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ABSTRACT

The most significant finding of the analysis of data pertinent to the earthquake-explosion discrimination problem is one based on results from the seismic detection, discrimination, earth noise, and digital filtering studies. At many of the high-gain stations, surface waves with periods between 20 and 50 seconds are visually observed on seismograms nearly 100% of the time from shallow focus earthquakes with magnitudes as low as m_b=4.1 at epicentral distances of 20° to 25°. This period range, especially between 30 and 50 seconds, corresponds to a pronounced minimum in the level of earth noise observed on noise spectra from all of these sites (Savino et al., 1972a; Murphy et al., 1972) which differ greatly in geographical location, geologic setting, and depth of overburden. The noise minima are the same to within 10 db on spectra from the vertical components and 18 db for the horizontal components at all these sites and are not subject to temporal variations in amplitude of one or more orders of magnitude such as occur for the 16 to 20 sec microseismic noise level (Murphy and Savino, 1972). Thus the very effective M_s-m_b discriminant, especially where M_s is based on surface waves with periods longer than 20 sec (Molnar et al., 1969; Savino et al., 1971), can be used to particular advantage at these world-wide sites. In addition, digital filtering techniques, such as polarization filtering of Rayleigh waves and azimuthal filtering of Love waves, have enhanced the signal to noise ratio for surface waves even more and in many cases have lowered detection thresholds determined by visual analysis techniques by as much as an (cont. over)

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OF COLUMBIA UNIVERSITY
PALISADES, NEW YORK 10964

Long-Period Seismological Research Program

Annual Report

Contract F44620-71-C-0082

14 April 1972

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Title of Work:	Long-Period Seismological Research Program

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SUMMARY

During the first year of the subject contract, the purpose of the research program was twofold:

1. To maintain the previously installed high-gain seismograph stations at the following five stations: Charters Towers, Australia (CTA); Fairbanks, Alaska (FBK); Eilat, Israel (EIL); Chiang Mai, Thailand (CHG); and Ogdensburg, New Jersey (OGD), and to install and maintain a sixth high-gain station at Toledo, Spain (TLO).

2. To conduct research on the long-period analog and digital data from the above six stations and from the two additional stations installed at Albuquerque, New Mexico (ALQ) and Kongsberg, Norway (KON), by personnel from the National Oceanic and Atmospheric Administration (NOAA).

During the months May to August 1971, maintenance trips were prepared for and conducted to the stations at CTA, FBK, EIL, and CHG. The purposes of these trips were to perform routine maintenance on the three-component seismograph systems, service the Astrodata digital recorders, and install uninterruptable power units at each site. The sixth high-gain station installed by personnel from Lamont-Doherty was completed in August 1971.

Research using the analog and digital data from the high-gain stations concentrated on the following topics:

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

2. Investigation of the spectral characteristics and temporal behavior of earth noise in the period range 10 to 100 seconds.

3. The development of various digital filtering techniques for enhancing the signal to noise ratio (S/N) of seismic waves from small magnitude (m_b<5) events.

4. Discrimination between earthquakes and underground explosions.

5. The detection of acoustic-gravity and slow moving gravity waves in the atmosphere on the high-gain seismographs.

The most significant finding of the analysis of data pertinent to the earthquake-explosion discrimination problem is one based on results from the seismic detection, discrimination, earth noise, and digital filtering studies. At many of the high-gain stations, surface waves with periods between 20 and 50 seconds are visually observed on seismograms nearly 100% of the time from shallow focus earthquakes with magnitudes as low as m_b=4.1 at epicentral distances of 20° to 25°. This period range, especially between 30 and 50 seconds, corresponds to a pronounced minimum in the level of earth noise observed on noise spectra from all of these sites (Savino et al., 1972a; Murphy et al., 1972) which differ greatly in geographical location, geologic setting, and depth of overburden. The noise minima are the same to within 10 db on spectra from the vertical components and 18 db for the horizontal components at all these sites and are not subject to temporal variations in amplitude of one or more orders of magnitude such as occur for the 16 to 20 sec microseismic noise level (Murphy and Savino, 1972). Thus the very effective M_s-m_b discriminant, especially where M_s is based on surface waves with periods longer than 20 sec (Molnar et al., 1969; Savino et al., 1971), can be used to particular advantage at these world-wide sites. In addition, digital filtering techniques, such as polarization filtering of Rayleigh waves and azimuthal filtering of Love waves, have enhanced the signal to noise ratio for surface waves even more and in many cases have lowered detection thresholds determined by visual analysis techniques by as much as an additional 0.2 to 0.3 m_b units thereby extending the applicability of the M_s-m_b discriminant to smaller magnitude events.

I. STATION MAINTENANCE

Preparation for the maintenance trips to CTA, FBK, CHG, and EIL began in May 1971. The field teams involved in these trips prepared all the necessary test equipment for foreign shipment and made arrangements for their trips with the different participating institutions. It was necessary to make major modifications to the inverters and battery chargers purchased from the Exide Company as part of the uninterruptable power units to be installed at each site. Inadequate wiring in the battery chargers was corrected and relays and timers were added to the inverters. All necessary additional power cables and electrical equipment (power switches, fuses, relays) were purchased and prepared for shipping.

One man from each team spent as much time as necessary to learn how to perform a complete acceptance test on the Astrodata Digital system. One complete set of spare digital cards and a tape deck were taken to CTA and FBK to repair the digital recorders at those sites. Prior to the maintenance trips, the digital systems at CTA and FBK were inoperative while the header data on the recorder at EIL was incorrect. By the end of the maintenance trips to these three stations, all three digital recorders were working properly.

It had become apparent that most of the failures of the digital recorders incurred since the initial installation of the high-gain stations were a result of the station voltages being either too low or not sufficiently regulated, and repeated failures of the station power (especially at CTA and CHG). Thus, in addition to the uninterruptable power units which were installed at all the sites, new power lines and transformers were installed at CTA and CHG. The uninterruptable power unit, described in more detail in the High-Gain Long-Period Seismograph Station Instrumentation Report (Lamont, 1971), consists of an inverter, battery charger, battery rack, and 20 six volt batteries. Standard tests of the seismograph systems at each site were performed. These tests included redetermination of seismometer and galvanometer free periods, damping characteristics, current sensitivities, and absolute frequency responses of the low and high-gain outputs of the three component systems. Copies of the absolute frequency response determined at that time were forwarded to Texas Instruments and the Seismological Data Center in Asheville, North Carolina, for distribution to users of the high-gain data.

The maintenance teams at CTA and CHG also installed microbarographs and anemometers, obtained at no cost to this contract. Data from these instruments are being used in the study of long-period earth noise at those two sites.

Failure of the Cipher tape decks in the digital recorders at FBK on 22 August 1971 and TLO on 15 September 1971 necessitated special maintenance trips of approximately one week duration to each site. The FBK system was repaired on 30 October 1971 and the TLO system on 5 November 1971. Since these respective times both digital systems have been operational.

The digital recorder at CTA failed for the second time on 29 August 1971. At that time we contacted a digital technician based in Townsville, Australia, to service the CTA system. As of 15 March 1972, after many attempts, he was unable to repair the CTA recorder. Thus arrangements were made to ship a complete new digital unit from Lamont to CTA. We expect this station to be digitally operational by 15 April 1972.

On 26 December 1971, the digital technician from Townsville, Australia, was sent to Chiang Mai, Thailand, to work on the digital recorder at that site, CHG, which has been out of operation since 1 May 1971 . He was successful and CHG has been digitally operational since 1 January 1972.

Lamont personnel had, during the time period requested, sent instructions and replacement parts for many tests to be carried out on the digital recorder by personnel responsible for the routine maintenance of the seismic equipment at CHG. All of these attempts were unsuccessful. In fact, it is now evident that station operators at most of the sites, although proficient in their maintenance of the seismograph systems, cannot cope with the complexities of the digital recorders. For this reason we have attempted to contact qualified digital technicians in Spain, Israel, and Thailand who can service the digital recorders in those countries. We feel that this is the most efficient way to maintain these systems.

II. INSTALLATION OF THE STATION AT TOLEDO, SPAIN

During the time period 15 July to 17 August 1971, installation of the sixth high-gain station was completed at Toledo, Spain. This station is equipped with a digital recorder and an uninterruptable power unit. The high-gain station is located in a newly excavated tunnel about 4 km from the Toledo Geophysical Observatory. Personnel from the Toledo Observatory, under the direction of Dr. Gonzalo Payo, are responsible for the daily maintenance and record changing of the high-gain station. Peak recording magnifications obtained at this station are: for the vertical 70k at 40 sec; E/W 36k at 47 sec; N/S 36k at 40 sec. The three letter code for this site is TLO. A detailed installation report covering this station is in preparation (Cory, 1972).

III. DATA

Seismograms from OGD, CTA, CHG, FBK, TLO and EIL are sent to Lamont-Doherty and records from KON and ALQ to NOAA at Albuquerque, New Mexico, for quality control. After approximately two to three weeks the seismograms are normally forwarded to the Seismological Data Center in Asheville, North Carolina, to be film chipped (70 mm negatives). Recently, the seismograms have been sent to the VELA Seismological Center in Washington, D.C. for review before going to Asheville. The 70 mm film chips are available to all interested parties at normal costs. Table 1 is a summary of the availability of film chips and the status of seismograms as of 1 April 1972.

Magnetic tape data are received at Lamont from most of the high-gain stations normally about two to four weeks after the data are recorded at the various stations. Within seven days of receipt at Lamont, the tapes are edited, checked for errors, copied, and forwarded to Texas Instruments in Alexandria, Virginia. Portions of each tape copied at Lamont are inspected for quality control on a cathode ray tube. Any problems that are observed result in instructions sent via cable or telephone to the stations for tests of various components of the Astrodata systems. Table 2 summarizes the status of magnetic tapes received at Lamont from the high-gain stations as of 1 April 1972.

IV. RESULTS OF THE DATA ANALYSIS

A. Detection Thresholds for Surface Waves

Analysis of seismograms from the high-gain stations at Charters Towers, Australia (CTA); Fairbanks, Alaska (FBK); Chiang Mai, Thailand(CHG); and Ogdensburg, New Jersey (OGD), for the ultimate detection levels of body and/or surface waves from shallow events was completed. Recordings for approximately 1000 events, reported in the Preliminary Determination of Epicenters (PDE) monthly listings published by NOAA, in the magnitude range of m_b 3.3 to 6 were visually inspected for the presence of seismic waves. An event is considered as detected if body and/or surface waves are observed. Amplitude and period measurements were also taken and will be used in a separate M_s-m_b study of world-wide events.

The results of this study are presented in Figure 1. The numbers on this map represent the smallest values of body wave magnitude for events from which surface waves were observed 100% of the time. Because of the limited number of earthquakes occurring within the available recording times (5 to 6 months) from CTA, FBK, and CHG, recordings from FBK were used to determine thresholds for events in central Alaska, the Gulf of Alaska, the Aleutians, and the Kuriles-Kamchatka regions; CHG for Hokkaido, Honshu, Ryukyu, and the Mid-Indian Rise; and CTA for the remaining regions of the western Pacific, the Easter and South Sandwich Island regions. Approximately 2 1/2 years of seismograms from OGD were used to determine values for all the remaining regions.

The magnitudes for those events in the Gulf of California, southern California, Nevada, and the Vancouver Island region were determined using Evernden's (1971) magnitude relationships and P wave amplitudes and periods given in the Earthquake Data Reports published by NOAA. All other magnitudes were computed using the Gutenberg-Richter (1956) formula.

It is important to note that in many regions we are able to occasionally observe surface waves from events with magnitudes as much as 0.5 units less than the 100% value in the same region (e.g., m_b 3.7 events in Vancouver observed at OGD). In addition, in most cases, surface waves with periods between 30 and 40 seconds are observed from the smallest events studied, m_b=3.6 at 5 to 10° from FBK; m_b=3.3 for the Gulf of California seen at OGD about 35° away.

Another important observation is that for events in the western United States, Love waves can often be seen on the N/S high-gain component seismograms written at OGD even though Rayleigh waves are not observable. A paper describing the results of this study, Rynn et al. (1972), will be submitted to the Journal of Geophysical Research for publication.

B. Detection Capabilities of 8 High-Gain Stations versus the WWNSS

A detailed investigation of seismograms from all eight high-gain stations for the time period 8 September 1971 to 15 September 1971 (inclusive) was undertaken to compare the number of earthquakes recorded at these eight stations with the number reported by NOAA in the monthly listings of the PDE. While long-period surface waves, of both the Rayleigh and Love type, are the primary type of seismic wave that the high-gain detection results are based on, events are reported in the PDE listings on the basis of the recording of short-period body phases at at least a few of the stations of the WWNSS. The results are shown in Figure 2 in the form of a histogram.

The numbers inside the hatched (lower) sections in Figure 2 refer to the number of earthquakes reported in the PDE and observed at the station indicated; the solid sections refer to the number masked at a particular station; and the stipled sections to the number of unreported events observed at a particular high-gain station. Of the 103 reported events (the hatched section of the column designated WWNSS), 79 were recorded on one or more of the seismograms from the eight stations as indicated in the column adjacent to that for the WWNSS. Of the remaining 24 reported earthquakes, 15 were definitely not observed at any of the high-gain stations. Six of these 15 events were assigned focal depths greater than 100 km, 6 others were not assigned any body-wave magnitudes, and the remaining 3 were assigned magnitudes less than 4.0 and occurred at distances greater than 25 to 30° from the closest high-gain station.

The number of events observed on the combined high-gain seismograms but unreported by NOAA is 73. This gives a total of 152 events observed during this time period or approximately 20 per day. During this same time period short-period body phases from 197 events were reported in the bulletin from the Large Aperture Seismic Array (LASA) in Montana. Note that we cannot compare these numbers with one from the PDE program since many of the earthquakes that are detected at a few isolated stations of the WWNSS are not located and thus go unreported. For this reason the number of unreported, but detected, events for the WWNSS is left open-ended. To be sure it is in excess of the total number observed on the high-gain seismograms and probably also the number reported in the LASA bulletin.

The number of NOAA-reported earthquakes with surface wave trains masked by the coda of larger events is 9 for the combined seismograms from all eight high-gain stations. This number is not greatly different from the numbers of masked events at any one station and points up one of the most important problems with the detection of long-period surface waves from shallow events. While more sophisticated analysis techniques than the visual one employed in this study would probably identify some of these masked events, it remains to be seen how successful these techniques will be in routine practice. Notice, however, that the number of surface waves (79+73=153) detected on the combined high-gain seismograms is about double the number detected by a single high-gain station.

C. Long-Period Earth Noise

A preliminary investigation of the spectral shape and level of background noise in the period range 10 to 100 sec recorded at seven of the high-gain stations was completed. Both vertical and horizontal noise spectra, based on approximately 4 hours of data recorded on the digital systems, were computed for each site.

In Figure 3 the vertical noise spectra for all the sites are shown for purposes of comparison. These spectra are not corrected for instrument response but are plotted at the correct absolute level at 40 sec. Two very important results based on the data in Figure 3 are:

1. There is a pronounced minimum in earth noise between 30 and 40 seconds at these six widely separated sites. Note also that the amount of overburden at these sites varies from 0 m at CHG to 543 m at OGD. This same result applies to the horizontal components of earth noise at these sites.

2. The absolute level of this noise minimum is the same at all six sites to within 10 db.

These two results indicate that the period range 30 to 40 sec can be used as a window for observing surface waves from small magnitude events (Section IVa). As Molnar et al. (1969) and Savino et al. (1971) have shown, the M_s-m_b discriminant between earthquakes and underground explosions is more effective when M_s is based on the amplitudes of surface waves with periods near 40 sec, rather than 20 sec.

A further important result of the study of noise is that the shape and level of the vertical and horizontal noise spectra, at those high-gain sites with appreciable overburden (EIL, 200 m and OGD, 543 m), are the same over the entire passband, 10 to 100 sec. Also, in contrast to horizontal noise levels at those stations with appreciably less overburden, the horizontal noise levels at EIL and OGD have not been observed to undergo diurnal or short-term (a few days or less) aperiodic variations.

The results of this study have been written up in a paper entitled "Preliminary Observations on Long-Period (10 to 100 sec) Seismic Noise at Several Worldwide Locations" by A. Murphy, J. Savino, J. Rynn, G. Choy, and K. McCamy, and submitted to JGR for publication.

D. Digital Filtering

The results discussed in section IVA and B were based on visual analysis of the high-gain seismograms and indicate that these seismograph systems are very effective monitors of world-wide seismicity. Any further enhancement of the signal-to-noise ratio of the small signals recorded on these systems would represent an important improvement in the detection capabilities of these stations and the applicability of the very effective M_s-m_b discriminant to small magnitude events. Two digital filtering techniques, that seem to provide such signal enhancement, are presently being developed at Lamont.

These techniques were briefly discussed by Savino et al. (1972b) and will be described in more detail in a forthcoming paper by Choy and McCamy (1972).

Both digital filters are time varying adaptive filters since their transfer functions are shaped to pass frequency bands where the signal-to- noise ratio is momentarily high. One of these filters, a polarization type, is used to enhance Rayleigh waves of small amplitude with periods between 20 and 50 seconds. The transfer function for this filter depends on the relative phase spectrum between the vertical and the horizontal components of ground motion. In this way, the seismic data can be filtered to suppress all but quadrature polarization thereby passing only Rayleigh waves. This filter, applied to the digital data recorded at the various high-gain stations, has consistently resulted in an enhancement of signal-to-noise of at least 6 db for surface waves from small magnitude events.

The second filter, an azimuthal type, is used to enhance Love waves and is designed to pass energy approaching a station from a particular azimuth. This filter is especially well suited for detecting Love waves from small events that are masked by surface waves from larger magnitude events. In some cases, the enhancement is dramatic, as much as 14 db.

Since both of these time varying filters have a built-in strategy of signal enhancement, they perform better than passive techniques such as band-pass or matched filtering. Our experience has been that the earthquake signature as recorded is not really broad band at periods longer than 30 to 50 sec and, hence, makes an unsatisfactory matched filter. Signal enhancement by matched filtering using either the surface wave train or the entire event is poor. In some cases, the result scarcely exceeds the signal-to-noise ratio of the original seismogram. Bandpass filtering passively rejects both signal and noise. At the present time, both the polarization and the azimuthal filter are being applied to surface waves from small magnitude earthquakes and explosions recorded digitally to assess the ultimate detection capabilities of the high-gain station.

E. Discrimination Between Earthquakes and Presumed Underground Explosions in Central Asia

Previous results from a high-gain station on the M_s-m_b discriminant between earthquakes and underground explosions in different regions of the world were reported by Molnar et al. (1969), Evernden et al. (1971) and Savino et al. (1971). These earlier studies were based on data recorded at OGD. In this section we will concentrate on results from one of the more recent stations, that at Eilat, Israel. This station is approximately 30° from presumed Russian underground explosions and exhibits a lower detection threshold for surface waves from these presumed explosions and earthquakes in the same general region than the stations at Chiang Mai, Thailand (CHG); Konsberg, Norway (KON); and Toledo, Spain (TLO).

In Figure 4, peak-to-peak amplitudes of Rayleigh waves recorded at Eilat with periods near 20 sec (left-hand plot) and 40 sec (right-hand plot) from earthquakes in the Kirzig-Sinkiang-Tadzhik-Tibet region (closed circles) and presumed Russian explosions (open circles) are plotted as a function of m_b (NOAA). The ordinate on the 20 sec plot describe the M_s scale for these events as indicated by the numbers and arrows. Although the data are limited there are two rather important points about Figure 4. Firstly, the earthquake and explosions populations are completely separated even though the measurements are restricted to a single station. Secondly the two populations do not show any sign of convergence at the low magnitudes. This latter result is similar to that found at OGD for earthquakes and explosions in the western United States, the Aleutians, and the Novaya Zemlya region (Molnar et al., 1969; Savino et al., 1971).

While the detection threshold for surface waves from the presumed explosions (Figure 4) is rather high, about m_b 5.5 or M_s 3.2, it is important to note that these results are based on visual analysis of seismograms only. The digital filtering techniques described in the previous section should improve the threshold value at this station.

F. Detection of Air Waves

Acoustic-gravity waves from an event on 14 October 1970, presumed to be a Chinese atmospheric explosion, were observed on high-gain vertical and horizontal component seismograms written at three different locations in the world. Reliable group velocity data for the atmosphere over propagation paths as long as 97° (10,800 km) were obtained for the period range of 30 seconds to 375 seconds. These data are in agreement with theoretical dispersion curves that are based on the COSPAR-model atomsphere with the effects of winds included. Seismic body and surface waves from this atmospheric event were also recorded at the three stations and were used to determine an epicenter. On 14 April 1971, slow speed gravity waves from another pressure disturbance of meteorological origin were observed with periods between 240 seconds and 360 seconds on seismograms at Ogdensburg, New Jersey. The seismic recordings of the acoustic-gravity and the slow speed gravity waves are attributed to ground motion produced by surface loading and not to direct pressure effects on the instruments. The observed displacements and tilts from both events are in agreement with those predicted by static loading theory. At the Ogdensburg station, the rock layer above the instruments (543 m) acts as a wavelength filter suppressing wind noise of short wavelength while passing signals from long wavelength (coherent) disturbances in the atmosphere. A paper (Savino and Rynn, 1972) describing these results was submitted to the Journal of Geophysical Research for publication.

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TABLE 1

STATUS OF HIGH-GAIN FILM CHIPS AND SEISMOGRAMS

AS OF 1 APR 1972

STATION NAME;NO	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
701- FBK	1971	X	X	X	X	STATION DOWN			X	**	**	**	**
726- CHG	1971	X	X	X	X	X	X	X	X	*	*	*	*
731- CTA	1971	X	X	X	X	X	X	X	X	*	*	*	*
734- EIL	1971	X	X	X	X	X	X	*	*	*	*	NOTE	
782- OGD	1971	X	X	X	X	X	X	X	X	*	*	*	*
755- KON	1971									X	X	X	**
707- ALQ	1971											X	X
TLO	1971								*	*	*	*	*
STATION NAME;NO	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
701- FBK	1972	**											
726- CHG	1972	**											
731- CTA	1972	**	**										
734- EIL	1972	NOTE											
782- OGD	1972	**	**										
755- KON	1972	**	**										
707- ALQ	1972	**	**										
TLO	1972	*											

X Chips Available

** Records sent to VELA Seismological Center, March 1972, to be forwarded to Asheville

* Records sent to VELA Seismological Center, February 1972, to be forwarded to Asheville

NOTE No data received from EIL since Oct. 1971

TABLE 2

THE STATUS OF HIGH-GAIN MAGNETIC TAPES FROM JAN '71 TO APR '72

(OGD) OGDENSBURG, NEW JERSEY

DATE	TAPES	CONDITION	DATE	TAPES	CONDITION
JAN 4	004-018	* GOOD DATA	OCT 1	274-281	GOOD DATA
	019-033	" "		281-289	" "
FEB 2	033-037	" "		289-298	" "
	042-057	" "		298-307	" "
	057-060	" "	NOV 3	307-316	" "
MAR 2	061-064	" "		316-324	" "
	064-072	" "		324-333	" "
	072-079	" "		333-333	TEST TAPE
	079-086	" "		333-335	" "
	086-093	" "	DEC 7	335-341	GOOD DATA
APR 3	093-098	" "		341-348	" "
	098-105	" "		348-354	" "
	105-112	" "		354-361	" "
	112-119	" "		361-003	" "
	119-126	" "	JAN 3	003-010	" "
MAY 6	126-132	" "		010-018	" "
	132-140	" "		018-025	" "
	140-147	" "		025-032	" "
	147-154	" "	FEB 1	032-039	" "
JUN 3	154-162	" "		039-046	" "
	162-168	" "		046-053	" "
	168-175	" "		053-060	" "
	175-184	" "	MAR 1	060-067	" "
JUL 3	184-191	" "		067-074	" "
	191-207	" "		074-081	BAD DATA
	207-215	" "		081-088	" "
AUG 3	215-224	" "		088-094	" "
	224-233	" "	APR 3	094-095	TEST TAPE
	233-242	" "			
	242-251	" "			
SEP 8	251-260	" "			
	260-262	" "			
	263-270	" "			
	273-273	TEST TAPE			

TABLE 2 (cont.)

(KON) KONSBERG, NORWAY

DATE	TAPES	CONDITION
SEPT 7	250-262	* GOOD DATA
	262-276	" "
OCT 3	276-292	" "
	292-305	" "
NOV 1	305-319	" "
	319-333	" "
	333-347	" "
DEC 13	347-361	" "
	361-003	" "
JAN 6	006-019	" "
	020-034	" "
FEB 3	034-046	" "
	046-063	" "

(TLO) TOLEDO, SPAIN

DATE	TAPES	CONDITION
AUG 17	229-244	* GOOD DATA
SEPT 1	244-252	" "
	253-261	" "
NOV 6	310-311	" "
	314-325	BAD DATA
	326-340	GOOD DATA
DEC 6	340-354	" "
	354-003	" "
JAN 3	003-017	" "
	017-031	" "
	031-045	VARIED DATA
FEB 14	045-059	VARIED DATA

TABLE 2 (cont.)

(CHG) CHIANG MAI, THAILAND			(FBK) FAIRBANKS, ALASKA		
DATE	TAPES	CONDITION	DATE	TAPES	CONDITION
JAN 2	023-031	* GOOD DATA	JAN 21	021-025	*GOOD DATA
FEB 1	032-045	" "		025-040	" "
MAR 20	079-092	" "	FEB 9	040-056	" "
APR 3	093-106	" "		056-072	" "
	107-120	" "	MAR 13	072-088	" "
MAY 1	121-134	" "		088-094	" "
	135-148	" "	APR 14	104-109	" "
	149-155	" "	AUG 8	220-236	" "
OCT 20	293-304	BAD DATA	OCT 30	303-314	" "
NOV 1	305-314	" "	NOV 10	314-330	" "
	315-324	" "		330-346	" "
	325-334	" "	DEC 12	346-362	" "
DEC 1	335-345	" "		362-015	" "
	345-355	" "	JAN 15	015-031	" "
	355-362	" "		031-047	" "
JAN 1	001-010	GOOD DATA	FEB 16	047-063	" "
	011-021	" "		063-079	" "
	022-031	" "			
FEB 1	032-045	" "			

TABLE 2 (cont.)

(CTA) CHARTERS TOWERS, AUSTRALIA

DATE	TAPES	CONDITION	DATE	TAPES	CONDITION
JAN 7	007-023	* GOOD DATA		038-050	BAD DATA
	023-044	BAD DATA		050-051	TEST TAPE
FEB 13	044-061	" "		051-060	BAD DATA
MAR 3	062-078	" "	MAR 1	061-071	" "
	078-091	" "			
APR 2	092-094	TEST TAPE			
	094-110	BAD DATA			
	110-127	" "			
MAY 18	138-150	" "			
	151-163	" "			
JUN 18	169-178	" "			
JUL 6	187-197	GOOD DATA			
	197-209	" "			
	209-217	BAD DATA			
AUG 5	217-226	" "			
	226-235	GOOD DATA			
	235-245	" "			
SEP 3	246-255	" "			
	256-265	BAD DATA			
	265-275	" "			
OCT 2	275-285	" "			
	286-292	" "			
	300-309	" "			
NOV 6	310-321	" "			
	321-333	" "			
	333-344	" "			
DEC 11	345-356	" "			
	356-002	" "			
JAN 3	003-014	" "			
	014-022	" "			
	023-023	TEST TAPE			
	023-025	" "			
	025-035	BAD DATA			
FEB 7	038-038	TEST TAPE			

(EIL) EILAT, ISRAEL

DATE	TAPES	CONDITION	DATE	TAPES	CONDITION
JAN 7	007-023	* GOOD DATA			
	023-039	" "			
FEB 8	039-055	" "			
	056-072	" "			
MAR 14	073-088	" "			
	088-104	" "			
APR 14	104-120	" "			
	120-136	" "			
MAY 16	136-147	" "			
JUN 2	153-164	" "			
	169-174	" "			
	178-195	BAD DATA			
JUL 14	195-210	GOOD DATA			
	210-226	" "			

* GOOD DATA: "Majority" of data on tape is good.
(Less than 5% of records on tape are bad.)

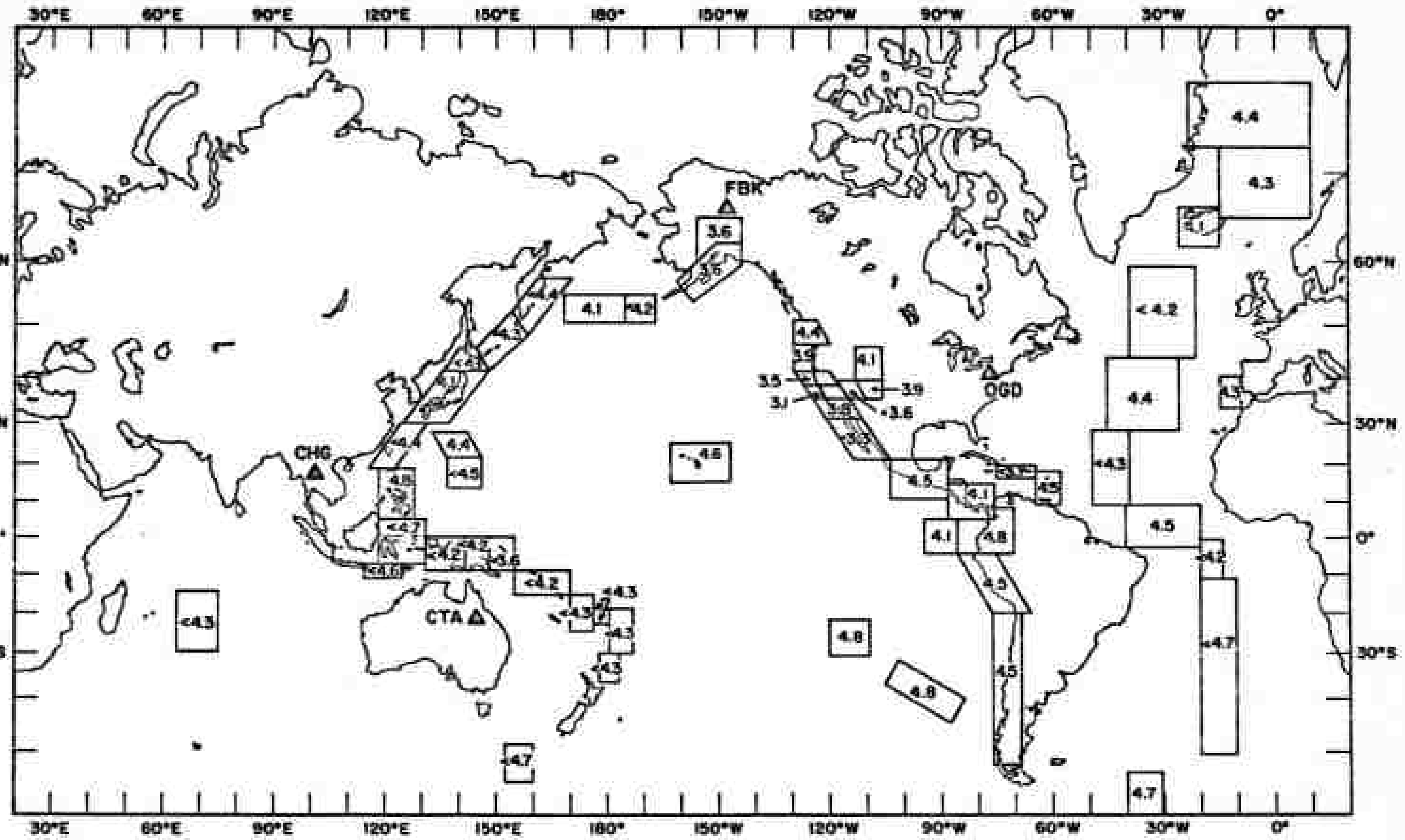
FIGURE CAPTIONS

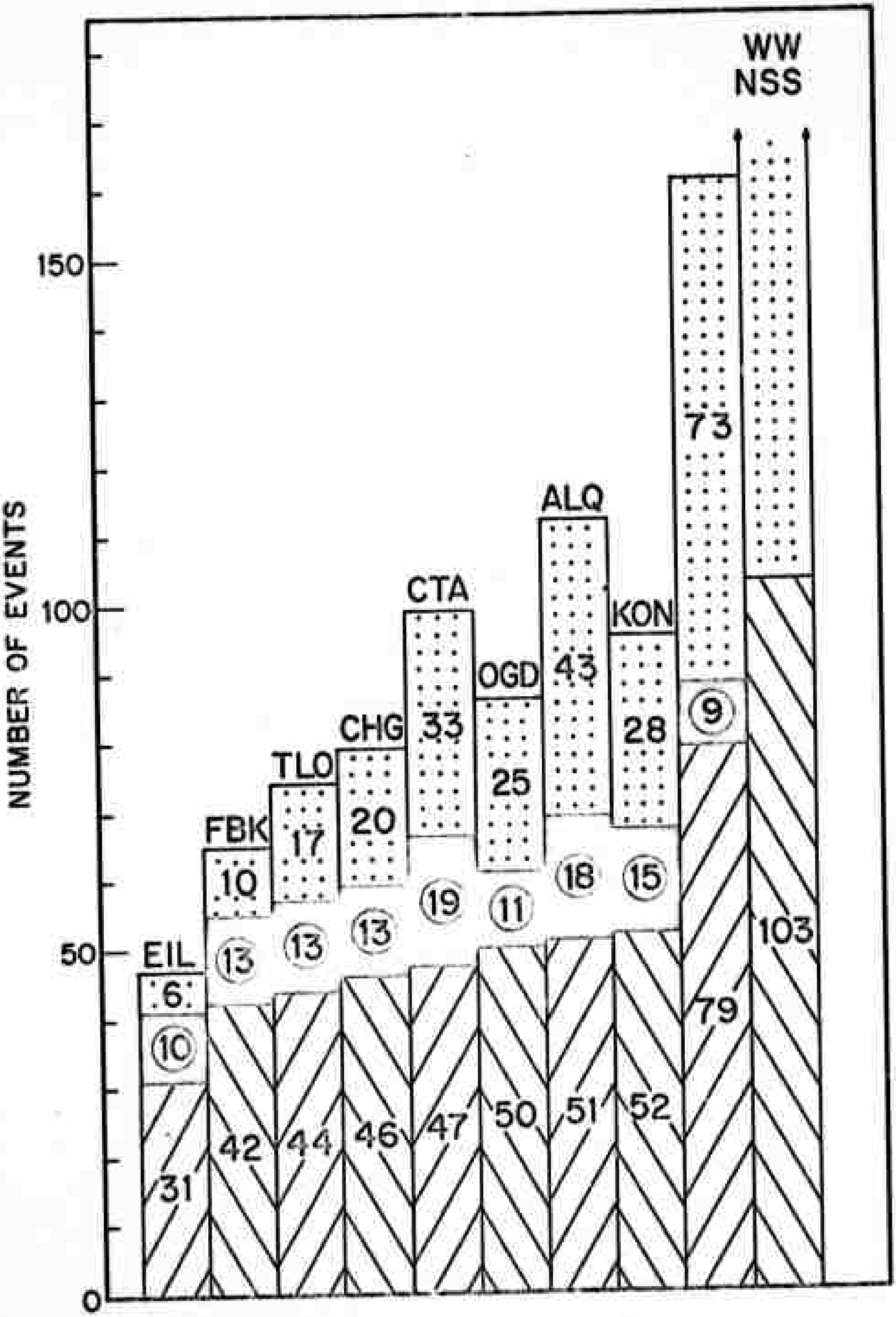
Figure 1. Map of the world showing the locations of four of the high-gain seismograph stations (solid triangles) and the smallest magnitude events for which surface waves were observed 100% of the time at one of the four sites: FBK, CTA, CHG, and OGD as listed in the text.

Figure 2. Histogram comparing the detection capabilities of the high-gain stations with that of the WWNSS.

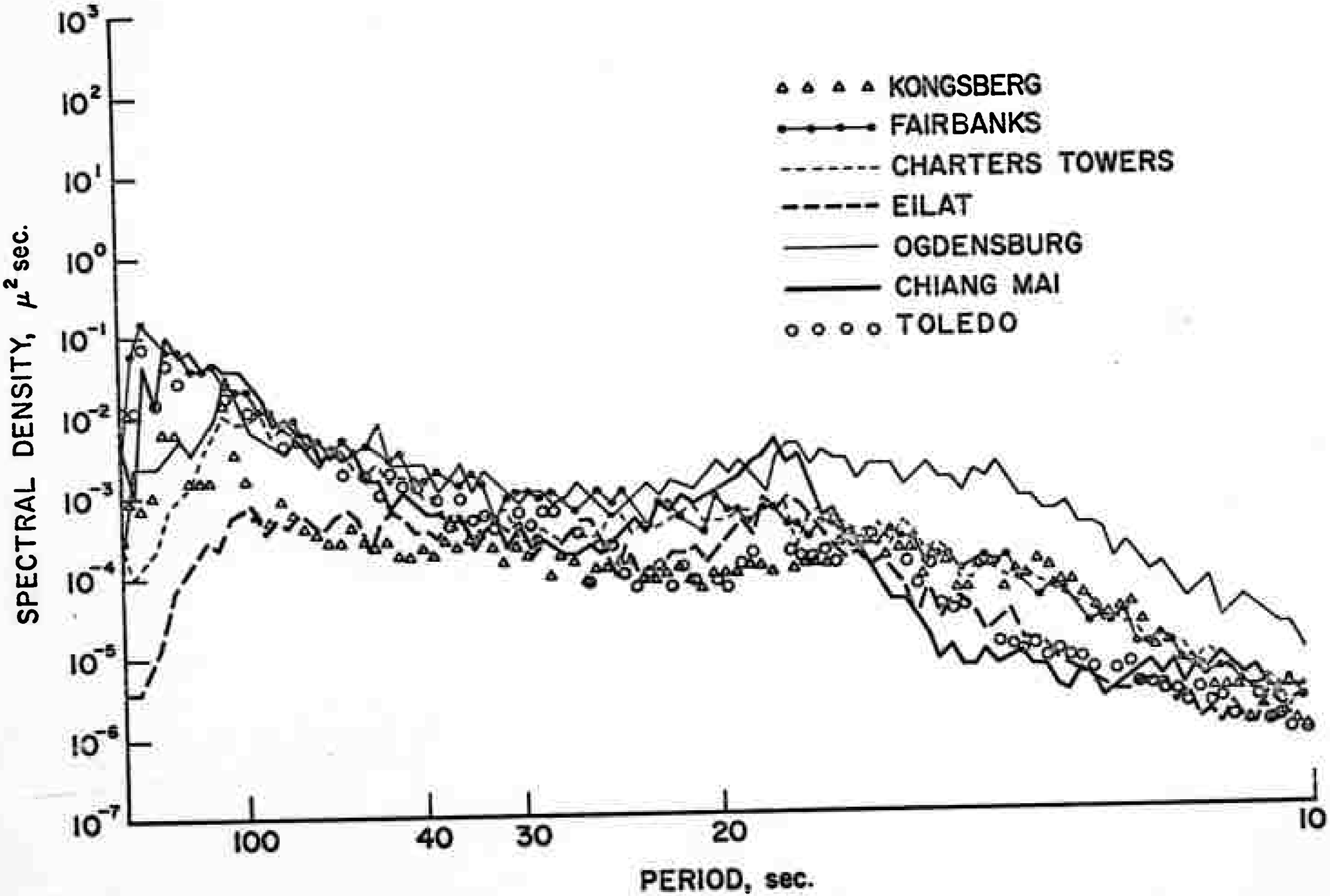
Figure 3. A comparison of vertical noise spectra computed for seven of the high-gain stations. These spectra are not corrected for frequency response but are plotted at the correct 40 sec noise level.

Figure 4. M_s-m_b and 40 sec (Rayleigh waves) for earthquakes in the Kirzig-Sinkiang-Tadzhik-Tibet region (closed circles) and presumed Russian explosions (open circles). All of these measurements were taken from seismograms from the station at Eilat, Israel. Note the pronounced separation of the two populations.

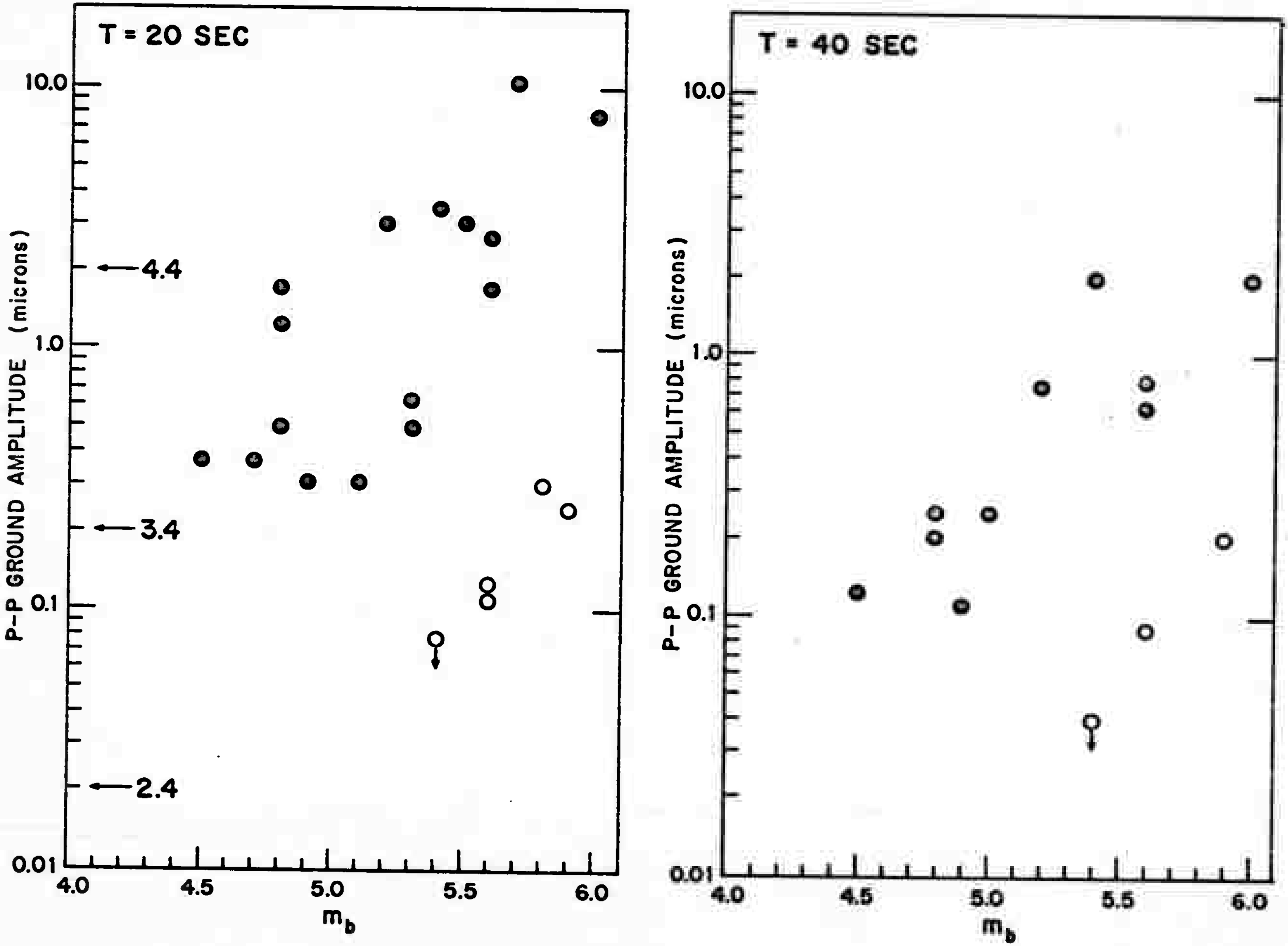

30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
60°N
30°N
0°
30°S
FBK
OGD
CHG
CTA
3.6
4.1
4.2
4.4
4.3
3.5
3.1
3.9
3.6
4.6
4.5
4.8
4.7
4.2
<4.3
<4.2
<4.7
3.6


NUMBER OF EVENTS
0
50
100
150
EIL
6
10
31
FBK
10
13
42
TLO
17
13
44
CHG
20
13
46
CTA
33
19
47
OGD
25
11
50
ALQ
43
18
51
KON
28
15
52
73
9
79
WW
NSS
103

27



SPECTRAL DENSITY, μ^2 sec.
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
KONGSBERG
FAIRBANKS
CHARTERS TOWERS
EILAT
OGDENSBURG
CHIANG MAI
TOLEDO
100
40
30
20
10
PERIOD, sec.


T = 20 SEC
P-P GROUND AMPLITUDE (microns)
10.0
1.0
0.1
0.01
4.4
3.4
2.4
4.0
4.5
5.0
5.5
6.0
m_b
T = 40 SEC
P-P GROUND AMPLITUDE (microns)
10.0
1.0
0.1
0.01
4.0
4.5
5.0
5.5
6.0
m_b