FINAL REPORT

ANALYSIS OF SEISMIC REFLECTION DATA FROM THE HUNTON ANTICLINE

Funding Agency:	Oklahoma Water Resources Board
Project:	Development # 08S0733
Project period:	15 June2008 – 15 Sept 2008
Date of submission:	05 March 2009

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Abstract

Seismic reflections from boundaries within the Cambrian-Ordovician Arbuckle-Simpson aquifer correlate with boundaries seen in well logs and rock samples. Seismic surveys at different geologic scales within this karst aquifer display the same fault character regardless of the survey's target depth. Faults observed at intermediate depths in the Arbuckle-Simpson aquifer extend upward to the location of mapped fault traces, and such faults are seen clearly on ground penetrating radar and electrical resistivity imaging surveys. Some of these faults also extend downward cutting the basement, and, in one instance, form a graben at the aquifer/basement boundary. This suggests that mapped fault locations, confirmed by near-surface geophysics, may be a fingerprint of steeply dipping faults extending through the carbonate section into the basement.

Introduction

The Arbuckle-Simpson aquifer of south-central Oklahoma (Figure 1a) is a fractured-karst aquifer that is the source of water for approximately 39,000 people in the area surrounding the cities of Ada and Sulphur. It also provides water to the Chickasaw National Recreation Area. Recently, proposals have been made to supply water from the aquifer to more distant population centers. In order to evaluate the groundwater resources of the aquifer, a 5-year study by the Oklahoma Water Resources Board was initiated in 2003 (Osborn, 2003). The work presented in the present paper is a component of the geophysical surveys conducted in conjunction with this study.

Geologic setting of three seismic surveys

A SW-NE geologic cross-section through the aquifer (line D-D' on Figure 1a) shows a broad dome, the Hunton Anticline, in the center of the cross-section (Figure 1b), and complex folding and faulting at the southern and northern margins of the cross-section. We have analyzed data from three seismic surveys crossing the lower Ordovician Arbuckle and Timbered Hills Groups comprising the anticline. The geologic scale of these surveys ranges from the deep aquifer/basement contact (at a depth of approximately 3500 ft), through intermediate boundaries within the aquifer (at depths of 3500- 600 ft), and extends through the shallow epikarst to the ground surface. The image of the

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shallowest features seen in the seismic surveys was also supplemented by electrical resistivity imaging (ERI) and ground-penetrating radar (GPR) surveys. Three seismic surveys are considered in the present paper (Figure 2).

Anschutz Line OK 3-80: basement, deep aquifer

Description of Anschutz Line OK 3-80

Seismograph Service Corporation Party M conducted initial test recording for Line OK 3-80 on 21 Feb 80. Optimal recording parameters were determined by stacking 10, 20, or 30 sweeps from a group of three Pelton vertical vibrators. The chosen sweep parameters were 15 to 20 sweeps per VP, up-sweeps from 14 to 56 Hz, and a sweep length of 16 s. A 48-channel DFS IV Instantaneous Floating Point system recorded the data. Geophones were model GSC 20D having a natural frequency of 8 Hz and a 3 in spike. There were 6 geophones per string, and 4 strings spanned 220 ft. The symmetric split spread length at each station was 11,440 ft. The shot interval was 220 ft giving a nominal fold of 24.

Production recording began on 22 Feb 80 and continued through 28 Feb 80. The sample rate was 4 ms. Professional Geophysics Inc. performed initial processing in March 1980, and Western Geophysical reprocessed the data in 2006, and the latter result was interpreted in the present study.

Basement reflection

The deepest continuous reflection on Line OK 3-80 (yellow horizon, Figure 3) is the reflection from the top of the igneous basement. The depth to this boundary was established by ray-trace modeling and well data to be approximately 3500 ft (Kennedy, 2008, p 38).

The most striking feature of the basement reflection is its horizontal disruption over a width in the seismic section of approximately 1.6 km and a coincident vertical disruption of 50 ms (equivalent to approximately 250 m). This substantial feature is larger than a karst dissolution feature such as a cave.

Fracturing

The enigma of the basement disruption is associated with large-scale and extensive faulting and fracturing (Figure 3). From the basement to the surface the aquifer is extensively chopped up. Steeply-dipping faults cut the basement reflection, and strong reflections above the basement show offset across a number of faults.

The association of the Blue River (top of Figure 3) and the basement disruption raised the possibility of inaccurate static correction in reprocessing by WesternGeco: the slow soil layer would be thicker in the Blue River valley than to either side and failure to account for this would cause an apparent sag in the basement reflection beneath the Blue River. Modeling, however, showed that this would be insufficient to cause a sag of 50 ms and an indistinct basement reflection (Kennedy, 2008). Furthermore, reflections directly above the basement are not blurred as would occur if inaccurate static corrections had been made. The inference is that B and C (Figure 3) are faults bounding a graben, a major structural feature in the basement.

Our interpretation is reinforced by an analogous seismic profile from the Ft. Worth Basin (Figure 4). Here the time equivalent of the Arbuckle-Simpson Group, the Ellenberger Formation, is buried below sediments to a much greater depth. But it exhibits the same through-going faults forming fault-bounded grabens. The linear fracture intensities in the two cases are 1.57 and 1.55 faults/km in the Oklahoma and Texas cases, respectively. Small synclines occurring above the basement are interpreted (Chopra and Marfurt, 2006) to be collapse features associated with reactivation of faults. This same process may have affected the formations underlying the Anschutz section.

Spears Ranch 3D cross-spread: intermediate aquifer depth

Exploration scale seismic profiles such as Line OK 3-80 are costly. The fact that basement-cutting faults from Line OK 3-80 extend to the surface motivated our attempt to locate such faults using less-costly, near-surface geophysical surveys. An obvious location for this attempt would have been at faults B and C along Line OK 3-80. However, the presence of well control, the need for an area in which to acquire a 3-D seismic survey, and the existence of electrical resistivity imaging results directed us to the Spears and Arbuckle-Simpson Ranch sites.

In 2007, the University of Oklahoma, assisted by the University of Texas, El Paso, and the PASSCAL facility of IRIS, acquired a single P-wave cross-spread 3D survey at the Spears Ranch (Figure 5). The sources were small dynamite charges and were recorded by Texan seismographs designed by Prof. Randy Keller. The basement boundary and intermediate to shallow boundaries within the aquifer were the primary targets of this survey. The Spears #2 well-logs and cuttings analysis provided control in identifying reflecting boundaries in the cross-spread.

Recorders were deployed along a N-S and a W-E line. Each shot along the lines was recorded at all stations resulting in high fold along the backbone of the survey (the N-S and W-E lines) and very low fold in between. The irregular shot spacing and non-orthogonality of the cross-spread contribute to sparse, highly variable fold. An example of successful groundroll attenuation by F-K filtering a shot gather is shown in Figure 6a, and Figure 6b identifies two reflections at approximately 160 ms and 640 ms on a CMP gather along the N-S backbone. The basement reflection seen on the Anschutz Line OK 3-80 (Figure 3) at approximately 400 ms could be the 640 ms event at the Spears Ranch. The shorter traveltime for the former may be explained by two factors: the former has been static-corrected to a datum of 1000 ft but the latter has not, and the former is 7 mi up-dip of the latter.

Although we have not completed processing the lowfold 3-D volume from the cross-spread, we have interpolated through the coverage area from the two high-fold lines to give some sense of the topography of the 160 ms reflection surface (Figure 7).

A-S Ranch profile: shallow aquifer and epikarst

We acquired a near-surface P-wave seismic reflection survey at the Arbuckle-Simpson Ranch 1 mile north of the Spears Ranch cross-spread. Targets were the lower part of the epikarst, which extends to at a depth of approximately 50 m (Sample, 2008) and sedimentary units in the aquifer itself beneath the epikarst. An 8-gauge Betsy gun was fired end-on into a roll-along spread and was recorded by a 24-channel StrataView system. We used vertical component geophones having a 40 Hz natural frequency. Minimal CMP processing included datum statics, surgical muting of groundroll, AGC gain, and bandpass filtering. The stacked section (Figure 8) reveals a reliable tie to boundaries logged and sampled in the Spears #2 well. The top of the Kindblade (Figure 8) is a strong reflection at approximately 100 ms. A reflection corresponding to the top of the Cool Creek agrees well with the early reflection identified on the Spears Ranch cross-spread (Figure 7), but the energy from the Betsy gun is unable to discern the 640 ms reflection identified on the cross-spread.

The most notable features revealed by the near surface seismic survey are two closely-spaced faults cutting the Cool Creek and Kindblade horizons (Figure 8). The faults do not appear to reach the surface, but this may be due to apparent blanketing by the refraction first arrivals, which were not muted before stacking. To investigate this further, supplemental geophysical surveys were conducted by OU and OSU in the same area as the Arbuckle-Simpson reflection survey. Superposed electrical resistivity Line ASR5.00B and ground-penetrating radar Line 2 intersect the seismic survey (Figure 9a) at the fault location. Both the ERI resistivity inversion (Figure 9b) and the GPR processed section (Figure 9c) show a fault extending to the surface in the same location as the fault identified on the seismic survey.

Correlation of fault location by geologic mapping and by geophysics

Geologic mapping of the Hunton Anticline as shown recently in Johnson (1990) identified the presence of faults long before the geophysical surveys described in the present paper were conducted. The map (Figure 10a) shows three major faults, which correspond very closely to the three faults we interpreted on Line OK 3-80. Projection upward of the interpreted basement disruption falls squarely between the faults. Faults A and B (Figure 10b) plunge through the entire aquifer, cutting the top of the basement and continuing into it. Faults B and C converge as they approach the basement, forming the graben described in Figure 3. Moreover, subsidiary faults were mapped between B and C (gray lines, Figure 10a), and reflections from these would add further to the indistinct reflection image of the graben observed on Line OK 3-80.

Conclusions

Seismic surveys such as OK 3-80 are costly. This paper has shown that faults and associated fractures can be located at intermediate depths by much smaller scale seismic surveys and even by electromagnetic and electrical surveys at shallow depths. This suggests that using near-surface geophysics to confirm the location of geologically-mapped fault traces may be an efficient strategy to locate basement-cutting faults.

Hydrologic significance

The need to delineate faults and fracture systems that may control groundwater flow is great. High fracture intensity, rapid vertical communication at a depth of 1820 ft in the Spears #1 well (Osborn, 2007), reported fresh water in exploration wells (Kennedy, 2008), and potential lateral flow in the Reagan sandstone at the base of the aquifer (Kennedy, 2008) all suggest the importance of deep fractures to groundwater recharge and their importance in groundwater flow simulation.

References

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Acknowledgements

We are grateful to Professors Randy Keller and Todd Halihan and their staffs and students at OU and OSU, respectively; to Mr. Steve Harder and Galen Kaip of UTEP; and to staff from the IRIS PASSCAL facility, Socorro, NM, for their assistance in design and execution of the Spears Ranch Survey. The Anschutz Corporation kindly granted us permission to publish our analysis of their line OK 3-80. Devon Energy, the Oklahoma Water Resources Research Institute (OWRRI) and the Oklahoma Water Resources Board (OWRB) all helped fund the surveys. Software crucial to data reduction was provided by Schlumberger (Petrel), Parallel Geoscience Corporation (SPW), Seismic Microtechnology (Kingdom), Hampson-Russell (Elog), ION (GX II), and Sensors and Software Corporation (Ekko-Deluxe). Mr. John Bruno and Mr. Walter Spears were gracious in providing access to their ranches. I am especially grateful to Dr. Neil Suneson, OGS, for discussion and Ms. Noel Osborn, OWRB, for access to the Anschutz data and for encouragement to synthesize all geological and geophysical evidence.

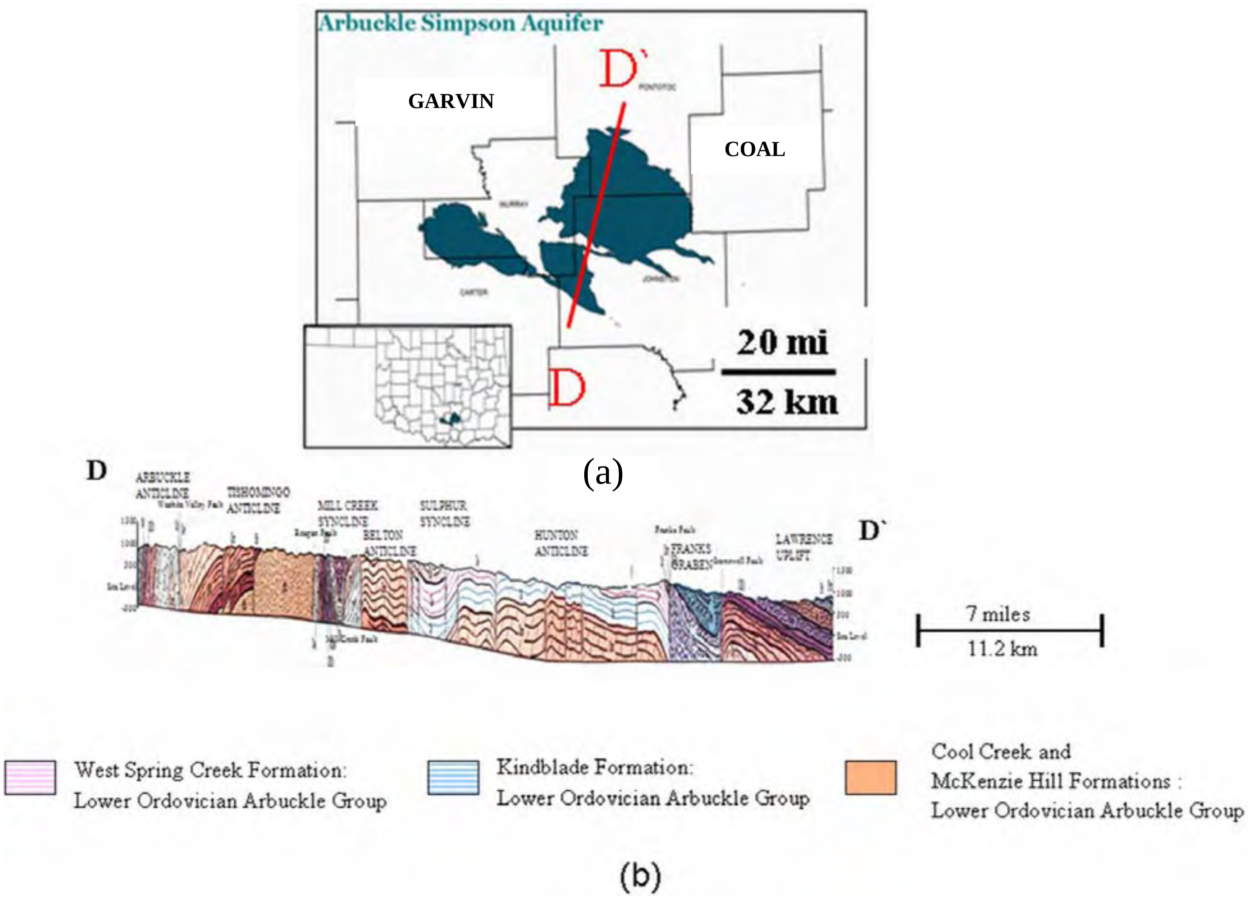

Figure 1 (a) The Arbuckle-Simpson aquifer of south central OK. D-D' is the approximate location of the geologic section shown in (b). The Hunton Anticline (b) is a broad uplift exposing the Lower Ordovician strata of the Arbuckle-Simpson aquifer.

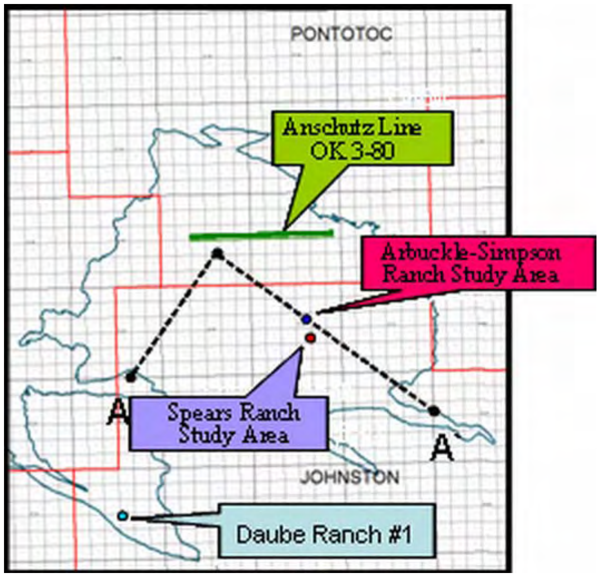

Figure 2 Locations of the three seismic surveys treated in the present paper. Logs from basement penetrating wells at the Daube Ranch, points A and A', and the point at the bend in-between, provide geologic control.

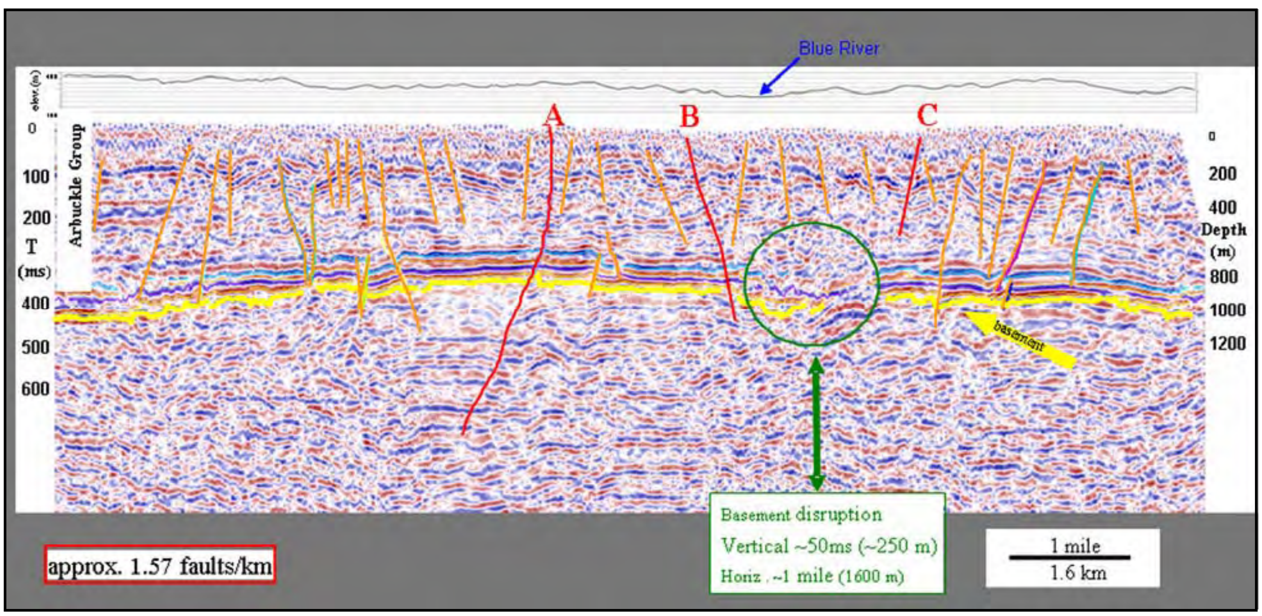

Figure 3 Anschutz Line OK 3-80. West is on the left. A,B, and C are major basement cutting faults, the latter two bounding a zone of basement disruption (green circle). The entire carbonate section above the basement is faulted and fractured.

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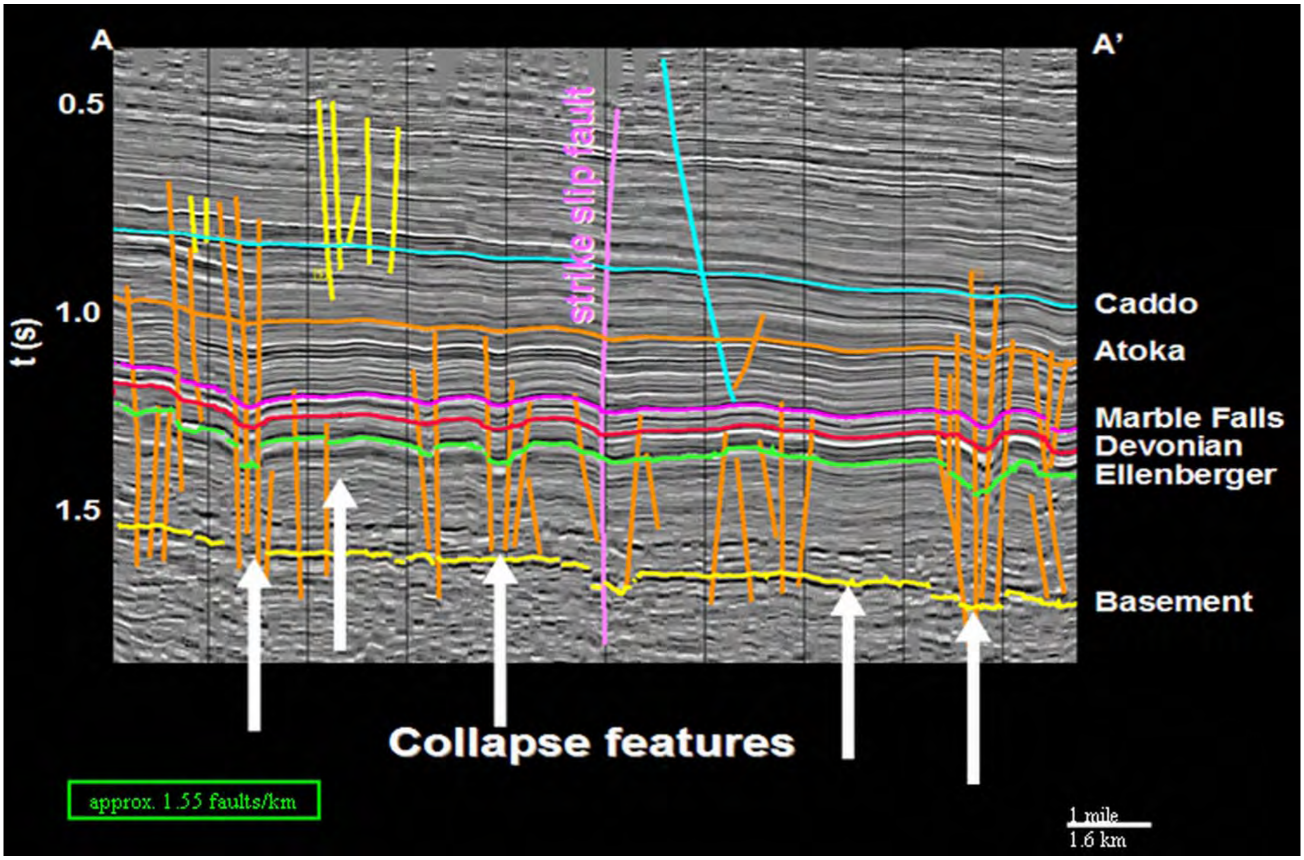

Figure 4 Profile from the Ft. Worth Basin through the Ellenberger Formation, a time-equivalent of the Arbuckle Group. Basement-cutting faults and extensive faulting and fracturing are associated with collapse features recognized in strata overlying the Ellenberger (from Chopra and Marfurt, 2006).

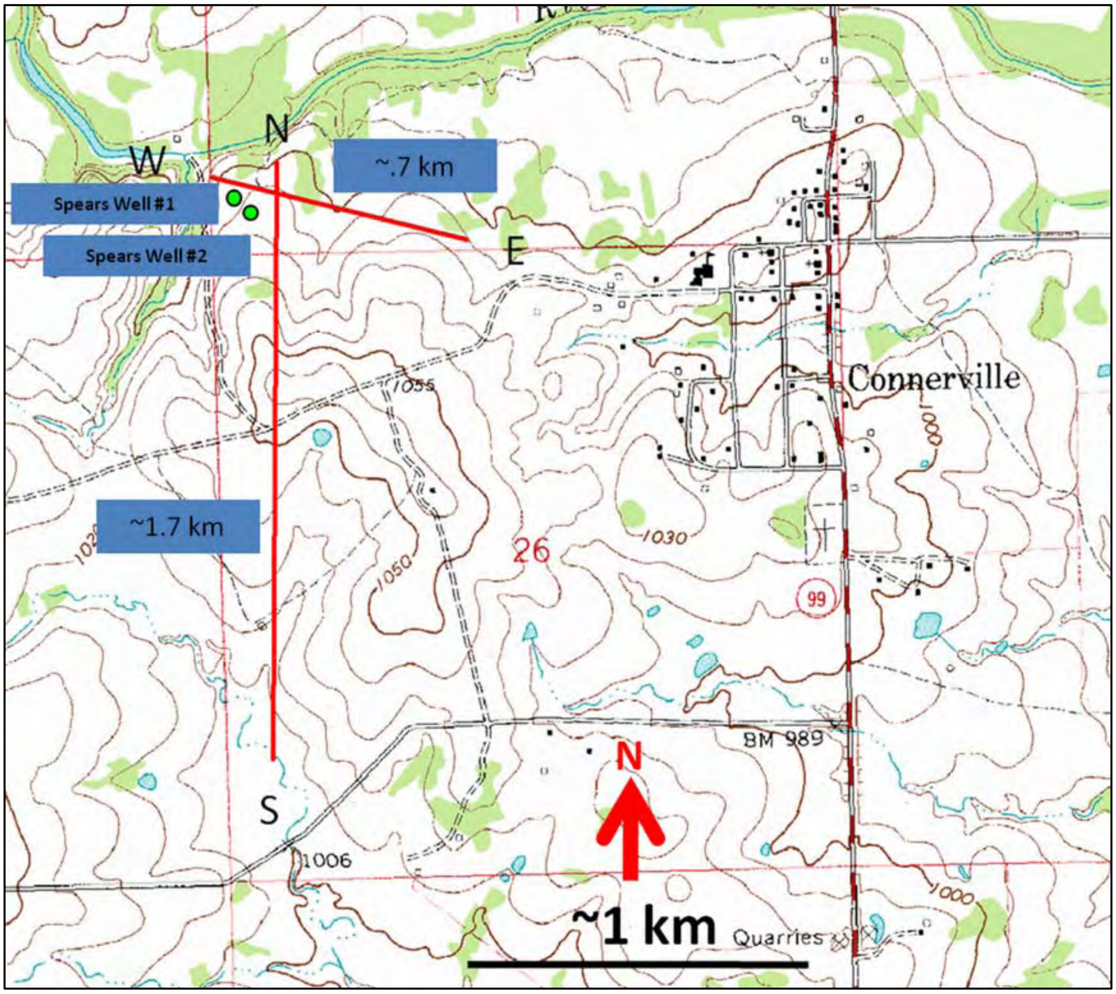

Figure 5 Cross-spread survey at the Spears Ranch. Recorders were located along the N-S and W-E lines, and each shot along the two lines was recorded by all recorders. The green dots are the Spears #1 and #2 wells.

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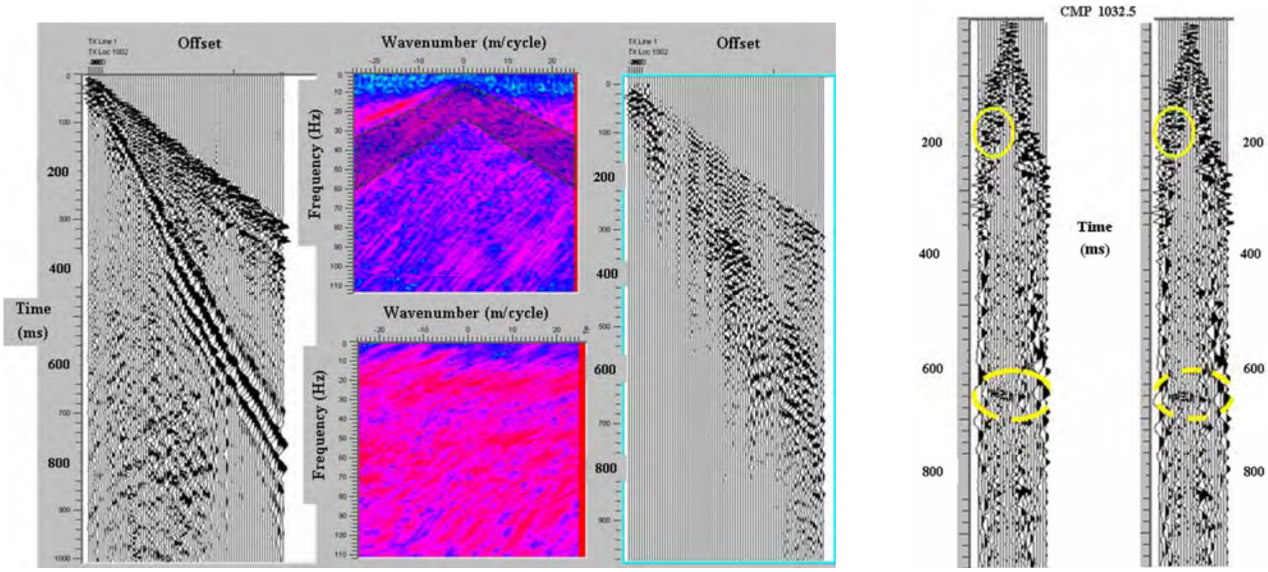


(a) (b)

Figure 6 (a) Groundroll removal from a representative shot gather along the N-S line of the cross spread. (a) *left:* unfiltered shot gather; *center:* F-K spectrum before (above) and after (below) F-K filtering; *right:* filtered shot gather. (b) CMP gather before (left) and after (right) F-K and bandpass filtering, and NMO correction. Processing in (a) reveals reflections at 160 ms (solid yellow ellipse) and at 640 ms (dashed ellipse).

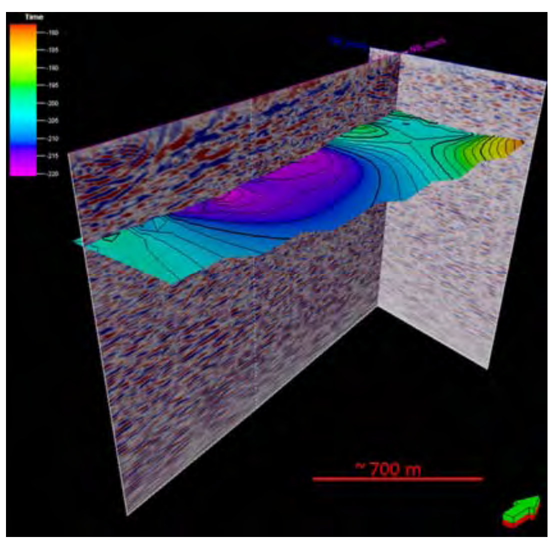


Figure 7 Horizon at 160 ms established by interpolation from picks on the N-S and W-E lines.

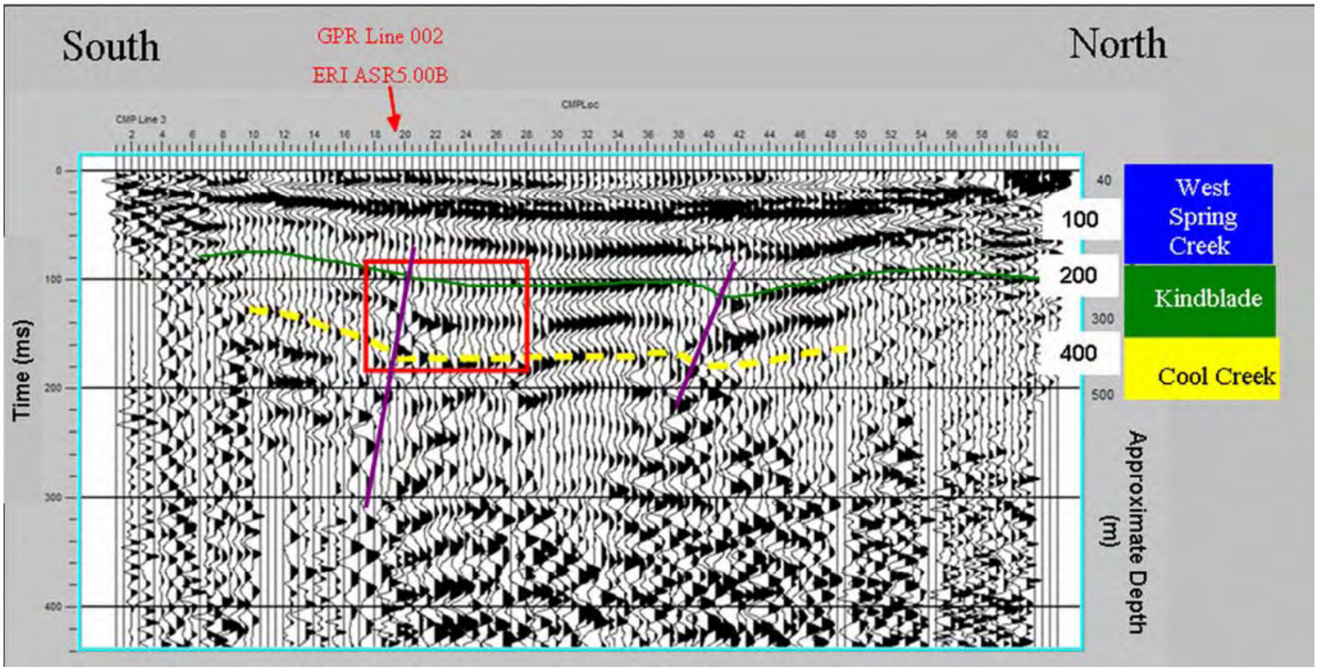
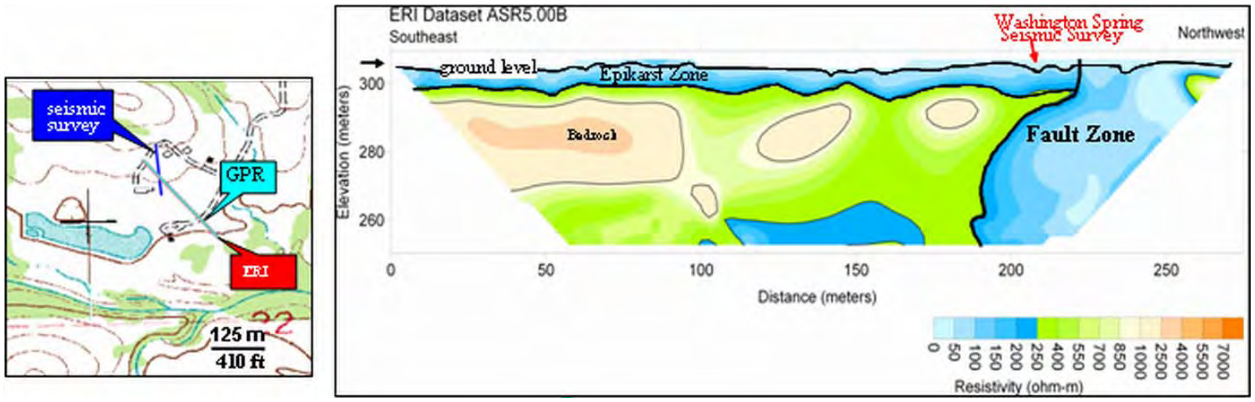
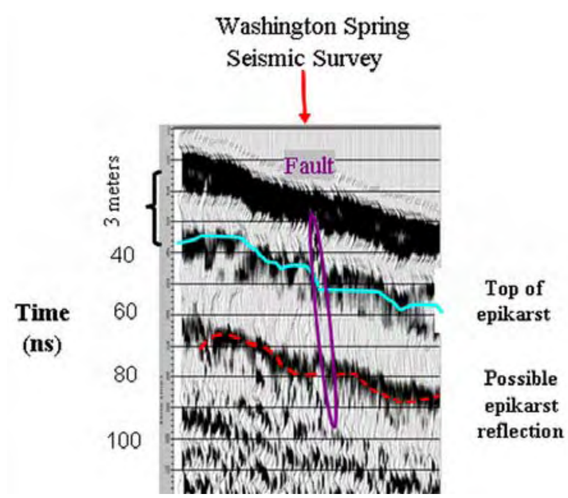


Figure 8 Arbuckle-Simpson Ranch near-surface seismic profile. Depth control from the Spears #2 well identifies the reflections from the top of the Kindblade and Cool Creek formations. Faults (purple) mark breaks in the reflections.

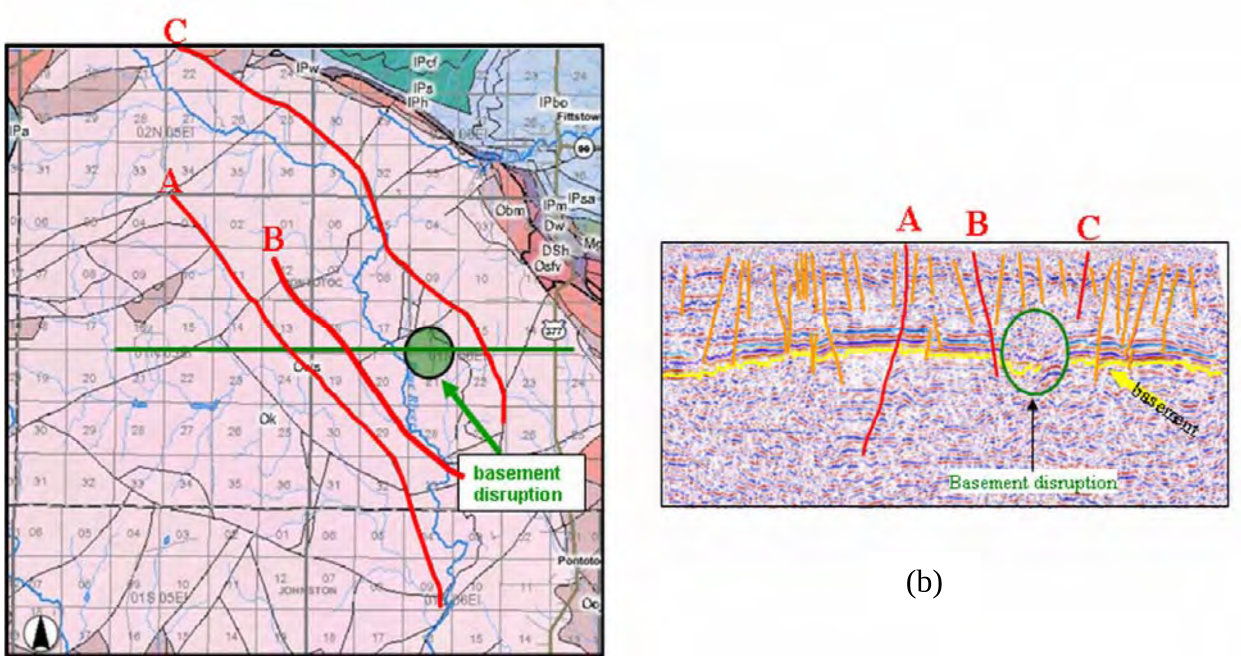


(a) (b)



(c)

Figure 9 Coincident surveys (a) locate the same fault by (b) ERI (from Sample, 2008) and (c) GPR methods. This fault is also seen on the near-surface seismic survey (Figure 8).



(a)

(b)

Figure 10 (a) Very close correspondence of geologically-mapped fault traces and faults identified on (b) the Anschutz Line 3-80.

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