IMPROVED PROCEDURES FOR DETERMINING SEISMIC SOURCE DEPTHS FROM DEPTH PHASE INFORMATION

QUARTERLY REPORT

Edward Page
Richard Houck

April 1, 1977
to June 30, 1977

Sponsored by:
Advanced Research Project Agency
ARPA Order No. 1620

APPROVED FOR PUBLIC RELEASE,
DISTRIBUTION UNLIMITED

Notice of Disclaimer

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency, the Air Force Technical Applications Center, or the U.S. Government.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (6)

2. GOVT ACCESSION NO.:

3. RECIPIENT'S CATALOG NUMBER: (9) Quarterly Rept. 1 Apr - 30 Jun 77,

4. TITLE (and Subtitle): Improved Procedures for Determining Seismic Source Depths from Depth Phase Information.

5. TYPE OF REPORT & PERIOD COVERED: Quarterly Report. 4/1/77 to 6/30/77

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): (10) Edward A. Page, Richard Houck

8. CONTRACT OR GRANT NUMBER(s): (15) F08606-77-C-0007, ARPA Order-1620

9. PERFORMING ORGANIZATION NAME AND ADDRESS: ENSCO, Inc., 5408A Port Royal Road Springfield, VA 22151

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: VT/7710

11. CONTROLLING OFFICE NAME AND ADDRESS:

12. REPORT DATE: (11) July 1977

13. NUMBER OF PAGES: 30 (12) 29p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): VELA Seismological Center 312 Montgomery Street Alexandria, VA 22314

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Seismic depth, depth phase, echo detection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The seismic source depth determination program was run on the Andreanof Islands event of 11/22/65. Several different subsets of the 14 seismograms available were run, and a source depth estimate of 25 km was obtained. Coding has been started on the SDAC implementation of the depth determination program. This version of the program features greatly increased flexibility for the analyst in obtaining output from any combination of the input data.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

406167

SUBJECT: Improved Procedures for Determining Seismic Source Depths from Depth Phase Information

AFTAC Project No..................................	VELA T/7710
ARPA Order No.....................................	2551
ARPA Program Code No..............................	6F10
Name of Contractor................................	ENSCO, INC.
Contract No.......................................	F08606-77-C-0007
Effective Date of Contract........................	1 October 1976
Reporting Period..................................	1 April 1977 to 30 June 1977
Amount of Contract................................	$89,923
Contract Expiration Date..........................	30 September 1977
Project Scientist.................................	Edward A. Page (703) 321-9000

INTRODUCTION AND SUMMARY

Activity during this quarter included both program development and additional data processing. The Andreanof Islands event (11/22/65) was processed through the seismic source depth determination program, with a series of runs being made using various combinations of the 14 stations available. Although four different depth plot peaks were observed consistently during these runs, further analysis eliminated three of them, resulting in a depth estimate of 25 km for the event.

In the area of program development, two techniques for eliminating cepstrum peaks due to the structure of the source spectrum were tried. Both methods attempted to flatten the source spectrum by inverse filtering, but neither was successful. Finally, coding was started on a new version of the depth determination program to be implemented at the Seismic Data Analysis Center (SDAC). In addition to allowing easier access to larger amounts of data, the SDAC system will provide greatly increased output flexibility, designed to simplify the analyst's task of deciding on the correct source depth.

MAJOR ACCOMPLISHMENTS

PROGRAM DEVELOPMENT

Andreanof Island Event

Data for the Andreanof Island event (11/22/65) consists of seismograms from 14 stations, with Δ's ranging from 34° to 73°; these seismograms are shown in Figures 1 and 2. Because of the large number of stations available, the depth determination program could be run using several different groups of stations, and the resulting depth plots could be compared to aid in deciding on the correct event depth. This technique proved to be quite useful, since several of the data groups, including the one having the largest number of stations (10), yielded four distinct depth plot peaks. The availability of results from additional station groupings made it possible to resolve this ambiguity and come up with a single depth estimate for the event.

Twelve runs of the depth determination program were made using different station groupings and input parameters. Composite depth plots from the most informative of these runs are shown in Figures 3-18; results for cepstrum computation windows of 25.6 and 51.2 seconds are shown for each data set. Characteristics of the station groupings used to obtain these depth plots are:

1. 5 stations, distributed over entire available range of Δ's.

2. 10 stations, distributed over entire available range of Δ's.

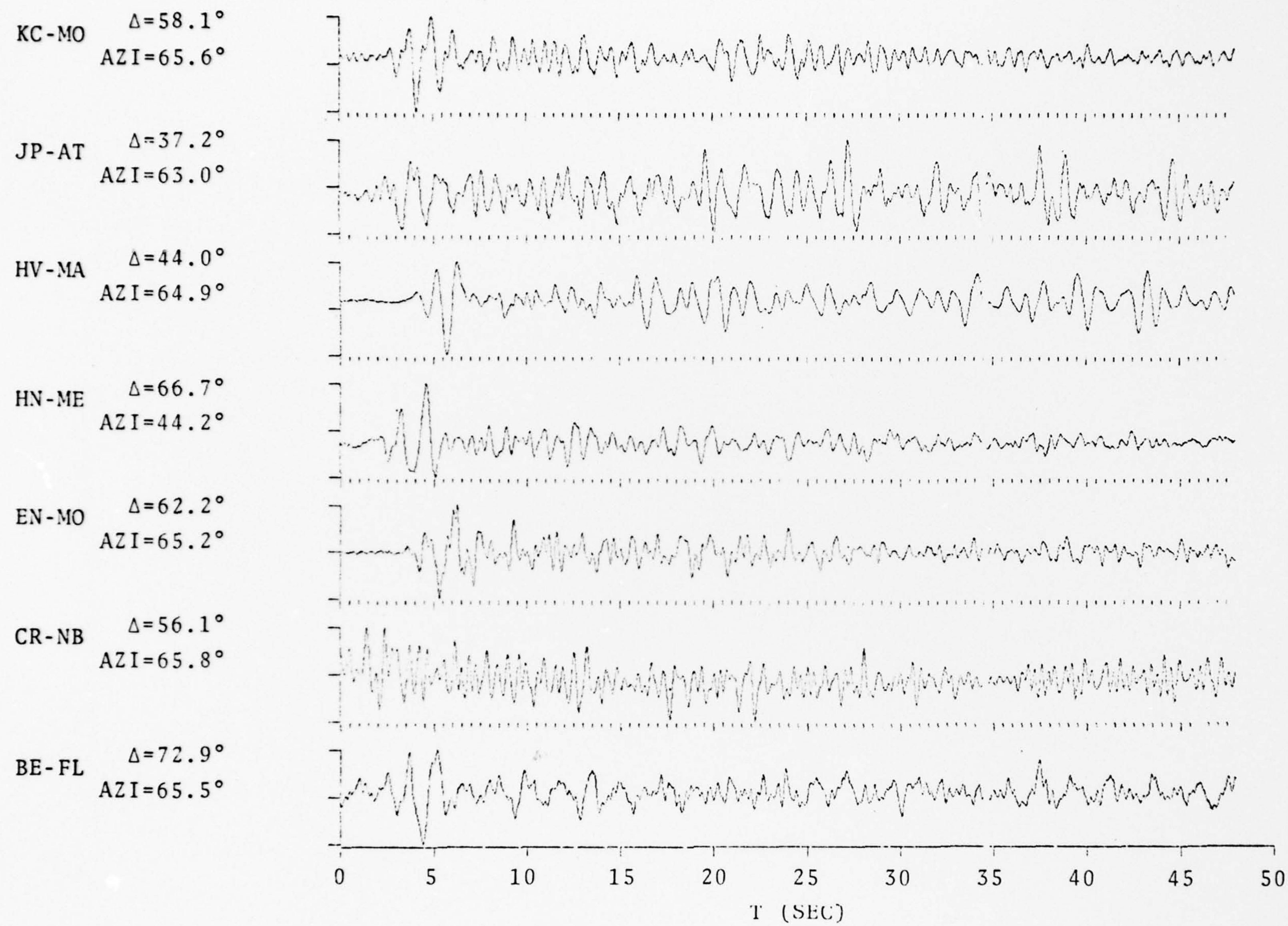

Figure 1
Andreanof Islands Event Seismograms

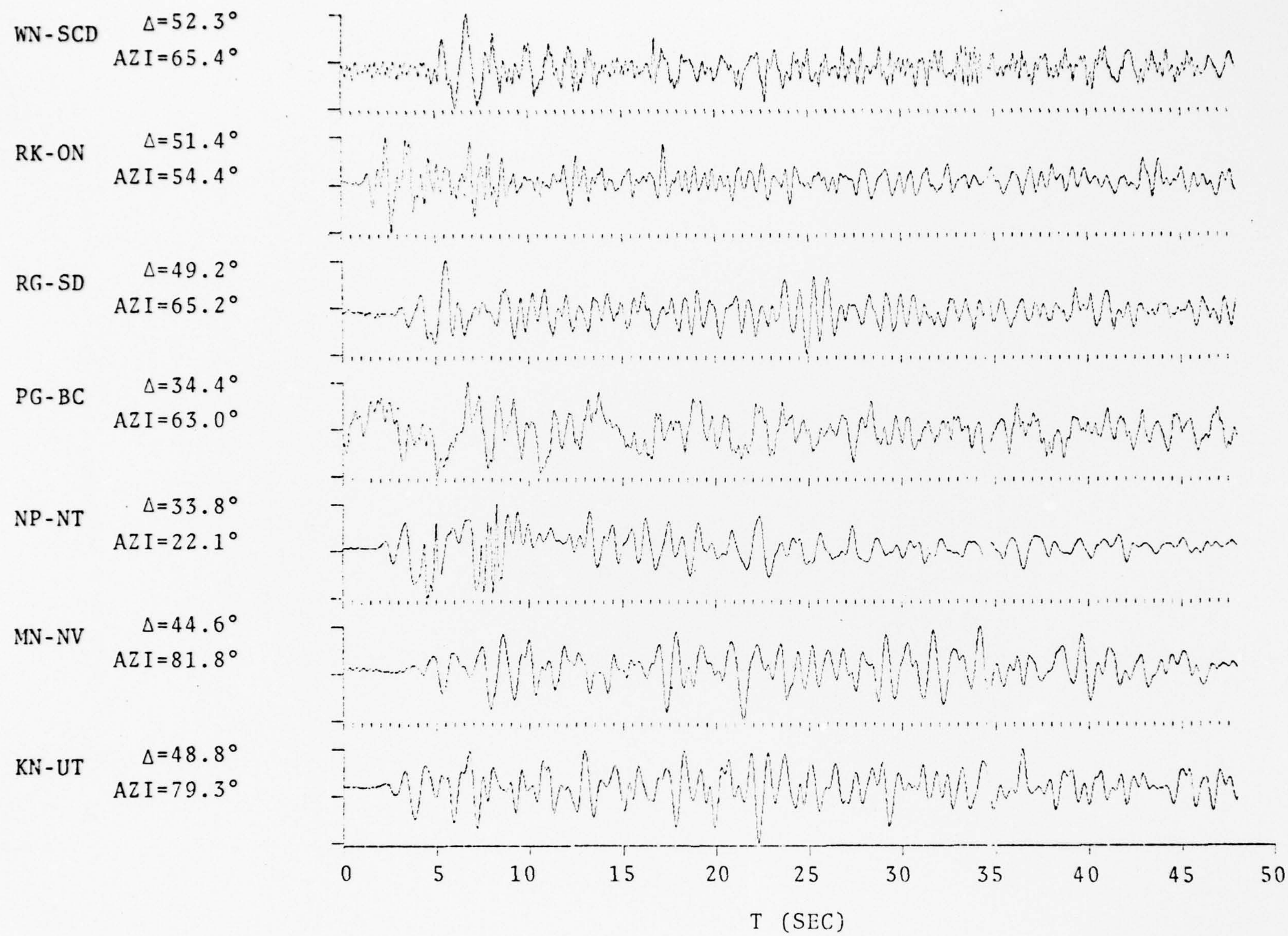

Figure 2

Andreanof Islands Event Seismograms

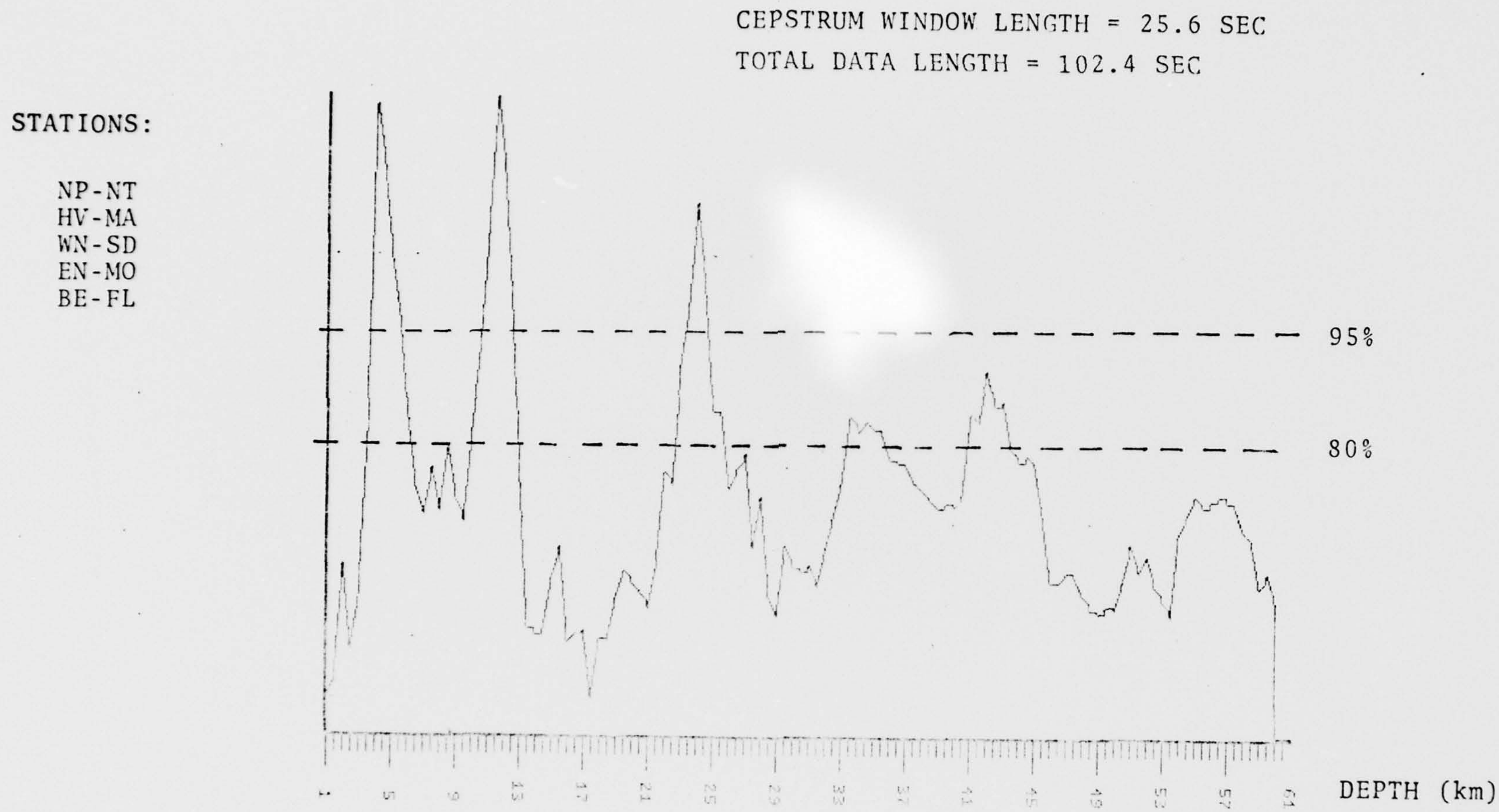

Figure 3

Composite Depth Plot, Data Set 1

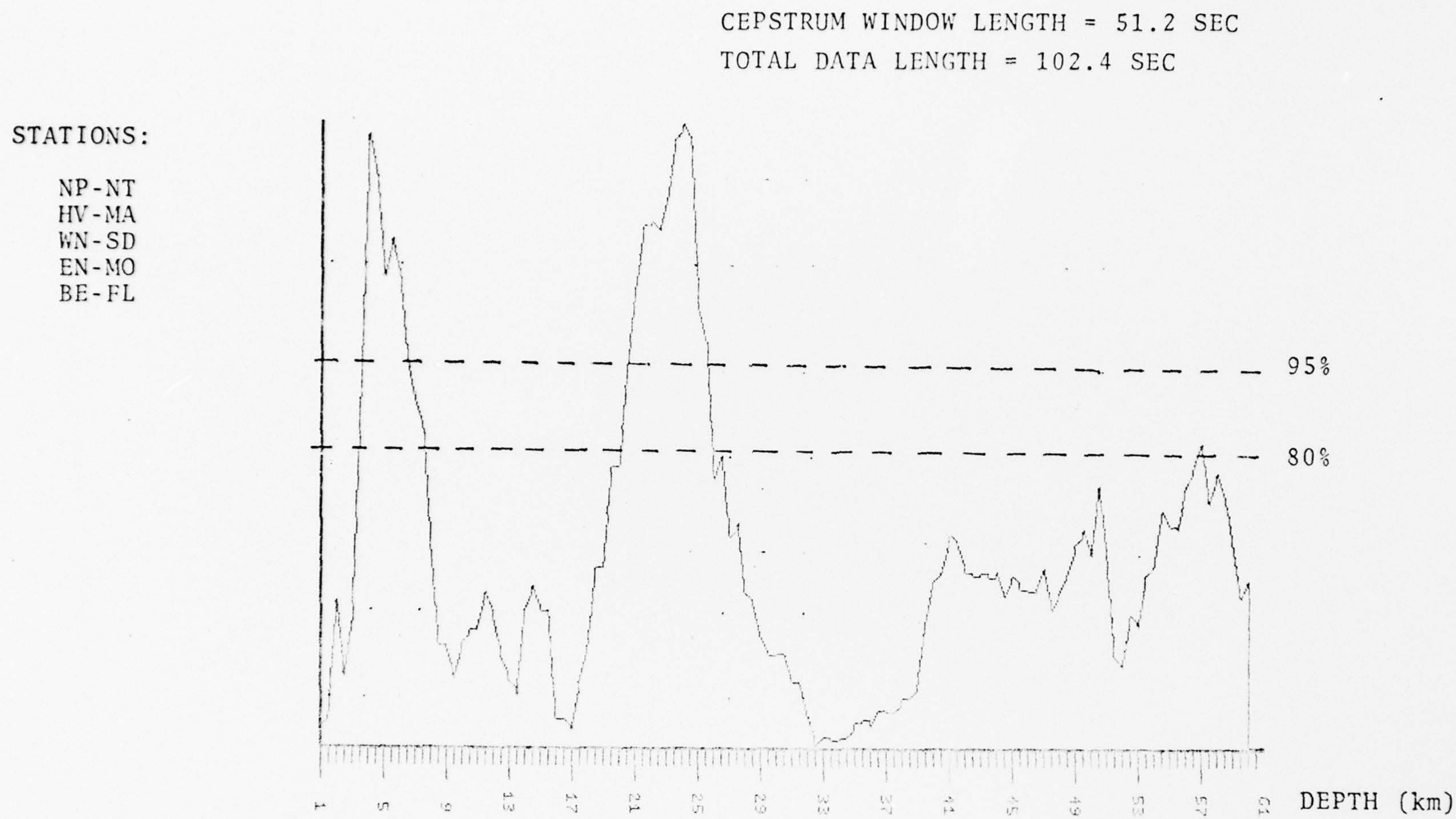

Figure 4

Composite Depth Plot, Data Set 1

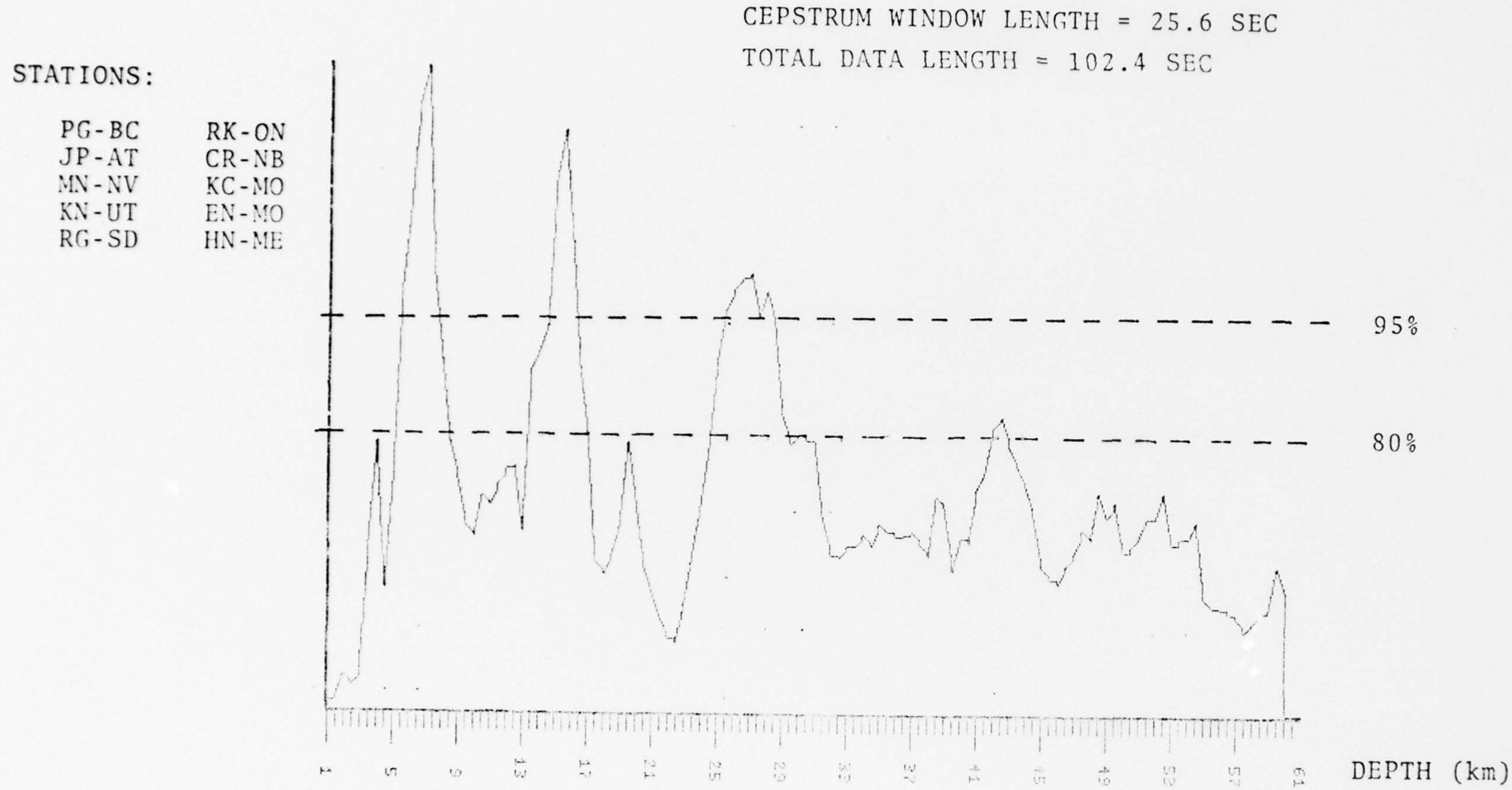

Figure 5

Composite Depth Plot, Data Set 2

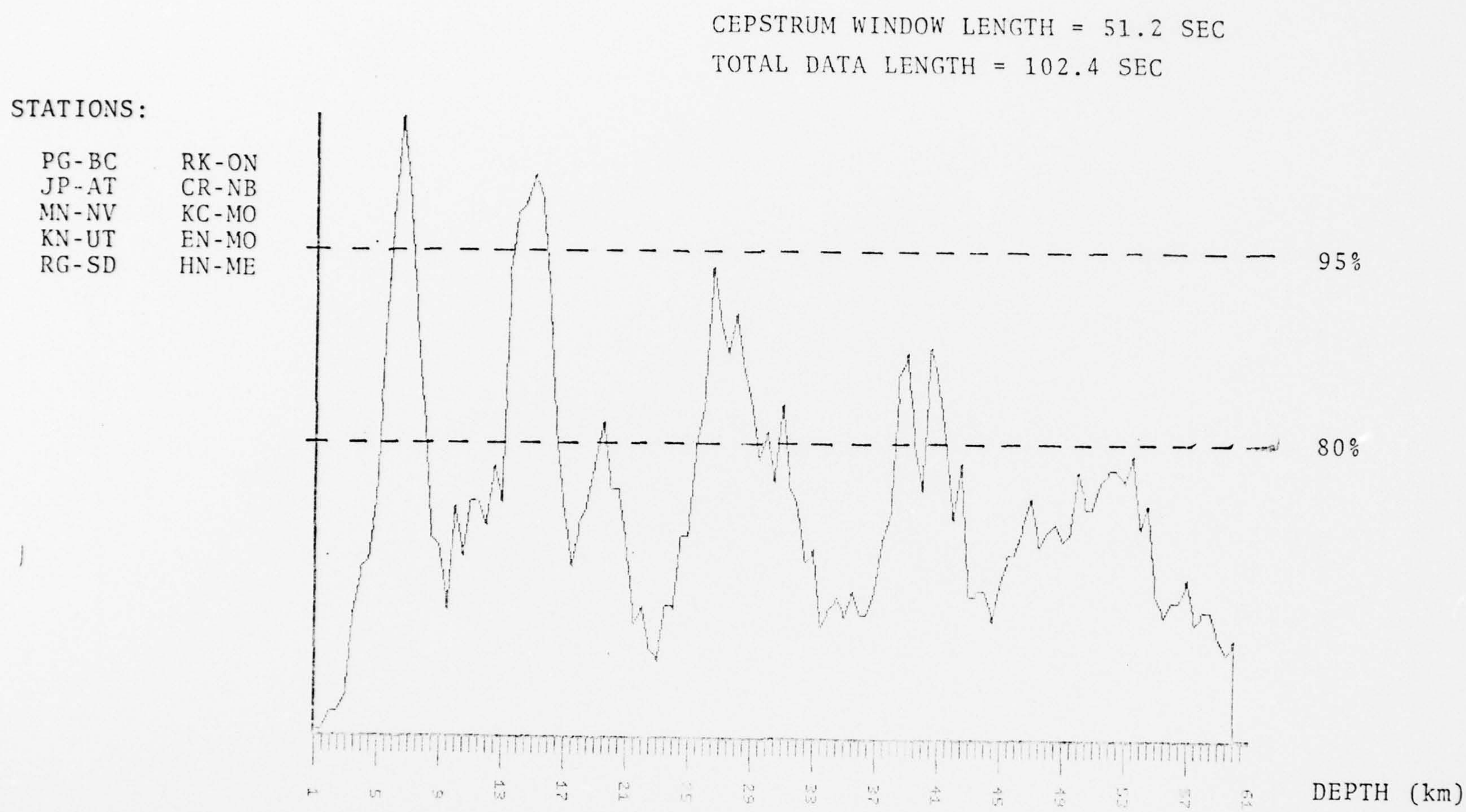

Figure 6

Composite Depth Plot, Data Set 2

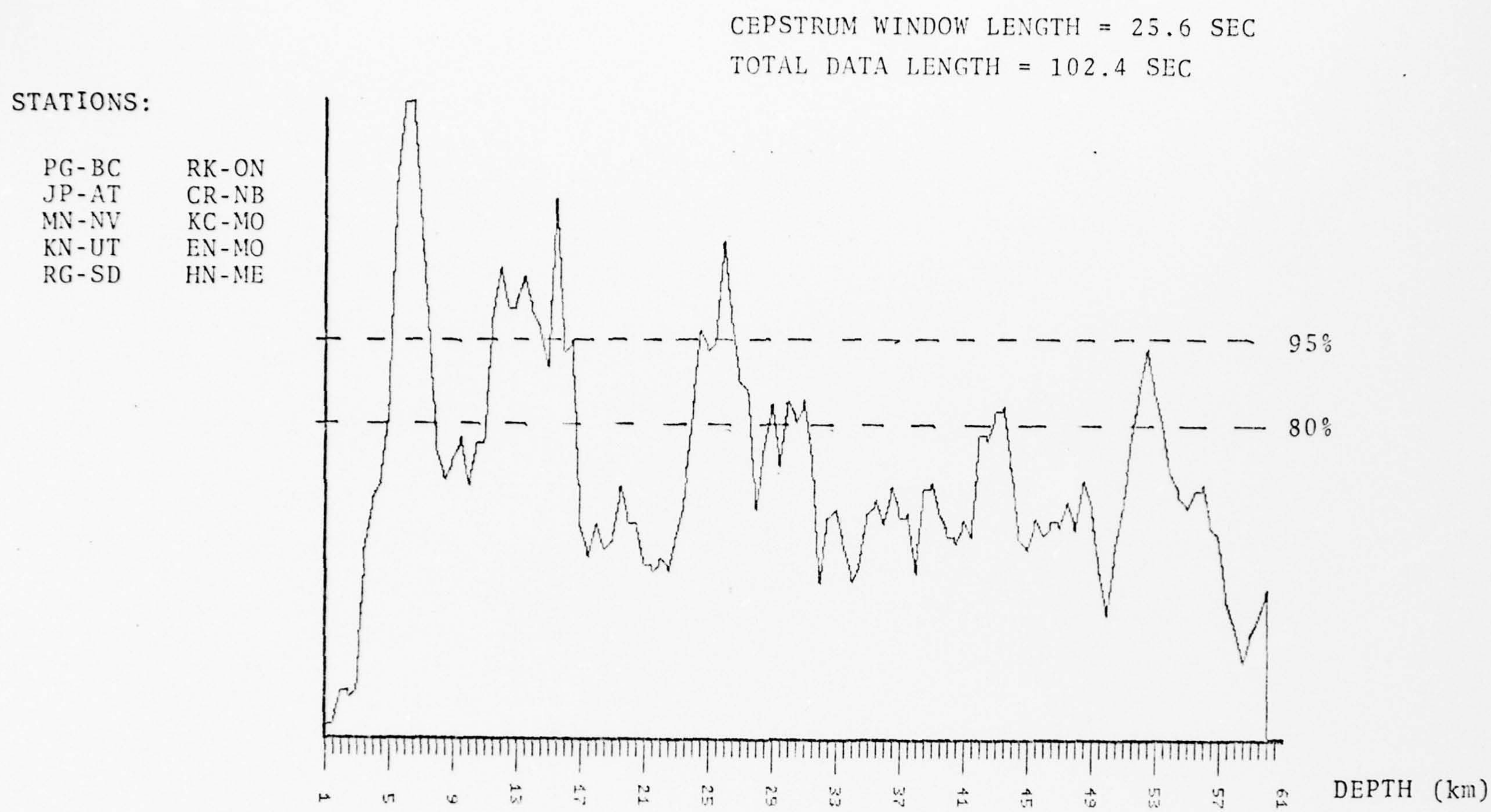

Figure 7

Composite Depth Plot, Data Set 2, Log Whitening

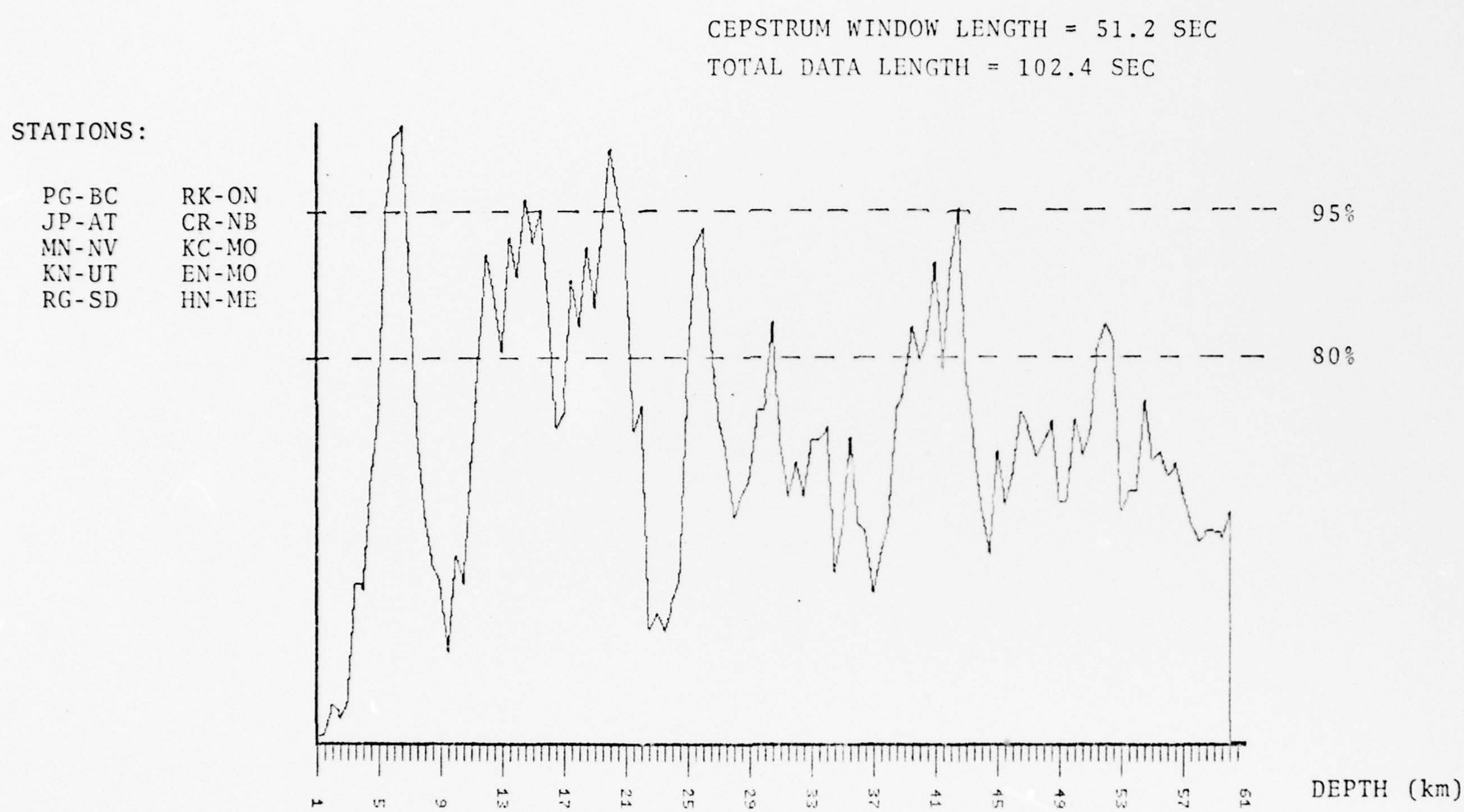

Figure 8

Composite Depth Plot, Data Set 2, Log Whitening

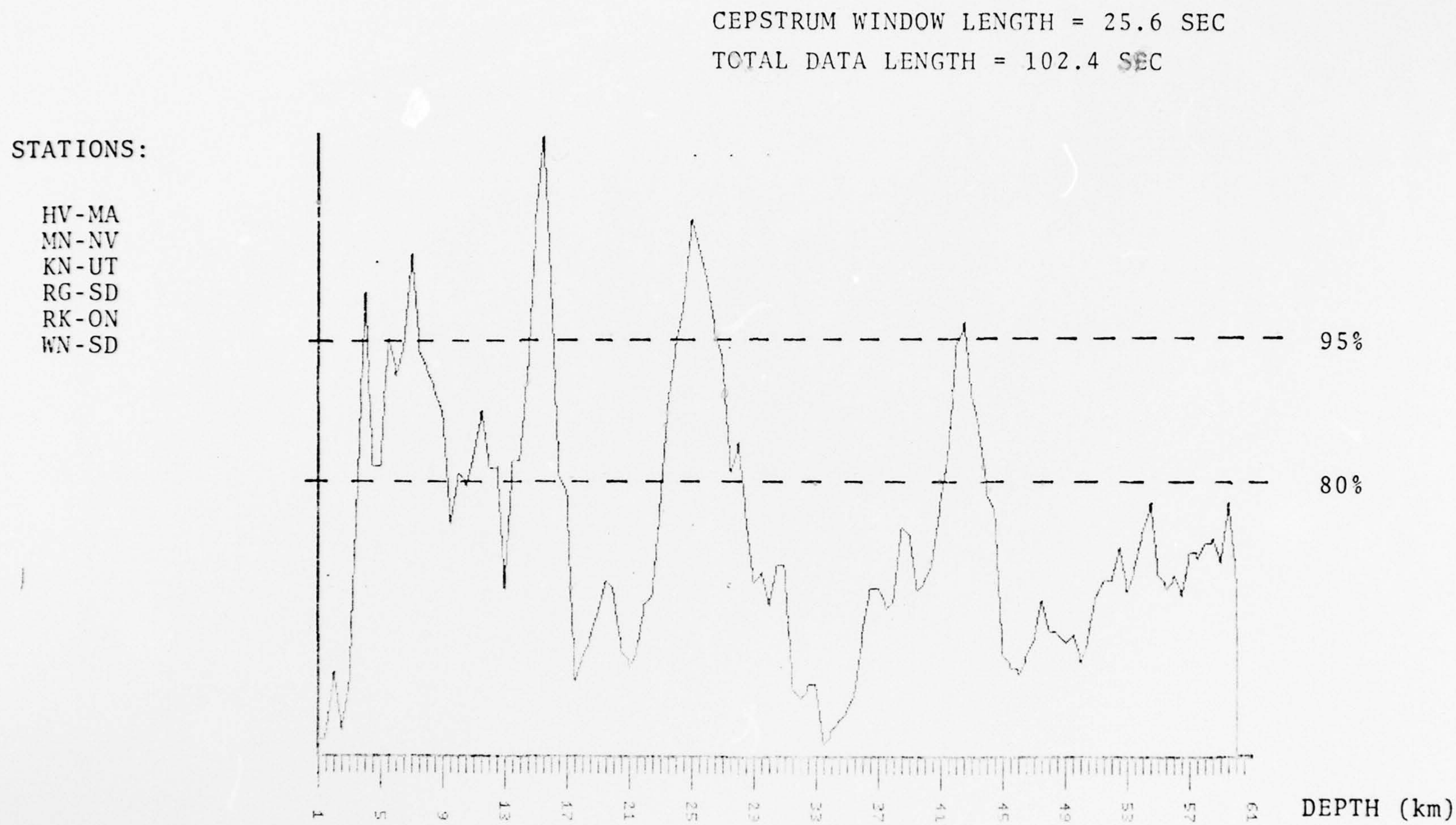

Figure 9

Composite Depth Plot, Data Set 3

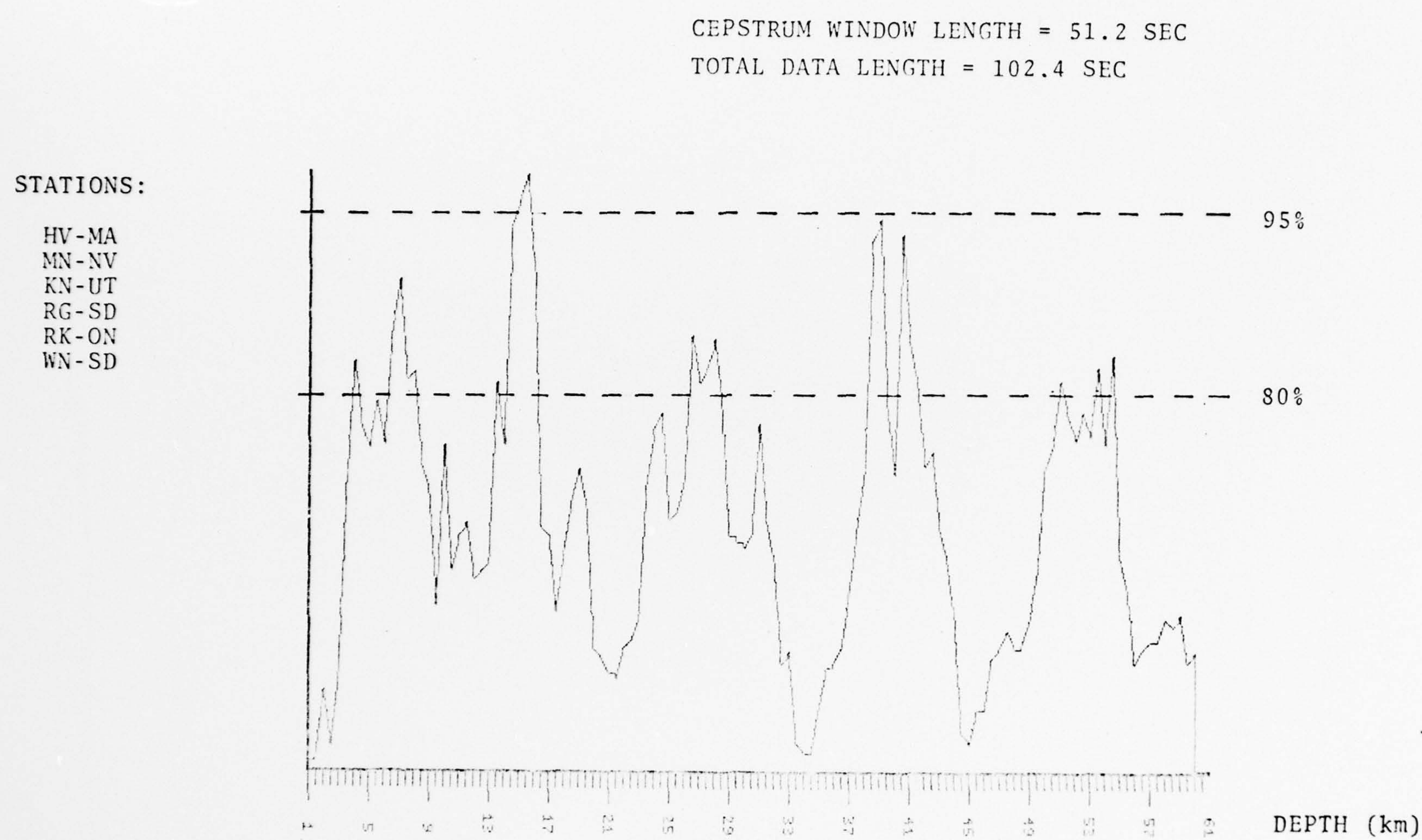

Figure 10

Composite Depth Plot, Data Set 3

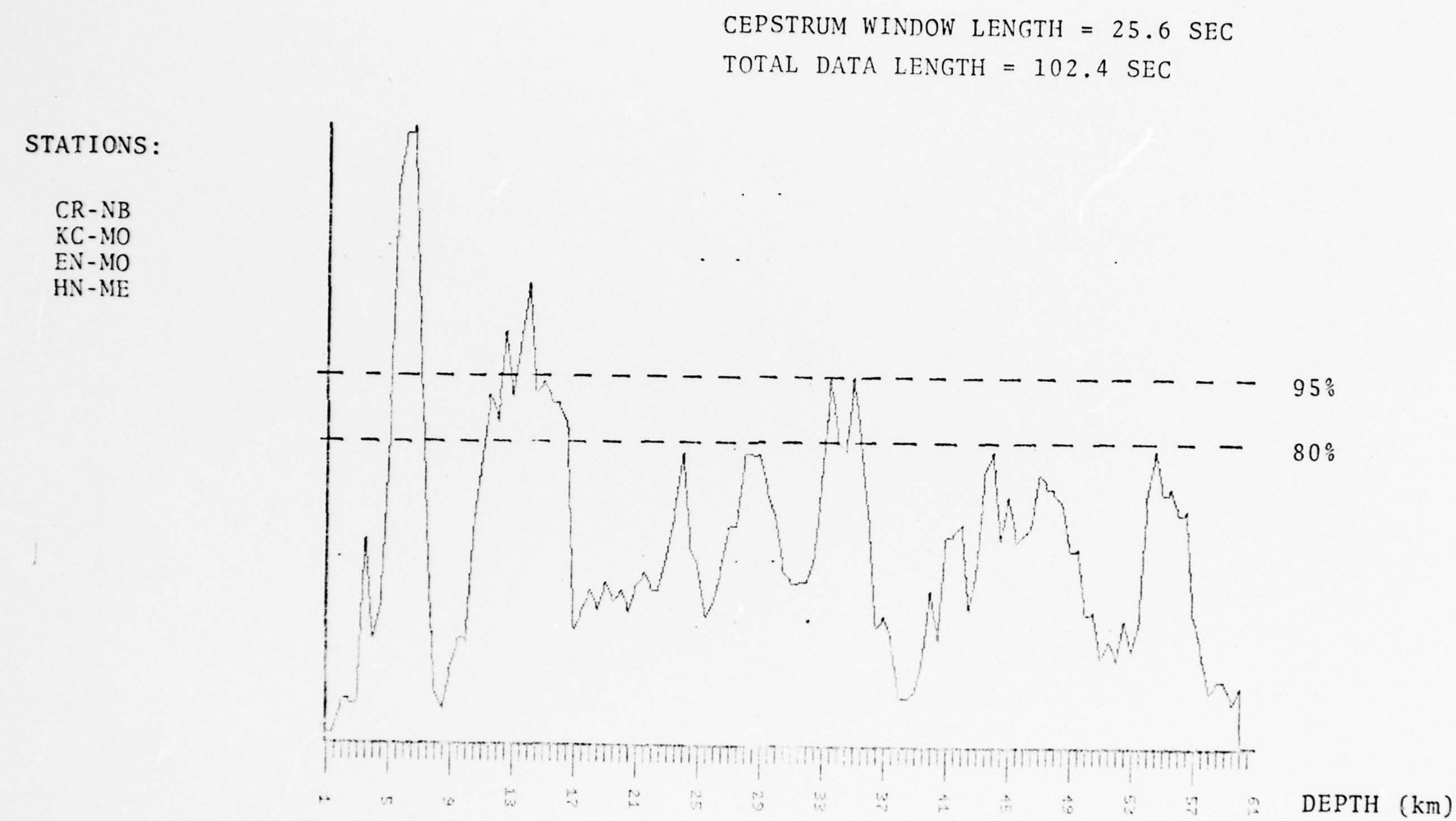

Figure 11

Composite Depth Plot, Data Set 4

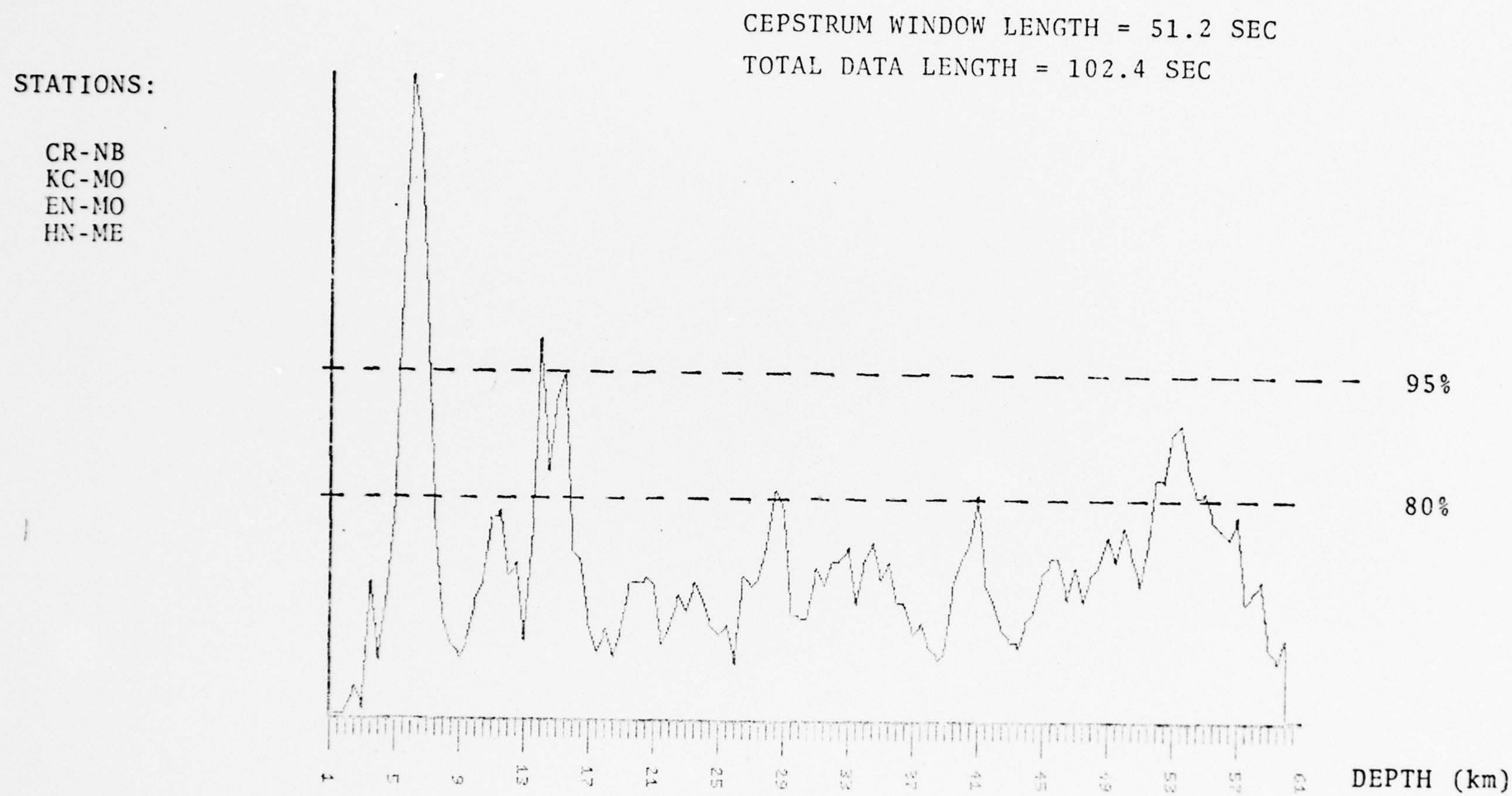

Figure 12

Composite Depth Plot, Data Set 4

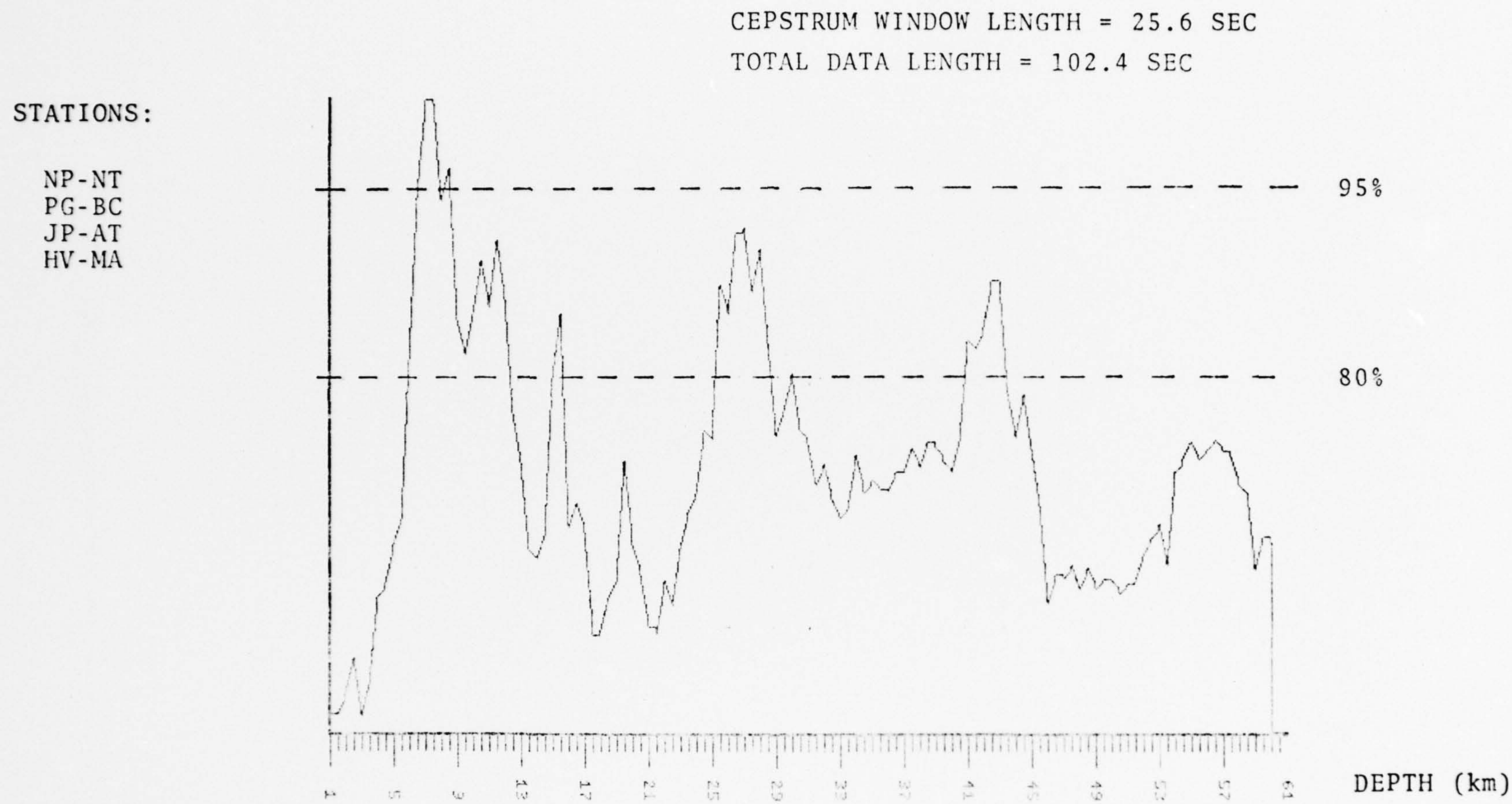

Figure 13

Composite Depth Plot, Data Set 5

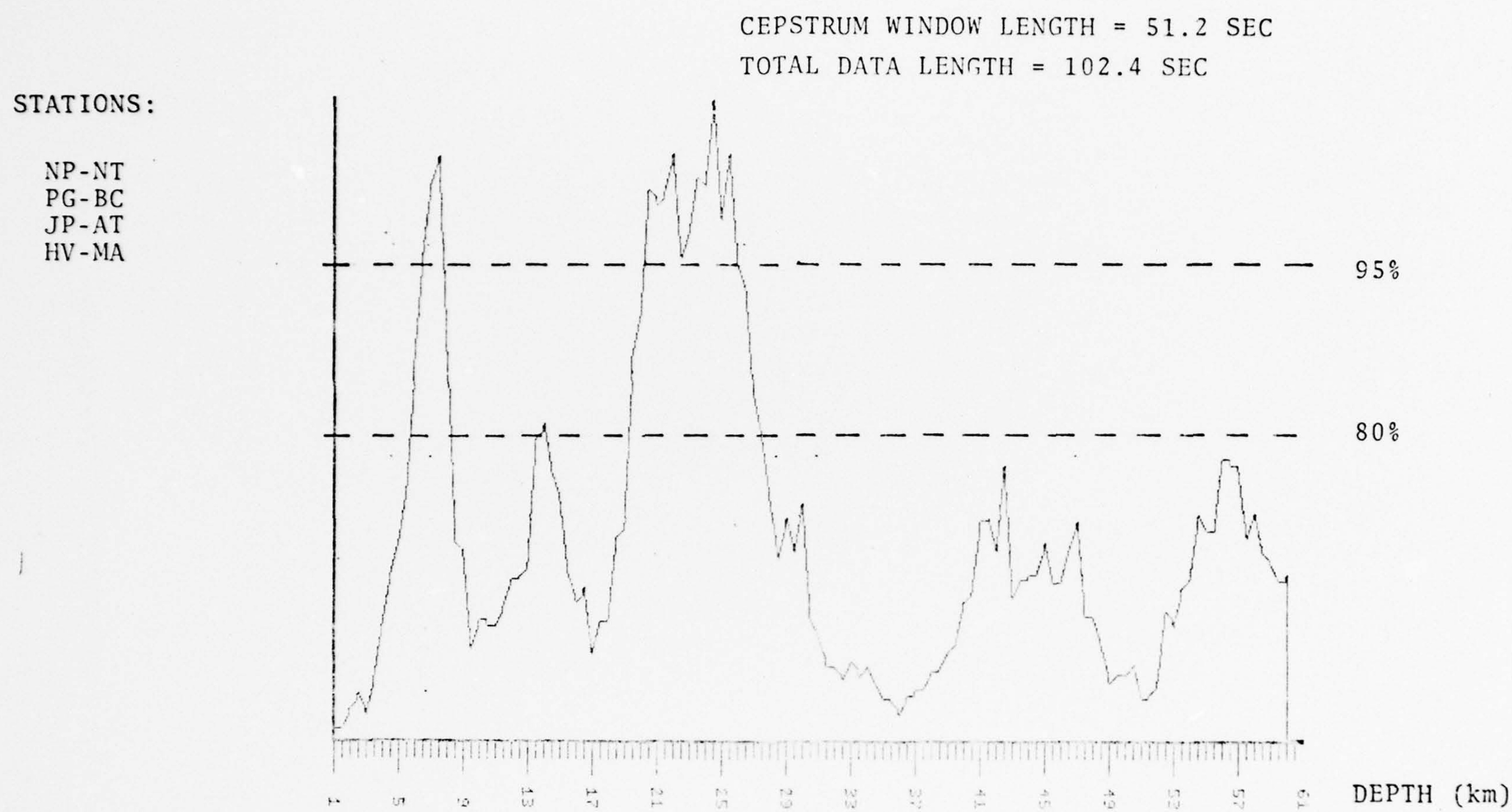

Figure 14

Composite Depth Plot, Data Set 5

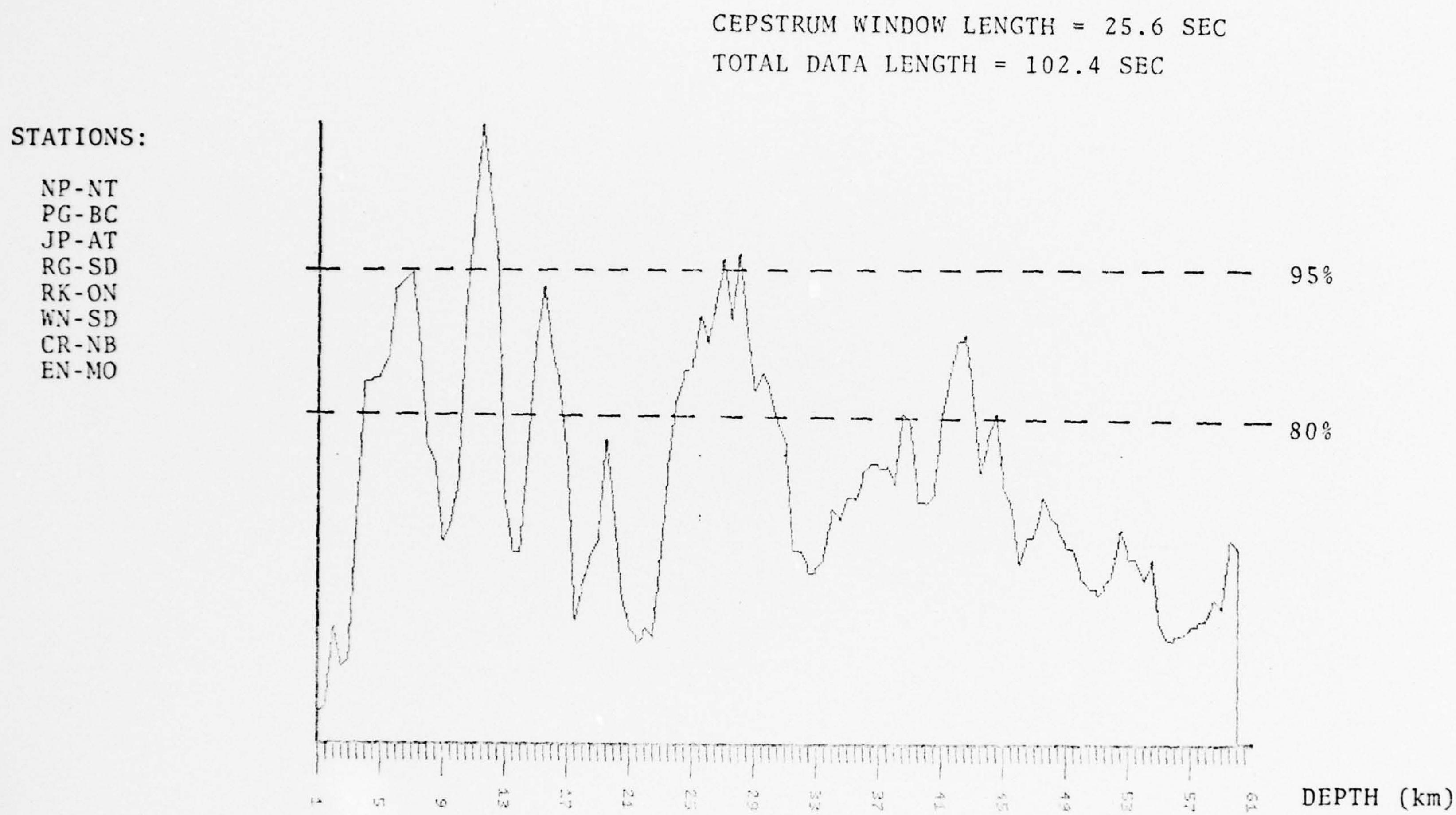

Figure 15

Composite Depth Plot, Data Set 6

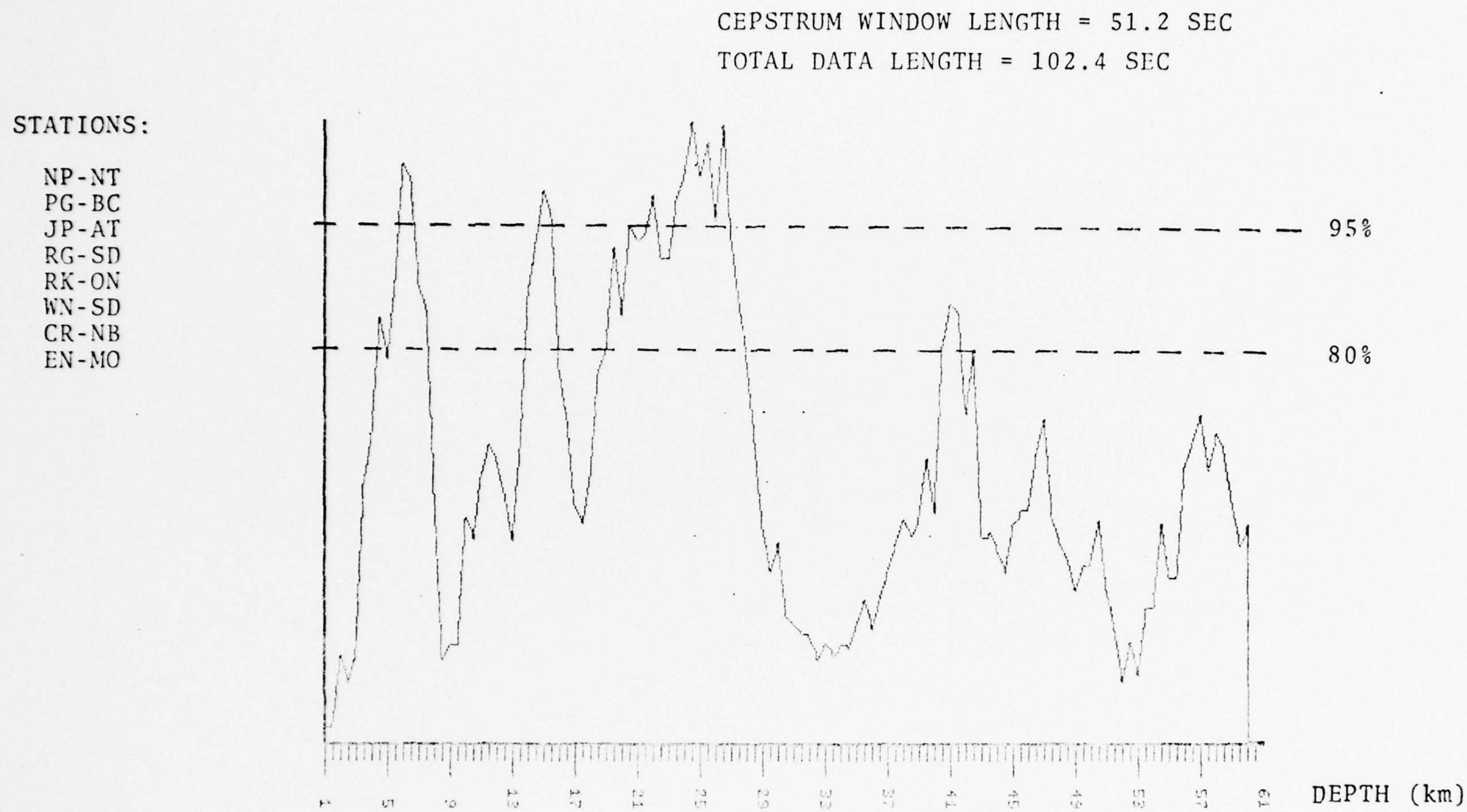

Figure 16

Composite Depth Plot, Data Set 6

CEPSTRUM WINDOW LENGTH = 25.6 SEC
TOTAL DATA LENGTH = 102.4 SEC

STATIONS:

NP-NT
HV-MA
MN-NV
KN-UT
CR-NB

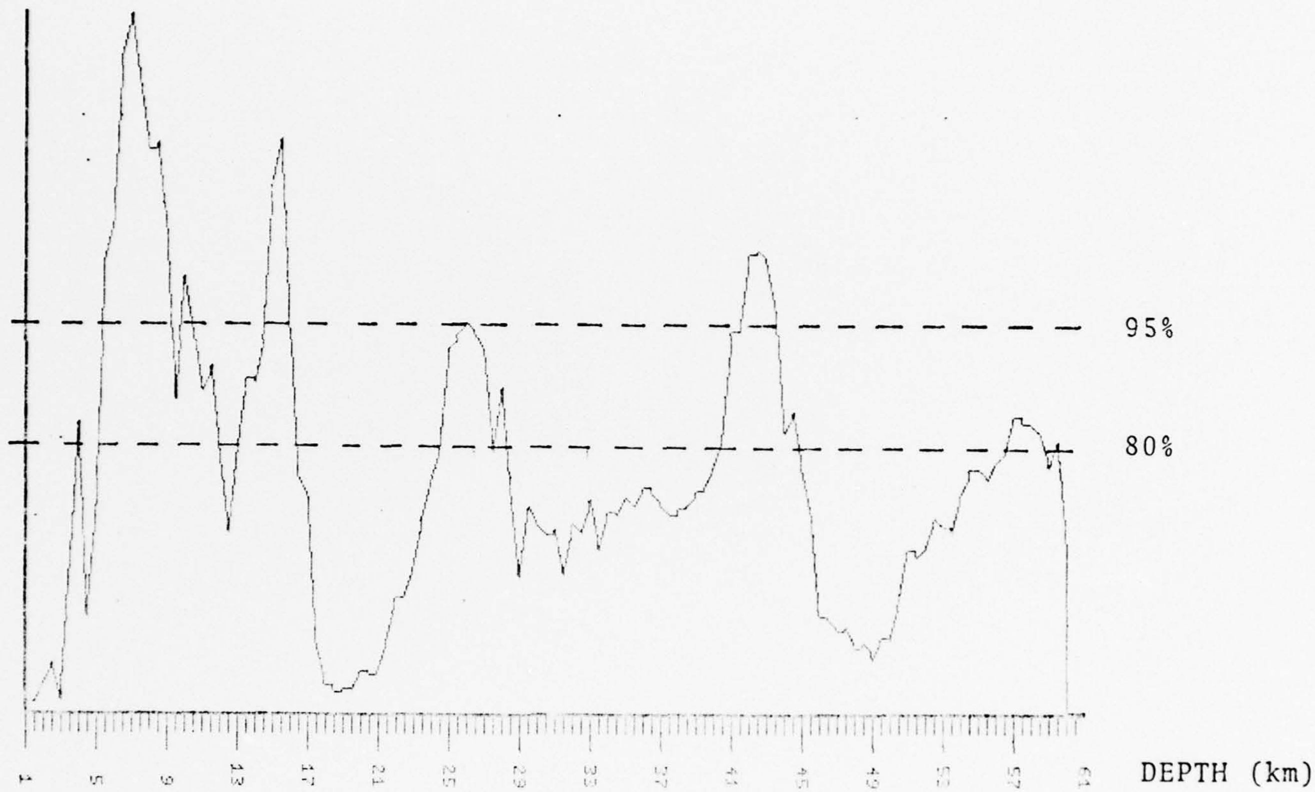

Figure 17

Composite Depth Plot, Data Set 7

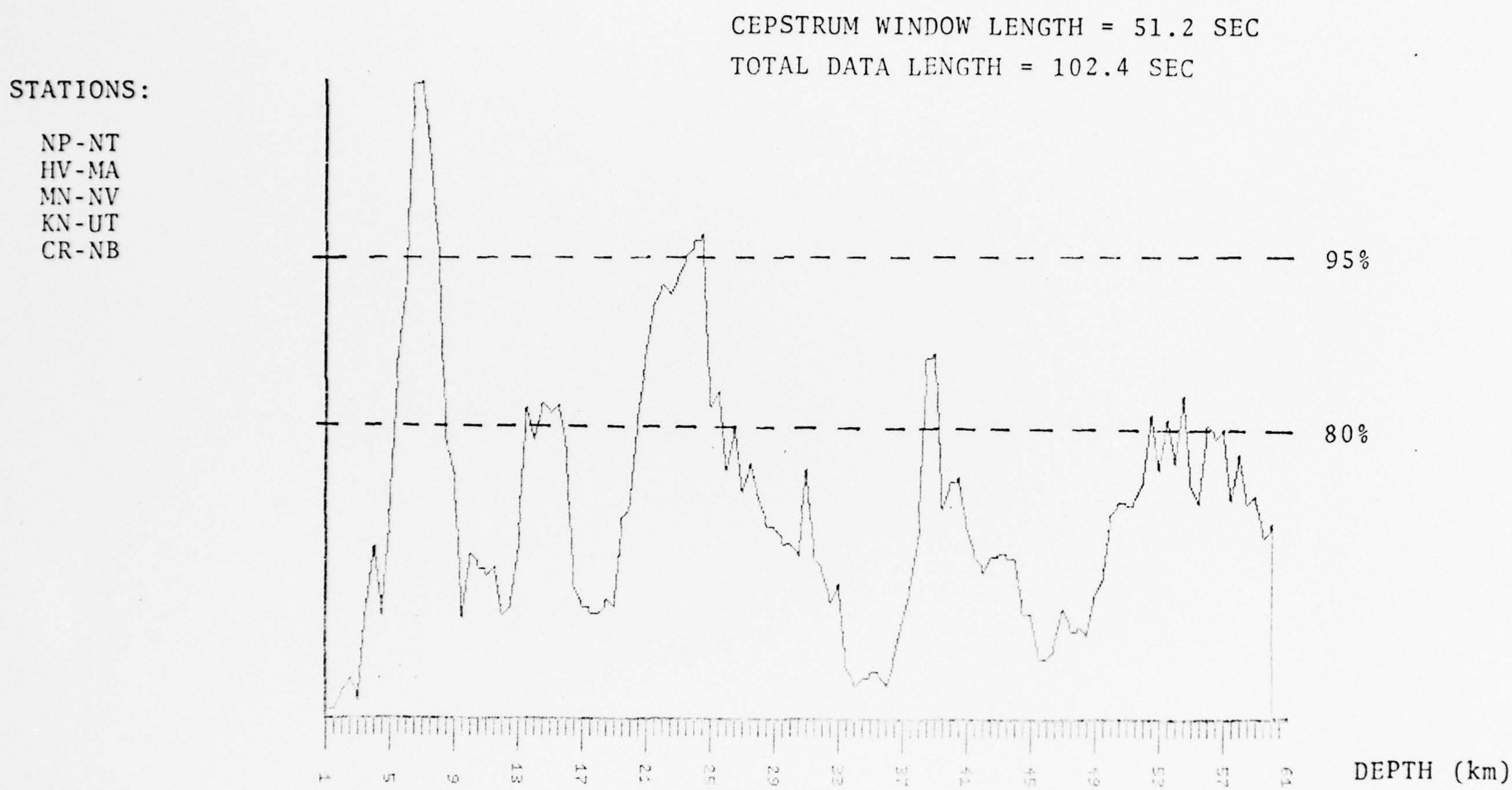

Figure 18

Composite Depth Plot, Data Set 7

3. 6 stations, Δ's within 5° of Δ = 48° (middle range Δ's).

4. 4 stations, Δ's within 5° of Δ = 61° (long range Δ's).

5. 4 stations, Δ's within 5° of Δ = 39° (close range Δ's).

6. 8 stations, arrival visible 7 seconds after P.

7. 5 stations, arrival visible 10 seconds after P.

All of the runs illustrated were done using the first 102.4 seconds of each seismogram.

It is evident from a quick examination of the plots in Figures 3-18 that the correct source depth for this event is far from obvious. Four different peaks reappear consistently, at approximate depths of 7, 13, 25, and 41 km. The sources of each of these peaks can be identified, however, by a more detailed analysis of the results.

The peak at 7 km, present with an amplitude above the 95% significance level on almost all of the depth plots, appears to be a product of the cepstrum processing. A peak corresponding to this delay time (approximately 1.8 second) has been present on most of the previous events, although usually not with such high amplitude, and is independent of the cepstrum computation window length used. This feature apparently arises from the truncation of the central peak of each cepstrum at a time of 1.6 second; techniques are being investigated for removing the central peak of the raw cepstrums without introducing this spurious peak into the depth plots.

Of the remaining three depth plot peaks, the one at 25 km occurs most frequently above the 95% level, and provides the best estimate of the source depth. This conclusion is supported by the observation of possible pP arrivals at a delay time of about 7 seconds on many of the seismograms.

The peak at 41 km also appears to represent a real seismogram feature, since several seismograms show possible arrivals at about 10 seconds after P. A 41 km peak represents a delay time of about 11.3 seconds, which is 1 second longer than the expected delay for sP from a 25 km event. This peak is most straightforwardly explained as a sP arrival from a source region with abnormally low S velocities. An alternative interpretation is that there are two good reflectors above the source, such as water bottom and water surface, with a two-way travel time of about 4 seconds between the two boundaries. Then, the 25 km peak would be the result of an echo off the bottom reflector, and the 41 km peak would come from an echo off the top reflector.

The 13 km peak, representing a delay time of about 4 seconds, corresponds to the expected difference peak from the 25 km and 41 km peaks.

Summarizing, the following conclusions about the four depth plot peaks have been reached:

- The 7 km peak is a product of the processing.
- The 13 km peak is a difference peak arising from the 25 km and 41 km peaks.
- Two interpretations for the 25 km and 41 km peaks are possible:

  1. The 25 km peak represents a p arrival (and thus the event depth), and the 41 km peak represents a slow sP arrival.

2. There are two reflectors above the source, with the 25 km peak coming from an echo off the deeper one, and the 41 km peak coming from an echo off the shallower one.

This event is a good one for illustrating how many factors can be involved in obtaining a depth estimate. Seismogram plots, delay time information, and depth plots from several different station groups were all used in the interpretation of this event. All this information should be easily available to an analyst doing routine depth determinations, and each of these features is planned to be included in future program implementations.

Removal of Source Spectrum Structure

Many of the events that have been processed through the source depth determination program have given depth plots with spurious peaks at shallow (<15 km) depths. These peaks could be results of structure in the source wavelet spectrum, and thus would be eliminated if power spectra were inverse filtered with the source wavelet before cepstrum computation. The depth determination program was modified to do this inverse filtering, and two methods for estimating the source spectrum were tried. The first of these methods averaged the spectra from each cepstrum computation window to obtain one source spectrum per station, and the second method calculated a separate estimate for each window by smoothing the actual spectrum for that window.

These techniques were tested on both real and synthetic data. On synthetic data, neither method worked as well as conventional processing, and, on real data, neither method worked at all. This negative result is due to the inadequacy of the source spectrum estimates; if a technique for obtaining accurate source spectrum estimates could be found, inverse filtering would probably have the desired effect.

SDAC Program Implementation

In order to provide easier access to Seismic Research Observatory data, the source depth determination program is being implemented on the IBM TS/44 system at the Seismic Data Analysis Center. Since this implementation already involves considerable program modification, it was decided to rewrite much of the program as a preliminary version of the analysis package that will eventually be used for routine source depth determination by an analyst. Currently, system flowcharting has been completed and coding has been started on this new program version.

The most significant difference between the SDAC implementation of the depth determination program and previous versions is the increased flexibility for specification of station groupings, seismogram time limits, and output displays available to the analyst in the new SDAC system. The general system flowchart (Figure 19) illustrates how this is accomplished. Basically, the depth determination system consists of two steps: one that computes all the necessary cepstrums from the seismogram input, and one that picks these cepstrums to generate depth plots. Cepstrums computed in the first step are written on the cepstrum file, which is read by the second step. The second step may also be run as a separate program; after viewing the first batch of depth plots generated by the system, the analyst may go back to the same cepstrum file and generate new depth plots using any desired combination of stations, window length, and total data length. It is planned that this generation of new depth plots will eventually be done on an interactive basis, without actually submitting a new program run.

Several other new features have also been incorporated into the SDAC depth determination system. These include optional plots of individual cepstrums, and optional cepstrum editing based on the phase of each cepstrum point.

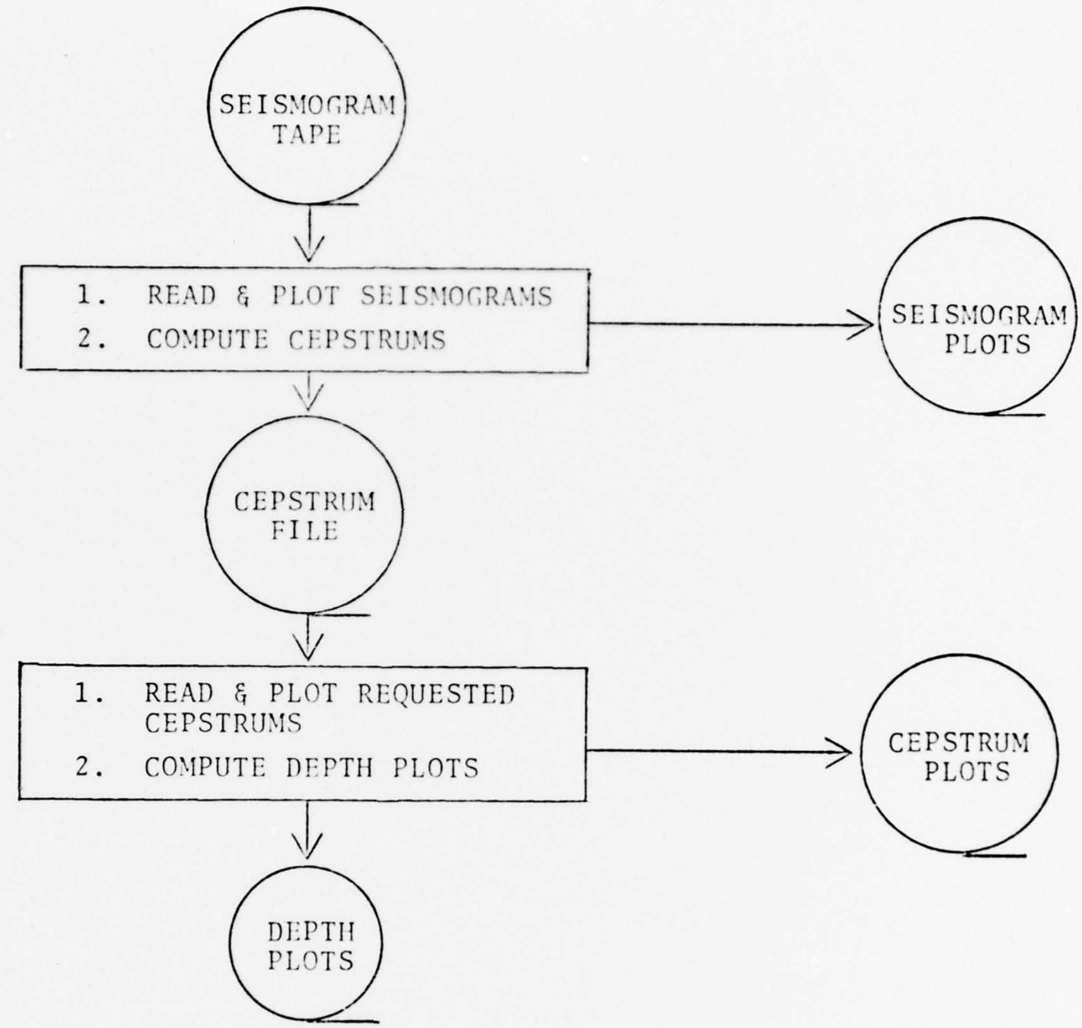

Figure 19

SDAC Depth Determination System