Seismic detection of shallow natural gas beneath Hutchinson, Kansas

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Summary

A high-resolution seismic reflection survey was conducted in order to identify shallow natural gas that had leaked from a gas storage facility near Hutchinson, Kansas. Gas presence produced both bright spots and dim spots on the seismic reflection profiles. Core and well log data from wells drilled to vent the gas indicate that the gas-bearing interval corresponds to thin dolomite layers, which have higher P-wave velocities than the surrounding shales. Gas within fractures in these dolomites appears to reduce the velocity of the dolomite interval down to or below that of the shales. Depending upon the magnitude of the gas effect, a dim out or bright spot is produced. As gas dissipates from a given location, the associated seismic anomaly is reduced.

Introduction

On January 17-18, 2001, a series of natural gas explosions and geysers occurred in the city of Hutchinson, Kansas, killing two people, destroying several buildings, and causing the evacuation of dozens of businesses and several hundred households. The source of this gas appears to have been a leak at the Yaggy gas storage field, 7 miles northwest of the city (Figure 1), which occurred two days prior to the explosions at Hutchinson. A casing failure in one of the gas storage wells at Yaggy allowed high-pressure gas to leak out of an underground storage cavern. After the initial high-pressure gas release around the storage site, the gas apparently traveled up-dip toward Hutchinson along previously unknown conduits.

A series of wells, based on 160-acre spacing, were drilled in and around Hutchinson to find and vent remaining underground gas to the surface. Of the first 36 vent wells drilled, only 8 found gas. It became apparent that additional information would be needed in order to more efficiently identify locations of gas.

In February 2001, the Kansas Geological Survey conducted a high-resolution seismic reflection survey in order to detect seismic anomalies, which might indicate the

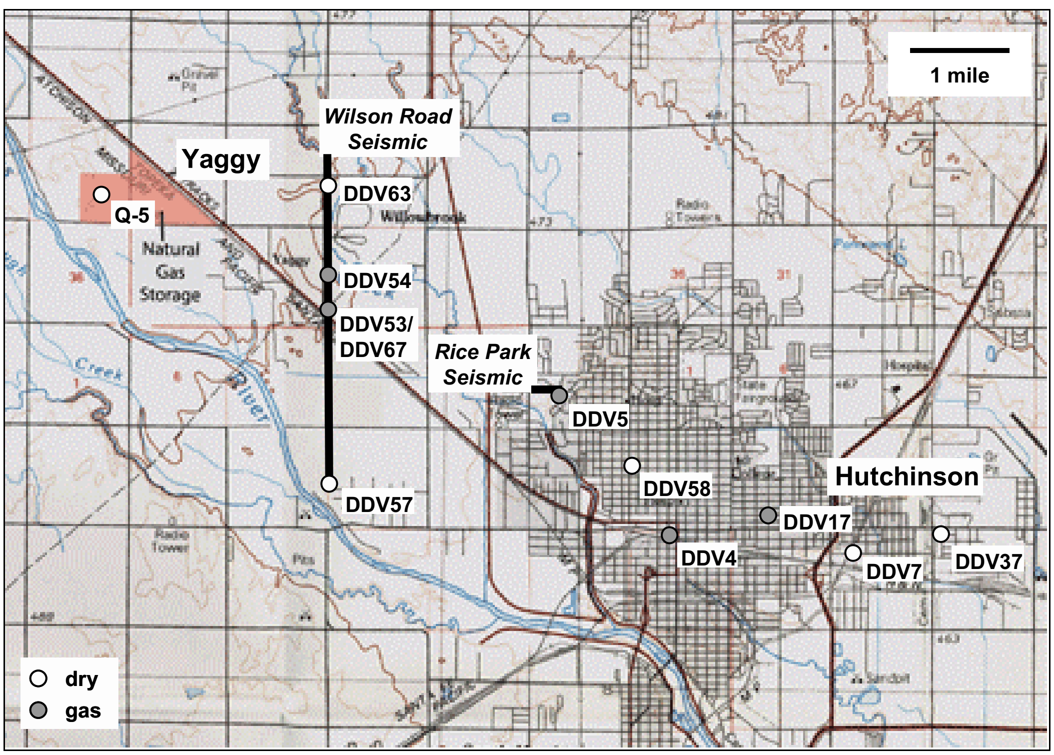

Figure 1. Map of Hutchinson showing locations of Yaggy gas storage field, seismic lines, and selected vent wells.

presence of gas and identify potential gas pathways from Yaggy to Hutchinson. Previous high-resolution seismic surveys by the Kansas Geological Survey have successfully identified amplitude anomalies associated with gas-bearing sandstones (e.g., Miller et al., 2000).

Acquisition, Processing, and Analysis of Seismic Data

A 1/3 mile long, east-west seismic line was located in Rice Park, on the west side of Hutchinson, and a 3-1/2 mile long, north-south seismic line was located on Wilson Road, between Hutchinson and Yaggy (Figure 1). The Rice Park line was located near one of the early vent wells which had found gas (DDV5).

High-resolution reflection data were acquired by a minivib (vibroseis) and vertical component geophones. An IVI minivib controlled by a linear up-sweep (5 s) from 30 to 300 Hz was deployed as a seismic source. Three Mark Products L28E 40 Hz geophones in series were planted in 1.5 m arrays every 2.5 m along the line. Data were recorded on four 60-channel, R60 Geometrics StrataView seismographs networked for simultaneous 240-channel recording. A 6-second record with a sample interval of 0.5 ms was recorded. The source interval was 5 m. Three shots were recorded individually at each source station. Data were saved uncorrelated and unstacked to allow evaluation of precorrelation-processing techniques (Doll et al., 1996) and to permit sweep-specific editing to reduce noise prior to vertical stacking. A split-spread geometry was used in data acquisition to provide reasonable velocity control for deeper reflecting events.

The data processing flow was as follows:

1. Correlation:
   Raw data were correlated with the ground force recorded on the first channel of each record.
2. Trapezoidal bandpass filter (61-122-250-300 Hz)
3. Spherical divergence correction (50 dB/sec)
4. Editing: first arrival muting; dead trace killing; surgical muting
5. Velocity analysis
6. Residual static correction
7. Normal moveout (NMO) correction
8. Common depth point (CDP) stack

Seismic reflections on the CDP stacked data were tied to known rock formations using synthetic seismograms created with sonic and density logs from the Q-5 well in Yaggy. At the level of the proposed gas-bearing interval, the Rice Park line appeared to show a dim out corresponding to the gas at DDV5 (Figure 2). On the Wilson Road line, two amplitude anomalies, approximately

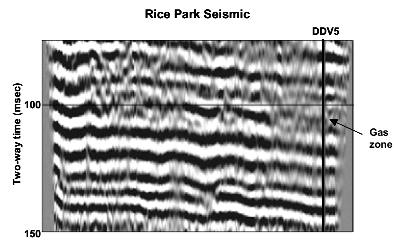

Figure 2. Rice Park seismic line, showing dim out in gas interval at DDV5.

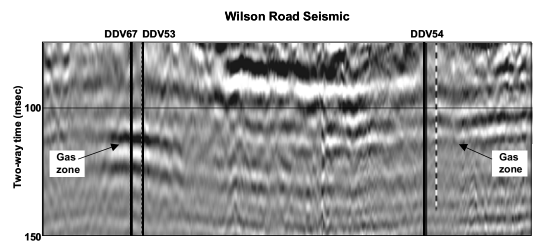

Figure 3. Portion of Wilson Road seismic line, showing bright spot at DDV53 and dim out at DDV54.

1/3 mile apart, were identified and drilled (Figure 3). One anomaly was a dim out (DDV54) and the other was a bright spot (DDV53). Gas was found at both locations.

This initial analysis of the seismic data indicated that, beneath Hutchinson, the physical properties of the gas-bearing zone and surrounding rock layers have significant lateral variation, so that, at locations separated by 1/3 mile or less, the presence of gas can produce different seismic anomalies. The nature of these lateral variations in physical properties was investigated using data from core and well logs.

Analysis of Core and Well Logs

Natural gamma ray and temperature logs were obtained in all of the vent wells.

In March 2001, core was acquired at two locations along the Wilson Road seismic line: DDV63 (dry hole) and DDV67 (gas). DDV67 was located approximately 75 ft from DDV53, which was actively venting a high volume of gas.

In the DDV67 core, several thin (less than 3 ft thick) dolomite layers occur at the depth of the gas-bearing interval. These dolomites can be correlated on gamma ray logs to other vent wells (dry holes, as well as those which have encountered gas), and have been labeled the "three-finger" dolomite. The gamma ray signature of the "three finger" dolomite indicates that this zone increases in shaliness to the north. The "three-finger" dolomite is observed in dry hole DDV63, but the core from this well shows that the interval is more shaly and gypsiferous in DDV63 than in gas well DDV67.

Dolomite is brittle, and prone to large fracture apertures and creation of new fractures upon contact with high-pressure gas. A northward increase in gypsum and shale, both less brittle than dolomite, would tend to inhibit migration of gas in this area. Moreover, locations of gas-producing vent wells between the Yaggy storage field and the city of Hutchinson correspond closely to the crest of a narrow, asymmetric, northwest-plunging anticline, suggesting that fracturing may have occurred preferentially along the crest of this anticline (Allison, 2001). Maps of shut-in pressure in gas wells calculated at the depth of the gas zone also indicate a correlation between higher gas pressures and crestal areas of the anticline (Bhattacharya and Watney, 2001).

Sonic and density logs were acquired in wells DDV57, DDV67, and DDV63 in March 2001. Sonic logs were acquired in wells DDV4, DDV5, DDV7, DDV17, DDV37, and DDV58 in October 2001, approximately nine months after the Hutchinson explosions. Although DDV4, DDV5, and DDV17 had originally encountered gas, none of these wells were actively venting gas at the time of logging.

In all of the sonic logs, the top dolomite of the "three finger" interval has a P-wave velocity that is significantly higher than the velocity of the surrounding shales. The lower dolomites of the interval are also faster than the surrounding shales in all wells except DDV67. The sonic log in DDV67 shows an anomalously low P-wave velocity within the lower two dolomites of the "three finger" interval (approximately 6000 ft/s, compared to a velocity of 8000 ft/s for the surrounding shale). This low velocity is most likely due to gas filling fractures in the dolomites. The resulting impedance contrast produces the bright spot seen at DDV53/ DDV67 on the Wilson Road seismic line. It is probable that the dim outs observed at DDV54 and DDV5 are produced when there is a slightly smaller gas effect, which generates velocities for the dolomite layers that are similar to the shale velocities.

Sonic logs for the six wells logged in late 2001 show a consistent character for the "three finger" interval, whether or not gas had been originally encountered in the wells. This suggests that when gas is no longer venting from a well, there is no observable difference in its seismic response as compared to a dry hole.

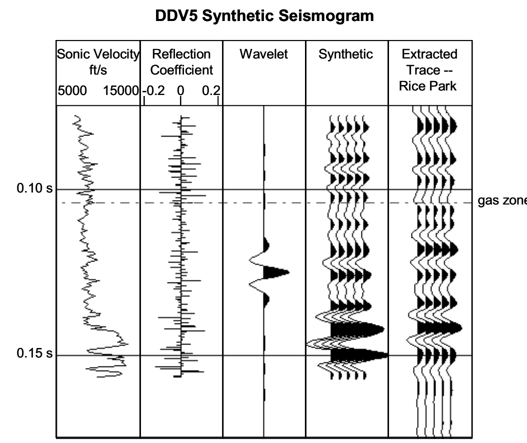

Figure 4. Synthetic seismogram created using the sonic log from DDV5 compared to CDP stacked traces from the Rice Park seismic line. The top of the gas zone is indicated.

A synthetic seismogram created from the DDV5 sonic log acquired in October 2001 has been compared to the Rice Park seismic data acquired in March 2001 (Figure 4). There is a reasonably good fit between the synthetic and the extracted trace except within the gas zone, where the polarity of the extracted trace appears to be reversed from the synthetic. This suggests that the anomaly on the Rice Park seismic line caused by gas may have disappeared as the gas has dissipated from this location.

Conclusions

Thin, fracture-prone dolomite layers appear to have served as a conduit for gas which leaked from Yaggy gas storage field to beneath the city of Hutchinson. Sonic logs show that the dolomites have P-wave velocities that are higher than the surrounding shales. When gas is contained within fractures in these dolomites, the velocity is reduced down to or below that of the shales, causing a dim out or polarity-reversed bright spot on the seismic data. Sonic logs acquired nine months following the Hutchinson explosions indicate that as the gas dissipates, these seismic effects begin to disappear.

References

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