Seismic monitoring at the Caspian Basin and surrounding regions: regional and teleseismic azimuthal anomalies.

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Caspian basin is a very attractive region for seismic monitoring installations, because it hypothetically covers main regions of a possible nuclear capability. However, deployment of automatic real-time monitoring system, if ever realized in this region, requires very specific configuration of the event locator. Also, existence of so called oceanic crust in the south Caspian Basin, depressing regional Lg and teleseismic surface waves, creates uncomfortable conditions for seismic event discrimination. With this, obvious advantages of the monitoring installation in this region follows simply from the number of regional events, located, for example, by the Caspian Seismic Network (CSN, installed by Cambridge University and SYNAPSE Science Center 3 years ago), and not located by any other seismic network. Better knowledge of the seismic structure of this region and properly chosen processing techniques of the intelligent monitoring systems may improve significantly monitoring capability of the network. In this paper we present results related to seismic event location, highlighting problems, raised before us during processing a data from 2 main seismic installations of the region: **Caspian Seismic Network**, deployed by us, and a **Geyocha small aperture array**, deployed by IRIS in a vicinity of Ashgabad.

The characterization of seismic sources is important in regions of potential nuclear proliferation such as the Middle East. From a seismic discrimination/verification point of view, this region is important because there are a number of countries in the Middle East which have a possible nuclear capability. Seismic monitoring stations for these countries are now located in the Former Soviet Union. The **Lg** phase, proven to be an effective discrimination/yield estimation phase, does not propagate across the Caspian thus preventing or at least greatly reducing its use. Very complex geological structure of the region causes strong azimuthal divergence of regional wave traines of most types. A better knowledge of the Caspian structure and its effect on regional seismic wave propagation will significantly improve seismic monitor capability for this and the surrounding region. Source properties for events greater than about mb 5.5 are now routinely determined from teleseismic data; however, determination of source properties for smaller events which are significant for seismic monitoring issues must be extracted from regional seismic data The analysis of regional seismic waveforms is more challenging than the analysis of teleseismic waveforms. For regional waveforms, source parameter estimation is strongly dependent on the crust and upper mantle structure because phase amplitudes depend on the both velocity structure which can vary strongly from region to region and the event source properties.

The characterization of regional seismic wave propagation is also essential in understanding the utility of various proposed regional seismic wave discrimination schemes.Improving the ability to discriminate between small earthquakes and explosions in the Middle East depends on an improved understanding of: (1) the crust and upper mantle velocity structure, (2) the amplitude and frequency characteristics of regional seismic phases Pn, Pg, Sn, and Lg, and (3) the source characteristics of moderate size seismic events in the region. This will allow for improved capabilities in locating and characterizing future seismic events and for assessing the utility of proposed regional seismic discriminants in this region.

Event location by the Caspian Seismic Network. A major restriction on such studies in the Middle East has been the scarcity of data recorded within the region To better understand the crust and upper mantle structure in the south Caspian region and its effect on regional seismic wave propagation, we have installed in 1993 six, three--component broadband digital seismographs around the south Caspian Sea in the former Soviet republics of Turkmenistan and Azerbaijan. The Turkmenian stations were situated near Krasnovodsk (KRV), Nebit-Dag (NBD), Dana-Ata (DTA) and Kizyl Atrek (KAT); in Azerbaijan the stations were situated near Lenkoran (LNK) and Baku (BAK). In June 1994 station BAK was relocated 100 km west to Shemaha (SHE), and in spring 1995 Azerbaijanian part of the network was unmounted, but Kara-Kala (KAR) station appeared in Turkmenistan . The Turkmenian stations were operated in cooperation with Dr. B. Karryev from the Institute of Seismology of Turkmenistan, and the Azerbaijan stations were operated in cooperation with Dr. S. Agamirzoev from the Geophysical Expedition of Azerbaijan.

Data at each site was recorded on a Refraction Technology 72a-02 data logger that is equipped with either Omega or GPS timing. Stations KRV, DTA, KAT and LNK have Guralp CMG-3T sensors and stations NBD, BAK and SHE have Geotech SL-210/220 long period sensors. All stations recorded data continuously at 10 samples per second and some had a triggered data stream at 50 samples per second. We were calibrating each station with a pseudo-random binary input on an annual basis and with a step function at each station visit (approx 6 weeks).

During more than a three years of operation, in addition to a large number of teleseisms, we have recorded several hundred local and regional events identified by the National Earthquake Information Center (NEIC), and have recorded many more local and regional events that are not identified by the NEIC. CSN increased much a quantity of very weak events, recorded in a territory of western Turkmenista - northern Iran. In this section we present data for the events, occured during a period of time Aug-1, 1994 - Sep-30, 1995. *For this period, more than 200 local events were recorded, not mentioned in seismic bulletins, and for 190 a location was made*. Among them:

- 92 - with magnitude less than 2;
- 80 - with magnitude from 2 to 4;
- 18 - with magnitude from 4 to 6.

Relatively “big” events (MD=2,0-3,0) are distributed almost evenly and relatively weak events (MD=0,8-2,0) are concentrated in a region of Krasnovodsk - Nebit-Dag.

With this, GSETT-3 stations recorded 65 seismic events occured within the same area (32°N-48°N and 45°E-65°E). Among them

- 31 - with magnitude from 2 to 4;
- 34 - with magnitude from 4 to 6.

As to the CSN operation in general, more than 900 events were registered during the same time. Among them:

- about 100 - with magnitude less than 2;
- about 150 - with magnitude from 2 to 4;
- more than 650 - with magnitude from 4 to 6;

- about 5 - with magnitude more than 6.

Among 4,7 thousand catalogue events, about 700 events were registered and associated with the catalogue by network stations. About 200 events among them were located with quality estimate of record A, about 350 - with estimate B, about 150 - with estimate C (A - SNR>10, no filtering required; B - 3<SNR<10, filtering is applied; C - the amplitude of a signal exceeds a level of background so slightly that even the filtering can not determine the first arrival of longitudinal and transverse waves. The event is associated basically by long-period surface waves).

The epicenter geographical coordinates were determined for 185 seismic events. In general, examinating the results of event location we can conclude that the network was capable to registrate

- almost all seismic events with calculated maximum amplitude in range more than 1000 nм,
- main part of seismic events in range from 100 to 1000 nм,
- considerable part of seismic events in range from 10 to 100 nм,
- and few number of seismic events in range less than 10 nм.

Thus the most part of events that took place but were not registered by network stations were in range less than 10 nм. The rest of them practically completely are in range from 10 to 100 nм and their concentration is clearly observed in the regions of the Pamirs-the Himalayas and of north-east Mediterranean. Using small aperture array technique would increase strongly a number of events, suitable for location. We intend to apply adaptive filtering schemes, implemented in the SNDA software packege (Seismic Network Data Analysis, SNDA, SYNAPSE Science Center), for the CSN installation.

CSN azimuthal capability CSN provided a registration of considerable part of seismic events in seismic active zones located on western coast of southern part of the Caspian sea, in Southern Iran. The seismic events are usually registered in a region of the Balkan, in Central Iran, in the Pamirs, in Northern China, on the Philippines, in Indonesia, on Japanese islands, on the Kuril Islands and Kamchatka.

At the same time the events with epicenters in Central and Northern Europe, in Scandinavia, in the Himalayas, on western coast of Sumatra are practically "invisible".

The registered events in range less than 10 nм are concentrated basically in near a region of location of network stations (southern part of the Caspian sea and Iran).

It is also important that we have registered events for a region of Arabian-Indian ridge but it is even more interesting that we can see their concentration in a region of Fiji islands on epicentral distances about 120-130 degrees with prevalent maximum quality estimate of record A.
Registered events in range from 10 to 100 nм are distributed practically in regular intervals. Big events are single and are concentrated in a zone of Japanese islands, the Kuril islands and Kamchatka as well as Philippines islands and Indonesia.

Study of a distribution of quality estimates give us:
- *obviously prevalent estimate A for a southern part of the Caspian sea, Japanese islands, the Kuril islands and Kamchatka;*
- *quality A and B for Iran, and*

- *for north-east of Mediterranean, the Pamirs-the Himalayas, Indonesia and Philippines the estimates are evenly distributed on all three categories.A, B, and C*

[You might add something here about your location capability]. We are using the teleseismic body wave data to determine station receiver functions which are interpreted in terms of the shear wave velocity structure beneath each site. We are also measuring surface wave phase velocity dispersion between the sites to determine the lithospheric velocity structure of the south Caspian basin, and using the regional waveforms to improve our understanding of regional seismic wave propagation in Iran.

P-wave azimuthal anomalies: The frequency dependence of backazimuth anomalies and the polarization characteristics can be indicative of the level of scattering in the P-wavefield due to inhomogeneities in the crust and upper mantle beneath the recording site. It is important to assess the level of scattering and its frequency dependence before attempting to extract information on the crust and upper mantle structure using the receiver function technique. We have measured the polarization using a technique discussed in Kanasewich (1981) and implemented by Harris (1980). For this, the rectilinearity of the particle motion over a specified time window can be obtained from the ratio of the principal axes of the diagonalized covariance matrix from the three component time series. The degree of rectilinearity can be determined by comparing the relative magnitude of the two largest eigenvalues; and the direction of polarization can be determined by considering the components of the eigenvectors associated with the largest eigenvalue with respect to the coordinate directions.

This procedure was used to examine the polarization of teleseismic P-waves in the 0.07-0.2 Hz and 0.3-2.0 Hz bands. Assuming an average crustal P-wave velocity of 6.4 km/s these bands correspond to wavelengths of about 96 to 32 km or crustal dimensions and about 21 to 3 km or subcrustal dimensions. Figure 7 shows an example of the measurement made on a teleseismic P-wave for the lower of these frequency bands, and the associated particle motion plots.The results of the polarization analysis in the two frequency bands are shown in Figures 8-10. The results are complex however some conclusions can be drawn from these plots. With the exception of station KRV the differences between the low frequency observed and the theoretical backazimuths are small. However, the highpass backazimuth anomalies are large indicating significant scattering.

At ABKT the lowpass measurements are essentially on azimuth while a pattern is present at higher frequencies. Arrivals from teleseismic sources northeast of ABKT are deflected to the north while arrivals from the southeast are deflected to the south. The division between this frequency dependent scattering is roughly parallel to the trend of the Main Fault of the Kopet Dag Mountains. Although the bearing results at station DTA are sparse, this pattern is not present 200 km east of ABKT. At station KRV both the low and highpass bearings are inconsistent with the expected azimuth of arrival. The mean difference between the expected and observed azimuth of arrival is ~17.5 degrees, counterclockwise about the station. These differences point to a mis-aligned seismometer. Stations NBD, KAT and LNK located within the Basin and all show significant scattering at higher frequencies while the lowpass bearings are variable.

Surface wave anomalies. Jih and Lyness (1992) and Nuttli (1981) constrained the attenuation parameters gamma and **Q** derived from Lg and characterize the Iranian plateau in general as a region of low **Q**<250, although the distinction between absorption and scattering remains obscure. Wallace et al, (1992) observes inefficient **Lg** propagation across northern Iran and the southern Caspian region. In addition to lateral variations in crustal structure, changes in topography have recently been shown to affect Lg propagation. Recent analysis of the logarithmic **rms** amplitude ratio of **Sn/Lg** (Zhang and Lay 1994) has shown that this ratio can be linearly related to changes in surface topography. It was also shown, that for travel paths across the southern Caspian region, the **Lg** phase is scattered or largely blocked (Kadinsky-Cade et al 1981), and this is also apparent in the data we have collected in the region immediately surrounding the Caspian.

Using data from our Caspian seismographic network we have observed that ***both the shorter and longer period surface wave train*** *is strongly attenuated or scattered within the southern Caspian basin*. Figure 13 shows that the south Caspian Basin also severely disrupts low frequency fundamental mode surface wave trains. Figure 13a compares long period seismograms for a mid-Atlantic ridge earthquake propagating along a great circle path between LNK and KAT. The LNK seismogram shows a dispersed fundamental mode wave train (~2400-3000 seconds) followed by scattered surface wave arrivals. The lowest frequency fundamental mode surface wave arrival seen in the LNK seismogram is clear in the KAT seismogram (~2600-2700 seconds) but the dispersed wave train observed at LNK is largely missing from the KAT seismogram and the overall surface wave amplitude has decreased significantly. Figure 13b compares seismograms for a north Mulucca Sea earthquake propagating along a great circle path between KAT and LNK, i.e., reversing the path of the event in Figure 13a. These seismograms exhibit the same degradation of the surface wave train and show that this is not, for example, an instrumental effect. *We have observed this phenomenon for all events propagating along great circle paths across the central portion of the south Caspian Basin*.

Surface waves propagating along the KRV--KAT great circle path across the Turkmenian Lowlands do not show the same disruption (Fig. 14) as those propagating across the main part of the basin (Fig. 13). Russian earth scientists have suggested that this region is structurally part of the south Caspian Basin and that the crust in the region consists of 10-15 km of sediment lying on "ocean--like" crust. The two upper seismograms in Figure 14a show one of four great circle path Rayleigh wave pairs recorded at stations KRV and KAT that are used to determine the dispersion curve. The comparison of the two wave trains in the lower part of the upper plot shows the match of the original KAT Rayleigh wave with the KRV Rayleigh wave after being filtered with the dispersion transfer function.

Regional Seismic Phase Arrivals Anomalies: Geyocha array site.

In this study we analyzed Geyocha array seismograms recorded from two China Lop Nor explosion and two regional earthquakes. Some characteristics of the events are enclosed in the Table 1

Table 1

Ev. n	Origin time	Source coordinates degr.	Source depth km.	Magni-tude mb	Epicenter distance degr.	Back azimuth degr.	P-wave appar. veloc.	Source type

1	**07.10.94 03:25:58.1**	**41.66° N 88.75° E**	**0**	**6.0**	**23.74°**	**71.29°**	**11.46**	**China nuclear test**
2	**10.06.94 06:25:58.0**	**41.69° N 88.79° E**	**0**	**5.7**	**23.77°**	**71.22°**	**11.46**	**China nuclear test (6 3C st)**
3	**18.10.93 13::57:14.6**	**22.13° N 62.85° E**	**10**	**5.2**	**16.29°**	**164.13°**	**8.67**	**Earthquake (11 3C st.)**
4	**02.10.93 01:17:30.4**	**39.07° N 69.97° E**	**14**	**5.0**	**9.35°**	**79.37°**	**8.04**	**Earthquake**

P-phase arrival direction estimation from Geyocha 3C seismograms of Lop Nor explosion on 07.10.1994

The real medium beneath the array has very complex geological characteristics and this seriously hamper the analysis of event phase characteristics. As result, even at the first seconds after phase onsets the particle motion has the form much more complicated then theoretically predicted one. In particular, the particle motion of the P-waves has the elliptic feature that is peculiar to heterogeneous and anizotropic media [Der, Z., Baumgart,D et al, 1993]. Table 2 encloses the results of polarization analysis of the P-wave of event *n1* made for recordings of the 12 VBB 3C Geyocha seismometers

Table 2

Seismometer	Back azimuth α	Incidence angle β
ORGH	63.8	18.4
NH	43.6	11.2
SWH	44.6	19.3
SEH	67.4	13.9
A22	68.7	19.2
B32	70.3	16.0
C22	76.6	12.2
D33	55.7	12.4
E22	61.1	16.0
F32	53.9	18.1
G22	46.2	17.9
H32	61.8	19.6
Mean values	59.5	16.2
RMS deviations from mean	10.3	3.0

We see that deviation of the azimuth and incidence angle estimates relative to their mean value are very high. This testifies that serious medium heterogeneity exists even inside the small array aperture (less then 2 Km). The mean value of the azimuth is about 22^o less then the real azimuth value equal to 71.3^o (Table 1). The anomaly polarization of the longitudinal waves in the area is already mentioned in [Pavlis, G, Al-Shukri, H, et. al., 1994].

At the same time the F-K analysis of the event P-wave-field made using recordings from 12 vertical Geyocha seismometers (Fig.8) gave the P-phase arrival azimuth estimate equal 67.6^0 that is much closer to the real azimuth value. The 4^0 deviation of the azimuth estimate to the North can be explained by the impact of the great Tibet and Tjan-Shan mountain provinces at the path of the wave propagation. The F-K estimate of the P-wave apparent velocity equal to 11.9 km/sec is also well corresponds to the value determined from the Jeffreys-Bullen travel time tables (11.46 km/sec).

The comparison of the results of polarization and F-K analysis allows to estimate the P-wave velocity in the medium beneath the array. Employment of the simplest relation $sin\beta_p = p_h V_p$ gives the value V_p =3.6 km/sec, that is significantly less than value V_p=5.5 km/sec assumed in the Jeffreys-Bullen Earth model but corresponds to results of the medium structure assessment by the receiver function analysis (Magino, S., Priestley, K., 1995)

P-phase arrival direction estimation from Geyocha 3C seismograms of Lop Nor explosion on 10.06.94

For some technical reasons the recordings only from 6 Geyocha sensors were available for the study. The azimuth and incidence angle estimates calculated from the available P-phase 3C seismograms by the conventional polarization analysis are listed in Table 3.

Table 3

Seismometer name	Back azimuth α	Incidence angle β
ORGH	**60.3**	**22.6**
NH	**36.3**	**9.5**
SEH	**39.8**	**22.6**
A22	**66.8**	**20.0**
B32	**74.0**	**19.7**
C22	**71.6**	**17.5**
Mean values	**61.5**	**18.3**
RMS deviation from mean	**15.2**	**4.5**

We see that the mean value of azimuth estimate is in 10^o less, then the real azimuth value equal to $71,2^o$.

The disposition of the seismometers providing the available seismograms is marked by crosses in Fig.1. It was very unlucky for the F-K analysis of signals arriving from the Lop Nor test site. For this reason the P-wave F-K map calculated by conventional algorithm applied to the Z-component seismograms has the very smoothed maximum (Fig.11). The estimates of wave arrival direction (azimuth α=77.5° and apparent velocity v_p=10.9 km/sec) are farther from theoretically predicted values than for the discussed above Lop Nor event *n1* (see Fig.8). The F-K estimates made using different time intervals of P-phase waveform demonstrated rather strong variability.

Such instability of the conventional Z-component F-K analysis stimulated us to employ generalized F-K analysis based on 2-components (horizontal) and 3-component seismograms recorded by the subarray. As it was seen from the event seismograms the P-phase has the rather powerful horizontal components that is related with the complex medium structure beneath the array. The generalized 2-component F-K analysis taking into account only transverse phase oscillations produced in the case the F-K map shown in Fig.13. The azimuth and apparent velocity estimates (α=69.5°, v_{ap}=11.7 km/sec) provided by this map significantly closer to the theoretical values (α=71.3°, v_{ap}=11,5 km/sec) than in the case of conventional Z-component F-K analysis.

The procedure of generalized 3-component F-K analysis of P-phase wave-field requires the information about longitudinal wave velocity V_p beneath the array. If this information is absent the generalized 3C F-K analysis can be made repeatedly with different suspected V_p values. The V_p value which provides the highest maximum of the F-K map can be regarded as the estimate of the real V_p value. (Note, that this method is statistically well grounded). This procedure applied to the 3C P-wave seismograms of the Lop Nor event *n2* gave the V_p estimate equal to 4.3 km/sec. The generalized 3C F-K map provides the azimuth estimate equal 67.7° which is closer to real value and almost the same as for the F-K azimuth estimate got for the Lop Nor event *n1* (67.5°). However, the apparent velocity estimate obtained by this method turned to be excessively high: 16.1 km/sec, that is almost in 1.5 times larger then the theoretical value.

Since the P-phase polarization even at the first seconds after onset moment is the strongly elliptic one it is natural to employ for the generalized 3C F-K analysis the elliptic particle motion polarization model. This attempt provided the F-K map shown in Fig.15. The P-phase azimuth and apparent velocity estimates got with the help of this algorithm (α=71.7^0, v_{ap}=12.1 km/sec) are greatly close to the theoretical values (α=71.3^0, v_{ap}=11.5 km/sec).

The P-wave medium velocity estimate can be based on the simplest equation $sin\beta=V_p/v_{ap}$ where β is the mean incidence angle from Table 3 and the v_{ap} is averaged value of the apparent velocity F-K estimates discussed above. The calculation gives in this case value equal to V_p=3.7, that is corresponds well to the value obtained for Lop Nor event *n1*.

Results discuss above allows to assert that employment of horizontal component seismograms in the framework of the generalized F-K analysis provides significant improvement of accuracy of seismic phase azimuth and apparent velocity measurements based on data from 3C microarrays. The accuracy of such analysis in the case of 6 station microarray with effective aperture about 0.5 km became comparable with the accuracy of conventional Z-component F-K analysis for NORESS type array with aperture 2.5 km. In any case the F-K analysis of microarray data provides much higher accuracy of arrival direction estimation then the polarization analysis of single 3C seismometer.

Surface waves arrival direction estimation from Geyocha 3C seismograms of Lop Nor explosion on 10.06.94

The 3-component seismogram of the central Geyocha sensor filtered in the frequency band 0.01-0.1 Hz is shown in Fig.20. The intensive Rayleigh and Love phase oscillations are explicitly seen in this figure. This gave the possibility to estimate the arrival parameters of surface waves with the help of generalized 3-component F-K analysis. The output maps of the analysis for the Rayleigh and Love waves are shown in Fig.21 and Fig.22. These maps provides the following estimates: for the Rayleigh wave - α=66.1° and v_{ap}=2.2 km/sec; for the Love wave - α=64.1° and v_{ap}=3.3 km/sec. The azimuth estimates for the both waves differ from theoretical value equal to 71.2°. This undoubtedly connected with the impact of Pamir and Tjan-Shan mountains which lie at the theoretical path of the wave propagation. The same reason probably explains the low apparent velocities of the surface waves which differ from velocities predicted by Jeffreys-Bullen Earth model (3.0 km/sec- for Rayleigh and 3.5 km/sec for Love waves).

Analysis of Geyocha 3C seismograms from Oman gulf earthquake on 18.10.93
. *Onset time estimation of the event wave phases.*

The 3-component seismogram of the event body waves are shown in Fig.28. . Table 4 gives the theoretical values of onset times for regional and teleseismic phases of the event calculated using NORSAR regional travel time tables and standard Jeffirs-Bullen travel tables. The results of these phase onset time measuring accomplished by the precise statistical Maximum Likelihood method (Pisarenko, V, Kushnir A. et al, 1987) are collected in Table 6.

Theoretical onset times ***Table 4***

Teleseismic phases		Regional phases	
Phase type	Onset time: h:min:sec	Phase type	Onset time:

			h:min:sec
P	14:01:06.39	Pn	14:01:02.92
S	14:04:07.60	Pg	14:02:06.78
L	14:05:51.93	Sn	14:03:50.14
R	14:07:29.09	Sg	14:06:12.87
		Lg	14:05:52.18
		Rg	14:07.28.32

Measured onset times ***Table5***

Seismometer component	Phase type:			
	Pn	Pg	Sn	S
E-component	14:01:07.05	14:01:55.32	14:03:28.77	14:04:07.16
N-component	14:01:03.75	14:02:00.47	14:03:25.78	14:04:28.09
Z-component	14:01:03.30	14:02:00.07	14:03:27.67	

Arrival direction estimation of the body wave phases.

In Fig.28 the margins of Pn, Pg and Sn time intervals are shown chosen for calculating phase power spectra and for estimating their arrival direction parameters with the help of wide-band F-K analysis. As it is theoretically predicted, the Pn phase has the most high frequency content: its spectrum maximum is situated at 0.7 Hz but there exists the second powerful spectral peak with frequency 0.4; the Pg phase has the single spectral peak at 0.55 Hz, and the Sn phase - at 0.33 Hz.

The F-K analysis maps for these phases are presented in Fig.30a - 30c. The most impressive in this maps is that estimates of Pn and Sn waves azimuths are equal 184.7° and 183.8°, i.e. coincides with the accuracy less than 1° (the apparent velocities of this phases are $V_{ap}(Pn)$=8.7 and $V_{ap}(Sn)$=8.0***).*** Note however, that these azimuth values differ from theoretical one (equal to α=164.1°) of about 20°. Such divergence can not be explained by the estimation error and obviously connected with the peculiarities of these wave propagation in the region. Note the both phases propagates along the boundary between the Earth crust and upper mantle and evidently this boundary has a laterally heterogeneous structure in the region. At the same time, the Pg-phase F-K azimuth estimate is equal to 169.1° and differ from the theoretical azimuth only in 5° (the Pg apparent velocity is $V_{ap}(Pn)=6.8$). Because the Pg phase propagates within the Earth crust the mentioned lateral heterogeneity of the crust-mantle boundary apparently does not affect strongly on this wave propagation. This matter is already discussed in the papers (Pavlis, G, Mahdi, H, Vernon, F, 1994), where was stated, that various wave phases demonstrate the different arrival azimuths in Central Asia region. However, the authors of these papers observed this effect only for the surface waves.

Study of event surface wave characteristics.

Fig.38 shows the 3-component seismogram of central Geyocha sensor rotated in direction of theoretical surface wave arrival. The very powerful Love and Rayleigh surface wave oscillations allow to investigate their polarization and spectral-velocity features.

Fig.40 demonstrates the results of the Love wave spectral analysis in the time and spatial domains. In Fig.40.a the power spectral density is depicted for the Love wave oscillations being observed at Fig.38 trace 2 during (300-600) sec time interval. The spectrum peak is focused in frequency band (0.025 -0.09) with maximum at 0.05 Hz.

The Fig.40.b shows the wide-band F-K analysis map for frequency band (0.03-0.08) Hz. It revealed the arrival azimuth and apparent velocity of the Love wave equal to α=157.6^o and V_{ap} = 3 km/sec. The azimuth of the Love wave arrival is less than theoretical one (164.1^o) for 6,5^o, and demonstrates the very high consistency in different frequency bands. This follows from the results of multiple narrow band F-K analysis presented in Fig.40.c and Fig.40.d. The F-K analysis was performed for 6 equidistant frequency bands with width equal 0.1 Hz in the range (0.03-0.08). From Fig.40.c one can see that the Love wave arrival azimuth does not practically change depending on the wave period. This contradicts with the results of paper (Pavlis, G Mahdi, H, Vernon, F, 1994) where such dependence were mentioned, however, for the other arrival direction of surface waves. Fig.40.d presents the Love main mode dispersion curve i.e. dependence of apparent velocity upon the wave period. This curve was gained in the result of multiple narrow band F-K analysis mentioned above. The dispersion curve good corresponds to the theoretical one following from the Guttenberg Earth model.

The power spectral density of Rayleigh wave longitudinal oscillations is shown in Fig.42.b; the spectrum was calculated using trace 1 of Fig.38 in time interval (400-650) sec. We see from this figure that the Rayleigh wave spectrum has the rather narrow peak concentrated in frequency band (0.05-0.1)Hz. with maximum at 0.08 Hz. The results of wide-band F-K analysis for time interval (400-550) sec in frequency band (0.05-0.1)Hz are shown in Fig.42.c. The Rayleigh wave arrival azimuth estimate is equal 168.8^o, that exceeds the theoretical value (164.1^o) at 4.7^o and the arrival azimuth estimate for the Love wave at 11.2^o. (Note that the theoretical azimuth is almost in the middle between the above surface waves azimuths). Such great difference between the Love and Rayleigh azimuth estimates can not be explained by the errors of the F-K analysis accounting for the very high signal-to noise ratio in the both phases. Here we again have to refer to complexity of the Earth crust and upper mantle in the region under study and propose to implement thorough investigation of the wave propagation peculiarities in this region, which attract the assiduous attention in regard of CTBT monitoring.

Conclusions.

This study has shown that the south Caspian has an anomalous crustal structure which has a pronounced effect on not only higher frequency regional seismic waveforms but also on lower frequency surface waves. The velocity structures from body wave modeling provide some insight into the effects of crustal structure on regional seismic waves propagating across the south Caspian Basin. It is clear from the Caspian data that both longer and shorter period surface wave trains are greatly scattered or attenuated for travel paths across the Caspian Sea, and to a lesser degree for paths across the Turkmenian Lowlands. The Lg phase is blocked for travel paths across the oceanic crust as well as in regions where the crustal structure includes rapid changes in thickness. If we consider the Lg phase to consist of multiple reflected S waves trapped within the crustal wave guide, then the receiver function modeling results suggest that the blockage is due to the abrupt change in crustal structure from a relatively simple model beneath ABKT to complex models beneath KAT and LNK. Although these are 1-D models and the basin is a 3-D structure, these observations support a scattering mechanism. Recent analysis of the logarithmic rms amplitude ratio of Sn/Lg (Zhang and Lay 1994) has shown that this ratio can be linearly related to changes in surface topography. The southern margins of the Basin and the eastern margin of the Turkmenian Lowlands range from below sea level at LNK up to 2 km in the Alborz Mountains. These features probably contribute to the Lg blockage, but these effects have not yet been examined.

Azimuth estimations based on data from a 3-component station or small aperture array provides the support for automated near real time event location based on observations from a single site. The results of azimuth estimation study made for recordings of Geyocha 3-component VBB array show that in the regions with complex medium structure as the south Caspian Basin azimuth measurements can be misleading and potentially provide the gross errors of epicenter location. The azimuth estimations by polarization analysis of 3-component seismograms exhibit great variability even for station distanced at 1-2 km. The F-K analysis of array data guarantees more precise azimuth estimates, especially while using generalized 3-component F-K algorithms. Nevertheless even F-K azimuth estimates reveals significant difference in azimuths of body and surface event wave phases arriving to Geyocha site from Eastern and Southern directions

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