UNESCO Chair on
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Geological Survey of Iran

Abstract:

The Talesh mountains, with a N-S trend located in the south west of the South Caspian Basin, is a part of the Alp- Himalia seismic belt. Due to the heavily populated cities (such as Astara, Talesh, Rezvan Shahr etc.) with about 3,000,000 population and forest coverage of the studied area, there is a huge amount of uncertainty concerning the Astara Fault System and its properties, which hinders all attempt for execution of morphotectonic investigations and seismic hazards analysis. In addition to seismic hazards analysis, the secondary phenomenon like extensive landslides and rock falls, the danger of tsunami is incident due to the earthquake event in the South Caspian Basin.

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Seismotectonics and Morphotectonics of the Talesh mountains

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Seismotectonics and Morphotectonics of the Talesh mountains

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ABSTRACT

The Talesh mountains, with a N-S trend located in the south west of the South Caspian Basin, is a part of the Alp- Himalia seismic belt. Due to the heavily populated cities (such as Astara, Talesh, Rezvan Shahr etc.) with about 3,000,000 population and forest coverage of the studied area, there is a huge amount of uncertainty concerning the Astara Fault System and its properties, which hinders all attempt for execution of morphotectonic investigations and seismic hazards analysis. In addition to seismic hazards analysis, the secondary phenomenon like extensive landslides and rock falls, the danger of tsunami is incident due to the earthquake event in the South Caspian Basin.

The Astara Fault System, with a total length of about 110 km and general dip toward west, forms the boundary of Talesh Mountains with Caspian Coastal Plain. Based on the morphotectonic studies, it is believed that most of present shortening in Talesh, is concentrated in the eastern front of this mountain along the Astara Fault System.

Geometrically, the Astara active fault, can be assumed as a wide zone, which consists of two majore faults: First, the Astara Thrust Fault (ATF), with three segments, is a nearest fault to the Talesh Mountain slop. The second major faults (ASF), is Astara strike-slip, which consists at least of two segments in the coastal plain.

The maximum measured horizontal displacements in ATF1, ATF2 are 1500 m and 840 m respectively. The minimum horizontal displacements along ATF2 and ATF3 are 90 m and along ASF2 is 70 m. The maximum measured vertical displacement along the ATF2 is 130 m., and minimum measured vertical displacement along the ATF and ASF are 10 and 5 m respectively.

The estimated rake angles for different segments varies from 0° to 12°. The estimated average slip-rate of the fault is about 1.5 mm/yr.

Historical seismic data regarding Astara Fault activities are not clear. However, the southern part of Astara Fault is assumed to be the source of historical earthquakes to Rasht City in 1709 AD and 1713 AD.

With respect to geometrical characteristic of the South Caspian Basin and eastern transgression of the fault, together with more than 20 km thickness of Cenozoic deposits, a seismic large event is not out of mind.

1- INTRODUCTION

The Iranian plateau is an extensive active crustal deformation and seismic activity zone located between the stable Arabian and Eurasian plates. Its present high elevation, active deformation, and seismicity with complex interactions of active thrusts and strike-slip faults are caused by the driving convergence forces of plates. The plateau is characterized by different tectonic units which inherited structures organized in diverse directions that have undergone long and complicated plate tectonic evolution since the Late- Proterozoic Era. The plateau consists of a composite system of collision-oblique transpresive fold-and-thrust mountain belts with active subduction zones.

The Alborz mountains of northern Iran form a high arc of mountains with pronounced topography around the southern coast of the Caspian Sea form the Talesh in the west to their junction with the Kopeh Dagh in the east. It forms part of the northern margin of the Arabian-Eurasian collision zone joining the Lesser Caucasus of Armenia in the northwest to the Paropamisus Mountains of northern Afghanistan in the east. The structural trend of the Alborz change from N110°E in the west to N80°E in the east, with a marked hinge at about 52-50°E with its restricted width of 60-120 km, the Albors is extremely steep, with flanks that abruptly going the plain along major fault on belt sides.

To the west, the Alborz joins the Talesh mountain, a N-S range along the western coast of the Caspian Sea. The Talesh is narrower than the Alborz, with a typical width of 150 km.

The range is dominated by N-S folds and thrusts, which swing smoothly in to an E-W trend at the northern and of the range where it meets the flat plains of the

Kura Basin (Berberian, 1983; 1997). The range contains a thick Paleogene volcano-clastic sequence.

The Astara Fault System (AFS), with a total length of about 110 km, and a general dip towards west, is located in the northwest Central Alborz, east of the Talesh Mountains and west of the South Caspian Sea.

1-1- TALESH MOUNTAINS

Generally, the most topographic feature of the studied area, is Talesh mountains, which is located west of the South Caspian depression. The highest peak of this mountain range is about 3065 m above the sea-level, and with a sinus shape, forms the mountain belt of the northwest Iran and southeast of the Azerbaijan territory (Figure 1). The rocks that have formed Talesh Mountains are the same as Alborz Mountain rocks and including thick Paleogene andesitic volcano-elastic sequences (Jackson et al., 2002). The interaction between Talesh and Alborz with the South Caspian Basin and the rotation of South Caspian Basin have an impact on the structural shaping of the southern and northern faces of Talesh Mountain, respectively. Thus, the deformations in northern and southern parts are more elastic than in the central of the Talesh Mountains (Zanjani et al., 2013). Talesh Mountain is a curved fold and thrust belt with N-S direction, but towards the north where Talesh Mountain meets the Kura Basin, the thrust trend is inclined to an E-W direction (Jackson et al., 2002 ; Allen et al., 2003).

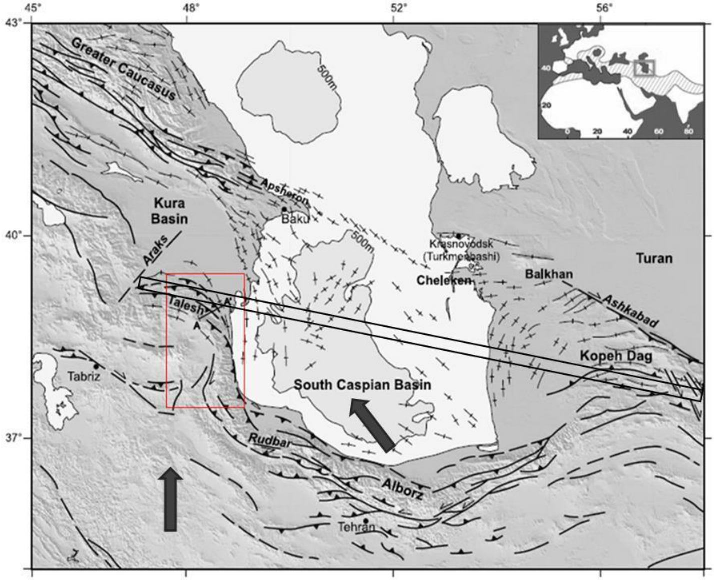


Figure 1: Structural map of the South Caspian basin and Talash thrust belt (Jackson et al., 2002) in the red rectangular box, the western bank of the South Caspian basin and the Talash thrust belt are limited from the north to the Kora subducted basin The from east to the Little Caucasus, and to the Alborz belt from the south. The direction of movement of the Iranian plate and the South Caspian basin relative to Eurasia is indicated by arrows.

The earthquake mechanisms of Talesh Mountains are different from those of Alborz Mountain and they are clear indicators of almost flat faults at depth of 15-26 km, which are deeper than the depth observed at Alborz Mountain and slip vectors are inclined towards the Caspian Sea. The focal depth of earthquakes clearly indicates underthrusting of the crystalline basement of the Caspian westwards underneath the Talesh Mountains (Figure 2). Based on reconstruction of folding and thrusting, the shortening of the northwest part of Talesh Mountain is estimated to be about 25 km, which is similar to shortening of the SW part of Alborz Mountain (Jackson et al., 2002). Zanjani et al., 2013 are believed that the depth of seismicity along the Caspian coast line to vary from 20 to 47 km, but in the west of Astara Fault System the depths are in the range of 20-25 km.

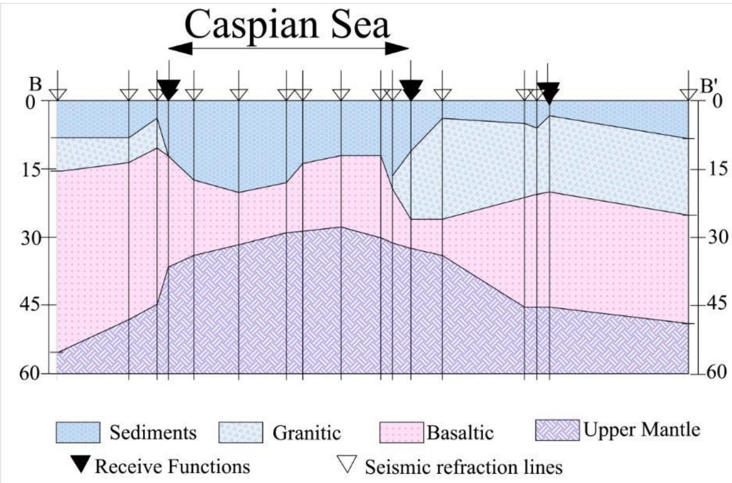


Figure 2: Cross-section of the crust and the upper part of the mantle between the Kura Basin and the western part of the South Caspian Basin, Turkmenistan and the Kopeh Dagh Mountains in the east. In general, this section includes four rock units of sedimentary rocks with a low speed of seismic waves, upper granite crust with a speed of P waves of 5.6 – 8.5 km/s, lower basalt with a speed of P waves of 5.6 – 8.7 km per second and the upper mantle. Dashed lines at a depth of 35 km indicate the Moho depth (Jackson et al., 2002).

The paleomagnetic data, suggests a clockwise vertical axis of rotation of about 18°-20° in Talesh Mountains. This is a common phenomenon in back-arc systems, especially in areas where subduction zones are severely curwed (Kissel and Laj, 1988). Obtained mechanism for divergent and transpressional zones, are the same for Neo-tethys roll back subduction zones (Figure 3) (Dewey, 1980 ; Brunet et al., 2003). Based on the Ar-Ar dating, the second phase of Talesh volcanic activity, stopped in Middle Eocene, which is contemporaneous to the rate of sedimentation of about 64 cm/k.y.

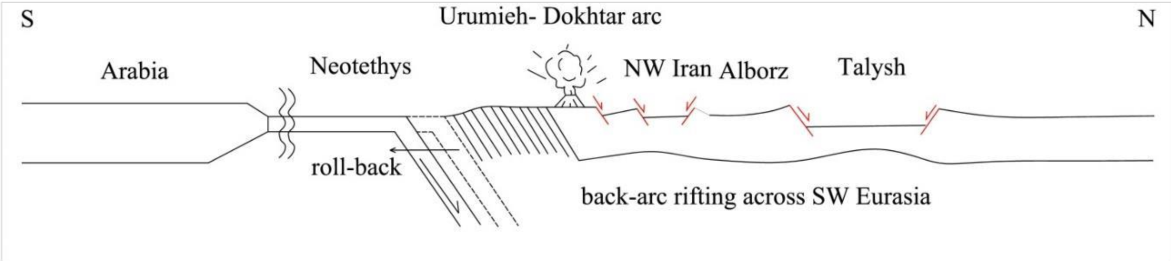


Figure 3: Schematic cross-section showing the roll back phenomenon of the Neotethys and the sequence of magmatism and extension in South West Asia (Vincent et al., 2005).

1-2- EVOLUTION OF THE SOUTH CASPIAN BASIN

Geological and seismological data indicate underthrusting (or subduction) of the South Caspian Lithosphere underneath the Apsheron, and contemporary movement of the South Caspian micro-plate towards the west. The boundary of South Caspian Basin in the eastern part of the block, using deformations and seismological data, is easily recognizable (Figure 4). Towards the east, the South Caspian Micro-plate, is bounded by the Alborz-Binalud fold systems, which has diverging characteristics, together with rotational over thrusting towards both north (south edge of the South Caspian Basin) and south (central Iran). The amount of lateral motion of the South Caspian Micro-plate estimated to be 35 km, even, it seems it is overestimated. This figure, based on the underthrusting of South Caspian Basin basement, underneath the eastern Caspian Fault, and its continuation towards the south (Figure 4 & Figure 5). It is probable that the South Caspian Basin moves with a rate of 8-10 mm/yr northwest or north northward direction towards Eurasia, and 13-17 mm/yr in the southwest direction towards Iran (Jackson et al., 2002; Figure 5).

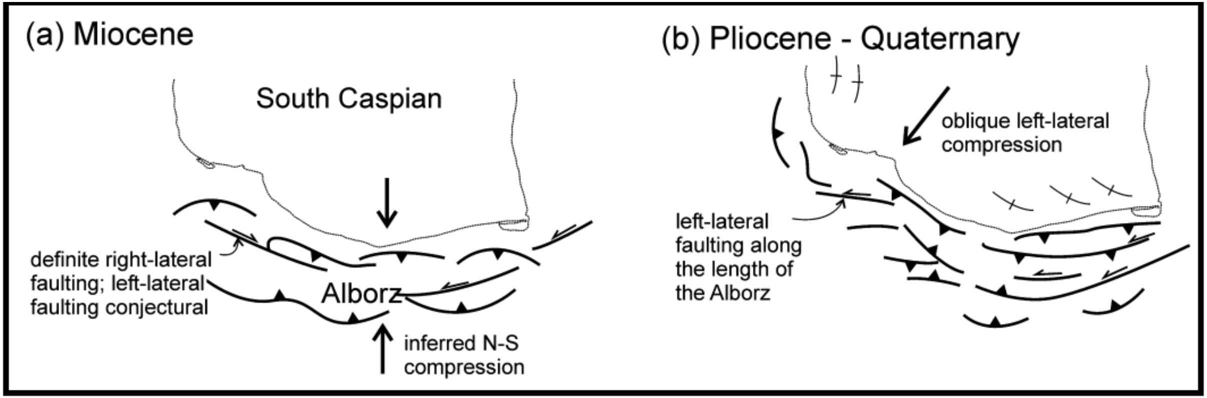


Figure 4: Cenozoic structural evolution in Alborz. a) The Miocene compressive deformation is accumulated by strike-slip faulting, which is probably due to the conjugate of right-lateral and left-lateral strike-slip faults. b) From Pliocene to the recent, continuity of compressional deformation of left-lateral strike-slip faults along the Alborz mountain, due to the west movement of the south Caspian basin with regard to Iran (Allen et al., 2003).

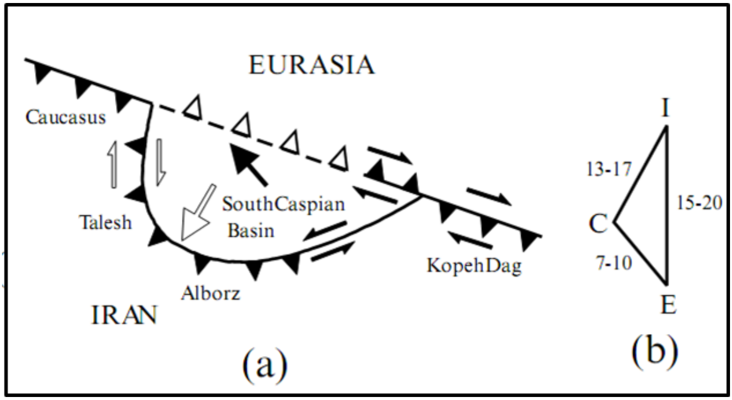


Figure 5: A schematic plan of the tectonics of the southern Caspian basin (Jackson et al., 2002). a) The current configuration shows subduction in Kopeh Dagh, Alborz, Talash and Eastern Greater Caucasus, and subduction with a dip towards the north under the Central Caspian. Pay attention to the left-lateral movement in East Alborz and the right-lateral component in Kopeh Dagh. The white arrow indicates the movement of the South Caspian Basin relative to Iran and the black color indicates the movement relative to Eurasia. b) The velocity triangle indicates the relative movement between Iran (I), Eurasia (E) and the South Caspian Basin (C) (velocity in terms of mm per year).

1-3- CRUST STRUCTURE IN NORTH IRAN

According to Dehghani and Makris (1983), depth of Moho is 25 km along the Caspian Coastal plain, 50 km in Azarbaijan, and about 35 km in Talesh Mountains (Figure 6). Mangino and Pristley (1998), believe that crust of the SW and SE of the Caspian basin is about 30-33 km.

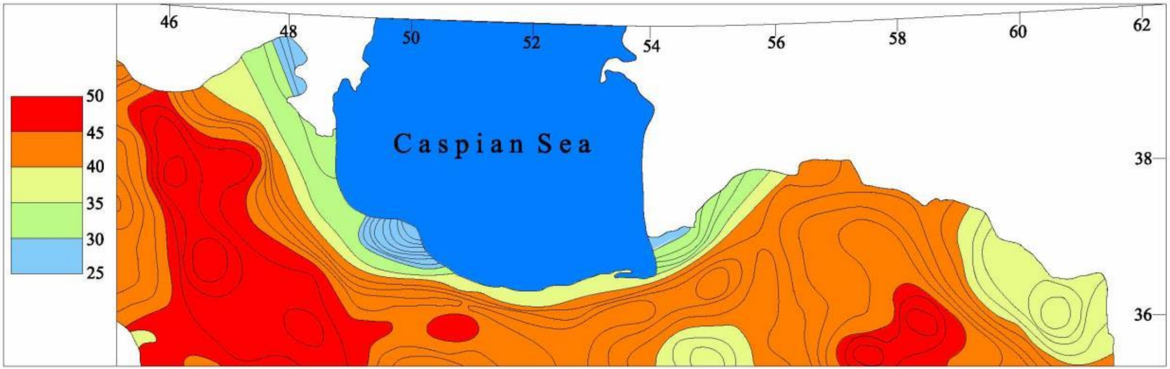


Figure 6: Iran's crustal thickness based on the depth of Moho gravimetry (Dehghani and Makris, 1983), the distance of the contour curves is in kilometers.

2- SEISMOTECTONICS

2-1- SOUTH CASPIAN BASIN

Several Investigation support the idea that interior part of the South Caspian Basin in compare with the Talesh Mountains is relatively aseismic (Pristley et al., 1994 ; Jackson et al., 2002).

2-2- TALESH REGION

Seismological observations reveal a specific seismic zone in a distance of 52 km from the margin of the Caspian Sea, east of the Astara Fault, along the Caspian Coast. The depth of seismic zone varies between 22 to 47 km, indicating the under-thrusting of the stable South Caspian Plate, underneath the Talesh Mountains (Pristley et al., 1994 ; Jackson et al., 2002).

Earthquake mechanism in Talesh are completely different with Alborz (Figure 7), which including activity of thrust, and very often planer faults (less often can be observed in Alborz), with depth of 15-26 km (deeper than Alborz) (Figure 8). Central depth of the seismic events is located in the lower part of sedimentary sequences. This phenomenon indicating a crystalline basement thrust in eastern Caspian and underneath the Talesh Mountains (Jackson et al., 2002).

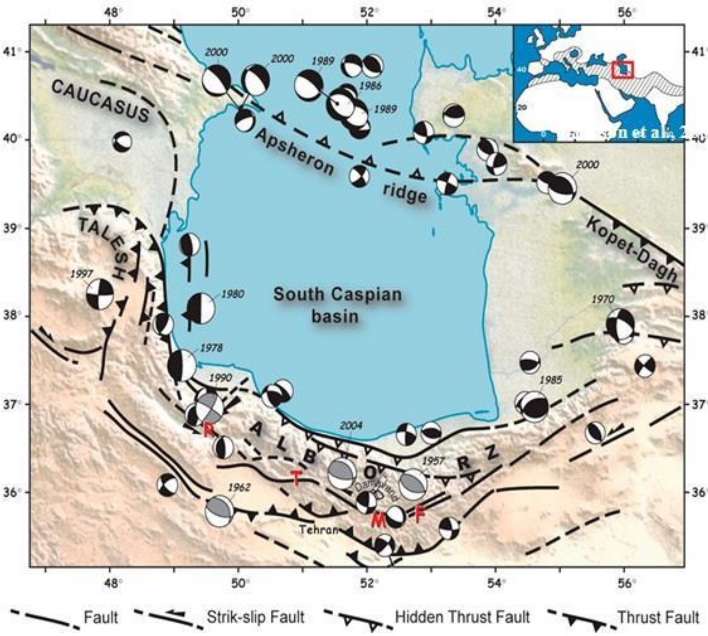


Figure 7: Scismotectonics map of the South Caspian region and its surrounding regions (Nazari, 2006).

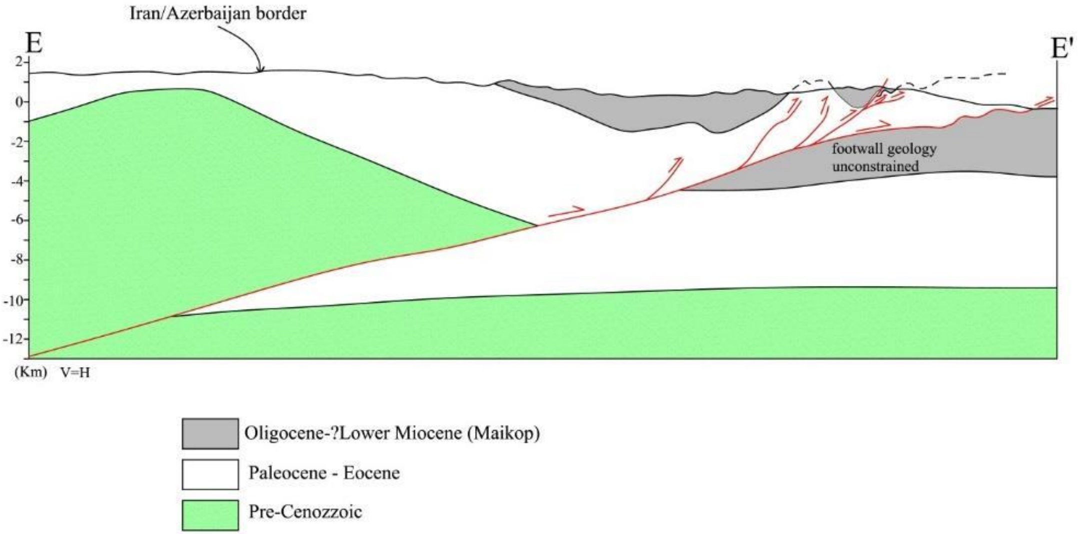


Figure 8: A schematic plan of the cross-section of North-East Talash in Azerbaijan. Most of the large earthquakes have occurred in the basement thrust at a depth of 10-20 km in Iran-Azerbaijan region. In contrast, the folding of young sediments occurs farther from the coast in the northeast (where the thrusts have penetrated to shallower areas). Horizontal and vertical scales are equal (adapted from Jackson et al., 2002 with slight modifications).

Seismicity in Talesh Mountains is characterized by infrequent events, in the lower crust, indicating westward under-thrusting of South Caspian Basin underneath the Talesh Mountain belt (Engdahl et al., 2006).

The epicentral regions of 16.04.1913, 11.08.1970, and 04.11.1978 (Siahbil earthquake), coinciding with Astara fault. Berberian (1983), believes that the 04.11.1978 Siahbil earthquake (Ms 6.0 and mb 6.1), is the result of activity of southern part of the Astara Fault. Body wave modelling of this earthquake indicate an event with trend of 168°, and dip of 90° WSW, and depth of 20±4 km (Berberian, 1983). Jackson et al., (2002), believe that depth of earthquakes due to the Astara fault activity, are 15 -22 km, with gentle dip towards the east. No earthquake data is available for Astara Fault, but 1701 and 1713 events might be related to activity of the southern part of this fault (Tchalenko, 1974).

2-3- ASATARA FAULT SYSTEM

The Astara Fault System with N-S trend and a length of about 110 km, is located west of the Caspian Coast, forms the boundary of Talesh Mountains with the Caspian Coastal Plain. Most of the fault trace is covered by coastal deposits of the Caspian Plain.

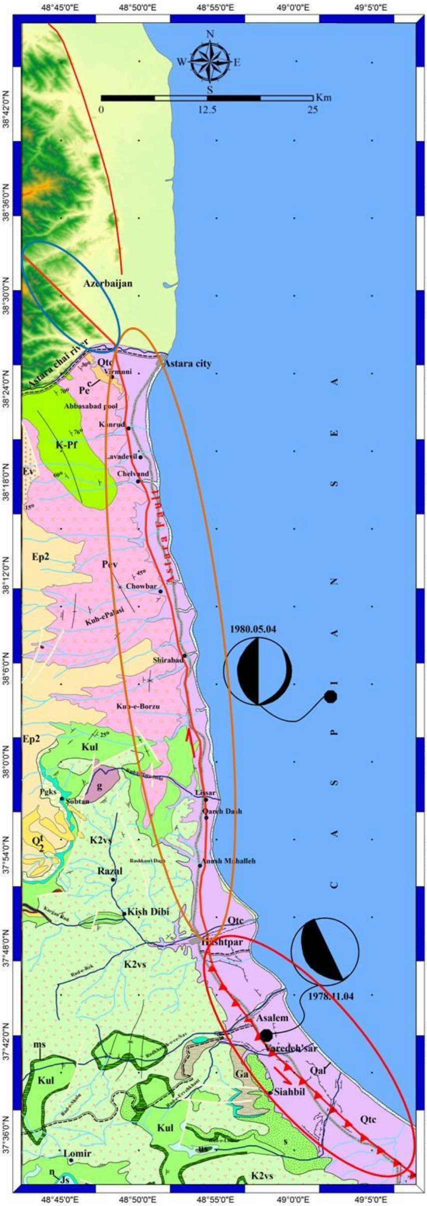
The morphological indices (shutter ridges, fault scarps, offset streams, …) together with gradual subsidence along the Astara mountain bordering fault, indicating the activity of the Astara Fault System.

2-3-1- SEGMENTATION OF THE ASTARA FAULT SYSTEM

Major faults, based on their structural characteristics, or rupture behavior during earthquakes, can be divided into different segments.

The first step for Astara Fault System segmentation, is to understand the trend varieties along the fault, on the basis of available geological maps and documents. In this regards, the Astara Fault can be divided to three major segments (Hessami et al., 2003; Berberian, 1997). (Figure 9 & Table 1).

- First Segment: with a NNW-SSE trend, located in southwest of the Caspian Basin, which caused the 4 Nov. 1978 Siahbil earthquake (Mw 6.1).
- Second Segment: with a N-S trend, in the western part of the South Caspian Basin, and it seems that 4 May 1980 earthquake (Mw 6.3), occurred in this zone (Figure 9).
- Third Segment: with a NW-SE trend, is located in the republic of Azerbaijan, and probably is the causative of 9 July 1998 earthquake (Mw 5.6).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38°12'0"N
38°6'0"N
38°0'0"N
37°54'0"N
37°48'0"N
37°42'0"N
37°36'0"N
N
W
E
S
Km
0
12.5
25
Azerbaijan
Astara chai river
Astara city
C A S P I A N S E A
1980.05.04
1978.11.04
Qtc
Pe
Abbasabad pool
Kanrud
K-Pf
Lavadevil
Chelvand
Ev
Ep2
Pev
Chowbar
Kuh-ePalasi
Shirabad
Kuh-e-Borzu
Kul
g
Pgks
Subtan
Lissar
Qareh Dash
K2vs
Razal
Kish Dibi
Hashtpar
Asalem
Varedeh'sar
Qal
Ga
Siahbil
Lomir
Js
ms
s

Figure 9: Geological map of Astara fault system taken from geological maps scale:10,000 (Geological survey of Iran). Red, orange, and blue ellipsoids represent the first, second, and third parts of structural segmentation, respectively (Barzegari, 2015).

The second step for segmentation, is using earthquake catalogue.

In this respect four events selected for segmentation (Table 1). In this manner, the fault plane solution of earthquakes also indicating the trend varieties.

Table 1: Earthquakes selected in the first stage for Astara fault system segmentation.

Date			Time	Epicenter		Magnitude (M_w)	Refernece
Year	Month	Day		Latitude	Longitude		
1978	11	04	1522	37.17	48.97	6.12	Engdahl et al. (1998)
1980	05	04	1835	38.07	49.04	6.34	Engdahl et al. (1998)
1981	08	04	1835	38.2	49.43	5.52	Engdahl et al. (1998)
1998	07	09	1419	38.71	48.50	5.69	Engdahl et al. (1998)

With regards to the fault plane solutions, it seems that the mechanism of Astara Fault in first segment is thrust with left-lateral strike-slip component, dipping 9°-12° towards the west. This is coinciding to the fault plane solution of 4 Nov. 1978 Siahbil earthquake (Figure 10). It is worth to mention that the mechanism of recent motion of the South Caspian Basin (NW trend), toward the Eurasia, is right-lateral (Jackson et al.,2002) (Figure 5).

The mechanism of the second segment is right-lateral strike-slip fault with a minor reverse component. This is agreement with fault plan solution of 4 May 1980 earthquake (Figure 9 & Figure 10).

To come to conclusion, the Astara Fault System, based on the trend varieties can be divided in to three segments. First segment with NNW-SSE, second segment with N-S, and third segment (out of the Iranian territory) with NW-SE trends (Figure 9).

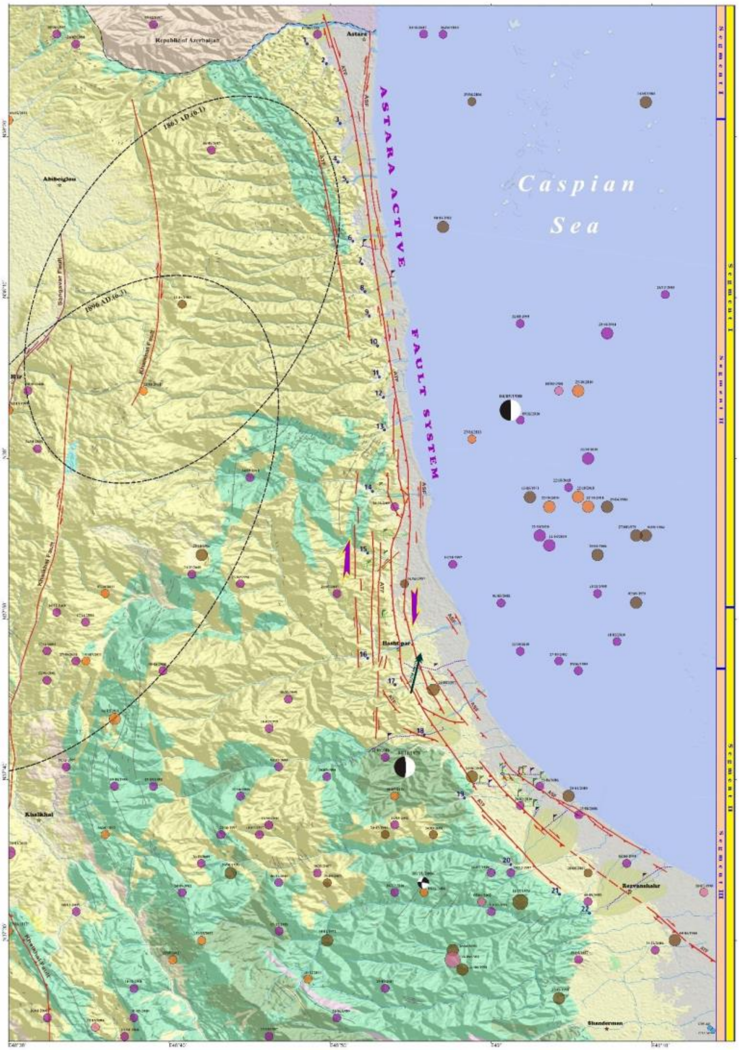

Figure 10: Seismotectonics map of Talash mountains

3- MORPHOTECTONICS

One of the most problems for recognition of morphological phenomenon along the Astara Fault System is forest coverage. It is worth to mention that using LIDAR images are very useful for this sort of regions, but unfortunately these images did not available for this study.

3-1- MORPHOTECTONIC EVIDENCES IN THE EAST SIDE OF THE FAULT

As mentioned earlier, even GPS slip vectors in Talesh indicating right-lateral movement, although earthquakes fault plane solutions point out only reverse components. Based on this investigation, in the eastern part of Talesh, the Astara fault, introduced as a fault zone with right-lateral strike-slip and reverse components (Figure 10 & Table 2). Moving from north to southern part, the reverse component increased.

Table 2: Seismotectonics and morphotectonic characteristics of Astara fault system.

Fault Name	Segment	Length (km)	Azimuth	Dip	Mechanism	H (m)		V (m)		Rake/ Segment	Slip rate (mm/yr)	Earthquake related	
						H_{min}	H_{max}	V_{min}	V_{max}			Instrumental	Historical
Astara Thrust Fault (ATF)	1	≤13	346°	70°-80°	Right-lateral Strike slip, Thrust component	190	1500	10	15	0.3°-4°	~ 1.5	24/06/1903; mb= 5.5 (AMB) 24/06/1907; Ms=5.9 (AMB) 11/07/1970; mb=5.2 (EHB) 04/11/1978; Mw=6.3 (EHB) 04/05/1980; Mw=6.5 (EHB) 05/11/2006; Mn=5 (ISC) 23/03/2008; Mn=5 (ISC)	1709 A.D. ?? 1713 A.D. ??
	2	≤63	354°	80°-90°	Right-lateral Strike slip, Thrust component	90	1000	10	130	5.7°-7.2°			
	3	≤32	322°	60°-70°	Thrust, Right-lateral component	90	9000	10	95	6.3°-11.9°			
Astara Strike slip Fault (ASF)	1	≤40	356°	80°-90°	Right-lateral Strike slip	80	840	5	30	1.9°-6.8°			
	2	≤24	316°	60°-70°	Thrust, Right-lateral component	70	500	5	40	0.6°-4°			

3-1-1- LINEAR VALLY

This phenomenon along the Astara Fault System can be observed in Saragah area, near Talesh city.

3-1-2- OFFSET STREAMS

The offset streams are formed in Havigh region, 27 km south of Astara and east of the Choobar village (Figure 11).

Figure 11: Cumulative dextral displacement of ~800m resulting from dextral slip of the Astara fault (red arrow) and the deviation of

the axis of the main river coarse (shown by the yellow arrow) in passing through the fault caused by the growth of the structure of compressional ridges due to The operation of the dextral shearing mechanism of the Astara fault in the west of Chobar village in the eastern slope of Talash mountains between Cretaceous pyroclastic and turbidite rock units and young deposits of the coastal plain.

3-1-3- FAULT SCARP

There are several fault scarps along the Astara active fault. Figure 12, is one of the fault scarps, with E-W trend and about 3 m. throw, near Gisum village, 5 km south of Asalam.

Figure 12: ~ 3 meter fault scarp near Gisum village, about 5 kilometers south of Asalem.

3-1-4- PRESSURE RIDGE

The pressure ridges can be seen in the vicinity of Talesh city, near Choobar and Paysara villages (Figure 11). Fast of the Choobar village, a pressure ridge caused 800 m cumulative right-lateral displacement in the river course, along the Astara Fault System.

3-2- SLIP RATE

The average mid-time displacement of the Astara Fault is about 307±30. Supposing this displacement occurred within the past 10,000 years, and considering angle of rake to be 5°, the horizontal and vertical slip-rates are 2.8±0.2 mm/yr, and 2.8±0.03 mm/yr, respectively. To bring to an end using obtained radiometric ages (Table 2 & Table 3), the total estimated slip rates will be 2±0.16 mm/yr (Table 2). Considering the maximum and minimum measured rake angles of the fault, the amount of horizontal slip rates from the total slip rate is 1.8±0.1, and vertical slip rate is 0.25±0.5.

Table 3: slip rate based on observed dextral displacement in Lisar river and 6 radiocarbon dating.

Displacment	Reference sample	Median Date (Cal BP)	Slip Rate (mm/Year)	Average Slip Rate
35000 mm	ASFT1-C1	27444	1.3	2±0.16
	ASFT1-C2	32335	1.1	
	ASFT1-C3	12855	2.7	
	ASFT1-C4	12868	2.7	
	ASFT1-C5	12931	2.7	
	ASFT1-C6	12910	2.7	

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