

**Receiver Comparison of Vertical Seismic Profile Data
from the GEM Site Well 0-6.**

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Kansas Geological Survey
Open File Report 94- 45

September 1994

Introduction

Two vertical seismic profile (VSP) data sets were collected at the GEM site, north of Lawrence, on September 17, 1994. The purpose of the data collection was to test the use of a hydrophone in VSP data collection and to compare the results to those obtained from a three-component downhole geophone (detailed in Martinez, et al. 1994).

The well used for the survey, GEMS well 0-6, is a 4", pvc-cased well with a total depth of approximately 80'. The water table was located approximately 20' below ground level. A natural gamma-ray log with generalized lithological information for well 0-6 is shown in figure 1.

Equipment & Data Collection

The data were collected using a hydrophone as a receiver, and an airless jackhammer as a source. The data were recorded on a Bison 2400 seismograph, with a 250 ms sample rate.

Both VSP surveys began at the bottom of the well (80'), and went to the water table. Data were recorded every 2.5' along this interval. The source was placed in two locations, the first was 15' due south of the well, and the second 1.5' south-east of the well. Each of the recorded traces consists of 5 impacts of the airless jackhammer, vertically stacked.

The observers' sheets from the survey are in Appendix A.

Data Processing

The data conversion and processing were performed using the program SierraSEIS on a Sun workstation. The same basic procedures were used to process both data sets. Unless specified, all figures are from the 15' source-offset data set. The SierraSEIS jobs used to perform the processing detailed below are included in Appendix B.

After importation into SierraSEIS, a front-end mute was applied to the data in order to remove spurious random noise above the first arrivals (figure 2). Then a frequency analysis was performed and the data was bandpass filtered accordingly (figures 3-4). Next, the downgoing waves were separated from the upgoing waves through the use of a box-car f-k filter (figure 5). The downgoing waves were then used to design a deconvolution operator for the data set (figure 6). Once a desirable deconvolution operator was designed, the upgoing waves were separated (figure 7), and the operator was applied to them (figure 8). Next the data were flattened by a static shift in order to correct them from one-way to two-way travel-times (figure 9). Finally they were stacked, and the resulting trace was repeated several times for viewing ease (figure 10).

The 1.5' source-offset data was deemed unusable, due to the high number of ringing events present throughout the entire recording time. The raw, 1.5' source-offset data is provided in figure 11.

Results and Conclusions

There are two reflectors seen on the VSP data set collected with the hydrophone. They are visible on the pre-stacked, flattened data (figure 9). These events are the top of the sand and gravel bed, and the top of the bedrock, respectively. When these data are stacked, however, the two reflectors merge into the single event seen in figure 10. This is due to the rather weak reflection from the bedrock, and the interference of other events, such as tube waves.

Comparison of the hydrophone data with the previously acquired three-component downhole geophone data reveals distinct similarities as well as marked differences between the two sets.

The coupling of the geophone to the well casing reduces the amplitude and number of tube waves recorded in comparison to the loose hydrophone (figure 12). This results in a large difference in overall data quality, as less filtering and deconvolution is necessary to properly image reflections (figure 13).

The three-component downhole geophone data has distinct reflections from the top of the sand and gravel bed at 40' and the bedrock surface at 70'. These reflections are located at 30 ms and 35 ms, respectively, on the stacked section. The stacked section from the hydrophone data does not resolve these two individual reflections (figure 14).

In conclusion, the three-component geophone provides more useable data than the hydrophone. However, the size of the geophone (2.5" diameter), limits its usage to holes with a minimum diameter of three inches. The geophone cannot couple to borehole walls with a maximum diameter greater than 8", due to the limited expansion of its air-filled bladder. The hydrophone is capable of recording data in a borehole of 1.5" or greater and does not rely on a sometimes troublesome air-filled bladder, making it a more versatile downhole receiver.

Bibliography

Martinez, A., Hopkins, J., Anderson, N. and Barrett, B., 1994. Shallow Vertical Seismic Profile (VSP) Survey of the GEM Site Well 0-6. KGS Open File Report 94-40.

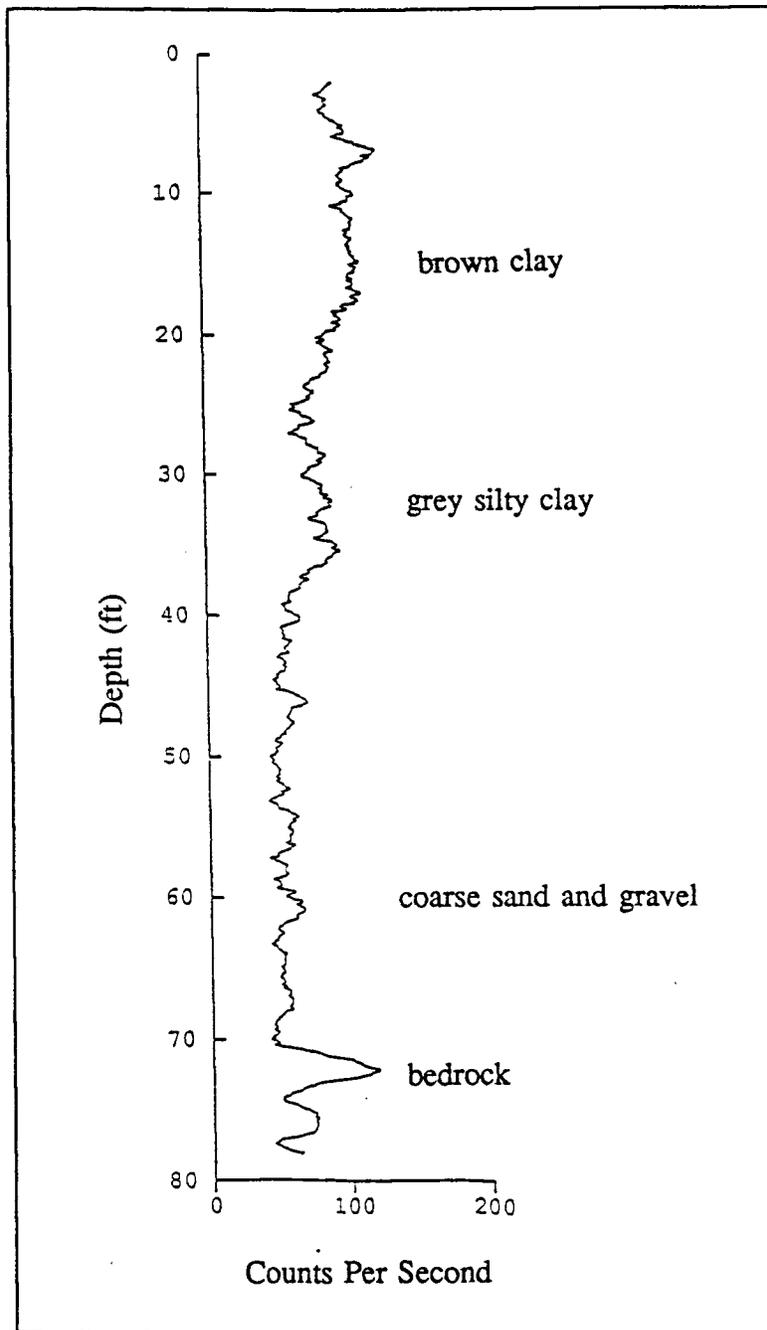


Figure 1: Natural gamma-ray log from GEMS well 0-6 (run 11/06/90). Note the base of the sand and gravel at approximately 40', and the bedrock surface at approximately 70' (Martinez, et al., 1994).

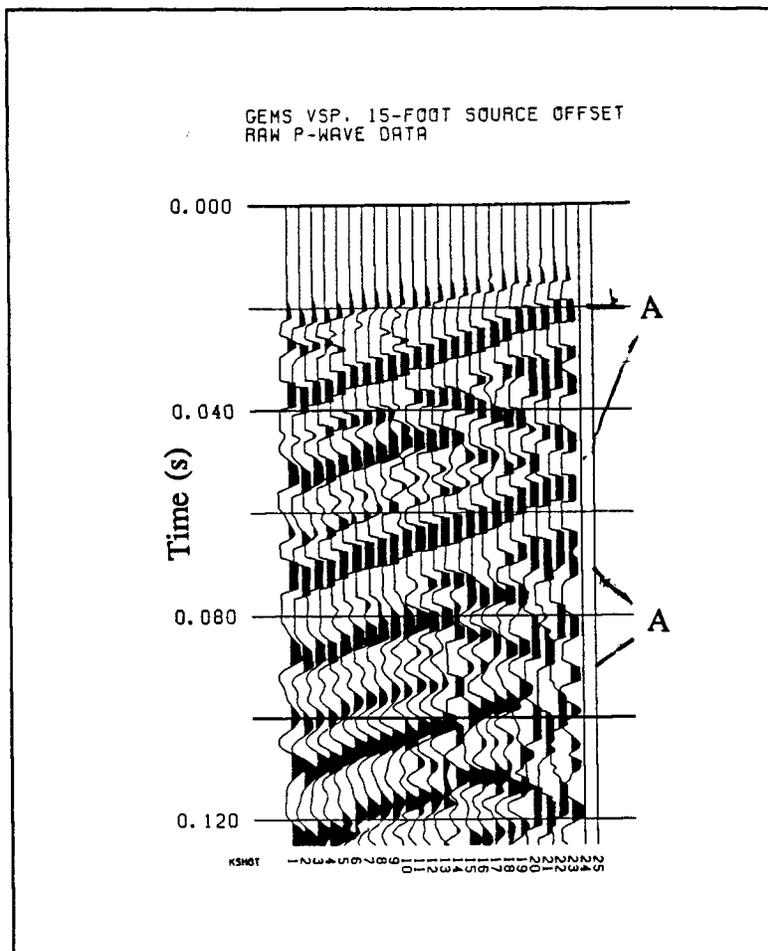


Figure 2: Field data. A front-end mute has been applied to the data above the first arrivals, and traces 24 and 25 have been removed. Note the multiple events (A) present throughout the data set.

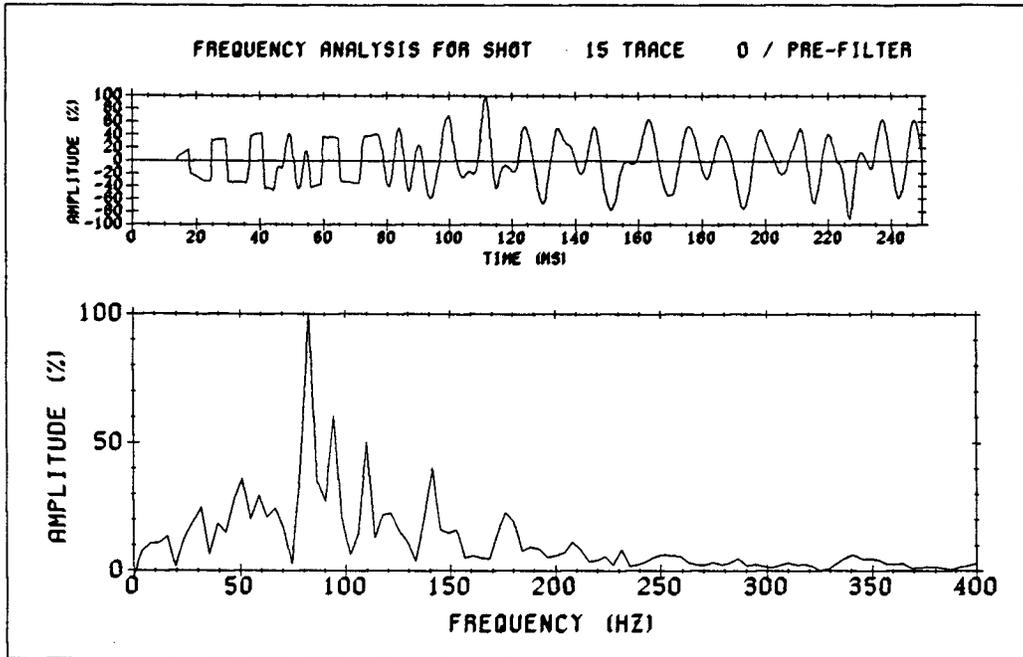


Figure 3: Frequency spectrum of trace 15 from the raw data. As seen above, the data has a dominant frequency of approximately 80 hz, and has spurious events both below 50 hz and above 200 hz.

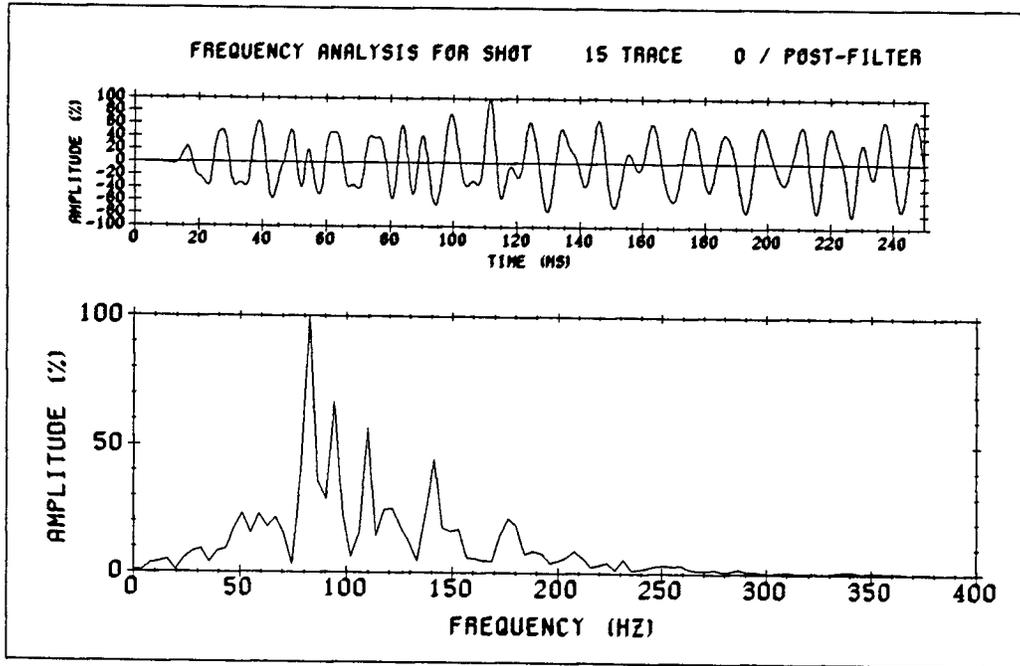


Figure 4: Frequency spectrum of trace 15 after bandpass filtering. A bandpass filter of 60-175 hz was applied to the raw data in order to reduce the effect of multiple events and high frequency noise. Note that the frequency spectrum amplitude has been reduced both below 50 hz and above 200 hz.

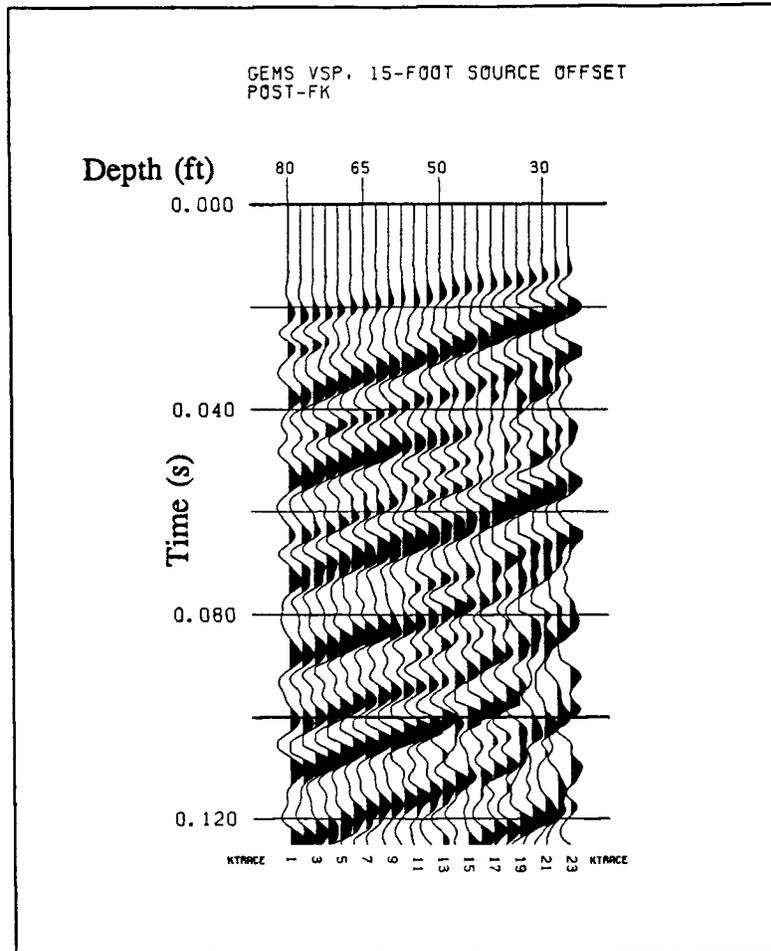


Figure 5: Downgoing waves. This figure shows the results of applying a boxcar-shaped (0.03-0.47 k) f-k filter to the raw data. Only the downgoing events, such as the first arrivals, remain. These data were used to design a deconvolution operator for the data set.

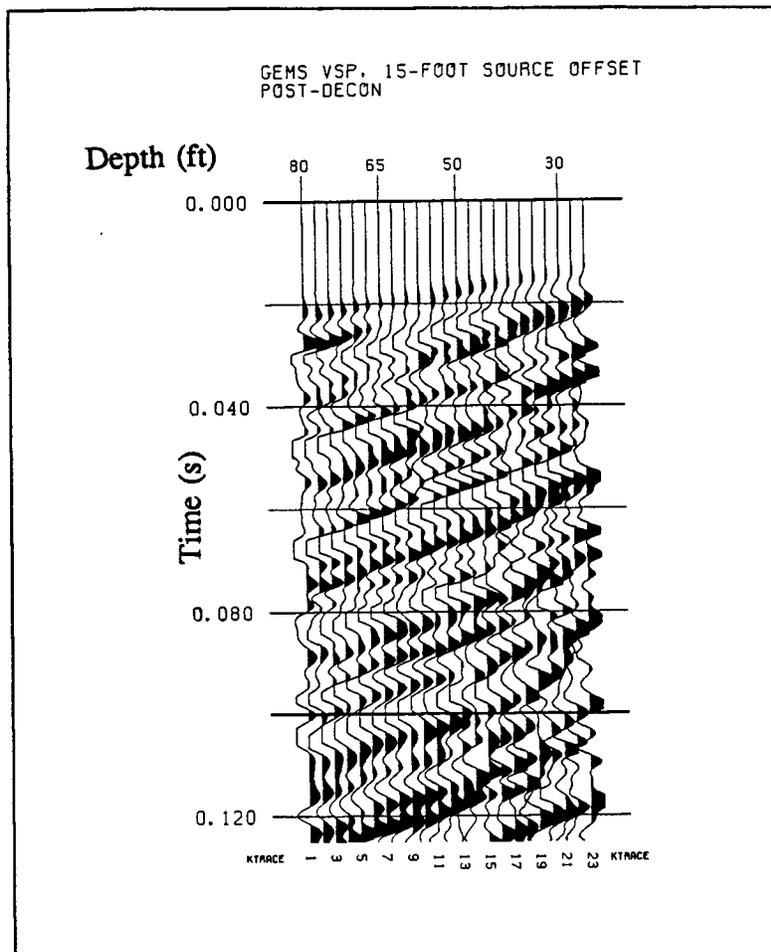


Figure 6: Downgoing waves, post-deconvolution. The results of applying a deconvolution operator to the data are shown in this display. The function applied had an operator window 150 ms, an operator length of 20 ms, and a prediction lag of 3 ms.

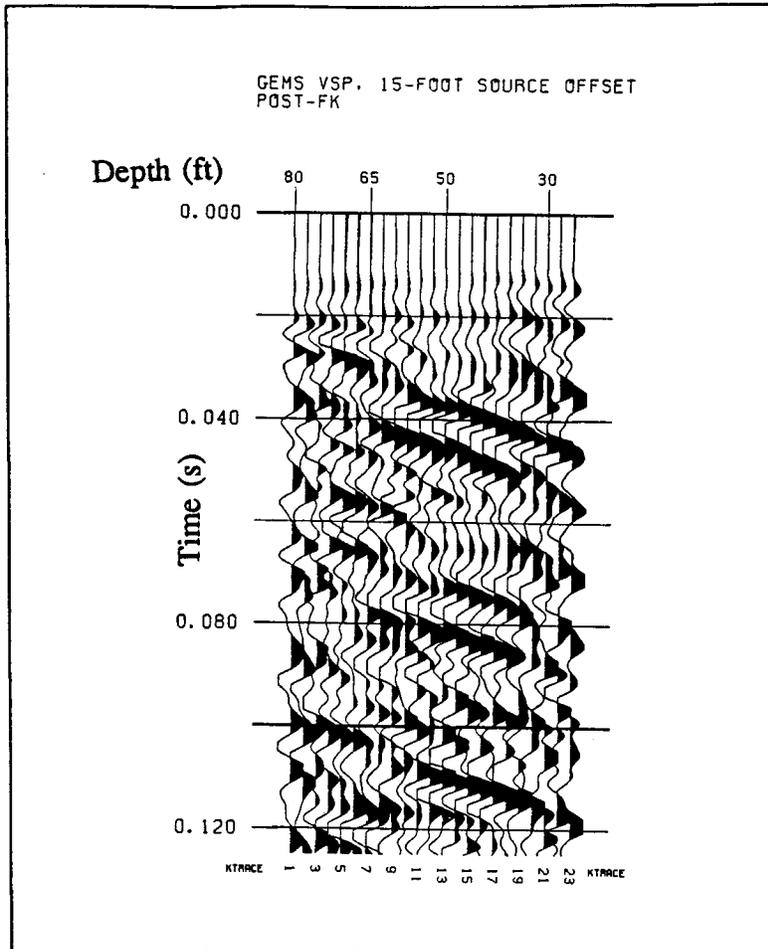


Figure 7: Upgoing waves. This figure shows the results of applying a boxcar-shaped (-0.47 to -0.03 k) f-k filter to the raw data. Only the upgoing events (reflections) remain.

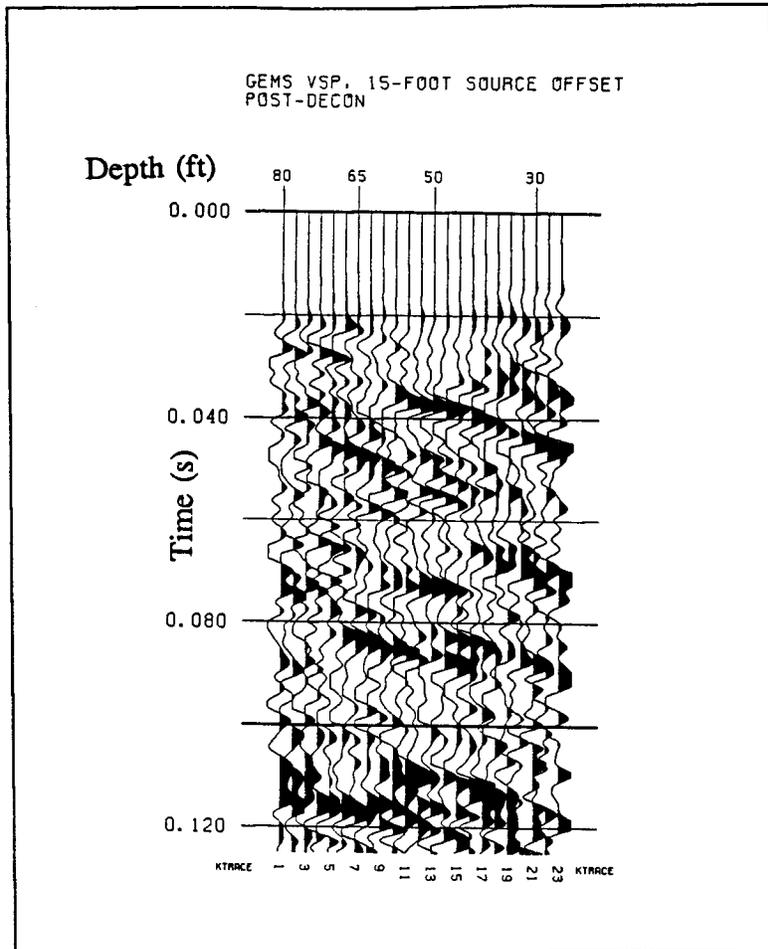


Figure 8: Upgoing waves, post-deconvolution. The deconvolution operator designed with the downgoing waves was applied. In addition, another deconvolution operator was applied in order to remove upgoing multiple events.

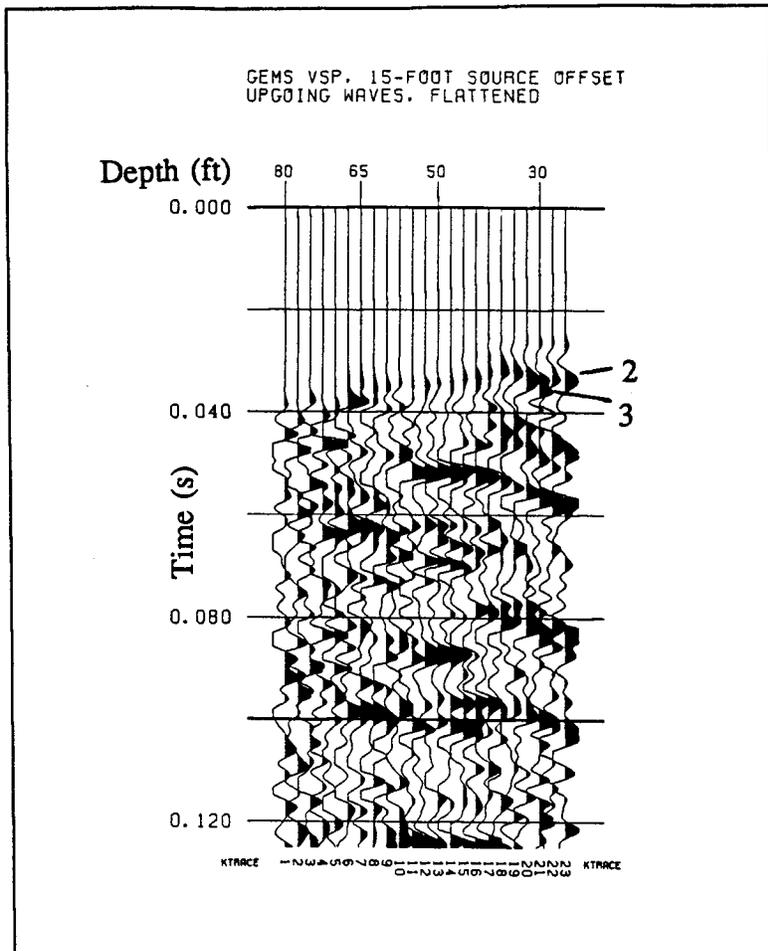


Figure 9: Flattened upgoing waves. This data set was corrected for depth by using the travel times from the first arrivals. This converts the data from one-way to two-way time, resulting in the reflected events becoming flattened. Events 2 and 3 are reflections originating from depths of 40' and 70' respectively. These are the top of the sand and gravel bed, and the top of the bedrock.

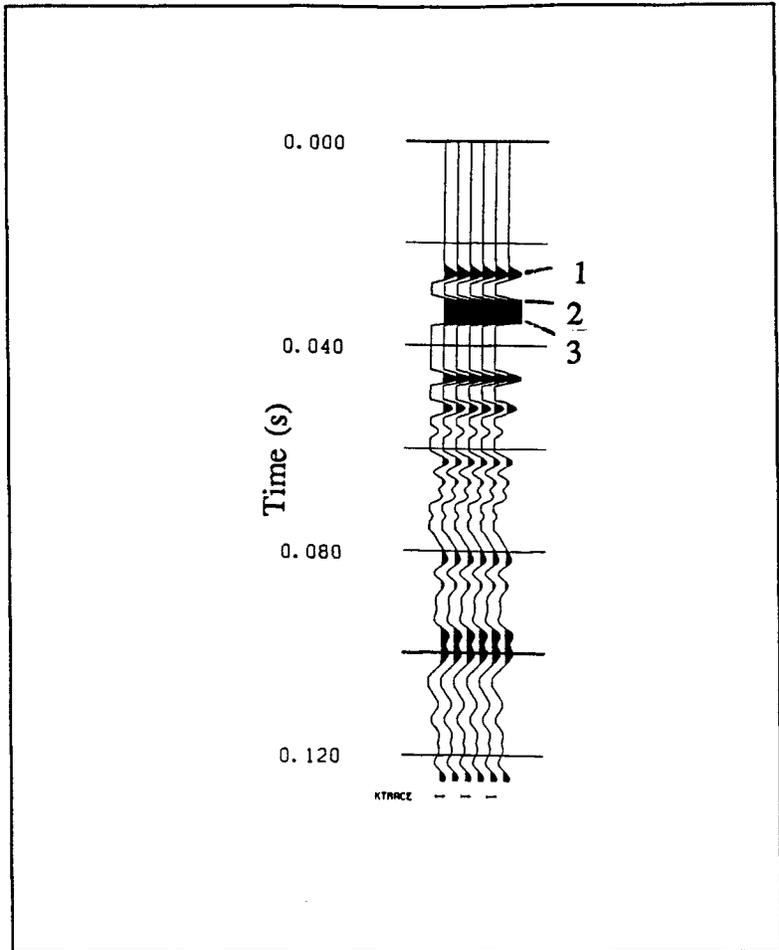


Figure 10: Stacked hydrophone VSP data. This is the result of summing the traces shown in figure 9. Event 1 is believed to be spurious noise. Events 2 and 3 from figure 9 have merged into one large trough, and are indiscernible from one-another. The lower events cannot be verified as to their nature due to the limited depths that the data were recorded.

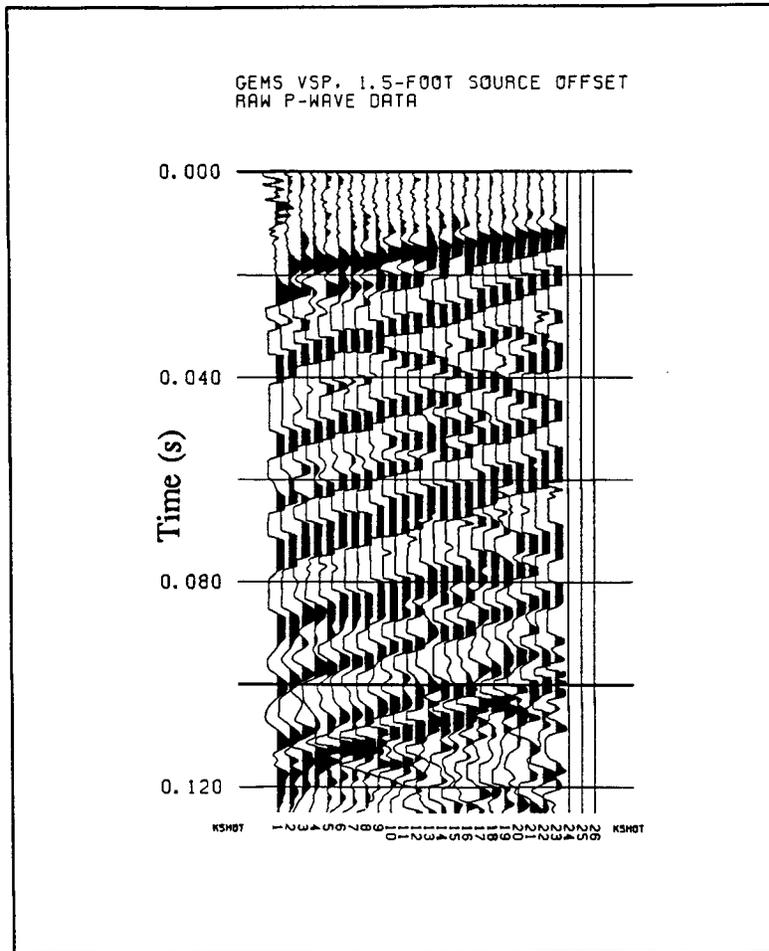


Figure 11: Raw 1.5' source-offset hydrophone VSP data. Note the many multiple events present in the data, due to the close proximity of the source to the well. The poor quality of this data set renders it essentially useless.

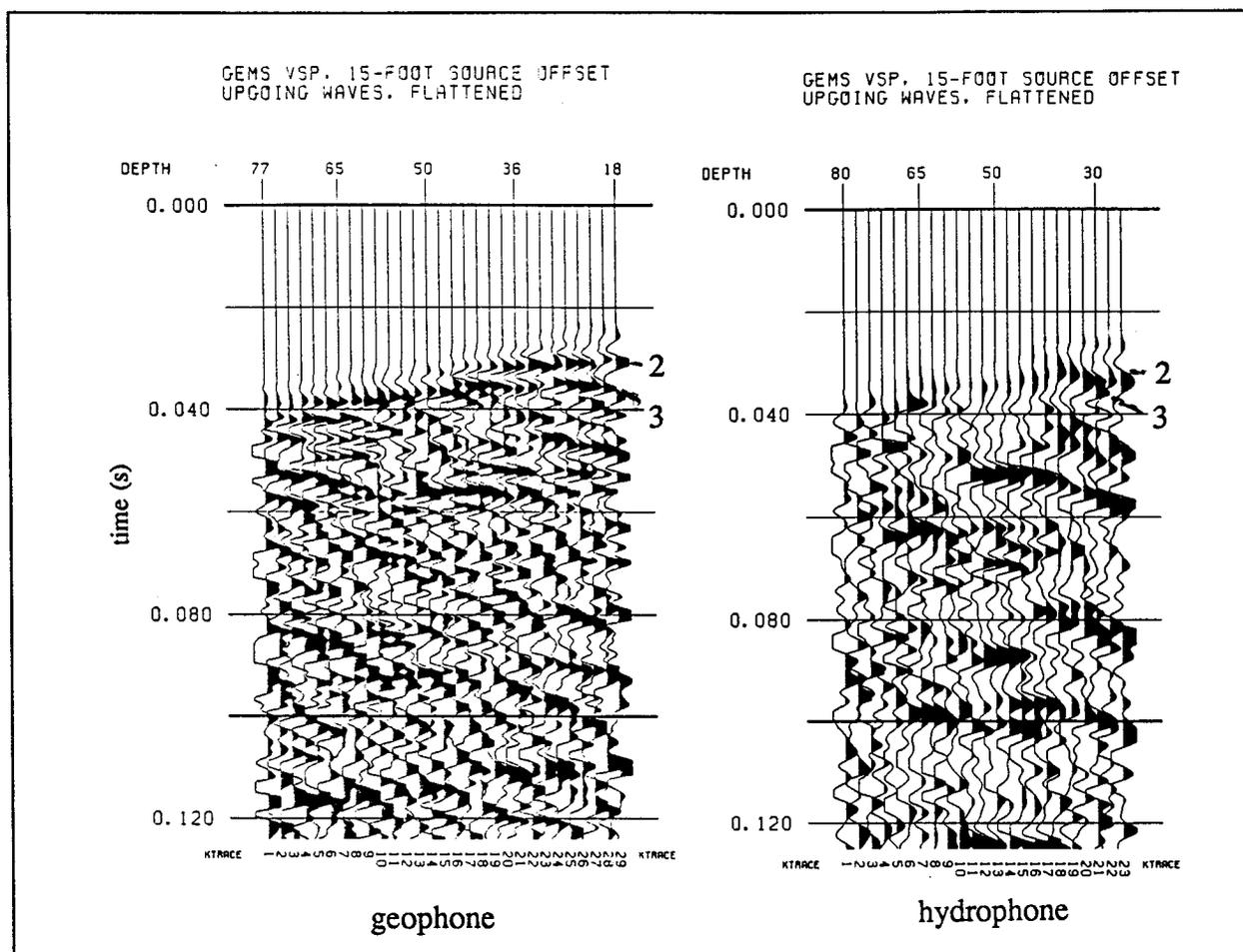


Figure 13: Flattened upgoing three-component geophone data versus hydrophone data. On both of these gathers, the reflections from the top of the sand and gravel (2), and the top of the bedrock (3), are visible. However, they are more easily discerned on the geophone data (modified from Martinez, et al., 1994).

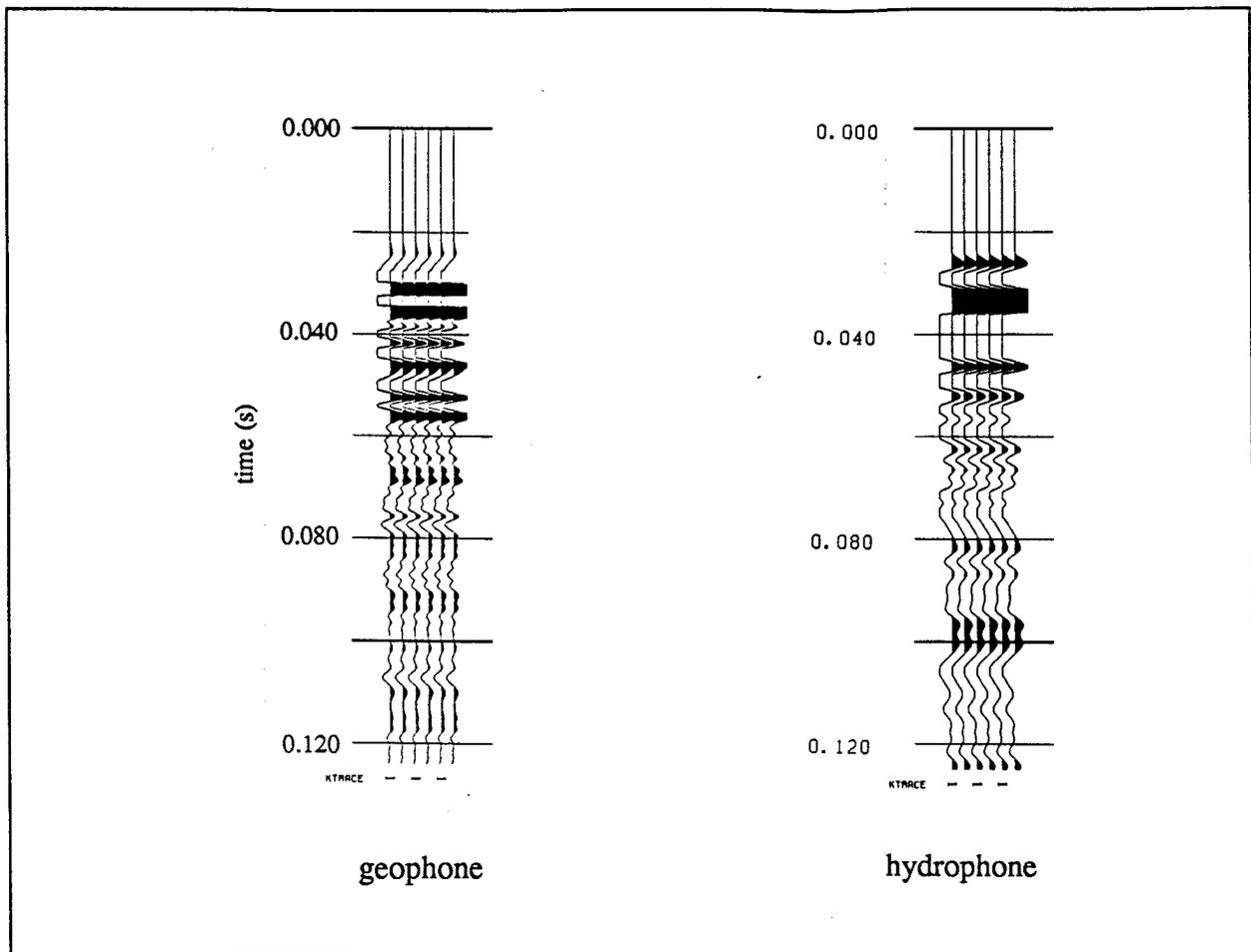


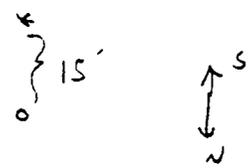
Figure 14: Comparison of three-component geophone stacked data to hydrophone stacked data. As can be seen above, the resolution of the stacked geophone data is much better than the stacked hydrophone data (modified from Martinez, et al., 1994).

APPENDIX A

Observers' Sheets

serial #	Test	depth from top of well (ft)
	0740	30
✓	0741	80'
✓ ✓	0742	77.5
✓	0743	75'
✓	0744	72.5'
✓	0745	70'
✓	0746	67.5'
✓	0747	65'
✓	0748	62.5'
✓	0749	60'
✓ ✓	0750	57.5'
✓	0751	55'
✓	0752	52.5'
✓	0753	50'
✓	0754	47.5'
✓ ✓	0755	45'
✓	0756	42.5'
✓	0757	40'
✓	0758	37.5'
✓ ✓	0759 0760	35'
✓	0761	32.5'
✓	0762	30'
✓ ✓	0763	27.5'
✓ ✓	0764	25'
✓ ✓	0765	22.5'
✓ ✓	0766	20'
	0767	

~15' S of well



source
airless-jack
w. plate

Low cut \rightarrow (open)
stack 5

no 758 (screw up) in setting (4' in)
lengths are OK

water table
at ~ 20' or less

done on 9/17/94

TEST

depth from top (ft)

(11.30)

~1.5' east of well

767	80'
768	77.5'
769	75'
770	72.5'
771	70'
772	67.5'
773	65'
774	62.5'
775	60'
776	57.5'
777	55'
778	52.5'
779	50'
780	47.5'
781	45'
782	42.5'
783	40'
784	37.5'
785	35'
786	32.5'
787	30'
788	27.5'
789	25'
790	22.5'
791	20' - WT
792	17.5'

(11:18)

APPENDIX B

SierraSEIS Jobs

- **Geometry Job.** This job defines the field geometry for later processors within SierraSEIS.

```

/JOB ACCT 'GEMSVSP' SCAN 72 FEET          15 -45
/GEOMETRY                                  16 -42.5
GEOMFILE 'GHVSP1'                          17 -40
SURVEY                                       18 -37.5
STBASE 1                                    19 -35
SPLIST D1 25 1                              20 -32.5
XYBASE 0, 0                                  21 -30
STATION                                       22 -27.5
 1  0 0                                       23 -25
 2  0 0                                       24 -22.5
 3  0 0                                       25 -20
 4  0 0                                       DATUM 0
 5  0 0                                       SPD R0,25
 6  0 0                                       TUH R0,25
 7  0 0                                       DVEL 1800
 8  0 0                                       $EOJ
 9  0 0
10  0 0
11  0 0
12  0 0
13  0 0
14  0 0
15  0 0
16  0 0
17  0 0
18  0 0
19  0 0
20  0 0
21  0 0
22  0 0
23  0 0
24  0 0
25  0 0
26 15 0
SHOT 1.0 AT 26 INTO 1
SINC 0 CINC 1 TO SHOT 25.0
PROF
SPEL R0,25
GPELX
 1 -80
 2 -77.5
 3 -75
 4 -72.5
 5 -70
 6 -67.5
 7 -65
 8 -62.5
 9 -60
10 -57.5
11 -55
12 -52.5
13 -50
14 -47.5

```

• **Processing Job.** This SierraSEIS job imports the raw VSP data and does the processes necessary to result in a final stacked trace. In several areas, the /PRMODCOM processor was used in order to transform the data from field files (data order 5) to common depth point gathers (data order 2) manually. It was necessary to transform the data in this manner because the /GATHER processor did not function properly.

```

/JOB ACCT 'GEMS' SCAN 72      /GATHER OUTSORT 2          15-foot source offset'
FEET                          /PRMODCOM INITPR          COMMENT 'Post-Decon'
/DIN FILENAME 'GHVSP1'      MODIFY KNSHOT UPDATE 1    TPATRACE 1, 7, 13, 21, 25
RESEQIT 1                   1                          TPAVALUE 80, 65, 50, 30, 20
/GEOMETRY GEOMFILE         /PRMODCOM                 TPATITLE 'DEPTH' TPAHGT
'GHVSP1' USE                MODIFY KTRACE UPDATE 1    0.08
/STATAPLY                   1                          /PRMODCOM INITPR
/DESPK                       /FKFILT                   MODIFY KSORT SET 5
/ZERO                        DESIGN -0.47 -0.03        /PRMODCOM
  FILE 24 TRACE 0           TAPER 0                  MODIFY KSORT SET 5
  FILE 25 TRACE 0          /DISPLAY HORZ 10 VERT 40 /STATAPLY
/MUTE                        TIMELINE 20, 40, 100     /STATAPLY
  BYFILE                    WINDOW 0 125              NOGEOM
  BYTRACE                   ANNOTATE TRAC EVERY 2    SHOTST 1 18, 2 20, 3 17, 4 19,
  FMUTE 1, 0 16            COMMENT 'GEMS VSP,       5 18, 6 16, 7 15, 9 15,
  FMUTE 25, 0 9           15-foot source offset'  10 13, 11 15, 16 13, 17 12,
/AGC WINDOW 20             COMMENT 'Post-FK'       18 12, 19 12, 23 12
/DISPLAY                    TPATRACE 1, 7, 13, 21, 25 /AGC WINDOW 30
  HORZ 10 VERT 40 TIMELINE TPAVALUE 80, 65, 50, 30,20 /DISPLAY HORZ 10 VERT 40
  20, 40, 100 WINDOW 0 125 TPATITLE 'DEPTH' TPAHGT TIMELINE 20, 40, 100
  ANNOTATE FILE           0.08                      WINDOW 0 125
ANNOTATE TRC EVERY 2      /DECONV                   ANNOTATE TRAC EVERY 2
COMMENT 'GEMS VSP,        PREWHITE 10              COMMENT 'GEMS VSP,
15-foot source offset'    ZONE 1                   15-foot source offset'
COMMENT 'Raw p-wave data' BYTRACE                      COMMENT 'Upgoing waves,
/AUX FILE 15 TRACE 0     OPERATOR 26 150 20 3     flattened'
/FREQAN                    DESIGN 26, 1 0            TPATRACE 1, 7, 13, 21, 25
  DESC 'Pre-Filter'        APPLY 26, 1 0, 25 0      TPAVALUE 80, 65, 50, 30, 20
  MAXFREQ 400             APPLY 27, 1 0, 25 0      TPATITLE 'DEPTH' TPAHGT
  FSCL 60                 /DECONV                   0.08
  THGT 0.5                PREWHITE 10              /PRMODCOM INITPR
  TSCL 25                 ZONE 1                   MODIFY KSORT SET 2
  PRINT                   BYTRACE                  /PRMODCOM
/ENDAUX                   OPERATOR 26 150 55 3     MODIFY KSORT SET 2
/STVF                      DESIGN 26, 1 0            /STACK
  BYFILE                  APPLY 26, 1 40, 25 40    /REPEAT NREPEAT 5
  BANDPASS ZERO           APPLY 27, 1 40, 25 40    /DISPLAY HORZ 10 VERT 40
  FILT 1, 60 18, 175 18   /MUTE                      TIMELINE 20, 40, 100
  APPLY 1, 2, 1 0, 25 0   BYFILE                    WINDOW 0 125
/AUX FILE 15 TRACE 0     BYTRACE                   ANNOTATE TRAC EVERY 2
/FREQAN                    FMUTE 1, 0 16            SJOJ
  DESC 'Post-Filter'      FMUTE 23, 0 11
  MAXFREQ 400
  FSCL 60
  THGT 0.5
  TSCL 25
  PRINT
/ENDAUX

```