SEISMIC ANISOTROPY AND SHEAR WAVE SPLITTING IN WESTERN ALBORZ AND ADJACENT REGIONS

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ABSTRACT

We have determined the shear wave splitting parameters using data from a temporary network of 21 broadband stations in the western Alborz region in northern Iran. Core refracted phases SKS and SKKS were used from over 1000 teleseismic waveforms to measure fast polarization directions and delay times in the stations. Events in the epicentral distance range of 90 to 130 degrees were used. The minimum energy and the rotation correlation methods were used to measure the splitting parameters. The average fast-axis azimuth and delay time obtained from the rotation correlation method are 22 ± 4º and 1.5 ± 0.2 sec, respectively. For the minimum energy method these values are 21 ± 5º and 1.5 ± 0.1 sec, respectively. The general trend of the fast axes is NE-SW. We suggest that the different fast axes directions in the north of the Alborz Mountains may indicate that the lithospheric structure in the Geelan region may be different from that in the Alborz region. The fast axes make a sharp angle with the trend of the mountain ranges; the Alborz, the Tarom and the Soltanieh Mountains. These directions are sub parallel to the motion of Iran with respect to Eurasia in the no-net-rotation frame of reference. In this respect, these results are in accord with previous results obtained in north western Iran (Arvin, 2013) and in eastern Turkey (Sandvol et al., 2003). The shear wave splitting results are interpreted as indicating the mantle flow in the asthenosphere beneath Iran.

INTRODUCTION

Measurements of seismic anisotropy constitute a very important tool for examining patterns of flow and mineral properties in the Earth's mantle. We can examine the splitting of SKS and SKKS phases and interpret them in terms of upper mantle anisotropy and deformation to understand the processes that occurs in the upper mantle.

Shear-wave splitting one kind of seismic anisotropy. When shear waves pass through an anisotropic medium, they split in to two components polarized orthogonally and propagating with different velocities. Shear-wave splitting can be measured via two parameters: the delay time (δt), the arrival time difference between the fast and slow components, and the fast axis direction (Φ), the polarization direction of the fast component. Seismic anisotropy has been observed in many environments and at many depths in the Earth, from the crust down to the core–mantle boundary. Anisotropy is widely accepted to be directly related to the mantle deformation, the alignment of rock-forming crystals that are intrinsically anisotropic. In this study we estimated fast axis and delay arrival time of wave to examine the asthenosphere properties in the upper mantle in western Alborz region.

DATA AND METHOD

We used data from a temporary network of 21 broadband stations that operated 2012 through 2014 in the western Alborz region in north western Iran (Fig. 1). The Network consists of a main line and a few offline stations and covers the Caspian lowland regions in the Geelan province and crosses into the western Alborz, Tarom and Soltanieh Mountains in the Zanjan province. Average inter-station spacing for the main line is around 12 km.

In order to characterize the upper mantle anisotropy, core shear phases such as SKS and SKKS are generally used. These phases are well detectable at distances between 90° and 130°. They propagate along steeply inclined rays near the surface, there are several advantages for using SKS: 1) The conversion to P in the outer core removes any splitting due to the source-side of the path; 2) When SKS leaves the CMB on the receiver side, it is radially polarized. Thus, in an isotropic medium, there is no SKS energy on the transverse component so that the presence of transverse energy indicates the presence of anisotropy (Silver and Chan, 1991).

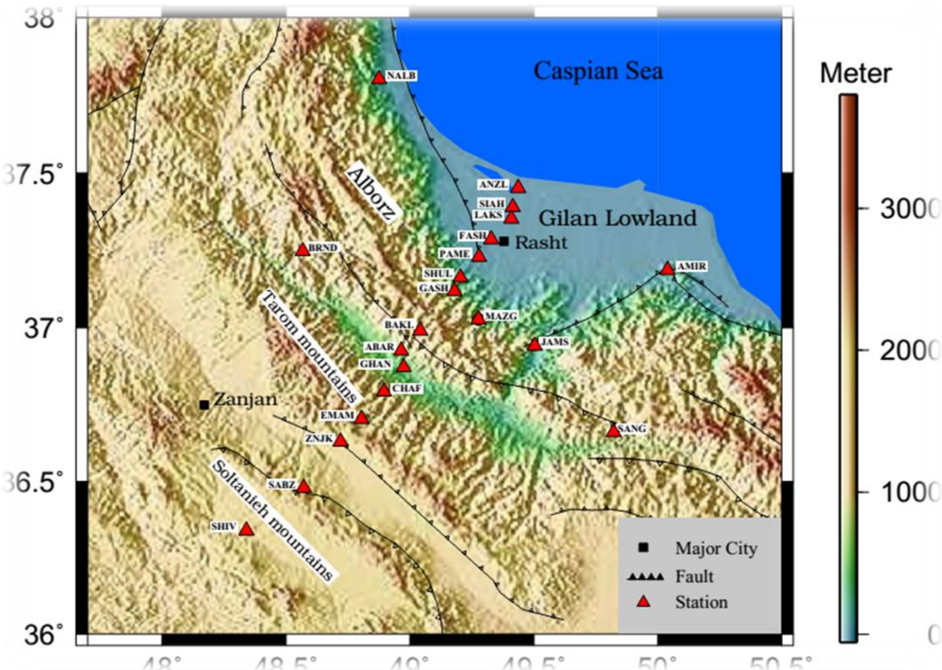

Figure 1. The map of used stations in our study. These broad band stations are belong to seismic network of Institute for Advanced Studies in Basic Sciences (IASBS).

We used two different methods to measure the splitting parameters, the Minimum Energy (Silver and Chan, 1991) and the Rotation Correlation (Bowman and Ando, 1987) methods. The Minimum Energy method applies a grid search approach to select a pair of splitting parameters (fast axis and delay time) which best minimizes the amount of energy on the transverse component. The Rotation Correlation method utilizes a grid search approach to identify the best fitting splitting parameters by rotating and time-shifting the horizontal components.

The SplitLab (Wیstefeld et al., 2008) software was used for this purpose. All waveforms were band pass filtered to retain energy between 0.04 and 0.15 Hz. This filter is appropriate for retaining signal at the period's characteristic of SKS and SKKS phases. Windows were manually chosen to encompass at least one period of the signal. We rated each measurement as good, fair, or poor, based on the quality of the data and of the results.

RESULTS

We examined SKS and SKKS phases from over 1000 teleseismic events of magnitude $M_w \geq 5$ at epicentral distances between 90خ-130خ to measure fast polarization directions and delay times in the stations. In this study we considered only good quality waveforms which had a signal to noise ratio great than 3. The deviation between estimates of fast axis direction and delay time calculated by the different methods was less than ±5 خ and ±0.1s respectively for good results. Waveforms are processed individually in each station. Waveforms with poor and fair quality were rejected because these waveforms had large errors. Fig. 2 shows rose diagrams for the measured fast axis directions by both methods for all 21 stations.

We calculated average value for each station. The results obtained from weighted averaging are shown in Fig. 3. These results are also shown in Table 1. As can be seen there is a close agreement between the results of the two methods.

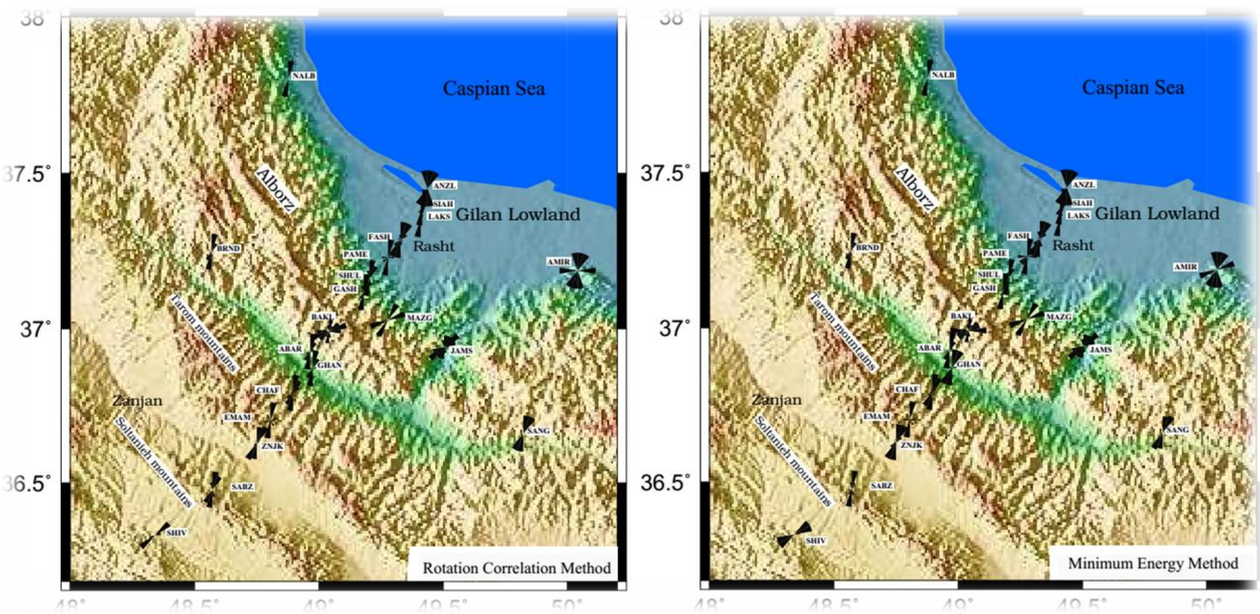

Figure 2. Rose diagrams of fast axis measurements. Left) Rotation correlation method, Right) Minimum energy method.

The average fast-axis azimuth and delay time obtained from the rotation correlation method are 22 ± 4 and 1.5 ± 0.2 sec, respectively and for the minimum energy method these values are 21 ± 5º and 1.5 ± 0.1 sec, respectively. The general trend of the fast axes is NE-SW.

Table 1. Calculated anisotropic parameters for each station by the minimum energy and the rotation correlation methods.

No.	Station	Latitude	Longitude	RC				ME			
				φ	δt	φ error	δt error	φ	δt	φ error	δt error
1	ABAR	36.92	48.96	23	1.3	4	0.16	17	1.4	11	0.05
2	AMIR	37.18	50.04	39	1.0	11	0.43	25	1.1	2	0.5
3	ANZL	37.45	49.43	7	2.1	0.6	0.06	3	2.1	5	0.09
4	BAKL	36.99	49.04	41	0.9	3	0.23	62	1.3	17	0.15
5	BRND	37.24	48.56	17	1.3	2	0.18	26	1.5	6	0.01
6	CHAF	36.79	48.89	20	1.2	1	0.33	18	1.7	0.8	0.17
7	EMAM	36.70	48.80	38	1.6	20	0.27	24	1.7	5	0.25
8	FASH	37.28	49.32	15	2.3	2	0.02	16	1.6	4	0.03
9	GASH	37.11	49.18	13	1.5	0.1	0.12	17	1.8	6	0.11
10	GHAN	36.87	48.97	12	1.6	7	0.18	24	1.2	5	1.6
11	JAMS	36.94	49.50	41	0.9	6	0.16	25	1.0	11	0.06
12	LAKS	37.35	49.40	14	1.6	0.1	0.08	10	1.6	2	0.06
13	MAZG	37.02	49.27	49	2.0	4	0.15	37	2.0	6	0.01
14	NALB	37.80	48.87	15	2.1	0	0	14	2.2	0	0
15	PAME	37.22	49.27	35	1.0	2	0.24	30	1.0	2	0.23
16	SABZ	36.47	48.57	10	0.8	2	0.26	24	1.0	11	0.06
17	SANG	36.66	49.82	21	1.3	0.2	0.29	23	1.7	2	0.03
18	SHIV	36.34	48.34	55	1.4	2	0.01	59	1.4	6	0.03
19	SHUL	37.16	49.20	14	1.1	2	0.31	15	1.3	5	0.12
20	SIAH	37.39	49.41	23	1.5	2	0.13	19	1.6	2	0.04
21	ZNJK	36.63	48.72	25	1.1	0.2	0.19	27	1.2	2	0.11

A relative uniformity is seen in the directions of the fast axes. The change of direction across different tectonic regions is smooth and no abrupt variation is seen in the region. Stations in the Geelan lowland region are a bit more northerly oriented than those in the mountainous regions further south.

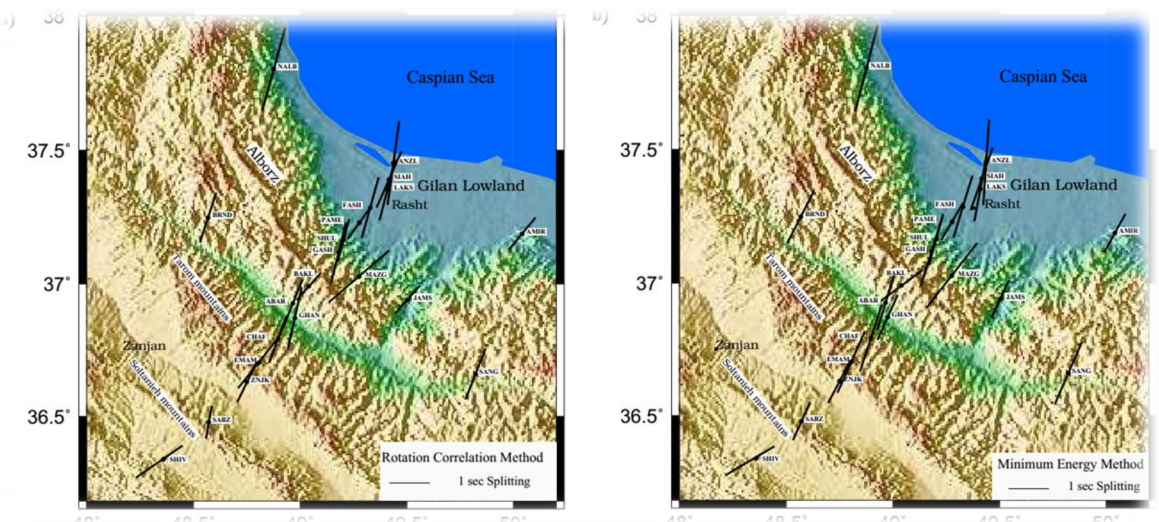

Figure 3. Weighted average of the obtained results via two methods: a) The Rotation Correlation, b) The Minimum Energy

DISCUSSION AND CONCLUSIONS

We obtained a number of null measurements in all stations. Measurements which have linear particle motion and little energy on transverse component are called null. Null measurements are generated from S wave propagation in an isotropic medium, or when the initial polarization direction is parallel with the fast or slow axis. A third possibility is that the assumed model of anisotropy is not true. In this study it is assumed that the model of anisotropy is hexagonal and single layer. Existence of null measurements can shows us that the anisotropy follows another model. Fig. 4 show null measurements at two stations.

The average of fast axis azimuth in the northern part of our study area (in SHUL, PAME, FASH, LAKS, SIAH and ANZL stations) is 18 ± 1.1خ and 17 ± 3.8خ for the rotation correlation and the minimum energy methods respectively, while in the southern part of region (in SHIV, SABZ, ZNJK, EMAM, CHAF, GHAN, ABAR, BAKL and GASH stations) these values change to 27 ± 0.9خ and 25 ± 6.9خ for the rotation correlation and the minimum energy methods respectively. These results are obtained from waveforms with signal to noise ratio greater than 3. This difference is no more than 8 degrees, but can point to a contrast in the nature of the lithosphere and upper mantle structure between the two regions. The South Caspian Basin is most probably a piece of oceanic lithosphere floored by an oceanic crust. The location of its southern boundary and its transition to continental Alborz, however, remains unknown, and it is unclear whether the Caspian lowlands are part of the south Caspian Basin or the continental crust of northern Iran.

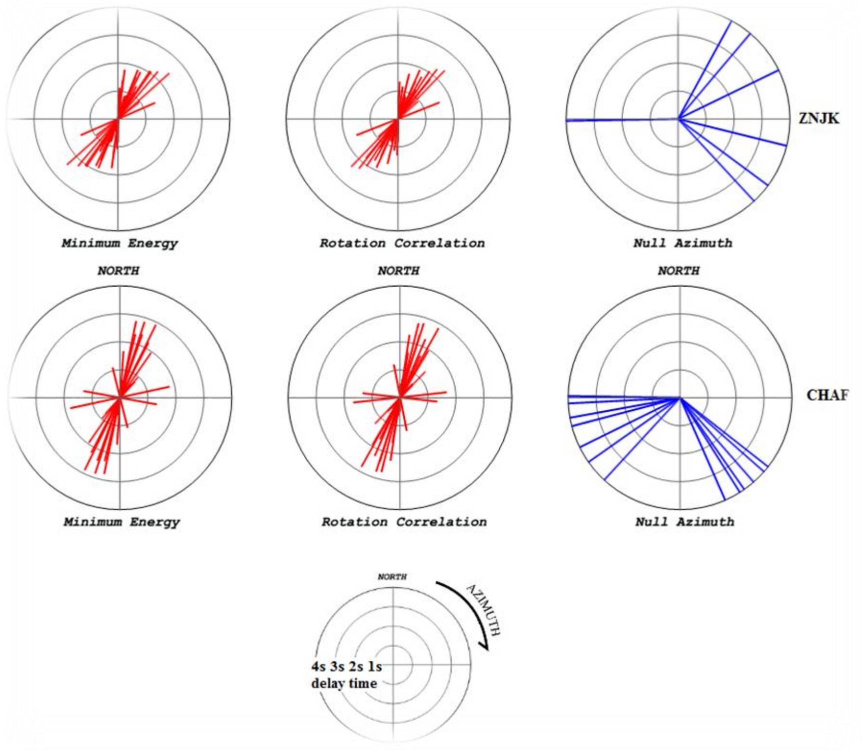

Figure 4. Null and non-null measurements obtained in ZNJK and CHAF stations.

We suggest that the different fast axis directions in the north of the Alborz Mountains may indicate that the lithospheric structure in the Geelan region may be different from that in the Alborz region. The fast axes make a sharp angle with the trend of the mountain ranges; the Alborz, the Tarom and the Soltanieh Mountains. As seen in Fig. 5 these directions are sub parallel to the motion of Iran in the no-net-rotation frame of reference. In this respect, these results are in accord with previous results obtained in north western Iran (Arvin, 2013) and in eastern Turkey (Sandvol et al., 2003). The shear wave splitting results are interpreted as indicating the mantle flow in the asthenosphere beneath Iran.

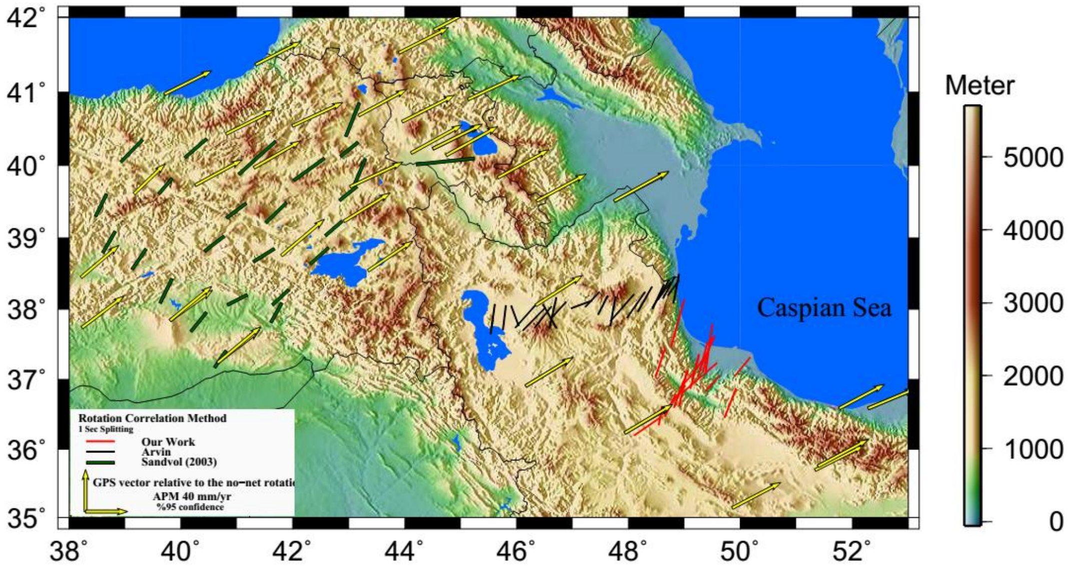

Figure 5. Fast axis directions and GPS vector in eastern Turkey and NW Iran. Fast axis are from our work (red), Sandvol et al. (2003) (green) and Arvin (2013) (black). GPS vectors are in the no-net rotation frame of reference and are taken from Kreemer et al. (2003).

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