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LONG PERIOD SEISMOLOGICAL RESEARCH PROGRAM

Lynn R. Sykes, et al

Lamont-Doherty Geological Observatory

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13. ABSTRACT  
The most significant result of the data analysis pertinent to the earthquake-explosion discrimination problem is based on the study of surface wave detection thresholds. Inclusion of data from the stations at Eilat, Israel (EIL), and Kongsberg, Norway (KON) show that long-period surface waves are observed from many shallow earthquakes located in central Asia with magnitudes between  $m_b=4.1$  and 4.5. These relatively low threshold values can often be lowered by 0.2 to 0.3  $m_b$  units by means of digital filtering techniques (polarization and azimuthal) thereby extending the applicability of the  $M_s-m_b$  discriminant to smaller magnitude events.

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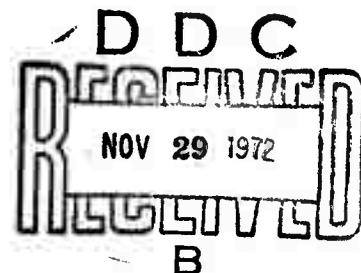
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Long-Period Seismological Research Program

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## SUMMARY

1.

During the first six months of the subject contract, the purposes of the research program were:

1. To maintain the six high-gain seismograph stations previously installed by Lamont while affecting an orderly transition of maintenance responsibilities for those stations to the NOAA group at Albuquerque, New Mexico. During the last two weeks in April personnel from Lamont closed out the station at Fairbanks, Alaska, and shipped all the equipment to Albuquerque.

2. To conduct seismological research on the long-period analog and digital data from the high-gain stations.

Analysis of the analog and digital data from the high-gain stations has been conducted on the following topics:

1. The determination of detection thresholds for long-period seismic waves from earthquakes and underground explosions.

2. Investigation of the spectral characteristics of earth noise at periods longer than 20 seconds.

3. Various techniques for enhancing the signal to noise ratio (S/N) of seismic waves from small magnitude events recorded digitally.

4. Various seismological investigations including the study of dc tilts associated with large ( $M_s > 7.5$ ) earthquakes and background secular tilts observed on the displacement outputs at the high-gain stations; surface wave spectra for swarm-type earthquakes; first motion studies.

The most significant result of the data analysis pertinent to the earthquake - explosion discrimination problem is based on the study of surface wave detection thresholds. Inclusion of data from

the stations at Eilat, Israel (EIL), and Kongsberg, Norway (KON) show that long-period surface waves are observed from many shallow earthquakes located in central Asia with magnitudes between  $m_b = 4.1$  and 4.5. These relatively low threshold values can sometimes be lowered by 0.2 to 0.3 $m_b$  units by means of digital filtering techniques (polarization and azimuthal) thereby extending the applicability of the  $M_s - m_b$  discriminant to smaller magnitude events.

## I. STATION MAINTENANCE

During the first three months of the subject contract, considerable time was spent preparing for and carrying out combined inspection - maintenance trips to the high-gain stations at Charters Towers, Australia (CTA); Chiang Mai, Thailand (CHG); Kipapa, Hawaii (KIP); and Matsushiro, Japan (MAT). As a result of these trips, several recommendations for improvements consist of the addition of air-conditioners in the recording rooms at CTA and CHG for more efficient operation of the digital recorders and instrument repair techniques that should result in greater continuity of the analog data. In addition, personnel at each site were thoroughly advised of the transition of maintenance responsibilities from Lamont to NOAA.

During the last two weeks in April a two man team from Lamont traveled to Fairbanks, Alaska, to close out the station FBK. All the equipment at that site, including the instrument tanks, were crated and shipped either by truck or airplane to NOAA at Albuquerque. The final recordings from FBK are dated 25 April 1972.

## II. DATA

Seismograms and magnetic tapes from all the high-gain stations

were sent to Lamont up to 1 September for quality control. As explained in previous reports, the magnetic tape data were examined on a playback system (cathode ray tube) and compared with the seismograms. The NOAA group at Albuquerque was advised of any malfunctions detected. After examining the tapes for quality control the tapes were copied and the originals forwarded to Texas Instruments. The seismograms are sent to the VELA Seismological Center before being film chipped in Asheville, North Carolina. Since 1 Sept. the NOAA group at Albuquerque has been copying tapes and sending the original tapes and seismograms directly from Albuquerque to the VELA Seismological Center. At the present time there is no back-log of seismograms from any of the high-gain stations at Lamont.

### III. RESULTS OF THE DATA ANALYSIS

#### A. Detection Thresholds for Surface Waves

In a previous publication (Savino et al, 1972a) and reports written under this contract, we discussed the results of a detailed investigation of seismograms from the high-gain stations at Charters Towers, Australia (CTA); Chiang Mai, Thailand (CHG); Fairbanks, Alaska (FBK); and Ogdensburg, New Jersey (OGD), for the ultimate detection thresholds for long-period surface waves from approximately 1000 shallow ( $h < 60$  km) events. The main conclusion of that study was that at many of these stations surface waves with periods between 20 and 40 seconds are consistently recorded from shallow earthquakes with magnitudes as low as  $m_b$  (NOAA) = 4.1 at epicentral distances of  $20^\circ$  to  $25^\circ$ . In these previous studies, however, there were not sufficient data to conclude anything about coverage in

central Asia.

In Figure 1 the surface wave thresholds expressed in terms of  $m_b$  (NOAA) are given for 59 seismically active regions of the world. An important qualification concerning the numbers within the rectangles in Figure 1 is that not every event that occurs in a designated region with the indicated magnitude will be recorded at one of these stations since the PDE program, which is the data base for this study, does not report every event at these low magnitudes in most of these regions. The additional data from EIL, however, indicates that threshold values in the Tibet - Iran - Turkey region are in the range  $m_b = 4.1$  to  $4.5$ . The various digital enhancement techniques that can be applied to the digitally recorded data at these stations should result in a further lowering of the threshold values in Figure 1.

#### B. Long-Period Earth Noise

In addition to a continuation of the study of the spectral characteristics of long-period earth noise (Savino et al., 1972b; Murphy et al., 1972), an investigation into the causes of changes in the background noise levels, especially on the horizontal components, at those stations with less than 30m of overburden is under way.

A striking contrast between the vertical - and horizontal - component noise levels for those relatively shallow sites is exhibited in the temporal variations of earth noise. Figure 2 shows three component noise spectra, uncorrected for instrument response, based on digitally recorded data from CTA. The data cover a 4 1/2 hours night-time period and an equal amount of time corresponding

to daylight hours on the following day. While the horizontal noise levels at periods longer than 30 sec undergo 10 to 20 db changes in level from day-to night-time hours, the level of the vertical component is the same for both time periods and is consistently lower than that of both horizontal-components at this relatively shallow (30m of overburden) site.

An indication of the cause of the variable noise levels of the horizontal-component seismographs comes a comparison of microbarograms and seismograms. Two sets of recordings, taken from the digital records at CTA, are shown in Figure 3. These data cover portions of the times included in the spectral calculations given in Figure 2. The seismic outputs were digitally filtered using a 6 pole 300 sec low-pass filter. During the daytime hours both horizontal components are seen to correlate quite well with the microbarogram (Figure 3) whereas during night-time hours, when atmospheric noise appears to be much less organized (i.e., compare the oscillatory behavior of the microbarogram for the day-time versus night-time hours), the correlation is reduced. The lack of visual correlation between the vertical component seismograms and the microbarograms on both occasions in Figure 3 is borne out by the more rigorous test of cross spectral analysis which indicates that there is no significant coherence between the vertical component of ground motion and local atmospheric pressure over the entire period range 10 to about 500 sec. This result is similar to that found at OGD by Savino et al., (1972b). Using a model of earth loading by random atmospheric disturbances, of short wavelength and small amplitude, these authors showed that there should

be no significant coherence between a vertical component seismogram and a microbarogram from the same location provided the seismograph is isolated from direct pressure effects as the high-gain seismographs are.

In general results from those stations with both seismic and microbaric instrumentation indicate that the atmosphere is an extremely important source of earth noise especially at periods longer than about 30 to 50 sec. With respect to the detection and discrimination problem, however, it is important to note that significant noise suppression can be achieved either by band - or high-pass filtering the horizontal data to eliminate the very long-period noise or by removing the correlatable noise recorded on a microbarograph and a horizontal seismograph. The above two techniques will not seriously affect the signal level in the period range 20 to about 50 sec and thus should retain the important discriminatory capabilities provided by Love waves (Molnar et al., 1969; Savino et al., 1971).

### C. Digital Enhancement Techniques

The use of long-period surface waves as a discriminant between explosions and earthquakes (e.g., the  $M_S - m_D$  discriminant) is limited by the present detection threshold for surface waves from small magnitude seismic sources. Improving the signal-to-noise ratio of recordings of long-period surface waves by 6 db (0.3 magnitude units) would be a welcome extension of the magnitude threshold of long-period instruments.

Filters employing a time varying response have been applied to long-period (20-60 sec) digital data from the high-gain seismograph

stations. To enhance Love waves, an azimuthal filter is designed which passes only energy approaching the stations from a desired azimuth. This type of filter offers the possibility of recovering an event buried in the coda of a larger event by use of recordings from a single station. For the enhancement of Rayleigh waves, a polarization filter is employed which passes only energy polarized as Rayleigh waves. These filters have resulted in an enhancement of signal-to-noise for small earthquakes ( $m_b < 5.0$ ) greater than that obtained by either matched or passive (e.g., bandpass or low pass) filtering. The results of this study have been written up by Choy and McCamy (1972) and submitted to JGR for publication.

#### D. General Seismological Investigations

Various Investigations employing the high-gain analog and digital data are currently under way. These include:

a.) A special study to determine the extent of coverage of world-wide seismic activity afforded by the high-gain stations installed by Lamont and NOAA, eight in all. This investigation is being conducted in cooperation with other seismic groups and will include results from several arrays (LASA, ALPA, NORSAR), the stations of the WWNSS, and various other smaller arrays in different countries. A listing of events occurring within a one month period (20 March - 20 February, 1972), compiled by Lincoln Labs, will be used as a data base for determining the detection thresholds of the high-gain stations.

b.) A study of dc tilts associated with large ( $M_s > 7.5$ ) earthquakes and background secular tilts observed on the displacement outputs at the high-gain stations. To date, dc tilts have been

observed at CTA after a large ( $M_s=8.0$ ) New Guinea shock and at OGD after a  $M_s=7.6$  earthquake in Sitka, Alaska. Additional large earthquakes are being investigated and the observed dc tilts, as well as dc strains, will be compared with theoretical calculations.

c.) First motion determinations and fault plane solutions. The high-magnification data at long-periods are proving to be extremely valuable for the determination of the proximity of a particular station to a nodal plane, and thus the determination of fault plane solutions using long-period body waves.

d.) Study of earthquake swarms. A study of an earthquake swarm that occurred in the Gulf of California on 20 March 1972 has been initiated. Swarm-type earthquakes, by their nature, tend to be of relatively small magnitude (e.g., maximum of  $m_b$  (NOAA) = 5.4 in the Gulf of California sequence) and to occur on oceanic spreading centers, often far from any land-based seismographs. For instance only 7 events were reported in the Preliminary Determination of Epicenters (PDE) listings of NOAA as occurring in the Gulf of California during the swarm, whereas very characteristic surface waves from 52 events in this swarm were observed on recordings, especially the horizontal components, from the high-gain station at Albuquerque, New Mexico. The high-gain systems offer a potentially useful tool for studying this important class of events.

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## FIGURE CAPTIONS

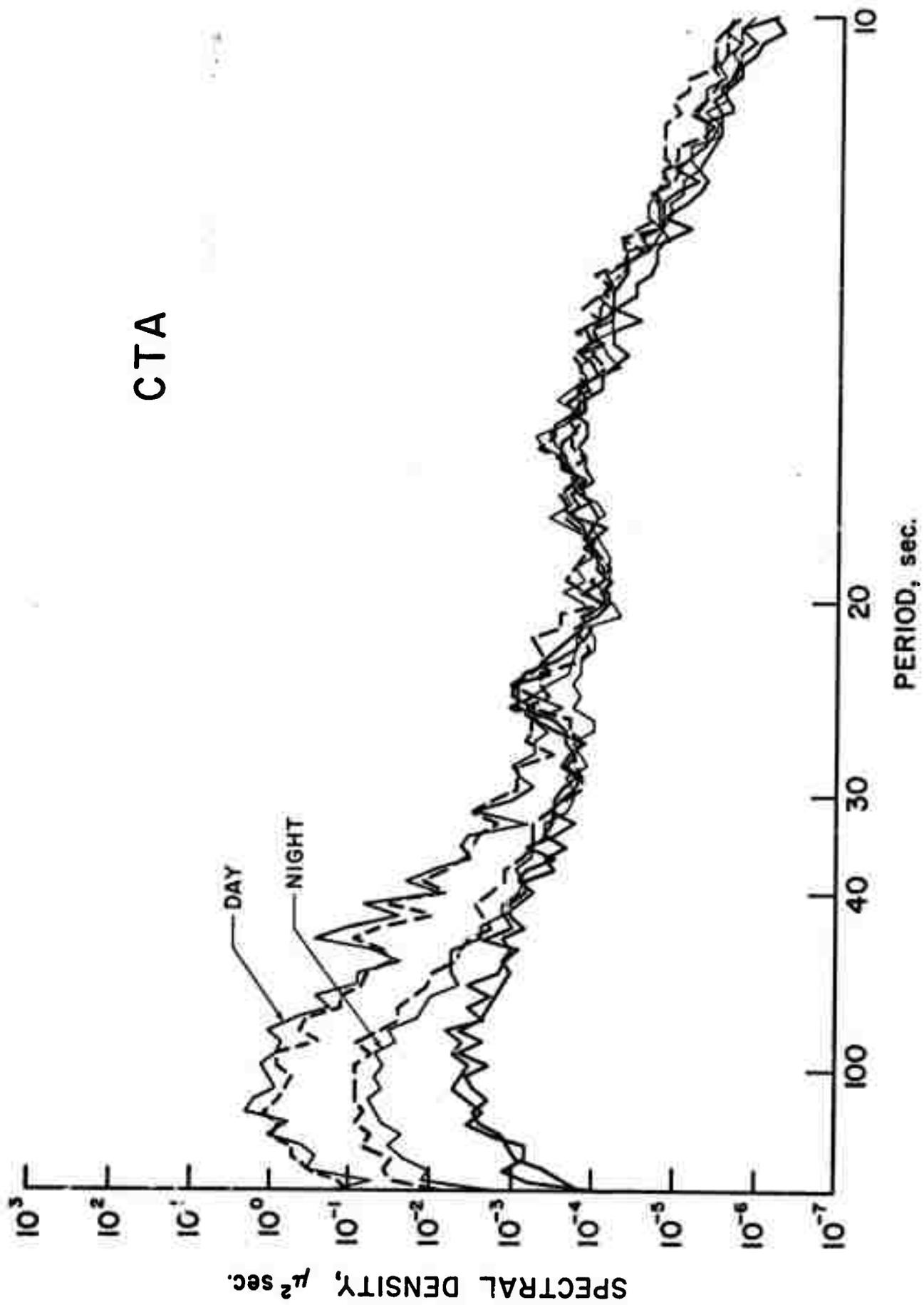
Figure 1. Map of the world showing the locations of the five high-gain seismograph stations (solid triangles) and the smallest magnitude events for which surface waves were observed at at least one of the five sites; FBK, CTA, CHG, EIL and OGD.

Figure 2. Power spectra from the three-component seismographs at CTA for a night-time period 256 minutes long and an equal amount of time the following day. These spectra are not corrected for instrumental response but are plotted at the correct level of 40 sec ground motion.

Figure 3. Playback of digital recordings from CTA of a microbarograph and the three-component seismographs. The signals are pre-filtered with a 300 sec low-pass filter. The individual traces are 1 1/2 hours long and are portions of the times included in the spectral calculations given in Figure 2.

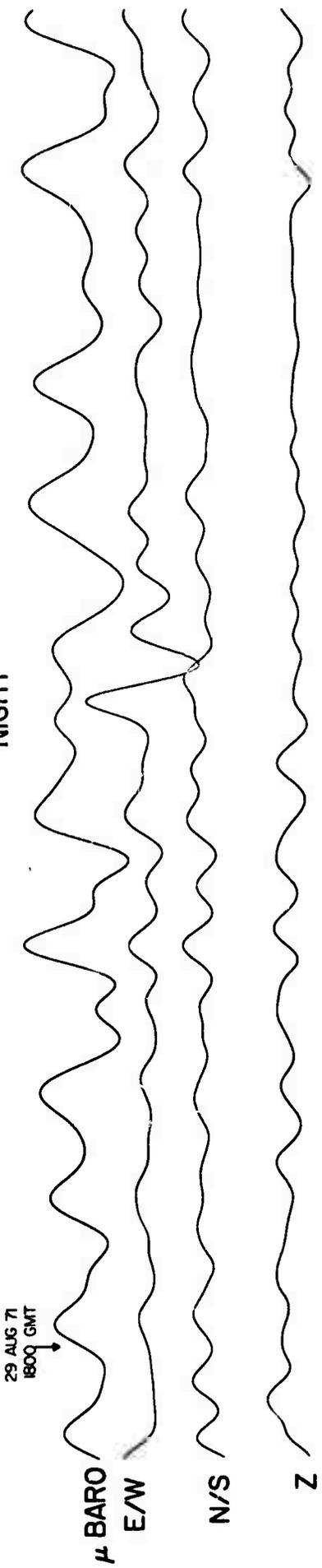


# CTA



CTA NOISE COMPARISON

NIGHT



DAY

