ANALYSIS OF FEATURE OF RECENT SEIZMICITY IN VLORA-ELBASANI-DIBRA SEISMOGENIC ZONE

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ABSTRACT

The Vlora-Elbasani-Dibra transversal fault zone is one of the most interesting and specific tectonic of Albanides geological structure. Geotectonic processes developed through its, are connected and find the explanation of a number of local and regional geological phenomena. The Vlora-Elbasan-Dibra fault zone plays the role of a barrier against the regional pressure tension. This is why its southeast regions is much more structured than in the northwest territories. This transversal fault zone of ENE extension, which dislocates the Albanides along all their width is marked out by diapiric cupola of Dumrea, the Quaternary Depression of Elbasan, the belt of trasversal structure of Labinot which continue with the trasversal flysch elevation of Golloborda (fig 1). The results of the analysis, based on the parameters of events and some features of seismicity that have occurred in the Vlora-Elbasan-Diber seismogenic zone during period of time 2001-2014, are presented in this paper. The goal of this study is to determine tipology of seismicity, the source parameters of the mainshocks and their aftershocks in order to shed light on the seismotectonics of the area on the stress field. The data used in this study were recorded by permanent broadband seismological stations that are part of the Albanian Seismological Network as well by neighboring seismic networks NOA, MSO, INGV and MEDNET. The epicenters were located using P and S onsets, a local velocity model (Ormeni., 2011) and the Hypoinverse program (Klein, F.W., 2002). A complete and homogenous catalog of the earthquakes is provided. The focal mechanism solutions using the Focmec routine in the Seisan package (Haskov and Ottemoler., 2008). On the Vlora-Elbasan-Diber seismogenic zone during period of time 2001-2014 the microseismic activity was intensiv, occurred a alot of small earthquakes and two event with magnitude M=5.0. Focal depth analysis reveals that this seismicity was mainly generated in the upper und middle crust under the tectonic conditions described previously. We analysed and determined the focal mechanisms of 6 september 2009 (M5.4), of the 21May 2014 (M5.2), of the 16 Aprile 2007 (M4.5), of the 9 July 2010 (M4.6) and of the compound earthquakes of 24 October 2008 (M4.5), using first-onset polarities. Some aftershocks did not occur along the same fault plane as the mainshock; they occurred on faults with different orientations, reflecting the activation of secondary structures in the Elbasan-Dibra transverse fault zone and demonstrating a variety of geologic structures in the area with heterogenous stress state and the stress axes may often undergo rotations. The Vlora-Elbasan-Dibra fault zone has produced earthquakes in the past, and is expected to continue to be active in the future. The goal of this study is to determine tipology of seismicity, the source parameters of the mainshocks and their aftershocks in order to shed light on the seismotectonics of the area on the stress field.

I. INTRODUCTION

The Albanian mountain belt is a segment of the Dinaride-Hellenide orogeny that trends NNW–SSE (Fig. 1). It was formed by Alpine orogenic processes related to the Apulia and Eurasia convergence and the closure of the Mesozoic Tethyan Ocean (Doglioni et al., 2007; Aliaj 2012). Elbasani- Dibra segment with direction SW-NE in Albania, represent an earlier transversal deep fracture, which was hit by the frequent and strong earthquakes, being active now. During the last century, several devastating earthquakes have occurred, causing casualties and substantial damage (Aliaj et al., 2012, Ormeni et al 2009, 2011). The previous strong event in the region was the Dibra earthquake on 30 November 1967 (GMT 07:23:50; Ms6.7; 41.41° N 20.44° E; h=9 km), which caused 19 deaths, 214 injuries and was associated with a N40°E ~10-km-long discontinuous or eroded surface rupture and a vertical displacement of 50 cm (Sulstarova & Kociaj 1980; Ambraseys & Jackson 1998). The focal mechanism solution of 30 November 1967 earthquake obtained from waveform modeling (Baker et al. 1997) shows normal faulting along NNE-SSW-trending planes with the T-axis indicating roughly E–W extension. The neotectonic faults in the broader region are high-angle normal faults that have variable trends, N–S or NNE –SSW or NNW–SSE (Kilias et al. 2001, Aliaj 2001), and this is manifested both in the earthquake focal mechanisms and the geomorphology (e.g., Anderson & Jackson 1987; Muço 1994; Louvari et al. 2001 and Ormeni 2009; 2011; Aliaj et al 2012).

II.DATA AND METHOD

The data used in this study were recorded by permanent broadband seismological stations that are part of the Albanian Seismological Network as well by neighboring seismic networks NOA, MSO, INGV and MEDNET. The earthquakes were located using data from three or more seismic stations. The epicenters were located using P and S onsets, a local velocity model (Ormeni., 2011) and the Hypoinverse program (Klein, F.W., 2002). A complete and homogenous catalog of the earthquakes is provided. The focal mechanism solutions for the main-shocks and selected aftershocks are based on the classical method of first-onset polarities, using the Focmec routine in the Seisan package (Haskov and Ottemoler, 2008).

III. GEOLOGICAL SETTING

The Elbasani-Dibra transversal fault zone of ENE extension, which dislocates the Albanides along all their width is marked out by diapiric cupola of Dumrea, the Quaternary Depression of Elbasan, the belt of trasversal structure of Labinot which continue with the trasversal flysch elevation of Golloborda. From point of view of the geological and tectonics-neotectonics phenomena the region where the studied zone is included take part in Krasta sub-tectonic zone, which is included in external area of Alpine folding. It is strongly affected by pre-Pliocene tectonics movement. The Krasta sub-tectonic zone has been deformed by folds, normal faults, as well as by strike slips from the main Alpine movement phases which folded the above mentioned tectonic zone (Aliaj et al 2001). Generally, the structures Krasta sub-tectonic zone extend from North to South (fig.1). The Elbasani-Dibra fault zone (ED), which represent a deep fault that has played an important role in development and structuring of inner Albanides in both sites of it. This transversal fault zone extends from Albania toward the FYROM to the NE. To this zone are related many geological phenomena: Evaporate diapirs of Dumrea and Peshkopi, tectonic window of Okshtumi; the tectonic displacement of Shpati ultrabasic massifs and Quaternary formations (Milushi. I., et.al. 2007); the presence of many buried anticlines under molasse formations; the new tectonic movements evidenced from the fresh normal tectonics and the forming of the erosion valleys; the presence of many hydrocarbon deposits and oil earmarks on surface; the source of the thermal waters; presence of the some hydrothermal mineralization and lastly, the frequent and strong earthquakes, being active now.

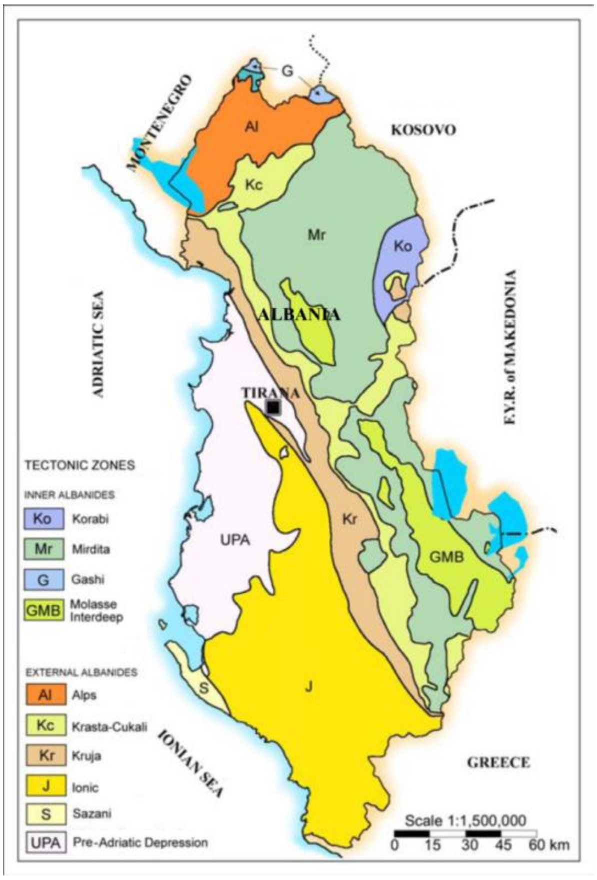

Figure1. Schematic tectonic map of Albania

IV. RECENT SEISMICITY

For period of time 2001-2014, on the Elbasan-Diber seismogenic zone, 1013 earthquakes with M_L>1.0 were located, of which 324 of magnitude M_L>=3 , 24 of magnitude M_L>=4, and 2 of magnitude ML>=5 and the strongest event with magnitude M_L=5.4 (fig 2). Focal depth analysis reveals that this seismicity was mainly generated in the upper und middle crust (Ormeni 2007), under the tectonic conditions described previously. Larger number of seismic events are present during 2008-2011 years . The strongest event occurred on 6 september 2009 (M5.4) and four others occurred on 19 Maj 2014 (M5.2), 16 Aprile 2007 (M4.5), 24 October 2008 (M4.5) and 9 July 2010 (M=4.6). These earthquakes highlight the increased seismic activity of the Elbasani-Dibra seismogenic zone.

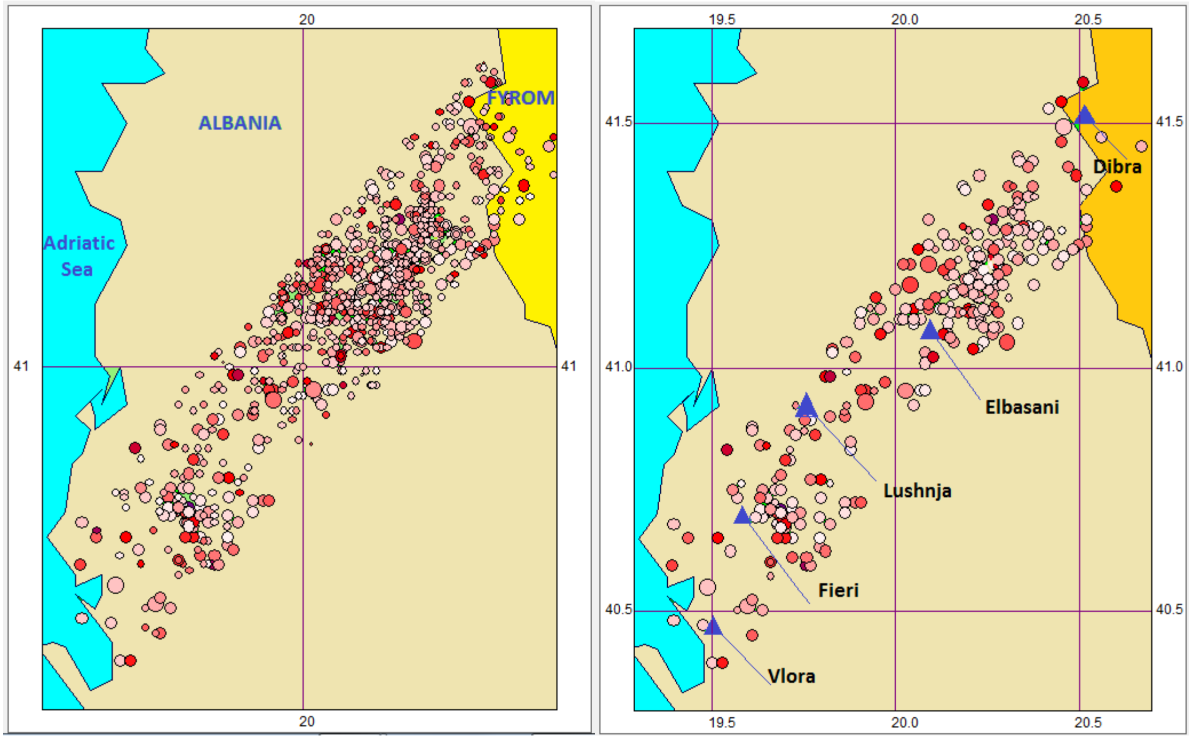

Figure 2. The map of earthquake epicenters occurred in Elbasan-Dibra zone during period 2001-2014 (M>1.0 left, M>3.0 right)

The moderate earthquake of the16th of Aprile 2007 at 07:38 local time, M4.5, 19km depth, occurred in the Bene village. In this serie, about 34 aftershocks with magnitude M_L=2.0-3.4 were located.

The24th October2008 compound (fourplet) earthquakes occurred near Kuturman village wih max magnitude M_L 4.5 (Mw=4.9 INGV, ETHZ), 19km depth,. In the series of about 52 aftershocks with magnitude M_L=2.0-3.4 were located. The 6 September 2009 earthquake occurred inland near Gjorica village with epicenter coordinates 41.49°N and 20.45°E, and it caused heavy damage in the villages of Gjorica, Qerenec and Shupenza in the Dibra district. Its hypocenter depth was 7.6 km, explaining the concentration of the destruction to the epicentral zone. In the series were located 250 aftershocks with magnitude M_L=1.5-4.3 depths ranging from 1-25 km. The 19 May 2014 earthquake occurred inland near Belshi town with epicenter coordinates 41.93°N and 19.92°E, and it caused heavy damage in the towns of Belshi, Cerriku and in the villages of Mollas, Gostim in the Elbasani district. Its hypocenter depth was 18 km. In the series were located 16 aftershocks with magnitude M_L=2.2-4.5 depths ranging from 1-20 km. Figure 3 shows the "b" estimate for the eleven years 2001 – 2014 (about 1013 events). For the period 2002-2006 the b value is lower than 0.7 decreasing for each year because there were not moderate events. After the 2007year the b value increased because there were a few moderate events in 2008 with magnitude (M4.5) and was generate the strongest event (M5.4) in 2009. In 2010 year were generated the compound earthquake with magnitude (M4.5). For the period 2011-2013 the b value is lower than 0.8 decreasing for each year because there were not moderate events. The smaller b-value at this two years means that the stress was high in the Elbasani region and was caused the 19 May 2014 earthquake (M5.2). In 2014 the b value increased because of the moderate event (M5.2) . The parameter b is believed to depend on the stress regime and tectonic character of the region. Changes in b-value are believed to be inversely related to changes in the stress level (Bayrak et al., 2002). The smaller b-value means that the stress was high in the Elbasani-Dibra region. The major shock Gjorica earthquake (M5.4) was preceded by an increase in b, followed by a decrease in months before this earthquake. After 2009 year the b coefficent has value bigger than 0.7 correlated with decreasing stress level.

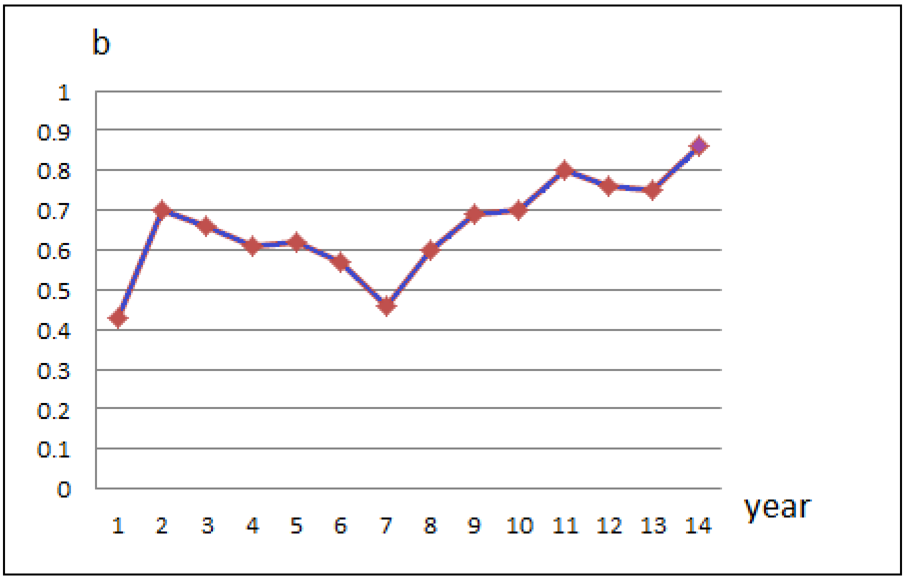

Figure 3.Temporarly distribution 'b' value for each year during this century for events with M_L>2.0

V. CHARACTERISTICS OF COMPOUND EARTHQUAKES

Occasionally, two or more events, often of similar size occur on nearby but different rupture surfaces close together in time, but with a delay such that their rupture times do not overlap.We call this clases of earthquakes compound earthquakes. They are of considerable interest because they imply rupture processes other then those predicted by elastic fracture mechanics. Perhaps the most common type of compound earthquake is when the rupture surfaces of two events are contiguous. The several events in the sequence need not have the same mechanism. Events in the series of sequences of Kuturman have not the same mechanism. The first ruptures in 24 October 2008 of Kuturman earthquake in Albania, for example were thrust and oblique-faulting events but they were followed closely from dominant rupture by normal-faulting and the fourth rupture by normal-faulting earthquake (fig 4). These earthquakes have occurred in a four-hour period successively migrated fron SW to NE. Compound earthquakes sometimes progress in a single direction, thereby define an earthquake migration. The earthquake of Kuturman progressed from Weast to East. These compound earthquakes cannot be explained with linear elastic fracture mechanics because the time delays between the individual events are to long to result from elastic processes. Because an earthquake dynamically loads the surrounding region, compound earthquakes can result from viscoelastic relaxation in the immediate postseismic period, resulting in a redistribution of loads.

VII. SEISMOTECTONIC INTERPRETATIONS FROM SOURCE PARAMETERS OF EARTHQUAKES.

We determined the focal mechanisms of the 6 September 2009 mainshock and six aftershocks M_L>3.9, the focal mechanisms of the 19 May 2014 mainshock as well the focal mechanisms of compound (threeplet) earthquakes using first-onset polarities. 1) The focal mechanism solution of the 6 September 2009 mainshock has an active plane striking (strike) 219.5° NE, an inclination of the hanging wall (dip) of 40° and a hanging wall displacement (rake) of -90° (downward motion), in good acordance with field observations. Based on the focal mechanisms, we find that the September 6, 2009 earthquake was caused by purely normal faulting in a NW-SE extensional stress direction. The first strong aftershock was 35 minutes after the mainshock and was caused by pure normal faulting with a dip of 30°. This aftershock has the same focal mechanism as the mainshock, i.e., it has the same radiation pattern. This shows that this aftershock occurred along the same fault as the mainshock. Focal mechanisms of two other aftershocks, on 6 September at 22h36m and 7 September at 15h20m, show normal faulting with a strike-slip component. The aftershocks on 7 September at 12h21m and 12 September at 18h06m and 18h42m show an oblique strike-slip motion. These focal mechanisms (fig 4, right) show the predominance of normal fault motion with a strike-slip component, and this normal fault motion is compatible with present-day NW-SE extension. Some aftershocks did not occur along the same fault plane as the mainshock; they occurred on faults with different orientations, reflecting the activation of secondary structures in the Elbasan-Dibra transverse fault zone and demonstrating a variety of geologic structures in the area with heterogenous stress state and the stress axes may often undergo rotations.

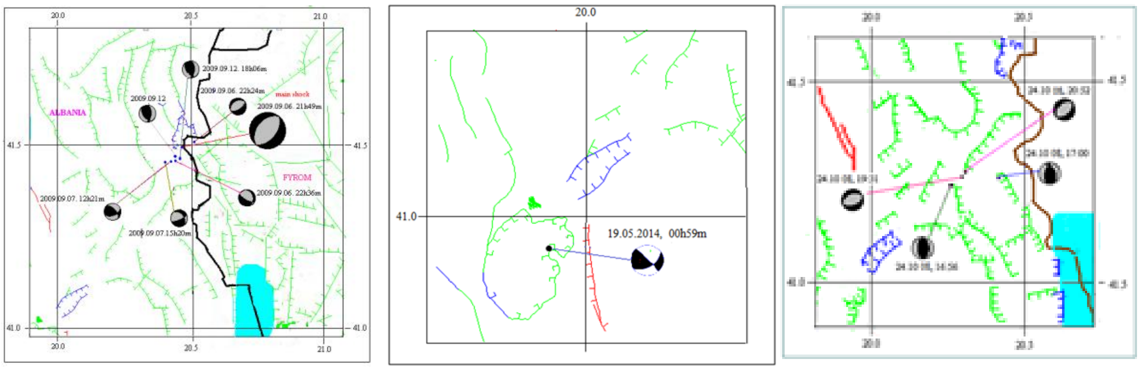

Figure 4. Seismotectonic map of Elbasani-Dibra and the focal mechanism of the 6 September 2009 mainshock and its aftershocks (right) and focal mechanisms of compound earthquakes 24 October 2008 (left)

This may suggest that during the mainshock, normal faults were reactivated within the regional (mean) state of stress, whereas the aftershocks with a strike-slip component correspond to the re-adjustment of displaced blocks within the local stress state.This transversefault zone is clearly outlined by the locations of aftershocks along this fault and their focal mechanisms (Ormeni 2009, 2013). In addition to the study of instrumental seismic data, a field investigation and collection and analysis of macro-seismic data was performed, allowing a full and comprehensive study of the triggering mechanism of the Gjorica earthquake. The field investigation in the epicentral zone revealed several coseismic fractures on the surface. They extend NE-SW and dip to the southeast at 40-50°. These information, in addition to the focal mechanism solution of this earthquake, shows an agreement with the general plane of the Elbasani-Dibra-Tetova transverse fault zone.

2) The focal mechanism solution of the the 19 May 2014 mainshock has an active plane striking (strike) 58° NE, an inclination of the hanging wall (dip) of 52° and a hanging wall displacement (rake) of 12° (downward motion) (Ormeni et.al 2014). Based on the focal mechanisms, we find that the 19 May 2014 mainshock earthquake was caused by oblique strike-slip faulting in a NW-SE extensional stress direction (fig 4, middle). This focal mechanisms is oblique strike-slip faulting, reflecting the activation of secondary structures in V-E-D fragmentary transversal fault zone.

3). The focal mechanisms solutions for compound (fourplet) earthquake are: for the first shock, Strike=180°, Dip=50° and Rake (Slip) =90° that was triggered from a pure thrust fault with an W-E stress direction (fig. 4, left). The fault plane, has a dip 50° and and is associated with the activation of the Elbasani-Dibra deep fault zone. The focal mechanism solutions of this earthquake demonstrate an ongoing horizontal extension (thrust faulting) along the fault in the direction of N-S. The solutions for the second shock are: Strike=190.2°, Dip=52.8° and Rake (Slip) =-64°. From the focal mechanism solution results that the earthquake of time 17h00m was triggered from a oblique thrust fault with an N-S stress direction. The third shock 19h31mis the strongest and the fourth time 20h52m have solution respectively: Strike = 249º, Dip = 40°, Rake (Slip) = -900 and Strike = 229.3º, Dip = 40° and Rake (Slip) = -900. (fig.4, left). From the focal mechanism solution results that the third and fourth earthquakes were triggered from a normal active fault with an NW-SE extensional stress direction

IX. CONCLUSIONS

This study focuses on the recent features of seismicity of Vlora-Elbasan-Dibra most seismogenic zone in Albania. The 24 October earthquake sequence is a typical example of a compound earthquake, involving, “two or more events, often of similar size, that occur on nearby but different rupture surfaces close together in time, but with a delay such that their rupture times do not overlap. Based on analysis of the focal mechanisms of moderate earthquake of Gjorica 2009, Cerriku 2014 and on the focal mechanisms of compound earthquakes of Kuturman 2008 and in previous strong earthquakes, the Vlora-Elbasani-Dibra-Tetova transverse fault zone plays an important role in the seismotectonics of Albania, as well as the FYROM. Focal depth analysis reveals that this seismicity was mainly generated in the upper and middle crust, under the tectonic conditions described previously. Analysis of focal mechanisms shows the predominance normal faulting with a oblique strike-slip component, and NNW-SSE extension in eastern Albania as a response to the convergence between Adriatic microplate and Albanian orogen. The Elbasan-Dibra fault zone has produced earthquakes in the past, and is expected to continue to be active in the future. This study of recent seismicity emphasizes many geologic and seismotectonic characteristics of the areas constituting a threat for nearby urban areas of Albania and the FYROM.The Vlora-Elbasan-Dibra transversal fault zone zone presents a significant seismic hazard to those living in eastern Albania, western Macedonia, and northeastern Kosovo; not only due to the Elbasan-Dibra normal-fault earthquake and compound earthquakes, but also due to the hundreds of earthquakes certain to follow the mainshock.

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