Delineation of salt dissolution sinkholes using minimal deployment shallow 3-D seismic reflection surveying

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SUMMARY

The advantages of 3-D seismic imaging are well founded for petroleum applications. Significant potential exists for this technique in delineating targets critical to shallow site characterization. The high cost and high technology nature as well as many assumptions appropriate for deeper petroleum problems are not realistic or feasible for near surface applications. A low fold, minimal cost 3-D survey designed around common offset and shallow seismic reflection techniques at a salt dissolution sinkhole in central Kansas provided valuable insight into the effectiveness and potential of minimal deployment 3-D surveys to delineate major structural features. Volumetric display enhanced the interpretability of this low cost but effective 3-D survey.

INTRODUCTION

Salt dissolution sinkholes are a common hazard in areas of petroleum disposal wells and solution mining in southcentral Kansas (Walters, 1977). The structural framework of these sinkholes is often complex and can rarely be understood from their surface expression. Hazards during the plugging of leaking wells and selection of appropriate grout horizons in problematic disposal wells are aspects of the remediation process where quick and cost effective images of the subsurface are important and feasible with seismic reflection techniques.

Two-dimensional seismic reflection surveys throughout Kansas have imaged the subsurface expression of sinkholes with some success (Miller et al., 1985; Knapp et al.,1989; Miller et al.,1996). Nevertheless, the irregular nature of the dissolution cavities impedes examination of 3-D structures with the 2-D lines alone. Control on fault orientation, structural relationships and differential growth predictions are a few of the problems not accounted for in previous studies.

Recent attempts have been made to apply 3-D petroleum techniques to near surface investigations (House et al., 1996; Siahkoohi and West, 1996; Lanz et al., 1995). The high cost of this technology makes it economically unfeasible for many shallow targets. Furthermore, complete evaluation of the method as it relates to near surface targets has been proposed to reduce and hopefully eliminate misuse and/or overselling of the technique for shallow applications.

This study evaluates a survey designed to investigate a sinkhole using common tools available for most near surface seismic reflection investigations, with a focus on particular issues:

- minimized cost
- minimized data with minimal detriment to image
- quick appraisal of structure
- use of lowcost 2-D software
- extrapolate between 2-D lines

The result is a low fold 3-D survey acquired using a fixed patch, sorted into 3-D CMPs and processed using 2-D algorithms.

DISCUSSION

Geology and previous seismic work:

The French sinkhole in southcentral Kansas is the focus of this study. The French Sink was formed in the vicinity of a disposal well which inadvertantly placed unsaturated brines in contact with evaporite sequences of the Hutchinson Salt Member of the Permian Wellington Formation. Dissolution of the salt beds caused the flexure and failure of the overlaying rocks, resulting in surface subsidence.

Several 2-D seismic surveys have been successful imaging the subsurface around sinkholes formed by dissolution of the Hutchinson Salt throughout Kansas. A recent survey conducted by the Kansas Geological Survey at the French Sink (Miller et al., 1996) produced images of the shallow subsurface with higher resolution and signal-to-noise than any of the previous investigations. In most studies, the most prominent reflections come from anhydrite layers within the salt sequence, and from the Stone Corral Formation above the salt. At the French site, the Stone Corral reflection can be observed at 240ms (240m) and reflections from the top of the salt identifiable at 310ms (400m). The high signal-to-noise ratio and potential resolution of 2-D CDP stacks from the French Sink reveals a conjugate set of normal and reverse faults centered on the disposal well.

Data acquisition :

The Stone Corral Formation is a seismic marker bed the survey was designed to target. Expanding the imaged depth window to include layers less than 60m deep and as deep as 600m was possible through careful parameter design and on-site testing. A fixed spread of 96 receivers was laid out in a square around the water filled sinkhole with 5 m spacing between stations. Shot locations were along the sides of two squares stepping out symmetrically 50 and then 100m from the square receiver spread (fig 1). The source was an IVI Minivib programmed to deliver three individually recorded up-sweeps from 30 to 300Hz. The pilot was real time telemetried to the seismograph with each of the three sweeps recorded individually on the seismograph with their pilot, correlated and vertically stacked.

Data were recorded on two 48-channel,24-bit Geometric Strata View seismographs networked for simultaneous 96-channel recording. Shot gathers were stored correlated in SEG2 format. Three 40Hz L28E Mark Products geophones were grouped in a lft circle. The simple design of this survey was intended to evaluate the effects of reducing the number of shot locations allowing data to be acquired in half a day. Crop land use in the southern portion of the study area prevented access to a few shot locations causing a slightly irregular fold distribution (fig 2).

Processing:
The basic processing flow was consistent with routine 2-D shallow reflection methodologies. Data were sorted into and processed as fifteen 2-D lines with source and receiver locations along each CMP line spatially distributed around the entire patch. This source receiver geometry resulted in low fold and irregular distribution of CMP locations which required resorting to an optimal bin size of 2.5m by 15m (fig 2). This rectangular binning preserved the integrity of the spatial resolution while increasing the CMP fold and velocity analysis control. The data were analyzed and moved out using two dimensional routines iterating between N-S and E-W directions until stack response was satisfactory.

RESULTS

This 3-D data set contains reasonable signal-to-noise ratio despite its low fold content (fig 3). The final stack sections are interpreted to possess structural features consistent with the 2-D lines. The Stone Corral reflection can be traced throughout the data volume exhibiting signs of both flexure and fault disturbance (fig 4). The lack of reflections at depths shallower than the Stone Corral event did not allow for confirmation of normal and reverse fault styles previously suggested on 2-D sections. This loss of coherent energy at shallow depths can be attributed to insufficient close offsets and reduced signal-to-noise ratio (likely due to fold) in comparison to the 2-D data. Fault deformation is also supported by diffractions produced at the edge of faulted Stone Corral blocks. A maximum vertical drop of about 20ms is interpreted at the center of the sink. Such diffractions are only present at lines sorted along the N-S direction, suggesting a preferential E-W direction of faulting. It is most likely these Fresnel zone-related diffractions were not observed in any of the 2-D lines since CDP locations were outside the area of maximum vertical displacement. Remarkable arrival patterns in response to bed termination and layers smaller than the radius of the first Fresnel zone are interpreted on some sections.

CMPs sparsely sampled the subsurface of a 220m by 220m patch centered on the sinkhole. Asymmetry in their distribution was caused by absence of shot points in the southeastern comer of the study area. The inability to shoot over the water filled sinkhole resulted in poor imaging of the center of the structure. Spatial sampling was satisfactory in light of the few number of shot points and recording channels.

The 2-D processing in both N-S and E-W directions helped define lateral variations in stacking velocity. 3-D volume display of the data assisted considerably in the interpretation of major structural features.

CONCLUSION

This study resulted in a low fold 3-D profile with reasonable stacking response. Consistency between interpretations of the 2-D and 3-D stacks is encouraging. The tradeoff between data redundancy and spatial sampling in the 3-D survey did not seem to significantly compromise the quality of the stacked sections. The lower signal-to-noise ratio of the 3-D profile allowed confirmation of only major structures observed in the 2-D lines. The greater spatial distribution of this survey assisted extrapolation of 2-D interpretations. Low cost and short turnaround were definite advantages. This survey minimized many of the more expensive and in some cases advantagious aspects of 3-D surveying to represent a good low-fold, low cost compromise. Plans are underway to double the number of shots and increase the layout to include 4 unique patches in hopes to evalution improvements and eventually determining optimum 3-D program for the objectives of this project.

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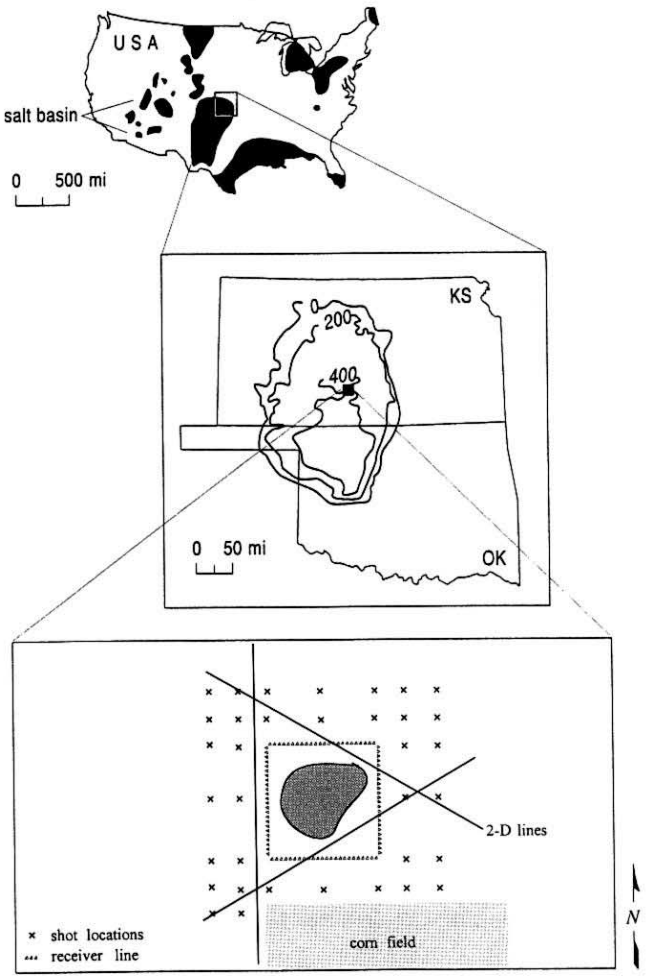

Fig 1. Site map showing relative locationsof (a) major salt basins in the United States (Ege, 1984) with (b) a generalized isopach map of the Hutchinson Salt Member in Kansas and Oklahoma (Walters, 1977), and (c) the relative location of the seismic reflections to the sinkhole.

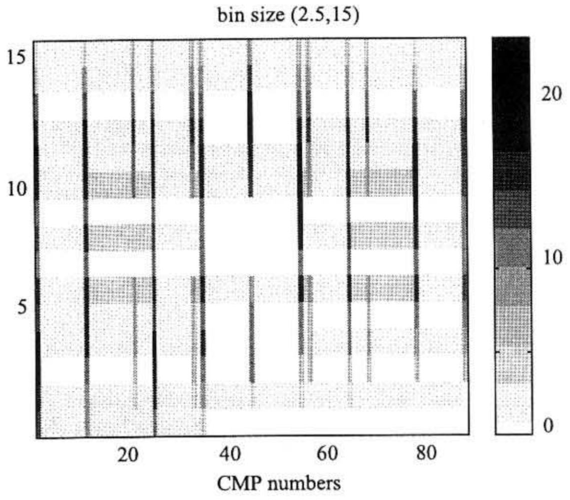

Fig2. Foldmap showing optimal bin size of 2.5m by 12m.

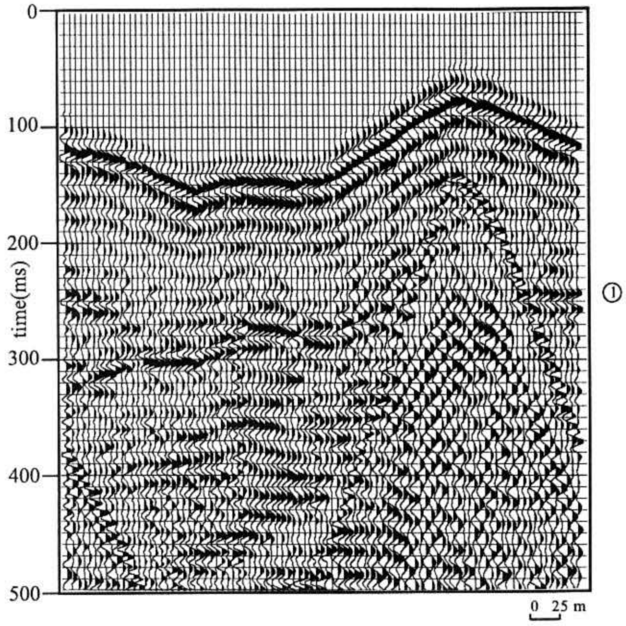

Fig 3. Filtered shot gather with Stone Corral anhydrite identified ① .

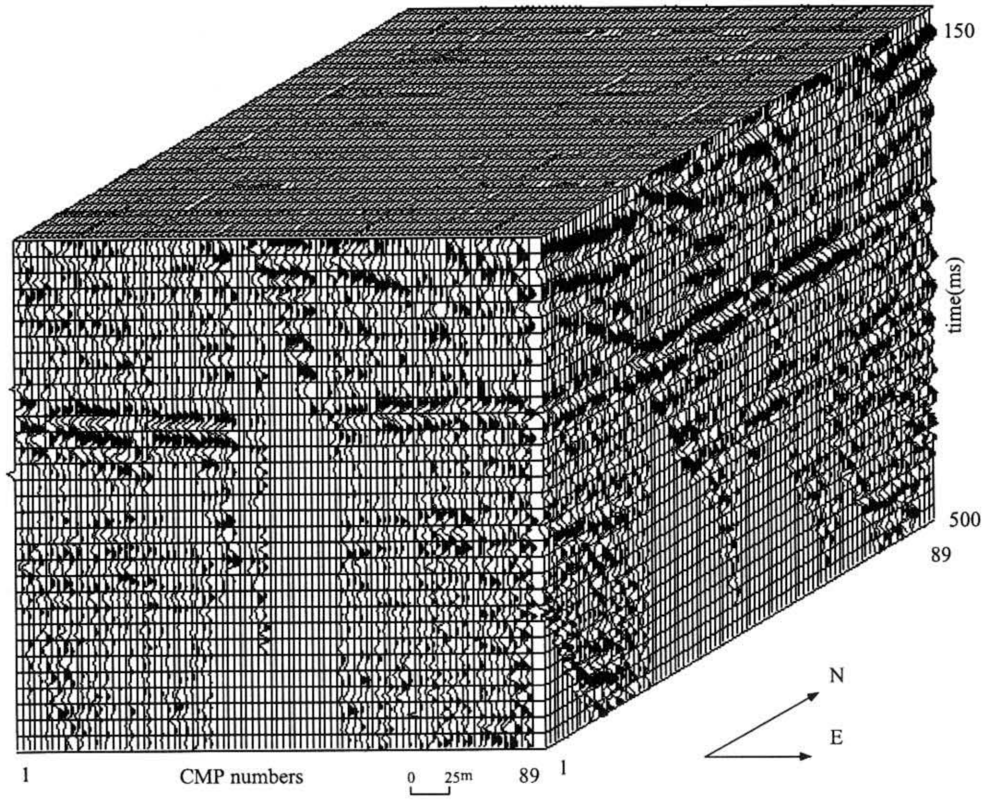

Fig4. Volumetric representation of CMP stack data.