Recent Seismic Activity of the Lezha-Ulqini Seismogenic Zone and its Associated Hazard

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ABSTRACT

The results of the analysis, based on the parameters of events and some features of seismicity that have occurred in the Lezha-Ulqini seismogenic zone during period of time 2001-2012, are presented in this paper. This seismogenic zone presents a significant seismic hazard to those living in northwestern Albania, southern Montenegro not only due to the pending earthquake but also due to a lots of earthquakes certain to follow the mainshock. In total, 112 earthquakes are registered during overmentioned period in this zone, and one with M_L=5.0 (Richter) occurred on 21 August 2009. Lezha-Ulqini seismogenic zone present a threat to nearby urban areas in Albania and the Montenegro. 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 and to evaluate the seismic hazard. The region affected by the August 2009 sequence, together with the seismogenic region of the 15 Aprile 1979 Ulqini event (M7.0), forms a roughly NW−SE-trending active seismotectonic zone in western Albania and continues through southern Montenegro.

KEY WORDS: Seismicity, Adriatic Sea earthquake, focal mechanism, faults, aftershocks

I. INTRODUCTION

The Albanian mountain belt is a segment of the Dinarides-Hellenides 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 [1],[5]. In 2009 one moderate earthquake of 21 August hit Northwestern Albania with intensity I_0=VI-VII (MSK-64) (Fig. 2). This earthquake highlight the increased seismic activity of the Lezha-Ulqinseismogenic zones in 2009. During the last century, several devastating earthquakes have occurred, causing casualties and substantial damage [15].
The epicenter of the M=5.0, 21 August 2009 earthquake, which caused no damage, was 17 km offshore west Albania in the Adriatic Sea. The most recent previous strong event in this region was the Ulqini earthquake of 15 April 1979 (GMT 06:19:40; Ms7.1; 41.94° N 19.408° E; h=8 km), which caused extensive damage along 100 km of the coastline, killed 129 people, injured 1554 people in the former Yugoslavia and Albania, and left more than 80,000 homeless [13].During this earthquake were observed tsunami wave with an amplitude 0.5-1 m in the Ulqin coastline. Other stronger earthquakes on record in the Lezha-Ulqini-Shkodra zone affecting Albania and Montenegro, such as the M_S6.9 earthquake on January 13, 1563; the M_S7.2 July 25, 1608 earthquake; the M_S7.2 and I_0=X(ten) degrees April 6 1667 earthquake; the

M_S6.6 June 1, 1905 earthquake [15]. The body waveform modeling inversion has confirm the focal mechanism of the mainshock of 15 April 1979 as a pure thrust mechanism and rule out the existence of considerable strike slip component in the motion. The mainshock occurred along a shallow (depth 7 km), low angle (14°) thrust fault, parallel to the coastline and dipping to the NE. The aftershock mechanisms also demonstrate that these earthquakes were caused by a compressional regime.

II. GEOLOGIC, TECTONIC / NEOTECTONIC SETTINGS OF ALBANIA AND THE LEZHA-ULQINI AREA

From a geologic standpoint, Albaniabelongs to the Dinarides, the southern branch of the Alpine folded belt. The Dinarides are separated into two portions: the Dinarides and the Hellenides. The Dinarides transition into the Hellenides in Albania, with most of the country encompassed by them where these are called Albanides. To the west, they are bounded by the Apulia-Gargano foreland. The Albanides consist of Ordovician to Quaternary magmatic and sedimentary rocks.

The Lezha-Ulqin area occurred at the border of Adria microplate and the Eurasian platform, where the folded Alpine Dinarides-Albanides-Hellenides mountain ranges are located and continental collision occurs [2],[3]. The seismicity is distributed in tectonic units of the Lezha-Ulqin area. The area consists of three tectonic units: the Albanian Alps, the Krasta Cukali and the Kruja units (Fig. 1). Carbonate formations from the Albanian Alps unit comprise the eastern and the northern part of region, outcropping along a narrow belt[7].

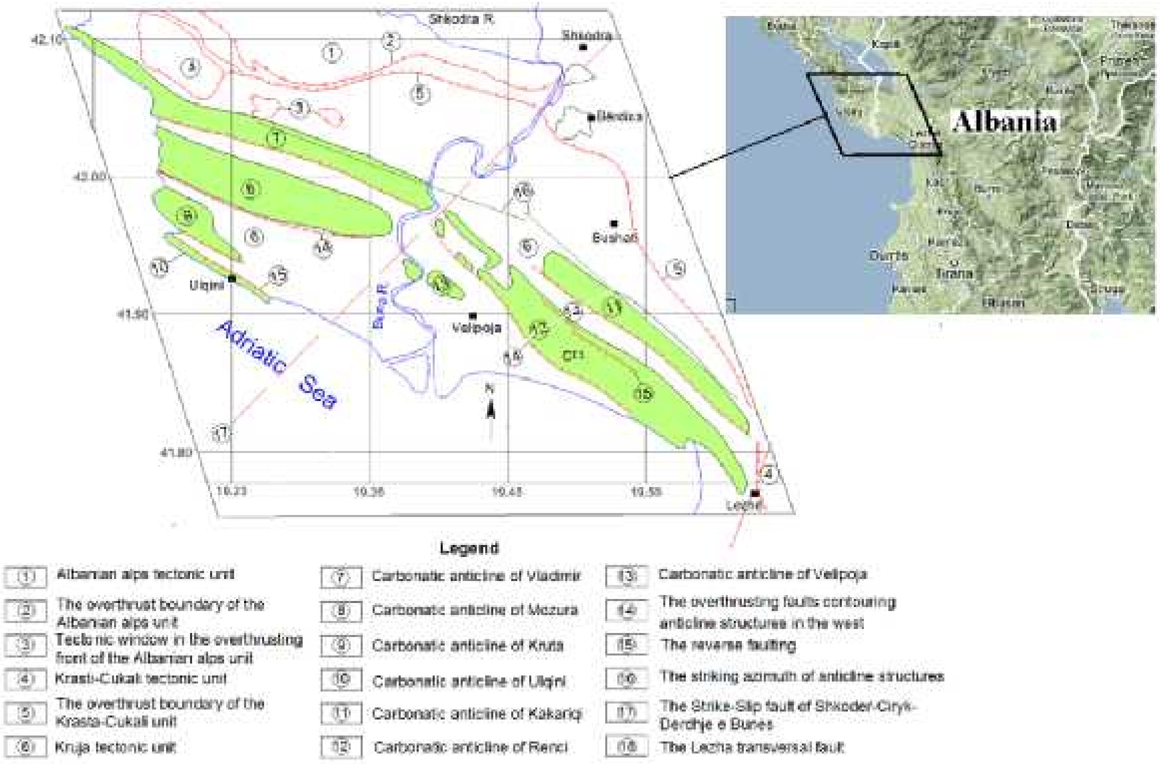


Fig.1. Tectonic features of the Lezha-Ulqini-Shkodra *area.*

The Albanian Alps do not continue further south. The cause of the southern closure of the Albanian Alps unit is controversial: it may be related to the strike-slip Shkoder- Peje fault (known as the Shkoder–Peje transversal fault) or have another cause. To the north, the Albanian Alps unit continues as the High Karst unit in Montenegro. The central part of the region has been built up by the Krasta Cukali unit, which continues to the northwest in

Montenegro, where it is known as the Budva unit. The Krasta–Cukali unit (Budva unit) is composed of carbonate formations, flyshes and volcano-sedimentary formations. In the east, the Albanian Alps unit over thrusts the Krasta-Cukali unit, while to the west, the Krasta–Cukali unit over thrusts the Kruja unit. The Kruja unit forms much of the western part of the region and is composed mainly of carbonate formations. In Montenegro, the Kruja unit is known as the Dalmatian unit, and within the Adriatic Sea, it over thrusts the Adria platform [1],[2],[4].In some cases where seismic energy failed to be released through these faults, reverse faults have developed, as in the Ulqin area. The buried orogenic front, which trends NW here, is expressed by thrusting of the Kruja zone over the Albanian Basin.

III. DATA AND METHOD

These earthquakes were recorded by permanent broadband seismological stations that are part of the Albanian Seismological Network (BCI, PUK, PHP, VLO, KBN and SRN), as well by neighboring seismic networks AUTH (FNA, IGT, NEST, THE, LKD2, MEV), MSO (PDG, BEY, BRY, BDV, HCY, NKY, PVY, ULC), INGV (MRVN, NOCI, SCTE, SGRT) and MEDNET (TIR). The aftershocks were located using data from three or more seismic stations. The formula to calculate local magnitude is $M_L=\log_{10}(A/1000)-3.37+3\cdot\log_{10}(D)$ that is divided with a regression coefficient for each station. The P- & S-wave arrivals from series of earthquake are accurately re-picked to obtain a high-quality data set. This data set provides highly precise hypocenter location determinations. The average of the root mean square (RMS) is 0.27s for all earthquakes, where minimum is 0.06s and maximum is 0.52s. The errors in the earthquake depths (vertical, error) are smaller then 3 km. The epicenters were located using P and S onsets, a local velocity model [12], and the Hypoinverse program [9]. A complete and homogenous catalog of earthquakes is provided. There were 112 earthquakes with $1.5\leq M_L\leq 5.0$, and two of them with $M \geq 4.5$ (Fig 2). The focal mechanism solutions for the 21 August 2009 main-shocks and selected aftershocks are based on the classical method of first-onset polarities, using the Focmec routine in the Seisan package [6].

IV. RECENT SEISMICIT

On the Lezha-Ulqini seismogenic zone, 112 earthquakes with $M_L>1.5$ were located, of which 27 of magnitude $M_L\geq 3.0$, 7 of magnitude $M_L>4$ and the strongest event with magnitude M=5.0 (fig 2). Focal depth analysis reveals that this seismicity was mainly generated in the upper und middle crust [10], under the tectonic conditions described previously. Larger number of seismic events are present during 2009-2012 years .

The strongest event occurred on 21 August 2009 (M5.0) and the other occurred on 26 March 2012 (M4.5). These earthquakes highlight the increased seismic activity of the Lezha-Ulqini seismogenic zone. The moderate earthquake of on 26 March 2012 (M4.5) at 04:08 local time, 21km depth, occurred in the Adriatic Sea. In this serie, about 5 aftershocks with magnitude M_L=2.0-3.4 were located. The 21 August earthquake hypocentral coordinates are 41.86°N and 19.13°E, with a focal depth 12.9 km. In the series were located 31 aftershocks with magnitude M_L=1.5-4.1 depths ranging from 1-25 km. Figure 3 shows the “b” estimate for the eleven years 2001 – 2012 (about 112 events). For the period 2003-2008 the b value is increasing for each year because there were not moderate events. After 2008 with the strongest event (M5.0) in 2009 the b value is lower than 0.7.

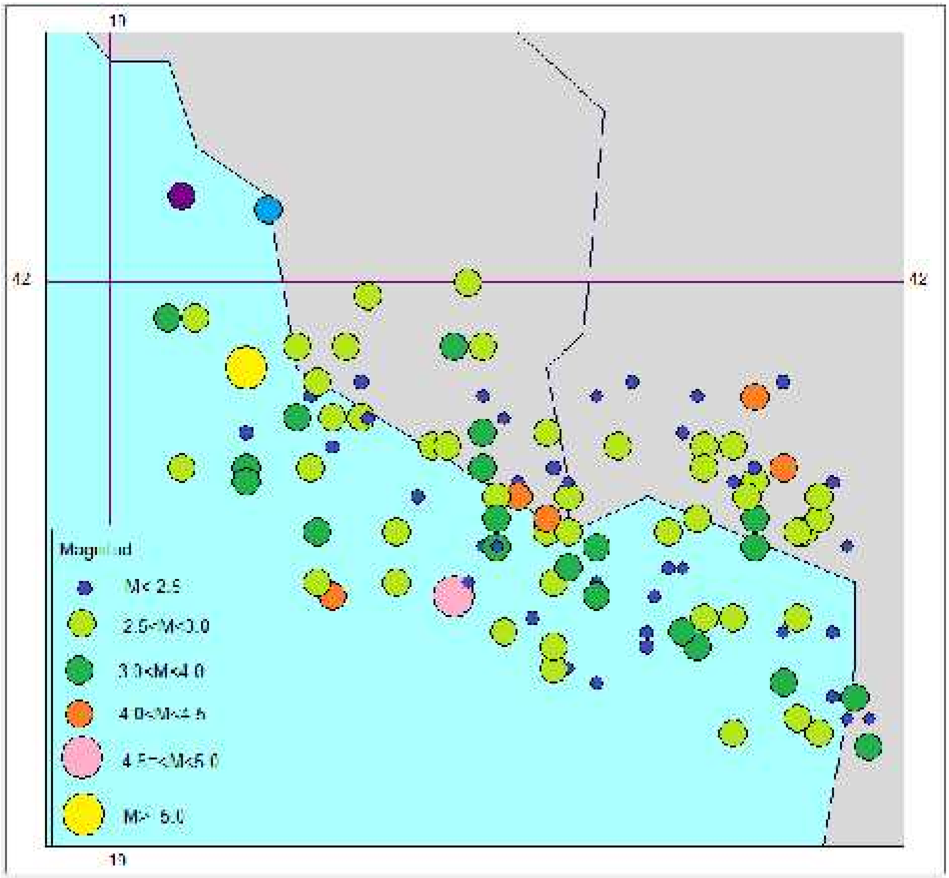


Fig 2. The map of earthquake epicenters occurred in Lezha-Ulqini zone during period 2001-2012

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. The smaller b-value means that the stress was high in the Lezha-Ulqini region. The major shock 21 August (Ulqini) earthquake (M5.0) was followed by a decrease in b-value in months before this earthquake. Before 2009 year the b coefficent has smaller values correlated with increasing stress level.

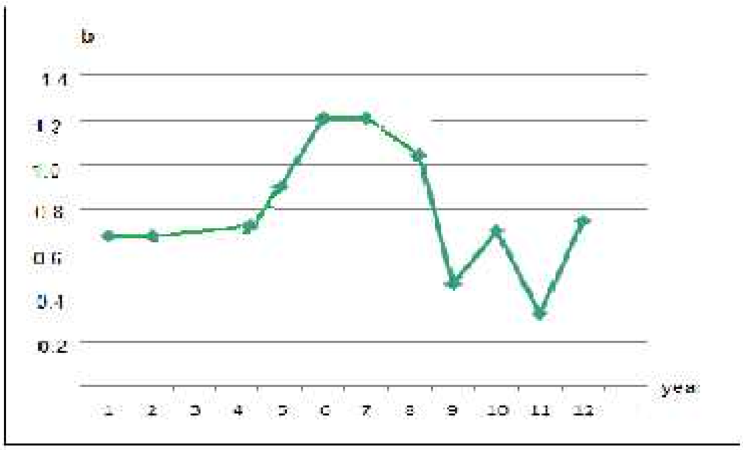


Fig 3.Temporarly distribution 'b' value for each year during this century for events with M_L>1.5

V. INSTRUMENTAL PARAMETERS AND FOCAL MECHANISMS SOLUTIONS OF EARTHQUAKE OF 21 AUGUST 2009

The 21 August earthquake hypocentral coordinates are 41.86°N and 19.13°E, with a focal depth 12.9 km. Figure 4 illustrates the distribution of aftershocks recorded from 21 August to 30 September 2009 with $2.0 \leq M_L \leq 4.0$ on the Dalmat coast. The epicenters of these secondary events are located northeast of the main-shock at 5-15km depth [11]. The aftershock activity developed in the seismically active upper crust beneath Albania, which has a thickness of 20-25 km [10].Aftershocks began immediately after the mainshock and were distributed along a narrow SE-NW belt with over the Adriatic coastline, but progressed towards the mainshock. The aftershock locations indicate that many occurred on subsidiary faults and were limited to the primary fault plane. Aftershocks that were distant from the mainshock rupture plane indicate that the stresses on cracks increased as a result of the mainshock.

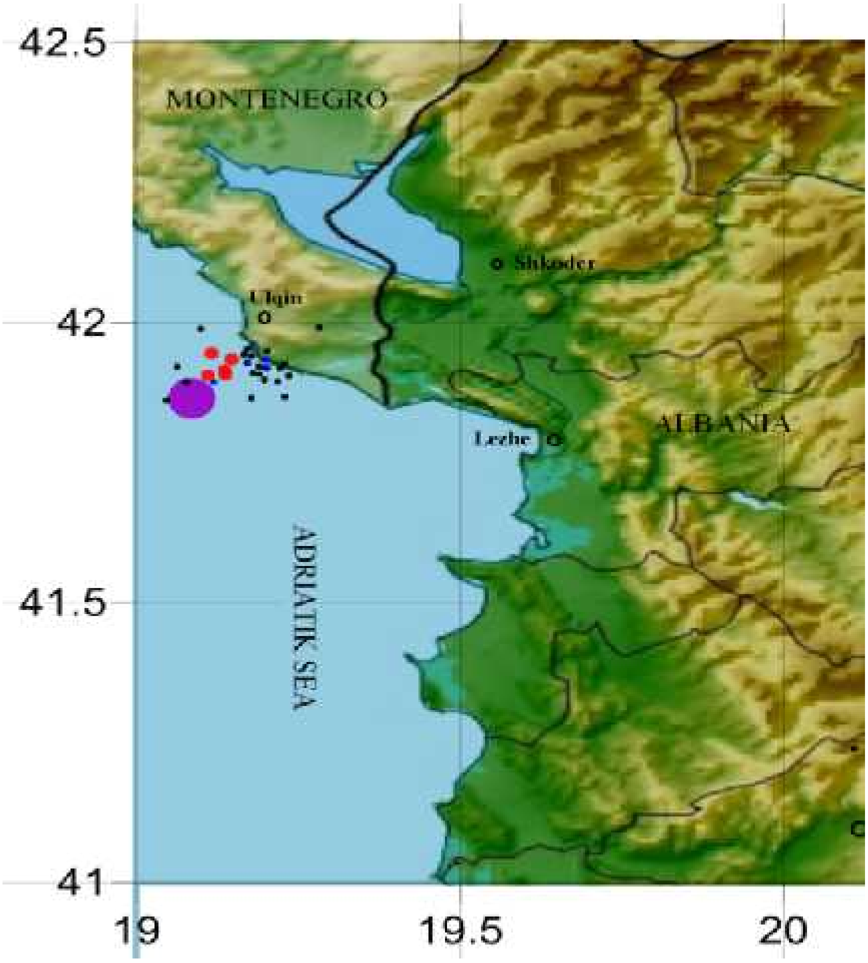


Fig. 4. Epicenters of mainshocks and aftershocks of the earthquake that occurred in 2009 in the Adriatic Sea.

We determined the focal mechanisms of the 21 August 2009 mainshock and three $M_L > 3.7$ aftershocks. The parameters of the four focal mechanisms are listed in Table 1. The 21 August 2009 mainshock has a strike of 158°, a dip of 50° and a rake (slip) of 90°.

VI. SEISMOTECTONIC INTERPRETATIONS OF ZONES FROM SOURCES PARAMETERS OF 21 AUGUST EARTHQUAKE SEQUENCE.

Here we study the rupture processes of the four strongest events in the aftershock sequence of the 21 August 2009 earthquake, focusing on the slip distribution along the fault planes. Analysis of the focal mechanism solution shows that the earthquake was triggered by pure thrust with a NE-SW direction of compression (Fig. 5). The hanging wall of the fault has a dip of 50° and its NW-SE trend is associated with activation of the Adriatic Sea deep crustal fault zone at the border of the Adriatic Sea platform and the orogen. The focal mechanism solution of this shallow earthquake demonstrates ongoing NW-SE horizontal compression (thrust faulting) along the Ulqincoastline.

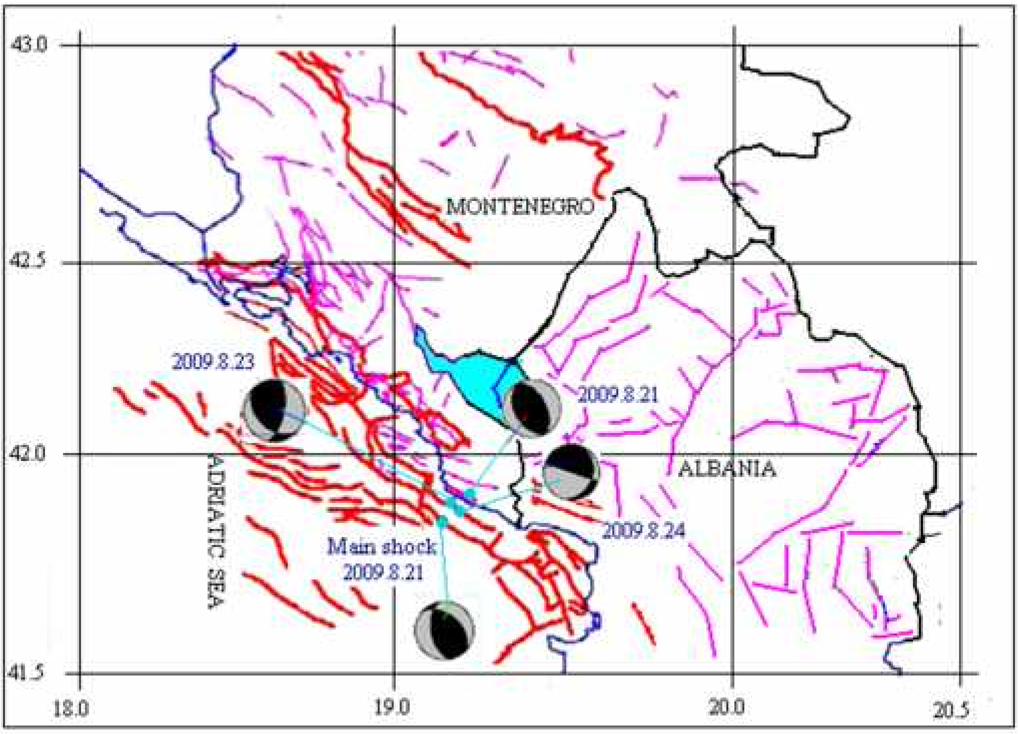


Fig.5. Detailed seismotectonic map of Lezha-Shkodra-Ulqini and the surrounding area based on seismic and geologic data [14], and focal mechanisms of the 21 August 2009 mainshock and its aftershocks with M_L>3.7.

The focal mechanism of the first aftershock, which occurred four minutes after the mainshock, indicates pure thrust faulting and for the 23 and 24 August aftershocks show thrust faulting with a strike-slip component.The focal mechanisms of the mainshock and the strongest aftershocks show that the seismic activity along the Adriatic coastline in the Lezha-Ulqin zone is due to regional compression (Table 1, Fig. 5). These earthquakes were caused by motion along a pure thrust fault with a NE-SW compressional stress direction. The axes of compressional stress are perpendicular to the coast of the Adriatic Sea. The dislocation planes activated by the earthquakes coincide with the fault planes based on geological and geophysical data. Thus, the 21 August 2009 mainshock was generated by the reactivation of a NW-trending reverse fault (N22W) in the Ulqin zone.

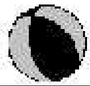
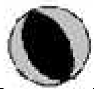
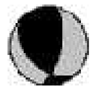
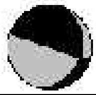
The associated seismic hazard has a direct connection with the geology of the location. While the seismic hazard resulting from thrust fault earthquake is well recognized and discussed, little attention has been given to quantifying the subsequent aftershock activity and its potential impact on communities in the region. Results of seismicity presented in this paper are intended to enable community officials and the general public to better understand the Lezha-Ulqini zone earthquakes threat and to encourage a more comprehensive discussion of the Lezha-Ulqini thrust fault zone with a NE-SW direction of compression.

Table 1. The focal mechanism parameters of the Ulqin main-shock and selected aftershocks

VII. CONCLUSIONS

This study focuses on the recent features of seismicity of Lezha-Ulqini most seismogenic zone in Albania.

Focal depth analysis reveals that this seismicity was mainly generated in the upper and middle crust,

N	Date Y/m/d	Time h:m:s	RMS (s)	Lat	Long	Depth (km)	M_L	Strike	Dip	Rake	Type of Mechanism.
1	09/08/21	13:37:56	0.05	41.86	19.13	12	5.0	158	50	90	
2	09/08/21	13:41:24	0.09	41.94	19.22	7.6	4.0	151	40	90	
3	09/08/23	21:44:53	0.18	41.91	19.18	12	3.9	11.1	64.	56	
4	09/08/24	00:03:22	0.24	41.90	19.18	15	3.7	108.5	90	65	

under the tectonic conditions described previously. Analysis of focal mechanisms shows the predominance of thrust faulting with a normal component onLezha-Ulqin in western Albania that is compatible with the present-day NE-SW compression.The 21 August 2009 Adriatic Sea earthquake ruptured along a dipping plane with a strike subparallel to the coastline and predominately thrust motion. The earthquake is consistent with hypothesis of the convergence of the Adriatic block and the European mainland. This sequence confirms the northwest continuation of thrust faulting along roughly NNW-SSE-trending faults related to the coastline of the Adriatic Sea.Thrusting faulting in Albania are likely to be the result of differences in gravitational potential energy between the lowlands of western Albania and the mountains in the east of the country. TheLezha-Ulqin fault zones have produced earthquakes in the past, and they are expected to continue to be active in the future. This study of earthquakes emphasizes many geologic and seismotectonic characteristics of the areas constituting a threat for nearby urban areas of Albania, and Montenegro.

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