Geoforensic analysis of high-resolution seismic reflection data to unravel the complex past of natural salt dissolution features in the upper 250 m

Brett E. Judy*, Richard D. Miller, Kansas Geological Survey

Summary

High-resolution seismic reflection data successfully imaged active and paleo-subsidence events associated with the natural dissolution front along the eastern margin of the Hutchinson Salt in central Kansas. Since late Tertiary, undersaturated groundwater has had access to the eastern edge of the Hutchinson Salt resulting in sporadic harvesting of the salt and a westward migration of its eastern front. Subsidence features resulting from leaching were imaged and interpreted as representative of the processes and mechanisms associated with dissolution. These data clearly support the working theory that leaching generally initiates at the top of the salt and then spreads horizontally along the upper sections of the salt. Dissolution been active both prior to Quaternary alluvium deposition and contemporaneously, indicating migration of voids resulting from solution removal of salt likely began during the late Tertiary. Also, “reactivation” of leaching or intermittent periods of active leaching is evident in paleo-subsidence features and possibly in currently active subsidence events (Miller, 2002).

Introduction

Sinkholes and subsidence events pose threats to transportation, infrastructure, property and human safety. Subsidence features can form through natural processes such as groundwater infiltration or the result of anthropogenic activity. Along the eastern margin of the Hutchinson Salt Member in south-central Kansas, dissolution events have been primarily characterized by naturally occurring processes. In an effort to better understand and possibly predict the dynamics of the dissolution front and the resulting subsidence features, the Kansas Geological Survey acquired high-resolution seismic data along a 20 km stretch of US Highway 50 approaching the natural dissolution front from the west (Fig. 1). The dissolution front is the most active region of natural dissolution within the Hutchinson Salt, where salt bed thickness decreases from 75 m to zero over less than 20 km (Walters, 1978). These high resolution seismic reflection data were processed and interpreted to identify active and paleo dissolution events for the purpose of gaining a better understanding of the formation and growth processes associated with the natural-salt dissolution front. This can lead to mitigation of the risks associated with active leaching and prediction of ground movement.

Geologic Setting

The Permian Hutchinson Salt is a laterally extensive rock unit within south-central Kansas covering 69,930 square km (Walters, 1978). The Hutchinson Salt is interbedded with laterally scarce insoluble beds composed of shale, anhydrite and dolomite with halite beds ranging from 0.15 to 3 m thick (Lambrecht, 2006). The Hutchinson Salt Member is part of the Sumner Group which is composed of the Wellington and Ninnescah Shale Formations along the eastern boundary of the Hutchinson Salt. Overlying the Hutchinson Salt is the Ninnescah Shale (top at approximately 30 meters deep) and the Upper Wellington (top at approximately 60 m deep) which are composed of thick shale, dolomite and anhydrite (Lambrecht, 2006). The Lower Wellington (top at approximately 190 m deep) underlying the Hutchinson Salt is composed of gray shale and anhydrite. The remaining 30 m above the Ninnescah Shale is mainly composed of unconsolidated Pliocene-Pleistocene Equus beds (Miller, 2007).

Preservation of this evaporite has occurred for over 250 million years which can be attributed to two main factors. First, the depositional environment resulted in shale being deposited beneath it and above it. These shale beds act as aquitards preventing groundwater flow into the Hutchinson Salt. Second, it has been situated in a relatively mild tectonic setting resulting in little faulting and fracturing within the formation, preserving the continuity of the confining shale beds.

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Seismic imaging of a salt dissolution front

The Hutchinson Salt is a west dipping unit with the shallowest subsurface depth along the eastern margin. The original dissolution front was located approximately 30 km east of its current extent. During the Cenozoic, south-central Kansas experienced approximately 175 m of surface erosion (Miller, 2007). The westward migration of the eastern margin began during the Late Tertiary is the result of increased access of unsaturated ground water along this shallow boundary (currently at 125 m) (Miller, 2007). The relatively flat topography along the paleo-dissolution front is the result of deposition of the Quaternary Equus beds. These Quaternary beds were deposited in conjunction with the resulting synform and depressed features created by the removal of the Hutchinson Salt. The deposition of the Quaternary beds along the dissolution front can help determine the ages of subsidence events.

Acquisition

Initial data acquisition was done to determine the potential impact of ground subsidence on US Highway 50. In 2003 an 8 km line of seismic reflection data were collected starting just south of Hutchinson Kansas. The data of focus was a continuation of this line which was collected along the south side of US Highway 50 east of Hutchinson, Kansas in June 2008. This line is 12 km and collected along the south side of US Highway 50. The data were collected using a 240-channel rolling fixed spread with 2.5 m receiver station spacing and two 40 Hz geophones with 14 cm spikes planted at each station in the south road ditch. The source station spacing was 5 m using an IVI Minivib 1 vibroseis source. Three 10 second 25-300 Hz up-sweeps were recorded at each location located along the road shoulder of US 50.

Seismic data were acquired with four, networked 60-channel Geometrics Strata View seismographs resulting in 240 recorded channels per shot gather. All shot records were stored un-correlated for potential improvement through precorrelation processing.

Processing

All processing was done using Winseis and SeisUtilities, processing software developed internally at the Kansas Geological Survey. A basic processing flow was used (Fig. 2).

A major focus throughout processing was preservation of the frequency bandwidth as well as noise reduction. Noise reduction was particularly important due to data collection along the heavily travelled US 50. Noise reduction processing focused on removal of cultural noise through trace editing and notch filters, removal of surface waves, air-coupled waves and first arrivals with surgical and top mutes. Spectral improvement/preservation involved precorrelation whitening, spectral balancing and NMO stretch mute analysis.
Analysis/Interpretation

Interpretation of shallow seismic data revolves around the shot gathers. Reflecting wavelets through the target window of 50 – 210 ms possess good trace to trace coherency and broad frequency bandwidths allowing accurate trace to trace reflection correlations. The reflecting events could not be identified through the noise cone which includes air coupled wave and Rayleigh wave wedge. After analysis of the shot records, it was determined the first sweep record at each source station had a significantly lower S/N ratio. This initial sweep was not included in the processing flow.

Due to the long offsets within the survey, careful analysis of CMP and shot gathers was necessary prior to and after NMO corrections. A thorough velocity function was created with emphasis on the target window to optimize the coherency and frequency content along the reflections.

The CDP stacked sections have interpretable reflectors along the Ninnescah Shale, Upper and Lower Wellington and the Hutchinson Salt Formations. A strong reflector near the base of the salt, likely anhydrite, can be correlated through most of the seismic line. The vertical bed resolution is roughly 5-10 meters depending on the specific interval. These reflectors have been identified from previous research using log correlated sections from the same seismic line (Rice, 2009). Multiple subsidence features have been identified, one of which is illustrated below (Fig. 3).

A paleo-subsidence feature that was active during the early Quaternary is displayed in Figure 3. Several Quaternary bed deposits are visible over this feature. The base of the unconsolidated sediments sags with the synform feature indicating deposition prior to failure. A draping Quaternary bed from the west suggest two periods of activity within the Quaternary with a final bed deposit that laterally thickens over the synform. Steeply dipping beds in the overlying shale along the east of this synform indicate the region of highest salt removal. Intra salt reflectors within the region of the leached salt are not present likely due to collapse into the voids left by the removed salt. Moving up from the removed salt interval, there is lateral expansion of the collapse feature with shallow dipping beds extending approximately 250 meters to the west. Highly undulated intra bedded reflectors are visible to the east of the removed salt. These are likely the result of creep.

Analysis and interpretation of the structure and geometry of the salt is currently ongoing. Figure 4 displays severe distortions and undulations within a thick section of salt. The distortions are present without any subsidence or indication of failure within the overlying shale units.

Conclusions

Severely distorted salt geometries along the upper section of the salt indicate a variety of potential processes. Glide creep from large differential pressures such as that indicated in figure 3 and 4 are likely due to the associated voids directly to the west. However, figure 4 displays distorted beds deep within the salt with no associated subsidence features. This is likely indicating larger scale salt tectonics or possibly a result of depositional and erosional processes prior to the deposit of the overlying shales. This would be contrary to the current interpretation that the overlying shales were deposited on a relatively uniform and undisturbed salt layer.

Interpretation of the subsidence events indicate leaching occurring in the uppermost section of the salt progressing laterally and downward.
Figure 3: This subsidence event was active during the Quaternary which is indicated by the sag within the overlying unconsolidated sediments. Continued removal of the upper section of the salt interval to the west resulted in shallower dipping beds along the western extent of the feature. Yellow box indicates possible glide creep associated with the dissolution feature to the west. Blue indicates Ninnescah Shale, red indicates Upper Wellington, yellow indicates Hutchinson Salt and green indicates Lower Wellington.

Figure 4: Severe distortions and undulations within a thick section of salt (red). The distortions are present without any subsidence or indication of failure within the overlying shale units. Yellow box indicates possible glide creep associated with the dissolution feature to the west.
EDITED REFERENCES
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REFERENCES


