CASE No. 15723
Division Exhibit No. 8

Evaporites, Casing Requirements, Water-floods, and Out-of-formation Waters: Potential for Sinkhole Developments

Dennis W. Powers
Consulting Geologist
140 Hemley Road
Anthony, TX 79821

Abstract

Sinkholes have developed rapidly where drillholes penetrating shallow evaporites and beds with unsaturated (with respect to halite) water are uncased or inadequately cased and cemented. The recent (1998) Whitten Ranch sinkhole developed over deeper evaporites. In this area, modest casing requirements through the evaporites and water-flood operations with out-of-formation waters may increase the possibilities of more such events.

The Whitten Ranch sinkhole near Jal, NM, developed with little warning late in 1998. The uppermost halite, in the Permian Rustler Formation, is more than 1500 ft below ground surface; the top of the Salado Formation is about 2000 ft deep. Although a natural origin cannot be ruled out, it is more likely that a nearby plugged and abandoned (P&A) water well to the Capitan reef permitted circulation of fresh water, solution of overlying evaporites, and upward chimney collapse through the thick redbed section and Ogallala Formation to the surface.

In part of southeastern New Mexico, surface casing is required to protect part of the redbed sequence that locally bears groundwater. The evaporite section may not be protected by cement in the production string to deeper units. Some areas show strong evidence of out-of-formation (high-pressure) waters, from water-flooding operations, in evaporite and redbed sections. Producing wells and wells scheduled to be P&A get checked for evidence of casing integrity. Nevertheless older wells P&A, and some wells still in production, may be subject to the same process suspected for the Whitten Ranch sinkhole. Will there be more such sinkholes?

A reasonable survey of conditions of out-of-formation waters, casing and cementing practices, casing integrity, and evaporite depths would be helpful in developing a better idea of the significance of these conditions and indicating whether additional sinkholes are likely to develop. No doubt liability concerns will make such a survey difficult.

General Background

The Whitten Ranch sinkhole (WRS) (Figure 1) near Jal, NM, developed sometime between August 31 and September 5, 1998. Although natural causes cannot be ruled out entirely, the most likely origin is through collapse after dissolution of evaporites in a nearby drillhole, Skelly Jal Water System #2. This is not the first example here or elsewhere of such collapse,

In 1980, the Wink Sink collapsed near Wink, TX, about 30 mi (50 km) south of the WRS. The geologic setting for the Wink Sink is similar to that of the WRS. The initial collapse occurred adjacent to a drillhole (Hendrick 10-A); as the sinkhole widened, it engulfed the wellhead casing within the sinkhole perimeter. Baumgardner et al. (1982) extensively examined the setting and history, concluding that dissolution of salt and upward migration of a cavity through collapse led to the surface sinkhole. Drillhole Hendrick 10-A is believed to have played a part in the solution and collapse, although Baumgardner et al. (1982) also interpreted natural dissolution of Salado Formation salt in the vicinity of the Wink Sink. Johnson (1989, 1993) further analyzed natural dissolution within the Salado in the vicinity, recognizing that some of the dissolution occurred as early as Salado time. Johnson (1989, 1998) also suggested that activities associated with drilling and drillholes may have contributed to the collapse.

Walters (1976) examined subsidence and collapse features in Kansas related to salt dissolution and related eight features to dissolution in oil and gas drillholes. Collapse was most spectacular around the W.M. Panning No. 11 well where a pit about 300 ft in diameter developed within hours. Walters (1976) noted that these features were rare (with an estimated 80,000 drillholes in Kansas). Walters (1976) also noted that the known features involved old holes drilled before the state required cementing the casing opposite fresh-water zones and that the drillholes were used for re-injection of undersaturated (with respect to sodium chloride) oilfield brines.

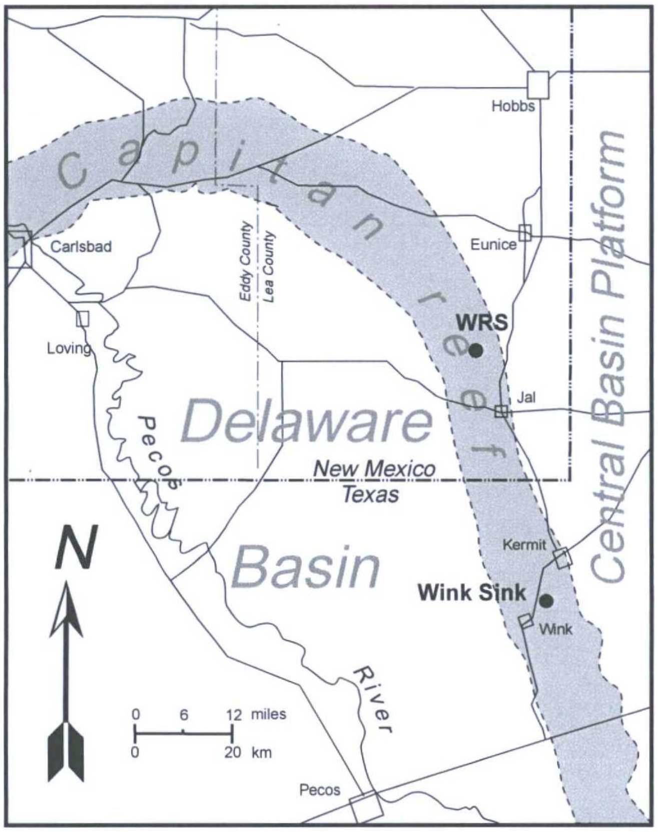

Figure 1. Location map showing the relationsip of Whitten Ranch Sinkhole (WRS) to the Wink Sink and tectonic elements of the Permian Basin in west Texas and southeastern New Mexico. Modified from Hiss (1975).

Whitten Ranch Sinkhole

Background

The WRS is located in the northwest ¼ of the southwest ¼ of section 9, T24S, R36E, (long. 103°16'34" W., lat. 32°13'48" N.), about 8 mi (13 km) north-northwest of Jal, NM (Figure 1).

Local residents Jimmy and Linda O'Rear noticed a small surface opening on August 31, 1998, at the site of the collapse. On the morning of September 5, they discovered the full-sized sinkhole (Figure 2). In discussing the sinkhole with the O'Rears, they recalled that

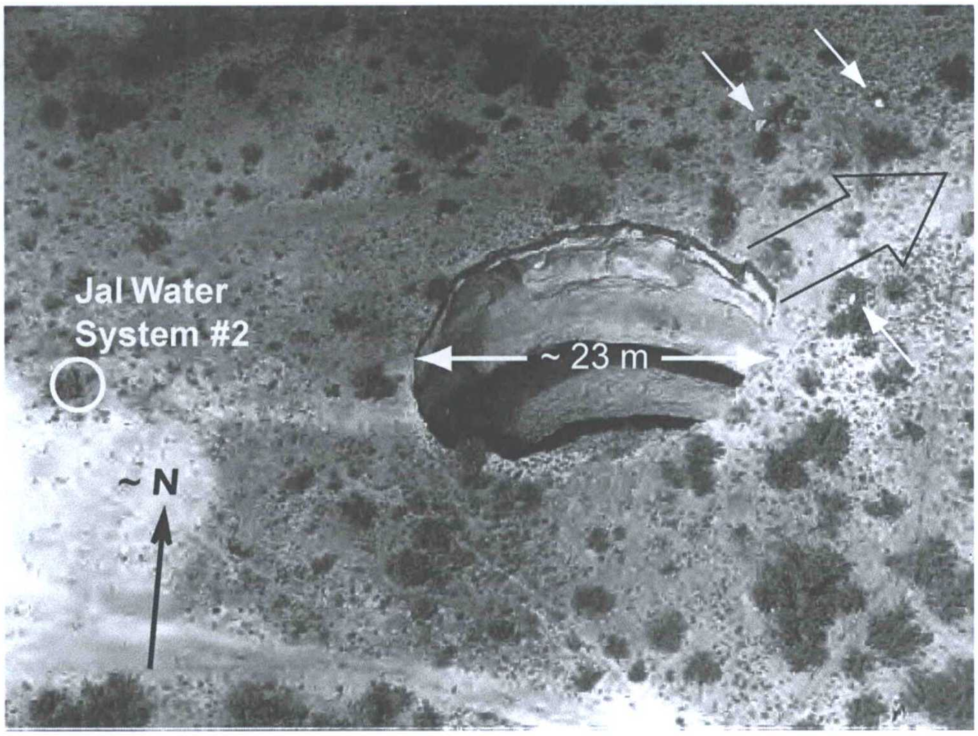

Figure 2. Low-angle aerial photo of WRS, taken to the north. Small arrows show the location of some larger clasts of Mescalero caliche blown northeast (outline arrow) by the collapsing material. The drillpipe for Jal Water System #2 is circled. Photo taken 9/15/98 by D.W. Powers.

their dogs were particularly disturbed the evening of September 4. In a newspaper interview, the Mr. O'Rear also indicated he had seen unusual activity of rattlesnakes in the area. It is not clear whether these observations narrow the time frame for the sinkhole. Inquiries about recorded seismic activity are pending.

Some media reports of the sinkhole give dimensions of 170 ft (52 m) in diameter and 185 ft (56 m) in depth. I used dimensions provided for a fence placed at a distance around the sinkhole to estimate sinkhole diameter from low-angle aerial photographs that I took on September 15, 1998 (Figure 3). The diameter appears to be about 75 ft (23 m) across. High-angle aerial photographs I took allow an estimate of the depth (Figure 4). The sun angle on September 15 is about 35° from vertical in this area around 1 pm (MDT) when the photograph was taken. As the shadow just covered the bottom, the depth can be estimated as about 107 ft (33 m). The sinkhole is reasonably cylindrical, permitting an estimate of the volume as about 4.7×10^5 ft^3 (1.4×10^4 m^3).

The sinkhole was not observed as it formed, but circumstantial evidence clearly indicates that at least part of it formed in seconds. Clasts of Ogallala Formation caliche are distributed along a lane northeast from the sinkhole, with some large clasts (about 3 ft or 1 m across) near the sinkhole (Figure 2) and

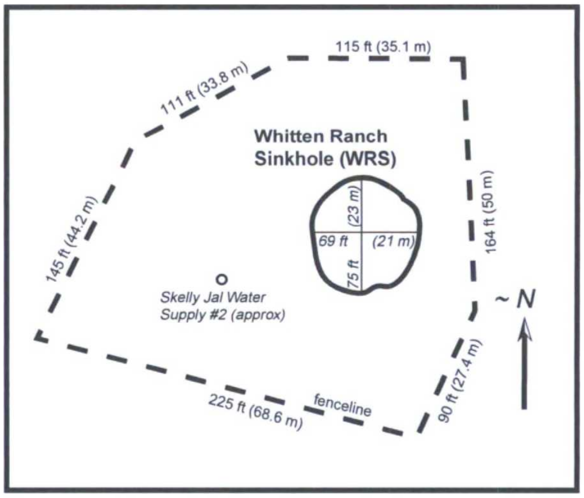

Figure 3. Fence dimensions used to estimate diameter of sinkhole from low-angle aerial photos. These dimensions are smaller than some other early estimates.

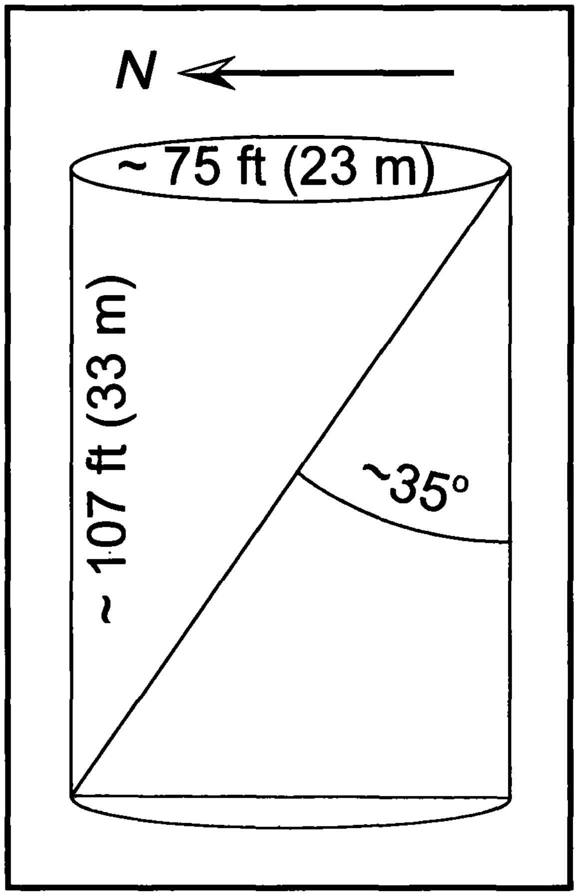

Figure 4. A high-angle aerial photo taken about 1 pm on 9/15/98 showed shadow projecting to about the fill on the north side of the WRS. Based on the sun angle and estimate of diameter, the depth to fill is estimated at about 107 ft (33 m).

clast sizes decreasing away from the hole. The aerial photograph also shows a lighter shading from caliche dust coating the light reddish brown surface sand. I suggest that the northeastern part of the sinkhole subsided first, whether by seconds or days, and that most or all of the southwestern part of the sinkhole then collapsed. As it collapsed into a void, it initially trapped and compressed air, which then released through a partially choked throat and blew Ogallala clasts from the collapsing mass and possibly from the northeastern lip of the sinkhole. The significance is that at least part of the sinkhole formed very quickly.

The O'Rears believe that there may have been water in the sinkhole on the morning of September 5 based on sounds from rocks tossed into the sinkhole. By the following day, they did not think they were hearing the same response. There was no evidence of water in aerial photos taken on September 15. The depth to Ogallala groundwater in a nearby windmill was recently measured at about 189 ft (58 m) below the surface. The depth to Ogallala groundwater at WRS would likely be about 175-180 ft (53-55 m), about the same as the greatest early estimate of depth of the WRS.

Geological Setting

The WRS is located on the Central Basin Platform, near its margin with the Delaware Basin to the west. The well known Capitan reef, of middle Permian age, underlies the site; the hole (Skelly Jal Water System # 2) adjacent to the WRS was drilled to this unit as a source of water in 1967 (Figure 5). The drillhole Albert Gackle (Chambers & Kennedy) Whitten #1 is also located in the southwest ¼ of section 9, and the stratigraphy is believed to be similar to that at the WRS. From drilling reports of the Jal Water System #2 and data from Whitten #1, depths to stratigraphic units at the WRS have been estimated: the Capitan is at a depth of 3600 ft (1098 m), the Salado is from 3310 to 1944 ft (1009-593 m), the Rustler from 1944 to 1510 ft (593-460 m), and the Dewey Lake Formation is from 1510 to 910 ft (460-277 m). Triassic age rocks of the Dockum Group overlie the Dewey Lake, and the late Tertiary Ogallala is probably about 200 ft (61 m) thick. The casing in the Whitten #1 well obscures geophysical logs at a depth of 400 ft, and the exact depth of the Dockum Group-Ogallala contact isn't known.

From analysis of geophysical logs, the middle Rustler (Tamarisk Member) includes the uppermost halite in the area, with a depth of about 1700 ft (518 m). The lowest halite is at about 3300 ft (1006 m), in the basal Salado. Less soluble sulfates extend upward to 1510 ft (460 m), to the top of the Rustler.

Like the Wink Sink area, both the Capitan and some of the redbeds above the Rustler can be sources of relatively low-salinity water.

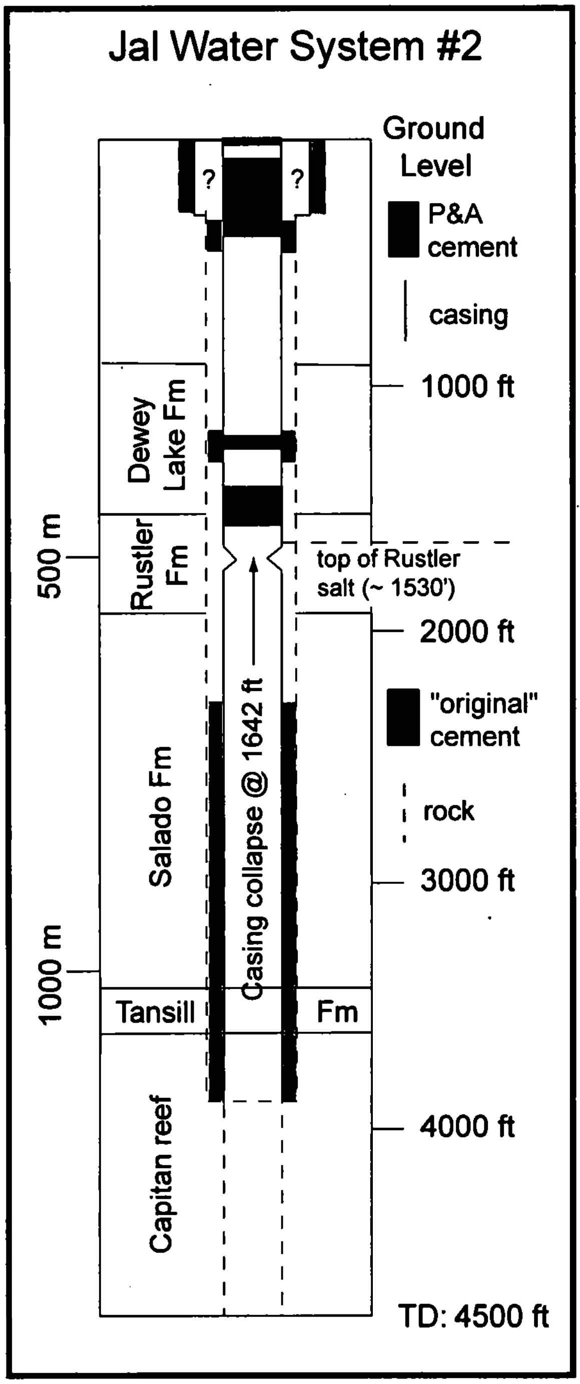

Figure 5. General stratigraphy and casing and cementing record for Skelly Jal Water System #2, located adjacent to the WRS.

Skelly Jal Water System #2

The #2 well is located 1980 ft (604 m) from the south line and 660 ft (201 m) from the west line of section 9. It is about the diameter of the sinkhole (75 ft; 23 m) west of the margin of the WRS. The well was spudded on October 3, 1967. A string of 13.375" (34 cm) casing was set to 353 ft (108 m) depth and cemented, with circulation back to the surface (Figure 5). The well was then drilled to a depth of 3890 ft (1186 m). New casing was set and cemented with 300 sacks of cement; a temperature survey indicated the top of cement at 2772 ft (845 m) depth. The well was drilled to 4500 ft (1372 m) and left as an open hole from 3890 ft (1186 m) to TD.

In 1979, work in the #2 well showed that the casing had collapsed at 1642 ft (501 m). The P&A worksheet shows a cement plug from 1550-1418 ft (473-432 m), 2 perforations at 1250 ft (381 m) with cement displaced below a packer at 1140 ft (348 m), 2 perforations at 400 ft (122 m) with cement from 414-72 ft (126-22 m), and a surface plug from 0-10 ft (0-3 m).

From the original drilling, I estimate that about 300 ft (91 m) of the upper Salado remained open behind the casing, as did all of the Rustler and most of the Triassic-age clastics. After P&A work, the plugs in the casing are from about the top of Rustler and above. The lower perforated and cemented zone is about the middle of the Dewey Lake. The upper perforated zone is estimated to be in the upper Dockum. The plugs apparently do nothing to prevent circulation through the production casing into the Rustler, and possibly Salado, through the collapsed casing.

Hydrological Setting Around WRS

At this time, I do not have enough local data to compare various sources of water in the vicinity of WRS. The water level of the Ogallala in ranch well northwest of WRS was reported as 195 ft (59 m)(Nicholson and Clebsch, 1961) and at 189 ft (58 m) recently. Triassic units in the general area include groundwater, but they are not close enough to indicate comparable potentiometric surfaces. Water levels and salinities for the Capitan are still to be determined.

It is likely that the situation at WRS is generally similar to the Wink Sink (Baumgardner et al., 1982). There the potentiometric surface for the upper water-bearing units is higher than for the Capitan, indicating downward flow between connected units.

Breccia Pipes as Possible Natural Analogues

Baumgardner et al. (1982) reviewed some of the natural analogues of collapse in evaporite settings where features formed similar to the Wink Sink. Over the Capitan reef at the northern edge of the Delaware Basin, columnar collapse structures ("breccia pipes") formed naturally that are at least 0.5 Ma old (Snyder and Gard, 1982). At the surface, they are about 800-1000 ft (244-305 m) across (Figure 6), similar to the Wink Sink, but about an order of magnitude larger than the WRS. One of these structures was encountered in a potash mine, showing that the breccia column is very close to vertical and maintains a similar size with depth. Drilling demonstrated that the "roots" must be at least as deep as the Capitan reef. Surface domal structure contrasts with downturned strata adjacent to the collapse at depth. Regional dissolution of salt, probably at the top of the Salado, created the surface dome by lowering the area around the pipe. Tilted pedogenic nodules of the Mescalero caliche show that this structure was created after the caliche, which is about 0.5 Ma old (Bachman, 1980). Gravity surveys showed little change in density, while electrical surveys showed a lower resistivity across the structure (see Powers, 1996, for a review of the program to investigate these features).

Snyder and Gard (1982) concluded that breccia pipes in the northern Delaware Basin developed by collapse within the Capitan reef, followed by collapse to the surface. Based on Bachman's (1980) premise, the hydrological system of the Capitan changed when the Pecos River eroded to the reef near Carlsbad, NM, and pressure was decreased. He also inferred that collapse was before about 0.5 Ma.

Large features in the area include the San Simon Swale and smaller San Simon Sink. The swale and sink are located over and adjacent to the Capitan to the northwest of the WRS. The swale and sink are both much larger than the breccia pipes.

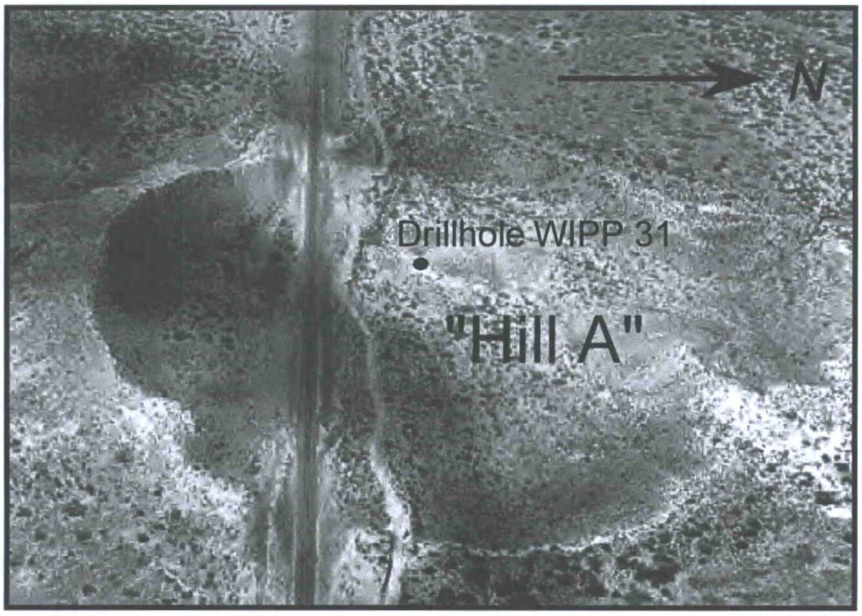

Figure 6. Aerial photograph of the surface collapsed dome structure of "Hill A," one of the breccia pipes over the Capitan reef in the northern end of the Delaware Basin. Bachman (1980) and Snyder and Gard (1982) showed the relationship to the Capitan and that the doming is caused by lowering of the surrounding area by dissolution of upper Salado salt after collapse.

Near the WRS, high altitude aerial photographs (Figure 7) do show circular features somewhat smaller (generally < 300 ft diameter) than known breccia pipes. Many of these features are located along linear trends about NW-SE. Bachman (1973) suggested that these features, which are observable over a much greater area, are aligned because they represent areas between long, linear dunes that are now gone or redeposited. Bachman believed they represent areas where infiltrating water was concentrated between the dunes and partially dissolved the near-surface Ogallala caliche. Based on soil surveys of Lea County, there is no evidence that these features are currently geologically active, though they do collect runoff. They are spread beyond the areal extent of the Capitan reef, so they are not likely related to the deep-seated breccia pipes of the northern end of the Delaware Basin.

Water Flooding as a Source of Dissolving Fluids

There are large water-flooding operations in Lea County, NM, for secondary recovery, especially from the Yates Formation. They are not implicated in the formation of the WRS, but it seems clear that some injected waters have not been contained in the target formation. New Mexico Oil Conservation Division (NMOCD) District 1 (Hobbs) has compiled some records of water flows in oil and gas holes within the district. Some of these are from the evaporites or formations above the redbeds.

One example, from T23S, R36E, shows several wells by different operators experiencing casing problems at depths of about 600-650 ft (183-198 m). In May of this year, Doyle Hartman tested the Emery King "NW" No. 6 well in section 1 for casing integrity and reported holes in the casing between depths of 641 and 653 ft (195-199 m)(Hartman, 2000). After an initial squeeze cement operation, pressure testing failed and the casing was cemented again. A pressure test below the squeeze zone was successful. After the drillhole was shut-in overnight, it flowed water. Wellhead pressures rose to 47 psi after 130 minutes of shut-in. The casing was squeeze-cemented a third time with different formulations, and the casing pressure tests showed the shallow water inflow was shut off.

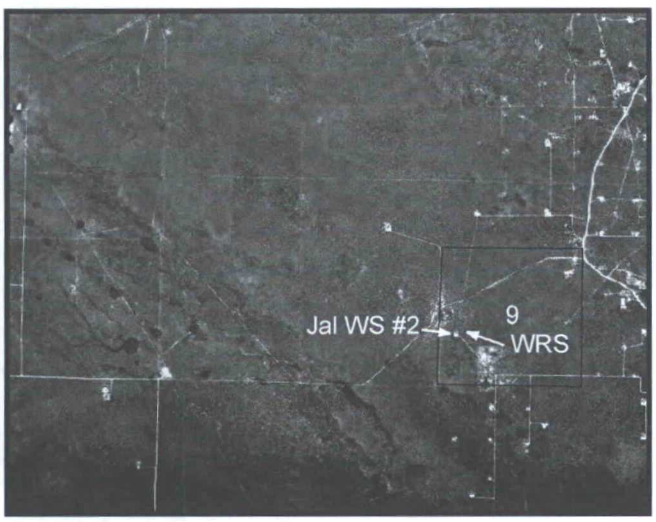

Figure 7. High-altitude aerial photo of area around WRS (11/97). Outlined area is a square one mile (1.62 km) on a side. Note small round dark areas west (left) side of photo along linear trends. Bachman (1973) attributed such features to caliche dissolution between paleodunes.

The Emery King leases show casing problems at, and fluid under pressure from, a zone I interpret as a fine-grained unit ("shale") based on high natural gamma. The unit is well above the top of the Dewey Lake, and it should be considered the basal shale of the Chinle Formation (Dockum Group). Hartman (2000) considers the source of these pressurized waters to be out-of-formation water from a nearby waterflood operation. Earlier studies of water resources for Lea County (Nicholson and Clebsch, 1961) indicate no potential for flow to the surface from these units.

Another example comes from T25S, R37E, where Hartman encountered high pressure flows from the lower Salado Formation in the Bates #2 well. After the flow was encountered, the NMOCD did not allow the well to be shut-in because the upper casing string only reached 450 ft in depth and would not prevent the formations above evaporites from being charged with high-pressure saline waters. There is no history of natural high pressure or high volume brines from this formation or this setting. The other potential source of high-pressure, high volume flows are nearby water-flooding operations, and it is clear that some waters are injected at pressures above the normal gradient. It is also noteworthy that the approved casing and cementing program was not considered sufficient to protect shallow units that may contain fresh water.

There are other examples from NMOCD records indicating shallow waters in evaporite units and also in some of the overlying clastics. Where the pressures, chemistry, or presence of water are uncharacteristic of the formation, it is reasonable to consider water-floods as a source. Various reports and documents indicate that regulatory agencies and industry recognize out-of-formation waters in the area.

Casing Requirements

NMOCD Rule 107 specifies casing and tubing requirements. "Any well drilled for oil or natural gas shall be equipped with such surface and intermediate casing strings and cement as may be necessary to effectively seal off and isolate all water-, oil-, and gas-bearing strata and other strata encountered in the well down to the casing point." In practice, wells in areas such as around the WRS generally have a surface casing string to a few hundred ft cemented back to the surface. An intermediate string usually is cemented in the lower part, leaving a portion of the evaporite sequence, and possible part of the overlying clastics, with an open annulus.

In the Delaware Basin, drillholes in the area where potash mines and resources exist (NMOCD District 2), the requirements are more stringent for cementing intermediate strings to protect the evaporites.

Evaporites, Casing Requirements, Water-floods, and Out-of-formation Waters

The WRS and the Wink Sink are closely associated with nearby drillholes that have casing problems and likely circulation of water causing dissolution of evaporites prior to collapse. Although it is not possible to eliminate natural processes in either case, the circumstantial evidence favors the drillholes as the significant causal agent. The shallow water-bearing units and the deeper Capitan are both possible sources of undersaturated water to dissolve the evaporites.

The annulus behind the casing was uncemented through a section of the evaporites in drillholes near both sinks. This appears to be a common situation for drillholes in the area; it is possible there are tens of thousands of such drillholes. Although casings may be tested to show integrity, the Emery King lease drillholes suggest that casings can be attacked from outside more easily when not protected by cement.

Although water-floods and out-of-formation waters are not implicated in either the WRS or the Wink Sink, there is a growing body of evidence that water-floods are leading to more occurrences of out-of-formation water. Most of these waters will have potential to dissolve evaporites once they reach such formations. In addition, natural and created oil-field brines have potential to corrode exposed casings and add to problems for dissolution.

Bottom Line

The WRS and Wink Sink illustrate how dissolution of evaporites around or in association with drillholes that have casing problems can cause sudden collapse and sinkhole formation. Nevertheless, the potential for further collapse is unassessed; various factors that may contribute to this potential haven't been examined in detail.

It seems likely that a high proportion of drillholes in Lea County, for example, have an open annulus through significant portions of the evaporite section and some of the overlying clastics. One line of investigation would be to assess the numbers and distribution of these drillholes. A pilot phase on a small scale (townships selected to represent certain kinds of problems, for example) would be helpful.

Another line of investigation would be to assess casing problems. A pilot phase in which areas are selected to show relationships in, near, and away from water-floods might be appropriate.

It also would be appropriate to thoroughly review the history and effects of at least one older and one recent water-flood operation in association with a review of out-of-formation waters and the investigations of casing problems. Industry and regulators have cooperated in some previous studies, and these more limited ventures offer some basis for more thorough assesment.

From a pilot investigation of these areas, it should be possible to make a preliminary assessment of whether the WRS and Wink Sink are isolated examples unlikely to be repeated. If it appears more such events are likely, a more precise strategy for assessing the probability and patterns can be developed.

Much of the area in New Mexico and west Texas where such events might occur is lightly populated. Nevertheless, drillholes are so numerous that there are still many located near or in populated areas. As the casings in drillholes age, it seems that the likelihood of such events would increase. The drillhole adjacent to the WRS was about 32 years old when the collapse occurred. The Hendrick well was 52 years old when the Wink Sink collapsed.

Although it may be appropriate to change the requirements for casing and cementing drillholes in the area discussed, this would not address the issue of existing drillholes completed according to the current regulations.

To have a useful evaluation, regulators and industry will have to have confidence in the group or agency conducting the study and be willing to cooperate. There is little reason for either to support such a study as long as there is perceived (or real) liability. Public records can provide considerable information for preliminary phases or possibly a pilot study, but useful conclusions may be beyond such a study without more detailed data available only through industry. Here we have the elements that make progress difficult: an industry operating under regulation, an unanticipated problem of undetermined significance, and unresolved liability concerns. Although a start can be made on assessing the significance of collapse around drillholes with existing information, some creative solution to the liability concern seems required before a thorough assessment can be made.

Acknowledgments

I thank Jimmy and Linda O'Rear for information and a tour and DonWhitten for permission to inspect the WRS. Dave ("Delaware Basin") Hughes and colleagues at WIPP helped with background information. The NMOCD District 1 Office (Hobbs) personnel maintain invaluable records for the industry. Various oil and gas industry operators have provided useful information.

Initial studies of the WRS were supported by the Westinghouse Geotechnical Engineering of theWaste Isolation Pilot Plant. This particular article and all work on it have not been funded by Westinghouse or any other agency or company, and the conclusions reached are mine.

References Cited

Bachman, G.O., 1973, Surficial features and late Cenozoic history in southeastern New Mexico: USGS-4339-8, US Geological Survey, Denver, CO.

Bachman, G.O., 1980, Regional geology and Cenozoic history of Pecos region, southeastern New Mexico: Open-file Report 80-1099, US Geological Survey, Denver, CO.

Baumgardner, R.W., Jr., Hoadley, A.D., and Goldstein, A.G., 1982, Formation of the Wink Sink, a salt dissolution and collapse feature, Winkler County, Texas: Report of Investigations No. 114, Bureau of Economic Geology, Austin, TX, 38 p.

Hartman, D., 2000, First notice and documentation of out-of-zone waterflood injection into fresh water strata in the vicinity of section 1, T-23S, R-36E, N.M.P.M.: letter to L. Wrotenbery, New Mexico Oil Conservation Division, dated June 15.

Hiss, W.L, 1975, Thickness of the Permian Guadalupian Capitan aquifer, southeast New Mexico and west Texas: Resource Map 5, New Mexico Bureau of Mines & Mineral Resources, Socorro, NM.

Johnson, K.S., 1989, Development of the Wink Sink in west Texas, U.S.A., due to salt dissolution and collapse: Environ. Geol. Water Sci., v. 14, p. 81-92.

Johnson, K.S., 1993, Dissolution of Permian Salado salt during Salado time in the Wink area, Winkler County, Texas, *in* Love, D.W., et al., eds., Carlsbad Region, New Mexico and West Texas: Forty-fourth Annual Field Conference Guidebook, New Mexico Geological Society, p. 211-218.

Johnson, K.S., 1998, Sinkholes in evaporite rocks: American Scientist, v. 86, p. 38-51.

Nicholson, A., Jr., and Clebsch, A., Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: Ground-water Report 6, [New Mexico} State Bureau of Mines and Mineral Resources, Socorro, NM, 123 p.

Powers, D.W., 1996, Tracing early breccia pipe studies, Waste Isolation Pilot Plant, southeastern New Mexico: A study of the documentation available and decision-making during the early years of WIPP: SAND 94-0991, Sandia National Laboratories, Albuquerque, NM, 54 p. + app.

Snyder, R.P., and Gard, L.M., Jr., 1982, Evaluation of breccia pipes in southeastern New Mexico and their relation to the Waste Isolation Pilot Plant (WIPP) site, with a section on Drill-stem tests, WIPP 31, by J.W. Mercer: Open-File Report 82-968, US Geological Survey, Denver, CO, 73 p.

Walters, R.F., 1976, Land subsidence in central Kansas related to salt dissolution: Solution Mining Research Institute, Flossmoor, IL, 144 p.