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Seismicity and Tectonics of the Black Sea

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Abstract

The Black Sea, a complex basin between the Arabian, Anatolian and Eurasian plates, is a feature of special interest for understanding the geologic history of the region. It was formed as a "back-arc" basin over the subduction zone during the closing of the Tethys Ocean. In this paper, we present the seismic activites and fault mechanisms of earthquakes in and around the margins of the Black Sea. An increase of broad-band seismic stations since 2005 around the Black Sea, especially in Turkey, has provided the capability for the detection, location and source mechanism studies of earthquakes in the Black Sea basins. The data show that there are a significant number of earthquakes in the Black Sea, mostly of magnitude M_w = 4.0 or smaller. The seismicity increases toward the margins, with the largest events at the margins. The focal mechanisms indicate primarily N-S compression with some E-W component. The mechanisms are consistent with the GPS observations, where Westward motion of the Anatolian Plate and N-S deformation of the Caucasus take up most of the motion of the Arabian Plate. Only small motions (about 1 mm per year) are transmitted through the Pontides, and the Black Sea is being compressed in N-S direction. In this study we locate and determine fault plane solutions of 25 recent earthquakes, with a magnitude higher than M = 3.7, in the region and combined these with existing network data from the margins, in order to determine the current tectonics.

Keywords

Black sea, Oceanic basins, Seismicity, Focal mechanisms, Stress analysis

Introduction

In the past few decades, the Black Sea has been the subject of intense geological and geophysical studies, including deep seismic sounding, reflection profiling, gravity and magnetic surveys for scientific and petroleum exploration purposes [1,2].

The region is controlled bythe collision of the Arabian and Eurasian plates of mid-Miocen age. This type of thrust generation as a result of compressional regime extends east-west.

Avagyan, et al. [3] deal with the recent tectonic stress evolution in the area, especially the Lesser Caucasus and adjacent regions. The present stress field, derived from the kinematics of active faults, corresponds to a strike-slip regime with both transtensional and transpressional characteristics. However, both the micro fault kinematic data and the distribution of Neogene to Quaternary volcanic clusters demonstrate changes of the stress field orientation through time since the beginning of the Arabia-Eurasian collision. A NW-SE orientation of compression was dominant between the Palaeogene and the late Early Miocene, a NE-SW orientation prevailed between the Late Miocene and the Quaternary.

According to previous GPS studies, the shortening rate axes are almost perfectly oriented at 45° to the fault plane for right lateral slip on the North Anatolian Fault (NAF). Shortening axes are normal to the thrust structures in the Caucasus [4-6] as shown in Figure 1.

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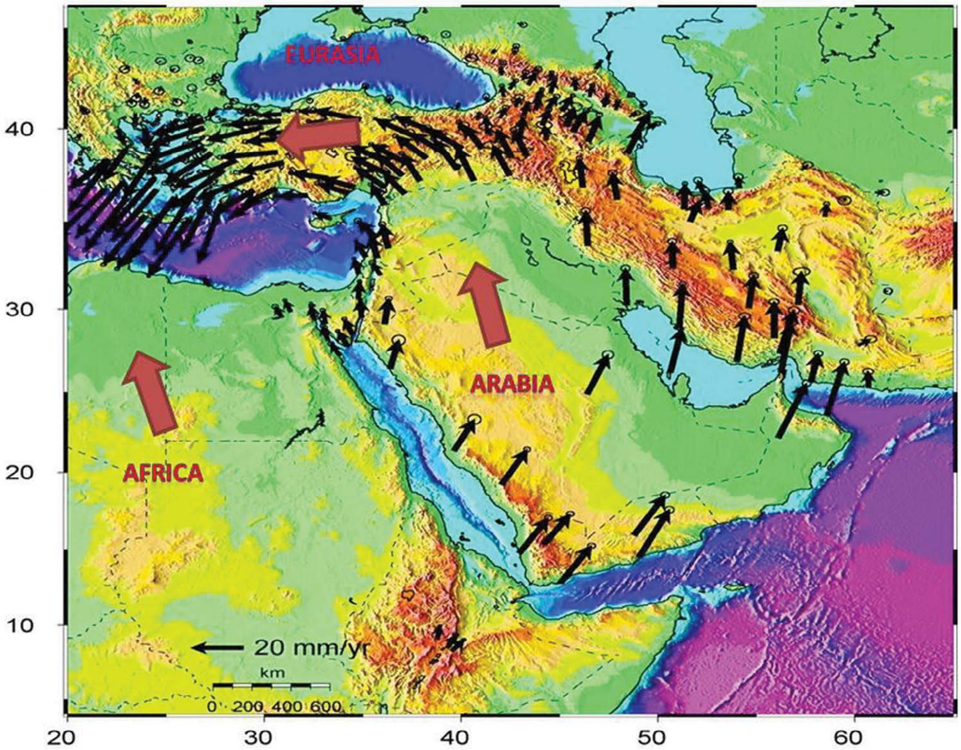

Figure 1: Main tectonic structures, GPS Velocity distribution and movement directions [6].

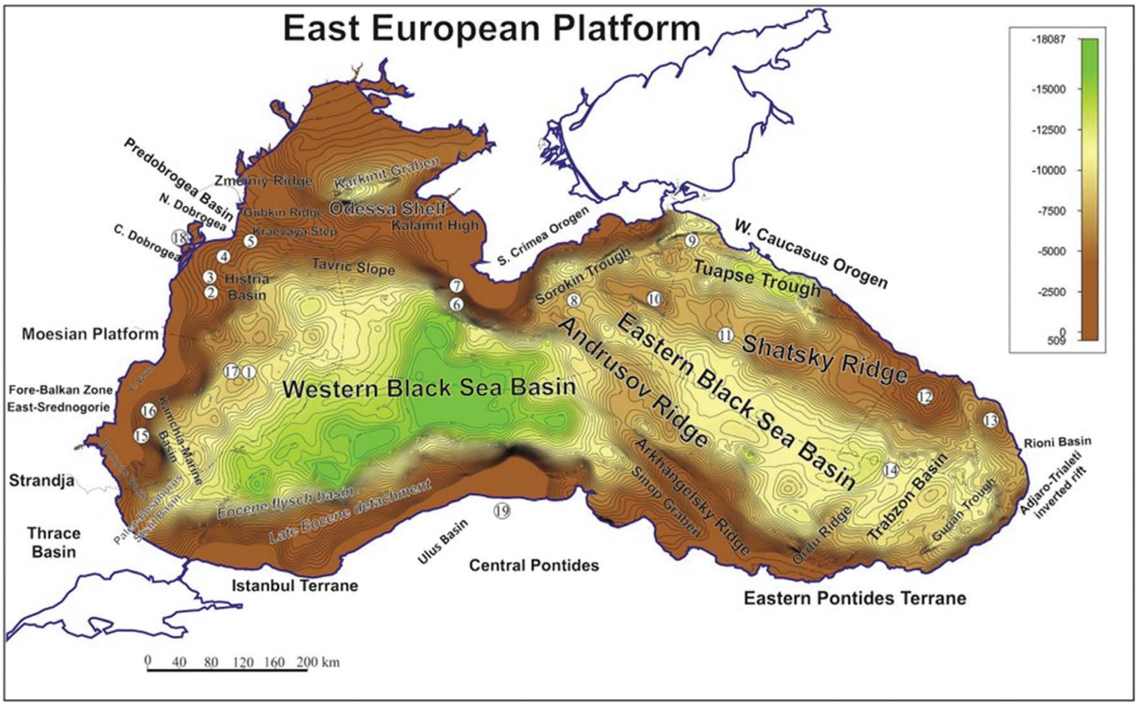

Figure 2: Basement topography of the Black Sea Basin, and the prominent features [7].

The Black Sea, consists of the two oceanic basins separated bymid sea ridges (Figure 2). There are obvious implications for the geometry of extension and rifting within the western and eastern Black Sea basins and the role of broader plate configuration and kinematics in controlling controlling the structures [1].

The deepest part of the basins have oceanic crustbelow a thick cover of sediments, at a depth of about 10 km. The margins and the ridges have continental crusts [1,7,8,10].

According to the previous studies in the region using multi-channel deep seismic reflection-refraction, gravity and magnetic data, the eastern and western basins with

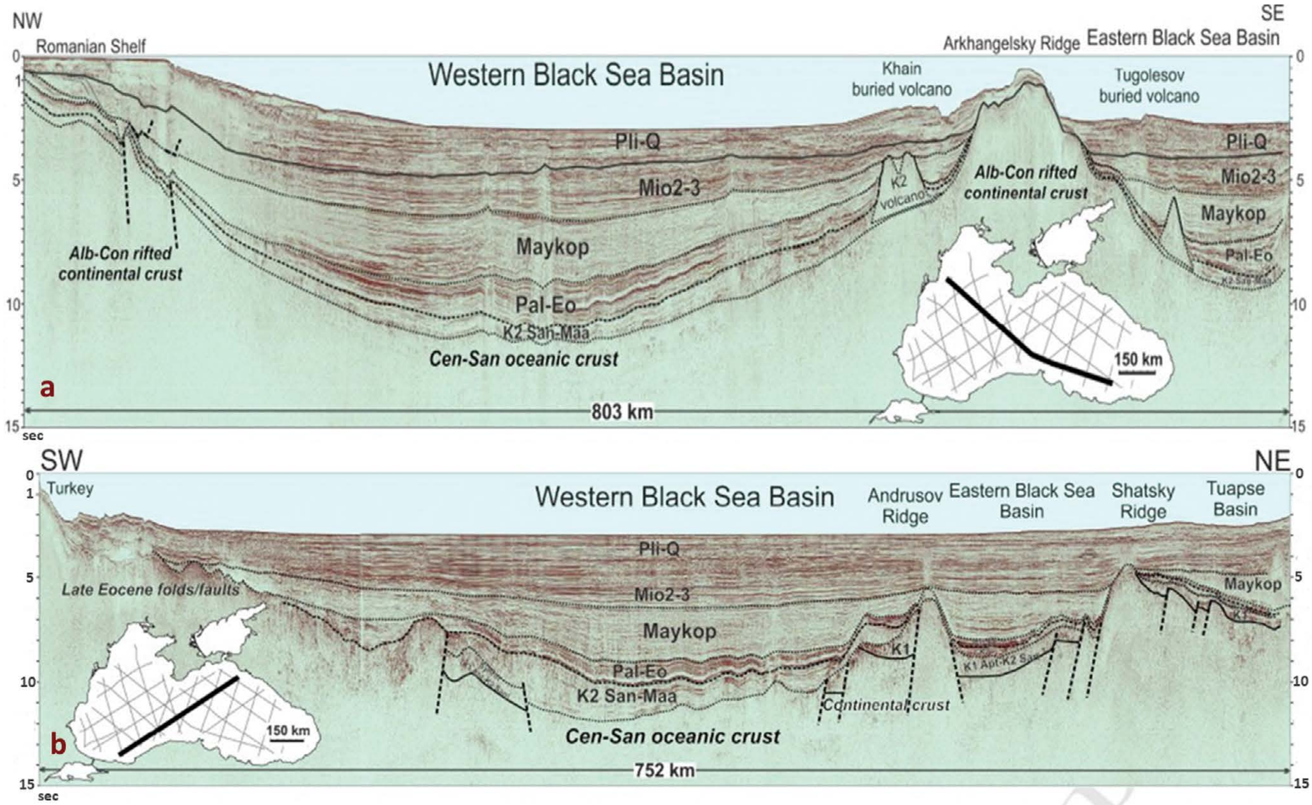

Figure 3: Seismic section along two seismic lines in the NW(a) and NE(b) directions. The sections show the sedimentary layers and basement topography [10].

oceanic crust, show the different structural features [9-13] (Figure 3).

Geological and geophysical evidence including offshore seismic reflection profiles [14], offshore morphology [15], onshore geology and morphology [16], and recent seismic activity [17,18] support the idea that the compressional tectonic regime is still active in the Eastern Black Sea region. South-west part of the Black Sea do not show important seismic activity to decide whether compressional or tensional regime is active.

Black Sea comprises western and eastern sub-basins which mainly opened in the Eocene [19]. The northern margin of the Black Sea has been identified as active thrusting along the Greater Caucuses from Georgia to the Crimea [20,21].

It is seperated by the mid-Black Sea ridge, a region of thinned continent crust, from the north-west-trending east Black Sea basin, which has oceanic crust with < 12 km of sediment cover. Unlike the west Black Sea basin, the ridges and basins in the eastern Black Sea are intersected by a large number of faults [14].

In this paper, we present the seismicity and fault mechanisms of earthquakes in and around the margins of the Black Sea.

Seismicity

Previously, the former Soviet Union, Bulgaria, Romania, Turkey have publised various earthquake catalogs about seismicity. But because of the lack of sufficient seismic stations in the region, catalogs were not homogeneous and complete. Therefore, the detection of the earthquakes was not complete.

Although seismic activity is sparse in the basins relative to the surrounding region of the Caucasus and Turkey, the broad-band seismic networks established in surrounding countries, especially in Turkey since 2005, have provided the capability for the detection, location and source mechanism studies of earthquakes in the Black Sea basins (Figure 4) [22].

In the previous studies, seismicity in the Black Sea has been considered in general terms. A preliminary study about fault plane solutions for recent earthquakes was published by Bayrak, et al. [23]. In this study, all the available data in the catalogue are used [24]. Figure 5 shows the cumulative number of earthquakes since 1976. Changes of slope in the curve in Figure 5 are due to the increased number of stations and detection capabilities.

Significant increase in the number of earthquakes was seen in the region especially after 2006, primarily due to the new stations established in this region after 2005. Frequency-Magnitude distributions of earthquakes are shown in Figure 6 for two different time intervals: 1900-1976 and 1976-2015. The recent period shows the great improvement in detection, with the magnitude of com-

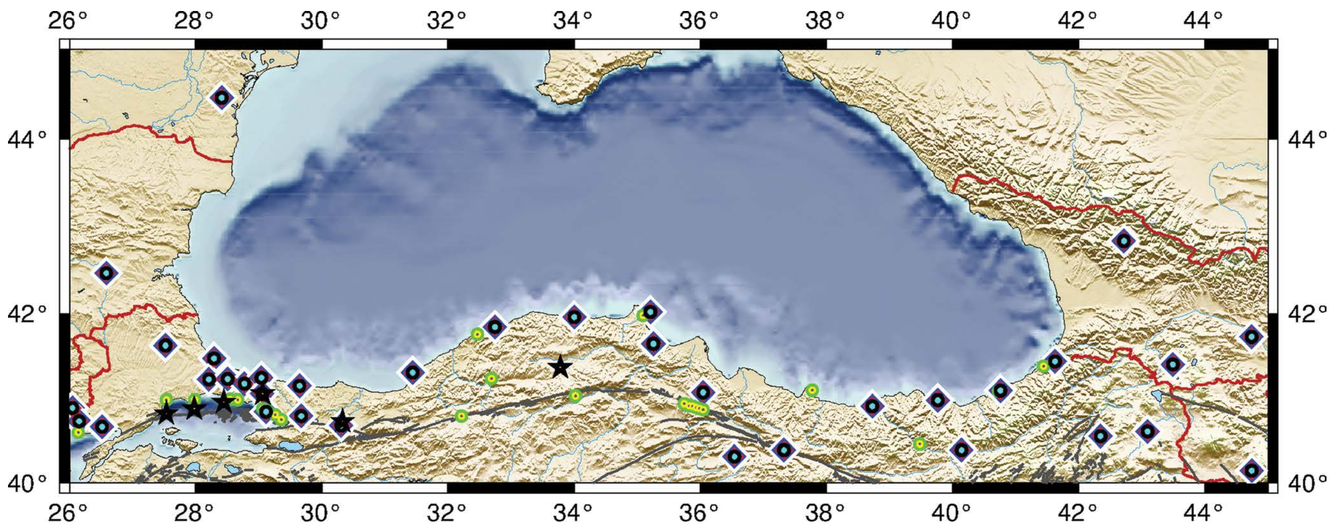

Figure 4: Seismic stations in the region (diamonds show broad-band BB, Green circles the strong-motion SM), Stars show short period SP-with strong motion SM or BB stations).

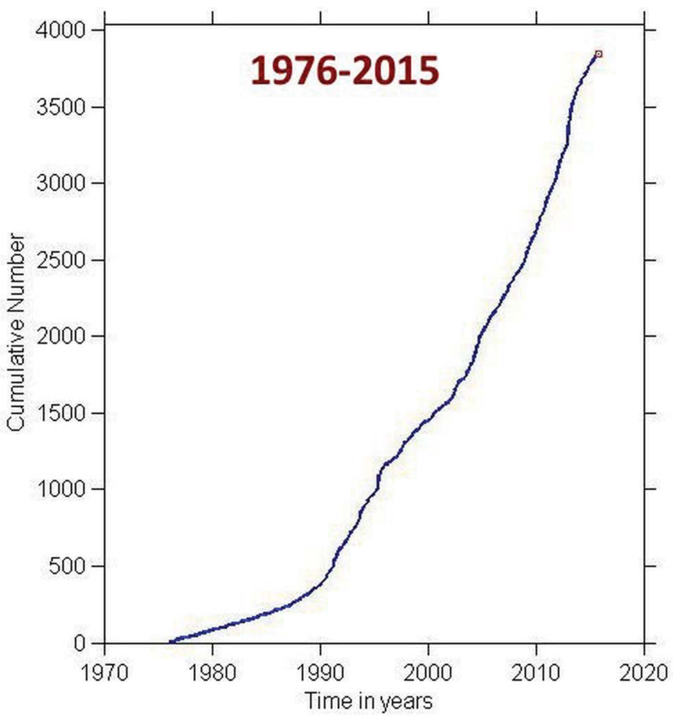

Figure 5: Number of earthquake occurrence - time correlation (distribution of the earthquakes by years between 1976 to 2015).

pleteness M_L = 2.7 in the Black Sea region. For our study we used earthquakes M ≥ 3.0.

Frequency-Magnitude distribution was analyzed by two different methods. Maximum Likelihood (MLM) [25,26] and Entire Magnitude Range (EMR) [27], and are shown in Figure 6. The results were similar.

There are a significant number of earthquakes in the Black Sea, mostly of magnitude M_w = 4.0 or smaller (Figure 7).

The seismicity increases toward the margins, with the largest events at the margins. The seismic activity in the region is greater offshore of Georgia, along the basin edges between Crimea and Russia, Bulgaria-Romania, the Bulgaria-Turkey-Trachea borderline and the middle part of Southern Black Sea - offshore Turkey. The Western and Eastern basin of the Black Sea - inner basin have very few earthquakes. The seismicity pattern in the northeastern Turkey and the Caucasus corresponds to the plate interactions.

Source Mechanism

Using the data from broad-band stations, we calculated CMT for earthquakes with magnitudes higher than M = 3.7, which occured between 2006 and 2015 (Figure 8 and Table 1) [28-30]. We used regionally recorded

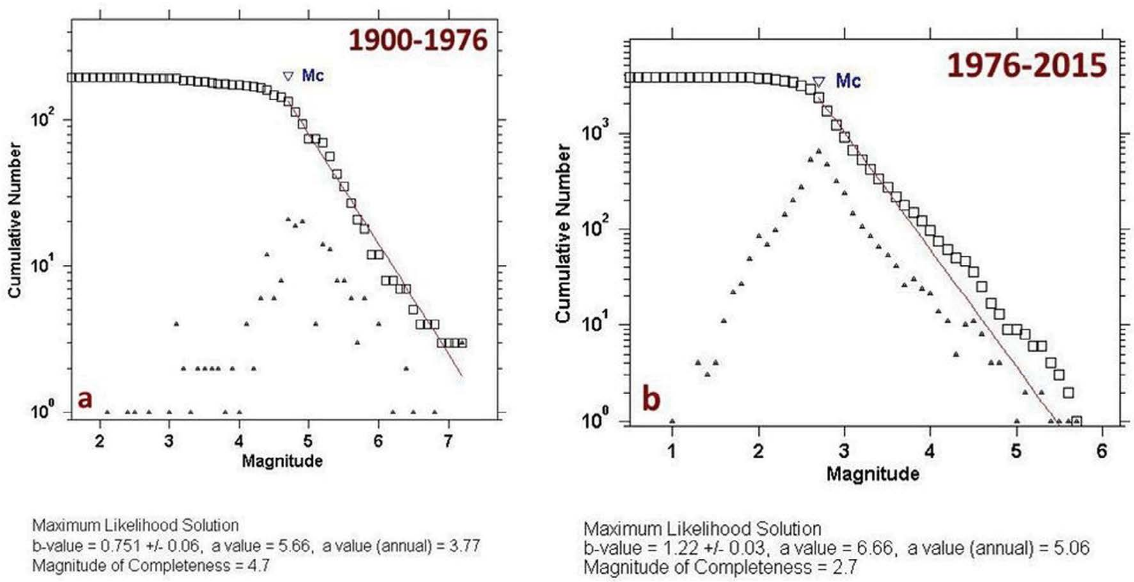

Figure 6: Frequency-Magnitude relation for two different time periods and detection threshold (Mc).

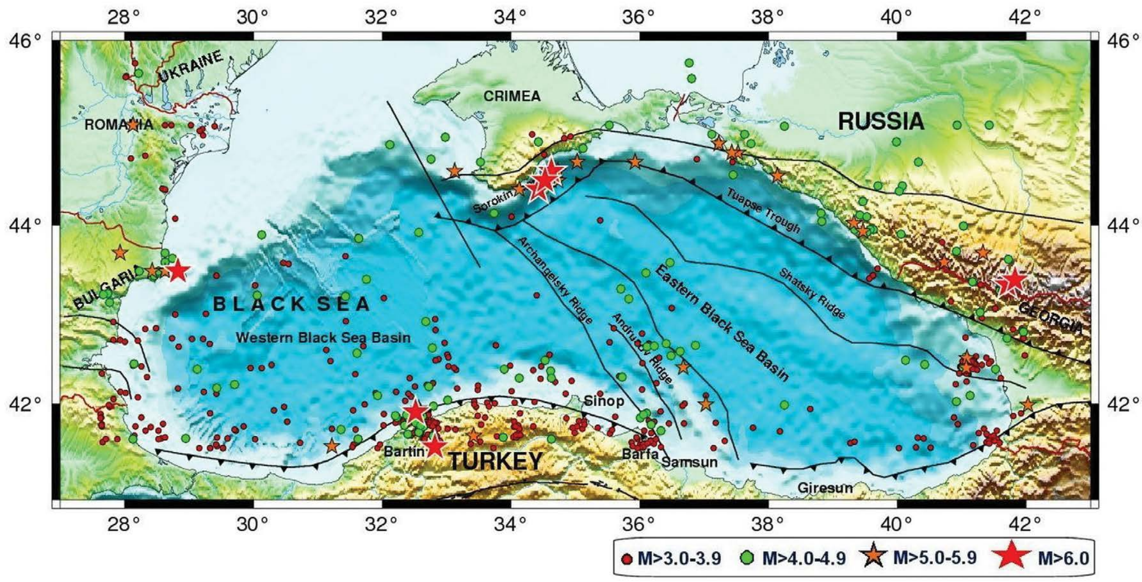

Figure 7: Recent seismic activity of the Black Sea region (red stars show M ≥ 6.0; orange stars show M ≥ 5.0; green circles show M ≥ 4.0 and red circles show M ≥ 3.0 earthquakes in the period of 1900-2015).

broad-band velocity waveforms for CMT solutions. Usually we calculated moment tensors with Moment Tensor Inversion Techniques [31,32]. We used the earthquakes recorded by at least 4 digital broad-band seismic stations. The earthquakes between 1968 and 2006 we used global data or published results.

The focal mechanisms indicate primarily N-S compression with some E-W component. The mechanisms are consistent with plate motions, where westward motion of the Anatolian Plate and N-S deformation of the Caucasus take up most of the motion of the Arabian Plate. Only small motions (about 1 mm per year) are transmitted through the Pontides, and the Black Sea is being compressed in an N-S direction.

The fault plane solutions of the earthquakes occurred in the Black Sea especially, in recent 6 years, generally have oblique strike-slip faulting in northeastern part (Bulgaria-Romania borderline offshore waters). After 2008 a series of important earthquakes occurred especially in the southern coasts of the Black Sea and offshore Georgia.

In the southern Black Sea and in the middle part, especially offshore of Bartın, around Kastamonu, offshore of Samsun, the reverse faulting component dominated solutions expressing compressional tectonic regime. The strikes of earthquakes generally lie parallel to the basin. This fault geometry shows that a compressional stress is effective in the region.

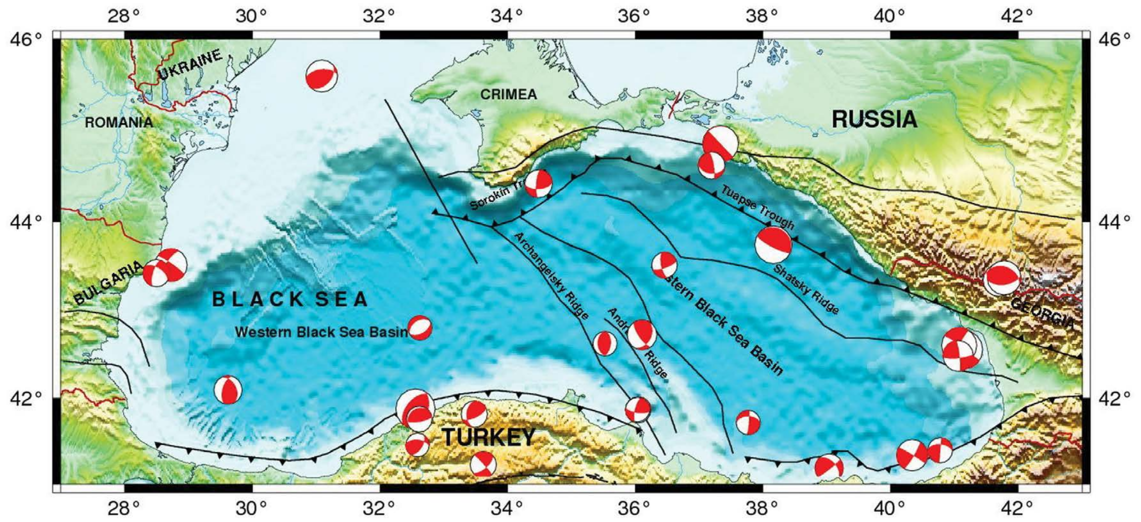

Figure 8: Fault mechanisms in the region (time period: 1968-2015).

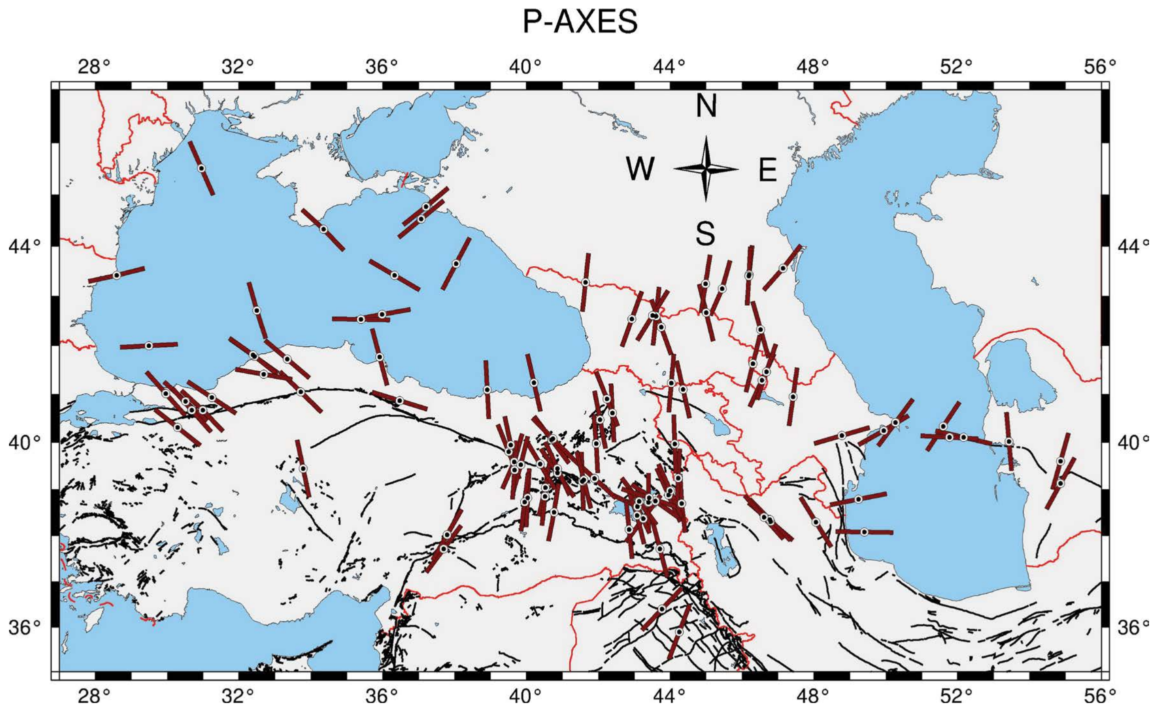

Figure 9: Stress analysis of the region P_{max} compressional axes.

The earthquakes in central part of the Black Sea located on faults associated with the ridges.

These earthquakes show that the region is not a seismic and produces earthquakes from time to time, though not very frequently. Offshore of Bafra, earthquake activity started in July 2014 and continued until September 2014 at times causing anxiety in the region.

Conclusions

The important earthquakes in the region (Mw > 6.0) generally occurred in southeastern Crimea, the Georgia mainland, offshore of Bulgaria, offshore of Bartın (coast of the Black Sea). Since 2005 no other important earthquakes have occurred apart from those. The depths of the earthquakes were generally between 10 and 35 km. Largest earthquakes occurred at the boundaries of Black Sea. The mechanism of the large events at the margins indicates and oblique deformation of the region combined with North-South compression and East-West shear.

Stress pattern based on focal mechanism solutions of the earthquakes in the region show that largest compressional axis (P_{max}) is oriented in N**NW**-S**SE** direction. In the eastern part of Black Sea, especially in offshore Georgia, the largest compression axis (P_{max}) is found to be N**NE**-S**SW** (Figure 9).

With improved instrumentation many small events have been detected at the shelf margins of the Black Sea.

It is most likely that this events are located on the faults formed during the opening of the Black Sea.

The deep basin of the Black sea is relatively aseismic. The earthquakes in the central part of the Black Sea are associated with the ridges oriented in SE-NW directions.

Acknowledgments

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