PL-TR-95-2008

DEVELOPMENT OF TULSA GSE SYSTEM/CD OPEN STATION AND SPECTRAL DIFFERENCES IN REGIONAL SIGNALS RECORDED AT DIFFERENT DEPTHS

J. E. Lawson, Jr.

Oklahoma Geological Survey Observatory
Number One Observatory Lane
Box 8
Leonard, Oklahoma 74043–0008

26 December 1994

Final Report
November 17, 1992 to December 26, 1994

Approved for public release; distribution unlimited

PHILLIPS LABORATORY
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE, MA 01731–3010

SPONSORED BY
Advanced Research Projects Agency (DoD)
Nuclear Monitoring Research Office
ARPA ORDER No. A-128

MONITORED BY
Phillips Laboratory
CONTRACT No. F19628-92-K-0028

This technical report has been reviewed and is approved for publication.

JAMES F. LEWKOWICZ
Contract Manager
Earth Sciences Division

JAMES F. LEWKOWICZ
Director
Earth Sciences Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	26 DECEMBER 1994	Final; NOV 17, 1992 to DEC 26, 1994

4. TITLE AND SUBTITLE

Development of Tulsa GSE System/CD Open Station and Spectral Differences in Regional Signals Recorded at Different Depths

5. FUNDING NUMBERS

PE: 62714E

PR 2A10 TA GM WU AA

Contract F19628-92-K-0028

6. AUTHOR(S)

J. E. Lawson, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Oklahoma Geological Survey Observatory
Number One Observatory Lane
Box 8
Leonard, OK 74043-0008

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Phillips Laboratory
29 Randolph Road
Hanscom AFB, MA 01731-3010

Contract Manager: James Lewkowicz/GPEH

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

PL-TR-95-2008

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Remote mount NFS, anonymous FTP, and Gopher Plus (not connected with Iris DMC software) were used to make real-time data from a "GSE Workstation" available over the internet. Gopher Plus seemed a perfect method for quick searching of a file tree by hierarchical menus, and making automated binary transfers. It was felt that a better method could not be custom designed. Gopher Plus has been in use now for one year. FTP and NFS were abandoned. Gopher Plus is ideal for all transfers outside dedicated E-mail and other methods selected for GSETT-3.

Vertical motion seismograms of many mining blasts are often very different when recorded from a 748 m depth seismometer than when recorded from 432 m or five meters. This difference was investigated as a discrimination method that might be automated and incorporated into the IMS. The difference was due to the absence of Rg at 748 meters. The populations of earthquakes and blasts were not sufficiently overlapping in distance and size to test the difference for events in general. At this point, this method is only known to classify events as: 1) Definite mining blasts, and 2) Events that may be blasts or earthquakes. The difference between seismograms at different depths does not justify the use of deep boreholes, but deep borehole studies should be continued for study of signal/noise below 0.2 Hz and above 5.0 Hz. Deep borehole studies should include three-component broadband seismometers.

14. SUBJECT TERMS

Tulsa open station, boreholes, long-period noise, earthquakes and explosions, discrimination, seismic monitoring, gopher.

15. NUMBER OF PAGES

50

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

(THIS PAGE INTENTIONALLY LEFT BLANK)

Table of Contents

List of Figures

Page

List of Tables

1. DEVELOPMENT OF TULSA GSE OPEN STATION

1.1 SUMMARY

At the beginning of this contract, the Tulsa GSE Open Station consisted of a Sun SPARC 1+ workstation running Teledyne Geotech GSE software. All data were indexed in an Oracle data base in CSS 3.0 format. The system also had two Sun Sparc SLC workstations. All workstations were on an internet connected thinnet ethernet LAN. The Open Station recorded 16 seismic channels and three geomagnetic channels. With this number of channels, having an aggregate 484 samples per second, 170 MB of data were recorded per day. This amount of data is slightly more than that specified for an array in GSE/US/84.

Part of this contract involved hardware additions to the system. These additions included an additional four GB disk storage and a Geotech KS54000–0103 seismometer in a 119 meter borehole to replace broadband signals from Geotech BB–13s in an underground vault.

The contract also included development of a method to make all data on disk (recent real-time continuous data, plus event data) available on the internet. Methods that were tested on line for a period of at least six months were NFS remote mount, anonymous FTP, and Gopher Plus (no connection with Gopher software at the Iris DMC).

Remote NFS proved an excellent way to use files seamlessly between two closely cooperating facilities; in this case, Southern Methodist University and the Oklahoma Geological Survey Observatory. NFS does not appear to be viable for general data sharing between many institutions.

Anonymous FTP is a generally available protocol, and is effective at data transfer. However, the data receiver has to have advance knowledge of the sender's data structure (we provided this by finger and also in the FTP files). Even with this knowledge, the receiver must navigate carefully through the data tree in small steps without aid of menus. Anonymous FTP is satisfactory but very cumbersome for the receiver.

Gopher Plus appeared to be ideal for distribution of data in a structured tree. The contents of each directory are displayed as a menu. Because a help file can be placed at each menu level, a data receiver can obtain data on her or his first access. Gopher Plus is very user friendly. One needs only to select directories from successive menus. When a waveform is finally selected, the Gopher Plus server and client start a binary transfer of the file.

NFS, Gopher Plus, and Anonymous FTP can coexist on the same computer or computer network on a LAN. They can even interact. We used Gopher to distribute not only our own data, but also NFS-mounted data from Southern Methodist University. This was successful but very slow compared to direct access to SMU.

Anonymous FTP was eventually discontinued, and the continuous NFS crossmounting between the OGS and SMU was dropped, leaving only Gopher Plus, which has now been in use for one year.

Another type of data transfer is the running of a continuous updating display at a remote point using the "GSE Workstation" "Channels" and "Sentinel" program. "GSE Workstation" refers to a suite of data-acquisition and analysis software developed by Teledyne-Geotech Alexandria Labs under DARPA/NMRO contract. As Sentinel can be replaced by a Getchannels program, channels and Getchannels could be used for continuous transmission of data as it is recorded. This places a heavy load on network convections, and requires close cooperation of the sender and receiver.

1.2 HARDWARE UPGRADES TO THE GSE SYSTEM

1.21 Workstation

When recording 16 seismic channels and three magnetic channels (all channels listed in Table 1 except vlpz) the real time data retained on disk was often as little as 1.5 to 2.5 days. The GSE system had only part of a 660 MB disk available for real time data. The GSE software removes only entire days to make more space, sot he allowed real time space was often 40% empty. The GSE software also requires an elaborate soft link table to have real time data spread over more than one Unix filesystem, and the linktables must be remade if the configuration (i.e., sample rate on one channel) is changed. Therefore, under this contract, we ordered the largest SCSI disk available, 2.1 GB formatted, in order to build the largest possible real time waveform file system. On first attempt to use the new disk the workstation gave bad FSCK messages on this disk. We learned that SunOS4.1.1 could not have a single *physical disk* larger than one gigabyte. SunOS4.1.1 would not even allow a disk larger than one GB if it were partitioned into smaller filesystems, that would also have defeated our requirement for one very large filesystem. SunOS4.1.2 could be patched to allow larger disks, and native SunOS4.1.3 will allow larger disks. We purchased and installed SunOS4.1.3. After a few weeks of downtime to get the new operating system running, we were able to start using a 2.1 gigabyte real time waveform filesystem. However

Table 1. GSE Data Channels Recorded in June 1994 Excluding RDAS State-of-Health Channels

Station	Channel	Samples/sec	Sensor	Location
TUL	sz	40	GS-13	4 m deep vault
TUL	sn	40	GS-13	4 m deep vault
TUL	se	40	GS-13	4 m deep vault
TUL	zz[a]	10	KS54000-0003	119 m bore
TUL	zn[a]	10	KS54000-0003	119 m bore
TUL	ze[a]	10	KS54000-0003	119 m bore
TUL	lz[a,e]	1	KS54000-0003	119 m bore
TUL	ln[a,e]	1	KS54000-0003	119 m bore
TUL	le[a,e]	1	KS54000-0003	119 m bore
TUL	vlpz[a,f]	1	KS54000-0003	119 m bore
TUL	mag Z	10[b,f]	FM-105B	surface vault
TUL	mag D	10[b,f]	FM-105B	surface vault
TUL	mag H	10[b,f]	FM-105B	surface vault
RLO[c]	sz	40	S-13	tank vault
VVO[c]	sz	40	S-13	tank vault
SIO[c]	sz	40	S-13	tank vault
LNO[d]	sz1	60	23900	748 m bore
LNO[d]	sz2	60	23900	432 m bore
LNO[d]	sz3	60	20171	5 m bore

[a] At the beginning of the contract BB-13a in a 4 m-deep, walk-in vault were used. The vlpz mass position could record temperature variations and large earthquakes. With the KS54000-0103, earth tides are clearly recorded on the vlpz channel.

[b] At the beginning of the contract the EDA FM-105B fluxgate components were only recorded at one sample per second.

[c] Remote sites at distances of 75 km (RLO), 60 km (VVO) and 50 km (SIO). The signals arrive by analog radiotelemetry.

[d] The TUL 119 m bore is about 60 m from the 4 m walk-in vault, and midway between the vault and the Russian Designated Seismic Site bore. The LNO borehole is about 400 meters away. A separate station designator has always been used for the LNO bore. Another contract (DEPSCoR) provides for an 800 m bore about 100 m from the LNO bore. The broadband 3C seismometer in the DEPSCoR bore will also be designated as station LNO.

[e] At the beginning of the contract, the lz, ln, le channels were calculated from BB-13 to sample per-second signals using a 6-Pole IIR bandpass filter with corners at 0.0625 Hz and 0.001 Hz, with decimation to 1 sample per second. Because the lp signals are in separate files on real-time disk data, and are separately archived on 8 mm helical scan tape, they are listed as separate channels. After the KS54000-0103 replaced the BB-13a, the IIR filter lower-corner frequency was changed from 0.001 Hz to 0.0001 Hz.

[f] In November 1994 the bb sample rate was changed to 20 samples per second to be compatible with use in GSETT-3. This channel then corresponded to the definition of "vbb" given in Peterson (1993). His definition of "vbb" is a seismometer flat to velocity from 0.2 sec to 360 sec period, samples 20 times per second. The nomenclature used at TUL was not changed from bb to vbb. The lp filter band was narrowed slightly, the 3dB low-frequency point being changed from 0.0001 Hz to 0.0002 Hz. The digital filter failed at 0.0001 Hz low cut when the sample rate was changed from 10 to 20 per second 6. This does not correspond to Peterson's (1993) definition of VLP.

UNIX operating systems normally require 10% free space, so we had closer to 1.9 GB available. This did allow nine days real time data to be kept continually on disk.

Other disk space problems were very limited space for dearchived or event data, and limited Oracle database space. The event data was moved to a 600 MB space remote mounted on a SUN 3/50 (on loan from Lawrence Livermore National labs). The Oracle TM database was expanded onto the second 2.1-GB disk purchased under this contract. Later, when the SUN 3/50 had a hardware failure, the event data was recovered from a back-up tape and put on the second 2.1-GB disk.

Many other problems associated with the SPARC 1+ workstation were overcome by two soft changes: building larger kernel tables with a MAXUSERS of 128, and adding filesystem swapping. Filesystem swapping allows swap space to be created on any disk without even rebooting. According to Loukides (1991), filesystem swapping is a feature of SunOS, but not of BSD or System V Unix in general.

The Sun Sparc 1+ was depressingly slow. If it got behind, a backlog of 50 runnable processes might develop. This took hours to clear and fragmented data into files as small as a few seconds instead of the standard one hour. With funding from another contract (DEPSCoR), we replaced the 25 MHz Sparc 1+board, with a 40 MHz Sparc 2 board using an 80-MHz Wytek (TM) Mu Power processor. In many bench marks this combination runs at 90% to greater than 100% of the SPEC marks for a one-processor SPARC 10. In the upgrade, the two SCSI 1 ports were replaced with a one SCSI 2 port and one "fast SCSI Z" port. The improvement was drastic. The new processor runs 500 to 800 context switches per second, and keeps the run queue always below seven. The processor is usually loaded to only 40% capacity, although if a computer-intensive process (e.g., FFT with several hundred thousand points) starts, the processor will briefly load to 100%.

1.2.2 KS54000-0103 SEISMOMETER

A 119 m borehole was drilled into the Pennsylvanian shales (including some thin sandstones and limestones). The 119 m bore was cased with 19.4 mm ID pipe and cemented from top to bottom. The bore was located midway between the Oklahoma four-meter-deep walk-in ("historical" in TTBT language) vault and the Russian Designated Seismic Site 32-m bore. The completion of the new 19.4 m x 1119 m borehole for under $17,000 (as compared to $70,000 for the Russian DSS 305 mm x 32 m bore) suggests that it is advantageous to omit any "seismic experience" requirements from the specifications.

The Omaha District of the U.S. Army Corps of Engineers had a seismic experience requirement for the DSS. All bidders were required to have drilled one U.S. Government-funded seismic borehole within the last five years. Omitting the seismic experience requirement had the advantage of allowing local contractors with many years experience in regional geological conditions to bid.

The KS54000-0103 was oriented with a gyro tool, by using the gyro to find the direction of the holelock. After many measurements and some calculation the holelock (Bishop's Hat) orientation is found. A directional ring at the bottom of the seismometer is then turned and locked so that the key on the seismometer will force it to turn until the horizontal components point in the desired direction. This method is somewhat cumbersome. It requires borrowing one of the half dozen gyro tools in the world, and there are many chances for error. When the first motions of large P waves seemed inappropriate, the visual correlation of microseisms of vault GS–13 and the KS54000–0103 were used to estimate the true orientation. The seismometer was turned exactly 90 degrees (within error limits) from its correct orientation. Switching horizontal outputs and reversing the polarity of one horizontal component changed microseisms to the expected near identity between vault and borehole, without reinstalling the seismometer.

Because of many lightening problems with equipment, we took three steps to reduce danger to the expensive and relatively inaccessible KS54000-0103. The borehole was connected by 0000 fine-stranded copper-cable to the RDAS in the vault. The KS54000 power was supplied by amorphous solar panels through a switching supply. The panels and the switching supply were not connected to anything but the seismometer. The 18-pair analog cable was carried from the borehole to the vault by heavy steel conduit.

The top of the borehole was sealed with a cap designed to be airtight. On several occasions a value in the cap was opened briefly. Air always entered or left the valve suggesting that the pressure was near the different barometric pressure at the time the valve was last opened. The valve was placed so that the borehole could be evacuated and perhaps backfilled by helium. This has not yet been done, but it is hoped that it will reduce convection in the bore and decrease horizontal component noise. Helium has a high thermal conductivity that can transport heat so rapidly that temperature differences to start convection do not occur. Geotech uses both a vacuum (inside the seismometer modules) and helium (in the case outside the seismometer modules) to suppress convection.

The noise in the long-period noise window (centered around 35 seconds and extending from perhaps 25 to 60 seconds (Savino et al., 1972; Murphy et al., 1972) was of particular interest. It is in this LP window that surface waves from very small earthquakes and some larger nuclear explosions may be recorded and used for mb–Ms or Moment-Tensor discrimination. The horizontal components are necessary if corrections are to be made for tectonic-strain relief by a nuclear blast.

Because of overlapping difficulties of converting CSS 3.0 to SAC and the failure of the one computer with SAC installed, power spectral densities were not done. Instead straight FFTs of the time series were made with the GSE software ""Interspec" module. A typical time series for FFT is shown in Figure 1. Only the middle three (broadband) traces were used. The interval was selected from a 96-hour earth tide (KS54000-0103 vertical mass position) display as being free of moderate earthquakes. After display of the 120–minute segment, the Zn, and especially the Iz, In, and Ie traces revealed a small earthquake that required cutting the interval to 97 minutes. Figure 2 shows the FFT smoothed over an 0.01 Hz interval. In the spring and summer three distinct microseism peaks (on this record 63.2, 143, and 226 mHz) are not unusual. In the winter the 143 and 226 mHz peaks increase in amplitude and merge. The Z trace shows a shape very similar to Jon Peterson's NLNM (New Low Noise Model) described in Peterson (1993).

Of particular concern to discrimination research is the failure of the horizontal components to match the NLNM in the LP window. I define the "breakaway" point as the period beyond 10 seconds at which the noise on both horizontals rises, often rapidly, above the vertical noise. On the TUL KS54000–0103, breakaway is at about 26 seconds (referring to Figure 2). The breakaway point is not caused by well known horizontal wind noise. It occurs at the same place regardless of wind conditions.

In Savino et al. (1972) breakaway was apparent at HGLP (High Gain Long Period) stations at Charters Towers, Chiang Mai, and Toledo. Breakaway was not obvious at Fairbanks, Eilat, and Ogdensburg. From Peterson (1993) I selected PSD plots of borehole and deep (30 m or more) vaults to check for breakaway. At a suggestion of Bob Hutt, I omitted borehole sites using KS36000 and KS36000–0103 seismometers. I used all vault sites of 30 m or greater depth with STS1/vbb seismometers. The results are shown in Table 2.

The instrumental noise does not seem to account for horizontal breakaway. Gary Holcomb (personal communication) has a number of plots where STS–1, STS–2, and KS54000 seismometers recorded in pairs in the same or nearby vaults or boreholes. He then graphed the non-coherent noise between the pair. This noise shows a tendency toward horizontal breakaway, but it is most often at periods exceeding 100 seconds, and or is below the NLMN. Some combinations of vertical and horizontal curves for the STS–2 showed a breakaway point above NLMN and at periods under 100 seconds. In general, it appears that the horizontal breakaway in Table 2 is not instrumental noise. It may well be true earth noise. That the two sites expected to be noisiest (islands, Raratongo and Guam) have a very short-period breakaway (9–10 seconds) also suggests an earth-noise source. Most others breakaway at 25 to 50 seconds with notable exceptions at ANMO (450 sec) and MAJO (85 sec). Bob Hutt (personal communication) states that ANMO is installed very similarly to the other bores, and that the expertise and experience of the staff at the USGS Albuquerque Seismological Center may not explain the difference. If the local staff expertise accounts for the quiet borehole, it does not produce an unusual breakaway for the Albuquerque 36-meter vault that breaks away at 25 seconds.

Table 2. Horizontal Noise Breakaway from KS36000–0103 Stations with Boreholes and STS1/vbb Stations with Vaults 30 m Deep or Deeper.

Station	Location	Vault or Borehole	Depth (m)	Rock	Breakaway in Seconds Period
ALQ	Albuquerque	V	36	granite	25
ANMO	Albuquerque	B	100	granite	450
CCM	Cathedral Cave	V	51	limestone	40
CHTO	Chiangmai	B	100	granite	30
CTAO	Charters Towers	V	37	granodiorite	35
ERM	Erimo	V	30	slate	45
GAR	Garm	V	30	granite	15
GNI	Garni	V	60	basalt/tuff	25
GUMO	Guam	B	100	limestone	9
KIP	Kipapa	V	36	basalt	40
KONO	Kongsberg	V	340	gneiss	25
MAJO	Matsushiro	V	48	quartz diorite	85
NNA	Nand	V	30	granite	50
NWAO	Narroyin	B	100	granite	30
OBN	Obninsk	V	30	limestone	25
RAR	Raratonga	B	100	basalt	≤10
SNZO	S. Karori	B	100	graywacke	30

Note: Values were read from graphs in the Appendix of Peterson (1993).

The method of borehole mounting may affect horizontal noise. Bob Hutt (personal communication) stated that a KS54000–0103 in a 3–meter borehole with sand poured around it was, in the absence of wind, quieter on the horizontal components than a deeper KS54000–0103. Sand has not been tried at the Oklahoma Geological Survey. A very experienced petroleum engineer warned us that dry sand may "set" over an extended period and require damaging fishing to remove the seismometer. Three meters ma be a safe depth for a sand "clamp," but 100 meters clearly is not a place to use sand.

Rodgers (1968) quantifies the separate response of any horizontal pendulum seismometer to horizontal motion and tilt. The tilt caused directly by Rayleigh and Love waves in the 25– to 60–second window of verification interest is small (Rayleigh) to zero (Love). However, moving pressure cells may tilt the ground in the 25– to 60–second range. This is made unlikely by the Oklahoma 119 m installation that shows about the same breakaway regardless of wind conditions. This installation is in less competent rock (Pennsylvanian shales) than many others. A grant from DEPSCoR will allow us to place a broadband seismometer in Cambro-Ordovician dolomite, at 800 m beneath the surface. That facility may reveal something about the cause of horizontal breakaway.

Figures 3, 4, and 5 are general seismograms to illustrate the signal quality of the KS46000–0103 installation. Figure 6 illustrates the overall configuration of the GSE system, including the DEPSCoR borehole and seismometer that are not yet installed. Current plans differ from the diagram in that the Remote Data Acquisition System will be moved to the vault, and signals from the 5–meter, 770–meter, and 800–meter boreholes will be brought overland in optical fibers.

1.3 DISTRIBUTION OF OPEN STATION DATA

1.31 INTRODUCTION

One of the main considerations in selecting a method to distribute data over the internet was to avoid segmenting data to order. Any segmentation caused literally hundreds of accesses to the ORACLE 6 database. Before hardware upgrades, discussed above, the Sparc 1+ with disk access at SCSI 1 speeds simply would not do more than one slow segmentation at one time. Segmentation occurred during the "dearchive" process in which real time waveforms from disk (or tape if they were no longer on disk), were taken from selected channels, for selected times, and given a distinctive "event" name. Although these were called events, many of them were noise samples. Others were events in the sense of being discrete earthquakes, mining blasts, or nuclear blasts. The dearchive resulted in one or more dot w files, e.g,, BEXAR91A04,TUL.SZ.W, BEXAR91A04.TUL.SN.W, and additional files for each component. Dearchive also produced one dot wfdisc file, e.g., BEXAR81A04.wfdisc. More than one dearchive at a time, or one dearchive when the system was very busy, resulted in a buildup of the run queue. This buildup would cause NRTM (Near Real Time Manager) to stop accepting data, that would then be buffered in the front-end computer, the RTDS (Real Time Data Server). A remote copy of the buffered data would then start in parallel with transmission in real time data over the ethernet. The run queue became longer, NRTM could not accept more data, and the files began to be fragmented into seconds instead of one hour each. Each of these tiny files had its own dot wfdisc to be loaded into the database, and dot wfdisc loader built up a queue of thousands. The machine would be found, apparently frozen, requiring minutes to take input from the keyboard. In these circumstances the run queue would exceed 50. Real time data had to be suspended (and often lost) while the dot wfdisc loader cleared its queue and the run queue was cleared. This ceased to happen with the SPARC 2/Wytek 80 MHz Chip upgrade, although dearchive or segmentation was still slow.

Not only did the difficulty segmenting lead to avoiding segmenting at all for data distribution, it lead to using one or both Sun SLC as data distribution machines to keep any load off the data-acquisition machine. All the real time and event waveforms were NSF remote mounted on the SLCs for distribution by gopher or anonymous FTP. This gave some security, because no outside connection (except NSF remote mount) was ever made to the data-acquisition machine.

The considerations outlined above required real time data to be distributed by the channel hour along with the associated dot wfdisc file, which might contain lines for dot w files for an entire day. This required the receiver of the data to edit the dot wfdisc files, but the lines were clearly marked for component and hours, so the editing consisted of deleting unwanted lines. Several institutions that wanted event data for teaching purposes, without need for detailed time scales and other information, retrieved only the dot w files and plotted them one of several commercial x–y plotting packages. The dot w files were uniformly time-spaced, double-precision integers, except for the LP channels. The IIR filters which created the LP channels had a floating point output.

1.3.2 NFS (Network File System) REMOTE MOUNT

NFS allows a file tree from one Unix computer to be remote mounted at any file system point on another computer. NFS files from another machine act as if they were on a disc of the local machine, except for the delay in passing information over an ethernet LAN (for machines in the same facility) or over the internet for more distant machines. The idea for remote mounting entire seismic file systems is credited to "WUARCHIVE<' a general archive FTP server at Washington University at St. Louis. A README file from WUARCHIVE invited anyone to remote mount their several gigabytes of files for use as local files without making any sort of FTP connection.

NFS file systems or trees become available for mounting to other machines when they are listed in the /etc/exports file of their home machine (on whose disks they reside). NFS security measures may include exporting files read only, and exporting them only to a list of certain remote hosts. The local file-mount point may be renamed for convenience (or to conceal parts of the local file structure), by making a symbolic link and exporting the symbolic link. One security measure is not possible: exporting the file to another machine for re-export.

With cooperation of Gene Herrin, Paul Golden, and Nancy Cunningham, data files from SMU were mounted at Leonard and vice versa. Each set of files was about two gigabytes.

The SMU files were in four-hour channel segments. It was possible to transfer a 40-SPS four-hour segment in 1,714 seconds or 28.6 minutes. The transfer was timed by copying the apparently local NFS file to another file residing on the local machine. This transfer proceeded at 8.4 times real time over the internet in the daytime. Transfer should be faster if made at night, or if the final link to Leonard had been faster than a nominal 9.6 kilobaud. Actual transfer rates were around .8 to 1.5 kilobytes per second in the day and 2.5 to 3.8 kilobytes per second at night.

NFS, because of its simplicity and transparency, should have a place in data exchange. However, it would be mainly useful for facilities which wanted to use each other's data on a fairly regular basis. It is probably not the best tool for public data distribution.

1.3.3 FILE TRANSFER PROTOCOL

Anonymous (no password required, the user logs in as "anonymous" and gives an E–mail address as a password, although many systems accept any string as a password). FTP is a universal, familiar, but somewhat cumbersome system for transferring files. The seismic data tree can be remote mounted inside the FTP data area on a secondary machine to keep outside connections off the data-acquisition machine. FTP must be navigated by interactive requests to "pwd" (print current directory tree), "cd" (change directory), and "ls" (list files) of lower directories, or "ls–l" for a detailed file list showing file permissions, length of file in bytes, and data last modified. Files are retrieved by "get." The FTP link must be manually switched between ASCII and Binary made depending on the type of file transferred.

The FTP user may be required to guess the local file structure by wandering among directories, although frequently "README" files are scattered around for help. In addition to "README" files, a "finger" service was made. Typing:

```
finger openinfo@wealaka.okgeosurvey1.gov
```

would immediately retrieve an FTP instruction file.

We usually logged into a machine at CSS and FTPd data to it to evaluate a typical internet conditions. The typical FTP daytime transfer of 40 SPS data proceeded at 8 or 9 times real time. FTP is a universal, familiar, but not very user-friendly method for transferring seismic data. Although it is satisfactory, internet gopher plus is better.

1.3.4 INTERNET GOPHER PLUS

The internet Gopher Plus (not connected with a formerly used piece of software called gopher, operated by the Iris DMC), is a user-friendly, browse-and-transfer protocol using clients and servers. Its presentation of successive menus makes it a natural system for handling tree-like real time data structures. Help files can be placed on menus exactly where they are needed.

A gopher server was built on one of the SLC machines, and the real time and event files were remote mounted in the gopher data area. The gopher server is stateless. As soon as it sends its next menu, or a file, or a link file to another gopher server to the client, the server forgets the connection (although if implemented, it will write the connecting machine and directory, file, or link retrieved as a line in a log file). Only the client stores the connection information. If the client appears to thread its way through many directories, files, and different gophers, it is only storing a stack of link files by which the client can retrace its path backward, if desired.

Gopher transfers ran at about 9 times real time (40 samples per second). We could configure the gopher to treat all dot w files as binary, and the server automatically transferred in binary without the user switching modes. One change we made was to disable directory caching. Directory caches keeps all directories static for about fifteen minutes. This would prevent a new waveform file from being seen or fetched by a client for 15 minutes or so after it was opened. Without caching, a new waveform file is immediately seen and can be immediately copied, up to the point at which it is being written.

Gopher servers and clients are more or less public domain, and can be easily obtained for UNIX, VMS, PCs, MACs, Windows, other platforms. A gopher server can be run secure or open (we used both). A secure gopher server can permit one list of machines to browse only, and another list to browse and retrieve files.

X-mosaic can be used to access any gopher server. We have X-mosaic but find its local overhead in popping up many new X-windows to slow down gopher. The same is true of X-gopher. The fastest client is plain gopher plus using curses pseudo-graphics. Curses will work on simple windowless terminals. When X-mosaic client is used, a URL (Universal Resource Locator) strung like:

gopher://wealaka.olkgeosurvey1.gov/

points to the gopher server.

Figure 7 shows the successive operations in retrieving one of our waveform files at the Center for Seismic Studies using X-gopher.

As of June 1994 we have about 450 gopher connections per day. Some of these are for waveforms, but many are for some of the following text and graphics files:

postscript seismograms (mostly made with geotool) selected for educational use.

NEIS QED

YKA, SP, LP, and large event bulletins

GER P, onset, and FEIS

ERI automatic moment tensor solutions

Catalogs of Oklahoma earthquakes

Full text of nuclear testing treaties

Catalog of 1990+ known nuclear explosions.

2. SPECTRAL DIFFERENCES IN REGIONAL SIGNALS RECORDED AT DIFFERENT DEPTHS

2.1 SUMMARY

Surface mining blasts exhibit drastically different time-domain seismograms when recorded from a short-period vertical seismometer at 748 meters depth, when compared to the same blasts recorded at 5 m and 432 m depth. The reason for this difference was examined. The difference was the near absence of Rg at 748 m.

Oklahoma earthquakes, presumably at a depth of about five km, apparently do not produce Rg. Unfortunately, blasts more distant than about 100 km do not produce recordable Rg either.

Originally it was intended to quantify the difference in time-domain seismograms recorded at different depths by comparing them in the frequency domain using spectral ratios. This might have been an earthquake/blast discriminant usable on the IMS.

When it was determined that this difference in time-domain grams at different depths was due exclusively to Rg, there was no useful discriminant information based on depth from which the signal was recorded. The changes with depth appeared only to call attention to Rg, that could be determined either from inspection of the time domain grams, or by particle motion from a 3C seismometer set.

2.2 DIFFERENCES OF TIME DOMAIN SIGNALS OF REGIONAL EVENTS SENSED AT DIFFERENT DEPTHS

2.2.1 Equipment

At station LNO (about 370 meters horizontally from TUL), there are three short-period vertical seismometers sampled at 60 samples per second. Channel LNO/SZ3 has a Geotech 20171 seismometer in a five-meter deep borehole, that is one meter horizontally from a 770 m seven-inch cased and cemented borehole. The 770 m bore is filled to about 100 m from the surface by water containing Halliburton Anhib. In the deeper borehole there are two Geotech 23900 seismometers at depths of 432 (Channel LNO/SZ2) and 748 m (Channel LNO/SZ1). There is an analog amplifier in each seismometer casing. The signals are recorded by the second RDAS of the GSE system. The second RDAS is located beside the winch used to lower or raise the 23900 seismometers. Noise tests with these seismometers are described by Harben and Lawson (1992).

2.2.2 Appearance of Time-Domain Seismograms

Figure 8 is a seismogram of a ripple-fired limestone quarry blast from one of several quarries about 30 to 40 kilometers NNE of LNO and TUL. The LNO/SZ1 (748 m depth) is strikingly different from LNO/SZ2 (432 m) and LNO/SZ3 (5 m). The mostly likely explanation is the absence of a phase beginning at about 32 seconds that was tentatively identified as Rg. There is also some difference between 16 and 32 seconds. Figure 8 is unfiltered. The sample rate is 60 samples per second. These seismograms were filtered through a number of fourth-order causal Butterworth bandpass filters. It was found that a 1.0 to 2.0 passband (Figure 9) enhanced the difference more than any other passband used.

Similar seismograms of a 1992 Oct 05 earthquake of mbLg 2.6, 162 km from TUL and LNO are shown in Figures 10 and 11. There are some differences in SZ1 and the shallower traces, but nothing clearly identifiable as in Figure 7. The differences become very irregular when a 1.0 to 2.0 Hz bandpass filter is applied. There is unfortunately little overlap in position or even in distance of the mining blasts with high S/N and earthquakes.

2.2.3 Particle Motion as Determined by Geotool

Geotool is an "Interactive data analysis and display program" written by Ivan Hanson (Teledyne Geotech Alexandria Laboratories) and John Coyne (Center for Seismic Studies), with DARPA sponsorship. The version is a little uncertain, but it appears to be "geotool2." Geotool has a particle-motion module that displays squares representing vectors between successive samples on an r, phi plane where,

r = sqrt (2.* sin [theta]),

with theta being the half angle between the motion vector and vertical, and

phi = $\tan^{-1}$ (N–S component/E–W component).

Circles on the graph represent 15, 30, 45, 60, 75, and 90 (outermost circle) degrees with respect to vertical. The size of the square is proportional to the length or modulus of the vector. A filled square (all black) represents "downward" motion and an open square (all white) represents upward motion.

Because of unfamiliarity with a particle motion display that does not draw an actual particle track, a known signal was used to determine characteristic patterns on the geotool display. The signal was a high S/N ratio recording of the 1994 JAN 17 Northridge California earthquake on LP traces.

P waves (Figure 12) show as a line pointing to the source, with two clusters between about 30- and 75-degree circles with a gap in the center. On the source side of the circle, motion is mostly downward and on the other side motion is mostly upward.

LQ waves (Figure 13) have two clusters at 90° to the vertical. An imaginary line joining them is perpendicular to the direction from the source. With respect to the direction of travel of the wave, the left cluster is downward and the right cluster is upward. It is not surprising that a purely transverse wave moving parallel to the ground surface would have only motion at 90° to the vertical in a perpendicular direction to the source direction.

Also not surprising is the motion of a Rayleigh Wave (Figure 14) with both upward and downward directions at all angles to the vertical, forming a line in the direction of the source.

S waves (Figure 15) gave a less regular pattern. After viewing both S and Lg from many sources, I concluded that neither had a characteristic pattern. It appears that the characteristic patterns described above may be used to classify direct waves as P, Love, Rayleigh, and all others.

2.2.4 Identification of the Blast Phase Absent at 742 Meters

The particle-motion module of geotool was used to identify the particle motion of the phase absent at 748 meters depth. The only high-frequency, three-component channels available at the time were GS–13s in the TUL vault. These were used to identify the type of wave recorded simultaneously in the nearby (376 horizontal meters) LNO borehole, that had only vertical components. The TUL GS–13s were digitized at 40 samples per second instead of the 60 samples per second used for the borehole seismometers.

Figure 16 shows the three borehole traces and GS–13 three-component traces of a quarry blast about 40 km north of TUL and LNO. This figure is not filtered. Particle motion seems to clearly show a Rayleigh phase that should be considered Rg. Figure 17 shows the same seismograms as Figure 16, but all traces were filtered. The remaining seismograms are all filtered with a fourth-order causal bandpass filter with corners at 1.0 and 2.0 Hz (the frequency filters are another module of geotool).

Although the particle motion is less clear on Figures 18, 19, and 20, it appears to be Rayleigh motion and the phases are Rg.

One vertical motion seismometer at about 450 meters and one at about 750 meters can clearly identify an Rg phase from nearby blasts with a high S/N ratio. This may not be true in other geological sections. The 5 m and 432 m seismometers are in Pennsylvanian shales, and the 748 m seismometer is in a Cambro-Ordovician dolomite overlying Precambrian granite.

Apparently Rg can be easily picked off time-domain seismograms and confirmed with particle motion. There is no need for seismometers in deep boreholes to identify Rg. A three-component seismometer that could be operated at a number of depths would allow a useful detailed study of the variation of the wavefield with depth. The Oklahoma Geological Survey has DEPSCoR funding to place a three-component, very broadband seismometer at 800 meters depth, but it will not be operated at any intermediate depths.

Although deep borehole seismometers (i.e., significantly below 100 m) apparently are not needed to identify RG, they should not be abandoned. Young and others (1994) state that high-frequency noise measured in a Texas borehole continued to decrease to the deepest recording depth of 1951 m. Harben and Lawson (1992) show decreases in noise to 748 m depth. In the presence of a temporary continuous surface noise source, Harben and Lawson (1990) found orders of magnitude decrease of noise at frequencies of 10 to 20 Hz at depths to 750 m. The decrease in long-period noise below about 120 m has not been studied. Back as early as 1960 many noise studies were made to depths of up to 3,000 m. However, phototube amplifiers generally limited passbands to something like 0.2 Hz to 5 Hz. These studies show rather small signal/noise improvement at great depth as opposed to depths of about 100 m.

Studies in deep boreholes on land should continue, particularly boreholes equipped with these component broadband seismometers.

3. REFERENCES

Harben, P. E., and J. Lawson (1990). *Oklahoma deep-borehole seismic-noise measurements: characteristics as a function of depth in the presence of high-surface noise*, Lawrence Livermore National Laboratory, Livermore, CA, UCID-21612.

Harben, P. E., and J. Lawson (1992). *Seismic noise variations in a 770-m-deep borehole near Tulsa, Oklahoma*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-LR-112420. 10 p.

Loukides, Mike (1991). *System Performance Tuning*, O'Reilley, Sebastopol, CA.

Murphy, Andrew J., John Savino, John M. W. Rynn, George I. Choy, and Keith McCamy (1972). Observations of long period (10–100 sec) seismic noise at several worldwide locations, *J. Geophys. Res.*, **77**, 5042–5049.

Peterson, Jon (1993). *Observations and Modeling of Seismic Background Noise*, USGS Open File Report 93–322, 45 p., 49 appendix p.

Rodgers, P. W. (1968). The response of the horizontal pendulum seismometer to Rayleigh and Love waves, tilt and free oscillations of the earth, *Bull. Seism. Soc. Am.*, **58,** 1384–1406.

Savino, John, Keith McCamy, and George Hade (1972). Structures in earth noise beyond 10 seconds—a window for earthquakes, *Bull. Seism. Soc. Am.*, **62**, 141–176.

Young, Christopher J., Eric P. Chael, David A. Zagar, and Jerry A. Carter (1994). Variations in noise and signal levels in a pair of deep boreholes near Amarillo, Texas, *Bull. Seis. Soc. Am.*, 1593–1607.

FIGURES

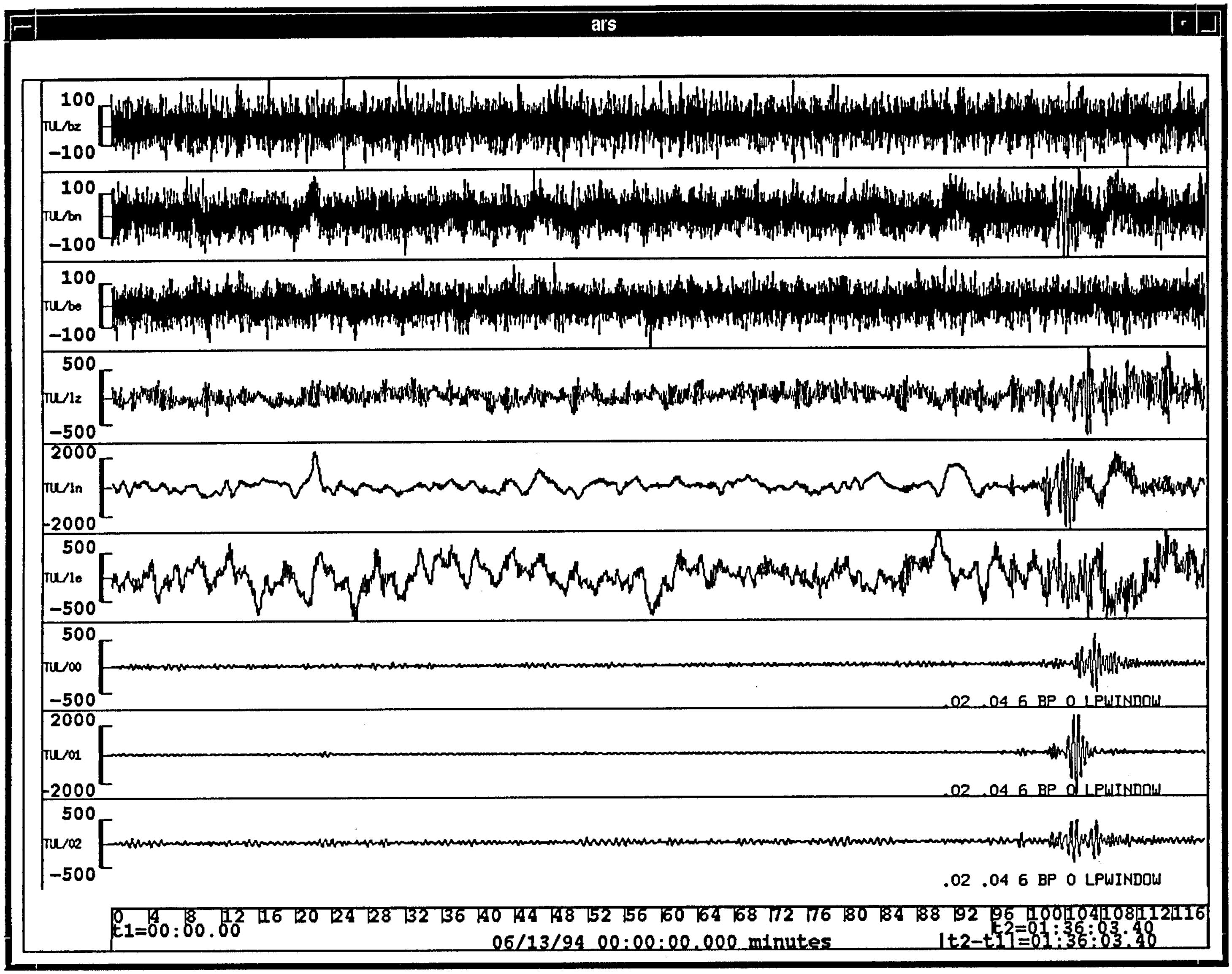
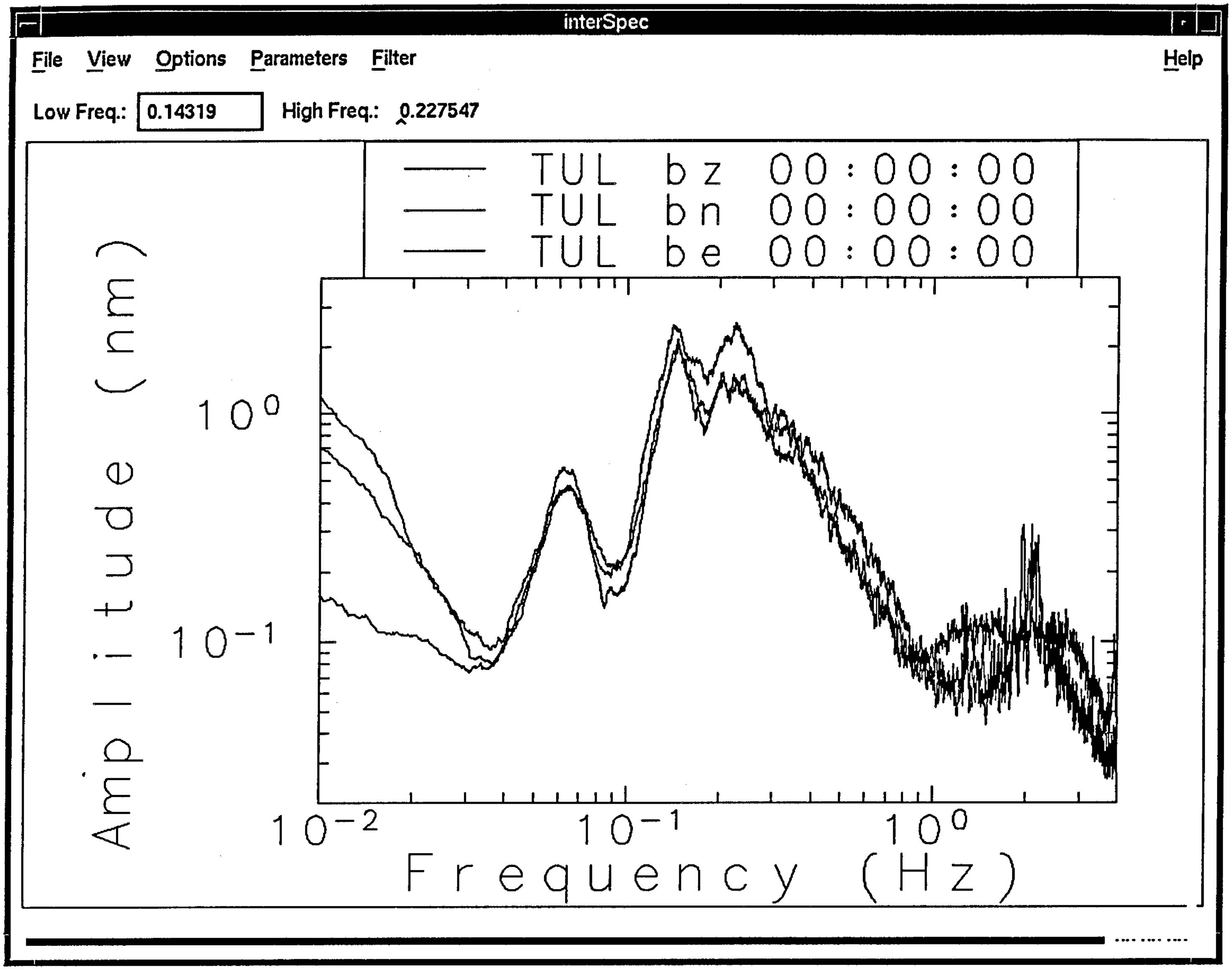


Figure 1. 120 minutes of TUL bb and lp trace 00, 01, and 02 are respectively lz, ln, le with a 0.02 to 0.04 Hz 6-pole bandpass applied. Because of the obvious earthquake around 97 minutes, only the first 96 minutes of the bb traces were used in the FFT.



Low Freq.: 0.14319

High Freq.: 0.227547

Figure 2. FFT (not PSD) of 57600 points of TUL bb signals from 000000 to 000136 UTC 1994 JUN 13. The points are smoothed by a 0.01 Hz window. During the spring and summer, it is typical for the double frequency microseisms to split, in this case with peaks at 226 and 143 mHz. The primary frequency microseisms peak at 63.2 mHz. "Breakaway" of bn occurs at 39.3 mHz (25 sec), and breakaway of be is at 37.5 mHz (27 sec). The "Amplitude" scale should be considered relative only.

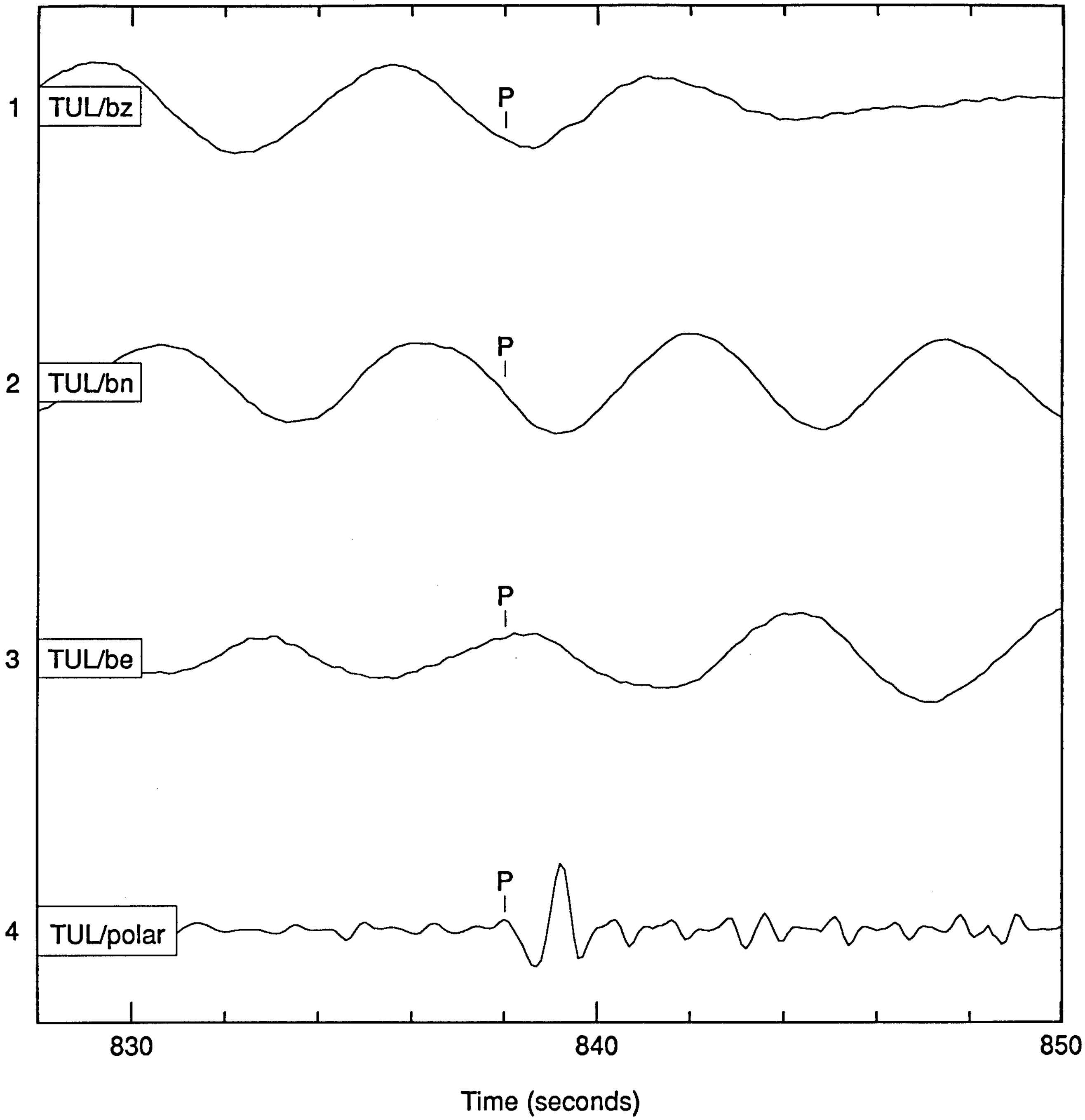


Figure 3. LOP Nor Blast P-phase. The lower three traces are unfiltered velocity channels from the KS54000-0103.

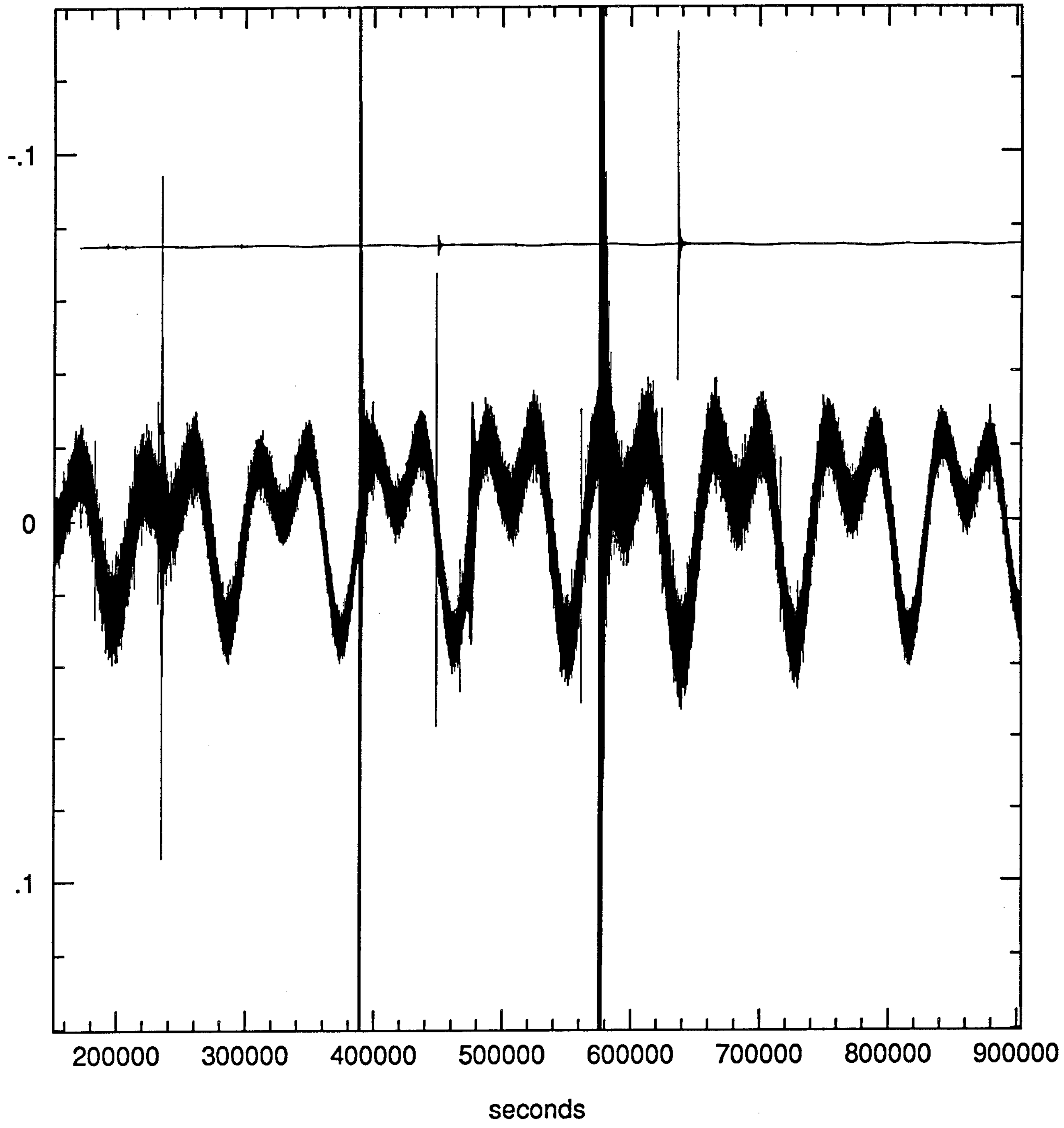


Figure 4. Six days earth tide recording. Earth tide (TUL/vlpz) recording from the mass position channel of the Z component KS54000–0103. The recording is from 1994 JUN 04, 03:34, to 1994 JUN 12, 20:46. The passband of 0.0 to 0.4 Hz (and one sample per second) allows recording of oceanic microseisms (represented by the width of the line), and larger earthquakes (represented with a spike, with or without a visible exponential decay). The largest four earthquakes from left to right are: JUN 05 South of Java, Indonesia, Ms 6.2; JUN 06 Colombia, Mw 6.8; JUN 07 Western Idaho, mb 4.9; JUN 09 Northern Bolivia, Mw 8.2. The upper line is the same data offset to the right with less than 0.01 times the gain of the main line. It gives an indication of the amplitude of the tides and other earthquakes compared to the Bolivian earthquake.

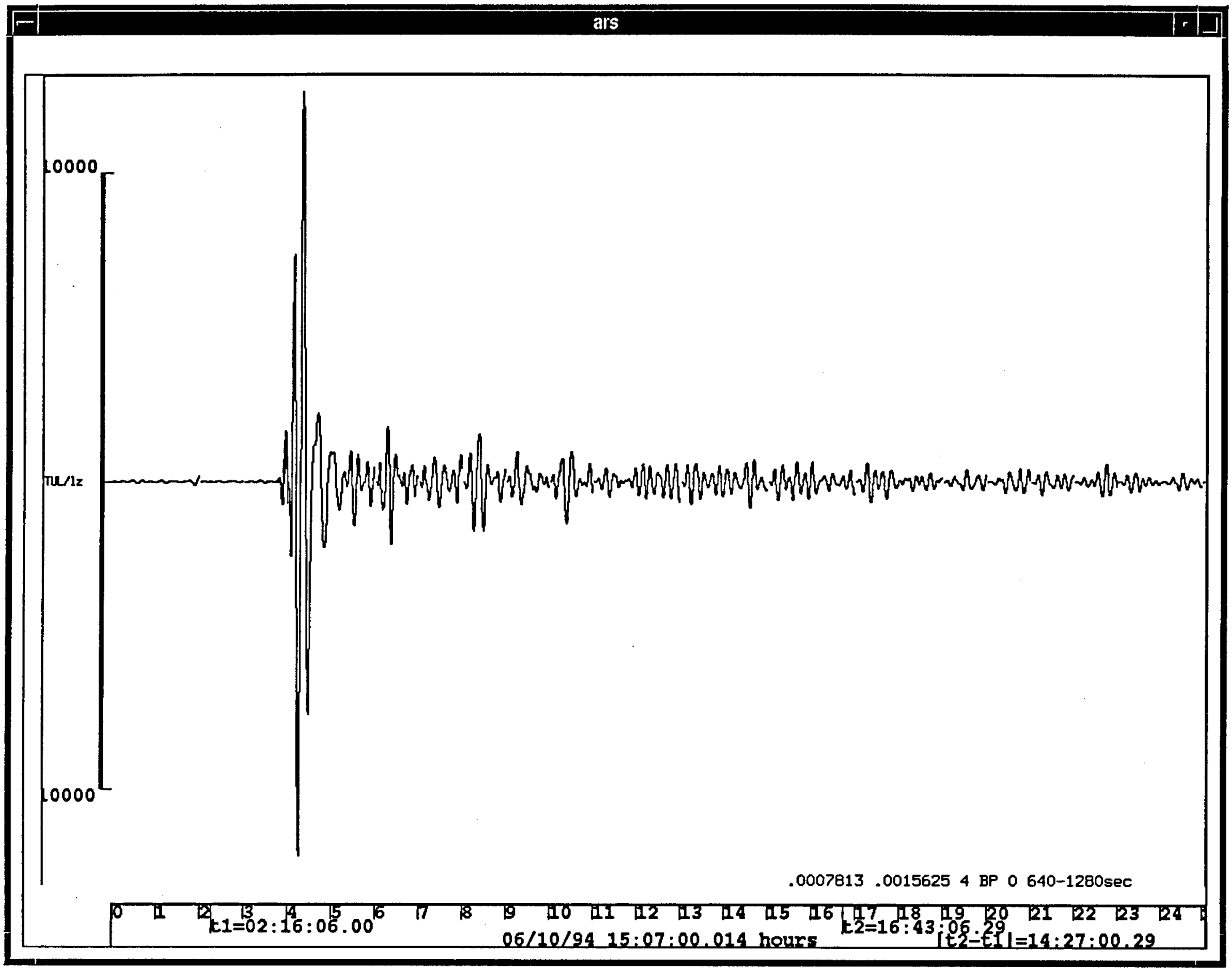


Figure 5. KS54000-0103 Vertical Velocity Channel. Fourth order filter 640 sec.–1280 sec. Deep Bolivian earthquake, Mw = 8.2, 1993 Jun 09. The bottom scale is in hours. Earth vibration modes are clearly above background 21 hours after the earthquake.

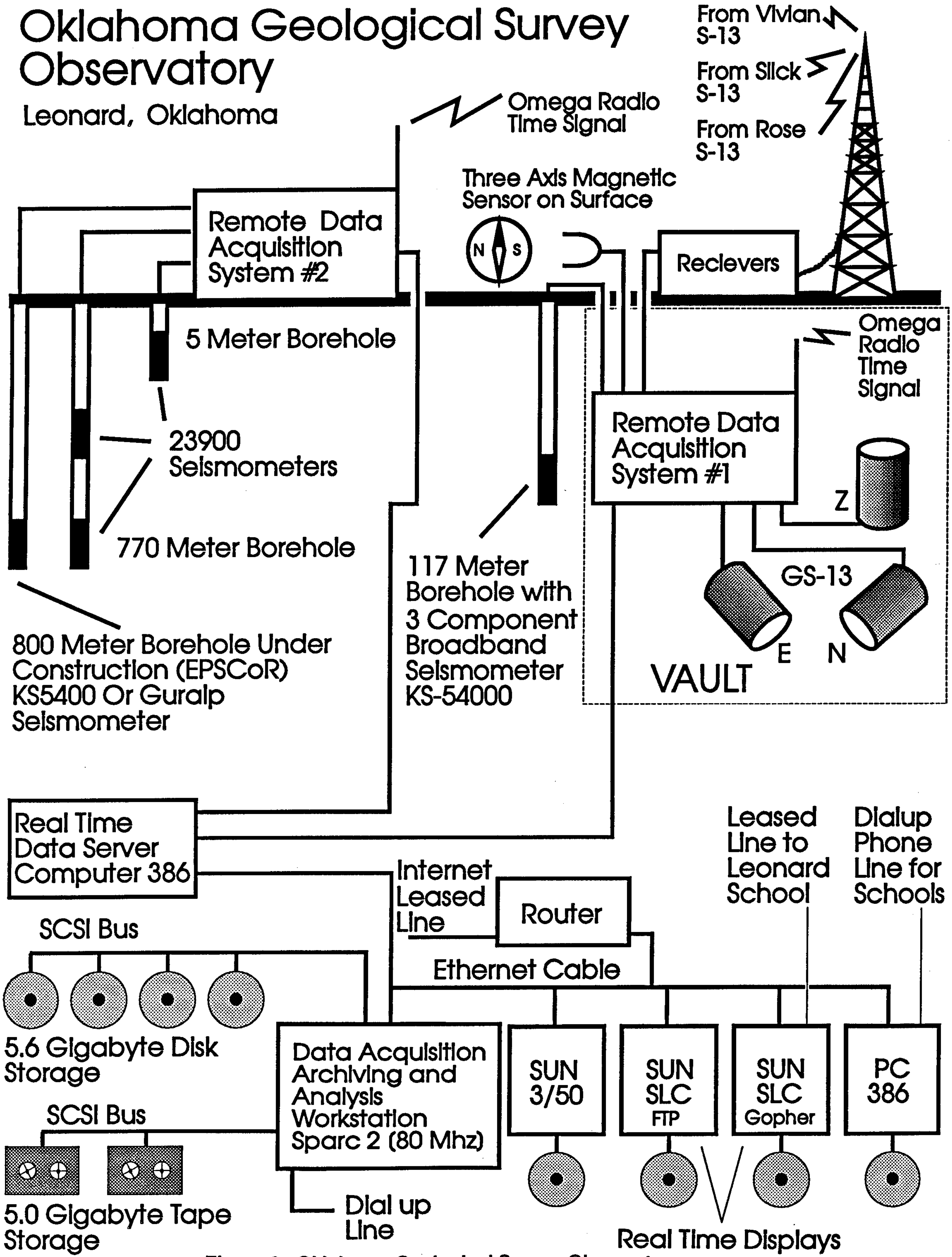


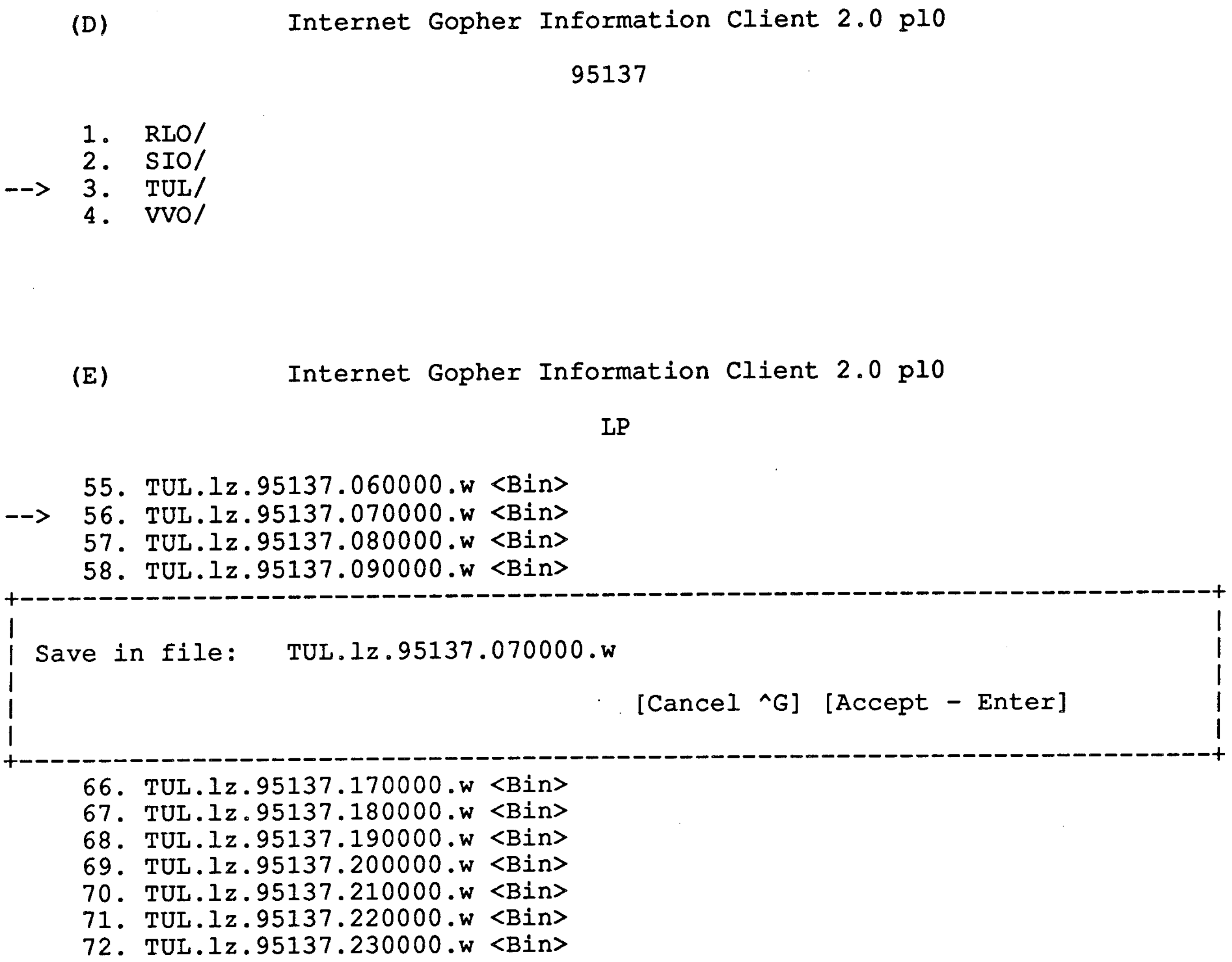
Figure 6. Oklahoma Geological Survey Observatory.

```
(A)           Internet Gopher Information Client 2.0 pl0

                      Root gopher server: wealaka

      1.  ---------------------------------------------------------------.
      2.  |WELCOME! OKLAHOMA GEOLOGICAL SURVEY OBSERVATORY  OPEN STATION |.
      3.  |near real time continuous and event seismic and magnetic data |.
      4.  |Oklahoma earthquake and nuke test catalogs, nuke test treaties|.
      5.  ---------------------------------------------------------------.
-->   6.  WAVEFORMS, last 9 days continuous waveforms + selected events/
      7.  TUL bz status/outages from GSETT-3 USNDC/AFTAC/
      8.  OKLAHOMA EARTHQUAKE CATALOG v earthquakes seismicity/
      9.  OKLAHOMA GEOLOGICAL SURVEY WAVEFORM, CAL, STATION, AND MISC INFO/
      10. OKGEOSURVEY POSTSCRIPT SEISMOGRAMS v seismogram earthquake earthqu../
      11. CATALOG OF KNOWN NUCLEAR EXPLOSIONS v test tests/
      12. connect to seismic sites outside Oklahoma/
      13. NUCLEAR TESTING TREATIES, RELATED TREATIES, DOCUMENTS v treaty/
      14. Seismic bulletins, info, some grams.ps  from sites outside OK/
      15. VERONICA: BOOLEAN SEARCHES OF ALL GOPHERSPACE/
      16. OKLAHOMA GOPHERS, MOTHER GOPHER, LIBERTY GOPHER/
      17. K12/
      18. keywords Oklahoma Leonard seismic seismology earthquake earthquake../
```

```
(B)           Internet Gopher Information Client 2.0 pl0

         WAVEFORMS, last 9 days continuous waveforms + selected events

      1.  *READ*NOW* to select Logbook or dearchive.
      2.  *READ*NOW* before selecting Logbook.
      3.  *READ*NOW* before selecting dearchive.
-->   4.  Logbook: Last approximately nine days continuous waveforms/
      5.  dearchive: Packages of waveforms from selected events/
```

```
(C)           Internet Gopher Information Client 2.0 pl0

           Logbook: Last approximately nine days continuous waveforms

      1.  95129/
      2.  95130/
      3.  95131/
      4.  95132/
      5.  95133/
      6.  95134/
      7.  95135/
      8.  95136/
-->   9.  95137/
      10. 95138/
      11. 95139/
      12. 95140/
      13. 95141/
      14. 95142/
      15. 95143/
      16. 95144/
      17. 95145/
      18. 95146/
```

Figure 7. (a) Top Level Gopher Plus Menu Displayed on Initial Connection. (b) Second Level Gopher Plus Menu. (c) Third Level Menu; Date Menu.



```
(D)            Internet Gopher Information Client 2.0 pl0

                                  95137

     1.  RLO/
     2.  SIO/
-->  3.  TUL/
     4.  VVO/
```

```
(E)            Internet Gopher Information Client 2.0 pl0

                                   LP

     55. TUL.lz.95137.060000.w <Bin>
-->  56. TUL.lz.95137.070000.w <Bin>
     57. TUL.lz.95137.080000.w <Bin>
     58. TUL.lz.95137.090000.w <Bin>
+-----------------------------------------------------------------+
|                                                                 |
| Save in file:   TUL.lz.95137.070000.w                           |
|                                                                 |
|                                  [Cancel ^G] [Accept - Enter]   |
|                                                                 |
+-----------------------------------------------------------------+
     66. TUL.lz.95137.170000.w <Bin>
     67. TUL.lz.95137.180000.w <Bin>
     68. TUL.lz.95137.190000.w <Bin>
     69. TUL.lz.95137.200000.w <Bin>
     70. TUL.lz.95137.210000.w <Bin>
     71. TUL.lz.95137.220000.w <Bin>
     72. TUL.lz.95137.230000.w <Bin>
```

Figure 7. (Continued)—(d) Fourth Level Gopher Plus Menu; Station Menu. (e) Fifth level menu; file menu. A file has already been pulled. The dotted box allows the file name to be replaced or edited on the client.

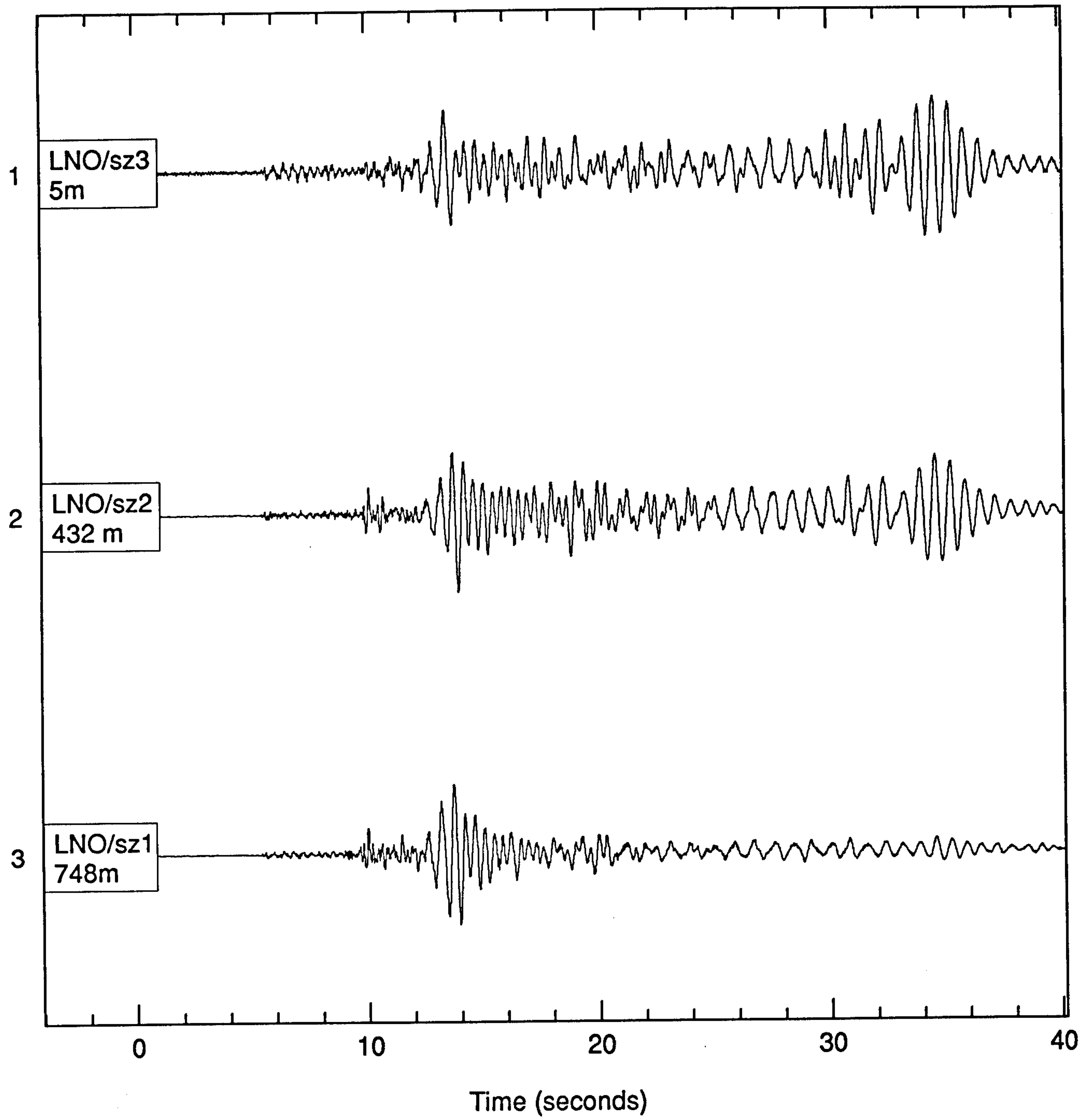


Figure 8. Time domain seismograms of a ripple-fired quarry blast about 40 km NNW of TUL and LNO. LNO/sz1 depth 748 m, LNO/szz depth 432 m, LNO/sz3 depth 5 m. Sample rate is 60 samples per second. This seismogram is unfiltered.

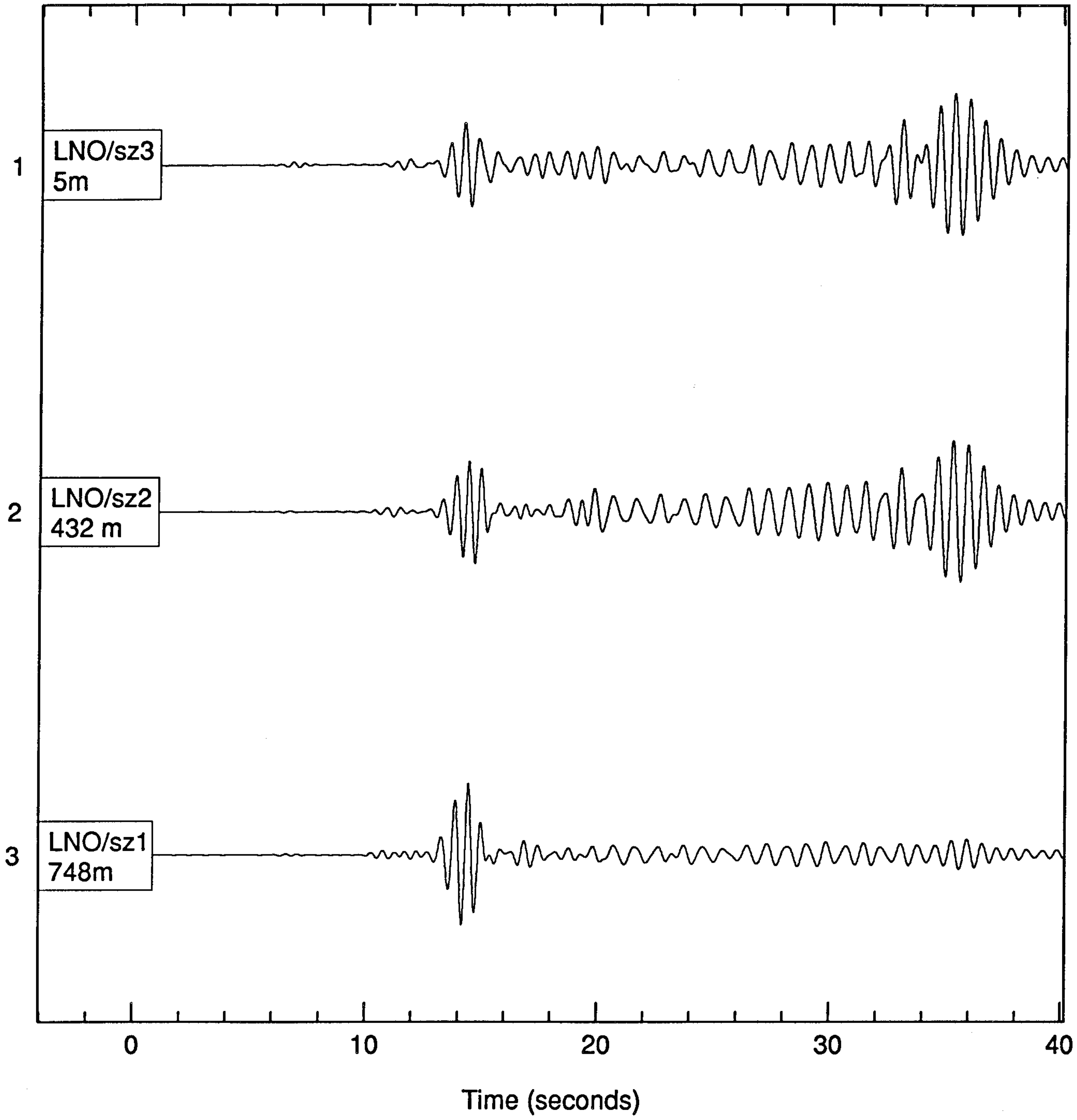


Figure 9. Same as Figure 8, except that a fourth-order causal Butterworth bandpass filter, 1.0 to 2.0 Hz, was applied.

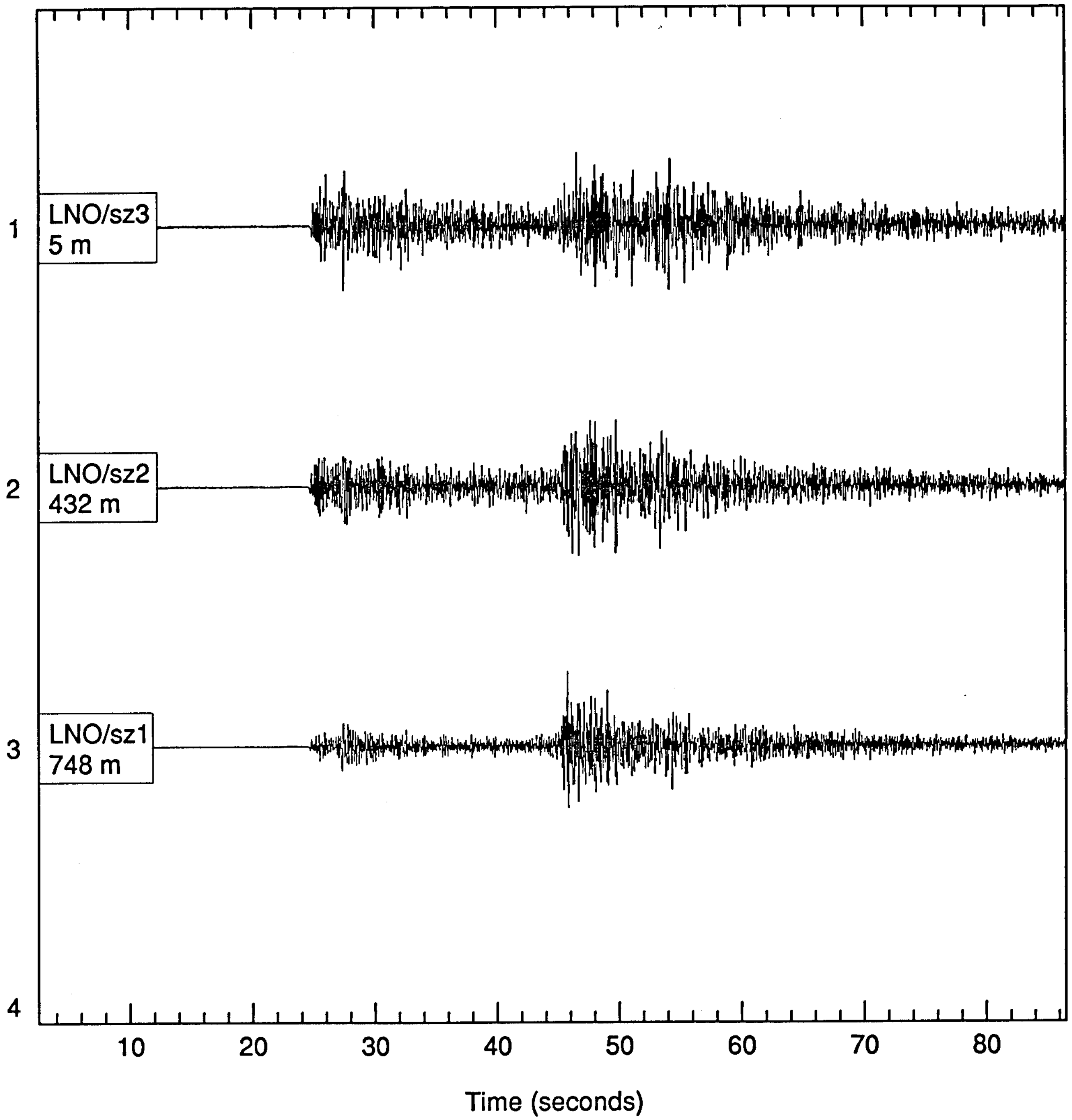


Figure 10. Earthquake 162 km from TUL and LNO Recorded from the Three LNO Borehole Seismometers.

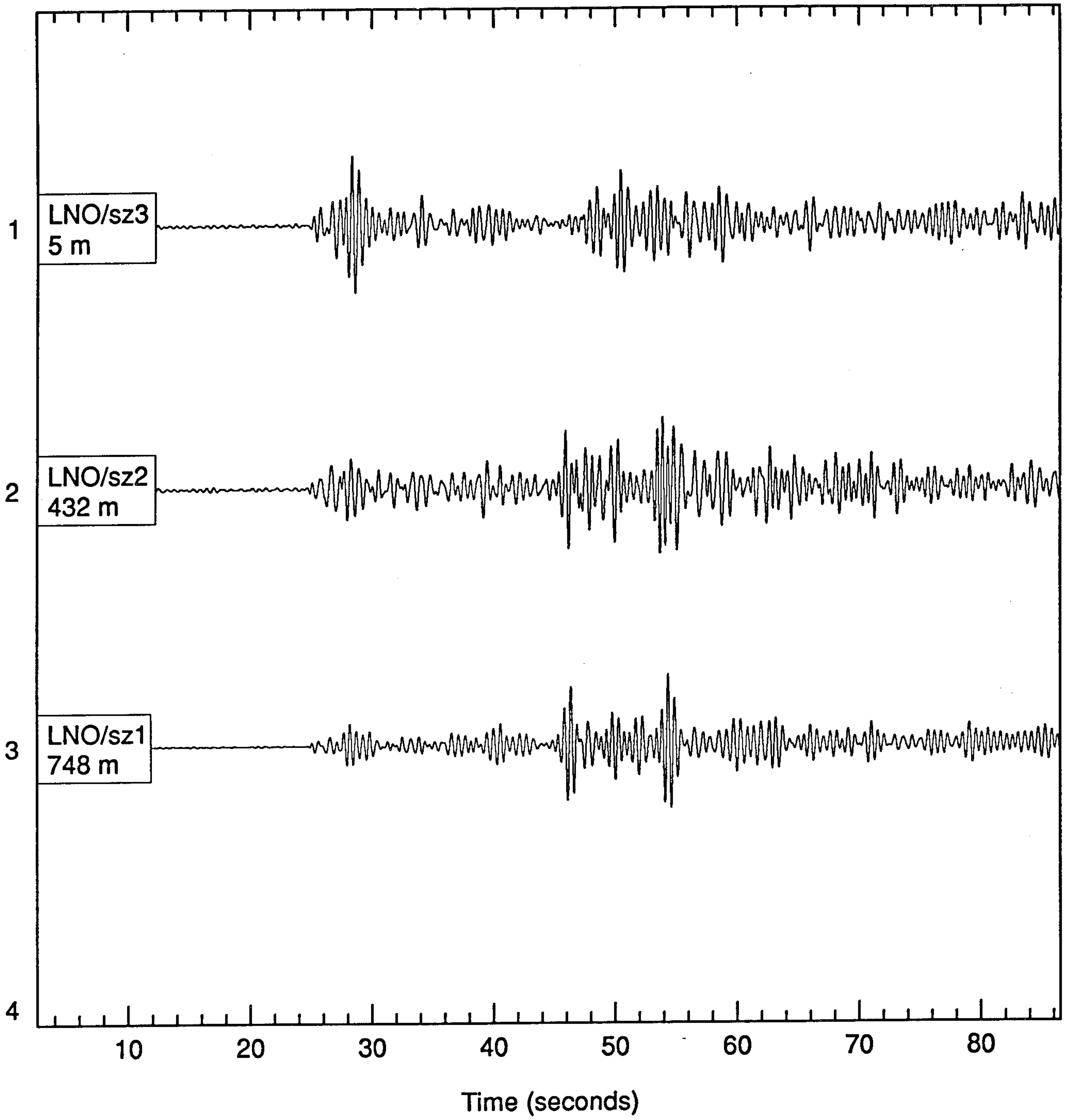


Figure 11. Same as Figure 10, except that a fourth-order causal Butterworth bandpass filter, 1.0 to 2.0 Hz, was applied.

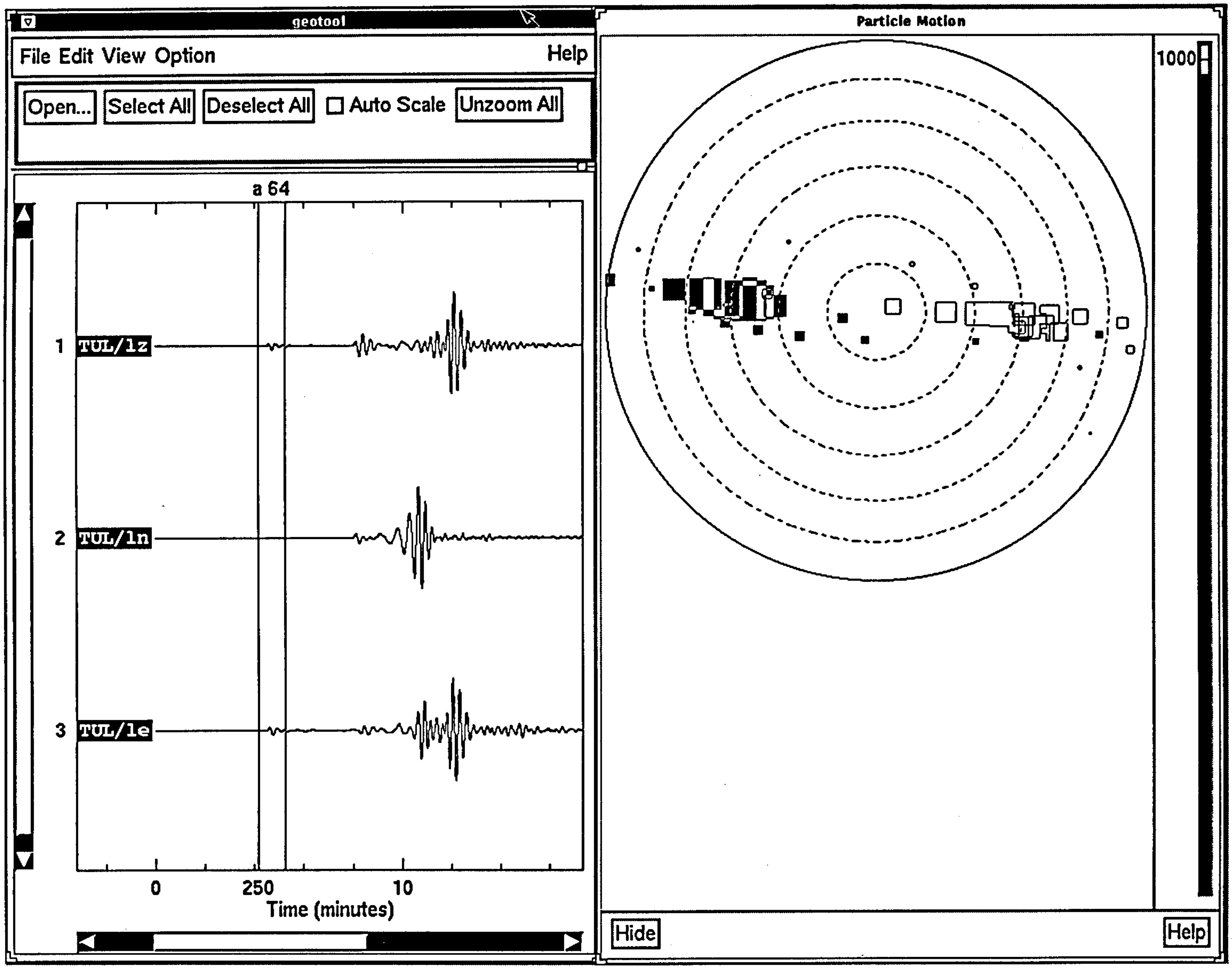


Figure 12. Characteristic P-Wave Particle Motion on Geotool.

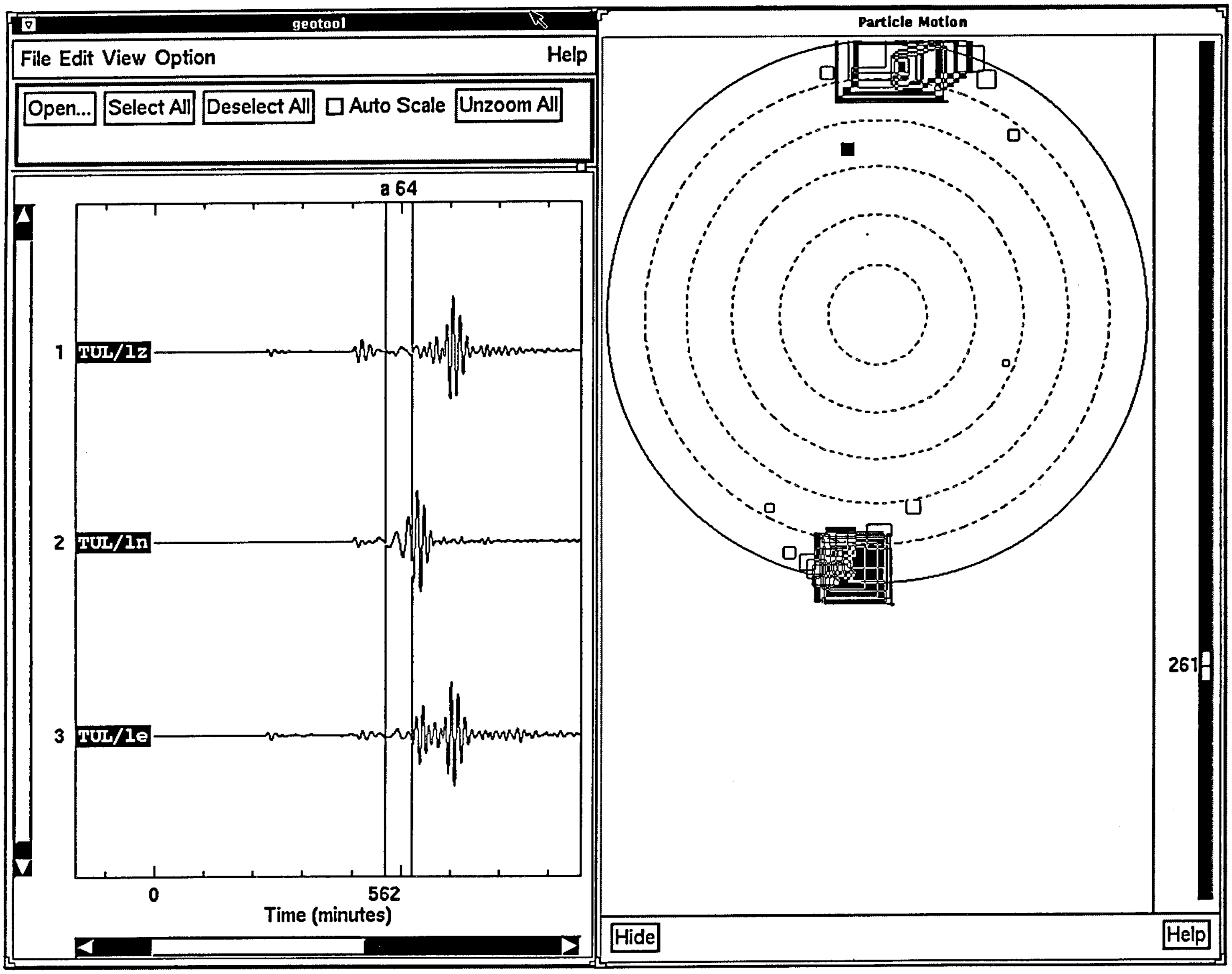


Figure 13. Characteristic Love Wave Particle Motion on Geotool.

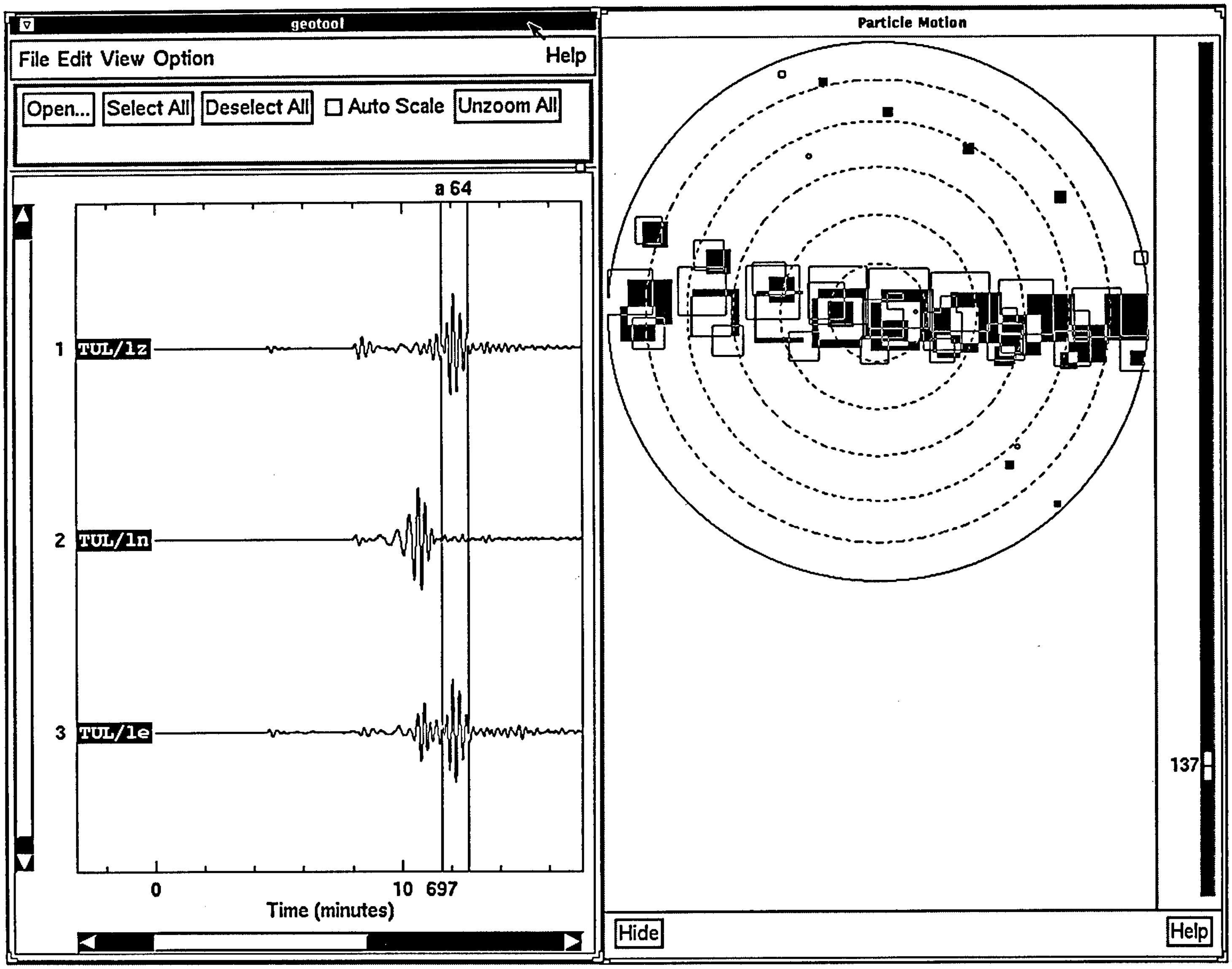


Figure 14. Characteristic Rayleigh Wave Particle Motion on Geotool.

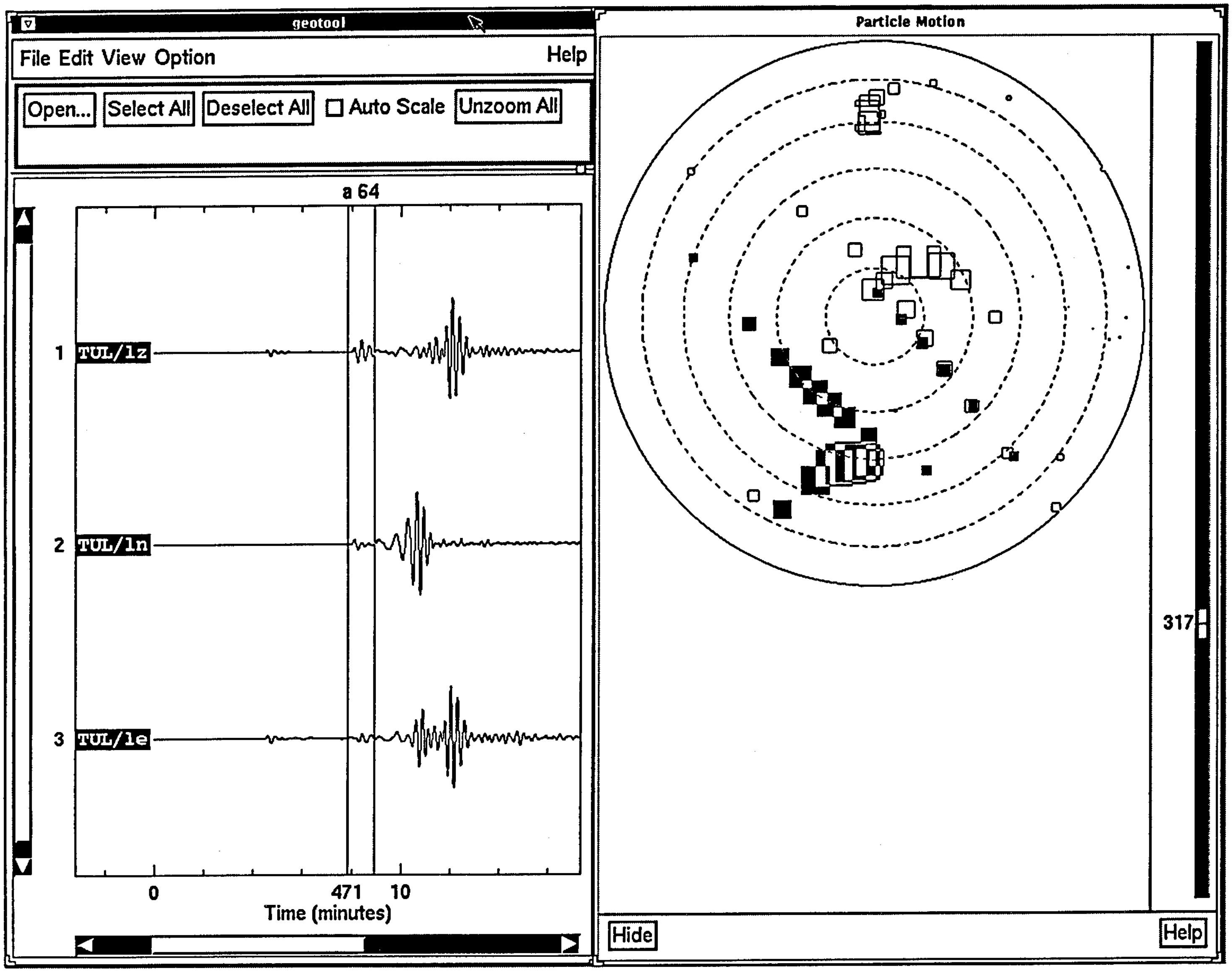


Figure 15. Non-characteristic Particle Motion on Geotool. In this figure, the source is an S wave, but Lg, P coda, and low S/N signals may produce similar patterns.

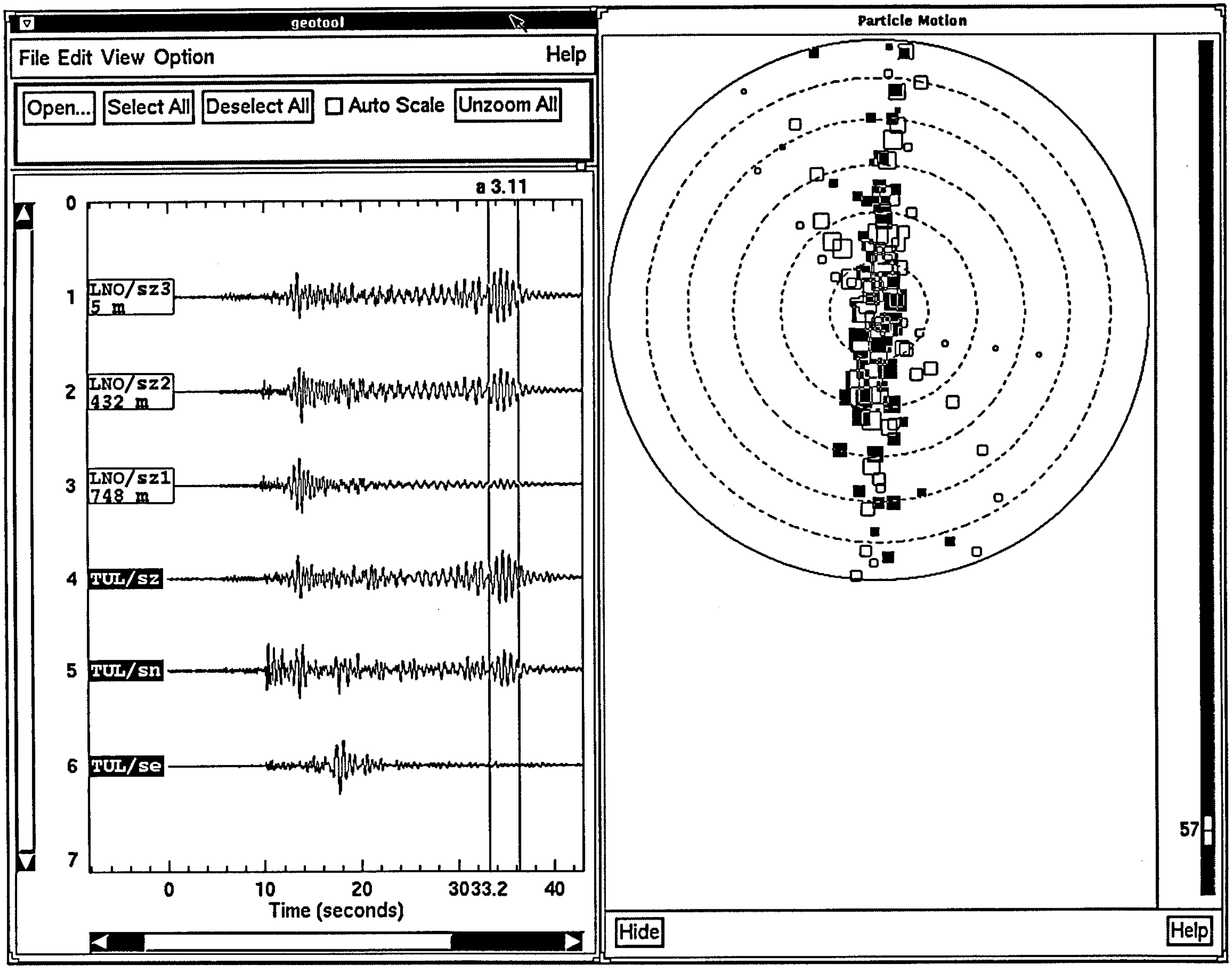


Figure 16. Rg Phase on Unfiltered Traces.

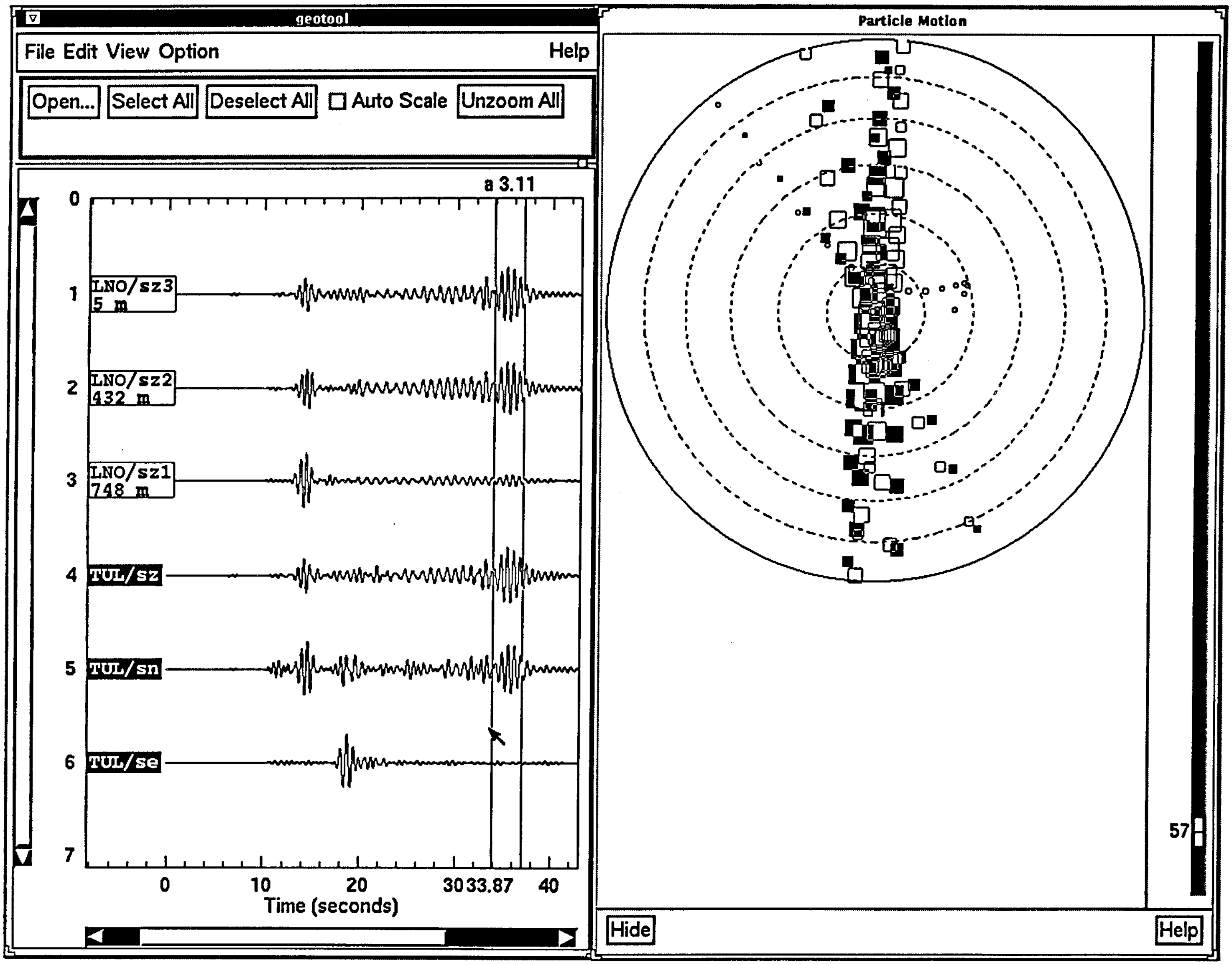


Figure 17. Same Seismograms as Figure 16, but all traces were filtered.

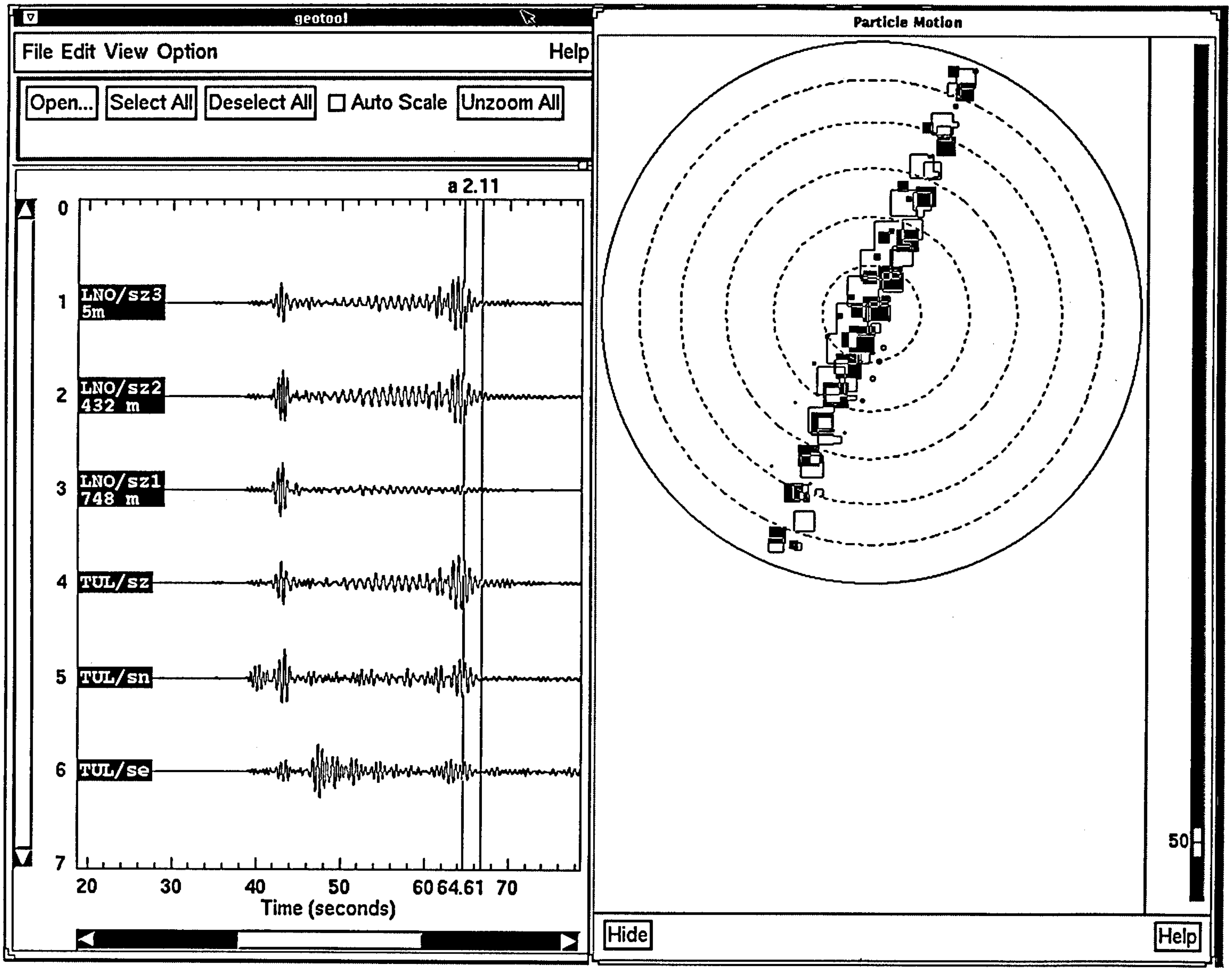


Figure 18. Filtered Seismograms.

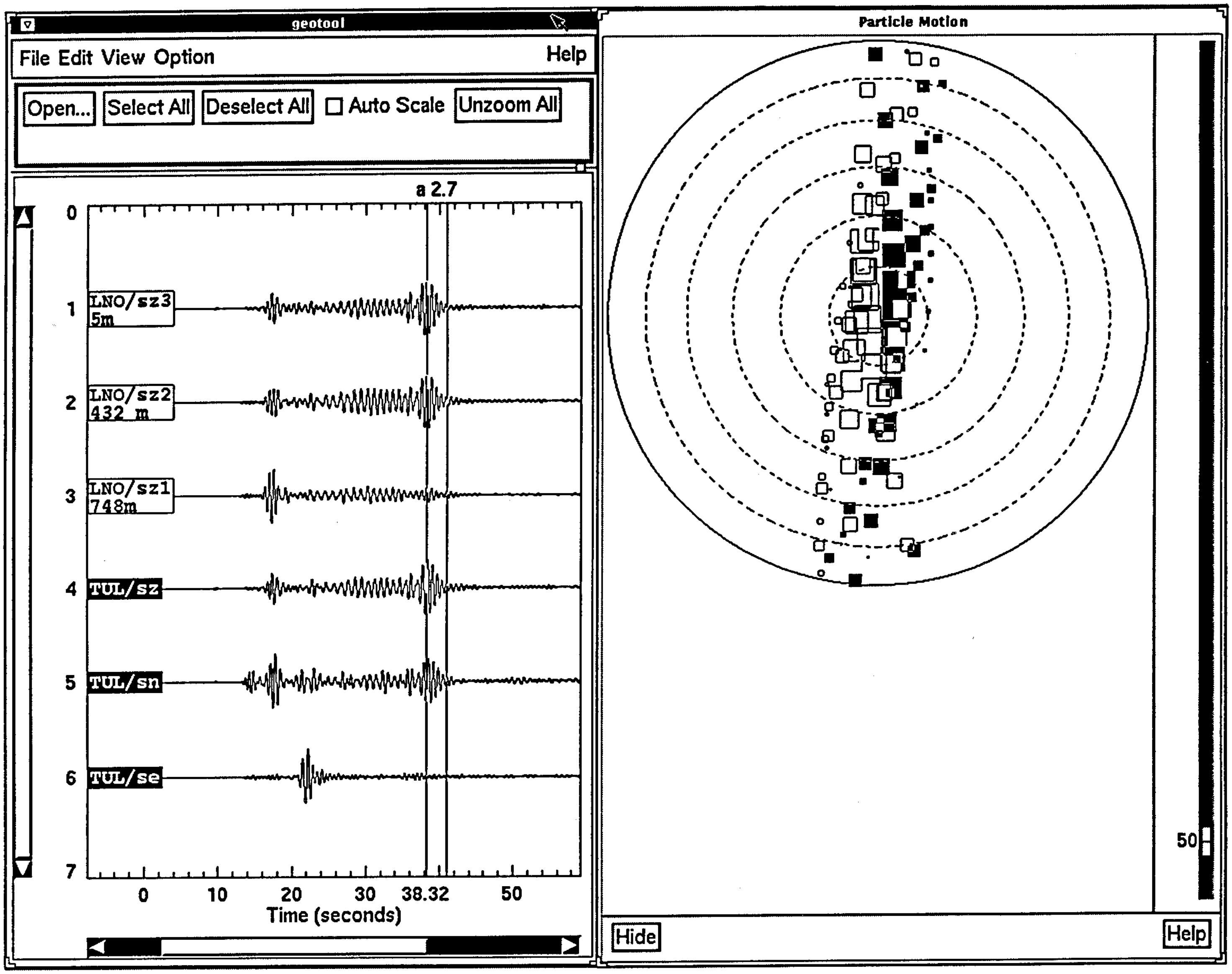


Figure 19. Filtered Seismograms.

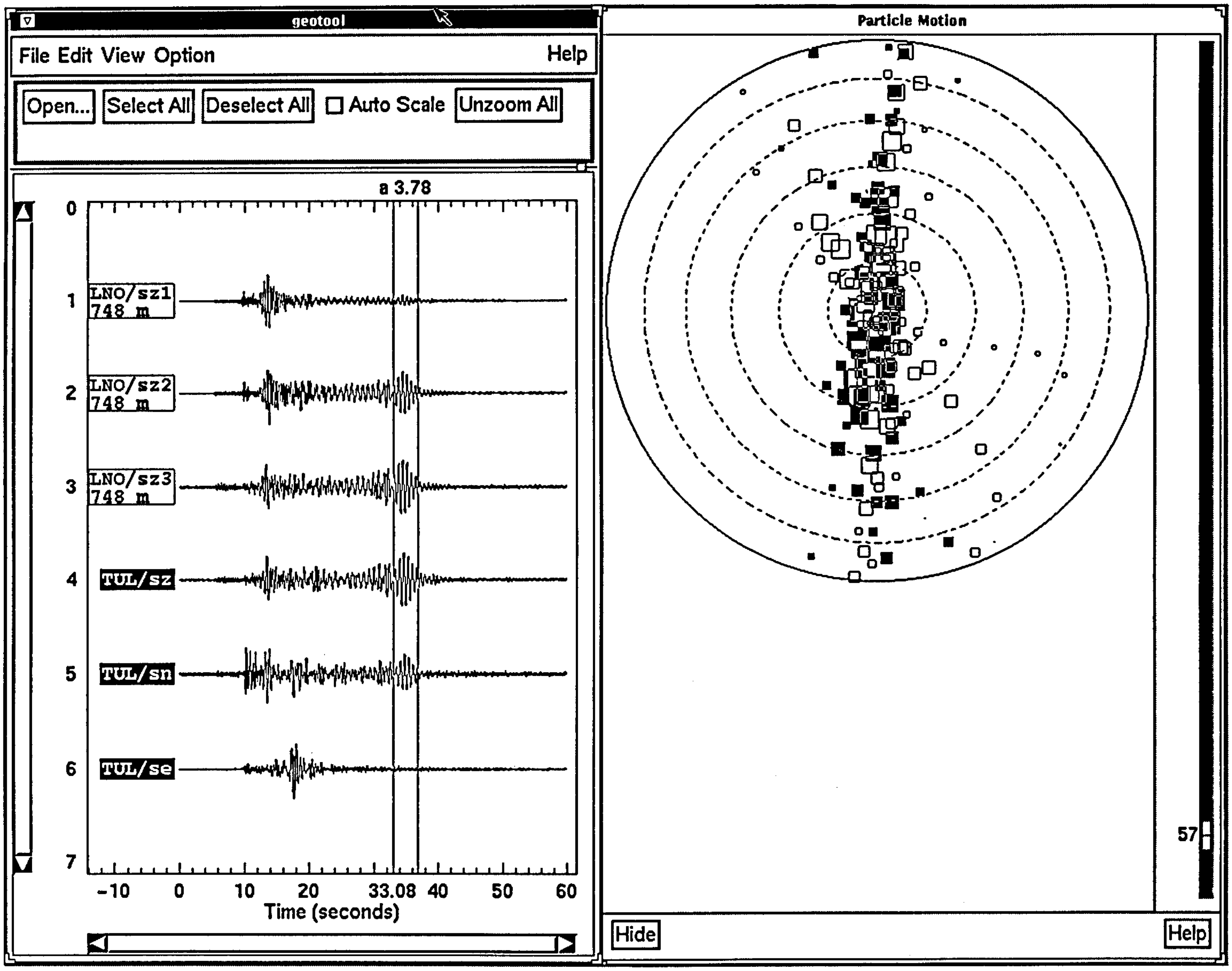


Figure 20. Filtered Seismograms.

Prof. Thomas Ahrens
Seismological Lab, 252-21
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Keiiti Aki
Center for Earth Sciences
University of Southern California
University Park
Los Angeles, CA 90089-0741

Prof. Shelton Alexander
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Dr. Thomas C. Bache, Jr.
Science Applications Int'l Corp.
10260 Campus Point Drive
San Diego, CA 92121 (2 copies)

Prof. Muawia Barazangi
Cornell University
Institute for the Study of the Continent
3126 SNEE Hall
Ithaca, NY 14853

Dr. Douglas R. Baumgardt
ENSCO, Inc
5400 Port Royal Road
Springfield, VA 22151-2388

Dr. T.J. Bennett
S-CUBED
A Division of Maxwell Laboratories
11800 Sunrise Valley Drive, Suite 1212
Reston, VA 22091

Dr. Robert Blandford
AFTAC/TT, Center for Seismic Studies
1300 North 17th Street
Suite 1450
Arlington, VA 22209-2308

Dr. Steven Bratt
ARPA/NMRO
3701 North Fairfax Drive
Arlington, VA 22203-1714

Dale Breding
U.S. Department of Energy
Recipient, IS-20, GA-033
Office of Arms Control
Washington, DC 20585

Dr. Jerry Carter
Center for Seismic Studies
1300 North 17th Street
Suite 1450
Arlington, VA 22209-2308

Mr Robert Cockerham
Arms Control & Disarmament Agency
320 21st Street North West
Room 5741
Washington, DC 20451,

Dr. Zoltan Der
ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151-2388

Dr. Stanley K. Dickinson
AFOSR/NM
110 Duncan Avenue
Suite B115
Bolling AFB, DC

Dr Petr Firbas
Institute of Physics of the Earth
Masaryk University Brno
Jecna 29a
612 46 Brno, Czech Republic

Dr. Mark D. Fisk
Mission Research Corporation
735 State Street
P.O. Drawer 719
Santa Barbara, CA 93102

Dr. Cliff Frolich
Institute of Geophysics
8701 North Mopac
Austin, TX 78759

Dr. Holly Given
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dr. Jeffrey W. Given
SAIC
10260 Campus Point Drive
San Diego, CA 92121

Dan N. Hagedon
Pacific Northwest Laboratories
Battelle Boulevard
Richland, WA 99352

Dr. James Hannon
Lawrence Livermore National Laboratory
P.O. Box 808, L-205
Livermore, CA 94550

Dr. Roger Hansen
University of Colorado, JSPC
Campus Box 583
Boulder, CO 80309

Prof. Danny Harvey
University of Colorado, JSPC
Campus Box 583
Boulder, CO 80309

Prof. Donald V. Helmberger
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Eugene Herrin
Geophysical Laboratory
Southern Methodist University
Dallas, TX 75275

Prof. Robert B. Herrmann
Department of Earth & Atmospheric Sciences
St. Louis University
St. Louis, MO 63156

Prof. Lane R. Johnson
Seismographic Station
University of California
Berkeley, CA 94720

Prof. Thomas H. Jordan
Department of Earth, Atmospheric &
Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

Robert C. Kemerait
ENSCO, Inc.
445 Pineda Court
Melbourne, FL 32940

U.S. Dept of Energy
Max Koontz, NN-20, GA-033
Office of Research and Develop.
1000 Independence Avenue
Washington, DC 20585

Dr. Richard LaCoss
MIT Lincoln Laboratory, M-200B
P.O. Box 73
Lexington, MA 02173-0073

Prof. Charles A. Langston
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Jim Lawson, Chief Geophysicist
Oklahoma Geological Survey
Oklahoma Geophysical Observatory
P.O. Box 8
Leonard, OK 74043-0008

Prof. Thorne Lay
Institute of Tectonics
Earth Science Board
University of California, Santa Cruz
Santa Cruz, CA 95064

Dr. William Leith
U.S. Geological Survey
Mail Stop 928
Reston, VA 22092

Mr. James F. Lewkowicz
Phillips Laboratory/GPE
29 Randolph Road
Hanscom AFB, MA 01731-3010(2 copies)

Dr. Gary McCartor
Department of Physics
Southern Methodist University
Dallas, TX 75275

Prof. Thomas V. McEvilly
Seismographic Station
University of California
Berkeley, CA 94720

Dr. Keith L. McLaughlin
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Prof. Bernard Minster
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Prof. Brian J. Mitchell
Department of Earth & Atmospheric Sciences
St. Louis University
St. Louis, MO 63156

Mr. Jack Murphy
S-CUBED
A Division of Maxwell Laboratory
11800 Sunrise Valley Drive, Suite 1212
Reston, VA 22091 (2 Copies)

Dr. Keith K. Nakanishi
Lawrence Livermore National Laboratory
L-025
P.O. Box 808
Livermore, CA 94550

Prof. John A. Orcutt
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dr. Howard Patton
Lawrence Livermore National Laboratory
L-025
P.O. Box 808
Livermore, CA 94550

Dr. Frank Pilotte
HQ AFTAC/TT
1030 South Highway A1A
Patrick AFB, FL 32925-3002

Dr. Jay J. Pulli
Radix Systems, Inc.
6 Taft Court
Rockville, MD 20850

Prof. Paul G. Richards
Lamont-Doherty Earth Observatory
of Columbia University
Palisades, NY 10964

Mr. Wilmer Rivers
Multimax Inc.
1441 McCormick Drive
Landover, MD 20785

Dr. Alan S. Ryall, Jr.
Lawrence Livermore National Laboratory
L-025
P.O. Box 808
Livermore, CA 94550

Dr.Chandan K. Saikia
Woodward Clyde- Consultants
566 El Dorado Street
Pasadena, CA 91101

Mr. Dogan Seber
Cornell University
Inst. for the Study of the Continent
3130 SNEE Hall
Ithaca, NY 14853-1504

Secretary of the Air Force
(SAFRD)
Washington, DC 20330

Office of the Secretary of Defense
DDR&E
Washington, DC 20330

Thomas J. Sereno, Jr.
Science Application Int'l Corp.
10260 Campus Point Drive
San Diego, CA 92121

Dr. Michael Shore
Defense Nuclear Agency/SPSS
6801 Telegraph Road
Alexandria, VA 22310

Prof. David G. Simpson
IRIS, Inc.
1616 North Fort Myer Drive
Suite 1050
Arlington, VA 22209

Dr. Jeffrey Stevens
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Prof. Brian Stump
Los Alamos National Laboratory
EES-3
Mail Stop C-335
Los Alamos, NM 87545

Prof. Tuncay Taymaz
Istanbul Technical University
Dept. of Geophysical Engineering
Mining Faculty
Maslak-80626, Istanbul Turkey

Prof. M. Nafi Toksoz
Earth Resources Lab
Massachusetts Institute of Technology
42 Carleton Street
Cambridge, MA 02142

Dr. Larry Turnbull
CIA-OSWR/NED
Washington, DC 20505

Dr. Karl Veith
EG&G
5211 Auth Road
Suite 240
Suitland, MD 20746

Prof. Terry C. Wallace
Department of Geosciences
Building #77
University of Arizona
Tuscon, AZ 85721

Dr. William Wortman
Mission Research Corporation
8560 Cinderbed Road
Suite 700
Newington, VA 22122

ARPA, OASB/Library
3701 North Fairfax Drive
Arlington, VA 22203-1714

HQ DNA
ATTN: Technical Library
Washington, DC 20305

Defense Technical Information Center
Cameron Station
Alexandria, VA 22314 (2 Copies)

TACTEC
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201 (Final Report)

Phillips Laboratory
ATTN: GPE
29 Randolph Road
Hanscom AFB, MA 01731-3010

Phillips Laboratory
ATTN: TSML
5 Wright Street
Hanscom AFB, MA 01731-3004

Phillips Laboratory
ATTN: PL/SUL
3550 Aberdeen Ave SE
Kirtland, NM 87117-5776 (2 copies)

Dr. Michel Campillo
Observatoire de Grenoble
I.R.I.G.M.-B.P. 53
38041 Grenoble, FRANCE

Prof. Hans-Peter Harjes
Institute for Geophysic
Ruhr University/Bochum
P.O. Box 102148
4630 Bochum 1, GERMANY

Prof. Eystein Husebye
IFJF
Jordskjelvstasjonen
Allegaten 41, 5007 BERGEN NORWAY

David Jepsen
Acting Head, Nuclear Monitoring Section
Bureau of Mineral Resources
Geology and Geophysics
G.P.O. Box 378, Canberra, AUSTRALIA

Ms. Eva Johannisson
Senior Research Officer
FOA
S-172 90 Sundbyberg, SWEDEN

Dr. Peter Marshall
Procurement Executive
Ministry of Defense
Blacknest, Brimpton
Reading FG7-FRS, UNITED KINGDOM

Dr. Bernard Massinon, Dr. Pierre Mechler
Societe Radiomana
27 rue Claude Bernard
75005 Paris, FRANCE (2 Copies)

Dr. Svein Mykkeltveit
NTNT/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY (3 Copies)

Dr. Jorg Schlittenhardt
Federal Institute for Geosciences & Nat'l Res.
Postfach 510153
D-30631 Hannover , GERMANY

Dr. Johannes Schweitzer
Institute of Geophysics
Ruhr University/Bochum
P.O. Box 1102148
4360 Bochum 1, GERMANY

Trust & Verify
VERTIC
Carrara House
20 Embankment Place
London WC2N 6NN, ENGLAND