CORRELATION BETWEEN B-VALUE AND DIFFERENT STYLES OF FAULTING IN THE CASPIAN SEA REGION

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ABSTRACT

The South Caspian Basin is a part of the Alpine-Himalayan seismic belt. This basin is limited from all sides by active earthquake belts. The diversity of the focal mechanism of earthquakes on the margins of this basin shows the complex tectonic activity of the region including strike slip faulting, large and small angle thrusting, and normal faulting. Data analysis shows that the b-value of the Gutenberg Richter Relation is variable in the region and is correlated to faulting style. While the highest b-values belong to the normal events, thrust events have the lowest b-values and Intermediate values mark strike-slip faulting. In the Caspian Sea basin, earthquakes occurring in the Apsheron-Balkhan seismic belt are deep with normal focal mechanism and b-value map shows an overall b-value for this region of about 1.2, whereas in the Talesh, western Alborz and eastern Kopeh Dag, where the dominant faulting mechanism is thrusting, low b-values can be extracted, of approximately 0.5. In the central Alborz and eastern Apsheron-Balkhan, strike-slip faults result in intermediate b-values. This also introduces the b-value as a stress-metre.

INTRODUCTION

The Caspian Sea is the largest closed body of water on Earth with a surface area of around 380,000 km2. This sea measures around 1,180 km North-South (between latitudes 36° and 47°) and as much as 480 km East-West (between longitudes 49° and 54°).It is a remnant of the Tethys Ocean that became landlocked about 5.5 M years ago due to plate tectonics (Kroonenberg et al., 2007). Five different countries border this sea, namely Iran, Turkmenistan, Kazakhstan, Azerbaijan and Russia (Fig. 1).

It is conventional to consider the basin of the Caspian Sea as having three parts (Froehlich et al., 1999; Kaplin and Selivanov, 1995):

A northern part, with a mean water depth of only 10 m,

A central part, where the water depth increases up to 788 m,

A southern part, wherein the water depth increases up to 1025 m.

Globally, the Caspian Sea region is a part of the Alpine-Himalayan seismic belt which is one of the two major seismic belts on Earth, and it is also surrounded by seismic active belts of earthquakes. Moreover, intense past seismic activities are apparent in the geological and tectonic setting of the region.

lowland plains, in the south eastern margin of the Caspian depression, have low slope and smooth surfaces starting in the mountainside toward the plains, and gradually reach areas with lower elevation. In this section, due to suitable climate conditions, for agriculture, lands have become modelled into gentler and move rounded shapes. In the southern margin, there is still evident morphology of the foothills and plain-like areas, which have been covered by marine terraces or younger alluvial deposits (1:100000 geological map of Gorgan, Geological Survey of Iran, www.gsi.ir). Available geological evidence shows that the faults between mountains and plain have played a fundamental role in tectonics. The south western area lacks apparent outcrops and is covered by young alluvial deposits. That is why there is a lack of geological data in this area. In northeast Iran and south Turkmenistan, southeast of the Caspian basin, morphology of Kopeh Dag Mountains range is observed (Fig.1). This NW-SE range of mountains is elevated up to 3000 m in its central and eastern parts but become lower towards the west where reaches lowland plains (Jackson, et al. 2002).

The Talesh Mountain range is oriented in a North-South direction along the western coast of the Caspian Sea in Iran and Azerbaijan. This zone is the westward continuation of the Alborz, but in this section, it is narrower, with a width reaching less than 50 km.The structure of the Talesh Mountain range is composed of folds and the N-S thrusts which gently swing into E-W direction at the farthest northern end where it is joining with the flat of the Kura Basin (Berberian, 1997).

The Greater Caucasus is a relatively narrow and tall mountain range (200-100 km width). It is oriented between the Black Sea and the Caspian Sea in a NW-SE direction. The height of mountains in this tectonic zone reaches above 5,000 m, culminating in Mount Elbrus with a high of 5,642 m in the central part going down to its minimum height towards the East namely the Caspian shore in the Apsheron peninsula (Buryakovsky et al., 2001). In the core of this mountains range, metamorphic rocks indicate the past tectonic activities (Jackson et al., 2002).

The Caspian Sea basin is an active region including different fault types. This research looks for finding a correlation between faulting styles and seismicity parameters.

METHODS

TECTONIC SETTING OF THE REGION

Three layers form the crust beneath the Caspian Sea region. Generally, a granitic crust beneath the sedimentary layer is located above a basaltic lower crust but the granitic crust is missing under the South Caspian Basin and the sedimentary layer has become thickened (Figs.1, 2,).

Figure 1: South-North and West-East cross-section lines of the Caspian Sea Basin.
The Cross-Section is illustrated in Fig. 2 (Source map from: http://www.unep.org/).

Seismic properties of the crust in the northern Apsheron indicate a typical continental crust with a thickness of 50-45 km (Mangino and Priestly, 1998). In contrast, the crystalline basement of the South Caspian Basin shows properties of an oceanic crust with a thickness of 18-15 km. This thickness is unusual for an oceanic crust, which is generally about 7 km (Jackson et al., 2002).

Fig. 2 shows that the South Caspian Basin is underthrusting beneath the northern Caspian crust. Considering this subduction, the middle Caspian, namely the Apsheron-Balkhan sill, is expected to be an active region.

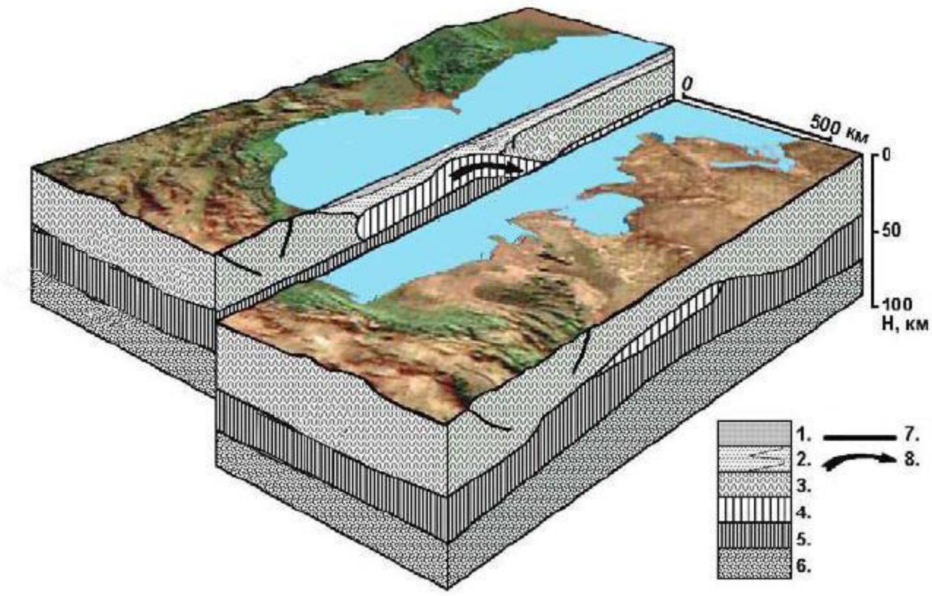

Figure 2: South-North cross-section (Fig. 1), showing a subduction process in the middle of the Caspian Sea. 1, water layer; 2, sedimentary layer; 3, granitic layer; 4, relicts of oceanic crust; 5, basaltic layer; 6, upper mantle; 7, major faults; 8, direction of subduction (after Ulomov et al., 2003).

The South Caspian Basin is one of the most important elements of collision between the Arabia and Eurasia plates. This basin, is apparently a rigid block, is limited from all sides by active earthquake belts, and is subducted beneath continental plates at its margin. Focal mechanism and depth of earthquakes on the margins of the South Caspian Basin is highly variable. Based on the earthquakes distribution over the Caspian Sea Basin the north part is almost without event while earthquakes have frequently occurred in the southern part. The diversity of the focal mechanisms in the west, east, south and middle of the Caspian Basin shows the complex tectonic activity of the region.

The South Caspian Basin, as an aseismic rigid block of about 300×300 km2, is surrounded by belts of intense earthquakes: Apsheron-Balkan, Kopeh Dagh, Alborz, Talesh, Kura Basin and Greater Caucasus (Fig.3).

Young thrust faults in Dagestan (northern side) have caused uplift and consequently deep notch drainage systems which follow the direction of the Caspian coastline and can be clearly seen on

Jackson et al., (2002) suggested that the Eastern Greater Caucasus is being thrust over the southern edge of the Russian plate. However, no seismic indicator has been observed for subduction of crust into the mantle. The earthquakes of 1668 and 1902 (M = 7) can probably be considered to be related to above meintioned thrusting (Berberian, 1997). Taking into account the straight direction of the Araxes River, Jackson and McKenzie (1984) proposed the presence of a northeast-southwest Strike-slip fault in the border between Iran and Azerbaijan.

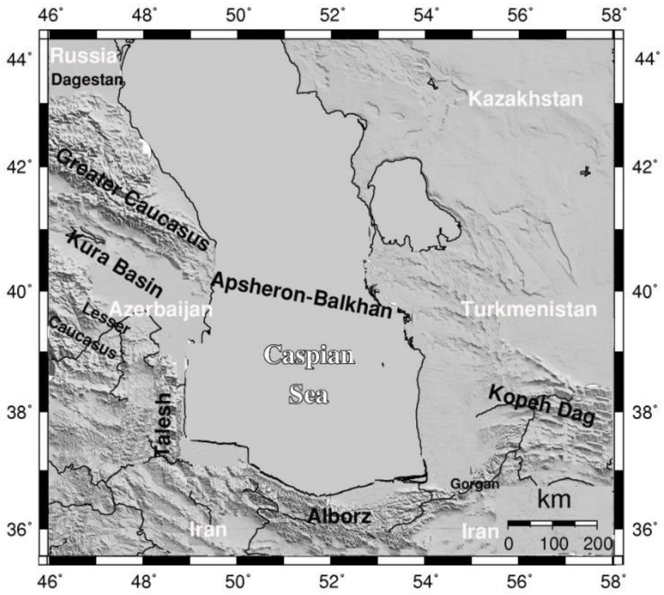

Figure.3. Active seismic belts

FREQUENCY MAGNITUDE RELATIONSHIP

The seismicity of a region refers to the type, size and frequency of the earthquakes that occur over a period of time. To evaluate the seismicity of a region, some other parameters of earthquakes should be taken into consideration such as the spatial and temporal variation, focal depth, and focal mechanism. The frequency-magnitude distribution of earthquakes is a statistical relationship which describes the number of earthquakes as a function of their magnitude. The frequency-magnitude distribution, FMD, of earthquakes in a given region can be described by a power law equation.

This equation was proposed by Ishimoto and Iida (1939) in the east and by Gutenberg and Richter (1944) in the west and is given as (Wiemer and Wyss, 2002):

$$\log N = \alpha - bM \qquad (1)$$

This relationship shows that the cumulative number of earthquakes, N, can be illustrated as a function of their magnitude, M . It means that N is the cumulative number of earthquakes with magnitude $\geq M$. The constant α, known as a-value, describes the general level of seismicity over a period of time in a study area. For example, a high a-value indicates a high seismicity in a given area. The parameter b, known as b-value, is the slope of the eq. 1, describing the relative number of large earthquakes to smaller earthquakes. For instance, a low b-value in a region indicates that the number of large earthquakes is more than that of small earthquakes.

Studies related to the b-value of the Gutenberg-Richter Power Law, frequency-magnitude distribution relationship, provide a leading source of information about the seismicity in a region (For example Wiemer and Wyss, 2002; Nuannin, 2006; Bhatt and Kumar, 2009).

To calculate the b-value in a region, it is important to consider the available data. A correct estimate of the b-value is dependent on completeness of the data source (Wiemer and Wyss, 2002).

For the Caspian Sea region the ISC catalogue is used for this research. Table 1 shows the four corner vertices of the Caspian Sea region in which the project's catalogues are defined. The created catalogue contains 3,499 events which occurred from 1931 to 2009 in the Caspian Sea region. In this section, all investigations are computed with the computer program ZMAP (Wiemer, 2001). ZMAP is an open-source code set of tools and is written in Matlab software. It is free and can be downloaded from http://mercalli.ethz.ch/~eberhard/zmap.zip.

At least 100 researchers, mostly seismologists, have applied ZMAP to analyze various catalogues (Wiemer, 2001).

Table1. Caspian Sea region.

Latitude	Longitude
36°N	46°E
36°N	55°E
48°N	46°E
48°N	55°E

In the first stage, a seismicity map of the region was plotted by loading data into ZMAP and the Caspian Sea shoreline was overlaid on the map (Figure. 4).

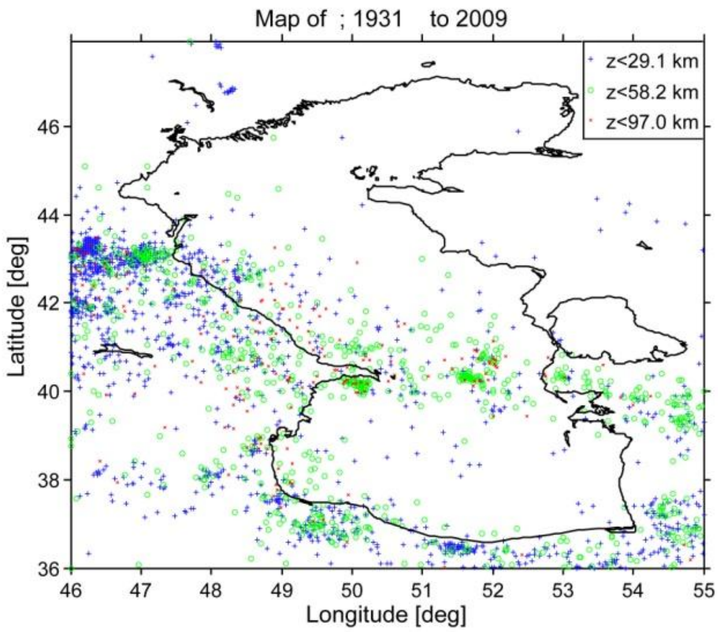

Figure 4.Seismicity map of Caspian Sea region (Based on ISC catalogue).

SPATIAL CHANGES OF THE B-VALUE

Most b-value investigations relate this seismicity parameter to the physical properties in an area (Wiemer and Wyss, 2002). For instance, a spatial variation map of b-values shows stress variations in the studied area. The spatial variation of the b-value over an area has been widely studied. It is believe that this parameter varies spatially over a region (Wiemer and Wyss, 2002; Schorlemmer et al., 2004).It is conventional that the global average of b-value is approximately one (e.g. Öncel and Wyss, 2000) but it has not been extended to some cases of seismicity such as induced seismicity (Nuannin, 2006) and volcanic areas (Schorlemmer et al., 2003). The regional variations of b-value are found to have a correlation with stress level variations. Laboratory experiments suggested a direct correlation between the b-value and material heterogeneity, also an inverse correlation between this parameter and the stress level (Scholz, 1968; Enescu and Ito, 2003) such that the temporal variation of the b-value can be suggested as an earthquake warning system (Weeks et al., 1978). It has been found that the b-value decreases with an increase in shear stress or effective stress (Wyss, 1973; Urbancic et al., 1992).

The b-value map illustrates stress variations in the studied. Spatial changes of b-value are mapped quantitatively using the maximum likelihood method (Wiemer and Wyss, 2002). Spatial mapping of the b-value can reflect the stress level and seismotectonics of the Caspian Sea region.

The maximum curvature method was applied to estimate minimum magnitude of completeness in each volume (Wiemer and Wyss, 2002). The area was gridded into cylindrical volumes using the constant radius method. Each volume has a radius of 50 km. This radius has to be at least as large as the grid spacing in order to make any sense. For grid spacing the centres of cylindrical volumes were positioned at nodes 10 km (0.10) distant from one another. The minimum number of earthquakes per gridcell is 20. The b-value was computed for every grid node and the b-value map was plotted (Fig. 5).

RESULTS AND DISCUSSION

Schorlemmer et al. (2005) suggested that the b-value can act as a stress meter. They explored the b-value for different types of faulting by analyzing several high quality catalogues. The listed earthquakes were categorized into thrust, strike-slip, and normal events regarding the rake angle. By plotting the b-values against the rake angles they found that in all samples the highest b-values belong to the normal events and thrust events have the lowest b-values. For the strike-slip faulting earthquakes they found intermediate values.

The faulting mechanism in the Caspian Sea region varies and the area can be approximately classified regarding the faulting styles . The South Caspian Basin was found to be surrounded by five active earthquake belts. It was realized that earthquakes in the Apsheron-Balkhan seismic belt are deep with normal focal mechanism. Fig. 5 shows an overall b-value for this region of about 1.2, whereas in the Talesh, western Alborz and eastern Kopeh Dag, where the dominant faulting mechanism is thrusting, low b-values can be extracted from the b-value map illustrated in this figure, of approximately 0.5. In the central Alborz and eastern Apsheron-Balkhan, strike-slip faults result in intermediate b-values. The correlation between faulting mechanism styles and the b-values in the Caspian Sea region can be clearly seen in Fig. 5.

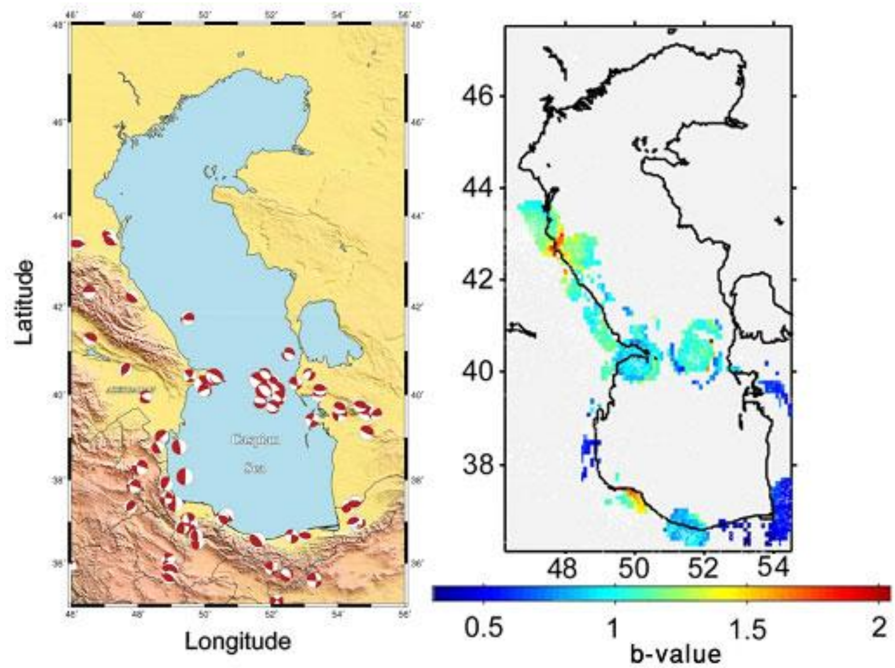

Figure .5. Faulting mechanism and the b-value. The left hand figure shows the faulting mechanisms (Obtained from IIEES) and the right hand figure shows the b-value map (data from the ISC catalogue) of the Caspian Sea region.

CONCLUSIONS

The Caspian Sea Basin, surrounded by several active belts of earthquakes, is a part of the Alpine-Himalayan seismic belt. Morphological and stratigraphical investigations documented in a variety of publications show an active tectonic for the Caspian Sea Basin and surrounding areas and almost all faults of the region can be regarded as active faults. In this research the b-value parameter of the Gutenberg-Richter Power Law was selected for examination. This parameter represents the relative occurrence of high and low magnitude earthquakes in a region; a low b-value indicates that the number of large earthquakes is greater than that of small earthquakes and vice versa. This parameter provides a leading source of information about the seismicity in a region (Wiemer and Wyss, 2002). It is believed that spatial variations of b-value show stress changes in the studied area (Wiemer and Wyss, 2002; Schorlemmer et al., 2004). Therefore spatial variations of the b-value in the Caspian Sea were mapped showing that values of this parameter have significant correlation with faulting mechanism styles in the region.

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