Seismic Reflection Survey of a Sinkhole ENG 2.3 in Ellsworth County, Kansas

Richard D. Miller. Don W. Steeples, and Jeffrey A. Treadway, Kansas Geological Survey

Salt dissolution sinkholes are present in many places in Kansas that are underlain by bedded salt within 2 000 ft of the Earth's surface. Several documented instances of dissolution and subsidence have occurred in association with petroleum related activities. Seismic reflection surveys in the vicinity of these sinkholes have proven to be a useful method of measuring subsurface sinkhole dimensions. Using the MiniSOSIE recording method, we were able to trace the top of the salt and also the vertical location of the Stone Corral anhydrite which is an excellent seismic marker bed. Salt dissolution of approximately l00 ft thickness has occurred at the locality discussed in this paper. The subsurface areal extent of the dissolution exceeds the surface extent of the subsidence by approximately an order of magnitude. The

years.

Introduction

Sinkholes resulting from salt dissolution are quite common throughout central and southern Kansas. The area surveyed for this paper is underlain by the Hutchinson salt member of the Permian Wellington formation. The Hutchinson salt member at the Janssen "B" 6 well site near Geneseo, Kansas, is approximately 150 ft thick at a depth of about 850 ft. Walters (1977) discussed the formation of sinkholes in south-central Kansas resulting from dissolution of the Hutchinson salt by unsaturated brines from disposal wells or from leakage of surface and/or shallow groundwater alongside well casings. Each rock layer above the salt dissolution cavity collapses into the void left by the layer below it. This domino effect progresses either catastrophically or gradually over years forming a surface depression.

Seismic reflection surveys offer a powerful method of acoustically imaging portions of the subsurface of the earth in the vicinity of some sinkholes. The successful use of the technique depends upon the existence of velocity and/or density contrasts in the geological materials within and surrounding the sink. In this paper geologic structures related to or defining the sink were detected and mapped in the subsurface.

Field operations

Two lines intersecting at about 90 degrees and nearly centered on the sinkhole were laid out in order to obtain the necessary subsurface information (Figure 1). Line 1 crossed the sinkhole from southeast to northwest with the low-numbered shotpoints (SPs) at the southeast end. A total of 83 SPs were occupied at 33 ft intervals on line 1. The county road running east/west, south of the sinkhole, was crossed during the shooting of line at CDP number 258. Highway 14 intersected the profile on line 1 at CDP number 306 and at CDP number 504 on line 2. Line 2 crossed the sinkhole from northeast to southwest with the low-numbered shotpoints on the northeast end. Line 2 contained 84 SPs also spaced 33 ft apart. Lines 1 and 2 intersected near the center of the surface depression at CDP numbers 280 and 480, respectively. The two lines represent a total of about a mile of lateral surface coverage.

Interpretation

Data quality of the two crossing seismic lines allows for a satisfactory interpretation of the present orientation of the Hutch-

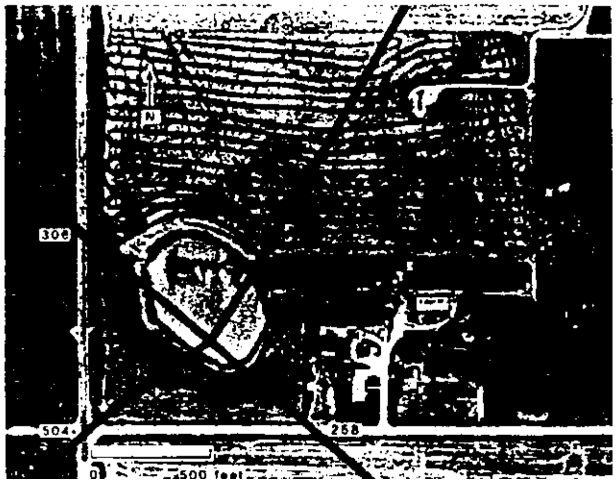

FIG. 1. Aerial photograph shows sinkhole's (filled with water) orientation and size in comparison to highway running north/south and county road running east/west.

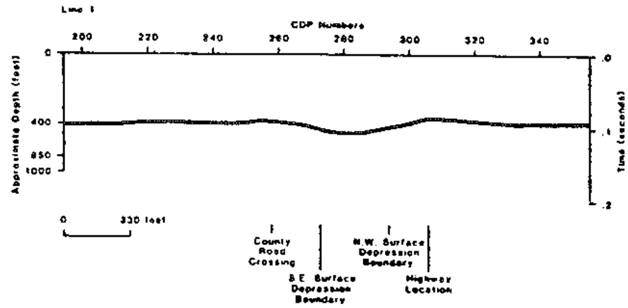

FIG. 3. Geologic interpretation predominantly consists of three clearly identifiable layers. Solid black layer represents Stone Corral anhydrite. Directly below anhydrite is red bed sequence represented by tight dot pattern. Third layer is top of Hutchinson salt member. It is clearly evident that disturbed salt extends under highway and county road.

inson salt and some overlying strata. Both sections show similar wavelet character above 170 ms. Below 170 ms the data quality is poor with nothing more than subtle hints of primary reflectors continuous across the sections. There appear to be multiple reflections on the seismic sections below the salt, so events below 170 ms should not be considered primary reflections.

Well logs from the area suggest the presence of sharp lithologic boundaries at 400 and at 850 ft. These boundaries have been identified as the Stone Corral anhydrite and the Hutchinson salt member, respectively, both of Permian age. There seems to be about 150 ft of relatively uniform salt underlying approximately 450 ft of red bed sequences. Strong acoustic boundaries should be present below 1 150 ft, but due to the lack of penetration of seismic energy through the salt, recognition of the deeper rock units is nearly impossible.

Line 1 traverses the sinkhole from southeast to northwest intersecting the county road at CDP 258 and State Highway 14 at CDP 306. The surface expression of the sinkhole extends from CDP 273 to CDP 294 on line 1. After examination of the seismic section, it is obvious where the salt has been dissolved in the subsurface (Figures 2 and 3). Suggestion of dissolution is present down to about 140 ms from CDP 261 to CDP 311. The strong marker bed at about 90 ms is the Stone Corral anhydrite, and the smaller amplitude doublet just below it is the acoustic image of the red bed sequences. The Hutchinson salt itself is represented by a strong singlet at about 140 ms. There seems to be approximately 15 ms of vertical variation present in the salt reflector equating to about 100 ft of downward displacement.

From CDP 195 to CDP 210 there appears to be a basin in the salt layer that is not present in the overlying Stone Corral. This could indicate active dissolution of the Hutchinson salt member during Permian time prior to the deposition of the Stone Corral anhydrite. Alternatively, it could indicate a water-filled void that is presently bridged by the Stone Corral. This also could represent an old drill site that had sufficient dissolution to allow slumping of units as high in the section as just below the Stone Corral. If that is the case, we might expect some surface sinking at the southeastern end of the line in the future.

Line 2 crossed the sink from northeast to southwest, crossing the county mad and State Highway 14 intersection from CDPs 504 to 508 (Figure 1). As on line 1, very strong reflectors can be identified above 140 ms with very poor data quality below that time (Figures 4 and 5). The character of the energy present on the seismic section of line 2 is easily matched with that on line 1. CDPs 480 on line 2 and 280 on line 1 represent the same subsurface point. The 3 ms of shift necessary to align the reflectors are undoubtedly the result of slight differences in stacking velocities and automatic statics application during processing.

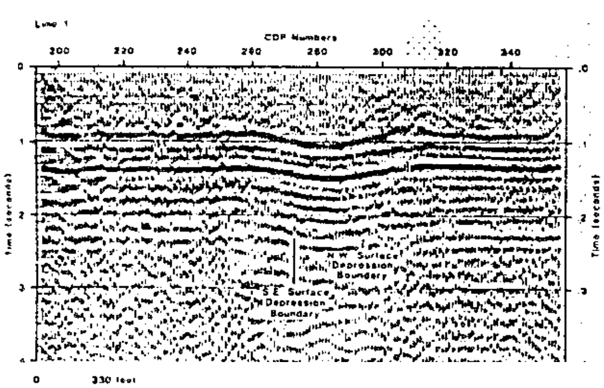

FIG. 2. Seismic section (line 1) shows quite clearly subsurface extent of dissolved salt layer at about 140 ms. Quiet zone at about CDP 302 from 90 to 100 ms depth represent some evidence for strain hardening' Data below 160 ms generally not result of primary reflections and are. disregarded.

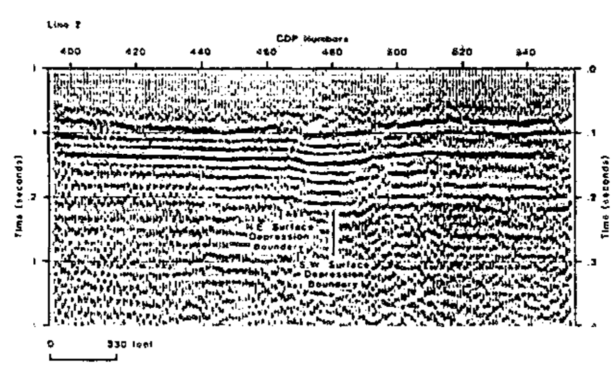

FIG. 4. Seismic section (line 2) ties to Figure 2 (line 1), at CDP 480 equating to CDP 280 (line 1). Here as line 1, subsurface extent of disturbed salt is quite clear. Poor data on flanks of sink are characteristic of reflection data over sinkholes.

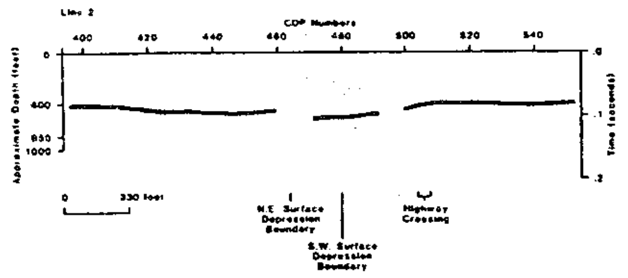

FIG. 5. Geologic interpretation is very similar to line' 1. Stone Corral anhydrite overlies red bed sequence and Hutchinson salt. As before, anhydrite is solid dark and salt is a large matrix dot pattern. Highway is at very fringe of subsurface expression of sinkhole.

Between CDPs 405 and 464 there seems to be a very steady gradational increase of about 6 ms in the arrival time of the wavelet identified previously as the salt in discussion of line 1. Displacement of the salt reflector between CDP 464 and 491 appears to be about 9 ms. This would imply a total salt displacement of about 15 ms which would represent approximately 100 ft of actual subsidence in the subsurface at the depth of the salt. This agrees quite well with line I. As on line I, the Stone Corral anhydrite and the red bed sequences lie directly over the Hutchinson salt member at around 140 ms (Figure 5).

Apparent arrivals after 150 ms are primarily the result of multiple reflections and should be disregarded. Predictive deconvolution was attempted to eliminate the multiples. After several variations in the parameters, it was concluded the successful elimination of multiples would require sacrificing some resolution and amplitude of first-order reflections from the salt and earlier events. Therefore, the use of predictive deconvolution to minimize the multiple problem was scratched.

On the western boundary of the structural low formed in the salt from dissolution there exists a significant drop in reflector clarity of the disturbed area. This corresponds to CDPs 304 through 312 on line I (Figure 2) and CDPs 493 to 503 on line 2 (Figure 4). This drop in data quality is associated in both cases with apparent highs of 5–7 ms in the Stone Corral. These highs may indicate strain hardening of units above the Stone Corral. Strain hardening has been observed in laboratory tests of rocks stressed to failure during earthquake simulation experiments. The strain hardening results in higher seismic-wave velocities, which could explain the time pullup observed in the Stone Corral. If this analysis is correct, future failure may be implied in the vicinity of CDPs 304–312 and 493-503.

The relative time map shows the present surface of the Hutchinson salt member (Figure 6). The time interval between the 6 and 22 ms contours represents about 100 ft of depth change of the salt layer forming the basin-type feature.

Conclusions

The present surface subsidence does not account for all the apparent subsurface dissolution of the Hutchinson salt member under the H. F. Janssen "B" 6 drill site. Comparing Figure 6 with the present surface depression, the salt shows a disturbed area more than 10 times that present at the surface. This implies that some material lying between :the Hutchinson salt and the surface is bridged in some fashion and is therefore supporting the weight of overlying strata. Release of this stress is likely. The mechanism for the release of the stress can progress anywhere from extremely gradual to catastrophic.

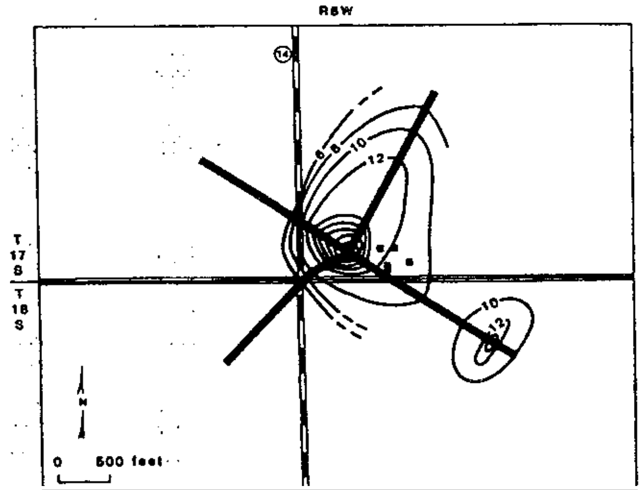

FIG. 6. Contours show relative time of reflector identified as top of Hutchinson salt. Thick dark lines show orientation of seismic lines with respect to east/west county road and north/south Kansas Highway 14. Suggestion of a smaller dissolution pocket can be seen on southeastern end of line 1.

From previous studies of active sinkholes in central Kansas, there exists no evidence here to suggest catastrophic collapse of the area directly above the disturbed salt beds. However, gravity slumping of overlying strata is expected to continue until total stress release is complete. The resulting depression at the surface could be as great or even slightly greater than the present subsurface dissolution limits (Figure 6). The extent of the sinking at the surface is almost certain at some time to affect Kansas Highway 14.