Shallow Vertical Seismic Profile (VSP) Survey of the GEM Site Well 0-6

by
Alex Martinez, John Hopkins, Neil Anderson, and Brooks Barret

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Introduction

A vertical seismic profile (VSP) data set was collected at the GEM site, north of Lawrence, on June 17, 1994. The persons involved in data collection were Alex Martinez, John Hopkins, Brooks Barret, and Ross Black. Equipment was donated by Neil Anderson, of the University of Missouri at Rolla.

Well 0-6 was used for the VSP survey. It is a 4", pvc-cased well with a total depth of approximately 80'. During the time of the survey, the water table was located at approximately 19' of depth. Figure 1 shows a gamma-ray log of the well.

Equipment & Data Collection

The data were collected using a Bison 1462 triaxial downhole geophone as a receiver and an airless jackhammer as a source. The data were recorded on a Bison 9024 seismograph, with a 250 microsecond sample rate.

The survey began at the bottom of the well (approximately 77'), and went to just above the water table (18' depth). Data was recorded every 2.5' along this interval. The triaxial geophone was held into place with an air-filled bladder, coupling the geophone with the well casing. The bladder had good coupling for the entire length of the survey. The source was placed 15' south of the well. Each of the recorded traces consists of 5 blows of the airhammer, vertically stacked.

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

Data Processing

All of the data conversion and processing were performed using the program SierraSEIS on a SUN workstation. The data set was first downloaded from the seismograph, reformatted, and imported into SierraSEIS. The first trace of each shot record (the p-wave component of the triaxial geophone), was separated and gathered together in a common depth point (CDP) gather (figure 2). An f-k filter was applied to separate the downgoing waves from the upgoing waves (figure 3), and a deconvolution function was applied to the upgoing waves in order to enhance the coherent events (figure 4). The CDP gather was flattened by a static shift, developed from information gained from the direct wave velocity (figure 5). The cdp gather was then stacked, resulting in a single trace, which was repeated several times for aid in clarity of events (figure 6).

The SierraSEIS jobs used for processing are in Appendix B.

Results and Conclusions

The upper events on the stacked section reveal several closely spaced reflections from the top of the water table at 19', the bottom of the sand and gravel at 40', and the bedrock surface at 70'. These reflections are located at 22 ms, 30 ms and 35 ms, respectively, on the stacked section. The interpretation of the reflection from the top of the water table is speculative, as there are only two traces within the interval around the water table. The reflection from the bottom of the sand and gravel is very strong and easily discernable from surrounding events on the flattened cdp data (figure 5). The bedrock reflection is less distinct, and appears to have some interference from other events, possibly shear waves, making this event's exact arrival time difficult to determine. The other, less coherent, lower events are also reflections, but there are no direct ties to the lithology of the area because they are below the data collection interval.

Acknowledgements

The authors wish to thank Terrance Huettl and Jim Butler for their assistance in obtaining well log information from the survey site. Ross Black also provided much appreciated guidance in the initial planning and data collection.

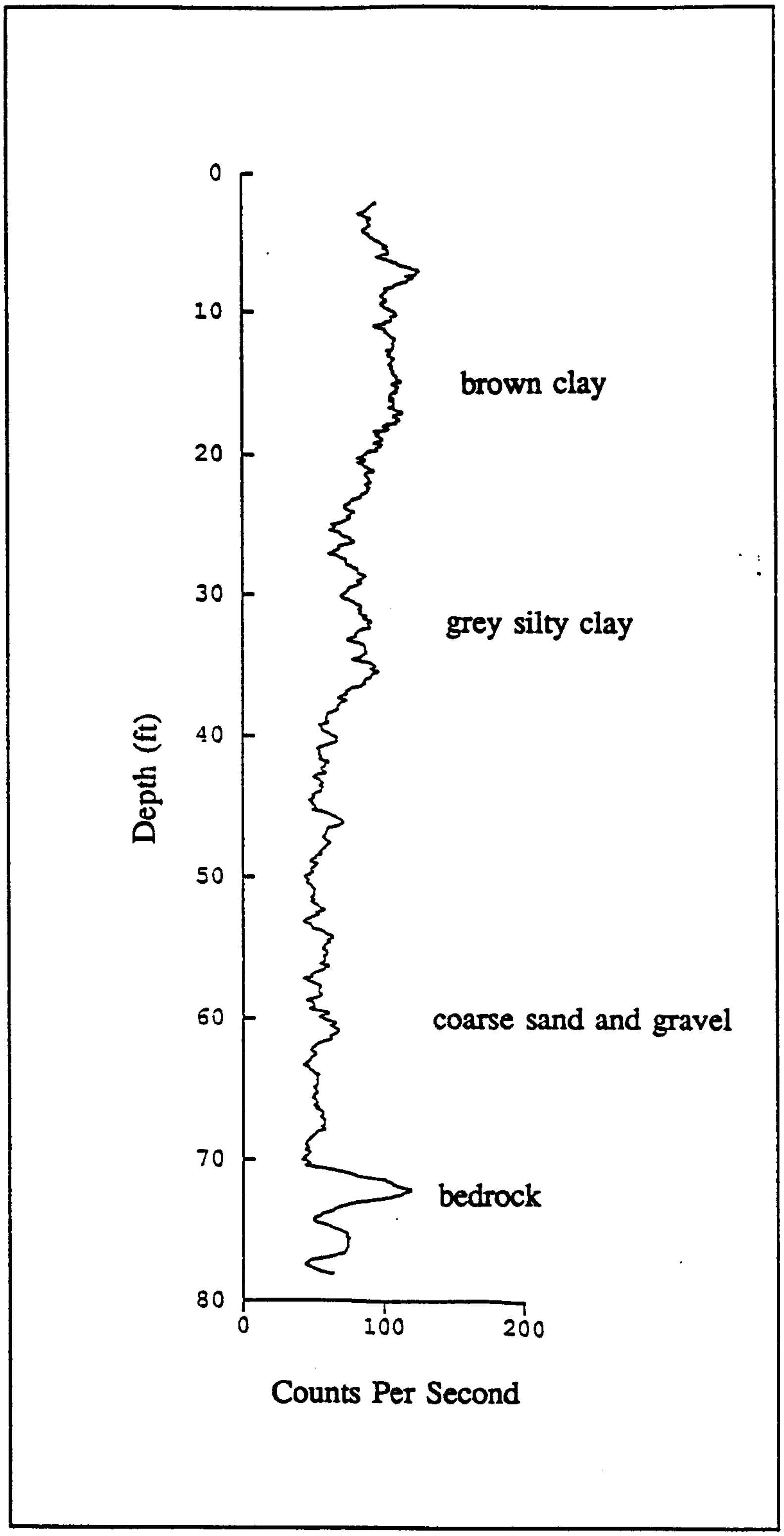


Figure 1: Natural gamma-ray log from GEMS well 0-6 (run 11/06/90). Note the base of the sand and gravel at approximately 40', and the bedrock surface at approximately 70'.

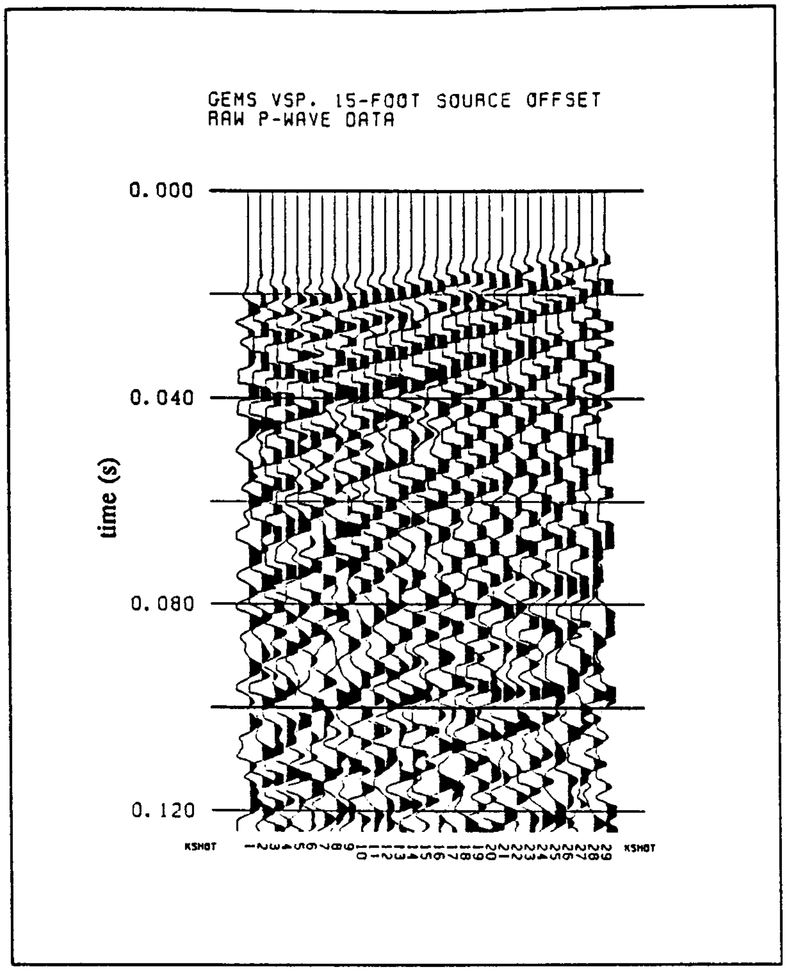


Figure 2: Raw field data. Discernable events on this display include the direct wave (the first arrival), and a tube wave. The tube wave extends from approximately 23 ms on trace 29 to 80 ms on trace 1. There are no readily seen upgoing waves (reflections) on this display. There is a possible reflection immediately below the first breaks on traces 23-28.

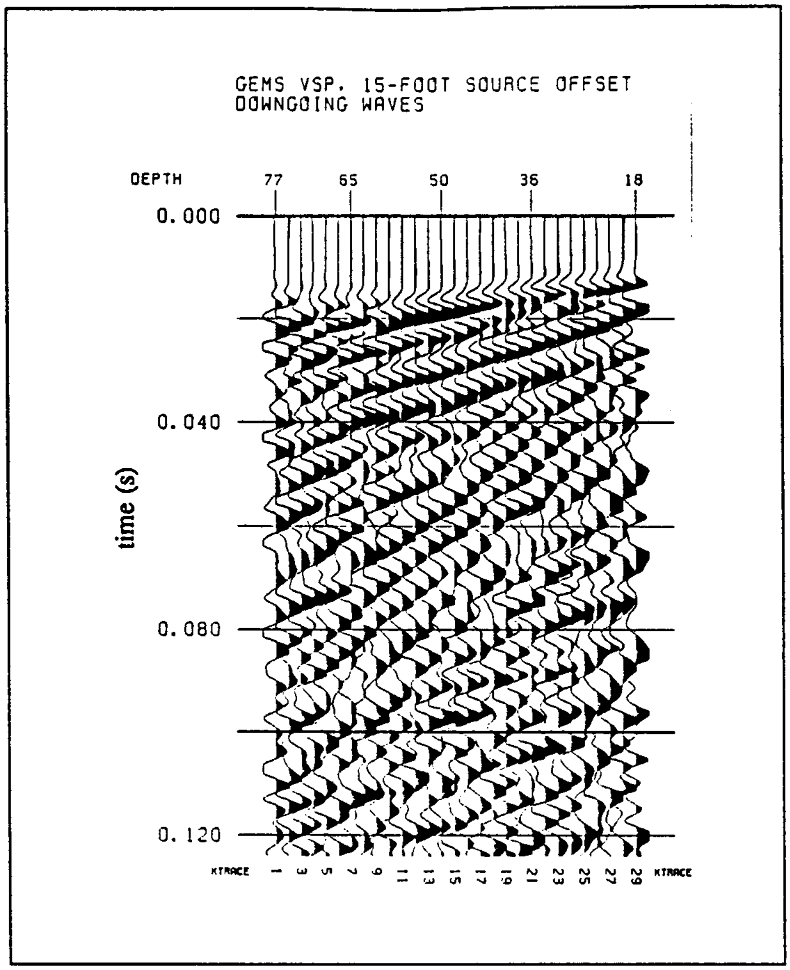


Figure 3: Downgoing waves. This display shows only the downgoing waves of the VSP data set. The waves were separated using a boxcar f-k filter which allowed only the downgoing waves to pass through. The direct wave and the tube waves are easily seen on this display.

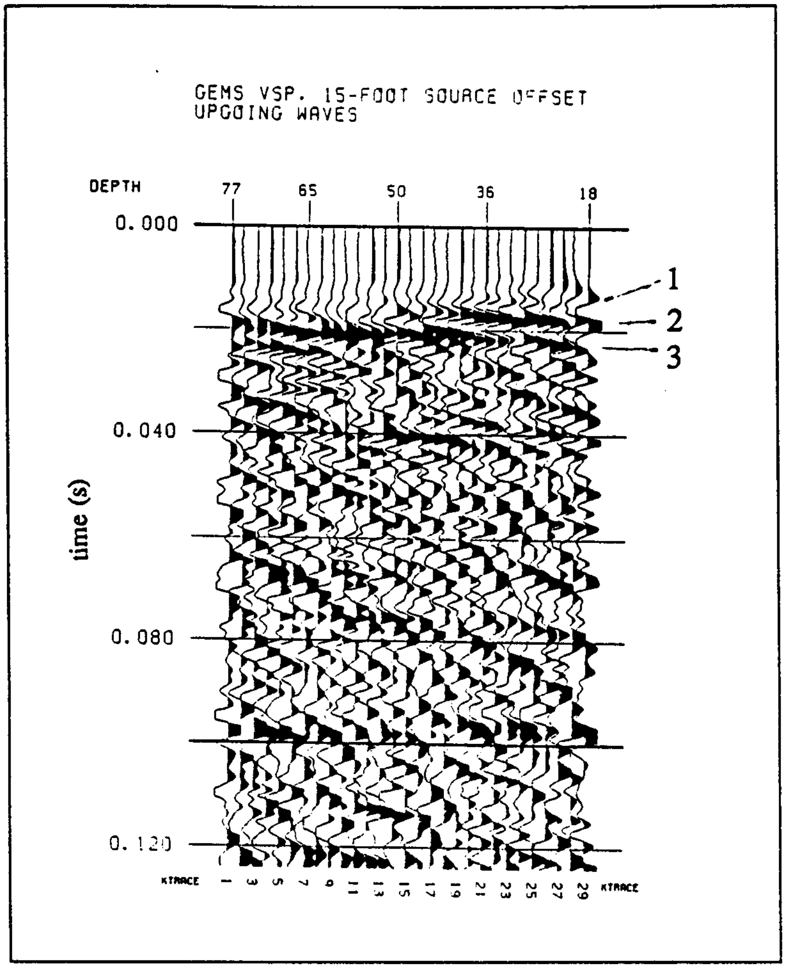


Figure 4: The upgoing waves (reflections). As with figure 2, the upgoing waves were separated from the total wavefield by using a boxcar-shaped f-k filter. A deconvolution function was applied to the data set in order to remove possible multiples and also to enhance the upgoing wavelets.

There are several events seen on this display: 1) This event is possibly only an anomaly, as it is seen on only the last two traces of the data set. The event, at beginning at 12 ms on trace 28, could be a reflection caused by the water table. The water table was at approximately 19 feet below the ground surface when this survey was performed, and this depth corresponds to this upgoing wave response. More data from above the water table is needed if this interpretation is to be proven; 2) The next upgoing event begins at a depth of 40 feet, on trace 17. This is a strong reflection, and can be followed to the end of the data set. This event corresponds to the base of the sand and gravel in the well; 3) The final event seen on the upgoing wave display is immediately below the second reflection. This event could be caused by the bedrock surface, located at approximately 70 feet of depth. The upgoing event seen here could be interpreted as terminating at 70 feet (approximately trace 5).

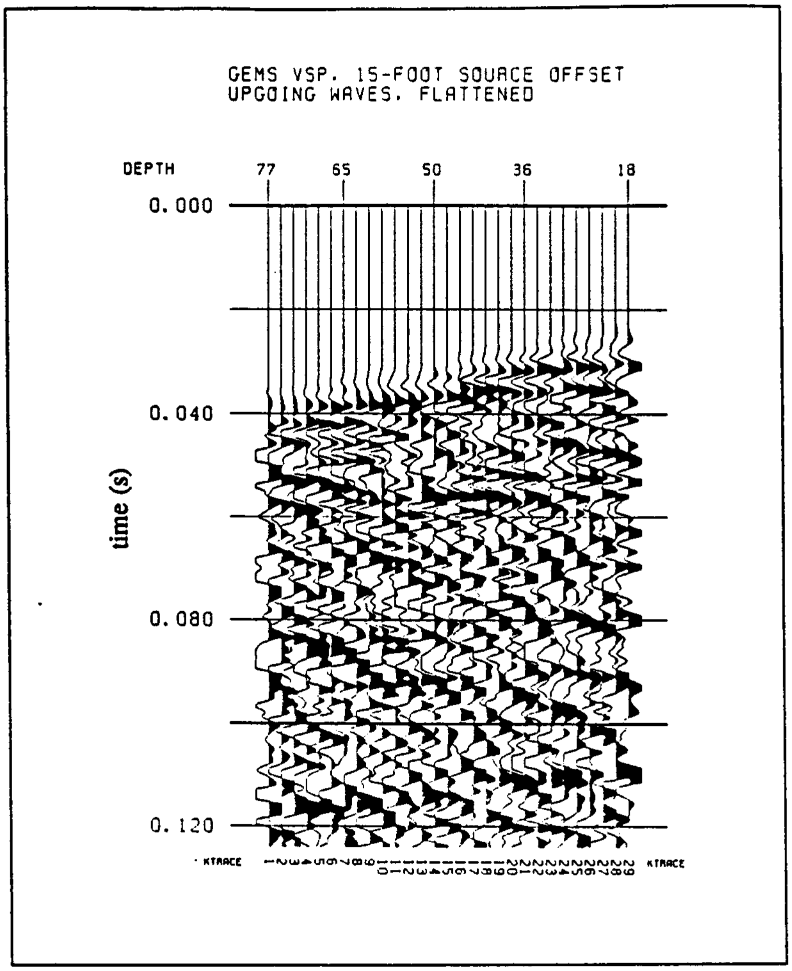


Figure 5: Flattened upgoing waves. This display shows the upgoing waves after they have been corrected for depth by using the travel times from the first breaks. Note that the reflections are now flat events, while the remainder of the display are not flat. This means the reflections will stack into a single trace, while the other events should cancel one-another out.

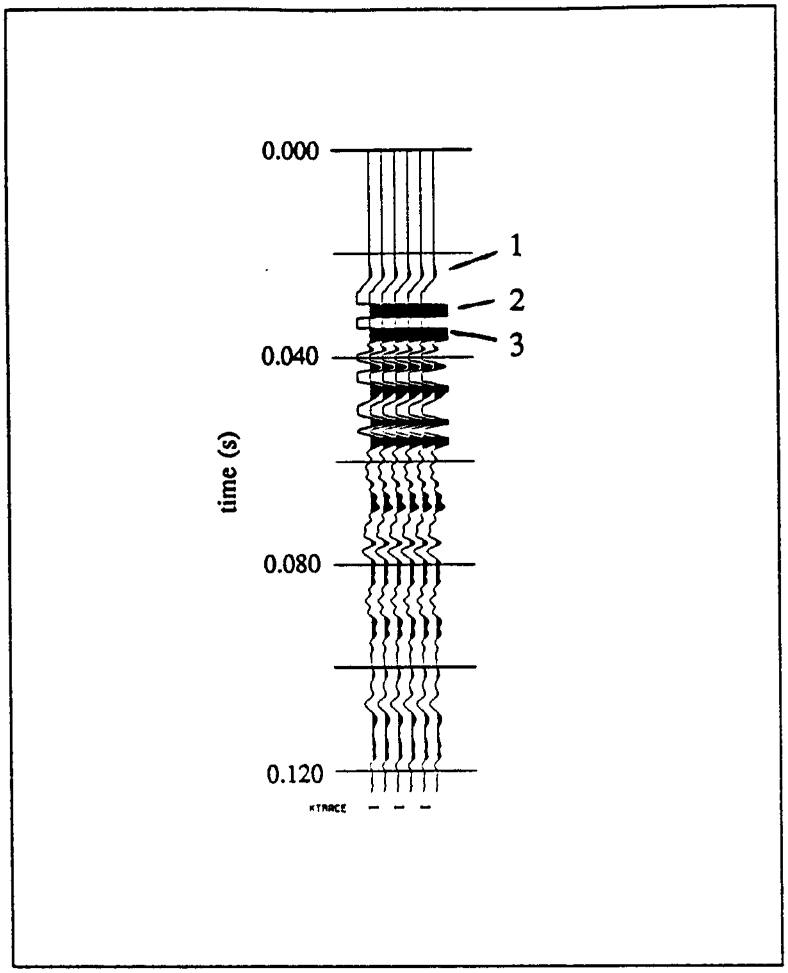


Figure 6: Stacked VSP data. This shows the upgoing waves after the data set has been stacked. The stacking process results in the summing of the upgoing traces into a single trace. This trace has been repeated several times for display purposes. Note the closely spaced upper events. These are the reflections from 1) the water table, 2) the base of the sand and gravel, and 3) the top of the bedrock surface. The other, lower events are most likely not reflections, having not been easily seen on the flattened upgoing-wave cdp gather.

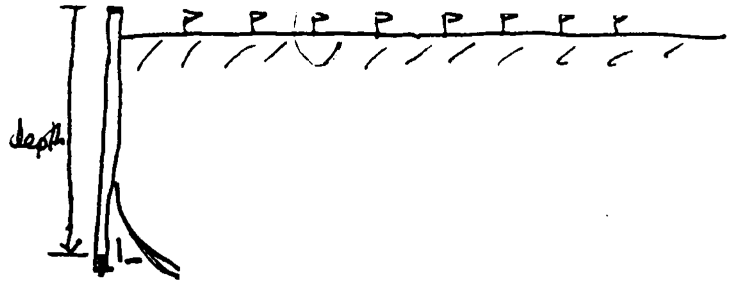
APPENDIX A

Observers' Sheets

[6/17/99]

77' of cable in hole

37 psi



Rec#	File Name	depth	Shot Station	Stacks	Source
69	MARK0073	77'	15ft	1	Airlos Jack no plate.
70	MARK0074	77'	15ft	5	"
71	MARK0076	75'	15ft	5	"
72	MARK0077	73'	"	"	"
73	MARK0078	71'	"	"	"
74	MARK0079	69'	"	"	"
75	MARK0080	67'	"	"	"
76	MARK0081	~~63~~ 65	"	"	"
77	" 0082	~~88~~ 63	"	"	"
78	0083	60	"	"	"
79	0084	58	"	"	"
80	0085	56	"	"	"
81	0086	54	"	"	"
82	0087	52	"	"	"
83	0088	50	"	"	"
84	0089	48	"	"	"
85	0090	46	"	"	"
86	0091	44	"	"	"
87	0092	42	"	"	"
88	0093	40	"	"	"
89	0094	38	"	"	"
90	0095	36	"	"	"

Rec #	File Name	Depth	Station	Stacks	Source
91	MARK0096	34	15ft	5	Airless Jack in ground
92	0097	32	15ft	"	"
93	0098	30	"	"	"
94	0099	28	"	"	"
95	0100	26	"	"	"
96	0101	24	"	"	"
97	0102	22	"	"	"
98	0103	20	"	"	"
99	0104	18	"	"	"

APPENDIX B

SierraSEIS Jobs

*** Geometry Job**: This job provides the necessary geometry information for SierraSEIS. The shots all took place at the same location, and the receiver locations just vary in the z-direction.

```
/JOB  ACCT 'GEMSVSP'  SCAN 72 FEET
/GEOMETRY
 GEOMFILE 'GEMSVSP1'
 SURVEY
  STBASE 1
  SPLIST D1 29 1
  XYBASE 0, 0
  STATION
   1   0 0
   2   0 0
   3   0 0
   4   0 0
   5   0 0
   6   0 0
   7   0 0
   8   0 0
   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
   26  0 0
   27  0 0
   28  0 0
   29  0 0
   30  15 0
 SHOT 1.0 AT 30 INTO 1
  SINC 0 CINC 1 TO SHOT 29.0
 PROF
  SPEL R0,29
  GPELX
   1  -75
   2  -73
   3  -71
   4  -69
   5  -67
   6  -65
   7  -63
   8  -60
   9  -58
   10 -56
   11 -54
   12 -52
   13 -50
   14 -48
   15 -46
   16 -44
   17 -42
   18 -40
   19 -38
   20 -36
   21 -34
   22 -32
   23 -30
   24 -28
   25 -26
   26 -24
   27 -22
   28 -20
   29 -18
   30   0
  DATUM 0
  SPD R0,29
  TUH R0,29
  DVEL 1800
$EOJ
```

*** Processing Job**: This job takes the data from its initial stages all the way to its stacked form. Note that there are numerous uses of the PRMODCOM processor. This was done because of the difficulties posed by the VSP data set, which SierraSEIS was not specifically designed to handle. These uses of PRMODCOM merely changed the data back and forth from shot-file space to cdp-space as needed during processing.

```
/JOB ACCT 'GEMS' SCAN 72 FEET
/DIN FILENAME 'GVSP1' RESEQIT 1
/AUX FILES D1 29 1 TRACES 0
/GEOMETRY GEOMFILE 'GEMSVSP1' USE
/STATAPLY
/DESPK
/MUTE
  BYFILE
  BYTRACE
  FMUTE 1, 0 15
  FMUTE 29, 0 7
/AGC WINDOW 20
/DISPLAY
  HORZ 10 VERT 40 TIMELINE 20, 40, 100
  ANNOTATE FILE EVERY 2
  COMMENT 'GEMS VSP, 15-foot source offset'
  COMMENT 'Raw p-wave data'
/AUX FILE 15 TRACE 0
 /FREQAN
   DESC 'FILE 15 TRACE 0'
   MAXFREQ 500
    FSCL 60
    THGT 1
    TSCL 50
   PRINT
/ENDAUX
/STVF
  BYFILE
  BANDPASS ZERO
  FILT 1, 50, 18, 300 18
  APPLY 1, 2, 1 0, 29 0
/GATHER OUTSORT 2
/PRMODCOM INITPR
 MODIFY KNSHOT UPDATE 1 1
/PRMODCOM
 MODIFY KTRACE UPDATE 1 1
/FKFILT
 DESIGN -0.47 -0.03
 TAPER 0
/DECONV
  PREWHITE 10
  ZONE 1
  BYTRACE
  OPERATOR 30 100 5 2
  DESIGN 30, 1 0
  APPLY 30, 1 0, 29 0
  APPLY 31, 1 0, 29 0
/AGC WINDOW 30
/DISPLAY HORZ 10 VERT 40 TIMELINE 20, 40, 100
 ANNOTATE TRAC EVERY 2
 COMMENT 'GEMS VSP, 15-foot source offset'
 COMMENT 'Upgoing waves'
 TPATRACE 1, 7, 14, 21, 29
   TPAVALUE 77, 65, 50, 36, 18
   TPATITLE 'DEPTH' TPAHGT 0.08
/PRMODCOM INITPR
 MODIFY KSORT SET 5
/PRMODCOM
 MODIFY KSORT SET 5
/STATAPLY
/STATAPLY
 NOGEOM
 SHOTST 1 19, 29 12
/MUTE
  BYFILE
  FMUTE 1, 0 35
  FMUTE 29, 0 20
/AGC WINDOW 30
/DISPLAY HORZ 10 VERT 40 TIMELINE 20, 40, 100
 ANNOTATE TRAC EVERY 2
 COMMENT 'GEMS VSP, 15-foot source offset'
 COMMENT 'Upgoing waves, flattened'
 TPATRACE 1, 7, 14, 21, 29
   TPAVALUE 77, 65, 50, 36, 18
   TPATITLE 'DEPTH' TPAHGT 0.08
/PRMODCOM INITPR
 MODIFY KSORT SET 2
/PRMODCOM
 MODIFY KSORT SET 2
/STACK
/REPEAT NREPEAT 5
/DISPLAY HORZ 10 VERT 40 TIMELINE 20, 40, 100
ANNOTATE TRAC EVERY 2
/ENDAUX
$EOJ
```