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FINAL REPORT

**SOURCE CHARACTERIZATION OF SELECTED
NORTH CASPIAN EVENTS
FROM THE RELATIVE EXCITATION
OF REGIONAL PHASES**

MASTER

Submitted to

Lawrence Livermore National Laboratory
P.O. Box 808
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Subcontract 2458001

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November 1981

B-81-306

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ABSTRACT

Seismograms of seven recent events (presumed explosions) which occurred during 1976-1979 in the North Caspian Sea region of the western Soviet Kazakh are compared at regional distances for their relative source excitation characteristics. The body wave magnitude estimates of these events range from 5.1 to 6.0. The data consist of analog and digital records collected at stations ranging in instrumental sophistication from temporary sites with single component smoke drum capability to those of SRO, ASRO and array (ILPA) configurations with digitally recorded down-hole observations.

The amplitude and frequency measurements of the analog seismograms for the first arrival and the peak amplitude of P coda as well as for the clear S wave signals recorded for different events at the same station are compared. Because of the similarity of the propagation paths and instrument site response for each recording station, the observed differences in the strength and frequency characteristics of the signal can safely be ascribed to the source. The insufficient signal-to-noise ratio renders the first amplitudes of the arrival on the analog records insensitive to small variations of the event magnitudes. The peak amplitude of the P coda, usually recorded within the first 10 seconds of the record, instead offers a more consistent parameter for the scaling purpose. Discernable variations in the overall frequency characteristics of the seismograms are noted for at least one of the events. The observed M_S - m_b relation for a limited number of M_S estimates further supports this distinction.

The spectral analyses of the digital data provide similar comparisons in the frequency domain. These comparisons are again made for both body and surface waves of different events at the same observation point. Only short period body waves are analyzed. Before the analysis of surface waves, seismograms were rotated and group velocity windowed. Because Kabul (KAAO) station furnished the most complete set of digital data for this study, the spectral amplitudes obtained at other stations are often compared with those of KAAO. In most cases the spectra are found to have the same shape differing in relative strength only. The latter was found to scale generally with peak amplitudes. However,

for some events the spectra indicate relative enrichment of low frequency or depletion of high frequency bands. In particular the inferred source spectrum of the December 18, 1978, appears different for both body and surface wave observations. These observations are best explained by a substantial reddening of corner frequency resulting from the longer source time characteristics of this event.

Two of the three short period vertical seismograms available at ANTO ($\Delta = 13.5^\circ$) show clear high frequency PcP arrivals. The unprecedented observations of this phase at such close-in distances may provide further means of source diagnostics for this region.

1.0 INTRODUCTION

The main objective of the project was to conduct a study of the seismograms of seven selected events (presumed underground nuclear explosions) in the North Caspian region of the western Soviet Kazakh (Azgir) recorded by regional stations. These events were examined for possible inferences as to their source characteristics. The hypocentral parameters of the events as listed by ISC and NEIS are given in Table 1. A search conducted on the NEIS Earthquake File for other seismic sources in the region extending from 45 to 55 degrees North and from 45 to 55 degrees East during the recording period of this study (1976 through 1979) led to a negative result. The recording stations used for this study are generally within a 20-degree distance range. A listing of these stations is given in Table 2. The distribution of the selected stations with respect to the source region is shown in Figure 1. The level of instrumental sophistication of recording systems varies considerably. They include five single-component semiportable seismographs with smoke-paper or ink-pen drum recorder, five WWSSN stations, three SRO and ASRO observatories and one seven-element array system. The SRO and ASRO records are available both in analog form on microfiche copies and in digital form on magnetic tapes. The ILPA array records are available in digital form at selected array elements. The restrictions imposed by nonuniformity of station characteristics did not in any way constrain the principal objective of the study, which places its emphasis on relative excitation features of the selected sources. The number of stations from which seismograms were studied for individual events varied between four and nine. The smallest number of data belong to the most recent event for which no WWSSN records had yet become available. Although the request for the seismograms of the locally run stations met with only limited success, the several available seismograms of this category which were analyzed revealed in a qualitative manner the same characteristic features which were obtained from more elaborate analysis of the digital data.

The study is conducted along two lines and hence is reported in two main parts. The first part is concerned with the measurements of the arrival times, amplitudes and frequency characteristics of signals recorded on local and

TABLE I

HYPOCENTRAL PARAMETERS OF THE SELECTED EVENTS

No.	Code	Date	Origin Time (GMT)	North Latitude (°)	East Longitude (°)	Depth (km)	m_b	M_s	Source*
1	284	19760729	04 59 58.0	47.81	48.10	0	5.9	4.4 3.9	ISC NEIS SHI
2	285	19770930	06 59 55.9	47.85	48.13	0	5.0 5.1		ISC NEIS
3	288	19781017	04 59 56.6	47.81	48.09	0	5.8	4.5 4.6	ISC NEIS
4	290	19781218	07 59 56.3	47.78	48.14	0	5.9 5.8	5.2 4.6 4.8	ISC NEIS KBL
5	292	19790117	07 59 55.8	47.87	48.06	0	6.0	4.6 3.8-4.1** 4.2	ISC TAB KBL
6	320	19790714	04 59 55.1	47.81	48.10	0	5.6		NEIS
7	321	19791024	05 59 56.6	47.81	48.16	0	5.8	3.9	NEIS KBL

* Station codes in this column indicate the observation points for our M_s estimate.

** Calculated from the modified attenuation relation (Evernden, 1971).

TABLE 2
LIST OF SEISMOGRAPHIC STATIONS

Code	Location	North Latitude (°) (') (")			East Longitude (°) (') (")			Elevation (m)	Approx. Distance (°)	Approx. Azimuth (°)	N. Comp.	Type	Time Cor. (sec)
TBZ	Trabzon	40	59	40.0	39	46	34.0	57	9	224	3	SP	+0.1
ERZ	Erzurum	39	54	54.0	41	16	36.0	1,850	9	215	1	SP	
TAB	Tabriz	38	04	03.0	46	19	36.0	1,430	10	188	6	WWSSN	-1.8
IRI	Qazvin	35	42	10.1	50	36	32.0	1,305	12	171	4	ILPS	+1.0
SHD	Shahrud	36	26	00.0	54	56	30.0	1,500	12	154	1	MEQ	+1.8
MAIU	Mashad	36	18	30.0	59	28	18.0	1,000	14	140	4-6	SRO/WWSSN	+2.6
ANTO	Ankara	39	54	00.0	32	47	00.0	732	14	240	4	SRO	
IST	Istanbul	41	03	56.0	29	03	33.0	132	15	251	6	WWSSN	+2.5
KHI	Kakhk	34	08	36.0	56	38	30.0	1,600	16	146	1	MEQ	0.0
TGI	Taghi-Ghambar	32	57	48.0	59	11	36.0	1,800	17	147	1	MEQ	-0.6
SHI	Shiraz	29	38	18.0	52	31	12.0	1,596	18	168	6	WWSSN	+0.2
KAAU	Kabul	34	32	27.0	69	02	35.0	1,920	20	123	4-6	ASRO/WWSSN	-1.1
SHIO	Shillong	25	34	00.0	91	53	00.0	1,600	41	107	4	SRO	-0.2

MEQ = Sprengnether MEQ 800

SP = unspecified short period sensor such as the Kinometrics Ranger, Geotech S13, etc.

FIGURE 1

WWSSN records. The results are presented in the form of propagation speed, and amplitude variations of recorded signal at individual stations. The latter group points to the relative magnitude of the studied event as sensed by individual stations. Several estimations of surface wave magnitude from WWSSN long-period vertical components have been made. These magnitudes and the stations at which they were recorded are also listed in Table I. For convenience, in Table I the events are also referred to by their sequential code numbers used by Seismic Data Analysis Center, Alexandria, Virginia.

In the second part, the spectral analysis of the digitally recorded signals at the SRO, ASRO and ILPA stations is performed. The most complete suite of records available for the selected events is recorded at KAAO. A complete analysis of both short and long period records at KAAO, therefore, constitutes the core of our spectral analysis, and the results are frequently used as a point of reference for other digital observations. The long period records were rotated into radial and transverse components in order to compare the relative strength of the Rayleigh and Love waves at this and other stations for which both horizontal components were available. No rotation of components was found necessary for ILPA, which lies nearly due south from the source region. The correlation of the observed peak amplitude with spectral amplitudes in different frequency bands was also studied for the digital data, and the results are presented in the final section of the report.

A very interesting feature of the digital records is the clear recording of PcP phase at epicentral distances as short as 13.5 degrees. No direct observation of this phase at such steep angles of incidence has thus far appeared in the literature. Regardless of whether these clear arrivals are due to lower attenuation in the mantle, particularly the upper mantle, to the reflective characteristics of the mantle-core boundary in this region, or to the nature of the sources studied, they may provide a tool for future scaling of underground explosions in the region.

The analysis of the data presented in this report suggests that the relative excitation of the recorded signals in the high and low frequency bands is not

uniform for all the events. Some of the studied events, notably 290, display a relative enrichment of low frequency signal, which suggests different source characteristics in depth, yield or, most likely, the medium of detonation for the event.

2.0 ANALYSIS OF THE ANALOG DATA

2.1 SCOPE

In this section the observations of the travel times, amplitudes and frequency characteristics of regional body waves are discussed. In addition, several M_s estimates are made from the period and amplitude observations of Rayleigh waves on long period records. Because of the diverse quality of seismograms, some of which were written at portable to semipermanent stations with less reliable or only generally known response characteristics, it was found most useful to rely mainly on comparisons of the seismograms recorded for different events at the same station. The limitations due to the differences in station characteristics did not affect the principal objective of the study, which focused on relative excitation features of the selected sources.

2.2 REGIONAL TRAVEL TIMES

Figure 2 shows the epicentral locations of the events as determined by NEIS and ISC. The ISC locations for the two most recent events have not yet been published. The accuracy of these locations is estimated between 1 and 2 kilometers in both latitude and longitude by these two centers. No systematic bias is apparent in relative epicentral locations of individual events calculated by ISC and NEIS, except for slightly more westerly location of ISC epicenters. Much better agreement between the reported origin times as compared to the computed epicentral locations is generally observed. The differences in the reported deviations from the exact hour mark appear to be substantiated by up to two-second delays observed across the whole regional network for some events relative to others, e.g., 285, 292, and 320 relative to 284 (see Table 1).

To combine all the measured phase arrivals in a single set of travel time curves, we adhered to the origin times and hypocentral parameters reported by NEIS. A set of station corrections for the source region of interest was determined by simple averaging of the residuals reported by NEIS and ISC for all seven sources at individual stations and were applied to the measured travel times with a

FIGURE 2
 EPICENTRAL MAP OF THE STUDIED EVENTS
 IN NORTH CASPIAN REGION
 AS DETERMINED BY NEIS AND ISC

negative sign. The station corrections so determined are listed in Table 2. In general, the signs and magnitudes of these station corrections agree with the physiographic and tectonic setting of the station locations. No correction could be determined for ANTO and ERZ stations due to lack of sufficient reporting by NEIS and ISC.

The preliminary analysis of the corrected travel times of the first arrivals suggests slightly different slopes for different azimuthal ranges. The resulting velocity for the southeast profile across the Caspian Sea and northeastern Iran ($\Delta = 12-170^\circ$) is 8.47 km/sec. For the southwest profile across the Caucasus and Black Sea regions ($\Delta = 9-150^\circ$) the average velocity is 8.26 km/sec. From the fewer and somewhat scattered observations of S_n a common curve with a slope of approximately 4.5 km/sec is obtained (Figure 3).

2.3 AMPLITUDE MEASUREMENTS AND BODY WAVE MAGNITUDES (m_b)

The agreement between NEIS and ISC magnitude determinations of the five events for which m_b estimations are given is within 0.1 magnitude unit. The logarithmic variation of the amplitudes of the regional phases at individual stations is expected, generally, to scale with the reported m_b estimates of the events. The measured amplitudes in this study include those of the first half-cycle of the recorded P and the maximum peak in the P coda. The S-wave amplitudes were measured whenever this phase was clearly identified. Consistent Lg observations could not be made in sufficient number to warrant an investigation of Lg amplitude variation. In fact of the limited data available to us, noting also that many of the short period seismograms were incomplete, the only station at which strength of the signal in the 3.3-3.6 km/sec group velocity window for one of the events emerged noticeably above the background is Tabriz ($\Delta = 9.80^\circ$). Extreme scarcity of consistent Lg observations for the present data agrees with previous inferences regarding the inefficiency of Lg propagation across the Caspian and Black Sea basins (Sikharulidze, 1963; Mindeli and Pataraya, 1972; see also Shishkevish, 1979). Also Barazangi et al (1981) in a recent study of regional phases in the Middle East and South Asia concluded that Lg phase does not propagate transverse to the regional mountain belts. These

FIGURE 3
TRAVEL TIMES OF THE REGIONAL PHASES
◦ ARE UNIDENTIFIED PHASES

exclusions greatly reduce the chance of observing Lg phase of the North Caspian events at stations to the south of Soviet border. Nevertheless, it is not justified to categorically deny, on the basis of the limited number of sources, all presumed explosion, the possible usefulness of this phase for source related studies, particularly in the face of contrary results reported by Gupta et al (1980), Barker et al (1981) and Nuttli (1981).

In view of the relatively high values of the observed velocities for the first arrivals, it is not clear to us whether they can categorically be identified as Pn. The range of distances varies from 9 to 20 degrees. While other reports of high Pn velocities along certain profiles in this region have recently been published (Kadinsky-Cade et al, 1981), because of strong suggestions of triplication, particularly at KAAO ($\Delta \approx 20^\circ$; see Figure 9), we refer to these observations as "first arrivals" rather than Pn. The ratio of maximum amplitudes in the P coda to those of first arrivals of different events were compared at each station. The wide range of variation of this ratio (nearly two orders of magnitude) observed for each event, as seen in Figure 4, is partly due to distance variation but mostly because of extremely small amplitude of the first arrivals, which often makes their noise contamination substantial. The majority of the observations are between 10 and 50 on the relative scale of Figure 4. A set of five observations at Kabul which were made on digital SRO records, also shown in Figure 4 by KA, show a relatively stable ratio of 10-14 at $\Delta = 20.5^\circ$.

The maximum amplitude of the P coda often occurs within the first 10 sec of the record and at the distance range of this study may result from the surface reflections or more likely by the near caustics condition resulting from triplications in the travel time. These maximum amplitudes, though more clearly scaled with event magnitudes (Figure 5a), also exhibit considerable scatter. Several factors contribute to the scatter. First, these observations represent the relative strength of the P wave rather than absolute ground motion amplitude. Therefore, they only provide the signal strength of different events at the same station in a relative sense. Secondly, the frequencies of the wave packets containing this maximum amplitude at individual stations differ from event to event as will be discussed in the next section. An improvement in the scatter is

FIGURE 4

RATIO OF MAXIMUM AMPLITUDE OF P CODA
TO THE AMPLITUDE OF THE FIRST ARRIVAL

achieved by applying a normalization procedure which takes into account the shape of the instrumental response (see the appendices) at each station. Thirdly, to consider their correlation with the size of events, i.e., to the estimated m_b , the ratio of the normalized amplitudes to the period of the pulse on a logarithmic scale should be compared. The advantage of this procedure is that, with attenuation factor and instrumental constant being identical at the same station, it provides an unbiased and direct comparison of the strength of the source at short periods. We have used the measured frequencies of $A_{\max}$, denoted by $F_{\max}$ and displayed in Figure 5b, to proceed through normalization and evaluation of the relative levels of $\log (A_{\max}/T_{\max})$ of the ground motion produced by different events at each station. The end results are given in Figure 6. This figure gives the relative excitation of short period P waves, or m_b , of these seven events as recorded by the regional stations used in the study. For comparison, the m_b estimate of each event as determined by NEIS is also given under the graph. With the possible exception of 292, the agreement is fairly good. No record of 292 at SHD is available for a direct comparison with the six other events. However, the TGI record of 292 shows a much weaker signal than was recorded for the 290 event. In Figures 4 through 6, except for WWSSN stations SHI and SKI, the same abbreviations as given in the legend of Figure 4 are used for the recording stations.

FIGURE 6

RELATIVE VARIATION OF $A_{\max}/T_{\max}$ OF THE
EVENTS AT DIFFERENT STATIONS.
THE SOLID CIRCLES BELONG TO
S OBSERVATIONS AT SHD.

2.4 RELATIVE FREQUENCY CONTENT OF SIGNAL

In seismology, estimates of frequency content of the recorded signal are used to obtain information regarding the source dimension and source time function of earthquakes. Earthquake sources, however, are generally located in brittle material with a relatively narrow range of rheological characteristics. The rheology of source material for underground explosions is far more diverse. The ductility factor or relaxation characteristics and the water content of the source medium may produce a recognizable signature on the radiated seismic signal, by relative enrichment or depletion of the frequency content in certain bands. Similar changes may also be introduced, to varying degrees, by strength and the depth of the source. Due to the selective narrow band filtering of short period instruments, it is difficult to resolve these often minute differences when they are masked by the attenuation characteristics of different propagation paths. However, for a fixed station and similar propagation path the resolution of the characteristic frequency differences should be straightforward.

Comparison of short period analog records of the seven events at different stations reveals a marked difference in the frequency characteristics of event 290 relative to other events. Figure 5b shows that the frequency of the highest peak in the P coda is lower for this event at Shahrud (S), Taghi-Ghambar (T) and Kakhk (K) than those for other events recorded at these stations. The same feature persists throughout the whole seismogram. Retraced segments of the 290 seismograms at Kakhk and Taghi-Ghambar are compared in Figure 7 with the records of two other events recorded by the same two stations. Although the measured frequencies of Figure 5b are considered approximate values, their shift toward lower frequencies is fairly convincing when the 290 seismograms are compared with those of other events recorded at these same stations. We shall further pursue this peculiarity of the 290 events in Section 3.0 of this report.

TGI
Dec. 18, 1978
08:03:

TGI
Oct. 24, 1979
06:03:

KHI
Dec. 18, 1978
08:03

KHI
July 29, 1976
05:03

FIGURE 7

RETRACED SEGMENTS OF SEISMOGRAMS
FOR EVENT 290 AT KHI AND TGI, COMPARED
WITH 321 AT TGI and 284 AT KHI

2.5 SURFACE WAVE MAGNITUDES

Very few M_S determinations have been possible for the events under study. All the M_S estimates by NEIS (for events 284, 285 and 288) are based on one data point. We have made several new M_S estimates from the measurements of vertical ground motion of Rayleigh waves at SHI, TAB and KBL. There are some disagreements on the exact procedure for M_S determination at epicentral distances up to about 20 degrees (Evernden, 1971).

A superficial survey of the few data points on which the teleseismic estimates of M_S are based, suggests a noticeable increasing trend with distance, with the possible exception of event 290, for this source region. Our new M_S estimates, using the standard formula

$$M_S = \log \left(\frac{A}{T} \right)_{\max} + 1.66 \log \Delta + 3.3,$$

and the stations at which they are made are also listed in Table I. Evernden's (1971) modification of the attenuation relation for Rayleigh waves at these regional distances would result in an increase of 0.3 magnitude unit for event 292 at TAB, with no appreciable change at SHI and KBL. In Figure 8 our regional M_S estimates and the available worldwide average estimates of M_S are plotted against the NEIS m_b estimates. For reference, a line given for $m_b - M_S$ relation of NTS events by Evernden et al. (1971) is also shown. As explained, the worldwide averages are generally higher than regional estimates. The regional M_S estimates, with the exception of 290, lie below the NTS line and almost define a line parallel to it. Interestingly enough, both the worldwide average and regional estimate of 290 indicate a much higher M_S than can be projected from other observations.

- M_S ESTIMATE
- ▲ WORLDWIDE (ISC & NEIS)
- X REGIONAL (THIS STUDY)

FIGURE 8
 m_b VS M_S CURVE OF THE NORTH CASPIAN EVENTS
 m_b s ARE BASED ON WORLDWIDE DATA (NEIS)

3.0 ANALYSIS OF DIGITAL DATA

3.1 SCOPE

In this section we compare the spectral characteristics of the recorded seismic signal of the selected events at several regional Seismic Research Observatories (SRO and ASRO) and at the Iran Long Period Array (ILPA). Seismic phases include short period P and S waves and long period surface waves. The seismic observatories include MAIO, KAAO, ANTO and SHIO. SHIO is located at an epicentral distance of about 41 degrees and is used as a reference point for three of the events it has recorded. The bulk of digital data was provided by the Seismic Data Analysis Center, Alexandria, Virginia, in prewindowed form. The number of available records for individual stations is given in Table 3.

3.2 SPECTRAL ANALYSIS OF BODY WAVES

The spectral amplitudes of short period P waves at KAAO (five events), SHIO (three events), ANTO (two events) and ILPA (three events) were calculated for all available components. The digital sampling rate for all the short period records is 20 per sec. The selected time window varied from 6.4 to 60 sec depending on the duration of the signal, and sometimes the analysis was repeated for different time windows. The main question regarding the relative signal strength addressed in Section 2.0 can be studied in more detail by examining the relative spectral amplitude of the recorded signals of different events at a single observation point. As seen in Table 3, the most complete set of short period records was collected at KAAO. The normalized short period vertical seismograms of the recorded P coda at this station are given in Figure 9.

In Figure 10a, we compare on a relative logarithmic scale both the spectral amplitudes and the peak amplitudes of events 285, 288, 320 and 321 with those of event 292. The expansion of the time window from 6.4 to 60 sec, to include near-surface and crustal reflections at the source and receiver and multiple arrivals due to triplication, does not change the resulting pattern significantly; however, it reduces the scatter of the linear trend. Based on these observations,

TABLE 3

LIST OF PHASES AND COMPONENTS FOR WHICH
DIGITAL DATA WAS OBTAINED IN USABLE FORM

Station	Event 284		Event 285		Event 288		Event 290		Event 292		Event 320		Event 321	
	SP	LP	SP	LP	SP	LP	SP	LP	SP	LP	SP	LP	SP	LP
KAAO	-	-	1	3	1	3	-	3	1	3	1	3	1	3
MAIO	-	3	-	-	-	-	-	-	-	-	-	-	-	-
ANTO	-	-	-	-	-	-	1	2	1	3	-	-	-	-
ILPA	-	-	1	9*	3+	3	3+	3	-	-	-	-	-	-
SHIO	-	-	-	-	1	3	-	-	1	-	1	-	-	-

* Three long period channels at three array elements

+ The short period window contained the beginning of S phase.

FIGURE 9
COMPARISON OF THE NORMALIZED SPZ TRACES OF P CODA AT KAAO

FIGURE 10
 P WAVE SPECTRAL AMPLITUDES VS PEAK
 AMPLITUDES AT KAAO AND SHIO.

the relative strength of the recorded signal at KAAO for events 288 ($m_b = 5.8$), 321 ($m_b = 5.8$) and 320 ($m_b = 5.6$) produced short period P waves of nearly identical strength. The resolution of the signal strength of these three events for the small differences in their reported m_b estimates, although not quite convincing, would be more justifiable along the spectral axis than by their peak amplitudes.

The similarity of spectral shapes, often in great detail, facilitated the visual comparison of spectra. The relative log amplitude ratio of two signals could be measured by overlaying the spectra of the two events and measuring the offset of the log amplitude axes. The visual matching of the spectra between two events recorded at the same station allowed a simultaneous estimate of the useful bandwidth of the signal above noise. The comparison was only made for the frequency interval for which sufficient signal to noise ratio was assured. For some intercomparisons, it would not be possible to overlay the spectra across the entire useful bandwidth. At frequencies below a given frequency, comparisons would differ for those frequencies above it. When this situation occurred, the spectral log ratios were estimated for the two different frequency bands. This crossover frequency for short period P waves was generally near 1 Hz. For the most part, however, spectra retained their fine structure of peaks and troughs from event to event with reduction in the useful band width due to decreasing signal or contamination by extraneous seismic sources. We believe the uncertainty of the measured spectral ratios does not exceed 0.1 unit on the logarithmic scale. All the available graphs of the computed spectra are shown in the appendices.

In Figure 10b the comparison of peak and spectral amplitudes is again made relative to event 292 for the three events recorded at SHIO, at two different frequency ranges. The SHIO spectral ratios in the higher frequency range correlate with peak amplitudes reasonably well, indicating that the wave packet with highest amplitude is made up mainly of higher than 1 Hz energy. The low frequency data, however, are more consistent with the KAAO observations of Figure 10a, and assign highest source strength to 292 and lowest to 320. The inconsistency of relative excitation of high frequency P wave observations at

KAAO and SHIO for 288 and 292 may serve to caution against such a comparison of the regional and teleseismic observations. Figure 11 shows the short period vertical seismograms of three events at SHIO. The lower frequency character of 292 relative to the other two events can be inferred by inspection of these seismograms. As seen in Figure 11, PcP is a clear arrival for events 288 and 292. The small window length of event 320 does not allow PcP to be observed. The relative peak amplitude of this phase for 288, as shown in Figure 10b, also scales well with P amplitude.

A similar observation is made when examining the spectral amplitudes of P and S waves recorded at ILPA for events 288 and 290 (Figure 12). As was observed for the observations of 292 relative to 288, here both P and S waves of event 290 show an enrichment in low frequency for all three components relative to event 288, whereas the latter event's P and S records are at least as rich in higher frequencies as 290. The consistency of the observations of this figure for all three components is remarkable. ILPA lies almost due south from the source region (170° azimuth) and thus the horizontal components are used without rotation. The lower frequency characteristic of 290 is quite clear on ILPA short period seismograms (Figure 13).

3.3 SPECTRAL ANALYSIS OF SURFACE WAVES

The six available sets of long period records at KAAO (no record is available for 284 at KAAO) are first rotated and then group velocity windowed before their spectra are computed. The sampling rate for these records is one per second. Comparison of the vertical and radial spectral amplitudes is made in Figure 14. These comparisons are, in general, made for similar group velocity windows. The window limits are specified on each spectrum shown in Appendix. Several features of Figure 14 are of interest. First, the data show a remarkable linear trend, pointing to the consistent scaling between vertical and radial components of the six events presented in the figure. As explained later, the 320 records are noisy and doubtful. Secondly, the similarity of the body wave analysis of Figure 10a to the surface wave grouping of this figure points to an identical interpretation of the relative source strength of these events by the analysis of both body and surface waves. Also, considering that no reliable short period

SH10 320065 5 716

SH10 292065 8 711

SH10 288065 5 712

FIGURE II
THE NORMALIZED SHORT PERIOD VERTICAL SEISMOGRAM OF
EVENTS 320, 292 AND 288 AT SH10

FIGURE 12
 RELATIVE SPECTRAL AMPLITUDES OF SHORT PERIOD P AND S WAVES
 FOR EVENTS 288 AND 290. 6.4 AND 60 SECOND TIME WINDOWS WERE
 USED FOR P AND S WAVES RESPECTIVELY.

FIGURE 13

COMPARISON OF THE NORMALIZED SHORT PERIOD VERTICAL COMPONENTS OF EVENTS 285, 288 AND 290 AT ILPA. NOTE THE LOW FREQUENCY APPEARANCE OF THE 290 RECORD. TH TRACES START AT 160 SEC AFTER HOUR MARK.

FIGURE 14

LOGARITHM OF SPECTRAL RATIOS OF RADIAL AND VERTICAL COMPONENTS OF RAYLEIGH WAVES RELATIVE TO EVENT 292. THE 290 OBSERVATION AT ILPA IS NORMALIZED WITH RESPECT TO 288.

record of 290 is available at KAAO, the data of Figure 14 provide the first comparison between the spectral amplitudes of events 290 and 292. The m_b estimate for both of these events is 6.0. However, Figure 14 clearly indicates that 290 generated far more Rayleigh waves than did 292. This difference was previously observed from the M_s estimates of analog records in Figure 8. The spectral amplitude information of the 290 and 288 events at ILPA provides additional confirmation of the relative source strength of event 290. Lacking a 292 record at ILPA, we plotted the 290 data relative to the 288 position per the KAAO data. In view of the fact that both worldwide and regional estimates of M_s for event 290 are based on few observations, the confirmation provided by spectral amplitude ratios is significant and lends support to the unusual richness of the 290 source in low frequency signal.

A similar plot for the correlation of spectral amplitudes between the vertical and transverse components of the long period surface wave at KAAO is presented in Figure 15. General features of the data resemble those of Figure 14. However, it is noted that, except for event 320, which deviates from the established trend of other data, no other event registers a greater ratio of transverse-to-vertical motion relative to 292. The long period records of event 320 used in this study appear suspicious for several reasons. First, while they have been provided to us as part of the record collection for event 320, their event identification tag reads 300, which was initially interpreted as an input error in the identification number. However, as can be noted in the long period record section of the six events at KAAO (Figure 16), all three records of the 320 event are complicated by interference patterns which could belong to a more distant event. The last earthquake listed by NEIS just prior to this event is a small earthquake (no reported magnitude) at 04:40:39 in the Philippine Islands region. In addition, while analyzing the transverse-to-radial ratios of all six events at KAAO, we noticed that for five events the logarithmic difference ranges from -0.17 to -0.25, while for event 320 it has an abnormal value of +0.08. On the other hand, we have noticed that the windowed records provided us have occasionally missed the targeted signal by several minutes. Disregarding event 320 in Figure 15, and considering that ILPA components deviate about 10 degrees from true transverse and radial directions, the data of Figure 15 present a relative scaling of source strength very similar to that of Figures 10a and 14.

FIGURE 15

LONG PERIOD VERTICAL AND TRANSVERSE AMPLITUDES
AT KAAO RELATIVE TO 292. THE 290 OBSERVATION AT
ILPA IS NORMALIZED WITH RESPECT TO EVENT 288.

FIGURE 16
THE LONG PERIOD ASRO RECORDS AT KAAO AFTER ROTATION
AND NORMALIZATION. SCALING FOR THE THREE COMPONENTS OF
INDIVIDUAL EVENTS ARE IDENTICAL

Some irregularity is also noted for the early and late parts of the 285 window. However, the signal-to-noise ratio appeared sufficiently high for the analysis to be made.

On the average, the ratio of the spectral amplitude of transverse to radial components is about 0.6, or -0.21 on the logarithmic scale. The main energy of the transverse waves is somewhat delayed relative to that expected for continental Love waves with an observed group velocity of about 3.0 km/sec, whereas the Rayleigh wave train on the vertical and radial components starts at a group velocity of 3.5 km/sec. Similar delays of the transverse components are observed at SHIO, ILPA, and MAIO. The transverse components generally consist of shorter period waves relative to vertical and radial components, and exhibit an interference pattern in the form of a double maxima on either side of the Rayleigh wave's Airy phase, as shown in Figure 17.

3.4 COMBINED SHORT PERIOD BODY WAVE AND LONG PERIOD SURFACE WAVE SPECTRA

Figures 18-20 present a comparison for the excitation of long period and short period waves observed for different sources at individual stations. In Figure 18 the comparison is made relative to event 292 for five events at KAAO and two events at ANTO. The short period spectral amplitudes on the horizontal scale approximately represent the body wave magnitudes, m_b , whereas the long period amplitudes on the vertical axis are related to the surface wave magnitudes, M_s . Again we note that events 292 and 290 excite about identical short period P waves at ANTO but differ in surface wave excitation, 290 being richer. On the basis of these data, however, the alternative possibility that event 292 excited less- than-expected surface waves relative to other events cannot be completely ruled out. Direct inspection of the long period time histories at ANTO, as shown in Figure 21, reveals extra wave energy of relatively higher frequency arriving at ANTO just ahead of the fundamental Rayleigh wave train. This extra energy has about the right group velocity for the first Rayleigh wave overtone, as it was initially assumed to be. When these waves could not be found on the ILPA and KAAO records, alternative explanations regarding the path rather than the

KAAO 288027 5 3 0

FIGURE 17

VERTICAL, TRANSVERSE AND RADIAL COMPONENTS OF THE
EVENT 288 AT KAAO DRAWN TO THE SAME SCALE

FIGURE 18

SPECTRAL RATIOS OF THE VERTICAL COMPONENT OF RAYLEIGH WAVE AS A FUNCTION OF THE PEAK VERTICAL AMPLITUDE OF SHORT PERIOD P WAVE ON A LOG-LOG SCALE RELATIVE TO EVENT 292

FIGURE 19

COMPARISON OF RAYLEIGH WAVE AMPLITUDE WITH PEAK AND SPECTRAL AMPLITUDE OF SHORT PERIOD P WAVES (BOTH VERTICAL AND HORIZONTAL AXES SCALE RELATIVE TO EVENT 290). THE SYMBOLS WITHIN A SQUARE BELONG TO EVENT 292 AT ANTO. OTHER DATA POINTS, ALL FOR ILPA, BELONG TO EVENT 288, EXCEPT THE TWO OBSERVATIONS AT LOWER LEFT WHICH BELONG TO EVENT 285. NOTE EACH DATA POINT HAS A COUNTERPART FOR THE EVENT 290, SUPERIMPOSED AT THE ORIGIN. (FOR FURTHER EXPLANATION SEE THE TEXT.)

SHORT PERIOD S WAVE PEAK
AND SPECTRAL AMPLITUDES OF 288 RELATIVE TO 290

FIGURE 20

COMPARISON OF RAYLEIGH WAVE AMPLITUDE WITH PEAK
AND SPECTRAL AMPLITUDE OF SHORT PERIOD S WAVE OF
EVENT 288 RELATIVE TO 290 AT ILPA. HORIZONTAL AND
VERTICAL DIAMETERS OF THE CIRCLE SIGNIFY E-W AND
N-S COMPONENTS.

FIGURE 21

THE LONG PERIOD VERTICAL COMPONENTS OF 290 AND 292
AT ANTO. NOTE THE ADDED SIGNAL ON 292
AT THE START OF THE WAVE TRAIN.

source were sought. The most satisfactory explanation, however, appears to be the contamination of the 292 wave train by coincidental arrival of the Rayleigh waves of an earthquake, $M_s = 4.7$, in eastern Iran, which occurred about seven minutes prior to this event. In fact, this extra wave packet can easily be deconvoluted visually when the two traces are overlaid. Because of the smaller amplitudes of this curious noise, its effect on the relative spectral amplitudes is not expected to be significant.

In Figure 19, a comparison of short and long period spectral amplitudes is made for events 288 (at ILPA) and 292 (at ANTO) relative to those of 290 at the same stations. For ILPA all three short period P-wave components in a 6.4-sec window and at two frequency bands are compared. For ANTO only the vertical component is available. The symbols enclosed by a square belong to ANTO observations. The remaining observations show the spectral amplitudes of event 288 relative to 290 at ILPA. Also in this figure, the peak amplitudes and their magnitude equivalence in the form of $(\frac{A_{max}}{T})$ are shown on the same relative logarithmic scale. As expected, the peak amplitudes lie between the two extreme values of spectral amplitudes estimated at frequencies lower and higher than 1 Hz. Figure 19 most notably suggests the near equality of m_b values for events 288, 290 and 292, and the relative depletion of high-frequency and enrichment of low-frequency body waves for 290.

Figure 20 presents the same comparison for the short period S waves at ILPA. The conclusions regarding S-wave observations at ILPA may be slightly different from those of Figure 19 in that there is no marked depletion of high frequency but a relative enrichment of low frequency, proportional to the trace amplitudes, of event 290 relative to 288. The body wave magnitude of 288, when compared on the basis of short period S waves, is about 0.3 unit smaller than that of 290. This indicates a higher sensitivity of short period S-wave amplitudes to whatever source properties caused a corner frequency shift in the direction of low frequencies.

4.0 SUMMARY AND CONCLUSIONS

In search of similarities and differences in the relative excitation of regional phases of seven North Caspian events, we have analyzed the seismograms which they produced at a number of regional stations. The seismograms were broadly grouped into analog and digital records and were analyzed separately. The short period analog records provided the travel time, amplitude and characteristic frequency of the body phases. The main objective of the analysis of the regional body phases was to compare, whenever possible, the amplitude-frequency characteristics of the recorded signal from several events at the same stations. In so doing, we eliminated the path and receiver effects on the signal and compared their source excitation in a relative sense. Several new M_s estimates were made from the measurements of the surface wave trace amplitudes on the long period WWSSN records.

The digital data consisted of one short period and three long period components at SRO and ASRO stations and six components at one or more elements of ILPA. The sampling rates are 1 and 20 per second for long and short period records respectively. Analysis of the digital data included spectral analysis of short and long period records of all events for which records were available at more than one station. Because the magnetically recorded data for this analysis were available in prewindowed form, the interpretation did not benefit from the additional potential of the complete time histories.

The general conclusion of this study may be summarized as follows:

- o The corrected travel times of the first arrival in the distance range of 9 to 17 degrees suggest slightly higher velocities along the southeast profile across the Caspian Sea and northeastern Iran than for the southwest profile across the Caucasus and Black Sea regions (8.47 and 8.20 km/sec).
- o The relative amplitude of the short period first arrival showed too much scatter, because of low signal-to-noise ratio, to be used for scaling purposes.

- o When signal to noise ratio is sufficiently high, the ratios of the maximum amplitude of the P coda to that of the first arrival at individual stations are quite stable. Therefore, the relatively noise-free maximum amplitudes at specified stations are better suited for scaling in a relative sense.
- o The characteristic frequency of the short period seismograms of event 290 appears lower than those of other events for the few stations which recorded 290 and one or more additional events.
- o The PcP phase of several of the events is observable at epicentral distances as short as 13 degrees and therefore this phase, above some threshold magnitude, may serve as a scaling tool for this region.
- o Several M_s estimates at regional distances suggest that, except for event 290 of which M_s is abnormally high, they are about 0.2 magnitude unit lower than the expected value of the NTS events for identical m_b s.
- o Both the regional and worldwide estimates of M_s for event 290 are about 0.7 unit too large relative to other events.
- o The spectral amplitudes of the short period P waves at KAAO in the frequency range of 0.3 to 3 Hz scale with the measured peak amplitudes. For these frequencies the relative excitation of the event 292 P waves is about four times that of 285, corresponding to about 0.6 magnitude unit. For events 288, 320 and 321, these ratios are nearly identical, amounting to about twice that of 285, or 0.3 magnitude unit.
- o The three short period components of S phase available for events 288 and 290 at ILPA suggest that the S-wave observations are more sensitive to the relative depletion of high-frequency energy for event 290.
- o Comparison of the vertical and radial components of the Rayleigh waves suggests that:
 - (a) In the period range of 10 to 50 sec they almost perfectly scale internally
 - (b) The relative Rayleigh wave excitation of the six events for which records are available, in increasing order, is: (285), (288, 320, 321), (292) and (290)

- (c) The relative strength of these source categories in terms of M_S units is: 0.0, 0.5, 0.6, and 1.0-1.2, respectively.
- o The transverse component of the surface wave arrives later than the continental Love waves are expected to arrive. They are generally of higher frequency than the Rayleigh waves and may consist mainly of laterally refracted Rayleigh waves. The spectral and trace amplitudes of the transverse components are, on the average, 0.6 of the radial components.
 - o In general, there is a tendency for the high frequency content ($f > 1$ Hz) of the short period P and S waves to saturate more readily, with the source strength, than the lower frequency content ($f < 1$ Hz). This would give a preference for the role of the high frequency signal in scaling of smaller sources, and low frequency signal for the larger sources.
 - o The most persistent contrast emerging from the analysis of all the data is the relative low frequency enrichment and/or high frequency depletion of event 290, which cannot be explained by propagation effect. There is strong evidence that the factors influencing this contrast are related to the differences in the source characteristics of this event. As was repeatedly demonstrated throughout this study, the observations were widespread both geographically and across the seismic phase boundaries. While source depth, yield and medium may collectively be responsible, there appear to be reasons for ruling out yield and depth as main factors. The excessive M_S to m_b ratio, identical reddening of corner frequency for body and surface waves, and absence of PcP observations for event 290 favor a longer relaxation time for the 290 source which could have resulted from the different properties of the medium in which the source was located (see, for example, Vasil'yev et al, 1979).

5.0 REFERENCES

- Barker, B. W., Z. A. Der and C. P. Mrazek (1981). The effect of crustal structure on the regional phases Pg and Lg at the Nevada Test Site, J. Geophys. Res., 1686-1700.
- Barazangi, M., J. Ni, K. Kadinsky-Cade, B. Isacks and J. Oliver (1981). Regional investigation of seismic wave propagation and velocities in the Middle East and South Asia, Seismic Wave Propagation and Source Characterization Symposium, Las Vegas, Nevada, 18-20 May 1981.
- Evernden, J. F. (1971). Variation of Rayleigh-Wave amplitude with distance, Bull. Seism. Soc. Am., 61, 231-240.
- Evernden, J. F., W. J. Best, P. W. Pomeroy, T. V. McEvilly, J. M. Savino and L. R. Sykes (1971). Discrimination between small magnitude earthquakes and explosions, J. Geophys. Res., 76, 8042-8055.
- Gupta, I. M., B. W. Barker, J. A. Burnett, and Z. A. Der (1980). A study of regional phases from earthquakes and explosions in western Russia, Bull. Seism. Soc. Am., 70, 851-872.
- Lehmann, I. (1962). The travel times of the longitudinal waves of the Logan and Blanca atomic explosions and the velocities in the upper mantle, Bull. Seism. Soc. Am., 52, 519-526.
- Mindeli, P. S. and Y. I. Pataraya (1972). Results of the investigations of propagation on short period seismic surface waves in the Black Sea Basin, AN Gruz SSR, Trudy Instituta Geofiziki, 29, 34-41.
- Nuttli, O. W. (1981). Lg-wave attenuation in the western half of the U.S.S.R.; Conclusions and implications for test-ban problems, presented in Seismic Wave Propagation and Source Characterization Symposium, Las Vegas, Nevada, 18-20 May 1981.
- Shishkevish, C. (1979). Propagation of Lg seismic waves in the Soviet Union, Rand Report N-1014-ARPA.
- Sikharulidze, D. I. (1963). Crustal studies using data on propagation of short-period surface waves, AN Gruz SSR, Trudy Instituta Geofiziki, 22, 57-70.
- Vasil'yev, Y. I., L. V. Molotova and M. N. Shcherbo (1979). On structure of the stress field at the focus and the focal parameters during an explosion in soft ground, Izvestiya, Earth Physics, 15, 796-804.

6.0 APPENDICES

APPENDIX I

SYSTEM RESPONSE OF THE INSTRUMENTS
USED IN THIS STUDY

* No detailed information is available for short period (SP) instruments at Trabzon and Erzurum.

FIGURE A
RESPONSE CURVES CHARACTERISTIC OF THE
STANDARDIZED WWSN INSTRUMENTATION. THE
SHORT-PERIOD CURVE IS PLOTTED TO THE LEFT
OF THE LONG-PERIOD CURVE.

FIGURE B
RESPONSE CURVE CHARACTERISTIC OF THE
STANDARDIZED HGLP INSTRUMENTATION.

FIGURE C
RESPONSE CURVES CHARACTERISTICS OF THE
STANDARDIZED SRO INSTRUMENTATION. THE
SHORT-PERIOD CURVE IS PLOTTED TO THE LEFT
OF THE LONG-PERIOD CURVE.

FIGURE D
RESPONSE CURVE CHARACTERIS-
TICS OF THE MEQ-800 SEISMO-
GRAPH

FIGURE E

NORMALIZED DISPLACEMENT RESPONSE,
IRANIAN LONG-PERIOD ARRAY, SITE 4

APPENDIX 2

The graphs of computed amplitude spectra are presented in chronological order. For each event, the short period spectra are shown first followed by the long period spectra. Within each category, alphabetical order is followed for the stations (ANTO, ILPA, KAAO, MAIO, SHIO). While all the available spectra are shown here, some have not been used in the analysis. Low signal-to-noise ratio, uncertainty about the signal, or lack of additional information for comparison are some of the reasons for excluding these spectra.

EVENT 284

EVENT 285

10.0000

10.0000

KAAO 285

1.0000

0.1000

0.0100

0.0010

0.0001

FREQ (HZ)

P Wave SP(Z)
6.4 Sec. Window

KAAO

285025

0.1000

1.0000

10.0000

100.0000

1000.0000

0.1000

0.1000

0.0100

0.0010

0.0001

0.0000

0.0000

KAAO 285

Surface Waves LP (T)
 $V_g = 2.0 - 3.8$ km/sec

FREQ (HZ)

KAAO

285029

0.0001

0.0010

0.0100

0.1000

1.0000

EVENT 288

10 -0000

0.0100 KAAO 288

0.1000

KAAO 288

0.0100

0.0010

0.0001

Surface Waves LP (T)

$V_g = 2.0 - 3.8$ km/sec

0.0000

FREQ (HZ)

KAAO

288027

0.0001

0.0010

0.0100

0.1000

1.0000

EVENT 290

ILPA 290

P Wave SP(Z)
6.4 Sec. Window

10.0000

ILPA 290

1.0000

0.1000

0.0100

0.0010

0.0001

FREQ (HZ)

0.1000

290100

1.0000

10.0000

100.0000

1000.0000

P Wave SP (E)
6.4 Sec. Window

10.0000

1.0000

0.1000

0.0100

0.0010

0.0001

ANTO 290

Surface Waves LP (N)

$V_g = 1.4 - 5.8$ km/sec

0.0001
FREQ (HZ)

ANTO

0.0010

290062

0.0100

0.1000

1.0000

0.1000

0.0100

0.0010

0.0001

0.0000

0.0000

ANTO 290

Surface Waves LP (E)

$V_g = 1.4 - 5.8$ km/sec

0.0001

0.0010

0.0100

0.1000

1.0000

FREQ (HZ)

ANTO

290062

1.0000

0.1000

0.0100

0.0010

0.0001

0.0000

0.0000

KAAO 290

Surface Waves LP (T)

$V_g = 2.0 - 3.8$ km/sec

0.0001

0.0010

0.0100

0.1000

1.0000

FREQ (HZ)

KAAO

290027

EVENT 292

B-81-306

6-68

TERA CORPORATION

10.0000

1.0000

KAAO 292

0.1000

0.0100

0.0010

0.0001

0.0000

Surface Waves LP (Z)

$V_g = 2.0 - 4.75$ km/sec

0.0010

0.0100

0.1000

1.0000

10.0000

FREQ (HZ)

KAAO

292027

1.0000

KAAO 292

0.1000

0.0100

0.0010

0.0001

0.0000

Surface Waves LP (R)

$V_g = 2.0 - 4.75$ km/sec

0.0010

0.0100

0.1000

1.0000

10.0000

FREQ (HZ)

KAAO 292027

0.1000

KAAO 292

0.0100

0.0010

0.0001

0.0000

0.0000

Surface Waves LP (T)
 $V_g = 2.0 - 4.75$ km/sec

0.0010 0.0100 0.1000 1.0000 10.0000 100
FREQ (HZ) KAAO 292027

0.1000
KAAO 292

EVENT 320

1.0000

EVENT 32I

B-81-306

6-95

TERA CORPORATION

0.1000

KAAO 321

0.0100

0.0010

0.0001

Surface Waves LP (T)

$V_g = 2.0 - 3.8$ km/sec

0.0000

0.0000

FREQ (HZ)

KAAO

321027

0.0001

0.0010

0.0100

0.1000

1.0000