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A seismic reflection survey in Grímsvötn, June 1997. Field report and preliminary processing

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Greinargerð KG-97-01

A SEISMIC REFLECTION SURVEY IN GRÍMSVÖTN, JUNE 1997

Field Report and Preliminary Processing, by Karl Gunnarsson

1. GENERAL SURVEY DESCRIPTION

The survey was intended to investigate the structure of the ice sheet covering the Grimsvötn caldera in glacier Vatnajökull. The main purpose was to determine the thickness of the ice, the underlying water layer and to attempt to detect possible new sediments carried into the subglacial lake by the 1996 "Gjálp" volcanic eruption. The project was instigated by the Science Institute of the University of Iceland, and and was carried out during the annual spring expedition of the Glaciological Society of Iceland (Jöklarannsóknafélagið). Magnús Tumi Guðmundsson of the Science Institute was in charge of the project, while the field work was lead by the present author. Kirsty Langley of London College and the experienced volunteer members of the Glaciological Society quickly adapted themselves to form an efficient field crew.

Three seismic lines were shot, named G97-3, G97-4 and G97-5. On lines 3 and 4 single fold seismic reflection was obtained by shots at each end of the 230 m long 24 channel spread. These lines are about 2160 m long. Line 5 has multichannel 6-fold coverage, and is much shorter. The total length of the line (cdp-range) is 525 m, and only the center section of the line, a 255 m long section, has full 6-fold data. Line 3 is a repeat of the previous line 3 shot in 1987, line 4 is in the northern part of the caldera where the greatest depth is expected. Line 5 is located at a site where a borehole was previously located and the bottom of the lake was reached. This gives an opportunity for absolute calibration of depth.

Exact positioning and surface elevation measurements along the lines by differential GPS-instruments were done independently by MTG and are not included in this report. Coordinates in this report are according to basic GPS and are less accurate.

2. DIARY

6 June. Friday night. Travel from Reykjavík to Kirkjubæjarklaustur

7 June. Travel to Freysnes. Delayed due to strong northerly winds.

8 June. Travel from Freysnes to Grímsvötn by the route past Jöklasel at Skálarfellsjökull.

9 June. First day of shooting. Start at the location of line 3 from 1987. This repeated line is called G97-3. Zero point is defined at approximately center of the line (64°25.164, 17°21.542). and the spread is laid out in a northerly directions from this point, the channel (phone) numbers and distance coordinates increasing towards north. Distances from shots to nearest phone are 5 m. Normal shot charge is 270 g (one stick of dynamite). Group (phone) intervals are 10 m. Files 1037.dat and 1038.dat recorded from shots at 0-position, at depths of 40 and 30 m respectively. It was decided to use shot depths of 35 m as 30 m gives slightly less energy, and theoretical estimates of "ground" water level is at about 30 m depth. A detonator is exploded at the surface at some distance off the end of the line, recorded in file 1036.dat. The record length this day was 1024 samples (512 ms) but after this it was decided to double the length.

10 June. Continue line 3. Shots are located at both ends of each spread. Files 1039-1046 (shot positions 240-960 m) are recorded. Then we move back to the 0-position on the line and continue

the survey south along the line. The geometry of the spread is kept unchanged (positive towards north). Files 1047-1049 (shot locations 0 to -240 m) recorded. Surface explosions are also recorded at shot location -240, 1/4 stick at 2 m depth (file 1050) and 2 sticks at 0.5 m depth (file 1051).

11 June. Line 3 is continued, progress towards the south end. Shot locations -480 to -1200 m are occupied, files 1052-1058. End of line 3. At the end of the line the surface elevation increases by about 10 m, and in these locations poor records are obtained. Suspect that the shot pulse is absorbed in dryer layers above the water saturation level, and try deeper shots at 47 m. Line 4 (G97-4) started, a new location. Start coordinates: 64°25.20', 17°19.60'; planned end point about 2 km away: 64°25.50, 17°22.00'. Progress along the line is towards WNW, and so do channel numbers and shot location. Shot locations occupied are 0 to 1200 m

12 June. Continue on line 4. Shot locations 1440 to 2160 m, files 1071-1077. Line 3 is crossed at distance coordinate 1490 on line 4. A sightseeing trip to the south end of Gjálp ice fissure.

13 June. Line G97-5 started as 6-fold multichannel recordings. The line begins a short way south of location 64°24.93'N, 17°20.20'W and runs north. The north end, shot location 240 m is about 25-30 m east of the weather station (pit dug out). Better positioning pending (M.T.G.). Distance and phone number increasing north. Boreholes are ahead of the spread (north end) at 20 m intervals. The entire spread is moved along with the shot. Offset to nearest phone (24) is 10 m. Shot locations 0-240 m are occupied (13 holes), corresponding to files 1078-1092, where file 1085 is an extra experimental shot at 30 m depth at 100 m. It should be noted that the two first spreads (shot loc. 0 and 20) had a 12.5 m interval between phones 12 and 13 instead of the normal 10 m. (It was noted later during processing that this fault was probably present during the shooting of entire line 4.)

14 June. Line 5 continued, but with a new setup. The drilling was discontinued but the old boreholes re-used. The shot location was moved to the trailing end of the spread, and the 20 m shifts towards north continued as before, until the entire spread lay outside the north end of the borehole line. Shot locations 0-240 were occupied in this way, corresponding to files 1093-1104, except for location 180 where the recording did not trigger and is missing.

The offset to nearest phone (1) turned out to be 20 m. This was not intended, but it is probably not serious to lose the 10 m offset and gain an extra one at the further end.

In this experiment with ready-drilled holes each shot and shift took 10 minutes, whereas each shot required 20-30 minutes when the drilling decided the pace.

The work finished at noon, and soon after that the equipment and operator left the area. Driving conditions on the glacier were found to be good, and we were back in Reykjavík at about midnight.

3. RECORDING PARAMETERS

Instrument: Geometrics ES-2401, 24 channel seismograph.
Cable: Two 12-channel cables with phone outtakes at 10 m intervals.
One phone per channel.
Geophones: Mark prod. L10A, 10 Hz.
Sampling interval: 0.5 ms.
Record length: 2048 samples or 1024 ms (except records 1036-1038 which are half as long).
Near offsets for lines G97-3 and G97-4: 5 m (note anomalies in a part of line3)
Near offsets for line G97-5: 10 m for front end (N), 20 m for back end.

The records were stored on 3"1/4 diskettes, 10 in number. The format is SEG-2, but has been be changed to SEG-Y format for processing at Orkustofnun. Note that the geometry parameters in the original record headers are not correct as they were not set during operation. An example of field print-out of two records is attached.

The stick of dynamite that was used for the normal shot charge is 270 g (25x400 mm). Boreholes were drilled with a hot water drill for each shot down to 35 m depth. At this depth there is probably water saturated ice that gives good coupling for the shot energy. Experiments for shots at depths of 30 and 25 m (see tables below) indicated loss of energy at shallower depths. The detonators used are of standard industrial type (not seismic) and the detonation delay is often more than a millisecond. According to experience 2, 3 or even 4 ms can be expected.

The two different geometry configurations used, single fold and 6-fold arrangements, are sketched in attached diagrams, where the equations for the cdp-numbers and the offsets are also given.

4. GEOMETRY TABLES

Explanation for the table headers:
file no. : number of the data file for each record as recorded on diskette.
sh.pos (m) : the shot position in meters along the line
sh. dir. :shooting direction index; positive for back end shot, i.e. when the wave travels in the positive direction along the spread; else negative.
shot depth : depth of the charge below surface in meters.

LINE: G97-3

file no.	sh.pos. (m)	sh. dir.	shot depth	shot no.	comments
1058	-1200	1	35	1	
1057	-960	-1	35	2	
1056	-960	1	35	2	
1055	-720	-1	35	3	
1054	-720	1	35	3	
1053	-480	-1	35	4	
1052	-480	1	35	4	
1049	-240	-1	35	5	
1048	-240	1	35	5	
1047	0	-1	35	6	
1037	0	1	40	6	
1039	240	-1	35	7	
1040	240	1	35	7	near offset 10 m
1041	485	-1	35	8	
1042	485	1	35	8	near offset 10 m
1043	730	-1	35	9	
1044	730	1	35	9	near offset 10 m
1046	975	-1	47	10	
Extra records:					
1036	0	1	0	6	detonator, longer offsets
1038	0	1	30	6	
1045	975	-1	35	10	
1050	-240	-1	2	5	charge of 1/4 stick of dynamite
1051	-240	-1	0.5	5	charge of 2 sticks of dynamite

Note: The interval between the shot position and phone 1 for the back end shot for the planned shot positions 240, 480 and 720 m was made 10 m instead of the usual 5 m, so the shot locations sequence becomes in reality 240, 485, 730 and 975 m.
File 1036 records a detonator exploded at the surface approximately 15 m (? distance not certain) beyond the end of the first spread positioned north of position 0 m.

LINE: G97-4

After studying the data it is apparent that the interval between phones 12 and 13 of each spread was consistantly to long by about 2.5 m (12.5 m instead of 10 m) during the shooting of the entire line 4. This fault was not discovered until at the start of line 5. The intervals between the shot locations are therefore 2.5 m more than the nominal 240 m, as they were positioned relative to the spread.

This irregular geometry is here accounted for by shifting every other shot location 5 m along the profile, as is seen in column 3. Then I choose to ignore the irregular offsets while calculating the cdp-numbers. In this way the shift in cdp-locations is everywhere less than 5 m from the actual locations, which is acceptable. The few cdp gaps can then be inerpolated or ignored. The offset parameter is, however, calculated according to the actual geometry of the spread, and therefore velocity calculations and nmo will be correct. In practice this is done by adding 2 m to the offsets of the outer half of the spread for each shot.

file no.	sh.pos. planned (m)	sh.pos. real (m)	sh. dir.	shot depth	shot no.	comments
1059	0	0	1	40	1	
1060	240	240	-1	35	2	
1061	240	240	1	35	2	
1062	480	485	-1	35	3	
1063	480	485	1	35	3	
1064	720	725	-1	35	4	
1066	720	725	1	35	4	
1067	960	970	-1	35	5	
1068	960	970	1	35	5	
1069	1200	1210	-1	35	6	
1070	1200	1210	1	35	6	
1071	1440	1455	-1	35	7	
1072	1440	1455	1	35	7	
1073	1680	1695	-1	35	8	
1074	1680	1695	1	35	8	
1075	1920	1940	-1	35	9	
1076	1920	1940	1	35	9	
1077	2160	2180	-1	47	10	
Extra records:						
1065	720	725	-1	35	4	1/4 stick

LINE: G97-5

file no.	sh.pos. (m)	shot depth	shot no.	comments
Line 5 with front-end shot location:				
1078	0	35	1	
1079	20	35	2	
1080	40	35	3	
1081	60	35	4	
1083	80	35	5	
1084	100	35	6	
1086	120	35	7	
1087	140	35	8	
1088	160	35	9	
1089	180	35	10	
1090	200	35	11	
1091	220	35	12	
1092	240	35	13	
Extra records:				
1082	80	35	5	faulty recording; of no use
1085	100	30	6	shallower shot experiment
Line 5 with back-end shot location:				
1093	0	35	1	
1094	20	35	2	
1095	40	25	3	
1096	60	25	4	
1097	80	35	5	
1098	100	25	6	
1099	120	25	7	
1100	140	35	8	
1101	160	35	9	
1102	200	35	11	
1103	220	35	12	
1104	240	35	13	

Note: Record for shot point no. 10 (180 m) in the second phase of the shooting is missing.

Because of the two shot arrangements some raypaths in the central section are repeated. This will only improve the final stack, but it must be checked that statics are not present to degrade the stack.

5. INITIAL PROCESSING

The processing described here deals with the reformatting to SEG-Y format and definition of trace header values. Processing was perfomed at Orkustofnun using the in-house "SY" programmes (for Unix) by Einar Kjartansson and others.

Procedure:

1) Field record files, one for each shot, are copied to the to the mainframe computer. They are then reformated to SEG-Y and combined to one file for each line. In the process the field record number, recorded as the original name of the field record files, is entered in header "fldr". After this stage the following header info are present in the files (example):
tracr=24 fldr=1064 tracf=24 ns=2048 dt=500 lcf=25
hcf=500 year=1997 day=162 hour=18 minute=23

2) In addition the values of shot number, cdp number, offset, shot depth and direction of shooting (wave travel) are defined according to the geometry tables and relations defined elswhere in this report. After this processing the headers contain values as the following list exemplifies:

tracr=1	trace-number in the file (reel)
fldr=1078	field record number as given in the field
tracf=1	trace-number in the field record (1-24)
shot=1	shot number
cdp=1	cdp number
offset=-240	offset, the distance from shot to receiver (m)
sdepth=35	shot depth (m)
ns=2048	number of samples
dt=500	sample interval (ms)
lcf=25	low cut filter for recorder
hcf=500	high cut filter
year=1997	date of record
day=164	
hour=13	
minute=55	
u1=-1	direction of wave travel from shot to receiver (1/-1)

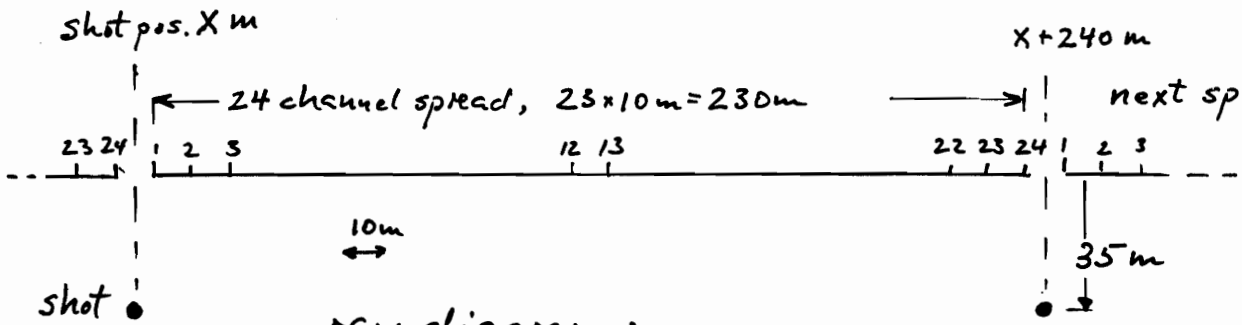
3) Finally some preliminary single fold sections (including a subset of line 5 data) were made by applying the following processing procedure:

- Gain as time to power 1.5
- NMO-correction using uniform velocity of 3500 m/s
- Time varying band-pass filtering: 200-450 Hz down to ca. 110ms; 70-380 HZ down to ca. 220 ms; 20-180 Hz below.
- "Mix"
- AGC gain window applied.

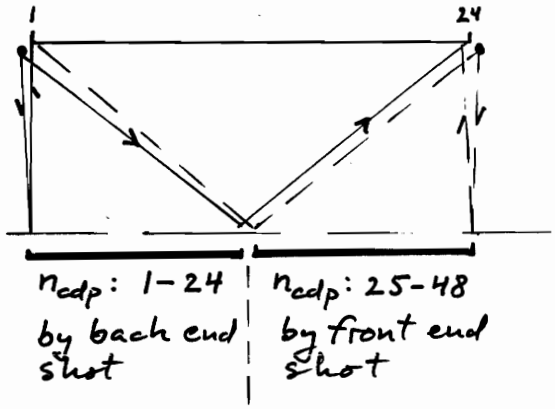
It should be noted that no attempt has been made to apply correcton for the time shift due to shot depths and the possible variation in detonator ignition response. The effect of the latter would possibly be detected by inconsistencies in the data.

Grímsvötn seismic survey, June '97
spread/shot geometry. K.G.

A. SINGLE FOLD DATA (Lines 3 and 4)



ray diagram:



cdp's are at 5m intervals, the first 2,5m from the shot position.
For each spread 48 cdps are obtained

Line 97-3: Shot positions between −1200 and +975 m

Back end shots: $n_{cdp} = \cancel{X_{sh}/5} + n_{ch} + (X_{sh}+1200)/5$

Front end shots: $n_{cdp} = (X_{sh}+1200)/5 + n_{ch} - 24$

Note: Because back shot offsets are ~~5m~~ 10 large by 5m for planned shot positions 240, 480, 720 (real numbers are 240, 485 etc.) the centre cdp for the three spreads is missing.

n_{cdp} ranges between 1 and 435

Line 97-4: Shot positiones between 0 and ~~2160~~ 2180 m

Back end shots: $n_{cdp} = X_{sh}/5 + n_{ch}$ $d_{offs} = (n_{ch}-1)\cdot 10 + 5$

Front end shots: $n_{cdp} = X_{sh}/5 + n_{ch} - 24$

n_{cdp} ranges between 1 and 436 (4 are missing due to shifts)

$\hat{d}_{offs} = d_{offs} \div 2$ m, if $|d_{offs}| \geq 125$

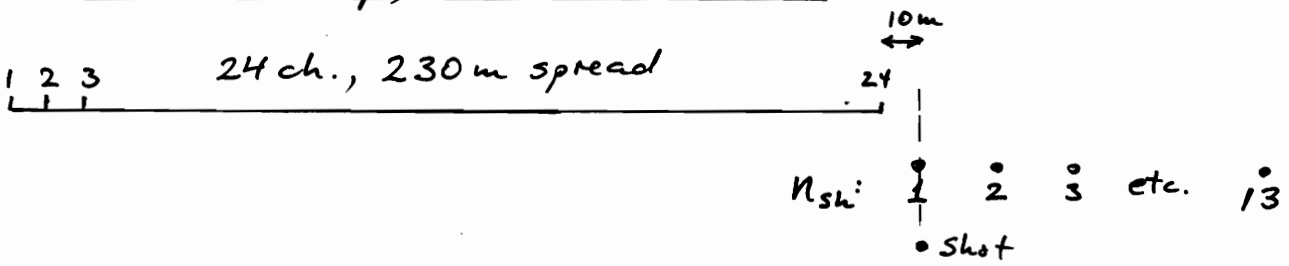
Note that the offset is defined negative for "front end" shots.

Grímsvötn seismic survey, June '97
spread/shot geometry. K.G.

B. 6-FOLD DATA (Line 5)

13 shotholes used with two setups.

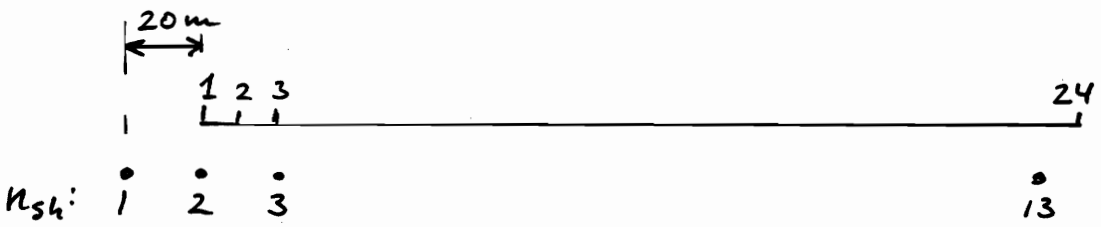
First setup, front end shots:



Front end shots: $n_{cdp} = n_{ch} + (n_{sh}-1)\cdot 4$, $n_{sh} = 1, 13$

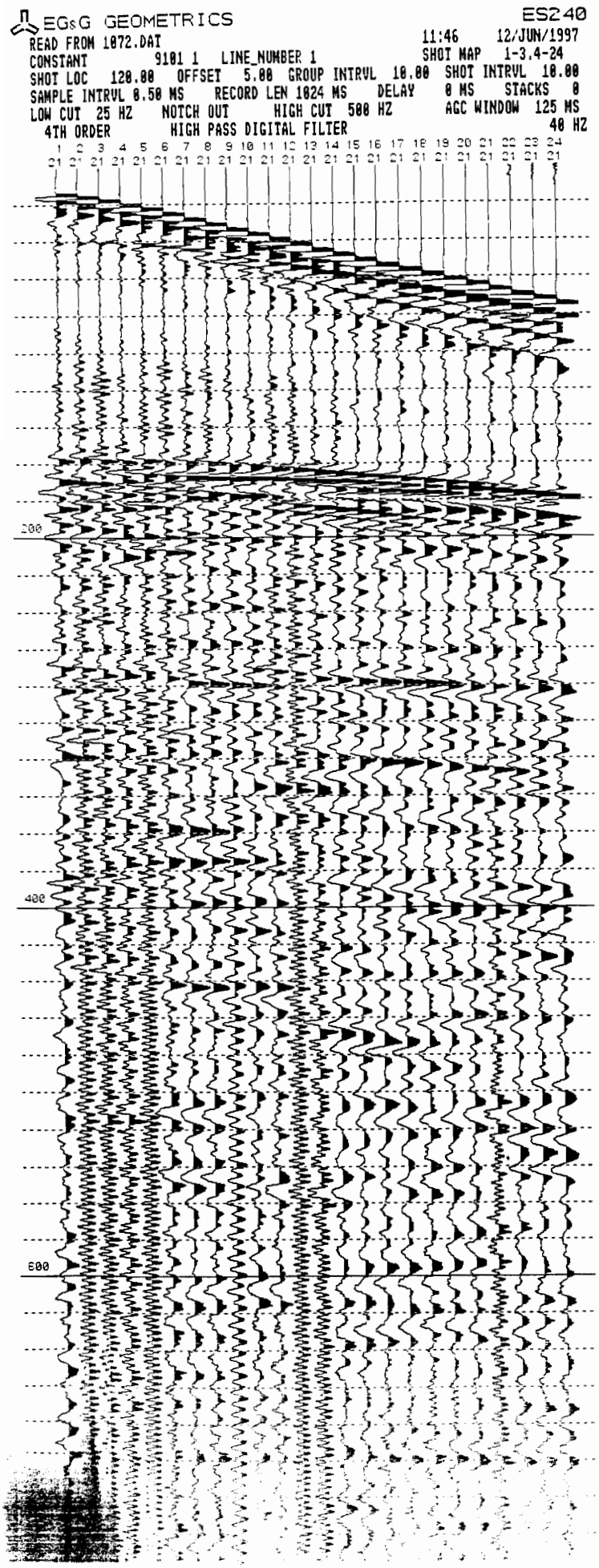
$d_{offs} = (n_{ch}-25)\cdot 10$ m

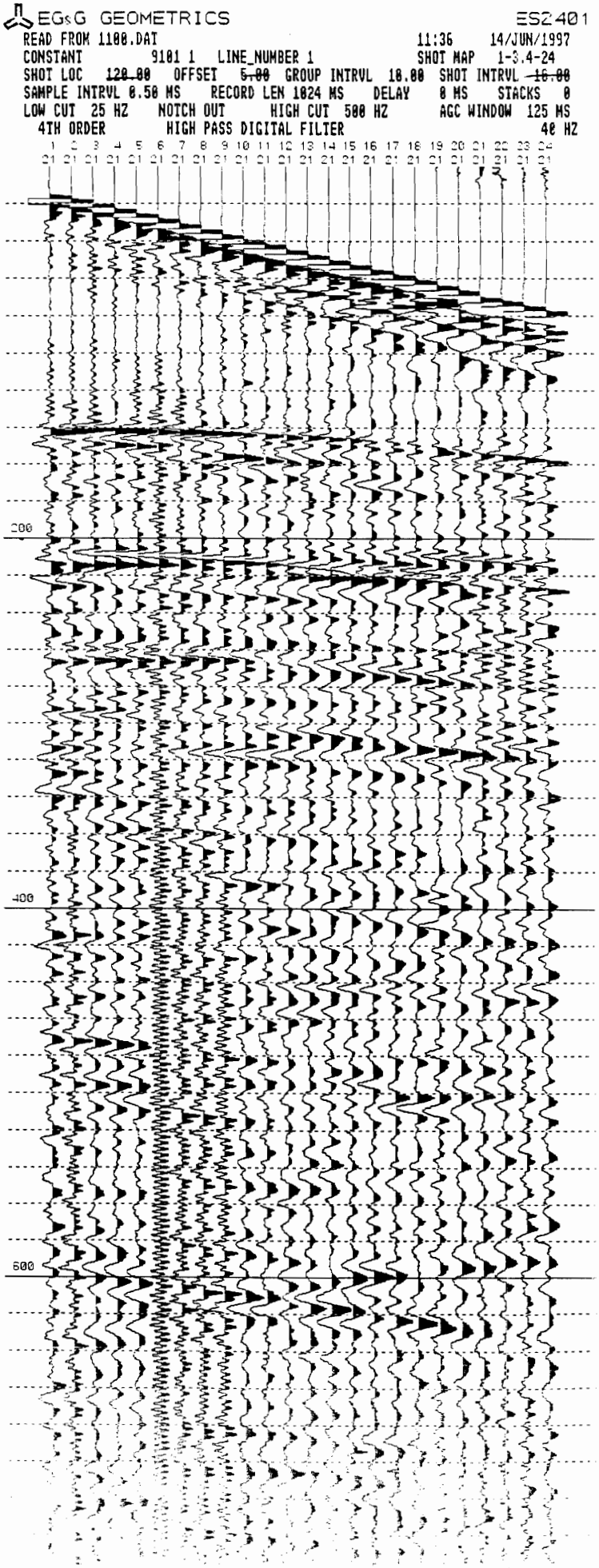
Second setup, back end shots:

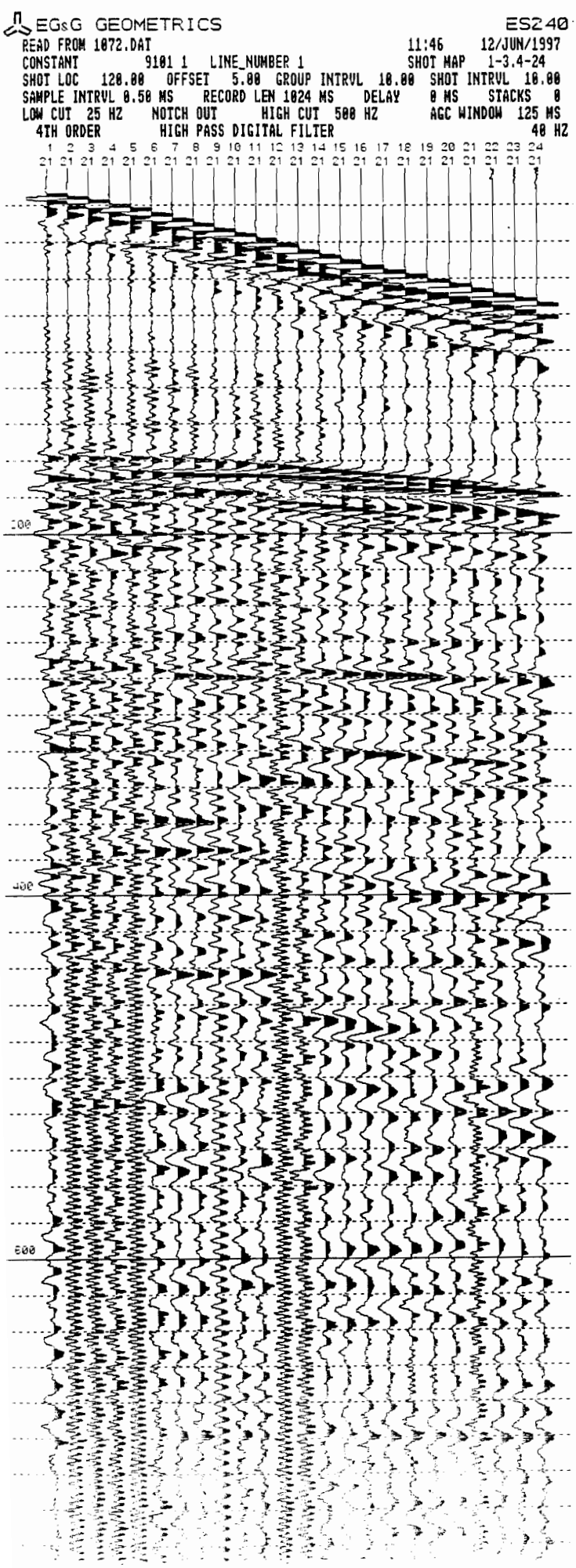


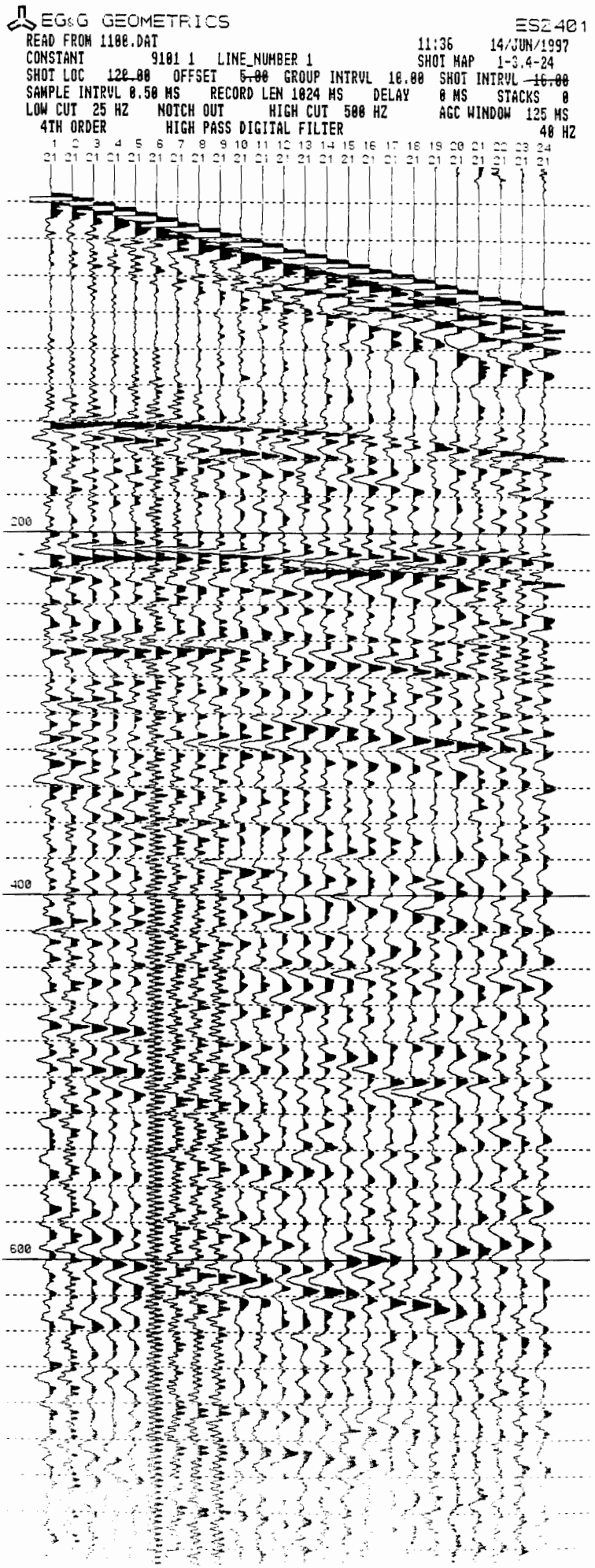
Back end shots: $n_{cdp} = n_{ch} + (n_{sh}-1)\cdot 4 + 26$

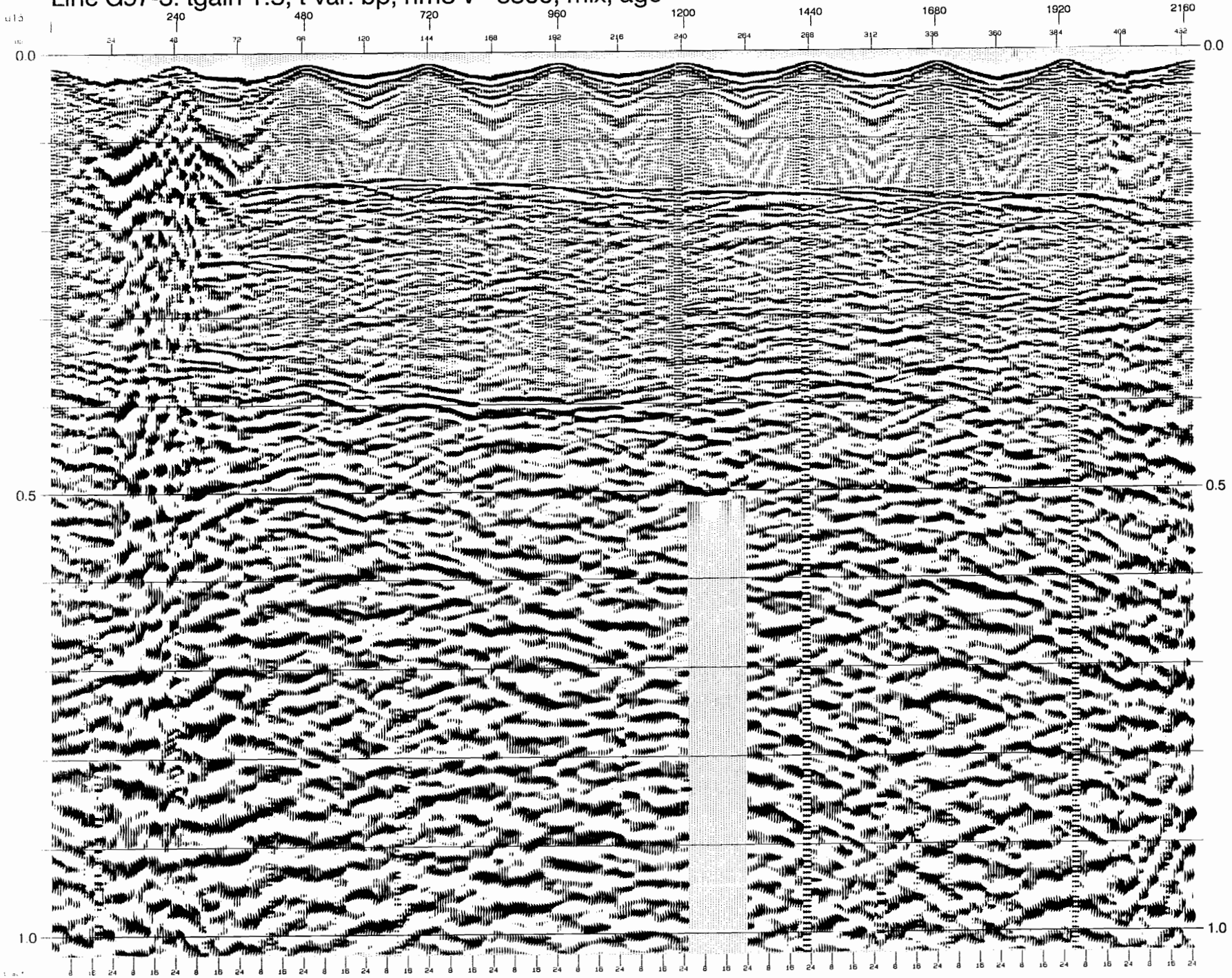
$d_{offs} = (1 + n_{ch})\cdot 10$ m

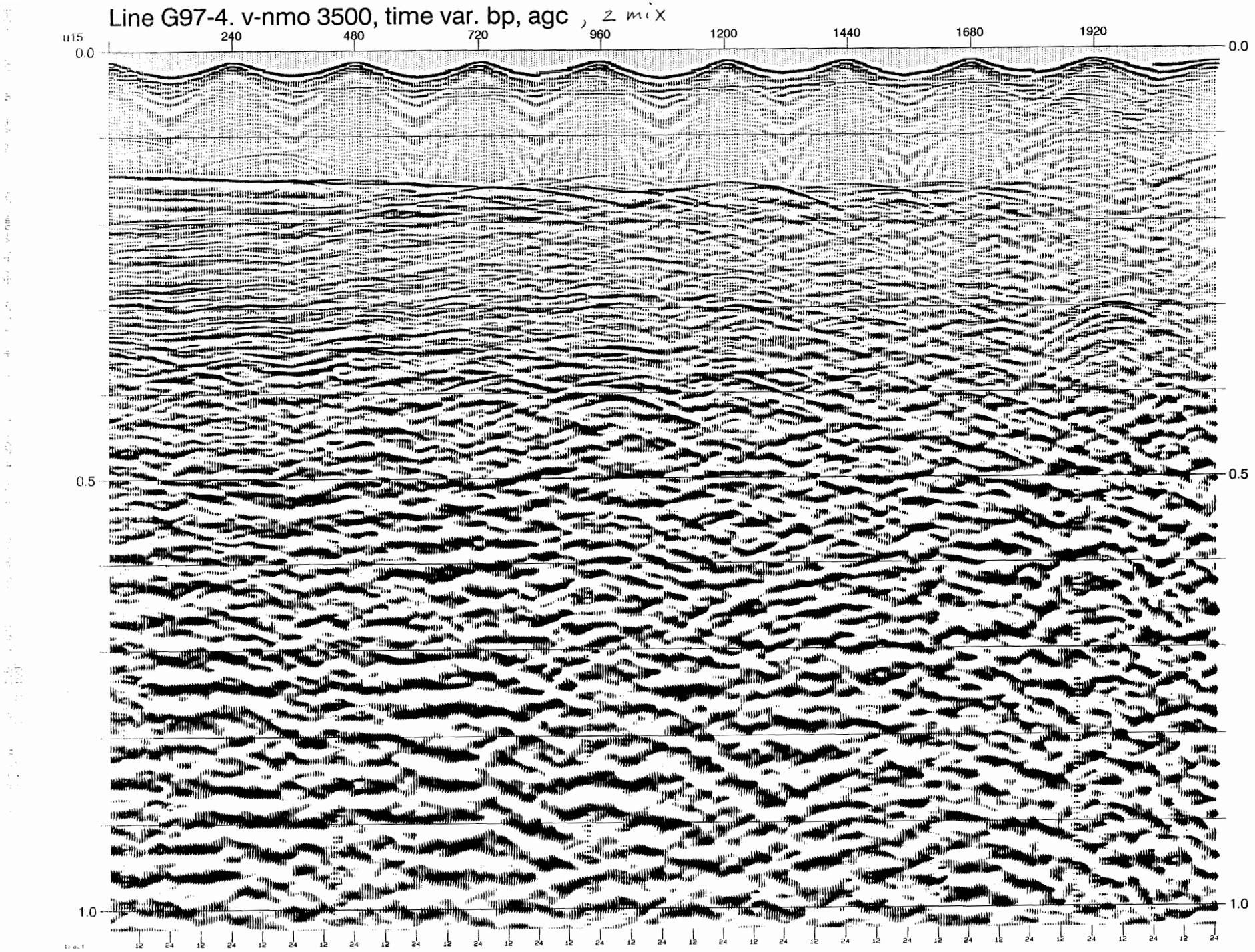

EGsG GEOMETRICS
ES240
READ FROM 1072.DAT
11:46 12/JUN/1997
CONSTANT 9101 1 LINE_NUMBER 1
SHOT MAP 1-3.4-24
SHOT LOC 120.00 OFFSET 5.00 GROUP INTRVL 10.00 SHOT INTRVL 10.00
SAMPLE INTRVL 0.50 MS RECORD LEN 1024 MS DELAY 0 MS STACKS 0
LOW CUT 25 HZ NOTCH OUT HIGH CUT 500 HZ AGC WINDOW 125 MS
4TH ORDER HIGH PASS DIGITAL FILTER 40 HZ
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21
200
400
600


EGsG GEOMETRICS
ES2401
READ FROM 1100.DAT
11:36 14/JUN/1997
CONSTANT 9101 1 LINE_NUMBER 1
SHOT MAP 1-3.4-24
SHOT LOC 120.00 OFFSET 5.00 GROUP INTRVL 10.00 SHOT INTRVL 10.00
SAMPLE INTRVL 0.50 MS RECORD LEN 1024 MS DELAY 0 MS STACKS 0
LOW CUT 25 HZ NOTCH OUT HIGH CUT 500 HZ AGC WINDOW 125 MS
4TH ORDER HIGH PASS DIGITAL FILTER 40 HZ
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21
200
400
600

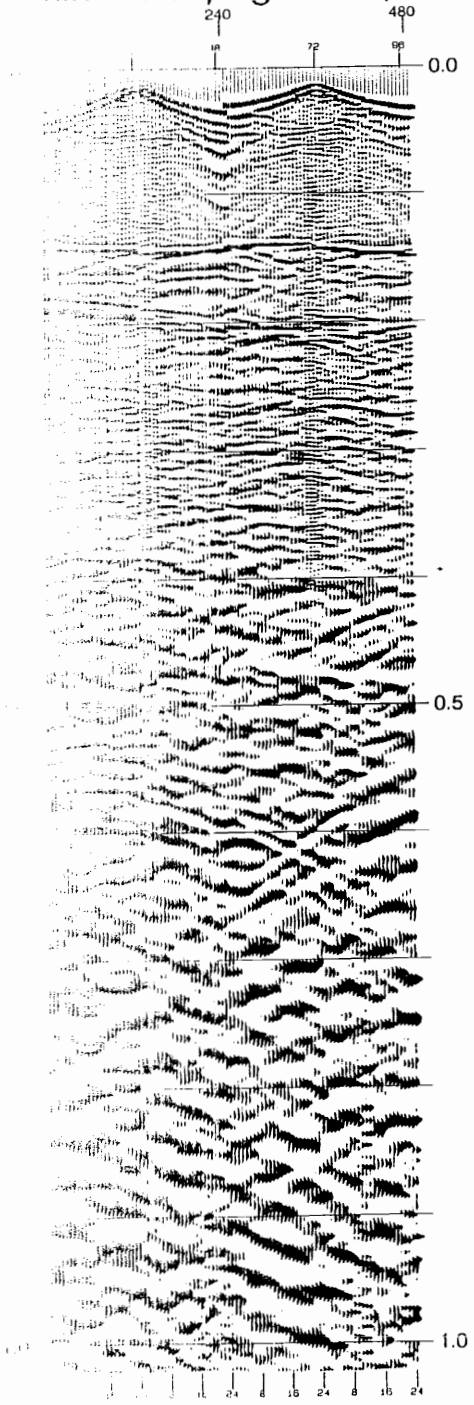

EG&G GEOMETRICS
ES240
READ FROM 1072.DAT
11:46 12/JUN/1997
CONSTANT 9101 1 LINE_NUMBER 1
SHOT MAP 1-3.4-24
SHOT LOC 120.00 OFFSET 5.00 GROUP INTRVL 10.00 SHOT INTRVL 10.00
SAMPLE INTRVL 0.50 MS RECORD LEN 1024 MS DELAY 0 MS STACKS 0
LOW CUT 25 HZ NOTCH OUT HIGH CUT 500 HZ AGC WINDOW 125 MS
4TH ORDER HIGH PASS DIGITAL FILTER 40 HZ
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21
200
400
600


EG&G GEOMETRICS
ES2401
READ FROM 1108.DAT
11:36 14/JUN/1997
CONSTANT 9101 1 LINE_NUMBER 1
SHOT MAP 1-3.4-24
SHOT LOC 120.00 OFFSET 5.00 GROUP INTRVL 10.00 SHOT INTRVL 10.00
SAMPLE INTRVL 0.50 MS RECORD LEN 1024 MS DELAY 0 MS STACKS 0
LOW CUT 25 HZ NOTCH OUT HIGH CUT 500 HZ AGC WINDOW 125 MS
4TH ORDER HIGH PASS DIGITAL FILTER 40 HZ
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21 21
200
400
600

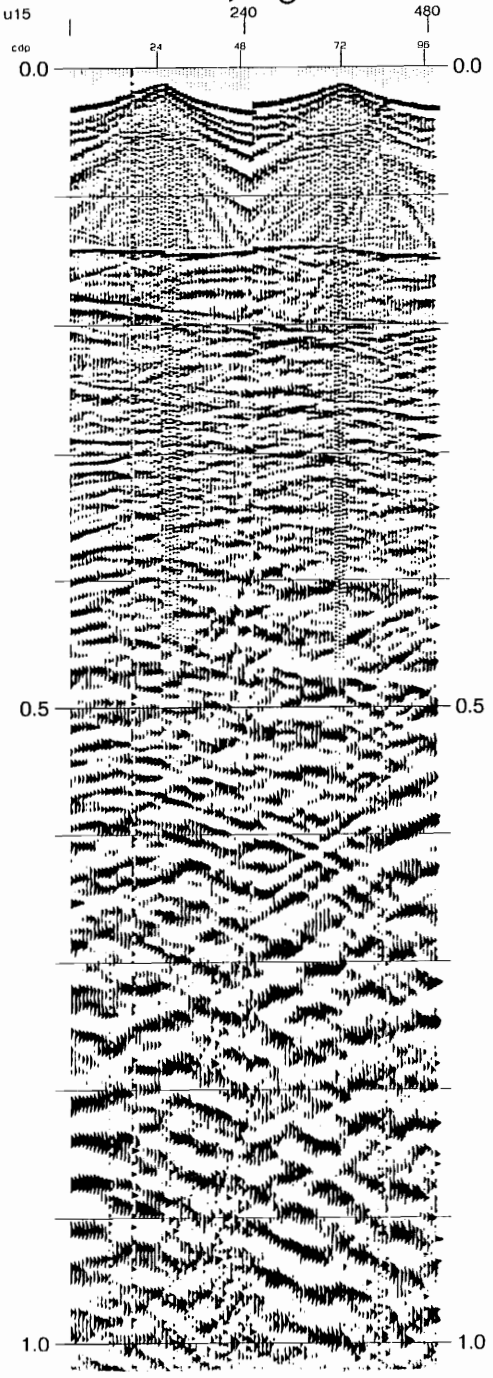

Line G97-3. tgain 1.5, t-var. bp, nmo v=3500, mix, agc
240
480
720
960
1200
1440
1680
1920
2160
0.0
0.5
1.0


Line G97-4. v-nmo 3500, time var. bp, agc , 2 mix
240
480
720
960
1200
1440
1680
1920
0.0
0.5
1.0

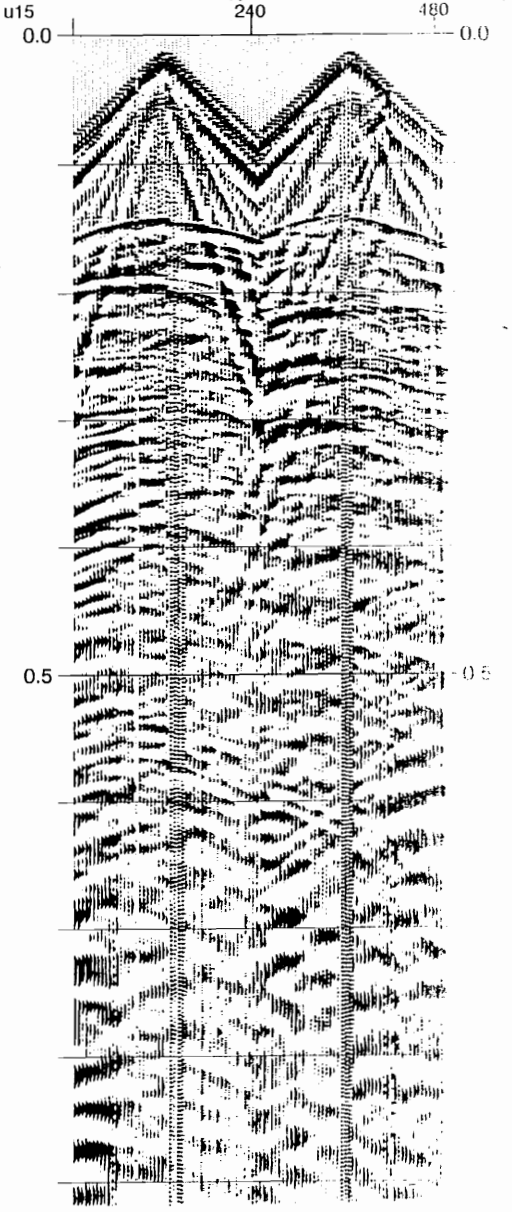
Line G97-3. tgain 1.5, tvice t-var. bp, nmo v=3500, mix, agc



Line G97-3. tgain 1.5, t-var. bp, nmo v=3500, agc



Line G97-3. Raw section, gain




```
syvplot -w -d jp -x 6 -c 1.5 -l cdp 24 -L 10 -l u15 240 -L 14 -u tracf 8 -B 200 -z 100 -w 290 -t Line G97-3. tgain 1.5, t-var. bp, nmo
kg  Wed Jun 25 16:42:12 1997
```

```
yvplot -w -l jp -x 6 -c 1.5 -l u15 240 -L 16 -u tracf 12 -L 12 -B 200 -z 50 -w 290 -t Line G97-3. Raw section, gain: t^2 < PIPE
g  Wed Jun 25 16:32:42 1997
```