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IMPROVED PROCEDURES FOR DETERMINING SEISMIC  
SOURCE DEPTHS FROM DEPTH PHASE INFORMATION

QUARTERLY REPORT

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| Implementation of the seismic source depth analysis package at SDAC has been completed. This version includes Calcomp plot output of seismograms, cepstrums, and depth plots, and allows the analyst to easily reprocess an event using different combinations of input data and analysis parameters. |                                                             |                                             |

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ARMED SERVICES PROCUREMENT REGULATION

→ Three new processing features have been developed: phase editing, an improved significance level algorithm, and computation of a depth threshold based on data bandwidth. Phase editing permits point-by-point editing of cepstrums, based on phase; the other two features are designed to assist the analyst in interpreting the final depth plots.

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## INTRODUCTION AND SUMMARY

During this quarter, implementation of the basic source depth determination procedure at SDAC was completed, and three new program features were developed. The system implemented at SDAC includes all the planned options for Calcomp plotting and "second pass" processing, and RUN files have been set up to make it easier to submit jobs.

The three program features developed during this quarter are:

- Cepstrum phase editing
- Improved significance level algorithm
- Computation of significance threshold due to data bandwidth

Phase editing gives the analyst the option of editing cepstrums point-by-point, based on the phase of each cepstrum point, before generating depth plots. The new significance level algorithm improves the statistical base of the significance level estimates by making five random delay time passes of each cepstrum instead of just one. Finally, the bandwidth-based significance threshold gives the analyst a quantitative estimate of the shallowest depth that can be determined due to the bandwidth of the input seismograms.

## MAJOR ACCOMPLISHMENTS

### IMPLEMENTATION OF BASIC SYSTEM

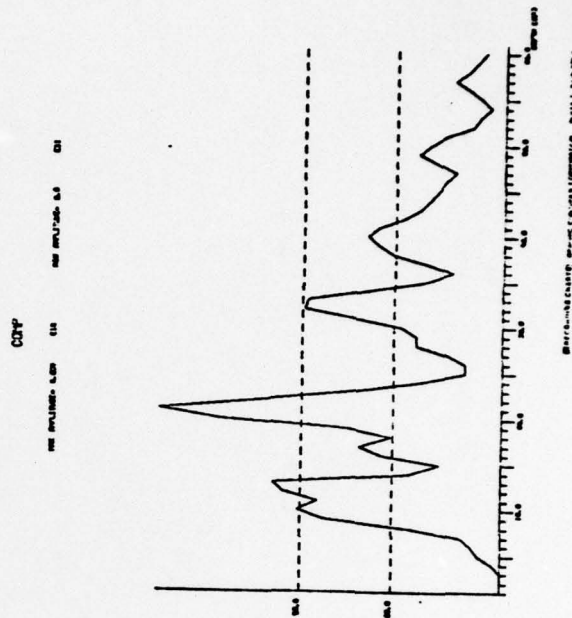
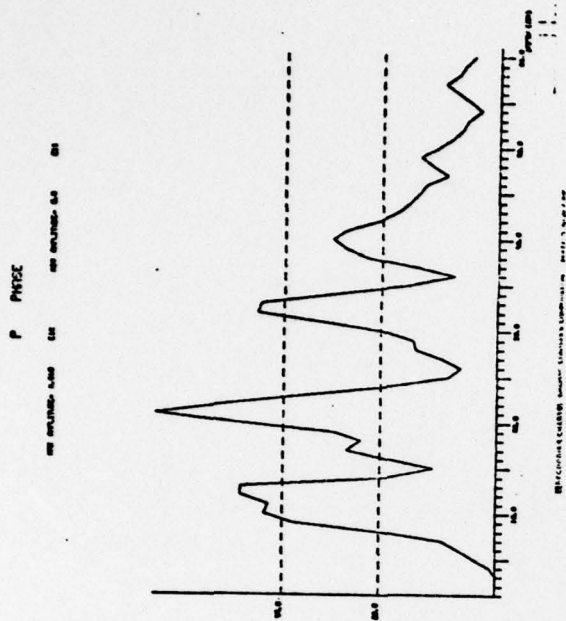
Implementation of the basic seismic source depth determination system, including all Calcomp plot options, control parameter override capabilities, and RUN files for job submission, has been completed. Two RUN files have been set up: one for executing the entire depth determination procedure starting from the seismograms, and another for executing only the second part of the procedure with a new set of analysis parameters, starting from a set of previously computed cepstrums. In a "second pass" run, any control parameter may be changed, and different combinations of stations and analysis start and end times may be used. The basic output of the program is a set of Calcomp depth plots, shown in Figure 1. Seismogram plots (Figure 2) and plots of individual cepstrums (Figure 3) may also be obtained, if desired.

### NEW ANALYSIS FEATURES

Three new analysis features were developed during this quarter. One of these (phase editing) has been implemented in the SDAC system; the other two presently exist only as test versions.

#### Phase Editing

The first new analysis feature allows the analyst to edit each cepstrum, based on phase, before generating depth plots. Since cepstrum peaks resulting from depth phases are expected to consistently have phases near  $0^\circ$  or  $180^\circ$ , phase editing should be useful in eliminating non-depth-phase cepstrum peaks. Phase limits are input to the program as phase angle intervals about  $0^\circ$  and  $180^\circ$ ; all cepstrum points having a phase outside these limits are edited out.



DEPTH PLOTS

DATE: 10/10/77

TIME: 10:00:00

STATION: 1000

DEPTH: 0.0 TO 1000

AMPLITUDE: 0.0 TO 1000

SUNSET TEST EVENT

9 14 77

LMT= 39.0

LON= 77.0

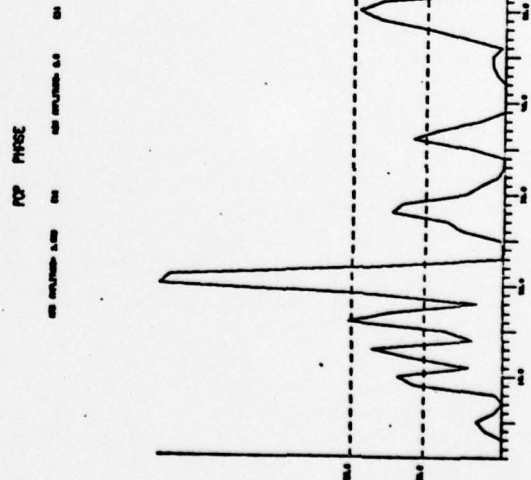


Figure 1. Depth Plots

SILENT TEST EVENT

9 14 77

LATITUDE- 39.0

LONGITUDE- 77.0

4

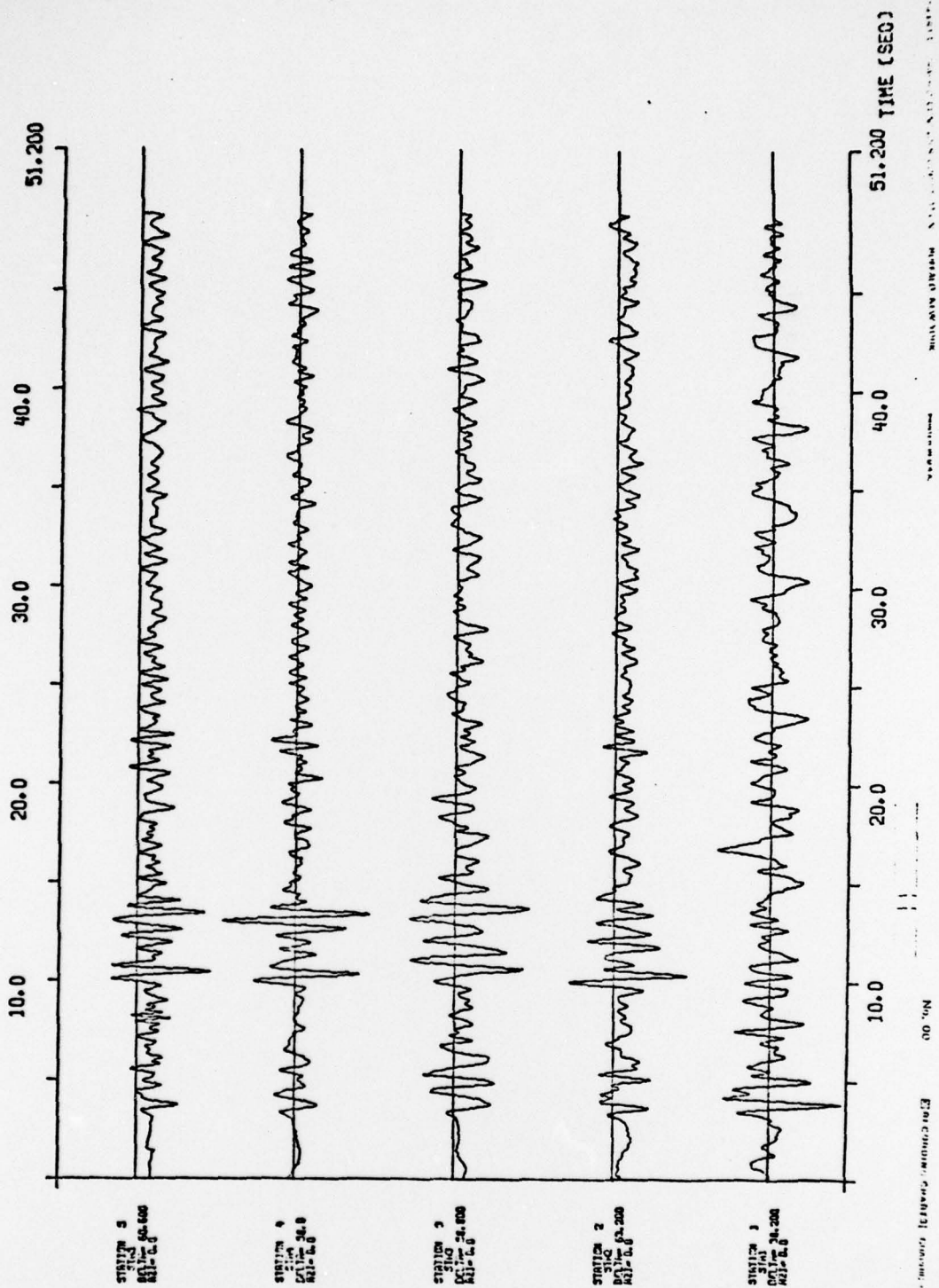


Figure 2. Seismogram Plot

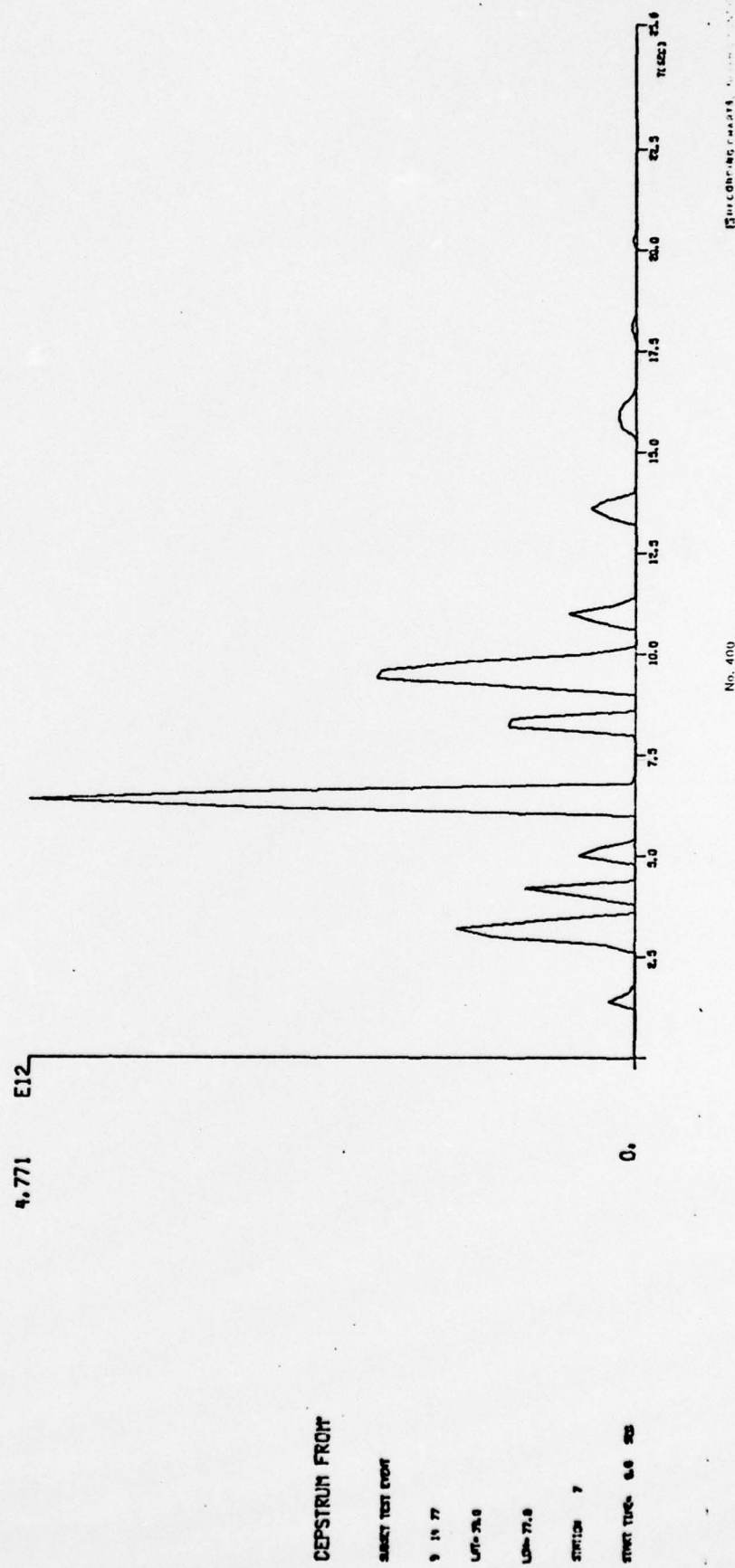


Figure 3. Cepstrum Plot

Depth plots illustrating the application of phase editing to the Illinois event (11/9/68) are shown in Figures 4-6. Figure 4 is the composite depth plot obtained using no phase editing, Figure 5 used only cepstrum points having phases between  $-25^{\circ}$  and  $25^{\circ}$  and between  $165^{\circ}$  and  $205^{\circ}$ , and Figure 6 accepted only phases between  $165^{\circ}$  and  $205^{\circ}$ . The best results are obtained using only those points with phases within  $25^{\circ}$  of  $180^{\circ}$ ; when cepstrum points with phases within  $25^{\circ}$  of  $0^{\circ}$  are also used, the depth plot deteriorates. Phase editing promises to be a useful addition to the depth determination procedure, but, as this example illustrates, its behavior needs to be studied using a larger data base.

#### Improved Significance Level Algorithm

The second new analysis feature is an improved version of the significance level algorithm. Briefly, the old significance level algorithm involves computing the distributions of depth plot amplitudes that result from picking cepstrum points at random times instead of the correct depth phase delay time. This distribution is used to determine the random depth plot amplitude that is greater than a specified percentage of the random depth plot points. Finally, this amplitude is marked on the final depth plot, to be used as an indication of the significance of depth plot peaks.

The new significance level algorithm differs from the old one in that, instead of computing just one random depth plot amplitude distribution, five separate distributions are computed. These five distributions are computed from the same cepstrums, but with five different sets of uniformly distributed random delay times. Five sets of significance levels are then determined, and an average and standard deviation is computed from these five numbers and written on the final depth plot.

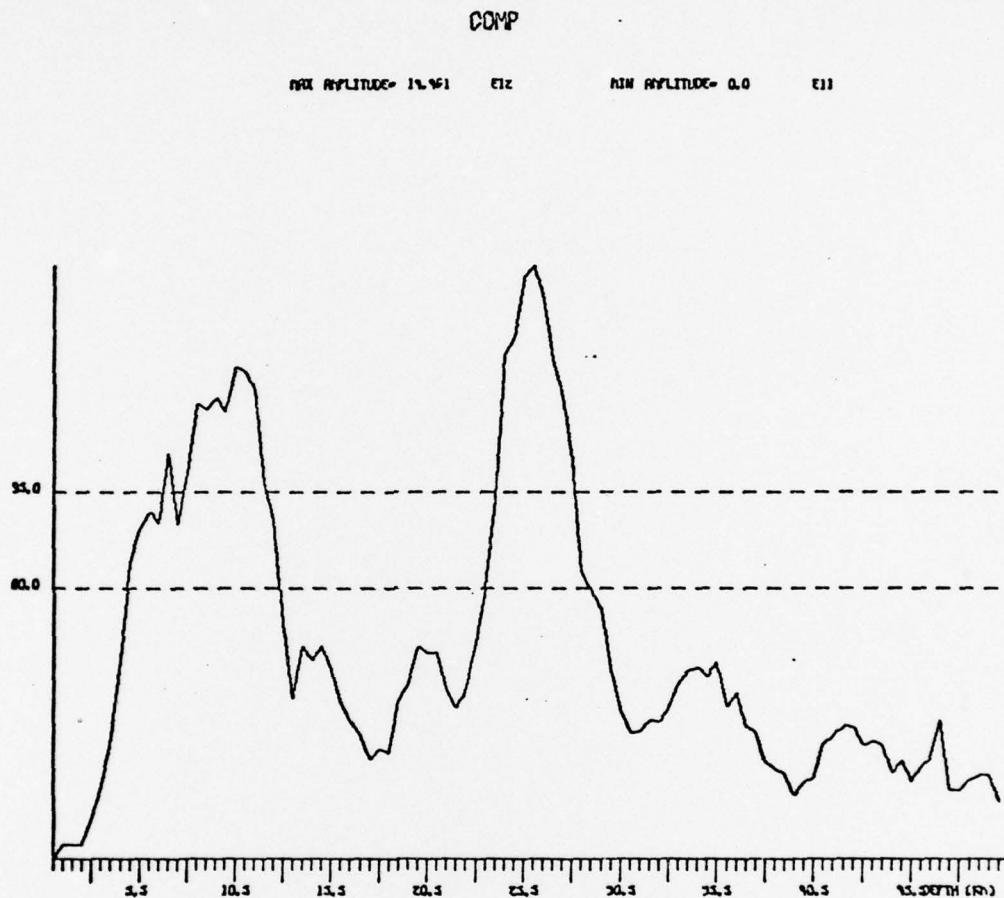


Figure 4. Illinois Event Composite Depth Plot.  
No Phase Editing.

COMP

MAX AMPLITUDE= 1.913

E12

MIN AMPLITUDE= 0.0

E11

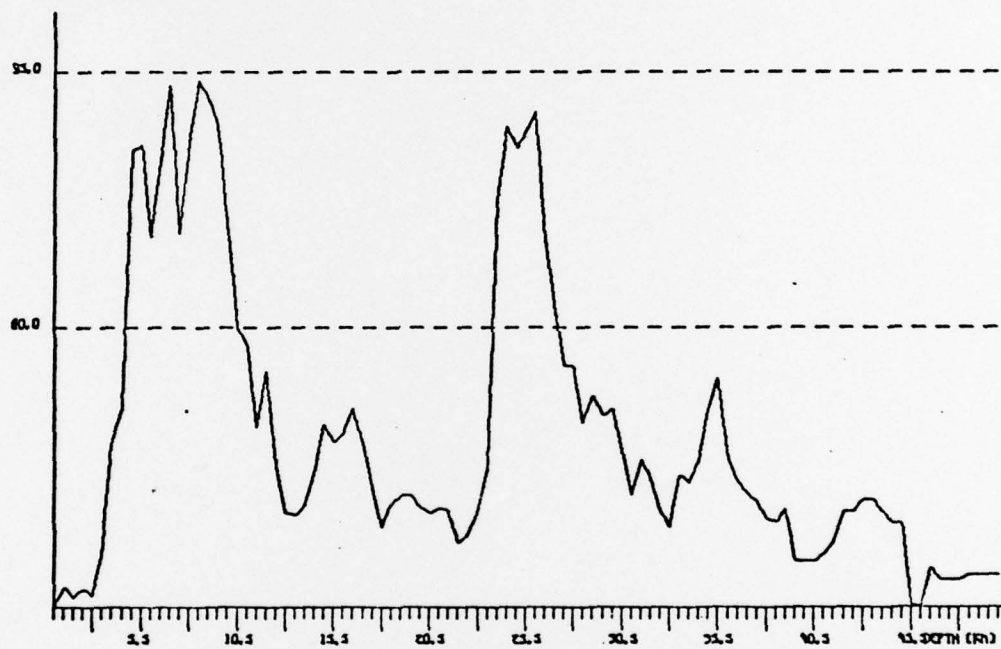


Figure 5. Illinois Event Composite Depth Plot  
Phases Allowed:  $0^\circ \pm 25^\circ$   
 $180^\circ \pm 25^\circ$

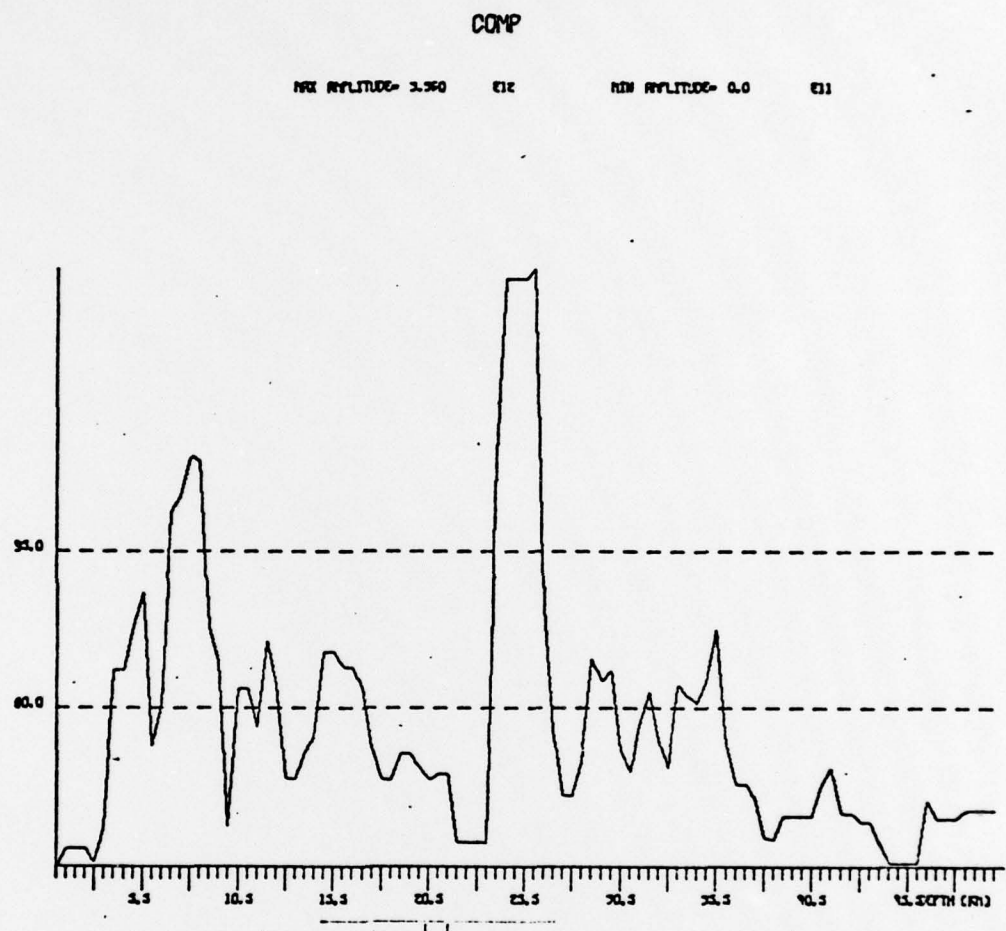


Figure 6. Illinois Event Composite Depth Plot  
 Phases Allowed:  $180^\circ \pm 25^\circ$

This technique results in two improvements over the previous method. First, the average significance level displayed on the final depth plot is a better estimate of the true significance level because it is computed from five estimates of the random amplitude distribution instead of just one. Second, since the central limit theorem implies that the five significance levels are normally distributed, the standard deviation provides a quantitative estimate of the reliability of the average significance level. Using this new algorithm, depth plots can be interpreted with greater confidence than previously possible.

#### Bandwidth-Based Significance Threshold

The last of the new analysis features provides a quantitative estimate of the shallowest depth that can be determined from a given set of seismograms. This is necessary because of the way the general structure of the cepstrum is affected by the bandwidth of the original seismogram.

The depth determination program computes a cepstrum by taking the power spectrum of the one-sided version of the seismogram power spectrum. Consequently, each cepstrum has low amplitudes at long lags, and, at short lags, a high amplitude central peak that becomes wider as the seismogram power spectrum becomes narrower. Unless the much smaller peak that corresponds to the echoed arrival falls outside this central peak, it will not be detected. Thus, the width of the central peak determines the shallowest depth (shortest delay) that can be detected from the original seismogram.

This effect is illustrated in Figure 7. A wide band seismogram has a power spectrum that is sufficiently broad for the modulation caused by the depth phase to be well defined. Consequently, the cepstrum has a narrow central peak and a distinct peak corresponding to the echoed arrival that dominates

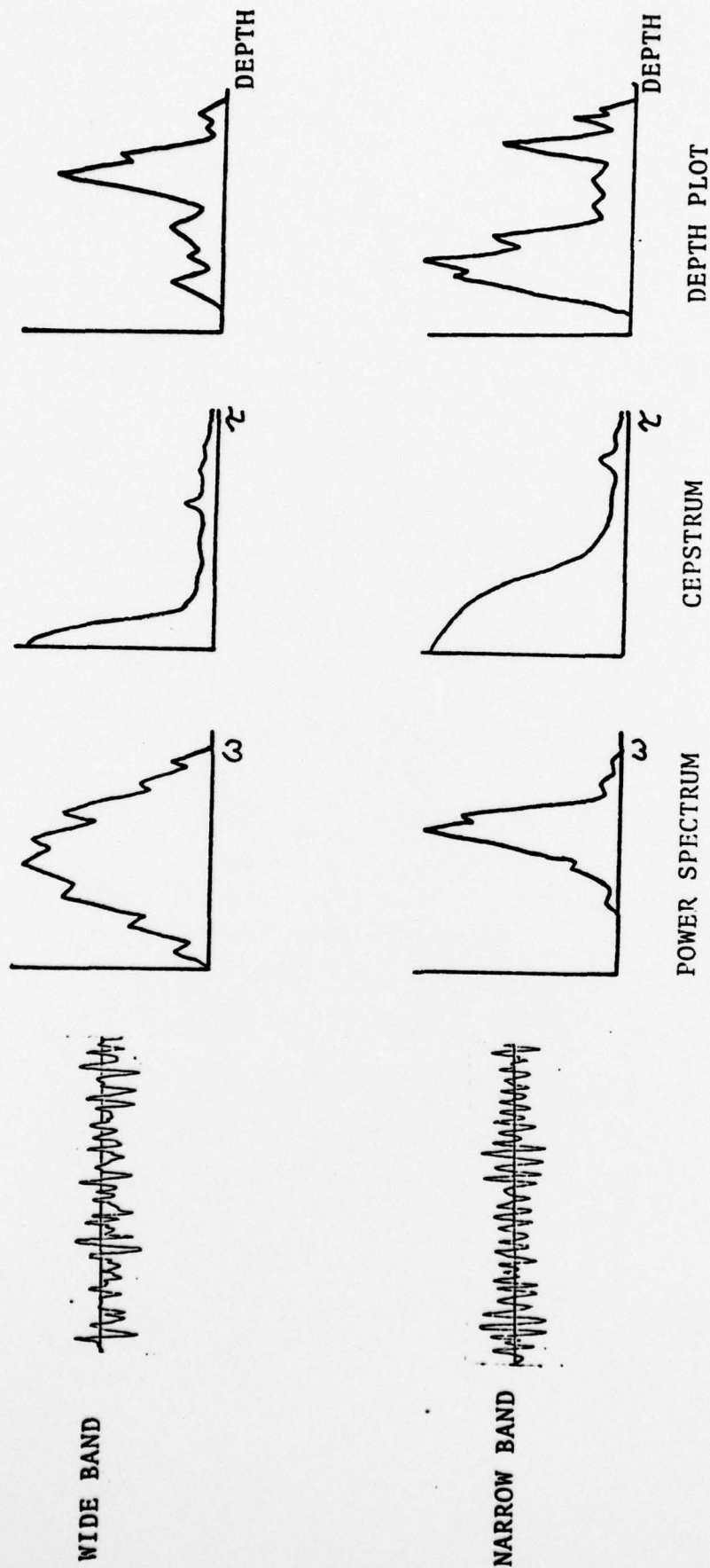


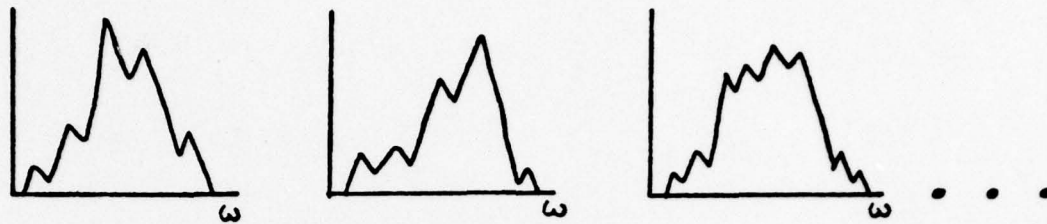
Figure 7. Effect of Narrow Band Data on Depth Plots

the final depth plot. In contrast, a narrow band seismogram has a power spectrum that is too narrow for any but very high frequency modulations to be detectable. The resulting cepstrum has a very broad central peak that would overwhelm any echo peaks occurring at short or moderate lags. Even when the depth phase has a sufficiently long delay time, interpretation of the final depth plot will still be complicated by the large, shallow depth peak that is produced by the wide central peak of the cepstrum. If an estimate of the central peak width were available, it could be used to determine the shallowest interpretable depth.

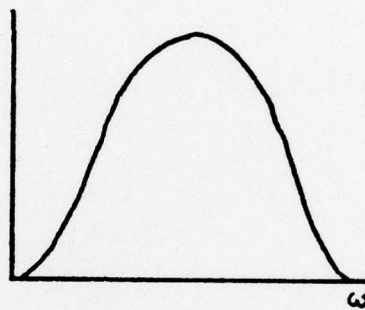
Figure 8 illustrates the technique developed to estimate the width of the cepstrum central peak. Since the final depth plot is produced from a large number of cepstrums, the first step is to calculate an average power spectrum from all the seismograms being analyzed. Next, this average power spectrum is smoothed to remove any depth-phase-generated modulation that hasn't already been eliminated by the averaging process. Finally, an average cepstrum is computed by taking the power spectrum of the positive frequency side of the smoothed average power spectrum. The time at which this average cepstrum first falls below 1% of its maximum value is used as the estimated shortest detectable delay time.

The shortest detectable delay time estimate is converted to depth and written in the depth plot label. This warns the analyst that any depth plot peak below this depth is likely to be a product of the seismogram spectra and not a true indicator of the source depth.

INDIVIDUAL POWER SPECTRA



SMOOTHED AVERAGE POWER SPECTRUM



AVERAGE CEPSTRUM

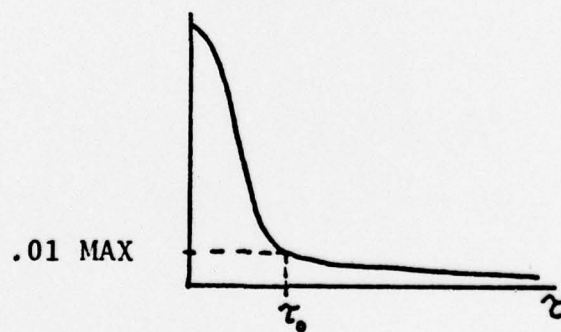


Figure 8. Computation of Narrow Band Threshold