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Some Features of Seismicity in Leskovik-Korca-Oher Fault Zone During this Century

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Abstract

During this century, the Leskoviku-Korca-Oher fault zone seismicity is dominated by 7 moderate earthquakes with magnitude M_L ranging 4.5 – 5.3. The database of this study composed of 2858 seismic events with M_L >0.5 is characterized by tectonic earthquakes with b-value 0.76. Most of the earthquakes have magnitude ranging between 1.8 and 3.3. The cumulative number of earthquakes during two decades trends to increase. Furthermore, on the Leskoviku-Korca-Oher territory there are approximately 1392 earthquakes with magnitude M_L ≥2.0, about 355 earthquakes M_L ≥3.0 with average depth 11km, about 30 earthquakes M_L ≥4.0 also 9 earthquakes M_L ≥4.5 and 4 earthquakes M_L ≥5.0. Statistics from 2001 to 2023 show that every year inside the Leskoviku-Korca-Oher territory occurs one earthquake with M_L >4.0 and every 5 years occurs an earthquake with a magnitude of 5.1 to 5.3 Richter. A series of earthquakes of maximal magnitude (M_L =5.3) started on June 01, 2019, at 04:26 (UTC), close to Floq village about 17 km south-west of Korça town expresses the increased seismic activity of the Leskovik-Korca-Oher seismogenic zone. We present results from statistics and analysis of focal mechanism of seismic events. The region affected enormous small earthquakes and by some moderate earthquakes during this century together with the strongest earthquake of the May 1960 M_L= 6.2, forms a roughly N−S trending active seismotectonic zone in southeastern Albania which presents a threat to nearby urban areas from Albania, Greece and the North-Macedonia.

Keywords: Moderate earthquakes, series, Focal mechanism, Faults.

Introduction

The Albanian orogen, as the most south-western part of the Euro-Asiatic plate, in convergence with the Adria micro plate, is divided in two areas with different tectonic regimes: the external area with compressive regime, representing its offshore part and the internal area with expanding regime, representing the continental area (fig. 1 left). The Albania region is one of the most seismically active region with tens of

destructive large earthquakes since the earliest recorded history and from the historical sources [1], [2]. The Leskovik-Korçë-Oher (L-K-O) fault zone in Albania has been a seismically active area from the historical sources and represents currently a high seismicity. Seismic activity in the Leskovik-Korçë-Oher fault zone during the current century has been characterized by micro-earthquakes, small earthquakes, and moderate earthquakes. Within this region, a total of 2858 earthquakes with a magnitude $M_L \geq 0.5$ Richter have been recorded, with an average depth of 11 km. Notably, this fault zone has experienced seven moderate earthquakes, including one with a maximum magnitude $M_L = 5.3$ near the Floq village, approximately 17 km southwest of Korça town. Various types of earthquakes have been observed in the area, including mainshocks and aftershocks, foreshock mainshocks and aftershocks, compound earthquakes, and swarms. Analysis of the focal mechanisms indicates that normal faulting with a strike-slip component predominantly occurs, oriented in a NNW to SSE extension direction in eastern Albania. [1]. [2], [3], [4]. This faulting pattern is believed to result from the convergence between the Adriatic microplate and the Albanian orogeny [5]. The Leskovik-Korçë-Oher half-grabens are considered the most dynamically active fault zone [6]. Data regarding earthquake depths suggest that the seismoactive layer in this region is located in the upper and middle crust. Several significant seismic events have been documented in the Korça zone and its surroundings, including occurrences in 548, 1673, 1871, 1889, 1878, 1896, 28 September 1906, 18 February 1911, 13 February 1912, 22 December 1919, 14 September 1920, 28 January 1931, and 26 May 1960 [2]. Recent moderate earthquakes and their aftershocks in the Leskovik-Korçë-Oher fault zone have been found to be triggered on normal faults combined with a strike-slip component, with an E-W extension stress direction, according to focal mechanism solutions.

Materials and Methods

The database of used in this study is based on Monthly seismological bulletin of Albanian seismic network [7]. This database consists of 2858 seismic events with a magnitude $M_L \geq 0.5$, primarily comprises tectonic earthquakes were maped (fig.1 right). Focal mechanism solutions were determined based on data from ASN, Albania GFZ. Potsdam, Germany, and NOA Athens, Greece [7], [8]. A comprehensive and consistent catalogue is available for the interpretation features of seismicity and focal mechanism parameters

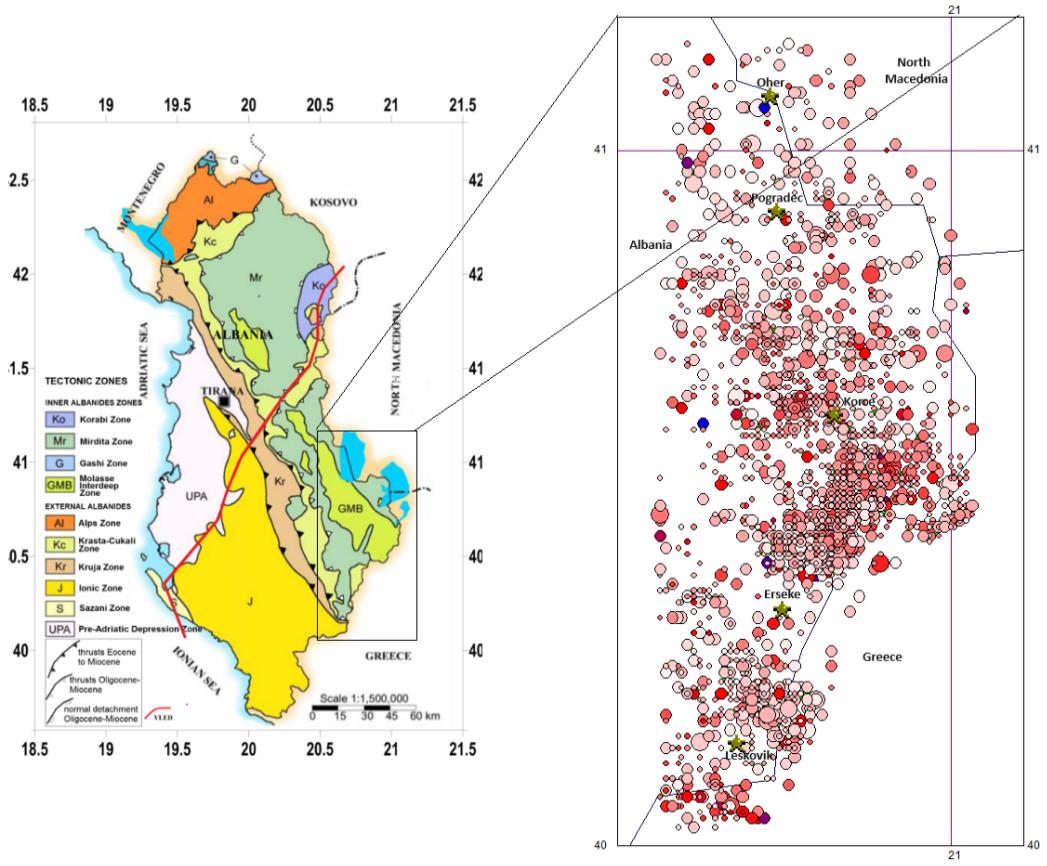

Fig 1. (Left) Tectonic map of Albania, (right) *Epicenter's map of earthquakes M≥0.5 occurrence in L-K-O fault zone during 2001-2023*

Results and Discussion

Some main feature of Seismicity

The Leskovik-Korçë-Oher is a fault zone with moderate level of seismicity, as highlighted also by the recent earthquake of June 1, 2019 (M_L 5.3), about 17 km southwest of Korça town and with effects in the Korça, Erseka and Maliqi towns. On Leskovik-Korçë-Oher during two last decades increased of seismic activity was recorded (fig .2 left). About 2858 seismic events were located with magnitude ranging 0.5 to 5.3 and average depth 11 km seismotectonic coefficient b is 0.76.

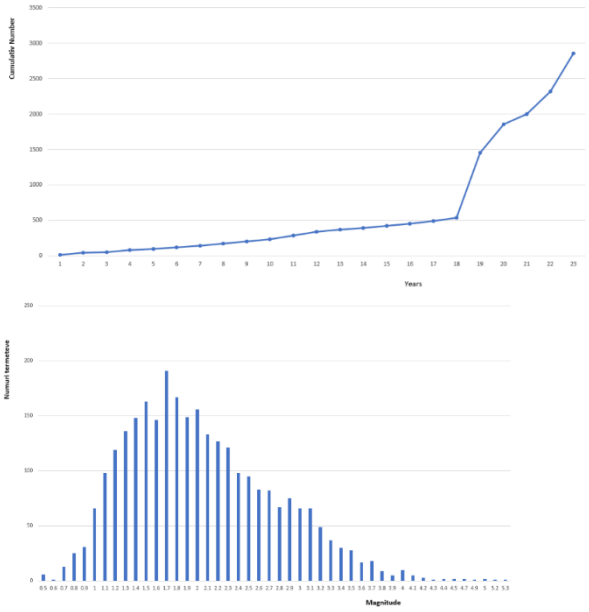

Fig 2. (Left) Annual cumulative number of earthquakes, (right) Distribution of the number of earthquakes according to the magnitude for L-K-O zone,

The cumulative number of earthquakes during this century, show highest seismic rate during 2019-2020 Years (fig. 2 left). The cumulative number of earthquakes until 2018 trends to increase gradually. We have a high increase during period of time 2019-2023. The highest increase during 2019 is related with series of Korça moderate earthquake of M_L5.3. In the other years it is related to automatic location program of earthquakes. About 355 of all earthquakes have magnitude M > 3.0 Richter with average depth 11 km, 30 of them with magnitude M > 4.0 Richter with average depth 12 km, 9 of them with magnitude $M_L \geq 4.5$ Richter with average depth 13 km and 4 of them with magnitude $M_L \geq 5.0$ Richter with average depth 13 km. Statistics from 2001 to 2023 show that every year inside this area occurs 1 earthquake with a magnitude greater or equal then 4.5 Richter and in every 5 years occurred 1 earthquake with magnitude $M_L \geq 5.0$ Richter. Figure 2 right, shows the number of located earthquakes grouped by magnitude. The maximum number of earthquakes is for magnitude ranging 1.0 to 3.1 Richter, while the catalogue is starting from magnitude 0.5 (fig 2 right). About 2690 or 94%are distributed in depth between 0 and20 km, and 6% are distributed in depth over 25 km and the maximum concentration is in depth between 1 and 15 km (fig. 3). By generalizing the data from the depths of earthquakes statements show that the seismoactive layer in L-K-O fault zone is in upper and middle crust. In conclusion of this study, the depth of earthquakes in the Albania territory are concentrated mainly in the earth's crust and a few in the upper most mantle.

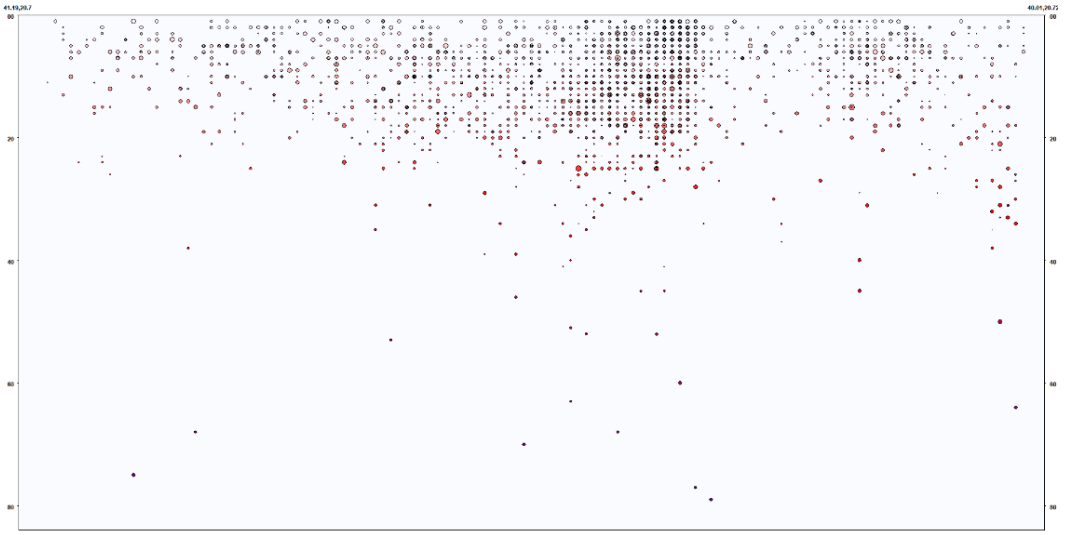

Fig. 3 Profile of distribution of earthquake to the depth

Focal mechanisms of earthquakes Mw≥5.0

We present focal mechanism solutions obtained from EMSC and ASN data for several moderate earthquakes (magnitude M>4.5) that occurred in the fault zones during this century. The parameters of the 18 earthquake focal mechanisms are listed in Table 1. The rupture processes of these strongest events for each zone, focusing on the slip distribution along the fault planes, were studied (see Figure 4). The focal mechanism solutions of the moderate earthquakes during this century indicate that the extensional regime was the primary cause of seismic activity along this zone. Based on the focal mechanisms, the motion of the earthquakes on 28 August 2008, 11 September 2010, and 01 June 2019 occurred on pure normal faults, with E-W extensional stress direction. The region affected by these sequences, along with the seismogenic region of the 1960 Korça event, forms a roughly N–S trending active seismotectonic zone in southeastern Albania. This poses a threat to nearby urban areas in Albania and Greece.

On November 23, 2004, an earthquake with a magnitude of Mw=5.3 occurred near the Germenji village at a depth of 15 km. The fault zone responsible for this earthquake extends from Germenj up to Shales and Shën Thanas villages. It is characterized as a normal fault with an orientation towards the NNE direction from the epicenter of the mainshock, with an inclination dipping towards the west. The segment of the fault between Germenji and Shales in the south was activated.The focal mechanism solution of the mainshock indicates an active plane striking 37° NNE, with a hanging wall inclination of 65° and a hanging wall displacement of -43° (representing downward motion). This analysis suggests that the normal faulting mechanisms with a left strike-slip component of the mainshocks are in good accordance with the geological setting.

On November 23, 2006, an earthquake with a magnitude of Mw=4.6 occurred near the Greece-Albania border, approximately 2 km from Albania, at a depth of 21 km. The focal mechanisms of this earthquake reveal an active striking plane (strike) of 280°NE, with an inclination of the hanging wall (dip) of 56°, and a hanging wall displacement (rake) of 29° (indicating downward motion). The mainshock was generated by the activation of the NE-trending normal fault of Bourazani – Ura e Zhepes along the Vjosa River. This focal mechanism suggests an oblique fault as a thrust fault, combined with a strike-slip component, which is in good agreement with the geological structure. Additionally, this focal mechanism indicates a roughly NNW-trending active fault zone in southern Albania that extends into northern Greece along the Vjosa River.

The epicentral zone of the September 11, 2010, earthquake series with a magnitude of Mw4.9 extends from Baban up to Vranisht, Plase, Rrembec, Sovjan, Pirgu, Kakac, Dardhe villages in the NNW direction from the mainshock epicenter. The focal mechanism solution of the mainshock reveals an active plane striking 182° NNW, with an inclination of the hanging wall of 42° and a hanging wall displacement of -90° (indicating downward motion). Based on this analysis, the pure normal faulting mechanisms of the mainshocks are in good accordance with the geological setting. The first strong aftershock with a magnitude of M=3.1 occurred 5 minutes after the mainshock and was caused by normal faulting, with a strike of 278° and a dip of 80°. Focal mechanisms of the other aftershock, which occurred on September 20 at 08:13 a.m. with a magnitude of M=3.4, indicate normal faulting with a strike of 247°. These aftershocks occurred along the same fault plane as the mainshock.

The focal mechanism solution of the earthquake that occurred on June 01, 2019, at 04:26 (Mw5.5), as provided by https://geofon.gfz-potsdam.de/, is as follows: Strike = 216°, Dip = 52°, and Rake = -88° (refer to Fig 1). The focal mechanism results indicate that this earthquake was triggered by normal faulting with an E-W extensional stress direction. Specifically, the mainshock's normal fault mechanism exhibits an active plane striking 216° NE, with the hanging wall inclined at 52° relative to the horizontal, and a downward displacement of the hanging wall relative to the footwall of -88°. Figure 4 depicts a portion of the seismotectonic model for the region of the Korçe-Leskovik seismic source zone, illustrating several faults and lineaments with neotectonic activity in the epicentral area. The Korca basin, a graben valley, asymmetric in shape with a much higher scarp to the east, located around 820 m a.s.l. The Quaternary deposits overlay the molasses deposits and are represented by alluvial and proluvial deposits composed of an alternation of silts, sands and gravels. [9]. The mainshock originated from the activation of a NE-trending normal fault of Flloq-Kamenice-Mollas, dating back to the Pliocene-Lower Pleistocene (or Pliocene-Quaternary) period [6].

No	Date Y/m/d	Time h:m:s	Lat	Long	Depth (km)	M_w	Nodal plane 1 and 2			Type of beachball
							Strike	Dip	Rake	
1	11/23/04	02:26:12	40.25	20.69	5	5.3	37 148	65 51	-43 -148	
2	11/23/06	13:21:41	40.08	20.58	33	4.5	280 173	56 67	29 143	
3	02/02/07	12:06:28	40.21	20.75	5	4.7	211 100	34 76	-155 -58	
4	08/28/08	03:37:28	40.67	20.67	13	4.6	358	30	-90	
5	09/11/10	15:47:12	40.64	20.89	7.0	4.9	182 °	42 °	-90 °	
6	06/01/19	04:26:17	40.47	20.71	14	5.5	216 35	52 38	-88 -90	
7	06/01/19	04:33:06	40.49	20.76	2	4.9	220 24	48 43	-79 -100	
8	06/01/19	04:51:57	40.47	20.80	14	4.7	215 25	51 40	-81 -99	
9	06/01/19	07:00:26	40.50	20.76	7	5.0	201 16	53 37	-86 -92	
10	07/31/19	14:21:01	40.51	20.79	13	4.7	206 354	70 23	-78 -120	
11	11/01/19	05:25:43	40.55	20.89	25	5.1	190 58	40 61	-130 -62	
12	05/11/21	21:31:05	40.48	20.91	20	4.9	242 23	42 55	-59 -115	
13	03/15/23	05:14:36	40.78	20.67	10	4.6	46 179	78 16	-77 -135	

Table 1. The focal mechanism parameters of the 8 moderate earthquakes with Mw > 4.5 occurred in LKO seismoactive zone and of the aftershocks of the June 1, 2019 Korca earthquake (green)

The focal mechanisms of the mainshock and its main aftershocks on June 01, 2019, Mw5.1 (at 04:33:06) and ML5.0 (at 04:51:57), as well as an aftershock of ML5.0 (at 07:00:26), all indicate normal faulting with a light strike-slip component. (fig 4). These mechanisms highlight the regional extensional regime driving the seismic activity. Although some aftershocks did not occur along the same fault plane as the mainshock, instead activating faults with different orientations, this diversity underscores the heterogeneous stress state and geological structures in the area [6].The dislocation planes activated by the earthquakes align with the fault planes according to available geological and geophysical data. The earthquake series of June 1, 2019 (Mw5.5), is associated with the tectonic activation of several fault lines, consistent with the seismotectonic map displaying multiple ruptures in the epicentral

area. Surface deformation observed from Sentinel-1A SAR data descending track correlates with the orientation of faults in the Flloq-Mollas zone near the earthquake epicenter [6]. These earthquakes resulted from motion along normal faults with an E-W extensional stress direction, related to parallel tectonic lines with extension in the NNE to NNW direction. (Fig 4). The focal mechanisms indicate the predominance of normal fault motion with a strike-slip component, compatible with the present-day N-S extension.

The earthquake May 11, 2021 (Mw=5.1) occurred about 27 km S-E of Korça town, in Greece, 3 km near the border with Albania at the depth of 8 km. The focal mechanisms of this earthquake has an active striking plane (strike) 23° NE, an inclination of the hanging wall (dip) of 15°, a hanging wall displacement (rake) of -115° (downward motion). The mainshock was generated by the activation of a NE-trending normal fault of Korfula – Kapshtice – Bilisht of Pliocene – Quaternary. This focal mechanism indicates normal faulting with a lightly strike-slip component in good agreement with the geological structure. This focal mechanism shows a roughly N–S-trending active fault zone in southeastern Albania that continues in the north of Greece.

The earthquake March 03, 2023 (Mw=4.6) occurred about 40 km S of Korça town, at the depth of 10 km. The focal mechanisms of this earthquake has an active striking plane (strike) 244° NE, an inclination of the hanging wall (dip) of 70°, a hanging wall displacement (rake) of -75° (downward motion). The mainshock was generated by the activation of a NE-trending normal fault of Bezhan-Nikolice – Dardhe of Pliocene – Quaternary. This focal mechanism indicates normal faulting with a lightly strike-slip component in good agreement with the geological structure. This focal mechanism shows a roughly N–S-trending active fault zone in southeastern Albania that continues in the north of Greece. Analyzes of focal mechanisms of this series show the predominance of normal fractures with strike-slip components in accordance with previous studies on the expansion regime in the direction VP - JL for this zone. The analysis of the obtained data reveals a very complex seismic situation, where the presence of a system of parallel or nearly parallel fault lineaments in the vicinity of the main fault affects the redistribution and transfer of tectonic stress. This zone characterized by active normal faulting. The depth of earthquakes is shallow up to 15 km and nodal planes have a strike between NE and NNW directions. Some of the aftershocks of the Mw5.5 earthquake that struck on June 1, 2019, happened on faults that were oriented differently from the mainshock, indicating a variety of geological structures in the region with heterogeneous stress states.

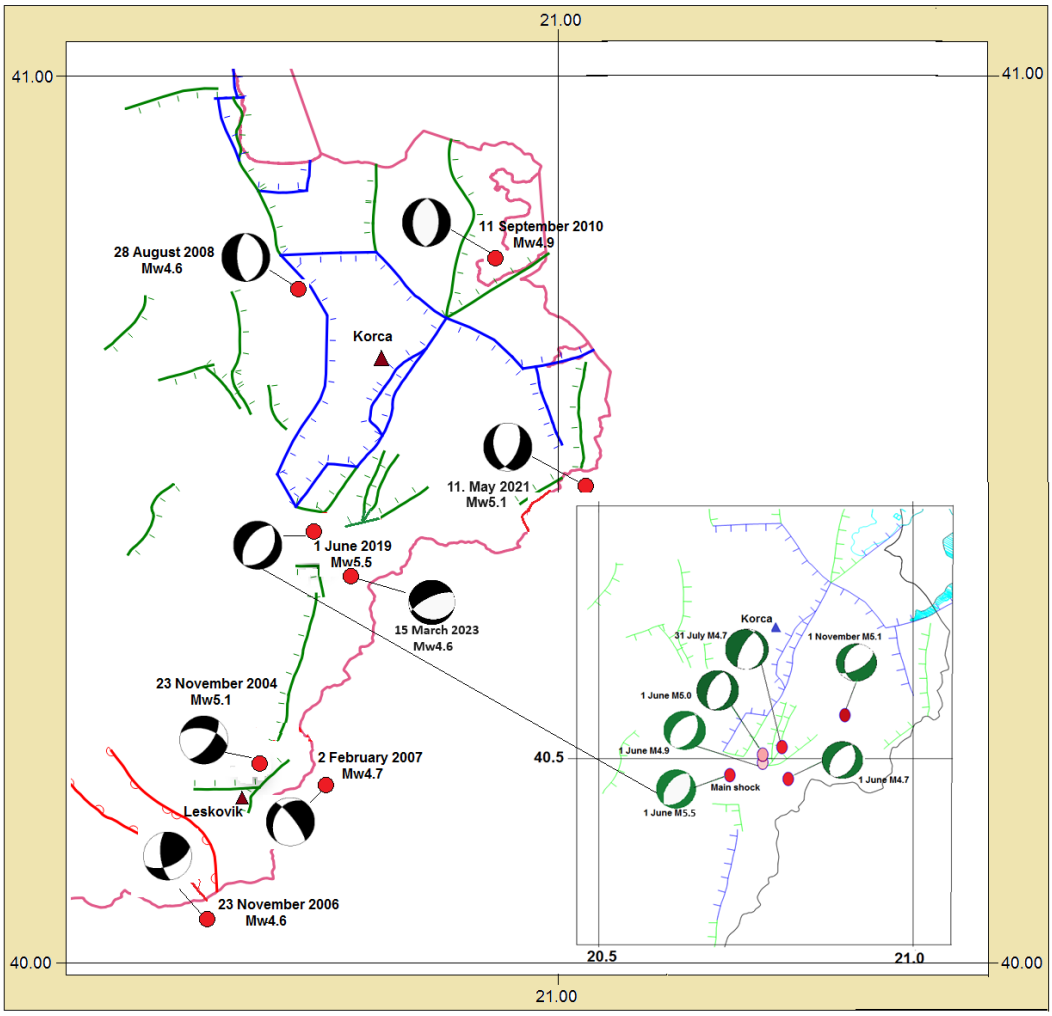

Fig. 4- (Left) Detailed seismotectonic map of Albania (Aliaj 2010) and focal mechanisms of 8 moderate earthquakes with Mw ≥ 4.5 occurred in L-K-O seismoactive zone, (right) aftershocks of June 1, 2019 earthquake (beachballs green color) .

Based on the geological and geophysical data, the fault planes and the dislocation planes caused by the earthquakes coincide. We can conclude that the June 1, 2019 (Mw5.5) earthquake series may have been caused by the tectonic activation of multiple fault lines. The temporal pattern of the aftershock activity indicates that this result is consistent with the seismotectonic map of four ruptures in the epicentral area. The three additional tectonic lines of the normal fault type that are situated in the vicinity of the series' aftershocks are combined of normal faults with strike-slip

components is evident in our active faults in LKO zone. The source parameters of these earthquakes and can be used to shed light on the seismotectonics of this area.

Conclusion

Throughout this century, the Leskovik-Korçë-Oher fault zone and its surrounding territory have experienced a total of 5835 earthquakes, with magnitudes ranging from 0.5 to 5.3 on the Richter scale. This zone exhibits various complex features from a neotectonic standpoint and in terms of the structure of the Earth's crust. Eight moderate earthquakes, with magnitudes ranging from 4.6 to 5.3, have occurred in this region during this time period. The focal mechanism solutions of these earthquakes, including the strongest earthquake on June 1, 2019, and seven other moderate earthquakes, indicate the predominance of normal faulting with a strike-slip component. The NNW-SSE extension directions observed in southeastern Albania are attributed to the convergence between the Adriatic microplate and the Albanian orogen. Further analysis of the focal mechanisms reveals normal faulting with a light strike-slip component in the Korça and Ohri region, and normal faulting with a strike-slip component in the Leskoviku region of southeastern Albania, which is consistent with the present-day N-S extension. Several strong aftershocks of the June 1, 2019 earthquake did not occur along the same fault plane as the mainshock; instead, they occurred on faults with different orientations, highlighting the variety of geological structures in the area and the heterogeneous stress state. The distribution of aftershock epicenters corresponds to the direction of axes of the primary fault plane. Overall, the focal mechanism solutions and distribution of aftershocks in time and space suggest that the moderate earthquakes were generated along parallel fault lineaments in the NNE to NNW direction. This study provides valuable insights into the geological and seismotectonic characteristics of the region, contributing to measurements for disaster protection in areas that pose a threat to nearby urban areas of Albania and Greece.

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