OKLAHOMA
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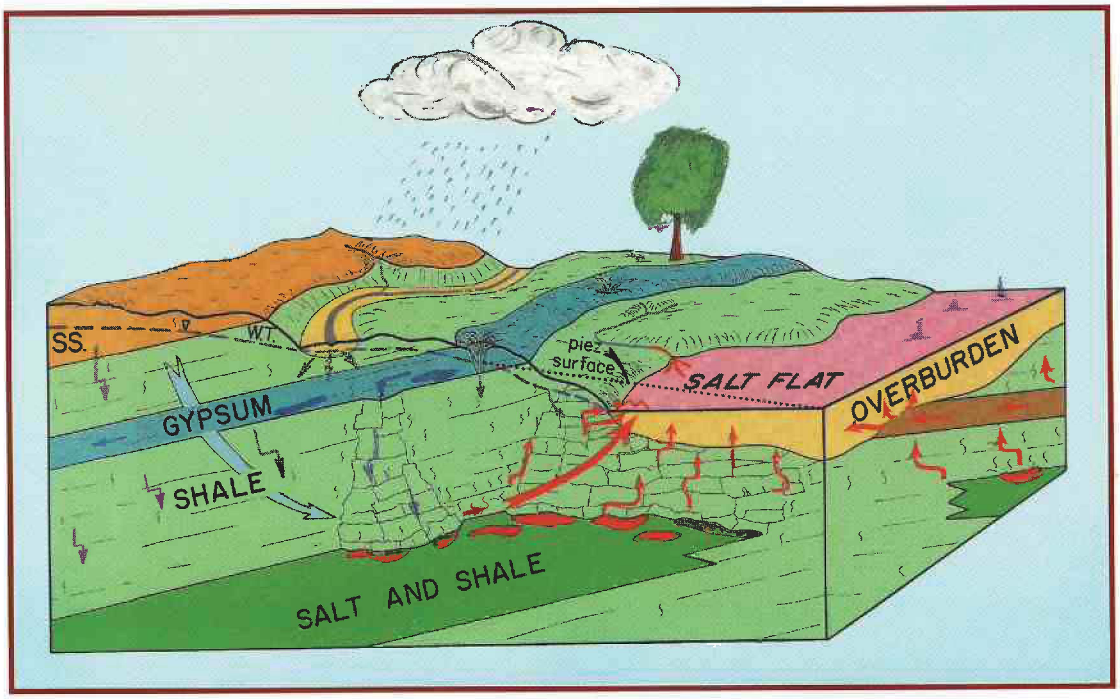
CIRCULAR 109

Evaporite Karst and Engineering/Environmental Problems in the United States



Kenneth S. Johnson and James T. Neal
Editors

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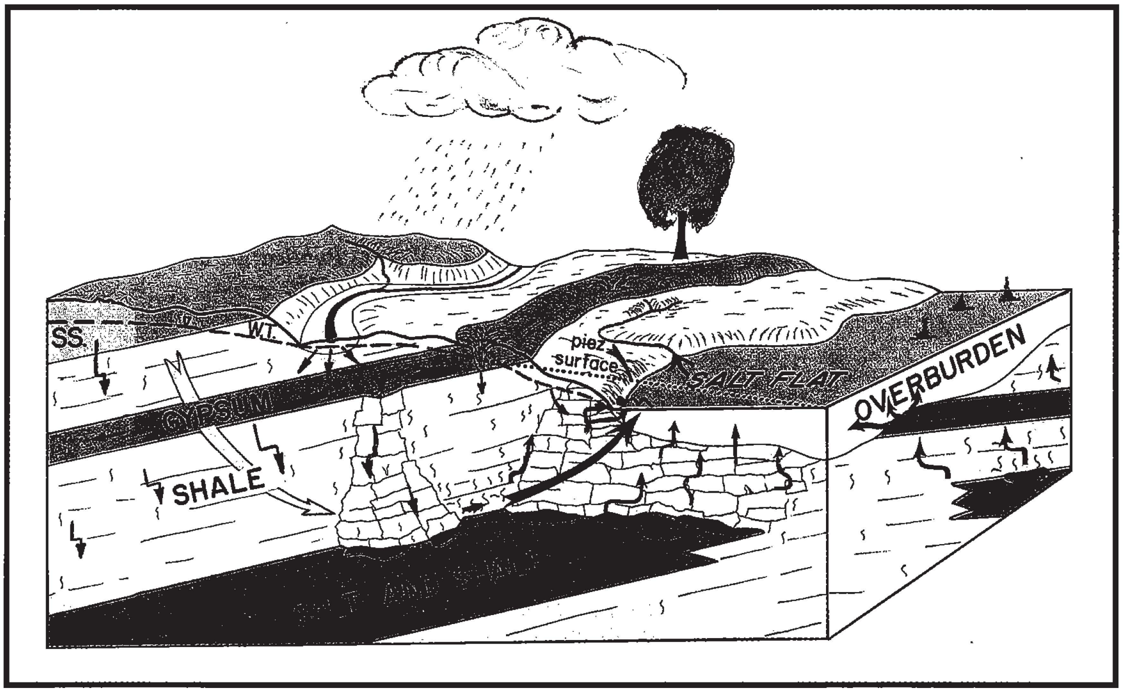

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OKLAHOMA GEOLOGICAL SURVEY

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Cover Picture

Schematic diagram of intrastratal salt karst in western Oklahoma. This is a colored version of the figure on p. 3 of this volume.

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PREFACE

Evaporite rocks, mainly gypsum (or anhydrite) and salt (halite), are the most soluble of common rocks. They are dissolved readily to form caves, sinkholes, disappearing streams, and other karst features typically associated with carbonate rocks (limestone and dolomite). Evaporites underlie about 35–40% of the contiguous United States, and are present in 32 of the 48 states. Evaporite karst (EK) is known to be present at least locally (and sometimes quite extensively) in almost all areas underlain by evaporites, and is much more widespread than is commonly suspected. The principal difference between evaporite and carbonate karst is that EK features can form rapidly, in a matter of days, weeks, or years, whereas carbonate-karst features typically take years, decades, or centuries to form.

EK can result from natural processes, wherein precipitation or ground water circulates through, and dissolves, an evaporite deposit. EK also can result from human activities, such as: construction upon, or directing water into or above, outcropping or shallow evaporites; and the drilling of boreholes, or making excavations, into or through subsurface salt deposits. Because evaporite dissolution is so rapid, EK features can quickly produce engineering or environmental problems that are hazards to humans and property; under some conditions, these problems can arise within a matter of several months or years. These hazards can include damage to, and/or collapse of, homes, buildings, civil projects (such as dams, bridges, and highways), and farmlands. Such hazards can cause great economic hardship, disruption of lives, and even loss of life.

This symposium volume is based upon a half-day theme session on EK that was held on October 28, 2002, in Denver, Colorado, as part of the annual meeting of the Geological Society of America (GSA). The session was organized and chaired by us, and was co-sponsored by the Engineering Geology, Hydrogeology, and Quaternary Geology and Geomorphology Divisions of GSA. We thank GSA and the three Divisions for their support in sponsoring the theme session. The EK session was held because of the growing awareness of karst problems in evaporite rocks. Although evaporite deposits and their associated karst problems are widespread in the United States, they have received scant attention from most geologists.

Co-sponsorship in the publication of this symposium volume has been provided by the United States Geological Survey and the National Cave and Karst Research Institute—National Park Service. Both these agencies are actively investigating karst and cave features throughout the nation, and we appreciate very much their participation in this project.

A total of 16 talks and posters were presented at the GSA meeting, and we then invited another 17 papers to be prepared especially for this volume. The 33 papers are grouped into *Introductory and General Papers*, and then into a series of geographic areas, based upon states. Each of the papers provides insight into significant engineering and/or environmental problems related to EK.

Technical editing, layout, and production of this volume were done by William D. Rose and Virginia Rose, of Rose Perspectives, Frederick, Maryland; coordination of editing and publication management was carried out by Christie Cooper, Oklahoma Geological Survey.

We hope that the GSA session and this symposium volume will heighten awareness in the geologic and engineering communities to the processes and potential engineering and environmental problems of EK. And we welcome contact from others interested in EK so that we can include them in plans for future sessions on this important subject.

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Jal Sinkhole in Southeastern New Mexico: Evaporite Dissolution, Drill Holes, and the Potential for Sinkhole Development

Dennis W. Powers
Consulting Geologist
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ABSTRACT.—Sinkholes have developed rapidly where drill holes that penetrate shallow evaporites and beds with unsaturated (with respect to halite) water are uncased or inadequately cased and cemented. The recent (1998) Jal sinkhole (also known as the Whitten Ranch sinkhole) developed over deeper evaporites. In this area, modest casing requirements through the evaporites, and waterflooding operations with out-of-formation waters, may increase the possibilities of more such events.

The Jal sinkhole developed with little warning late in 1998. The uppermost halite, in the Permian Rustler Formation, is >1,500 ft below ground surface; the top of the Permian Salado Formation is ~2,000 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 Permian Capitan Reef permitted circulation of fresh water, the solution of overlying evaporites, and upward chimney collapse through the thick red-bed section and the Tertiary Ogallala Formation to the surface.

In part of southeastern New Mexico, surface casing is required to protect part of the red-bed sequence that locally bears ground water. 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 waterflooding operations in evaporite and red-bed sections. Producing wells and wells scheduled to be P&A get checked for evidence of casing integrity. Nevertheless, older wells that have been P&A, and some wells still in production, may be subject to the same process suspected for the Jal 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 in indicating whether additional sinkholes are likely to develop. No doubt, liability concerns will make such a survey difficult.

GENERAL BACKGROUND

The Jal sinkhole (Fig. 1), near Jal, New Mexico, 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 drill hole, the Skelly No. 2 Jal Water System. This is not the first example here or elsewhere of such collapse.

In 1980 the Wink Sink collapsed near Wink, Texas, about 30 mi (50 km) south of the Jal sinkhole. The geologic setting for the Wink Sink is similar to that of the Jal sinkhole. The initial collapse occurred adjacent to a drill hole (No. 10-A Hendrick); as the sinkhole widened, it engulfed the wellhead casing within the sinkhole perimeter. Baumgardner and others (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. The No. 10-A Hendrick drill hole is believed to have played a part in the solution and collapse, although Baumgardner and others (1982) also interpreted natural dissolution of salt in the Permian Salado Formation 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 had occurred as early as Salado time. Johnson (1989) and Martinez and others (1998) also suggested that activities associated with drilling and drill holes may have contributed to the collapse. A more recent, second sinkhole in the Wink area (as well as some other collapse features in west Texas) is described elsewhere in this volume (Johnson and others, 2003).

Walters (1976) examined subsidence and collapse features in Kansas related to salt dissolution, and related eight features to dissolution in oil and gas drill holes. Collapse was most spectacular around the No. 11 W. M. Panning well, where a pit about 300 ft in

Powers, D. W., 2003, Jal sinkhole in southeastern New Mexico: evaporite dissolution, drill holes, and the potential for sinkhole development, *in* Johnson, K. S.; and Neal, J. T. (eds.), Evaporite karst and engineering/environmental problems in the United States: Oklahoma Geological Survey Circular 109, p. 219–226.

diameter developed within hours. Walters (1976) noted that these features were rare (with an estimated 80,000 drill holes in Kansas). Walters (1976) also noted that the known features involved old holes drilled before the State required cementing the casing opposite freshwater zones and that the drill holes were used for re-injection of undersaturated (with respect to sodium chloride) oil-field brines.

JAL SINKHOLE

Background

The Jal sinkhole is in the NW¼SW¼ sec. 9, T. 24 S., R. 36 E. (lat 32°13′48″N., long 103°16′ 34″W.), about 8 mi (13 km) north-northwest of Jal, New Mexico (Fig. 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 (Fig. 2). In discussing the sinkhole, the O'Rears recalled that their dogs were particularly disturbed on the evening of September 4. In a newspaper interview, 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. A seismic network operated in southeastern New Mexico did not record any signal associated with this event (R. Aster, personal communication).

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 (Fig. 3). The diameter appears to be ~75 ft (23 m) across. A similar low-angle aerial photograph (Fig. 4) taken October 23, 2001, shows that the surface diameter is about 50% larger. The approximate surface area in 2001 has been marked in Figure 2 (dashed white line) to show the difference. The collapse area appears to be offset somewhat to the west of the original sinkhole, closer to the No. 2 Jal Water System well.

High-angle aerial photographs I took in September 1998 allow an estimate of the depth (Fig. 5). The sun angle on September 15 is about 35° from vertical in this area around 1 p.m. (MDT) when the photograph was taken. As the shadow just covered the bottom, the depth can be estimated at ~107 ft (33 m). The sinkhole is reasonably cylindrical, permitting an estimate of the volume as ~4.7×10^5 ft^3 (1.4×10^4 m^3). By October 2001, debris in the sinkhole from collapse of the sides had filled the sinkhole to a depth estimated to be ~60 ft (18 m).

The sinkhole was not observed as it

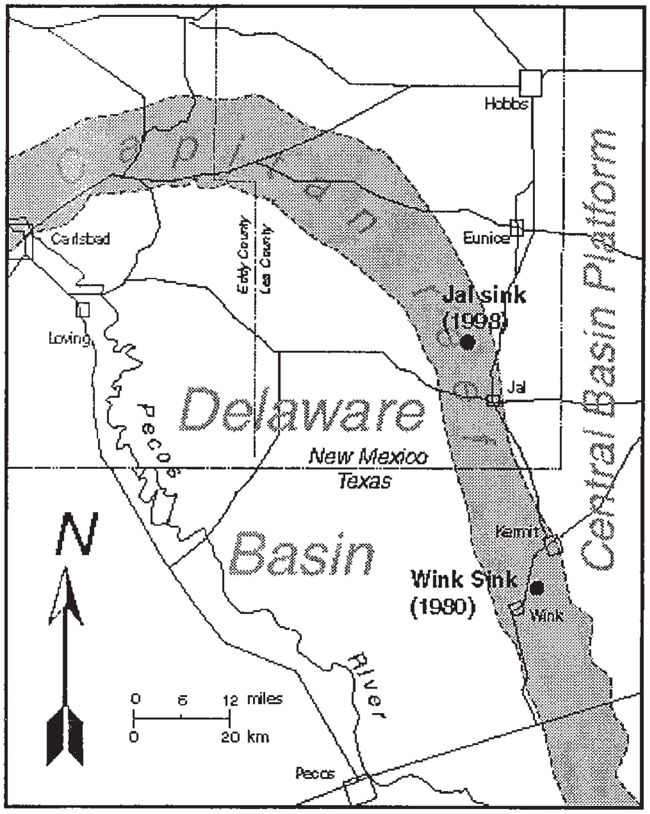

Figure 1. Location map showing the relationship of the Jal sinkhole to the Wink Sink and tectonic elements of the Permian Basin in west Texas and southeastern New Mexico. Modified from Hiss (1975).

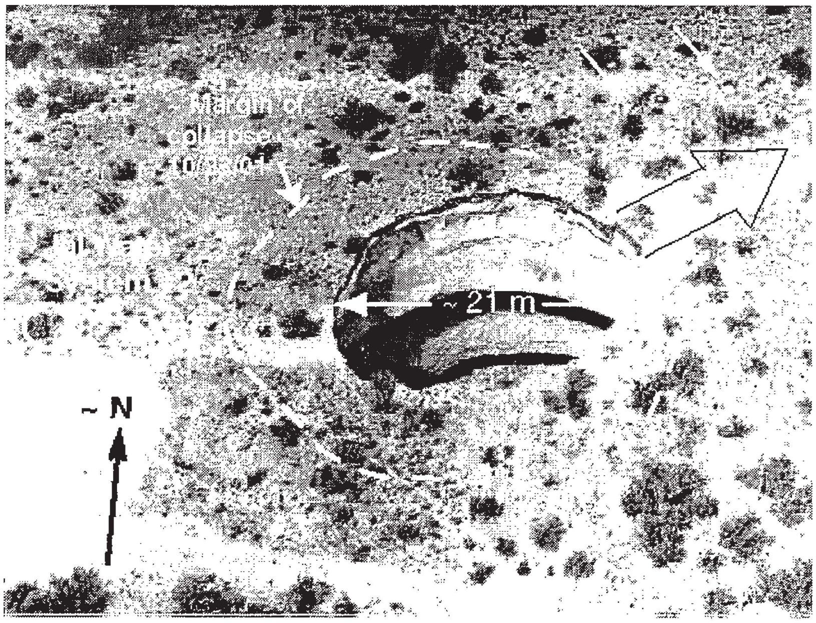

Figure 2. Low-angle aerial photograph of the Jal sinkhole, taken to the north. Small arrows show the location of some larger clasts of Ogallala caliche blown northeast (outline arrow) by the collapsing material. The drill pipe for the No. 2 Jal Water System well is circled. The dashed white line approximates the size and position of the surface collapse in October 2001 (see Fig. 4). Photo taken September 15, 1998, by D. W. Powers.

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 [1 m] across) near the sinkhole (Figs. 2, 4) and clast sizes decreasing away from the hole. The aerial photograph also shows a lighter shading from caliche dust coating the surface of the light reddish brown 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.

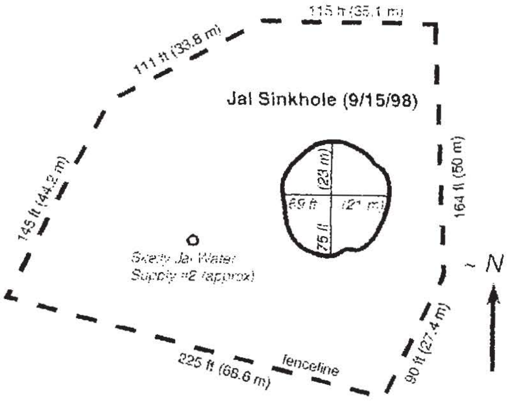

Figure 3. Fence dimensions used to estimate the diameter of the original Jal sinkhole from low-angle aerial photographs. These dimensions are smaller than some other early estimates.

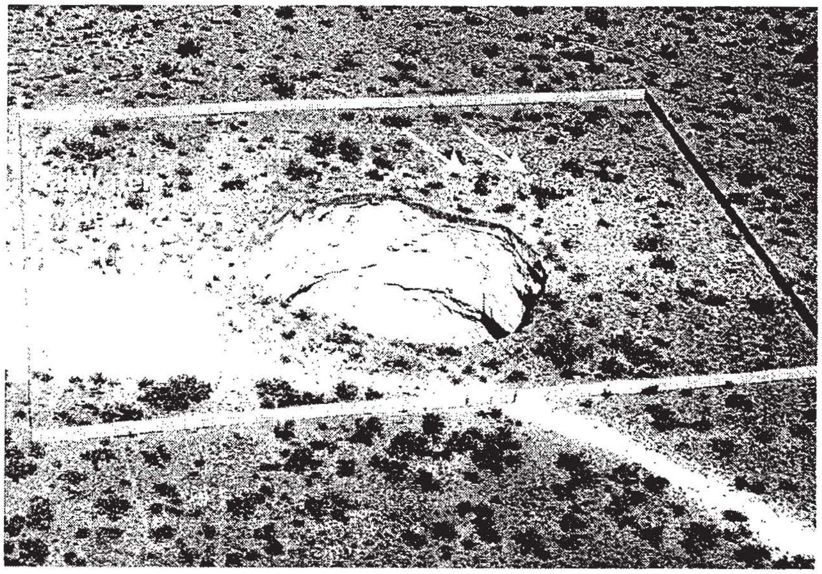

Figure 4. Low-angle aerial photograph of the Jal sinkhole, taken to the north, showing enlargement of the surface sinkhole with time. The approximate size and position are outlined on Figure 2 with a white dashed line. Arrows point to Ogallala caliche clasts, also shown in Figure 2. Photo taken October 23, 2001, by D. W. Powers.

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 photographs taken September 15. The depth to Ogallala ground water in a nearby windmill was recently measured at about 189 ft (58 m) below the surface. The depth to Ogallala ground water at the Jal sinkhole would likely be ~175–180 ft (53–55 m), about the same as the greatest early estimate of depth of the Jal sinkhole.

Geological Setting

The Jal sinkhole is 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 No. 2 Jal Water System) adjacent to the Jal sinkhole was drilled to this unit as a source of water in 1967 (Fig. 6). The Albert Gackle (Chambers & Kennedy) No. 1 Whitten well was also drilled in the SW¼ sec. 9, and the stratigraphy is believed to be similar to that at the Jal sinkhole. From drilling reports of the No. 2 Jal Water System and data from the No. 1 Whitten, depths to stratigraphic units at the Jal sinkhole have been estimated: the Capitan is at a depth of 3,600 ft (1,098 m), the Salado from 3,310 to 1,944 ft (1,009–593 m), the Rustler from 1,944 to 1,510 ft (593–460 m), and the Upper Permian Dewey Lake Formation from 1,510 to 910 ft (460–277 m). Triassic rocks of the Dockum Group overlie the Dewey Lake, and the late Tertiary Ogallala Formation is probably ~200 ft (61 m) thick. The casing in the No. 1 Whitten well obscures geophysical logs at a depth of 400 ft, and the exact depth of the Dockum–Ogallala contact is not known.

From analysis of geophysical logs, the middle Rustler (Tamarisk Member) includes the uppermost halite in the area, with a depth of about 1,700 ft (518 m). The lowest halite is at ~3,300 ft (1,006 m), in the basal Salado. Less soluble sulfates extend upward to 1,510 ft (460 m), to the top of the Rustler.

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

Skelly No. 2 Jal Water System Well

This well is 1,980 ft (604 m) from the south line and 660 ft (201 m) from the west line of sec. 9. The well casing was about the diameter of the sinkhole (75 ft [23 m]) west of the margin of the Jal sinkhole when it formed in 1998 (Fig. 2). The

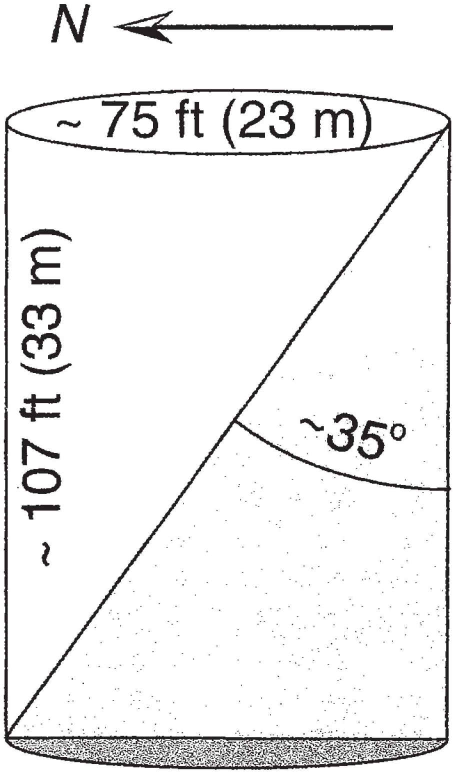

Figure 5. High-angle aerial photograph (Fig. 2) taken about 1 p.m. on September 15, 1998, showed shadow projecting to about the depth of fill on the north side of the Jal sinkhole, as shown in this diagram. Based on the sun angle and estimate of diameter, the depth to fill is estimated at ~107 ft (33 m).

well was spudded October 3, 1967. A string of 13.375-in. (34-cm) casing was set to 353-ft (108-m) depth and cemented, with circulation back to the surface (Fig. 6). The well was then drilled to a depth of 3,890 ft (1,186 m). New casing was set and cemented with 300 sacks of cement; a temperature survey indicated the top of cement at 2,772-ft (845-m) depth. The well was drilled to 4,500 ft (1,372 m) and left as an open hole from 3,890 ft (1,186 m) to total depth.

In 1979, work in the No. 2 well showed that the casing had collapsed at 1,642 ft (501 m). The P&A worksheet shows a cement plug from 1,550 to 1,418 ft (473–432 m), two perforations at 1,250 ft (381 m) with cement displaced below a packer at 1,140 ft (348 m), two perforations at 400 ft (122 m) with cement from 414 to 72 ft (126–22 m), and a surface plug from 0 to 10 ft (0–3 m).

From the original drilling, I estimate that ~300 ft (91 m) of the upper Salado remained open behind the casing, as did all of the Rustler and most of the Triassic clastics. After P&A work, the plugs in the casing are from about the top of the Rustler and above. The lower perforated and cemented zone is at 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.

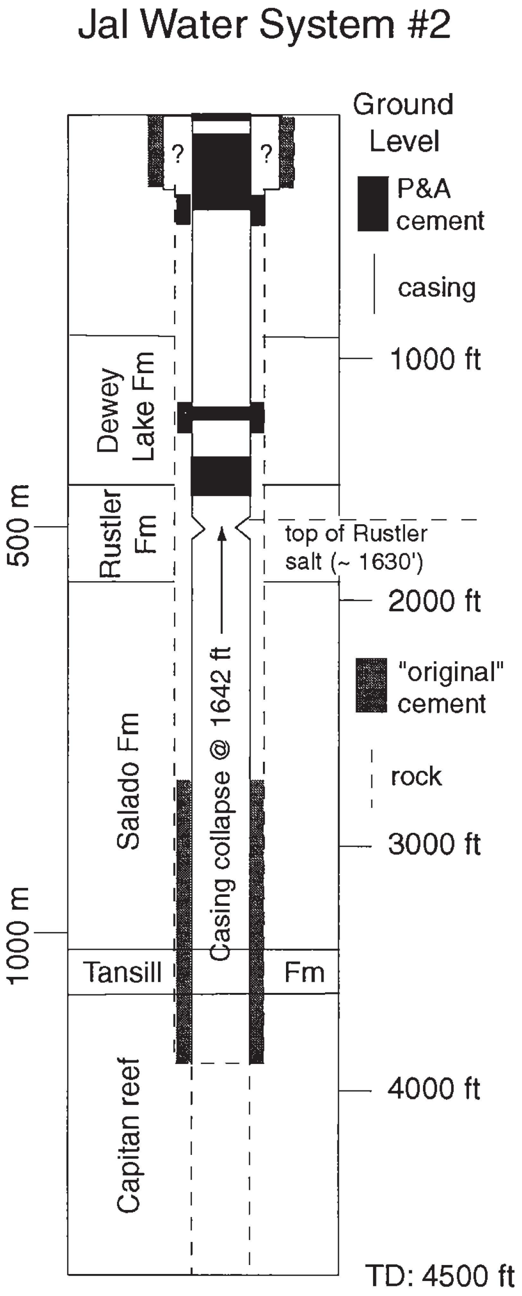

Figure 6. General stratigraphy and casing and cementing record for the Skelly No. 2 Jal Water System well, drilled adjacent to the Jal sinkhole.

Hydrological Setting Around the Jal Sinkhole

At this time, I do not have enough local data to compare various sources of water in the vicinity of the Jal sinkhole. The water level of the Ogallala in a ranch well northwest of the Jal sinkhole was reported as 195 ft (59 m) (Nicholson and Clebsch, 1961) and as 189 ft (58 m) recently. Triassic units in the general area contain ground water, 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 the Jal sinkhole is generally similar to that at the Wink Sink (Baumgardner and others, 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 ANALOGS

Baumgardner and others (1982) reviewed some of the natural analogs 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 (Snyder and Gard, 1982). At the surface, they are ~800–1,000 ft (244–305 m) across (Fig. 7), similar to the Wink Sink, but about an order of magnitude larger than the Jal sinkhole. 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 ~0.5 Ma (Bachman, 1980). Gravity surveys showed little change in density, whereas 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, New Mexico, and pressure was decreased. Bachman also inferred that collapse was before ~0.5 Ma.

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

Near the Jal sinkhole, high-altitude aerial photographs (Fig. 8) do show circular features somewhat smaller (generally <300 ft in diameter) than known breccia pipes. Many of these features lie along lineations that trend about northwest–southeast. 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 that they represent areas where infiltrating water was concentrated between the dunes, which partially dissolved the near-surface Ogallala caliche. Based on soil surveys of Lea County, New Mexico, 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.

WATERFLOODING AS A SOURCE OF DISSOLVING FLUIDS

There are large waterflooding operations in Lea County, New Mexico, for secondary recovery, espe-

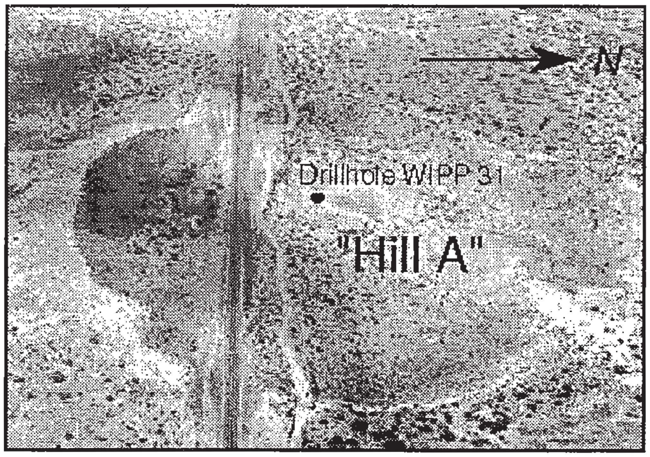

Figure 7. High-angle aerial photograph of the surface-collapsed dome structure of "Hill A," one of the breccia pipes over the Capitan Reef in the northern end of the Delaware Basin. Bachman (1980) and Snyder and Gard (1982) showed the relationship with the Capitan and showed that the doming was caused by lowering of the surrounding area by dissolution of upper Salado salt after collapse. Photo taken September 15, 1998, by D. W. Powers.

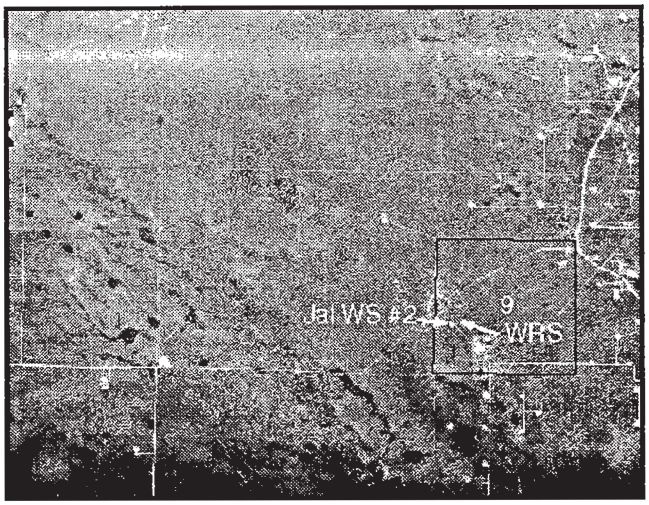

Figure 8. High-altitude aerial photograph of area around the Jal sinkhole prior to collapse. Outlined area is a square that is 1 mi (1.62 km) on a side. Note small, round, dark areas on the west (left) side of the photo along linear trends. Bachman (1973) attributed such features to caliche dissolution between paleodunes. Photo by National Aerial Photography Program, November 1977.

cially from the Permian Yates Formation. These operations are not implicated in the formation of the Jal sinkhole, but it seems clear that some injected waters have not been contained in the target formation. The 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 flows are from the evaporites or formations above the red beds.

One example, from T. 23 S., R. 36 E., shows several wells drilled by different operators that had casing problems at depths of ~600–650 ft (183–198 m). In May 2000, Doyle Hartman tested the No. 6 Emery King "NW" well in sec. 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 drill hole 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 that the shallow-water inflow was shut off.

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-ray deflections in the geophysical logs. The unit is well above the top of the Dewey Lake, and it should be considered the basal shale of the Triassic 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 T. 25 S., R. 37 E., where Hartman encountered high-pressure flows from the lower Salado Formation in the No. 2 Bates 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 waterflooding 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.

Other examples from NMOCD records indicate shallow waters in evaporite units and also in some of the overlying clastics. Where the pressures, chemistry, or presence of water is uncharacteristic of the formation, it is reasonable to consider waterfloods as a source. Various reports and documents indicate that regulatory agencies and industry groups 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 Jal sinkhole generally have a surface-casing string to a few hundred feet, cemented back to the surface. An intermediate string usually is cemented in the lower part, leaving part of the evaporite sequence, and possibly part of the overlying clastics, with an open annulus.

In the Delaware Basin, for drill holes 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, WATERFLOODS, AND OUT-OF-FORMATION WATERS

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

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

Although waterfloods and out-of-formation waters are not implicated in either the Jal sinkhole or the Wink Sink, a growing body of evidence indicates that waterfloods are leading to more occurrences of out-of-formation water. Most of these waters 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 dissolution problems.

THE BOTTOM LINE

The Jal sinkhole and the Wink Sink illustrate how dissolution of evaporites around or in association with drill holes 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 have not been examined in detail.

It seems likely that a high proportion of drill holes in Lea County, for example, have an open annulus through significant parts of the evaporite section and through some of the overlying clastics. One line of investigation would be to assess the numbers and distribution of these drill holes. 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 waterfloods might be appropriate.

It also would be appropriate to thoroughly review the history and effects of at least one older and one recent waterflood 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 assessment.

The second Wink Sink (Johnson and others, 2003, this volume), which formed during May 2002, suggests that more such events are likely and that a more precise strategy for assessing the probability and patterns would be helpful.

Much of the area in New Mexico and west Texas where such events might occur is lightly populated. Nevertheless, drill holes are so numerous that many are near or in populated areas. As the casings in drill holes age, it seems that the likelihood of such events would increase. The drill hole adjacent to the Jal sinkhole 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 drill holes in the area discussed, this would not address the issue of existing drill holes completed according to current regulations.

For a useful evaluation, regulators and industry will need 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 having more detailed data, which would be available largely 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 drill holes with existing information, some creative solution to the liability concern seems required before a thorough assessment can be made.

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