Interpretation of P-SV seismic data: Willesden Green, Alberta

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ABSTRACT

Two, crossed three-component (3-C) seismic lines and borehole seismic surveys were acquired in the Willesden Green area of central Alberta. The surveys were conducted to investigate the elastic response of a productive, fractured interval - the Second White Speckled Shale (2WS). In particular, it was proposed that fracturing in the 2WS might lead to seismic anisotropy: changes in the P- and S- wave velocities as a function of azimuth and shear-wave splitting. The borehole seismic measurements consisted of two offset vertical seismic profile (VSP) surveys, with source locations 900m north-east and 901m north-west of the well (location 8-13-41-6W5), and a zero-offset survey. Vertical vibrator sources and a wall-clamping, three-component receiver acquired high-quality VSP data over a depth interval of 400m to 2175m. The surface seismic surveys used two vertical vibrators, 3-C geophones, and receiver spreads out to 2520m offset. The lines were oriented NNW and ENE (70° from each other) and were processed for P-P and P-SV reflections, including anisotropic rotations.

In this preliminary study, we find an excellent tie among the synthetic seismogram, P-wave and P-SV VSP sections, and surface seismic sections. However, there is no obvious evidence of velocity change with azimuth or shear-wave splitting.

INTRODUCTION

Interest in three-component (3-C) seismic surveying has arisen because of the need for a more complete description of rock structure, stratigraphy, lithologic type, state of fracturing, and pore fluid. Pure P-wave measurements contribute admirably to this goal but have inherent problems (e.g., short-leg multipathing, thin-bed tuning) and limitations (e.g., insensitivity to fracturing, similar response from different rocks, small acoustic contrast across some boundaries of interest). Converted-waves (P-SV) also have shortcomings but can augment traditional P waves to provide an additional structural section, a probe for anisotropy, and an indication of rock type and saturant.

The overall goal of this survey was to see if 3-C seismic data could help find oil in the Second White Speckled Shale (2WS) of the Willesden Green area. The Cardium interval in this region is a well developed and mature oil producer. Production from other horizons (the Viking, Glauconitic sands, and the 2WS) has been more spotty although also worthwhile. The specific goals of the survey were to: i) investigate the elastic response of the 2WS, ii) search for anisotropy in the data, and iii) look for any anomalies that could be connected with oil production in the 2WS.

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The study of anisotropy in rocks is fairly complex in theoretical and practical terms. Basically, an S wave impinging on an anisotropic material should generally split into a faster propagating wave and a slower moving wave. These waves will propagate polarized in the direction of the fast and slow axes of the anisotropic material. Recording of these two split waves should provide an indication of the direction of anisotropy in the material. This in turn may be related to the state of stress of the material or its fracture direction and density.

The Willesden Green VSP surveys were conducted on February 12,1990, in the 8-13-41-6W5 Tripet et al well by Schlumberger of Canada. Subsequent processing was also completed by Schlumberger (as discussed later). In the fall (Sept. 30th to Oct. 2) of 1992, Response Surveys Ltd. acquired two 3-C surface seismic lines (WG-1 and WG-2) over the Willesden Green area. Line WG-1 was an east-northeast line which was crossed by line WG-2, a north-northwest line. WG-2 also passed near the well location. A location map of the two seismic lines and three VSP surveys is shown in Figure 1. The surface data were processed by Pulsonic Geophysical Ltd.(Cary et al., 1993) and are described later. The primary objective of the 3-C surface seismic shooting was to characterize the 2WS interval. The VSP data are intended to assist in this descriptive effort. Other relevant data sets include a sonic log, a short interval of an S-wave log, and interpreted formation tops.

WILLESDEN GREEN GEOLOGY

The Second White Speckled Shale (Second White Specks) of the Colorado group is an Upper Cretaceous fine-grained, laminated clay sediment. It was deposited in a shallow to open marine environment. This led to its characterizing feature - white speckles due to fossil debris. It is a good marker of about 25m thick in eastern Saskatchewan to over 90m thick in northwestern Alberta. It is overlain by the Colorado shales and underlain by the Belle Fourche shale. Some significant formation tops are given in Figure 2. The top of the 2WS is given at a subsrface depth of 2033m. The logs in Figure 3 show the 2WS as a high-velocity excursion on both P and S logs. This excursion is manifest as a well defined peak on the synthetic seismograms at 0.935s. The 2WS shale is both a source and reservoir rock. Macauley et al. (1985) report that as calcite in the source rock increases toward pure limestone, the hydrocarbon potential decreases. The Willesden Green area was chosen for this study as there five wells in close proximity that produce or have produced from the 2WS. However, a number of penetrations of the 2WS have not produced oil. Conventional P-wave prospecting has not been able to resolve better or worse places for drilling.

WILLESDEN GREEN VSP

There were three VSP surveys conducted in the Willesden Green project: two offset source surveys and one zero-offset survey. The goals of the VSP analysis were to i) assist in the interpretation of events seen on the surface seismic, ii) try to observe any anisotropic effects in the converted-wave (P-SV) sections.

Zero-offset VSP

The zero-offset VSP data were shot with a seismic source actually offset 100m north-east of the wellhead. This single Mertz 18 vertical vibrator source used a 12s sweep over a frequency range of 10 - 90 Hz. The receivers recorded data from depths of 400m to 2175m. The few shallow receiver positions were widely spaced - as check shots. Starting at 1290m, the receivers were separated by 15m. A wall-clamping 3-component tool (Schlumberger's SAT tool) was used. The vertical component of the receiver (geophone, sonde, seismic tool) only has been processed. As a vertical vibrator source has been used, we do not expect to record shear waves at this small source offset. A plot of the vertical component is shown in Figure 5. As evidenced by the continuity of the first-arriving P waves and the consistency and strength of the reflections from near the bottom of the well, this VSP is of quite good quality.

The data were processed using a conventional flow which includes: bandpass filtering (10-90 Hz), trace equalization on a window around the first arriving P waves, and a time-variant gain (T**1.7). The downgoing waves and upgoing waves were separated using median and f-k filters. A level-by-level deterministic deconvolution operator designed from the downgoing waves is applied to the reflections. A corridor mute is applied and the upgoing VSP data are stacked into a single trace - the VSP-extracted trace (VET) that is then repeated five times. The polarity convention used in the composite display is an impedance increase in the earth corresponds to a peak on the resultant seismic trace.

This VET is placed alongside the upgoing VSP data displayed in depth and two-way time and the sonic log in depth. This final interpretive product is called the L plot or composite display (Figure 6). To identify various events on the surface seismic, we correlate them to the VET, then via the VET in the composite plot, associate the seismic events with geologic interfaces on the log. Further details of VSP processing and composite plot interpretation can be found in Stewart (1990) and Geis et al.(1991).

Offset VSP

There were two offset VSP experiments conducted as part of the Willesden Green project. The goal of these surveys was to see if there was an appreciable difference in the converted-wave (P-SV) images constructed from the two different survey azimuths. Two Mertz 18 vibrators were used at each source position. They swept from 10 - 90 Hz for 12 s. One source position was 900.0 m to the north-east while the other was positioned 901.0 m to the north-west. Data were recorded over the depths of 990m to 2175m at intervals of 15m.

The first step of the offset VSP processing is to rotate the raw 3-C receiver data into the plane containing the well and shot point. This is done using the first-arriving P waves. Gain recovery - T**1.6 - is next applied to the vertical (z) and radial traces. The VSP records are trace equalized. Downgoing and upgoing waves are separated, then P and S waves are separated. This wavetype or modal separation is achieved by ray-tracing pure P (P-P) and P-SV ray paths, then projecting, in a time-variant manner, the vertical and horizontal traces onto their respective P or SV arrival angles. Deterministic deconvolution (designed on the total downgoing P wave) is applied to both the pure P and P-SV traces and followed by a 10-70 Hz bandpass filter. The pure P and P-SV traces are next mapped, by 2-D raytracing through the vertically layered velocity model, to create sections in two-way time and lateral offset. The pure P and P-SV sections are shown in Figure 7. We can see many similar events in the sections, such as the 2WS, but there are also some interesting differences in events and their character.

3-C SURFACE SEISMIC

Acquisition and processing

The two surface lines with a 60m source-point interval and 20m receiver interval were recorded by Veritas Geophysical Ltd. The lines were shot at a 70° to one another. The source consisted of four Mertz M18 vibrators sweeping for 12s over a 8 - 70 Hz range. Records were vertically stacked twelve times. The geophones used were three-component HGS 10 Hz receivers planted in an 45 cm augured hole. Burial of the geophones is thought to lessen the effects of wind and cultural noise. There were 252 live stations in a split-spread configuration providing far offsets of 2520m. This gives rise to a 42-fold data. Also a 9-geophone group of vertical-component phones (Oyo 14Hz) were deployed over 20m at the same stations to compare the vertical 3-C component to the array (note that the final processed sections showed little difference between the single channel and 9-geophone arrays). Thus, 1008 channels were simultaneously recorded . The 3-C data were acquired at a price that was about two times that of conventional vertical-component only data.

The processing flow for P waves was conventional from initial gain through final stack. Figure 8 shows portions of the two lines (WG-1 and WG-2) tied at their intersection point and the VET appended onto WG-2 at the well location. The full WG-2 line is shown in Figure 9. The P-SV processing flow included an anisotropic rotation to principle axes (Harrison, 1993), statics, depth-variant binning, and stack into a common-transmission-point bin (Cary et al., 1993). A P-Sv section in the slow direction of S-wave propagation for line WG-2 is shown in Figure 10.

INTERPRETATION

The surface seismic and VSP surveys were designed to investigate the possibility of anisotropy associated with fracturing in the 2WS. It was thought that the resultant fast and slow propagation directions could be in the northeast and northwest directions respectively. We see by comparing the pure P sections in Figure 8 however, that the two surveys shot at different azimuths correlate very well. Also spliced into the centre of the offset VSP maps (Figure 11) are the VET and a small portion of the surface seismic section (WG-2). Again the tie between all of the data is, in general, very good. The tie of the VSP data with WG-1 is, in addition, very good. With all of these sections from a range of azimuths (approximately 15°, 45°, 110°, 135°) providing a very similar picture, we conclude that P-wave anisotropy in the upper section (through the area of interest) is not evident. Below the area of interest there appears to be some stretching of the VSP maps in comparison to the spliced data.

In comparing the two different azimuth P-SV sections (Figure 12), we see the same excellent tie. The P-wave VET is spliced between the P-SV maps and, for the major events, appears to correlate well. For a closer comparison, the P-SV sections are sliced together at their mid-offsets (Figure 13). There is once again no obvious evidence of significant mismatch in these sections. It is possible that the P-SV sections are not oriented in the principle directions of anisotropy, and that there are split shear waves on both of them. This could give noisier-looking results, but perhaps still provide correlatable P-SV sections. However, the P-SV sections display very similar events as the pure-P sections suggesting that there is only a single set of events on the P-SV sections and thus no split shear waves. There are thus several possibilities with respect to anisotropy here: there is no anisotropy present, or it is too small to measure, or it is more complex than can be discerned with these particular seismic measurements.

The final plot correlates two P-SV surface seismic sections: line WG-2 with the slow shear component and line WG-1 with the fast component. Again, we do not see major discrepancies. The P-SV_1 section actually looks at bit stretched (slower) than the P-SV_2 section (see Figure 14).

CONCLUSIONS

The VSP and surface seismic data acquired in the Willesden Green surveys are of very good quality. There is an excellent tie among the synthetic seismogram, the P-wave and P-SV VSP sections, and surface seismic sections. From these ties, a compelling preliminary interpretation can be made of the seismic signature of the geology. However, at this point, there is no obvious evidence of P- or S-wave anisotropy. We will continue to reprocess and interpret these data for more subtle features

ACKNOWLEDGMENTS

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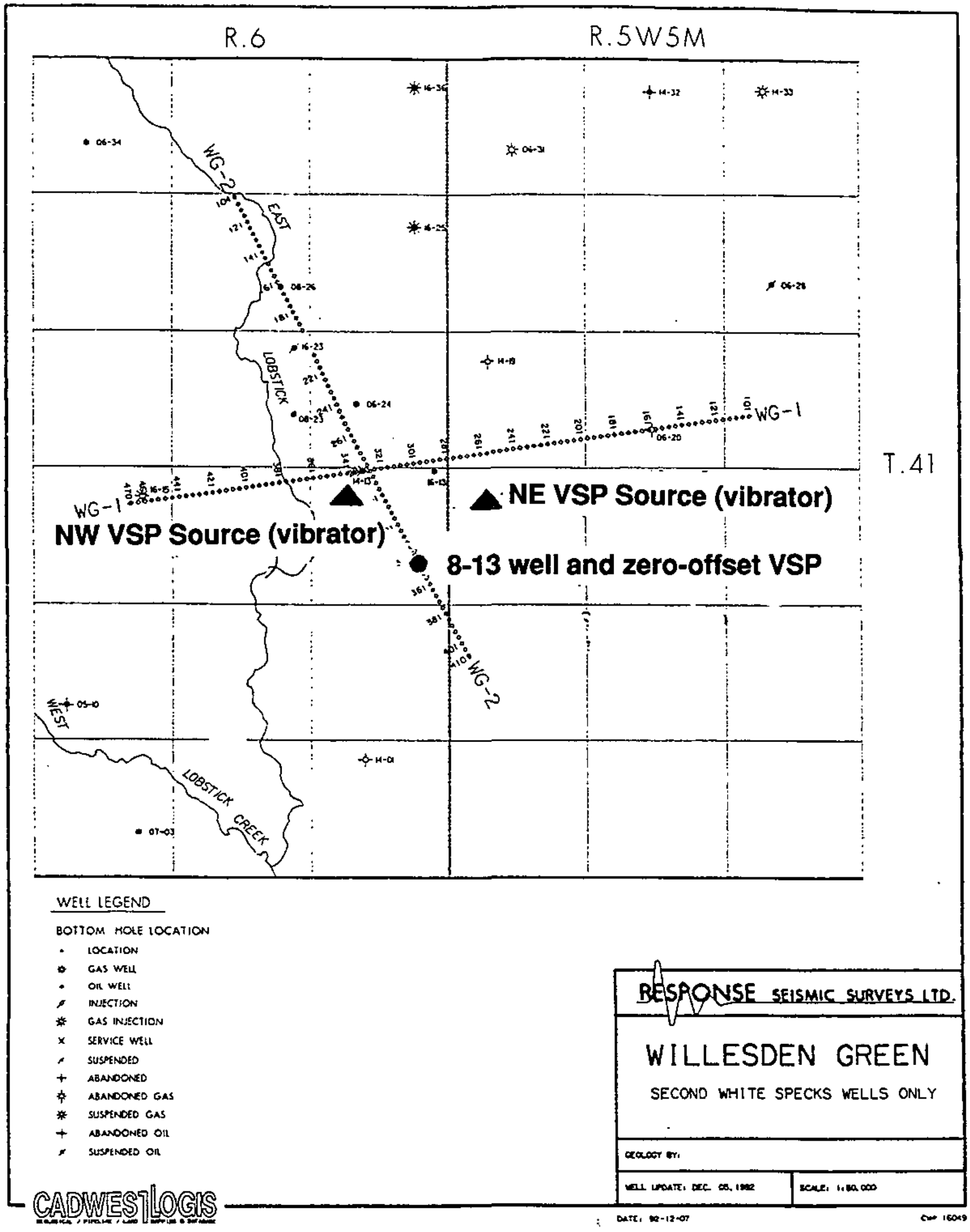

FIG. 1. Location map of the study area with seismic lines, wells, and VSP locations annotated.

Formation Tops
(8-13-41-6W5)

PAGE 1

08-13-041-06W5/00   Tripet Et Al Willgr 8-13-41-6   08-13-041-06 W5
WLLSDN 2w Specks L (ALTA)

*** Header ****		**** Elev/Depth **		* Co-Ordinates *		******** Dates *******	
License:	142815	Ground:	1030.0m	Lat:	52.52768d	FirstReport:	1990 Jan 16
Class:	NPW	Kb:	1034.5m	Lon:	114.72550d	Spudded:	1990 Jan 18
Status:	PD	FinalTot:	2200.0m	N/S:	497.3m N	RigRelease:	1990 Jan 27
Opr/Agt:	AK1	TrueVert:		E/W:	354.8m W	OnProd:	1990 Mar 23
Faulted:	No	PlugBack:				CurrStatus:	1990 Mar 23
Dir:	No	WhipStock:				LastUpdate:	1992 Feb 23

*** Digitech Tops ***

Formations	Depth (m)	SubSea (m)	Rank	Formations	Depth (m)	SubSea (m)	Rank
EDMTN	436.0	598.5	FRM	BDHTSS	1748.0	-713.5	SMB
KNEEHT	682.5	352.0	MRK	BDHTSB	1752.0	-717.5	MRK
BRPAW	1108.0	-73.5	FRM	CARD	1845.0	-810.5	FRM
BLYRIV	1251.0	-216.5	FRM	PEMBSS	1868.5	-834.0	SMB
BLYRSS	1251.0	-216.5	SMB	PEMBSB	1888.0	-853.5	MRK
BSLBLY	1387.0	-352.5	SMB	BLKSTN	1909.0	-874.5	FRM
BUCKSS	1500.0	-465.5	SMB	COL30	1980.0	-945.5	MRK
BUCKSB	1510.0	-475.5	MRK	SWSPK	2033.0	-998.5	MRK
RIBTNG	1512.5	-478.0	SMB	LCOL	2103.0	-1068.5	MRK
RIBTGB	1518.0	-483.5	MRK	BSWSPK	2103.0	-1068.5	MRK
K' PARK	1518.0	-483.5	FRM	LCRET	2142.0	-1107.5	SER
	1542.5	-508.0	MRK	BFSC	2142.0	-1107.5	MRK
COL	1650.0	-615.5	GRP	VIK	2165.0	-1130.5	FRM
FWSPK	1650.0	-615.5	MRK	VIKSND	2176.0	-1141.5	SMB

Completion	Top (m)	Base (m)	Date	S#	Source
JETP	2118.0	2128.0	1990 Feb 19	13	B
ACDS	2118.0	2128.0	1990 Feb 27	0	B
BRDG	2106.0	2114.0	1990 Feb 28	0	B
JETP	2037.0	2044.0	1990 Feb 28	13	B
JETP	2049.0	2058.0	1990 Feb 28	13	B
FRAC	2037.0	2058.0	1990 Mar 03	0	B
FRAC	2037.0	2058.0	1990 Mar 14	0	B
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LogType	Top (m)	Base (m)
RA	272.2	2192.0
DIL	272.2	2188.0
GR	1950.0	2179.0
CDL	2100.0	2179.2
AA	1840.0	2176.0
FT	1867.0	2193.0
MUD	1200.0	2200.0
CDL	2050.0	2179.0

CoreType	No	Top (m)	Base (m)	Amount (m)	Fluid	Analy
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CasingType	Size (mm)	Depth (m)
S	219.1	273.0
P	139.7	2199.5

Test	Date	Top (m)	Base (m)	Depth (m)	VOT (min)	BHP (kpa)	FFP (kpa)
	1990 Feb 27	2118.0	2128.0				

=S and Recovery : W// 6.7 CM

FIG. 2. Formation tops for the 8-13 well.

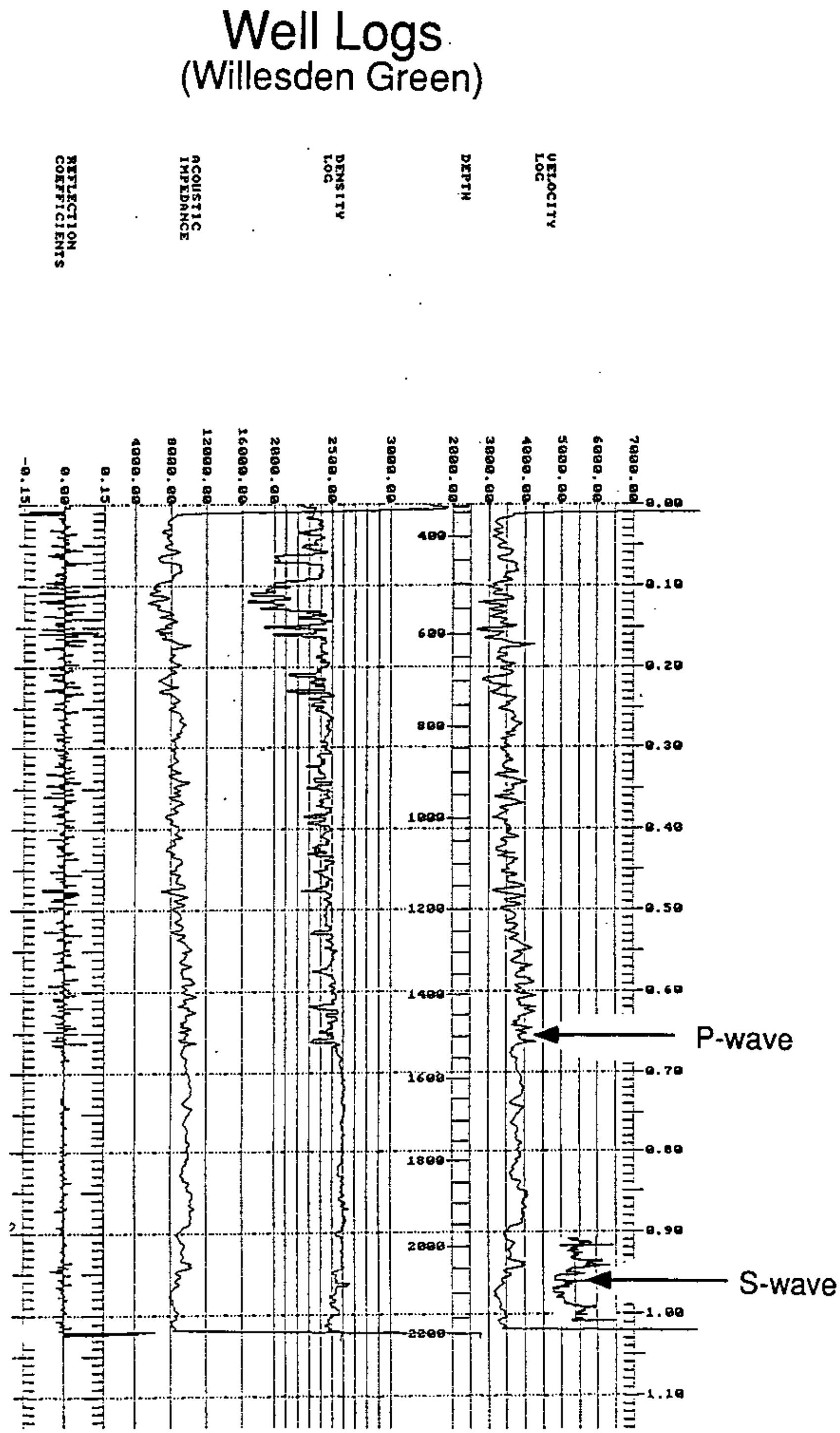

FIG. 3. Well logs from the Tripet et al (8-13-41-6W5) well. a) reflectivity b) acoustic impedance c) density d) P-wave velocity e) S-wave velocity.

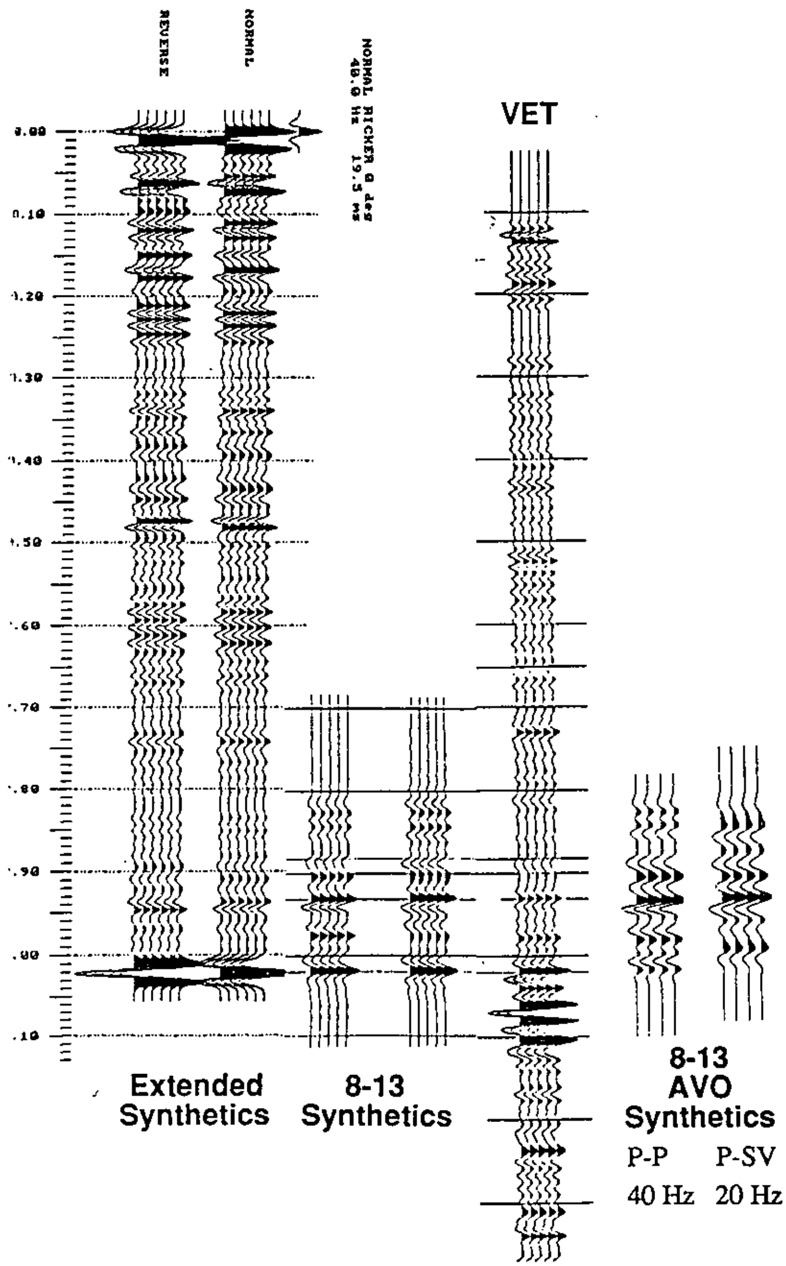

FIG. 4.Synthetic seismograms calculated from the 8-13 log with the VET spliced between zero-offset and AVO synthetics.

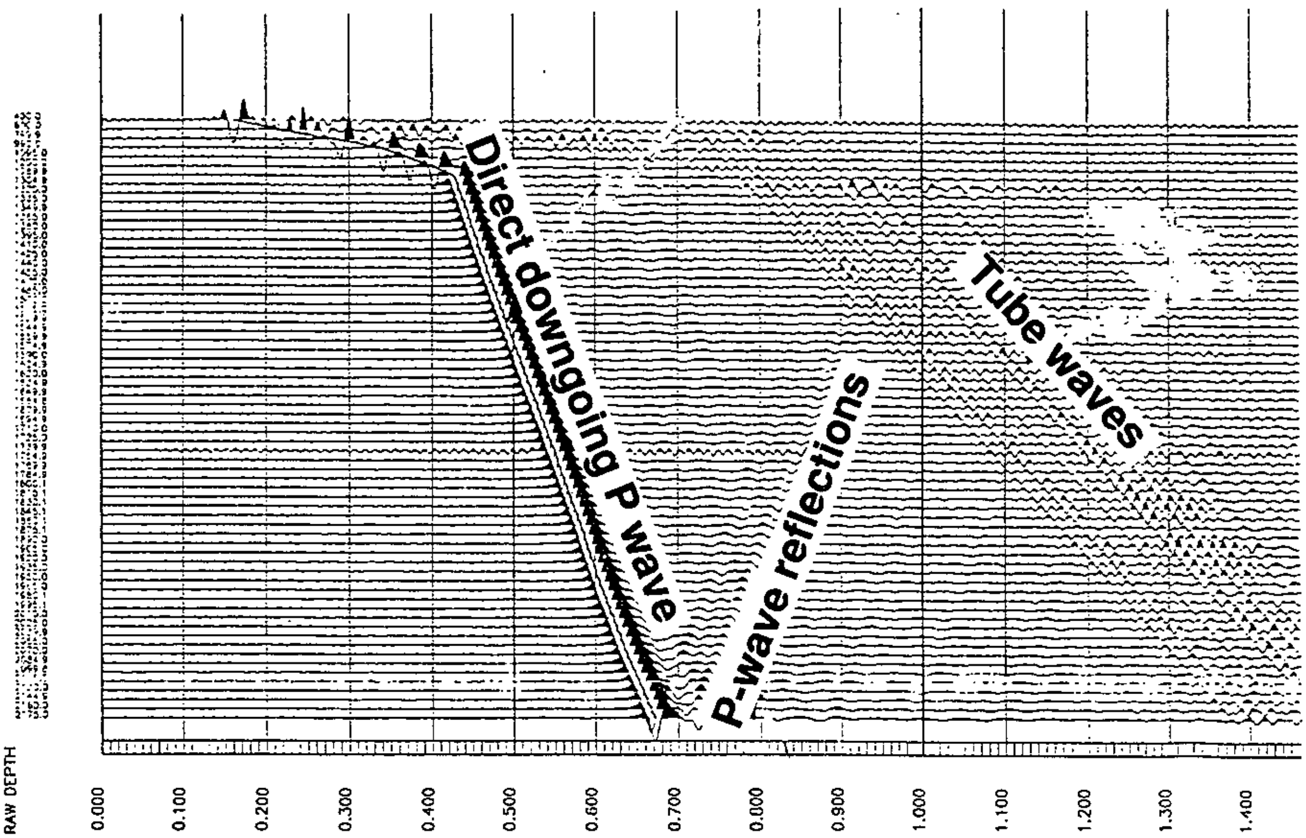

FIG. 5. Vertical component recordings from the zero-offset VSP.

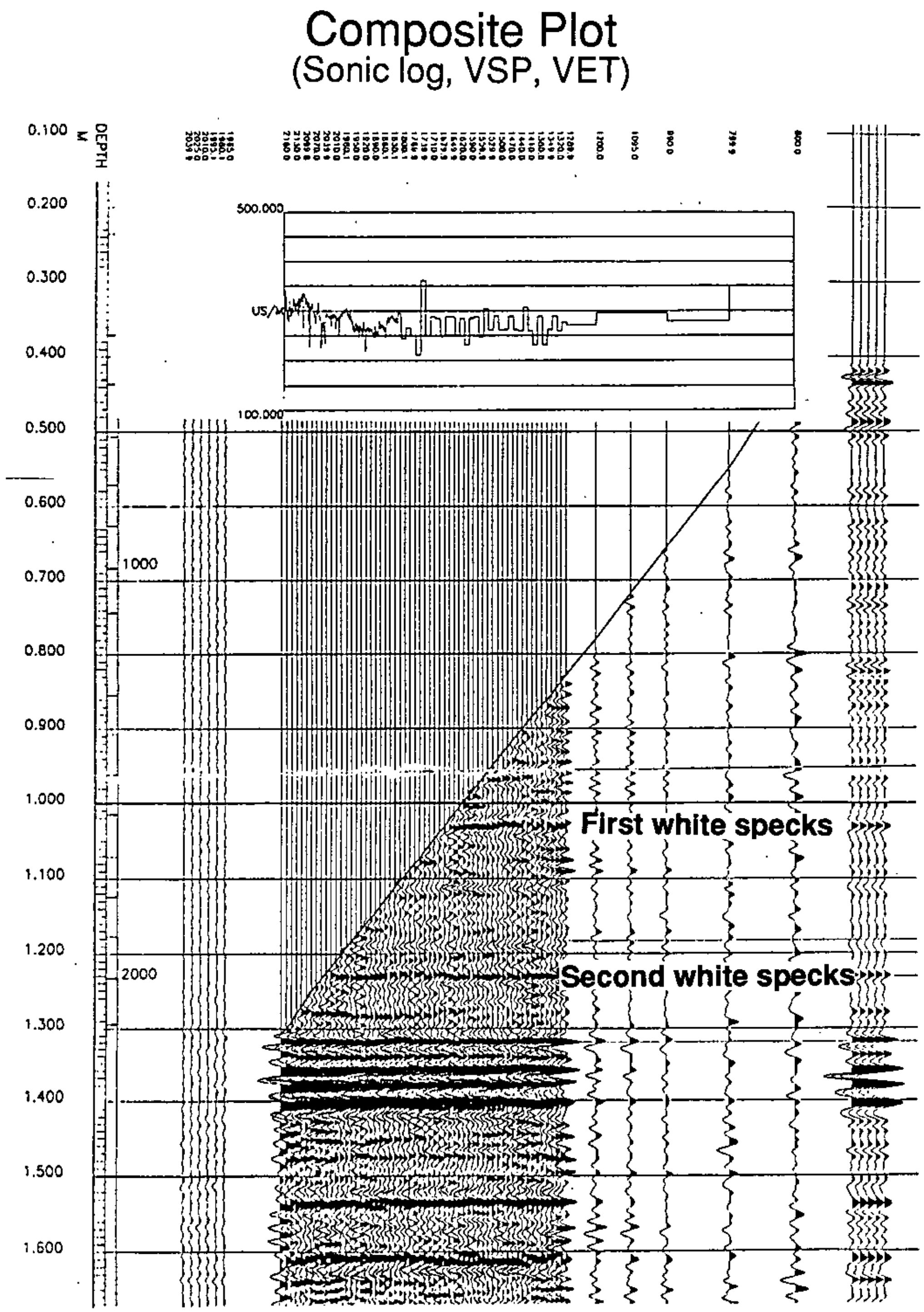

FIG. 6. Composite plot including the sonic log in depth, the zero-offset traces stretched to two-way time, and corridor stack (VET).

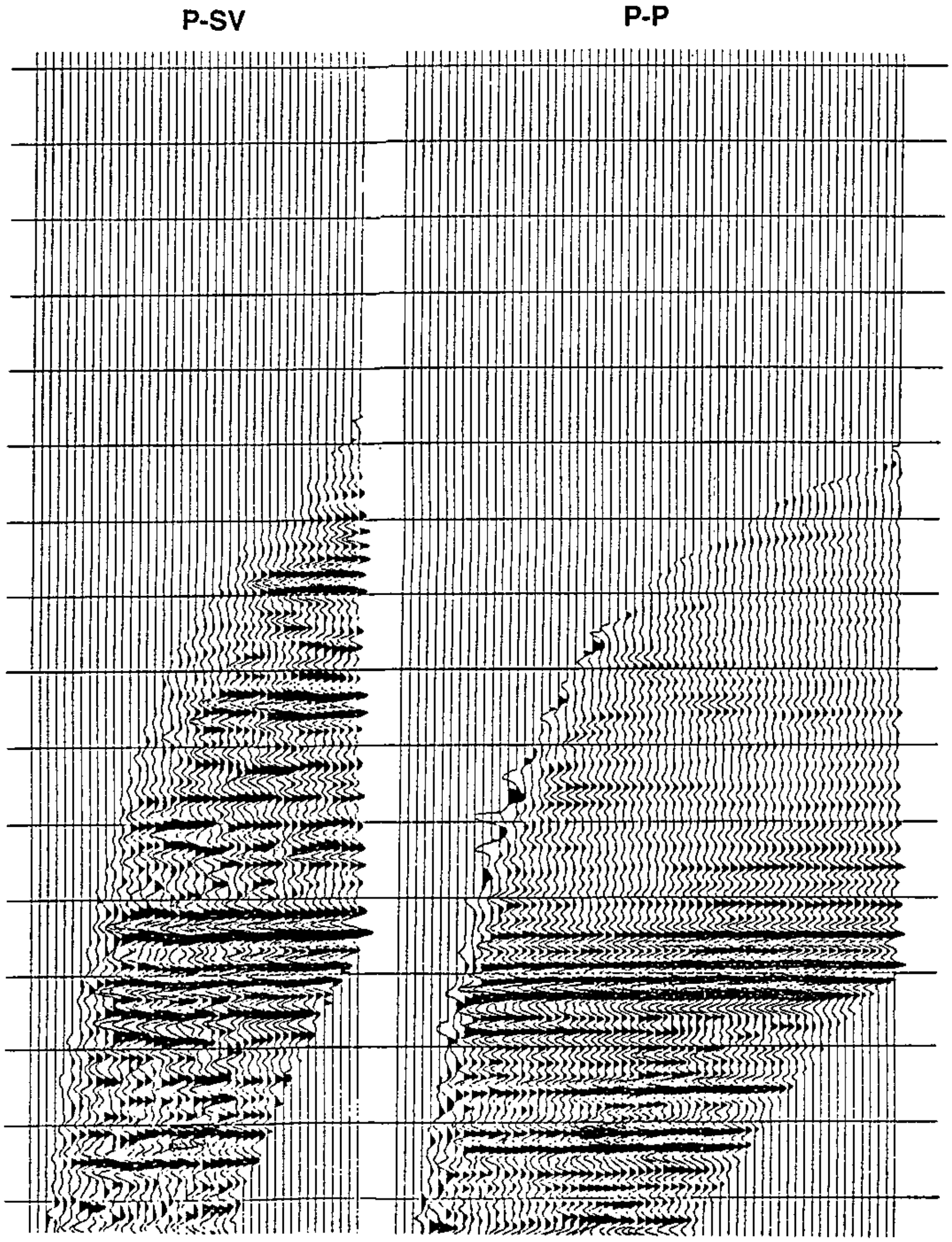

FIG. 7. Offset VSP sections plotted in two-way time.

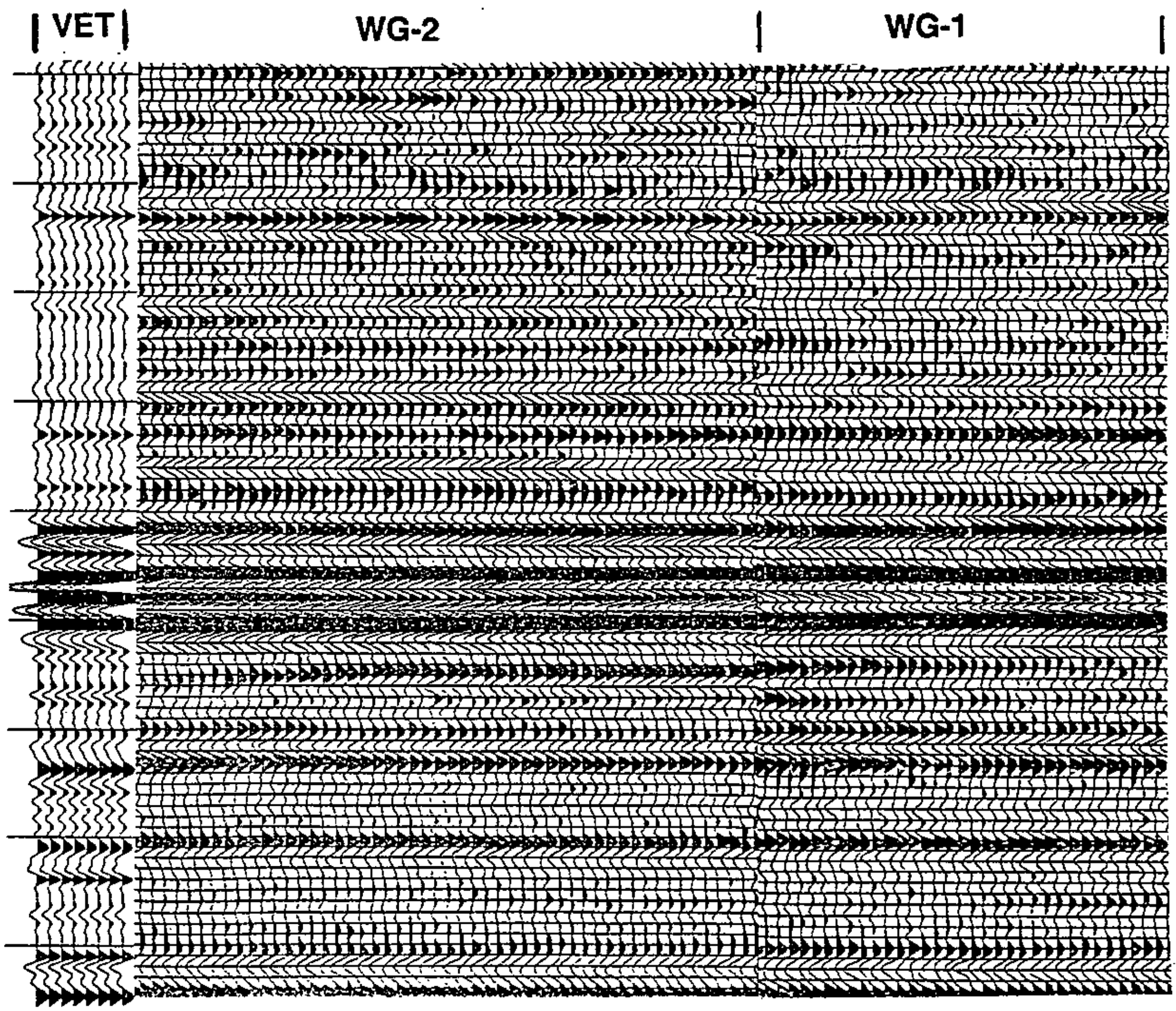

FIG. 8. VET spliced onto line WG-2 at the well location. Line WG-2 and line WG-1 spliced together at their intersection .

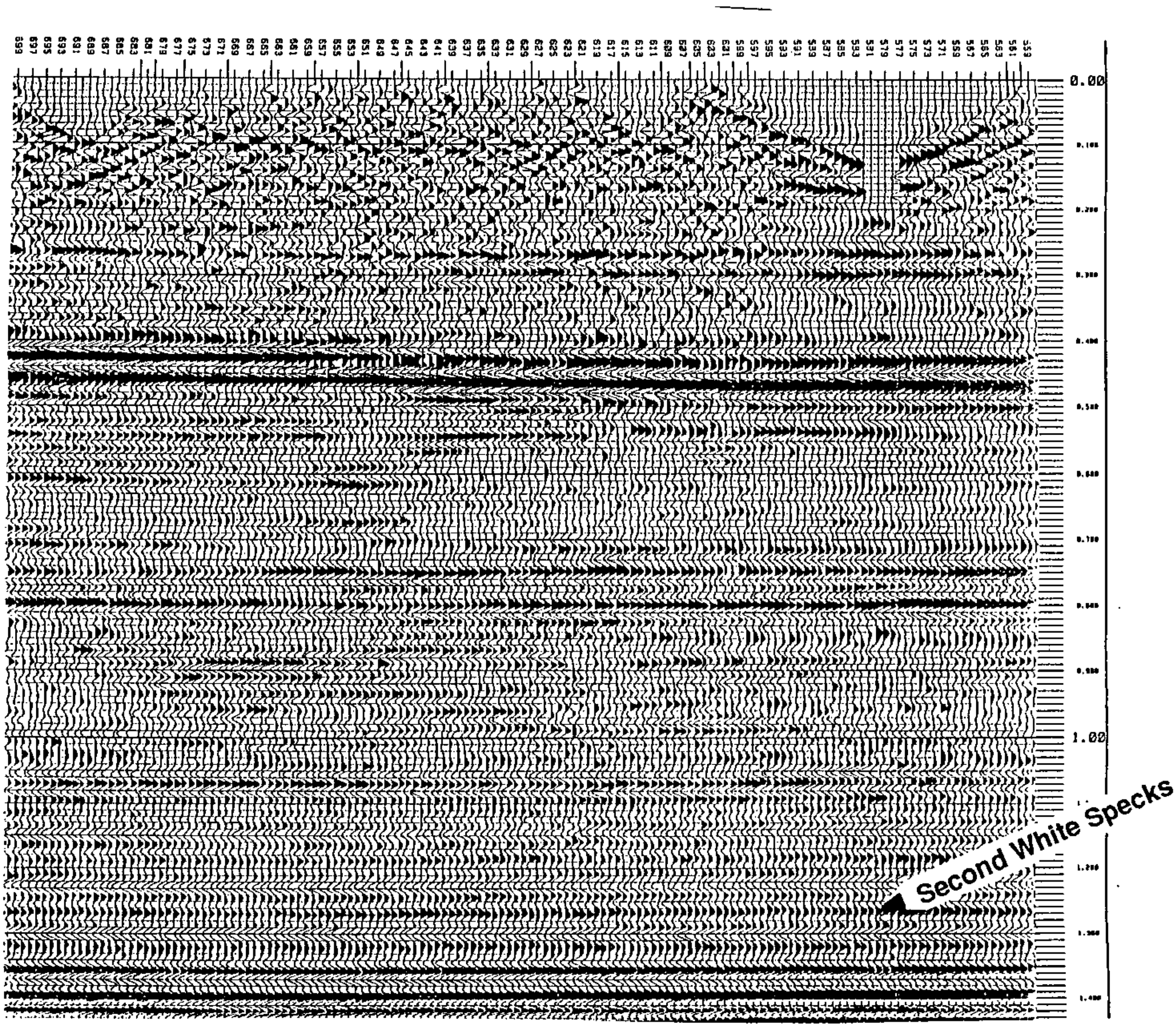

FIG. 9. P-wave seismic section with interpreted Second White Specks horizon annotated.

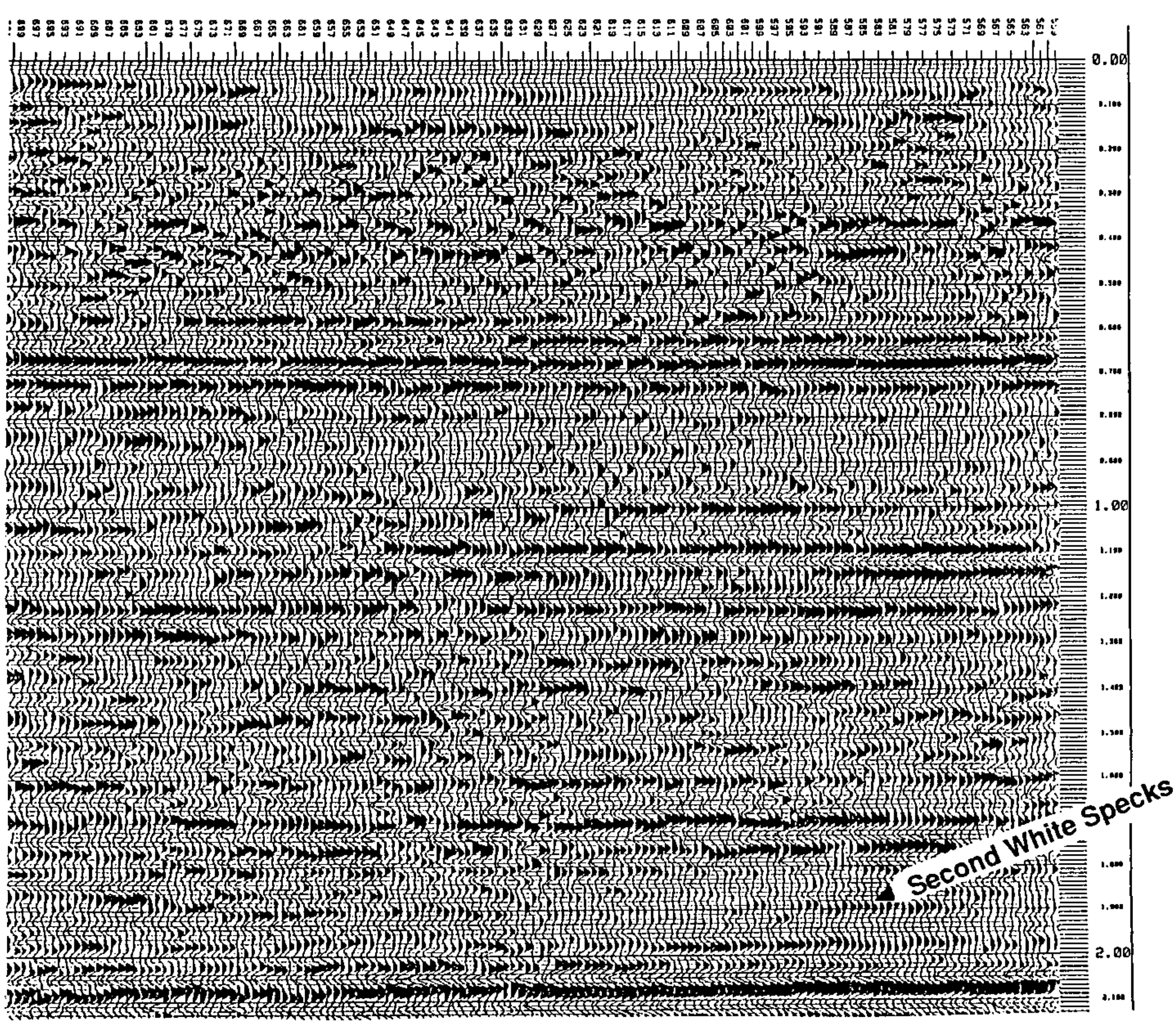

FIG. 10. Converted-wave section with interpreted Second White Specks horizon annotated.

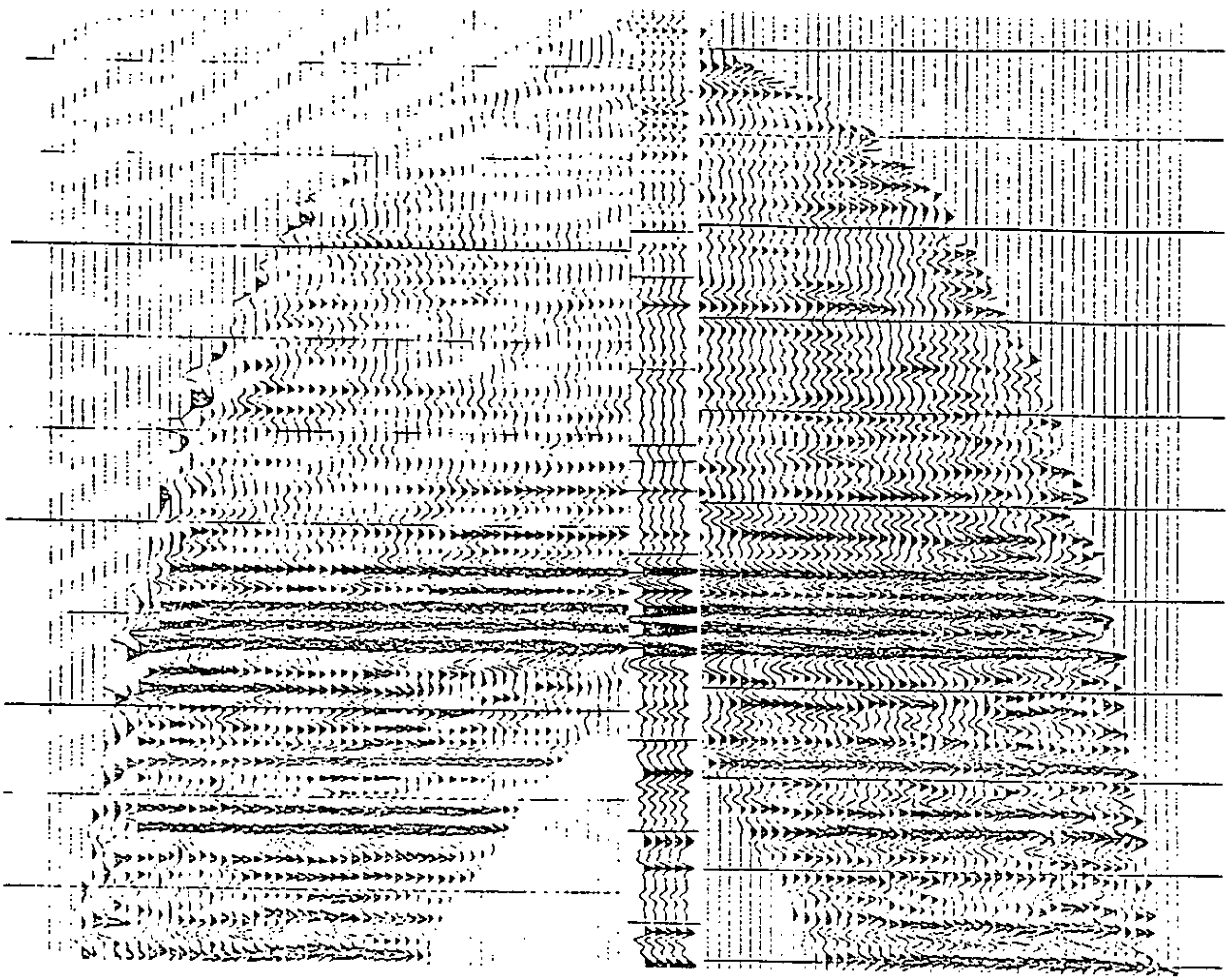

FIG. 11. Offset P-wave VSP from a) NW source and c) NE source with b) the VET spliced in between.

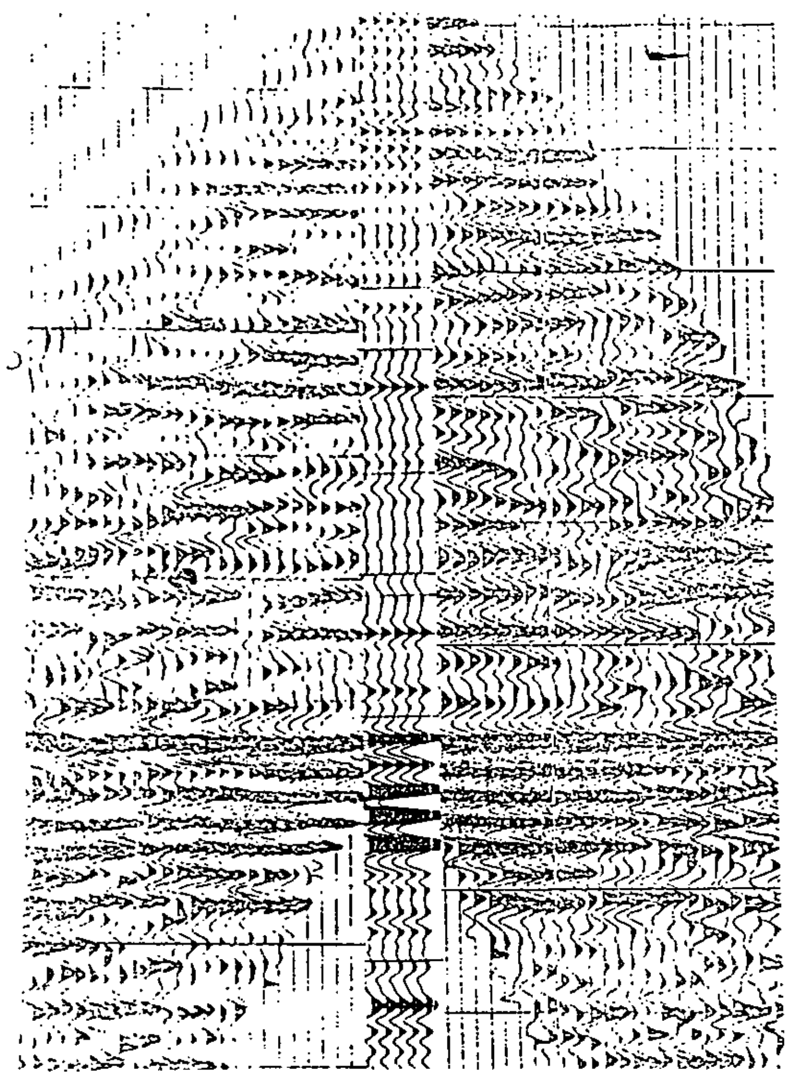

FIG. 12. Offset P-SV VSP from a) NW source and c) NE source with b) the VET spliced in between.

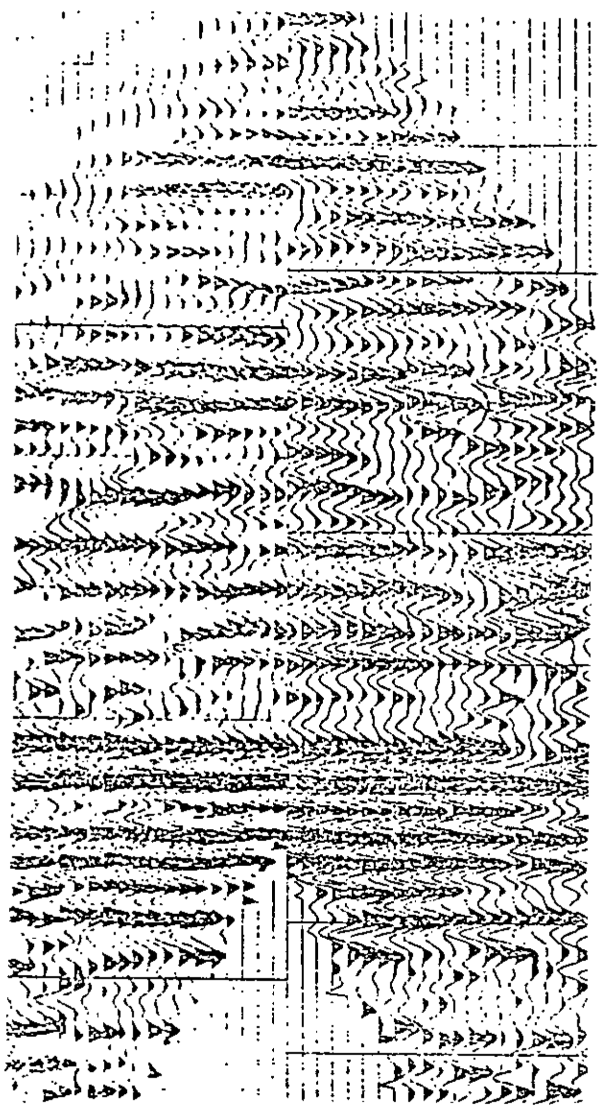

FIG. 13. Offset P-SV data, as in Fig. 9, now spliced closer together.

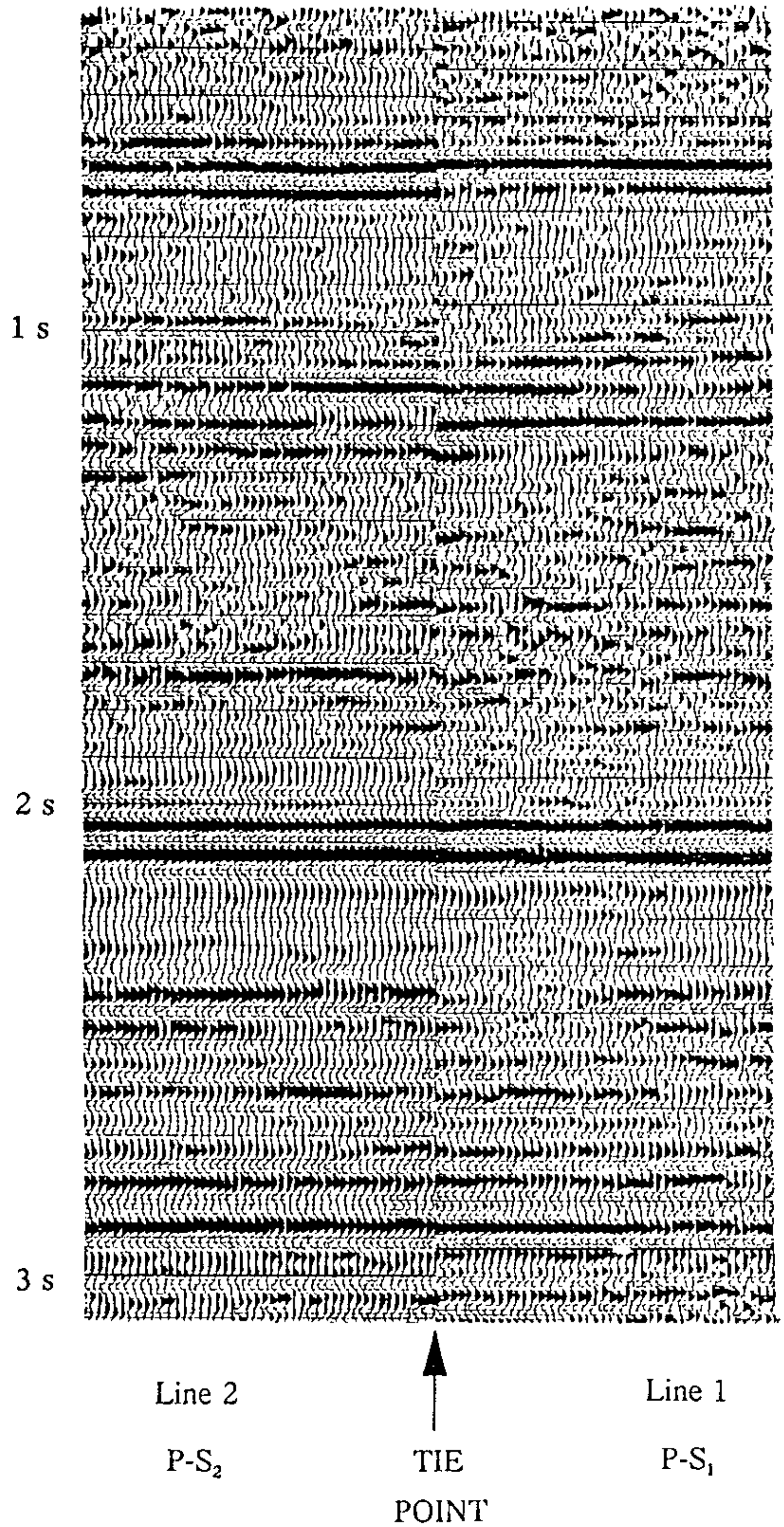

FIG. 14. Slow P-SV section from line WG-2 and fast P-SV section from line WG-1.