2-D and 3-D VSP Interpretation: Blackfoot Field, Alberta

Robert R. Stewart and Qi Zhang

ABSTRACT

A thorough suite of borehole seismic surveys have been conducted in the Blackfoot field, southern Alberta. The surveys consisted of two zero-offset VSP surveys and one deviated-well survey. In addition, a novel 3-D VSP was also conducted by downhole recording of the shots used in a 3-D surface seismic survey. The correlation among the VSP surveys is very good and unambiguously matches the surface seismic data. The VSP data show some evidence of multipathing and complexity in the top of the Mississippian.

INTRODUCTION

Borehole seismic measurements have proven useful for estimating rock properties near a well and imaging around it. A primary use for the VSP is to identify and correlate major reflectors across log, VSP, and surface seismic data. The VSP data considered here are first used for correlating the major reflectors in the Blackfoot field, then for imaging. This correlation has increased our confidence in horizons picked on the surface seismic data. We can also gain insight into the how the seismic wavefields is propagating in the Earth. This in turn helps understand and process the surface seismic data. The VSP data presented give an overview of the state the art in borehole seismology as there are zero-offset surveys, deviated surveys with both P-P and P-S images, and a new 3-D VSP technique.

The Blackfoot oil pool is located in Township 23, Range 23W4, just southeast of the town of Strathmore, Alberta. The reservoir is a fluvial/estuarine glauconite sandstone of the Lower Cretaceous at a depth of about 1550 m. The reservoir sand can have thicknesses up to 45 m. The geologic model of the reservoir is that of a filled, incised valley. While most seismic data in the area is quite good, the sand parts of the channel are somewhat difficult to distinguish on conventional P-wave seismic. This is in part because the neighbouring shales have a P-wave response similar to the productive sands.

There were four VSP data sets acquired in the area (Figure 1). Zero-offset VSP surveys were conducted in the 15-13-23-24W4 and 14-3-23-23W4 wells. The later well was a test down to the Cambrian and thus provided at continuous seismic signature in the deeper section. An offset source, recorded in a deviated well (4-16-23-23W4), provided both offset P-P and P-S images. Finally, surface shots from the northern part of the survey were recorded by a tool in the 12-16-23-23W4 well. Processing steps used in the VSP analysis sequence included downgoing and upgoing wave separation, deterministic deconvolution, stretch to two-way time, mapping to two-way time, and stack.

ZERO-OFFSET VSP

PCP Cavalier 15-13 -23-24W4

This VSP was acquired and processed in September 1992 by Schlumberger of Canada. The total depth of the well is 1650 m. The source used in the survey consisted of two Mertz 25 vertical vibrators sweeping over a range of 8-100 Hz. The source was

offset 85 m from the 15-13 wellhead at 340°. The receiver used was the DSAB tool. The composite plot is shown in Figure 2. The data are plotted in SEG normal processed polarity (an impedance increase is a peak on the trace) which is Schlumberger reverse polarity. There is a very good correlation between the synthetic seismograms and the VSP extracted trace. For later correlation purposes, the reflections from beneath the bottom of the borehole provide useful markers to align the various traces. Dominant reflectors are the base of Fish Scales, Viking, and coals. We notice what might be a downgoing S wave that appears to interfere with the upgoing P-P events. This may be an S-P conversion, which should be seen on surface seismic also. The top of the Mississippian is at about 1060 ms.

PCP Blackfoot 14-3 -23-23W4

The 14-3 survey was acquired and processed in February 1994 by Schlumberger of Canada. The total depth of the well was 2573 m. The source was a single Mertz 25 vertical vibrator using a sweep of 8-100 Hz over 12 s. The source was offset 92 m from the wellhead at 20°. The receiver used was the CSAT tool. The well had 177.8 mm casing @ 2384 m. Good reflectors on the data (Figure 3) include the lower Mannville coals, Banff, Exshaw, and Cambrian horizons. In these data, at the Mississippian unconformity we see a hint of complexity in the reflection. It appears that there is some structure just beneath the unconformity surface which gives another reflection. There could also be some multipathing in the lower Mannville as evidenced by the triplet at 1100 ms..

DEVIATED WELL VSP

PCP 4B Cavalier 4-16 -23-23W4

The 4-16 survey was acquired and processed in January 1996 also by Schlumberger of Canada. The total depth of this well is 1715 m. Two Mertz 25 vertical vibrators provided the source energy with a 8-100 Hz sweep over 12 s. The vibrators were offset 350 m from the wellhead at 223° (SW). The receiver was the CSI tool and there was 219 mm casing @ 162.m. Because of the offset source and deviation in the well both P-P and P-S sections could be constructed. Figure 4 shows the logs, synthetic seismograms, P-P and P-S corridor stacks. Again the correlations are quite compelling. It is very helpful having the P-P and P-S sections both processed to P-wave time using the VSP. This allows a more confident interpretation. The P-P section is shown in Figure 5 and P-S section in Figure 6. These sections are also matched to their corresponding surface seismic lines in Figures 7 and 8. The top of the Mississippian is at about 1040 ms on the P-P and P-S sections. We also note a possibly overcorrected S-S event at 1300 ms. From these sections it appears that the 4-16 well may just be starting to penetrate the reservoir sand as indicated by the emergence of a small peak close to the well TD.

3-D VSP SURVEY

PCP Blackfoot 12-16-23-23W4

A consortium of companies (The Blackfoot Seismic Project - BSP) joined together to shoot a full 3C-3D surface seismic survey over the Blackfoot field. PanCanadian Petroleum generously made the 12-16 well available to try an experimental downhole recording of the surface seismic shots - as they were being recorded by the 3-D surface patch. Western Atlas Logging Services used their 5-level, three-component tool in the

12-16 well to receive data from the 3-D surface shots. In all, 431 dynamite shots (4.0 kg each) were recorded by the downhole tool. The data were processed in a manner similar to offset 2-D VSPs with binning into a 3-D cells. The P-P section running north-south is shown in Figure 9. The continuous reflectors are nicely correlatable to the surface seismic section and synthetic seismogram also shown in Figure 9. For an experimental survey, the 3-D VSP turned out remarkably well. While noisier and lower frequency than the corresponding surface seismic, the major reflectors are readily identifiable. We also see similar features, on the top of the Mississippian near the 09-17 well, for both VSP and surface seismic data. We can also create a 3-D volume of the VSP data and apply all of the standard 3-D seismic interpretive techniques to it. A time slice (Figure 10) of the P-wave data at 1000 ms shows an image consistent with that of the 3-D surface seismic - a lower area to the SE of the well.

CONCLUSIONS

In this study, VSP data are used to correlate the reflectors in the Blackfoot region. We find that the major markers are quite correlatable across synthetic seismograms, VSP extracted traces, offset VSP images, and surface seismic data. The 3-D VSP sections also correlate nicely to the other VSP data and surface seismic sections. The 3-D time slices are promising to be a very useful interpretive tool.

FUTURE WORK

It will be useful to do correlations on the workstation between P-P and P-S VSP data. Isochrons and their ratios should provide further diagnosis of the sand channel (or the lack of it). A close look at the phase and amplitude differences among VSP traces and surface seismic data will also be interesting. Narrow corridor stacks and near-surface stacks would be helpful to identify multiples. Finally, we would like to invert the VSP sections for velocity and Vp/Vs values.

ACKNOWLEDGMENTS

The authors would like to thank the participants of the Blackfoot Seismic Project, and in particular PanCanadian Petroleum, for making these data available for our analysis. Mssrs. Bill Goodway, Garth Syhlonyk, and Dave Cooper have been most helpful in the supporting the recording of these VSP data and their analysis.

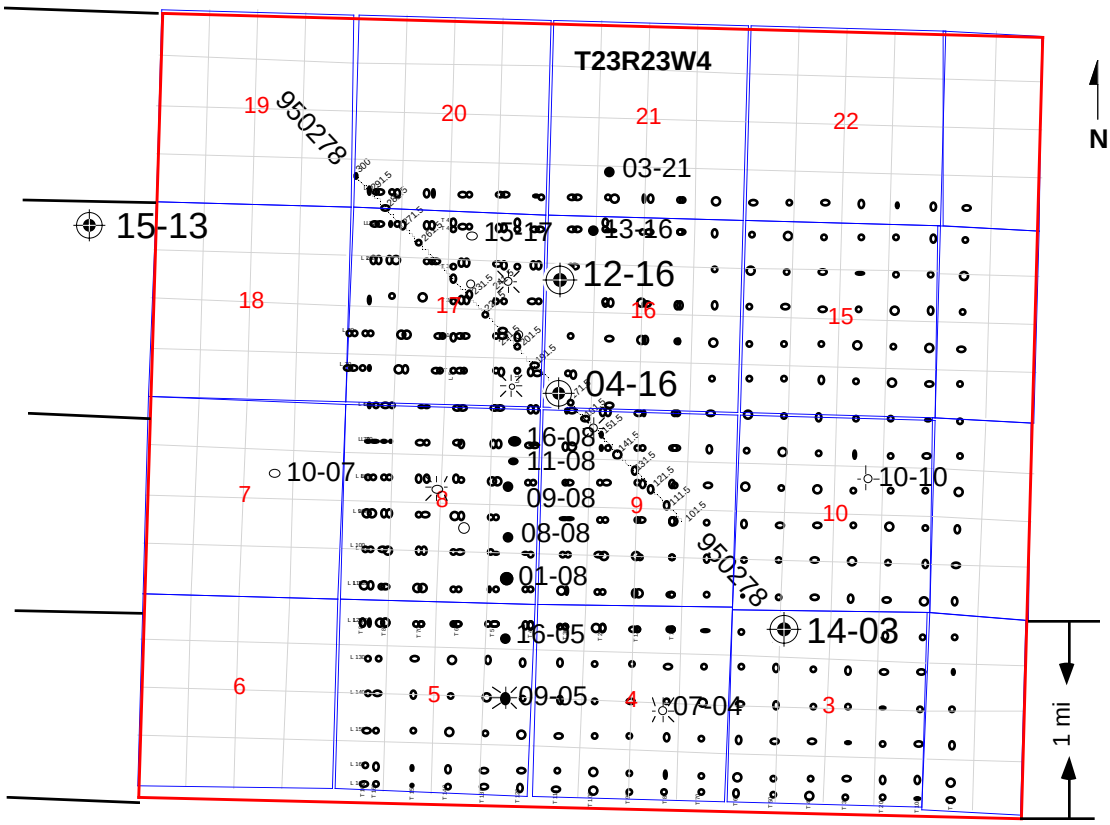

FIG. 1. Location map of the Blackfoot VSP surveys

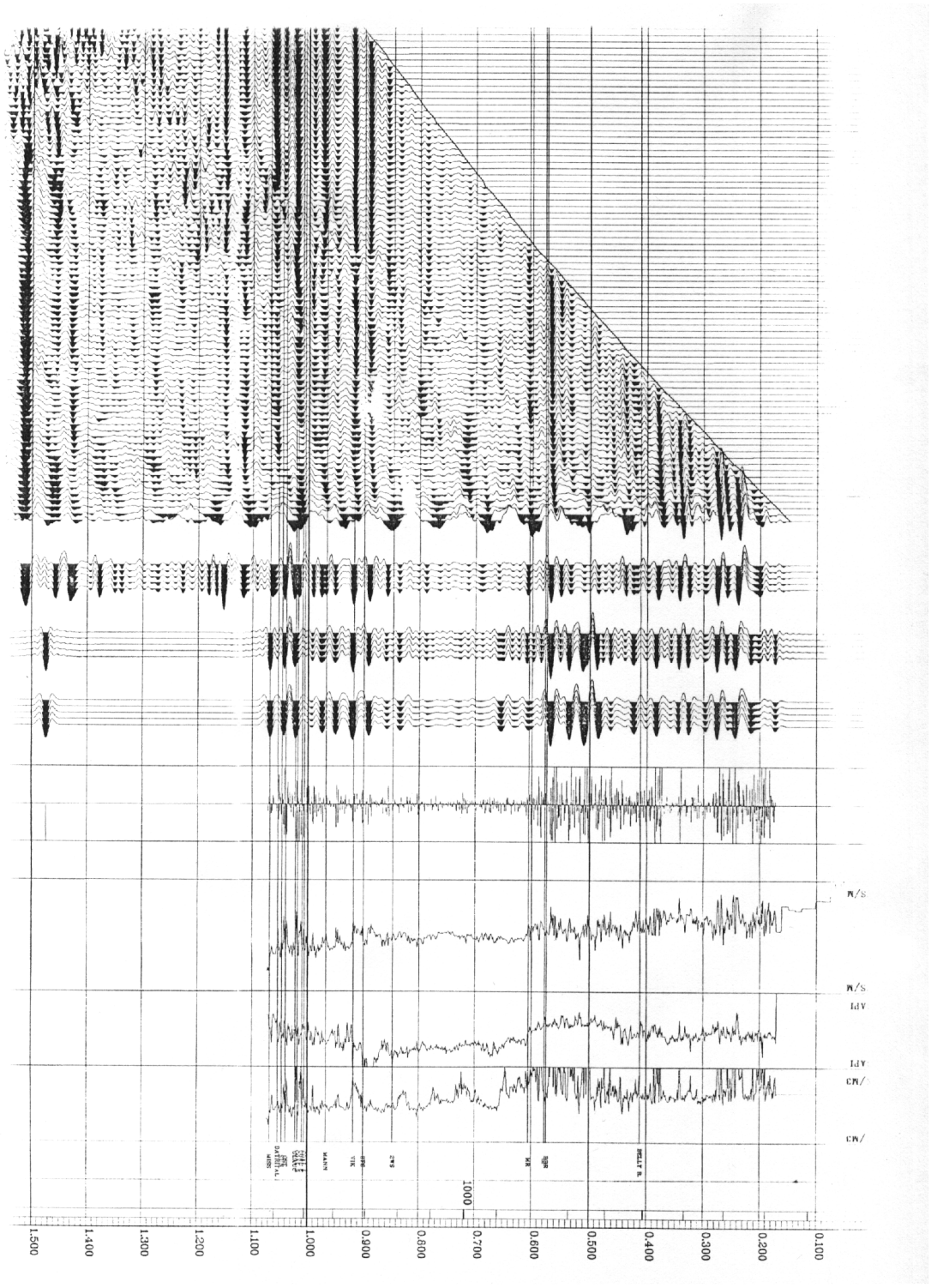

FIG.2. Composite plot for the 15-13-23-24W4 well

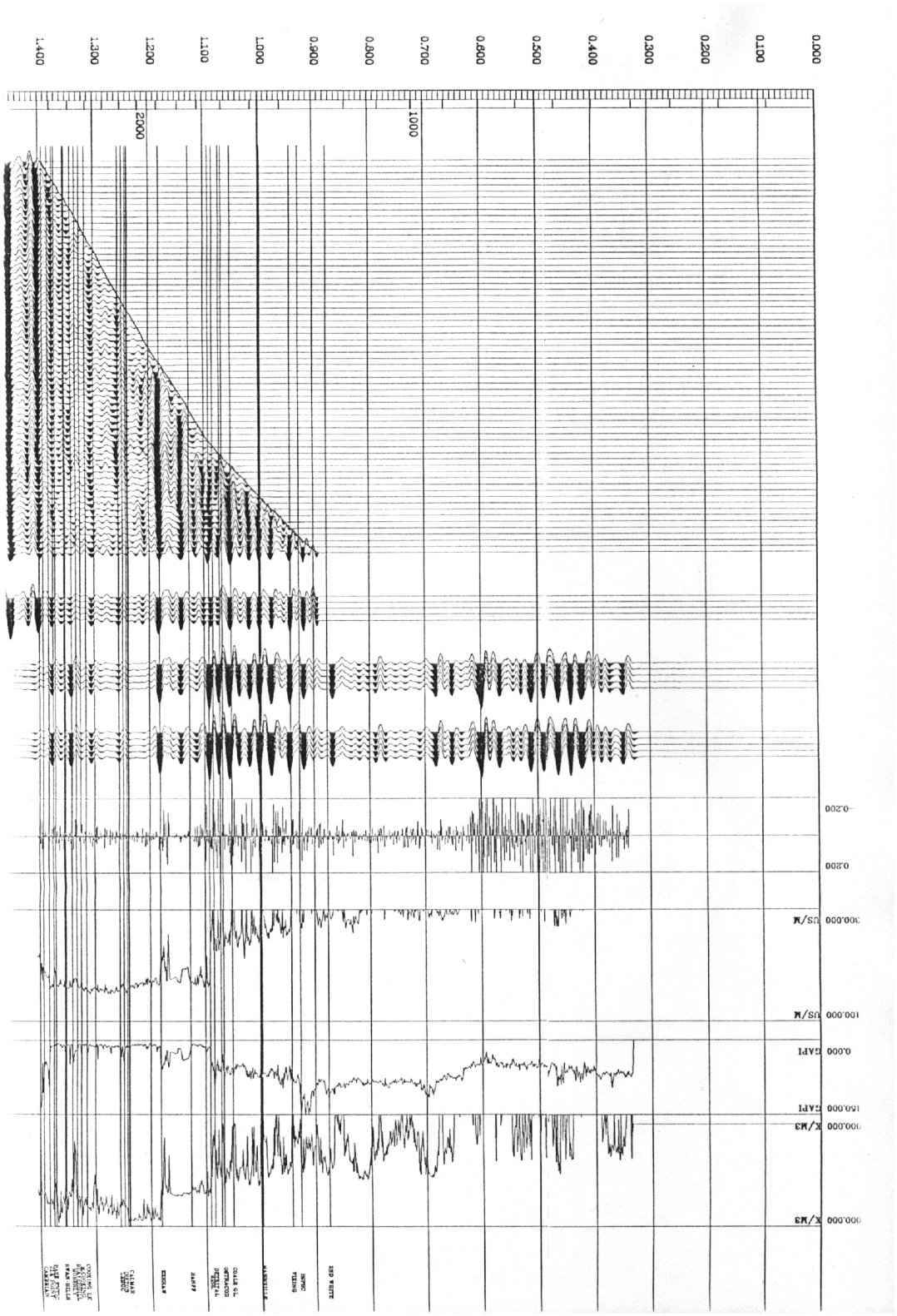

FIG. 3. Composite plot for the 14-3-23-23W4 well.

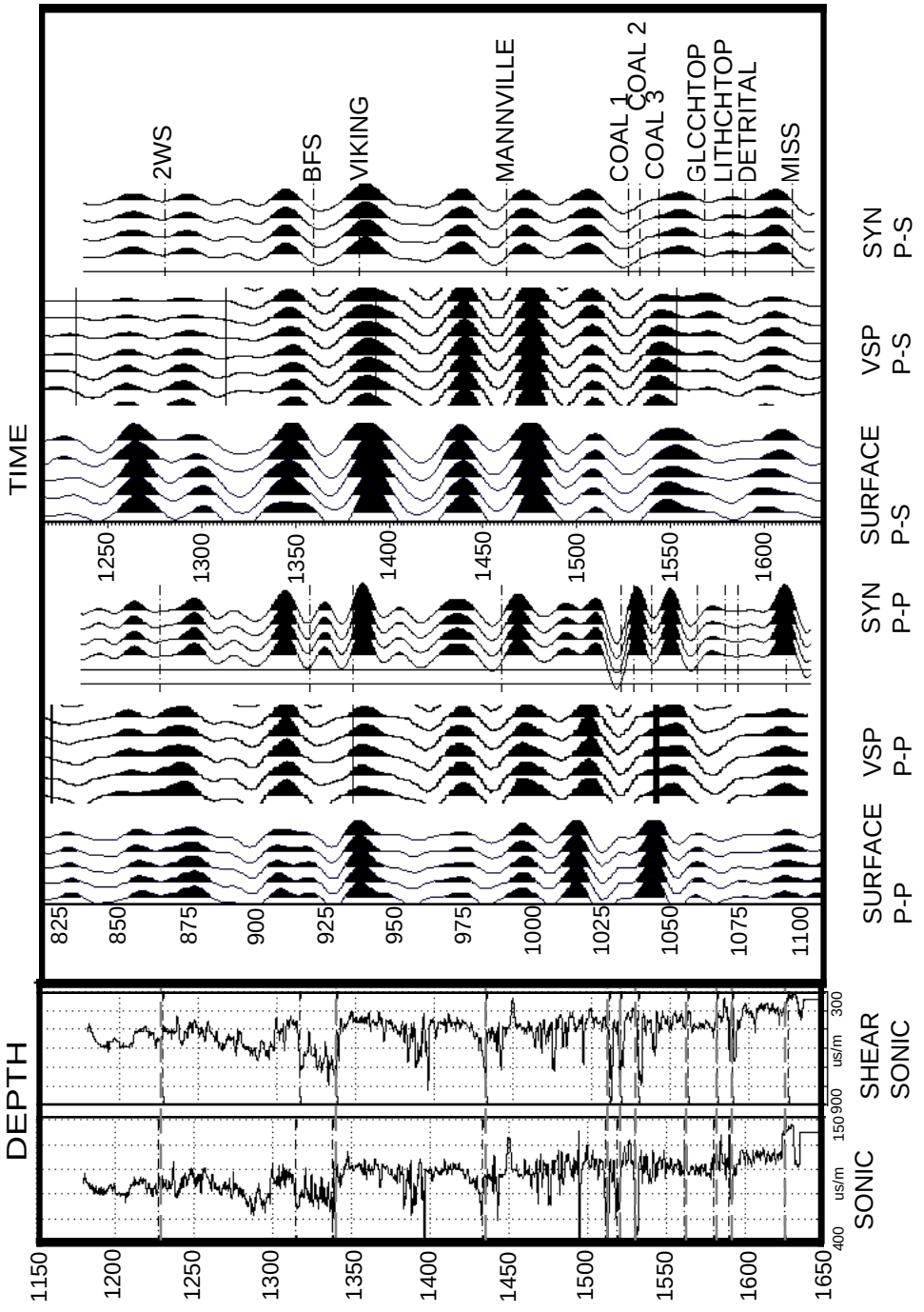

FIG. 4. Well logs, synthetic seismograms, and VSP traces for the 4-16-23-23W4 well

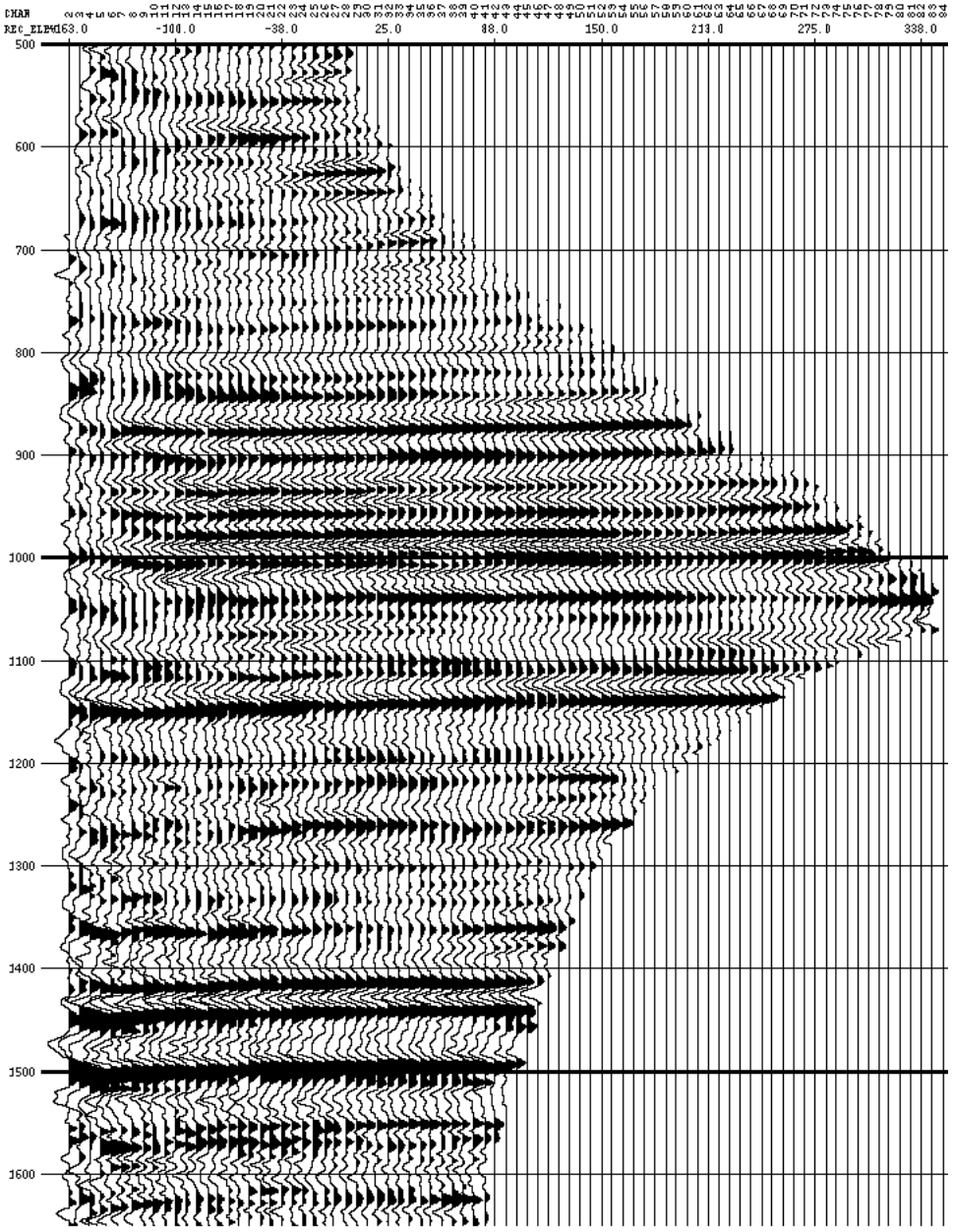

FIG. 5. P-P section for the 4-16 well.

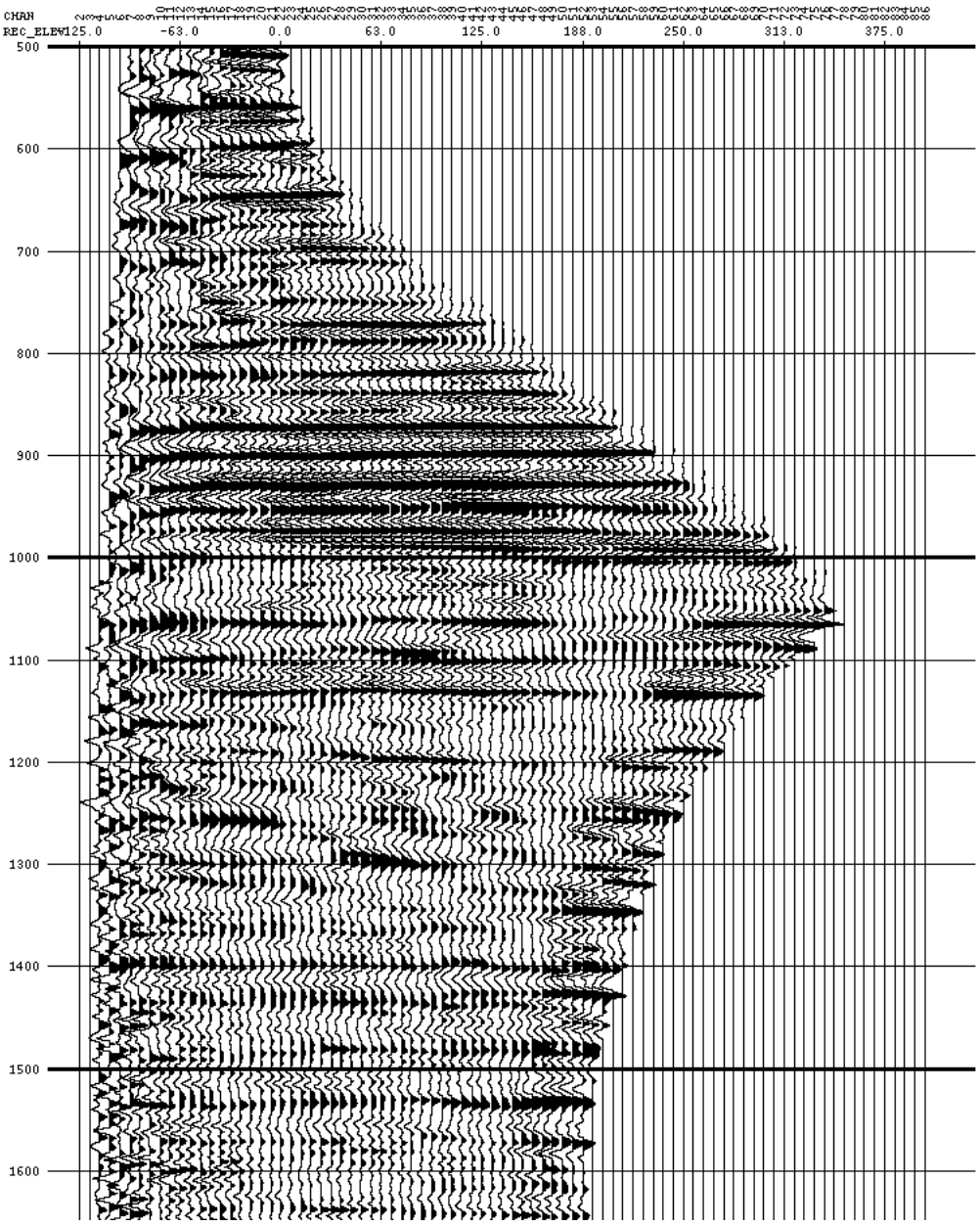

FIG. 6. P-S section for the 4-16 well.

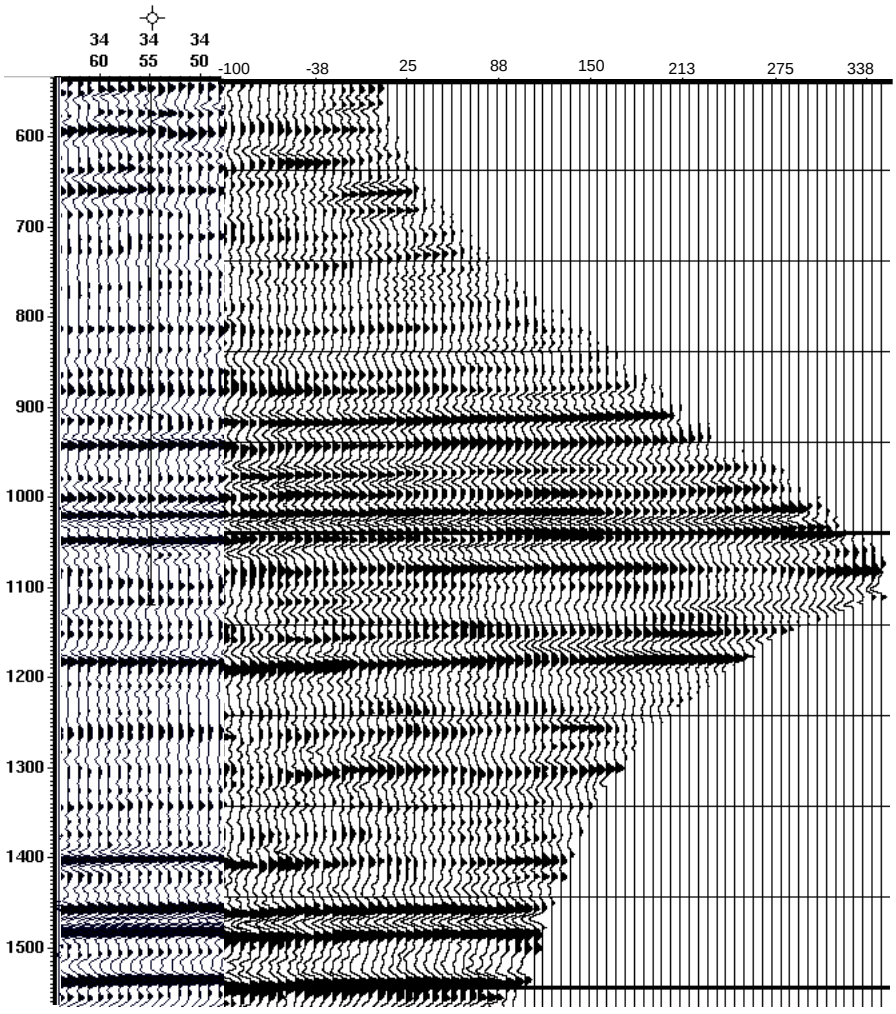

FIG. 7. P-P surface seismic and VSP sections near the 4-16 well.

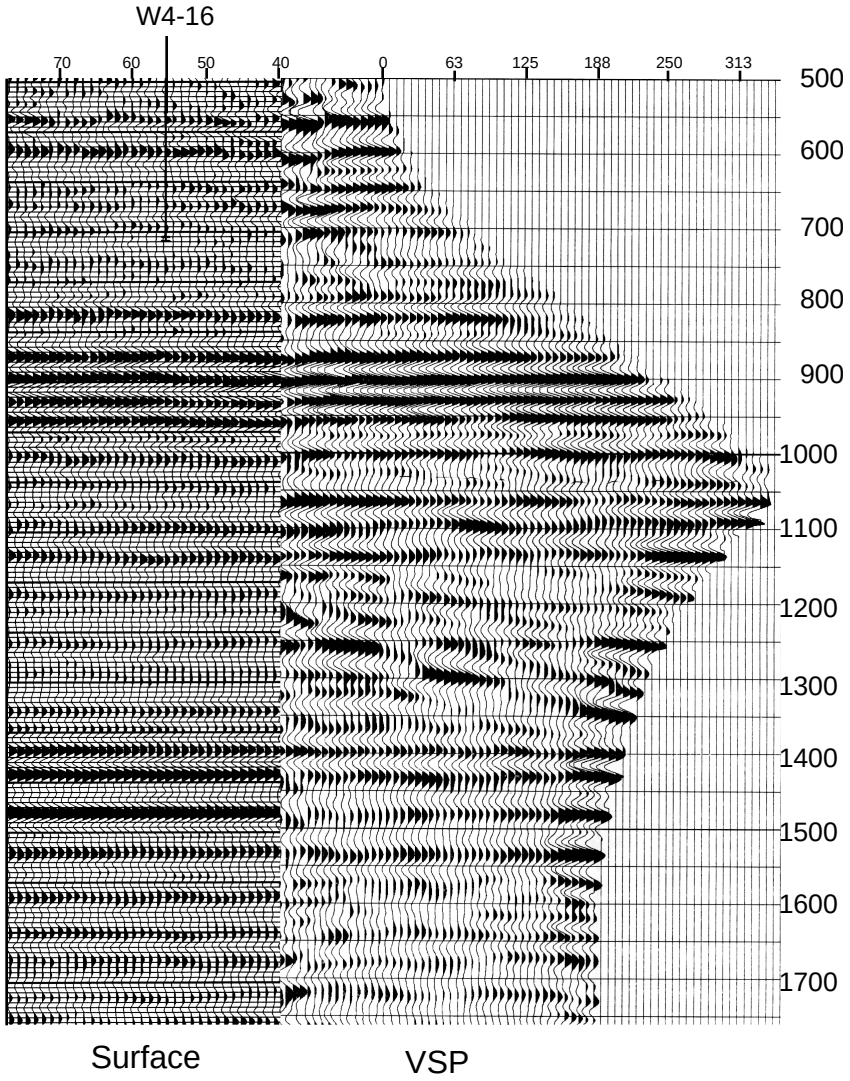

FIG. 8. P-S VSP and P-S surface seismic for the 4-16 well.

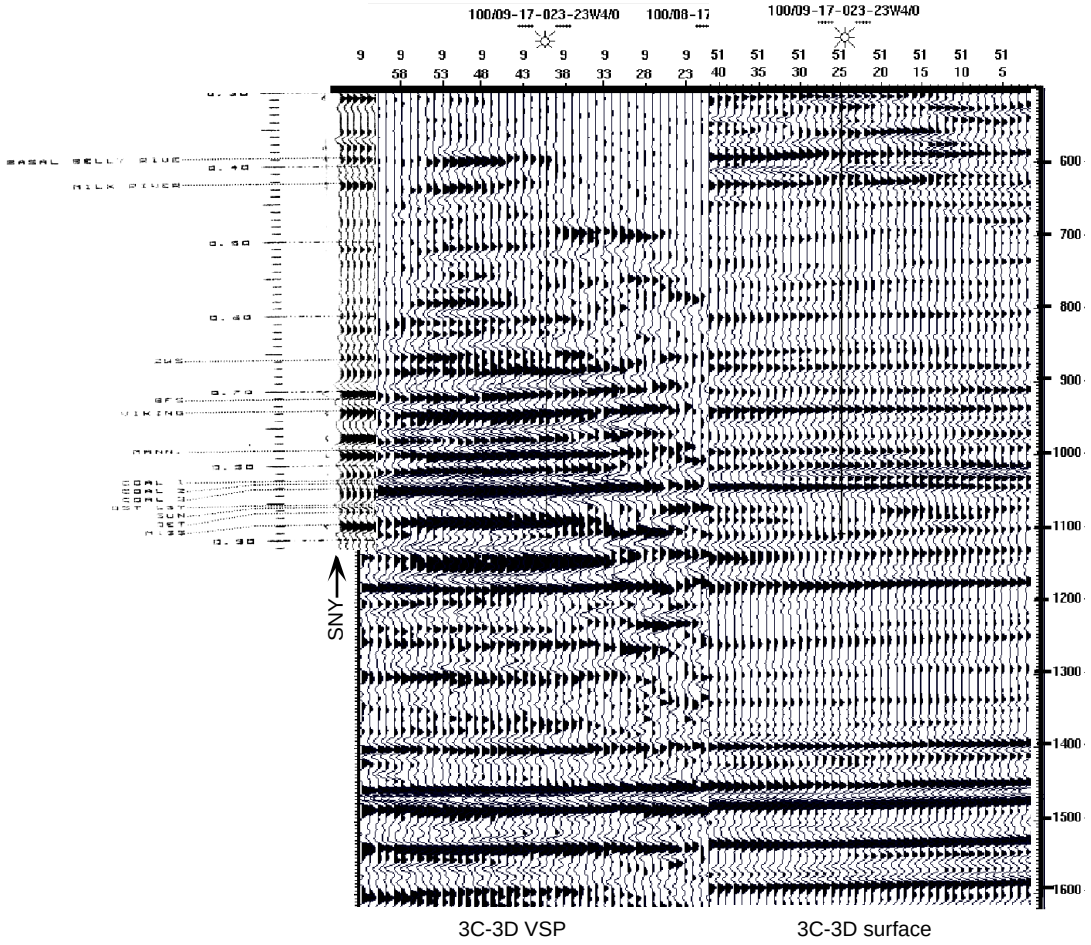

FIG. 9. 3-D VSP section for P-P waves correlated with the surface seismic section near the 12-16 well.

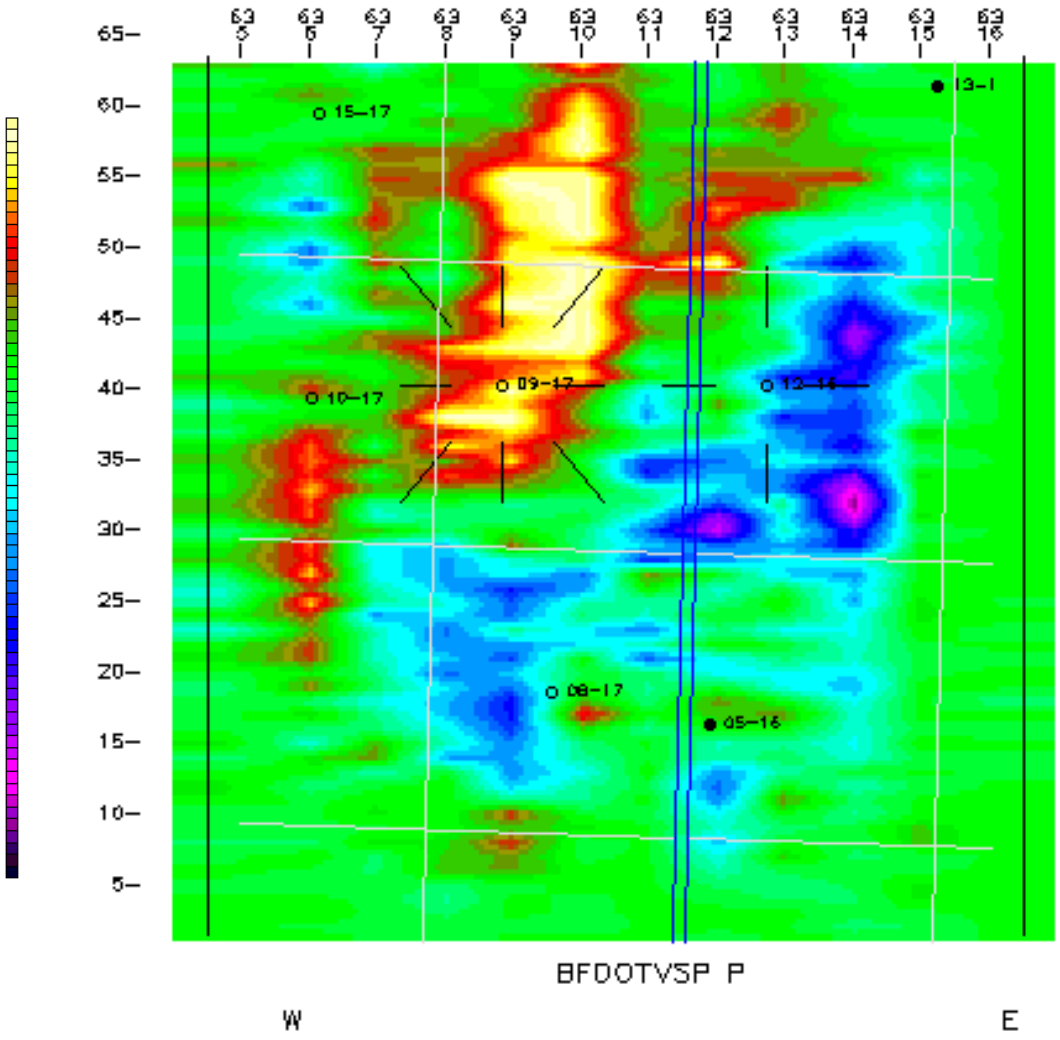

FIG. 10. 3-D VSP time slice at 1086 ms showing Mississippian structure.