High Resolution Seismic Reflection Investigation of Salt Dissolution Features in Kansas

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Abstract

The Kansas Department of Transportation (KDOT) is in the Preliminary Design Phase of several construction projects in central Kansas. These construction projects have one problem in common; they all cross underground rock salt mines and/or the natural dissolution front of the Hutchison Salt Member. These areas are considered "high risk" for gradual to catastrophic collapse. Through the use of the high resolution seismic reflection technique, zones of active dissolution and/or mined areas along the project corridors are delineated. This information is then utilized by the KDOT in route selection, remediation efforts, and to assess the potential for gradual to catastrophic collapse.
KDOT has previously acquired high resolution reflection seismic data in support of salt-dissolution studies in central Kansas. The success of the method at these sites has prompted KDOT to acquire additional data at the new study sites.

Figure 1: 1974 Sinkhole near Hutchinson Kansas (Walters, 1978).

Introduction

Karst-related sinkholes and subsidence features can be formed by natural processes or as a result of anthropogenic activities. The sinkholes in the KDOT study areas in central Kansas are products of both of these processes. Some have formed as a result of the collapse of underground rock salt mines; others as a result of the natural gradual dissolution of the Hutchinson Salt Member. The impact of this problem on highway infrastructure in central Kansas (in terms of cost and public safety) is a very real concern. It is critically important that KDOT personnel understand the processes and mechanisms involved, and develop a protocol for identifying problematic areas and assessing the potential for subsidence and/or catastrophic collapse.

The typical KDOT geotechnical investigation utilizes borehole control (to base zone of interest) and near surface information to develop geologic profiles and cross-sections. However, in the KDOT central Kansas study areas, these standard approaches are not economically feasible given the depths to the Hutchinson Salt Member (up to 1300 feet). Additionally, borehole control can be effectively used only in areas where correlations can be extrapolated from borehole to borehole. This is clearly not the case in mined-out areas and in areas where natural, variable salt dissolution occurs.

Through a cooperative effort by the KDOT and Kansas Geological Survey (KGS), a high resolution seismic reflection will be conducted in the central Kansas study areas. These surveys will enable KDOT to image the subsurface rock salt, and asses the potential for gradual subsidence and/or catastrophic collapse along each proposed project route. Dependant upon the results of each survey, alignment changes or remedial efforts may be required.

Geologic Setting

The Hutchinson Salt Member is part of the Permian Age Wellington Formation. The Wellington Formation is found at the surface and subsurface in much of central and south-central Kansas. The Wellington Formation can be divided into three distinct zones. The lowermost is a sequence of anhydrites, shales, siltstones, gypsum and dolomite. This lower section of the Wellington is approximately 250 feet thick. The middle section of the Wellington Formation contains the Hutchinson Salt Member. This section is characterized by salt layers interbedded with shale, anhydrite and gypsum. The middle portion of the Wellington Formation varies from 100 to over 550 feet thick. The upper portion of the Wellington is predominantly gray shale with minor deposits of gypsum and anhydrite.

Overlying the Wellington Formation are red and grey shales of the Ninnescah Shale Formation. In the Hutchinson area, near the salt dissolution front, the Ninnescah Formation is the uppermost bedrock unit and its eroded thickness is approximately 150 feet. North and west of this, the Ninnescah is overlain by Permian redbeds of the Nippewalla Group, which is between 250 and 400 feet thick in central Kansas. The uppermost unit of this group is the Harper Sandstone Formation, which is a major Permian aquifer.

In north-central Kansas, nearly 600 feet of Cretaceous rocks cover the Nippewalla Group. Marine shale, chalk, and sandstone characterize this portion of the subsurface. Of interest to engineering geologists are the Cheyenne Sandstone and the Dakota formations, both of which carry large volumes of fresh or brackish water.

The most recent material deposited in these areas is post–glacial alluvium. The alluvial material fills the river valleys and natural salt dissolution features. Thicknesses vary greatly from a thin veneer to over 100 feet.

Salt Related Subsidence and Collapse

There are five scenarios that trigger surface subsidence and/or collapse and related to Hutchinson Salt Member: natural dissolution, dry-mining activities, solution mining activities, hydrocarbon exploration, and brine-disposal wells.

Natural dissolution, primarily along the eastern edge of the Hutchinson Salt Member, has been creating shallow lakes east of Hutchinson area for thousands of years. Natural dissolution occurs where the rocks overlying the salt are thinnest (along the eastern edge of the Wellington outcrop/subcrop). In the areas, circulating groundwater is slowly removing the rock salt. Subsidence is generally gradual and is not considered a major transportation safety risk, but can necessitate costly, ongoing repairs and

maintenance. Subsidence is generally gradual, partly due to the slow rate of dissolution, and partly because up to 100 feet of mostly saturated alluvial sand and gravel lie atop the weathered Wellington bedrock along the eastern dissolutional edge of the Hutchinson Salt Member. Any small voids caused by the collapse shale beds overlying the Hutchinson Salt Member are thought to be filled with alluvium, greatly attenuating the impact at the surface.

Of greater concern to KDOT personnel are the man-made breaches in the salt layer. The areas with the most obvious potential for sudden collapse are those above dry, underground salt mines. There are 3 active underground dry salt mines in Kansas, and numerous abandoned mines. Current mining practice involves the room-and-pillar method, whereby approximately 25 percent of the salt is left to support the roof. Salt mining in central Kansas began in the late 1800's, however, and for many years there were no regulations to insure the long-term stability of the excavated caverns. These mines are of concern to KDOT because there is potential for catastrophic collapse. Perhaps as importantly, these mines are generally not overlain by unconsolidated alluvium, and brittle collapse features are often expressed at surface level.

Solution mining has always been the preferred method for removing the rock salts of the Hutchinson Salt Member. Typically, freshwater is pumped down a well into the Hutchinson Member, dissolving the salt and creating brine. The brine is brought to the surface and evaporated, producing very pure commercial salt. The size and shape of the subsurface cavern can be controlled and monitored by modern methods, and the uppermost beds of the rock salt are deliberately left undisturbed to decrease the possibility of collapse. Early solution mining in the area, however, concentrated on the upper surface of the salt and left voids in unknown locations[1]. Again, these mines are of concern to KDOT because there is potential for catastrophic collapse which is often expressed by brittle failure at surface level.

Mining activities have caused several documented sinkholes in central Kansas. Most of these documented failures are associated with salt plants in the Hutchinson area, including a subsidence feature in the downtown in 1925 which damaged the county court house. One of the most dramatic events occurred in October, 1974 near the Cargill plant on the southeast edge of Hutchinson. Over the course of 2 days, an area 300 feet in diameter dropped over 20 feet, damaging plant's rail yard (Figure 1). Then in October, 2000, an abandoned mine shaft of the former Crystal Salt Company in Kanopolis collapsed without warning, destroying part of a brick factory.

The fourth cause of salt-related subsidence/collapse in central Kansas involves oil production, which is scattered across the region. Oil and gas wells are drilled through the Hutchinson Member to reach deeper reservoirs in underlying beds. Thousands of wells have been abandoned in this region since oil was discovered in the early part of the 20th century. If these wells were not properly plugged, downward flowing freshwater from overlying aquifers can come into contact with the underlying rock salt. Over time, large cavities can develop. These can result in catastrophic collapse at the surface. These abandoned wells can also fail as a result of damage related to natural subsidence.

A fifth cause of salt-related subsidence/collapse is the failure of brine injection wells. Again – poor design or damage related to natural subsidence.

Kansas Department of Transportation Projects

As of this writing, the Kansas Department of Transportation has four projects for which we plan to use high resolution seismic reflection investigation procedures: Victory Road and US-50, Hutchinson US-50 Bypass, US-61 from Hutchinson to McPherson, and I-70 Sinkholes.

Victory Road and US-50

This project is located approximately 8 miles east of Hutchinson. Arial photos of this region from 1992 show no signs of subsidence. However, in 1998 the roadway had dropped approximately 1 foot. Surface monitoring was conducted and investigative boreholes were drilled. The center of the sinkhole was located about 100 feet to the north of the highway, surrounded by very symmetrical 300 foot diameter inverted cone-shaped depression. This sinkhole pools water year-round. Yearly settlement is approximately ten inches, with a cumulative settlement of over three feet.

A high resolution reflection seismic survey was at this site conducted in 2002. Two survey lines were utilized: one survey line runs east and west from the Victory Road-US-50 Junction; the second line runs perpendicular to US-50 along Victory Road. The information obtained during this survey was that the salt

solution feature was actually 5 times larger than its surface expression, and two additional inactive paleo-sinkholes were delineated. It was determined that the sinkholes are the result of natural salt dissolution. No voids were identified in the sinkhole and therefore, pose a low threat of catastrophic collapse.

This project will continue to be a maintenance issue. At this time there are no plans to take corrective measures.

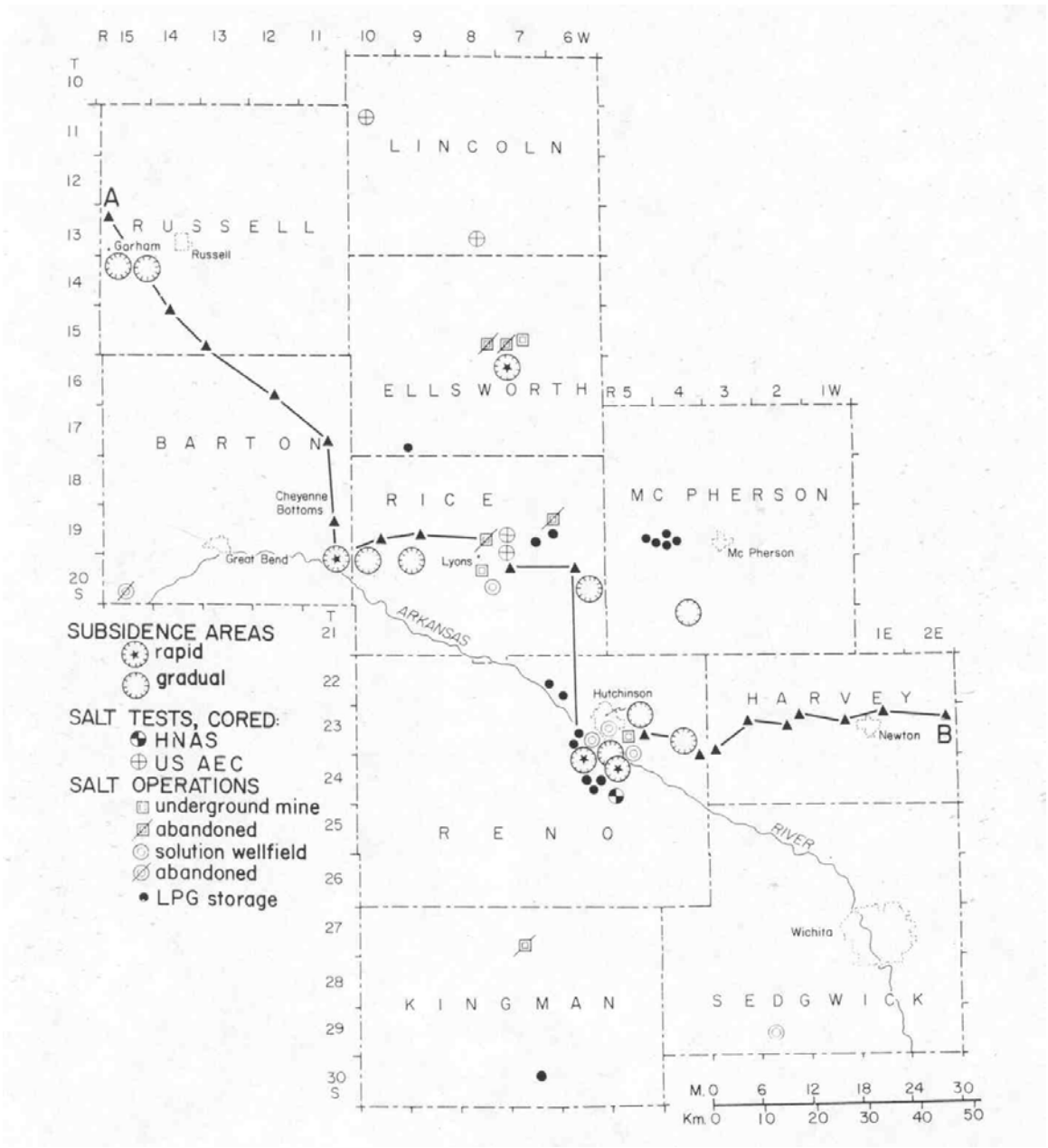


Figure 2: Index Map, Indicates location of cross-section, Abbreviations: Hutchinson Navel Air Station (HNAS); U.S. Atomic Energy Commission (AEC); Liquefied Petroleum Gas (LPG) (Walters, 1978).

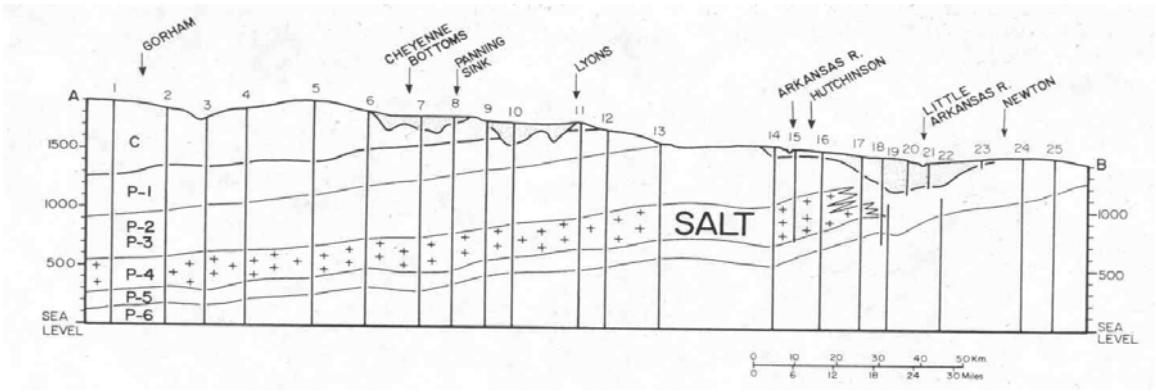
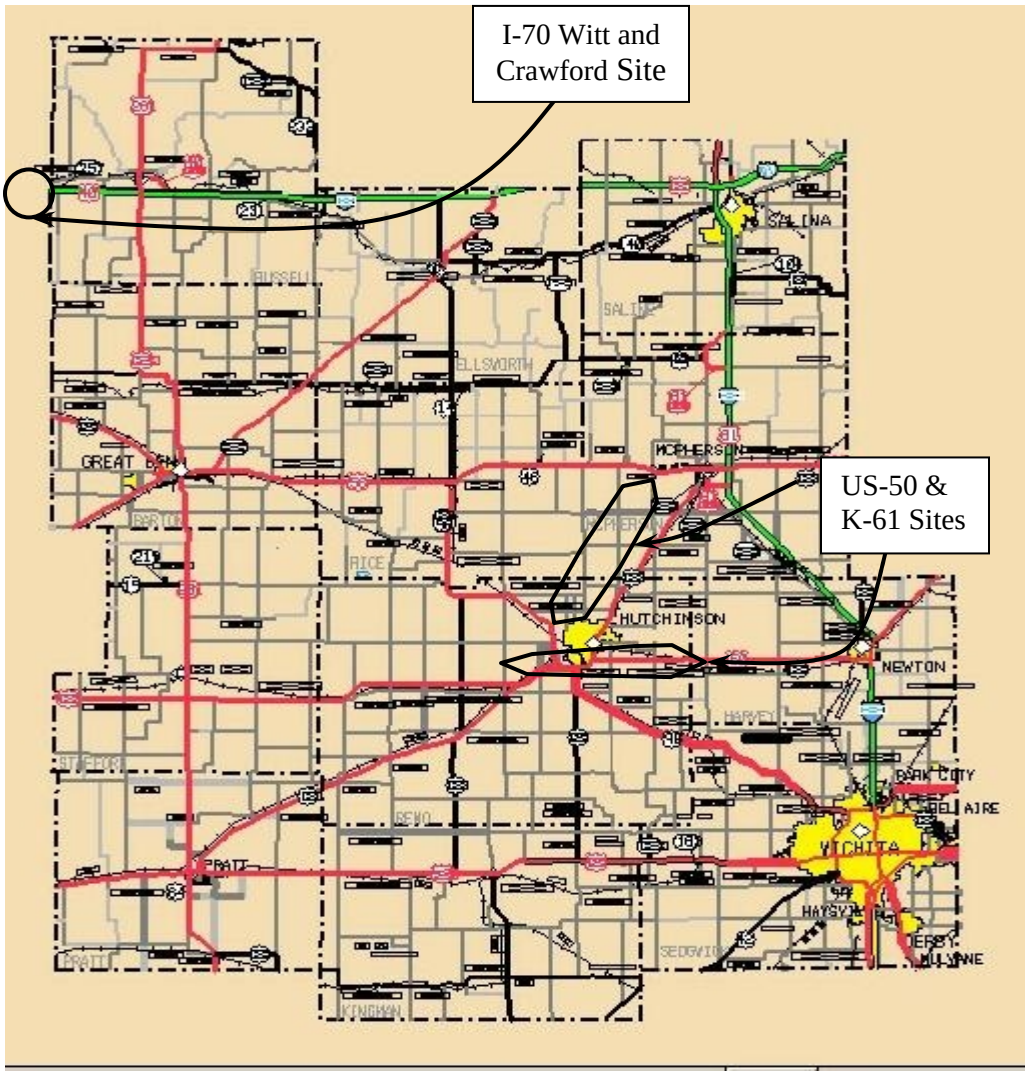


Figure 3: Cross-Section A-B Length of Section is 150 miles.
Note: Dissolution Front between Hutchinson and Newton (Walters, 1978).



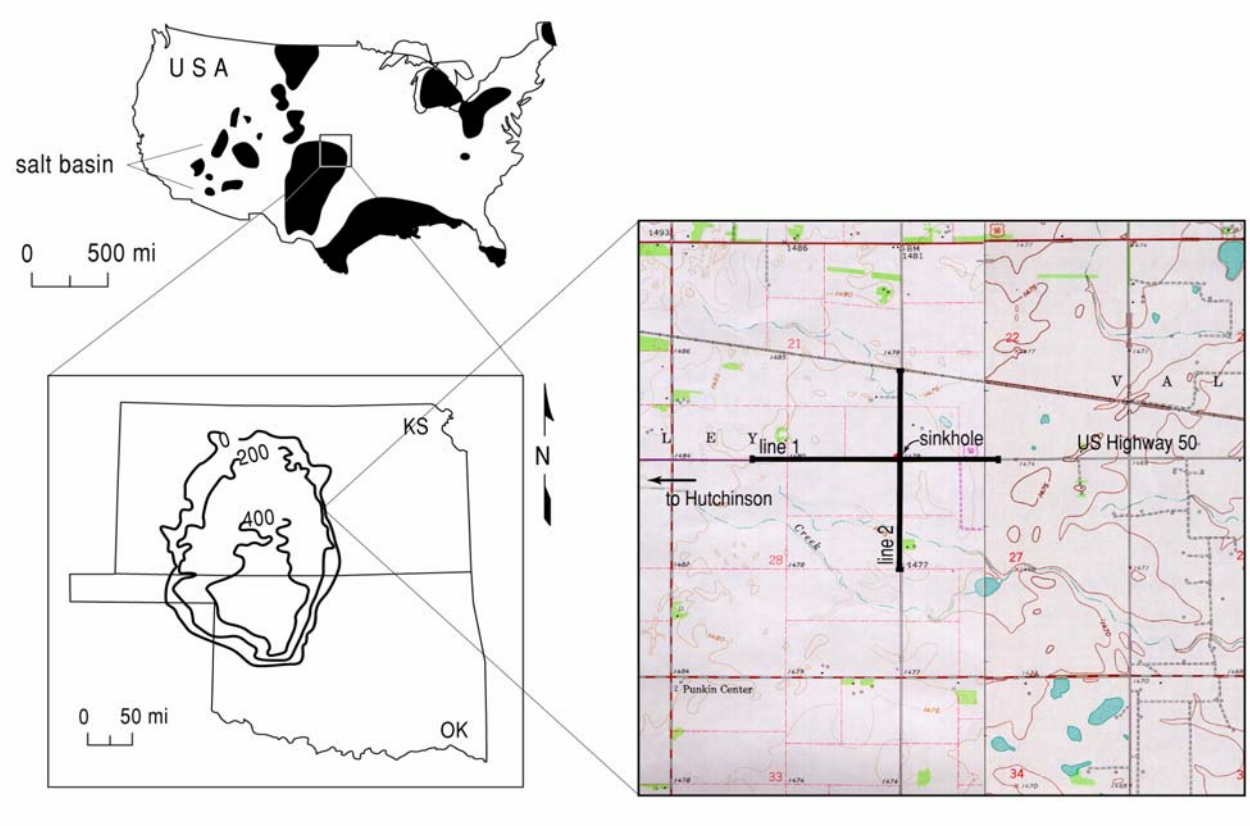


Figure 4: Salt Basins across the USA, Salt Isopach Map across Kansas, Oklahoma and Texas, and US-50-Victory Road Project area (Miller, KGS, 2002).

US-50 Hutchinson Bypass

US-50 is routed along the south city limits of Hutchinson. The proposed project is to upgrade the existing 2-lane roadway to a 4-lane roadway with improved interchanges. The new roadway will be constructed on a new alignment adjacent to the existing.

This area of Hutchinson is subject to three types of hazards associated with the salt beds. The area has been extensively room and pillar mined, dissolution mined and the salt is close enough to the surface to have natural occurring dissolution features. Several catastrophic collapses have occurred in the area. The first was recorded in 1914 approximately ½ mile to the north of US-50.

This past July, a high resolution reflection seismic survey was run along 5 miles along US-50. The data from this survey has not been interpreted in its entirety; however several areas of possible collapsed features have been noted in the preliminary review. One area of particular concern is in the center of a proposed “Diamond Interchange”.

Once the final interpretation of geophysical and geologic data is complete, it will be used to determine the collapse potential, remediation efforts and if relocation of the proposed alignment is required.

US-61 from Hutchinson to McPherson

This project is in the Preliminary Engineering Phase. The scope of the project is set with a new 4-lane alignment to the west of the existing two lane roadway. The new roadway begins at 17th street in Hutchinson and travels approximately 26 miles northeast to the south city limits of McPherson.

The proposed roadway will cross several miles of underground salt mines, and numerous oil fields. The salt dissolution front will also be traversed just to the north of the town of Inman. The dissolution front is known to be in excess of 1 mile wide (RERENCE??). Given the angle of intersection of the

highway and the salt dissolution front, up to three miles of paleo-sinkholes and collapsed areas will be encountered on this project. Numerous collapses have occurred (Big Sink etc.) near the project alignment. There is also an elevated risk of catastrophic collapses related to improper plugging of oil wells in the area. Data acquisition will commence in the spring of 2004.

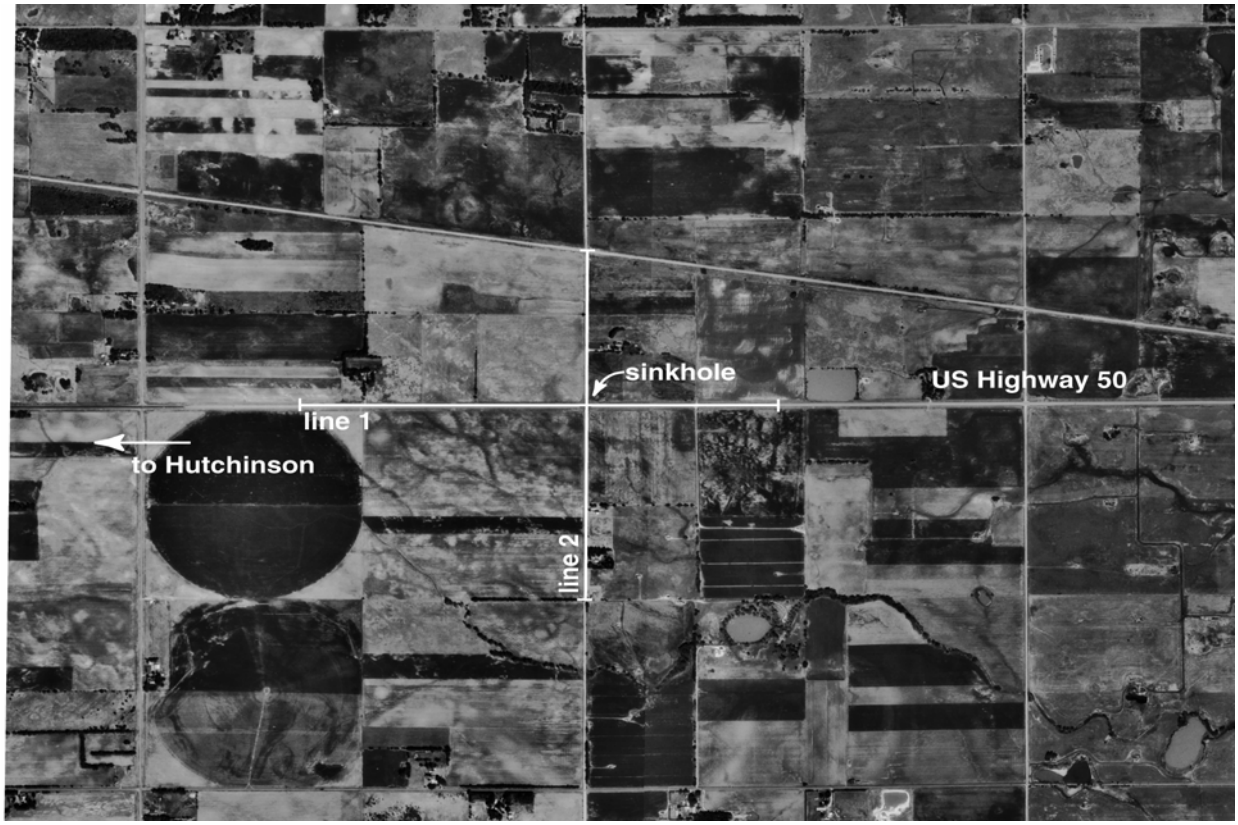


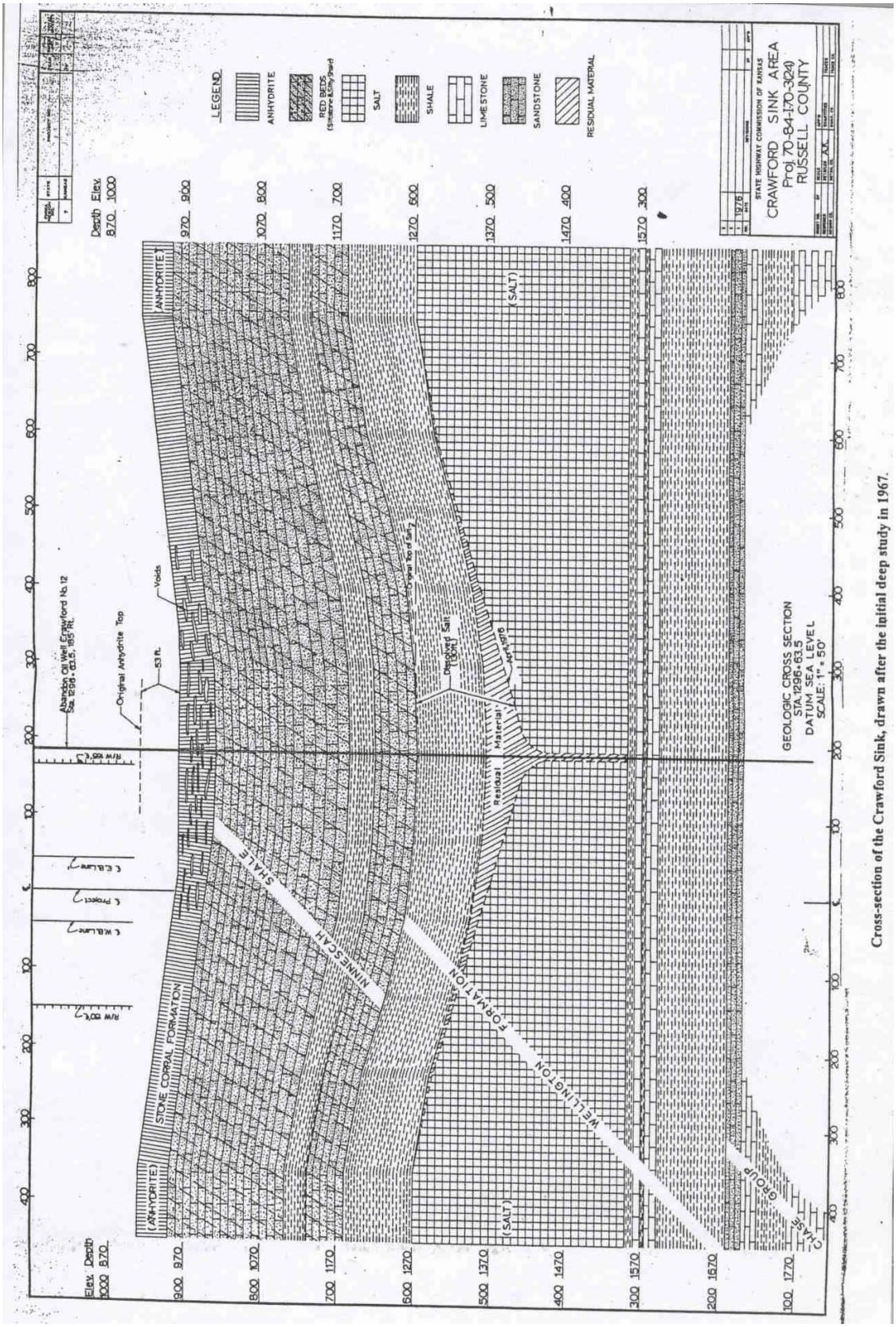
Figure 5: US-50 and Victory Road aerial photo (Miller, KGS, 2002).

I-70 Sinkholes

Along I-70 near Russell Kansas, the roadway crosses two sinkholes. These sinkholes have been actively settling the driving lanes. The ground surface is settling at a rate of over five inches per year with a cumulative total in excess of twenty feet. These sinkholes are the product of improperly plugged oil wells. The salt layer is approximately 1300 feet deep at this location. At least 3 wells are known to contribute to the leaching of the salt layers. These wells have been severed due to the shifting bedrock and proper plugging is now impossible.

Due to sight distance problems through the sinkholes, the grade line must be restored. The new project includes a Reinforced Concrete Box to allow drainage, widening of the fill area and new guard fence.

In 1978 a seismic line was shot across the sinkholes. It was discovered that several of the bedrock units had subsided over 36 feet from their original positions. A High Resolution Seismic Line will be conducted across the I-70 sinkholes this fall. A comparison of the two seismic lines will allow KDOT geologists to review the potential for catastrophic collapse and the amount salt remaining beneath the sinkholes.



Cross-section of the Crawford Sink, drawn after the initial deep study in 1967.

Figure 6: Geologic Profile of the Witt and Crawford Sinks (Croxton, 2002).

Investigation Procedures

The Kansas Geological Survey uses high-resolution seismic reflection for the KDOT subsidence investigations. Seismic signals are induced by a vibration truck that delivers three 10-second sweeps that cover the 25 to 250 Hz range. Four 60-channel seismographs are networked to simultaneously record 240 channels of input. Geophones are spaced every 8 feet; two geophones are used at each location for redundancy and signal strength. The vibration truck conducts sweeps along the geophone line at 16-foot intervals, making this a time-consuming process. With this setup, the geophysicists can interpret seismic reflections from beds 1000 feet below the surface.

Background noise is always a chief concern when conducting seismic surveys, and the KDOT projects offer a special challenge. In addition to the usual difficulties with noise from power lines, livestock near the geophones, first arrival waves, and so forth, the highway surveys must be performed adjacent to traffic. Most of this traffic is heavy; over 5000 vehicles use US 50 through Hutchinson on an average day, for instance. To reduce the effects of this background noise, traffic control must be used. The speed limit is lowered as with a construction zone, and flaggers are on hand to help slow traffic. Pilot cars can shuttle vehicles through the investigation area at low speeds. Where pilot cars are not practical, such as on interstate highways, data collection can be done in the early hours of the morning, when traffic is lightest.

Figure 6: Acquisition Equipment (Miller, KGS, 2002).

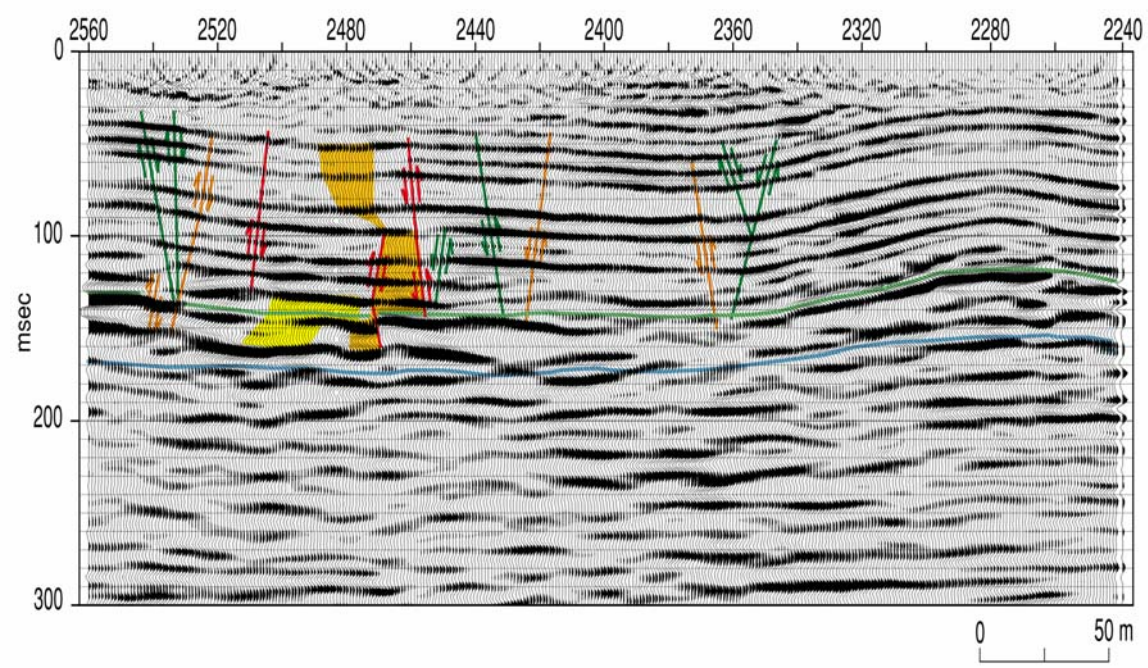


Figure 7: US-50 and Victory Road, East to West (Miller, KGS 2002).

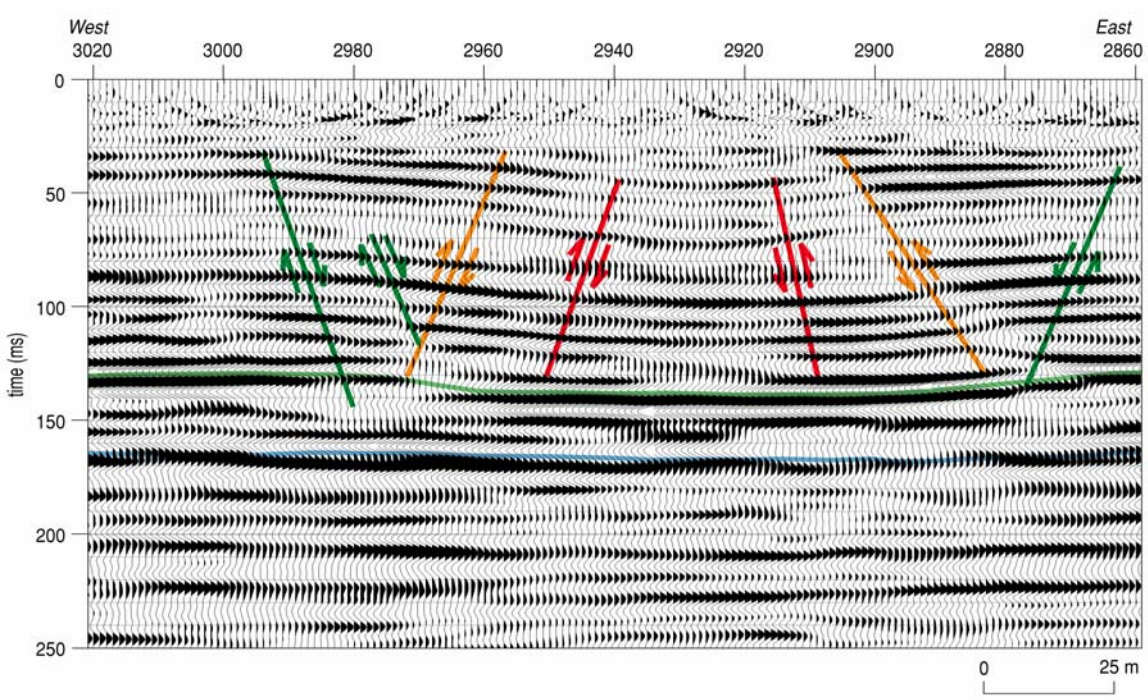


Figure 8: Paleo-Sinkhole with no surface indication (Miller, KGS 2002).

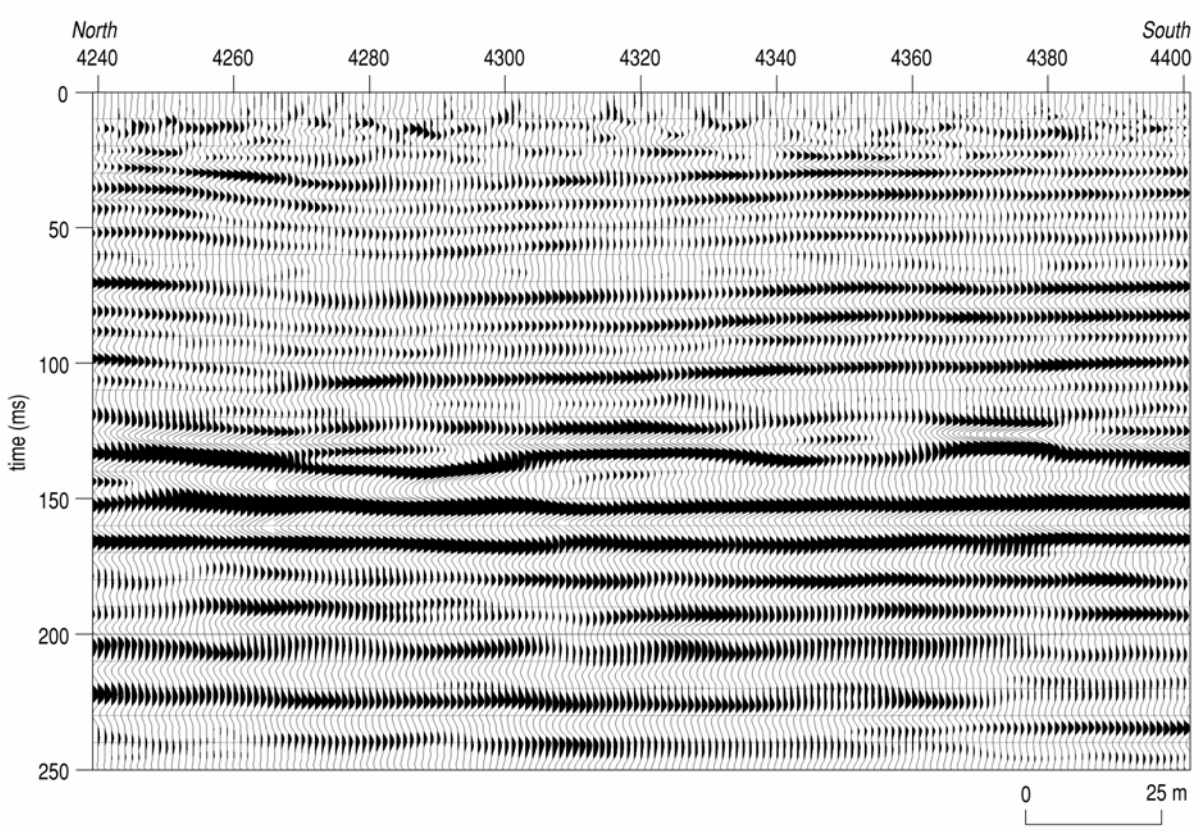


Figure 9: Undulations in Top of Salt Layer, Miller (KGS, 2002).

Conclusions

The Kansas Department of Transportation has several proposed projects that cross the Hutchinson Salt Dissolution Front as well as Underground Salt Mine Operations. Due to the excessive depth to the salt layer, normal Geotech Investigative Procedures are not cost-effective.

An economical alternative to drilling is required to investigate over 20 miles of roadway. The Kansas Geologic Survey in a cooperative effort with the Kansas Department of Transportation has or will conduct a High Resolution Seismic Survey on a total of four projects. The data and information collected will be used to select alignment alternatives, highlight areas of future maintenance concerns and/or catastrophic collapse potential.

The projects completed have shown no areas of catastrophic collapse but indicated several areas of increased maintenance activity and areas of future potential settlement of the roadway.

The use of High Resolution Seismic Surveys and other geophysical techniques will continue in areas of salt dissolution as well as other locations that are not conducive to drilling or other conventional geotechnical investigative procedures.

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