to again deepen the well to 945 m (3,100 ft) in December 1931, but no data are on file with the Texas Railroad Commission to indicate that the well was drilled deeper than 783 m (2,570 ft). The Bradberry and Sasser Company later filed a plugging record for the well in July 1951, referring to the well as being on the T. G. Hendrick "A" lease. The record stated that the well was shot "to part casing," but the depth (or depths) of these shots and their effect on the casing were not reported. The record did show, however, that the well was plugged with cement at depths from 783 to 655 m (2,570 to 2,150 ft). The wellbore above this was filled with mud and plugged at depths from 122 to 113 m (400 to 370 ft) with 25 sacks of cement, and then plugged at the surface with 15 sacks of cement. The well was then abandoned for 13 years.

In 1964, the Mallard Petroleum Company removed the shallow cement plugs and attempted to deepen the well. However, the drillers were unable to reenter the hole "because of junk" in the borehole. The well was then replugged in March 1964 with 90 sacks of cement at a depth of 323 m (1,060 ft), and with 10 sacks of cement at the surface. During this reentry attempt, the company removed more than 183 m (600 ft) of 25.4-cm (10-in) diameter casing, leaving an unlined borehole (presumably filled with mud) between 324 and 122 m (1,062 and 400 ft), or from the upper part of the Rustler Formation to just below the Santa Rosa Formation.

Salt Dissolution by Natural Causes in the Wink Sink Area

A number of studies have been conducted on salt dissolution in various parts of the Delaware Basin and nearby areas, including work by Ackers et al. (1930), Adams (1944), Maley and Huffington (1953), Hills (1970), Bachman (1976), Kirkland and Evans (1976), Anderson et al. (1978), Mercer and Hiss (1978), Anderson and Kirkland (1980), Baumgardner et al. (1980; 1982), Lambert (1983), and Johnson (1986). There is, in addition, overwhelming evidence that salt has been partly dissolved by natural processes in the vicinity of the Wink Sink (Baumgardner et al., 1982; Johnson, 1986). Abnormal and abrupt thinning of salt units with concurrent thickening of overlying rock units in the same area is major proof for this natural dissolution (Figure 2). The dissolution has been episodic in various parts of the Wink area, with evidence that it began as early as Salado time and then recurred during later Permian, Triassic, and Cenozoic time. Some natural dissolution of Salado salts may be going on at the present time, but there is no evidence currently available to confirm or refute this.

There is no evidence that a natural cavern existed in the vicinity of the Wink Sink prior to drilling of the Hendrick well 10-A. No cavities were reported in 1928 during drilling of the well, and subsurface conditions at and near the sink have not been examined by boreholes or other methods since development of the sink. The presence of permeable fracture zones or cavities in the area is indicated by the loss of fluids during the drilling of four of the oil wells located within 1.6 km (1 mile) of the Wink Sink (Baumgardner et al., 1982). The wells, drilled in 1927 and 1928, lost circulation at depths ranging from 291 to 699 m (956 to 2,293 ft). One well lost circulation during drilling in sand and red beds of the Dewey Lake Formation; one well lost circulation in dolomite of the Tansill Formation; and the other two wells lost circulation during drilling in the Salado Formation. These lost-circulation zones are permeable pathways that can allow for the movement of fluids within, above, and below the Salado Formation.

Salt Dissolution Related to Petroleum Activity in the Wink Sink Area

Although it is clear that most of the salt dissolution in the Wink area (including the dissolution trough) has resulted from natural processes, it is equally clear that some of the early-day oilfield practices employed during the boom period of the Hendrick Field may have contributed to the accelerated dissolution of salt in the vicinity of the Hendrick well 10-A and this may have caused the collapse of the Wink Sink. Similar collapse features have developed in the past above caverns that resulted from solution mining of salt or from unplanned borehole enlargement in salt beds penetrated during oil and gas operations.

Drilling and completion of the Hendrick well 10-A apparently were consistent with standard industry practices of West Texas during the late 1920s. In retrospect, however, several factors and events can be identified that may have contributed to development of a dissolution cavern in the Salado salt around this borehole. These include the probable use of a fresh-water drilling fluid, use of nitroglycerine to straighten the hole, the possibility of poor cement jobs inadequately sealing off the salt beds behind the casing, possible corrosion of casing by salt water, and removing some of the casing upon final plugging of the borehole. Such factors and events may have assisted in making the borehole a pathway whereby shallow ground water could have flowed down to and through the Salado salts.

Data are not available on the nature of drilling fluids used in drilling the Hendrick well 10-A, but in all probability the fluid consisted of fresh water (from local water wells) mixed with clays to increase its weight and viscosity. Such a fresh-water fluid would have dissolved some of the salt adjacent to the borehole during drilling operations, and thus would have enlarged or "washed out" the hole within the Salado salt sequence. Walters (1978) points out that oil wells drilled by similar rotary methods in central Kansas during the 1930s were enlarged considerably through the Hutchinson salt beds; holes drilled with 23-cm (9-in) bits were washed out to 1.5 m (5 ft) or more in the salt section. Therefore, it is quite likely that the Hendrick well 10-A borehole was at least somewhat enlarged and washed out within the Salado salt section during drilling.

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