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# Seismotectonics of Vlorë-Elbasani-Dibra Transversal Fault Zone (Albania): A Review

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**Abstract:** The Vlorë-Elbasani-Dibra transversal fault zone crosses from south-west to northeast the Albanides collision zone starting from Vlorë area to the Dumre diapir and continuing from Elbasani Quaternary graben to Dibra area, within the internal Albanides extensional zone. The Vlorë-Elbasani-Dibra seismogenic fault zone is expressed by an alignment of important historical and instrumental seismicity with 15  $M_s > 6$  earthquakes. The Vlorë-Berati-Elbasani segment of this fault zone during the year 1851 has been activated along all its length. The geological and neotectonic investigations and the focal mechanism solutions of earthquakes that occurred along the Vlorë-Elbasani-Dibra fault zone prove its division into two distinct fault zones: a) the Mali i Kanalit Block - Dumre diapir strike-slip fault zone NNE trending in transpression, and b) the Elbasani-Dibra normal fault zone NE trending in transtension. The Mali i Kanalit Block-Dumre diapir strike-slip zone NNE trending in transpression offsets dextrally and to SW the folds and thrusts of the Çika, Kurveleshi and Berati anticlinal belts of Ionian zone. The Neogene (mainly since Middle Miocene) offset of the Çika, Kurveleshi and Berati anticlinal belts from generally NW-SE trending to near N-S one has led to thrust's steepening and turning into high-angle strike-slip faults due to NE-SW oblique compression from the Albanides collision zone. The Othoni Island-Dhermi strike-slip fault offsets the dextrally dragged Devolli (to the east of Dumre diapir), Osumi (near to Berati town), and Vjosa (west of Shkoza village) rivers' valleys formed from the Middle Pleistocene (180,000 years) to historic times. The Othoni Island-Dhermi dextral strike-slip fault, that reaches the maximum velocity of greater than 5 mm/year to the south of it, is the only leading fault that shaped the Mali i Kanalit Block-Dumre diapir dextral strike-slip fault zone. Focal mechanism solutions of earthquakes that occurred on the Mali i Kanalit Block - Dumre diapir dextral strike-slip zone show their generation from strike-slip faults in transpressional motions. Focal mechanism solutions of earthquakes that occurred on the Elbasani-Dibra were generated from normal faults with dextral strike-slip movements.

**Keywords:** Geologo-neotectonic Investigations, Mali i Kanalit-Dumre Strike-slip Zone, Focal Mechanisms

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## 1. Introduction

The transversal fault zone Vlorë-Elbasani-Dibra, called also Vlorë-Dibra seismogenic belt, has been known after the Dibra earthquake of November 30, 1967 [37, 39] and later on has been treated in many seismological and seismotectonic studies. The Vlorë-Elbasani-Dibra seismogenic fault zone is expressed by a transverse earthquake belt, NE trending from Vlorë to Dibra region. The Vlorë-Berati-Elbasani segment of this fault zone during the year 1851 has been activated along all its length.

The Vlorë-Elbasani-Dibra seismogenic fault zone crosses the Albanides collision zone from south-west to northeast up to the Dumre Diapir and then from the Elbasani Quaternary graben to Dibra region, the internal extensional zone, and its

continuation in North Macedonia and Kosova.

Sulstarova et al. [41] paid much attention to the Vlorë-Elbasani-Dibra transversal fault zone, that is considered to be the most potential transversal seismogenic belt in Albania and nearby, and arrived in the following conclusions: "From focal mechanism solutions is quite clear that the southwestern part of Vlorë-Elbasani-Dibra transversal fault zone, from Vlorë Bay to Elbasani region, works as transtensional or transpressional strike-slip dextral type, whereas from Elbasani to Dibra region it works as normal fault with a dextral component of strike-slip, and as transtensional strike-slip dextral. From focal mechanism of the strongest earthquakes and microtectonic studies is concluded that in this transversal fault the motions are strike-slip dextral and generally transtensional".

The Elbasan-Dibrë segment of Vlorë-Elbasan-Dibrë transversal fault zone, NE trending, consists of fragmentary normal faults cutting across the Krujë and Krasta zones and divides into two main segments the Mirditë ophiolites [1, 2, 6, 8, 9, 12, 13, 14, 16, 18, 30]. Meanwhile, the neotectonic structure of Vlorë-Dumre segment of it is not clear up to nowadays.

The present study is supported by a number of obtained geological and neotectonic investigations, as follows: a) The determination of Othoni Island-Dhemri dextral strike-slip fault that separates two segments of Albanides collision zone [12-15], b) the GPS results demonstrating that Elbasan-Dibrë fault zone is mainly affected by an extensional displacement that does not extend till Vlorë [27], c) the Elbasan - Vlorë transfer zone offsetting the Krujë and Ionian nappes dextrally and to SW [26], d) Tectonic Map of Southern Albania scale 1: 200,000 showing the excellent offset of Çika and Kurveleshë anticlinal belts within Vlorë-Dumre area [42], and e) the oil-field structure of Kurveleshë and Berati anticlinal belts offset from generally NW-SE direction to N-S one within Vlorë-Dumre area [44, 45].

The analysis of geological and neotectonic investigations help me to better understanding the neotectonic structure of the Vlorë-Elbasan-Dibrë fault zone, and especially to examine the structure of Vlorë-Dumre segment as well as that of Elbasan-Dibrë one.

The aim of this study is to review the seismotectonics of Vlorë-Elbasan-Dibrë transversal fault zone and based on the obtained neotectonic structure examination and the focal mechanism solutions to propose a new geological interpretation for its separation into two distinct fault zones: a) the Mali i Kanalit Block - Dumre diapir strike-slip fault zone NNE trending in transpression, and b) the Elbasan-Dibrë normal fault zone NE trending in transtension.

## 2. Geological Setting

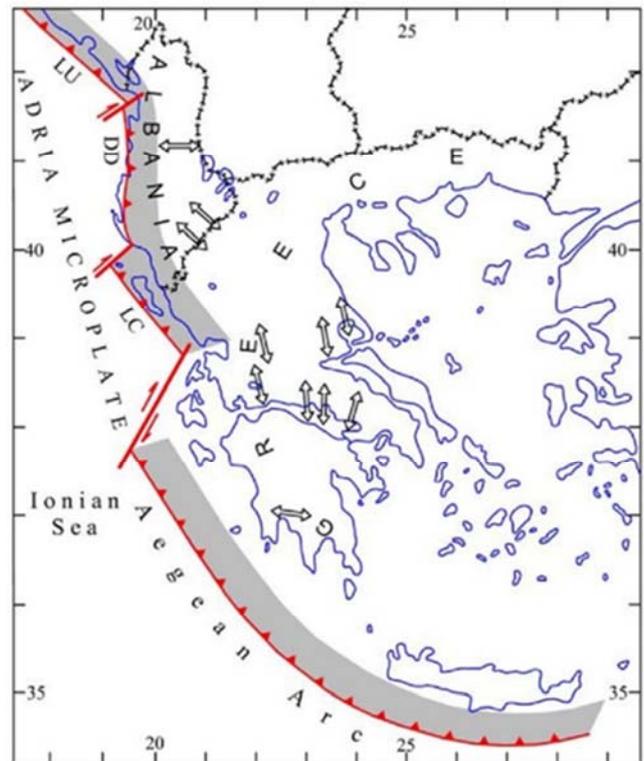
In Albania and Greece, along the southern convergent margin of Eurasia Plate, a northern segment of the margin belonging to the Adriatic continental collision, and a southern one belonging to the Aegean (Hellenic) Arc related to active oceanic subduction could be distinguished. The Adriatic-Eurasian collision has happened along the western coast of former Yugoslavia, Albania and central Greece. The boundary between the Aegean Arc and the Adriatic collision is the Cephalonia transform fault.

The Albanides is divided into the external collision domain in compression characterized by reverse faulting, and the internal domain in extension characterized by normal faulting. The Albanides (frontal part of Eurasian plate) collides with Adria Microplate that is fragmented into two subplates: the Apulian platform from Sazani Island to the south, and the Albanian basin (=South Adriatic basin) to the north of it [11, 14]. The Albanides orogenic frontal thrust is divided into the north-west trending Lefkas-Corfu segment, and the generally north-south trending Dhermi-Durrës segment which is shown in Figure 1.

We concentrate our study on the Vlorë-Elbasan-Dibrë transversal fault zone that crosses the Albanides collision zone

from south-west to northeast up to the Dumre Diapir and then from the Elbasan Quaternary graben to Dibrë area, the internal extensional zone, and its continuation in Macedonia and Kosovo.

The Vlorë-Elbasan-Dibrë transversal fault zone which trends from south-west to north-east and crosses all the Albanides [34, 41] and continues in Macedonia [20, 23] is named also as Vlorë-Dibrë seismogenic belt [37]. The Lushnje-Elbasan-Diber or Elbasan-Diber fault zone has been used in some studies [7, 10, 12, 13, 30, 31, 39]. From viewpoint of seismic source zoning, the Elbasan-Dibrë seismic source zone is characterized by a zone of fragmentary normal faults NE trending, along which strong earthquakes have recorded [10].



**Figure 1.** Southern convergent margin of Eurasia Plate: Adriatic collision and Aegean Arc (modified from Aliaj [11] with separation of two segments in the Albanides collision zone). Segments of Albanides collision zone are noted by capital letters: LC- Lefkas-Corfu, and DD- Dhermi-Durrës. LU- Lushnje-Ulqini segment belongs to the Dinarides.

The Elbasan-Dibrë fault zone, NE trending consists of fragmentary normal faults cutting across the Krujë and Krasta zones and divides into two main segments the Mirditë ophiolites. It is composed of the Elbasan Quaternary graben, the Labinoti transverse structures, the Golloborda transverse horst, the Tetova Quaternary graben in Macedonia and Morava e Binçës Quaternary graben in Kosovo. Its fragmentary continuation is more than 200 km long from Elbasan up to Gjilani in Kosovo [1, 2, 17, 24, 25]. The terrains of the Krujë and Krasta zones to the north of Elbasan are also ruptured by a system of northeast trending normal faults [47].

The present-days tectonics is controlled by NE-SW to E-W compressive stress in the western part of the country which is

connected with the subduction of the Adria microplate lithosphere and extensional stress in the internal domain [13, 16, 18], where the major extension direction varies from E-W along the Drini (Korça-Peshkopi) normal fault zone N-S trending [4, 12, 15] to NNW-SSE at the south of Kolonja basin in NW Greece [22].

### 3. Geological and Neotectonic Investigations for Seismotectonics of Vlora-Elbasani-Dibra Fault Zone

The obtained geological and neotectonic investigations that are analyzed here helped me to better understand the seismotectonics of the Vlora-Elbasani-Dibra Fault Zone.

#### 3.1. Othoni Island-Dhermi Dextral Strike-slip Fault That Separates Two Segments of Albanides Collision Zone [3, 12, 14, 15 18]

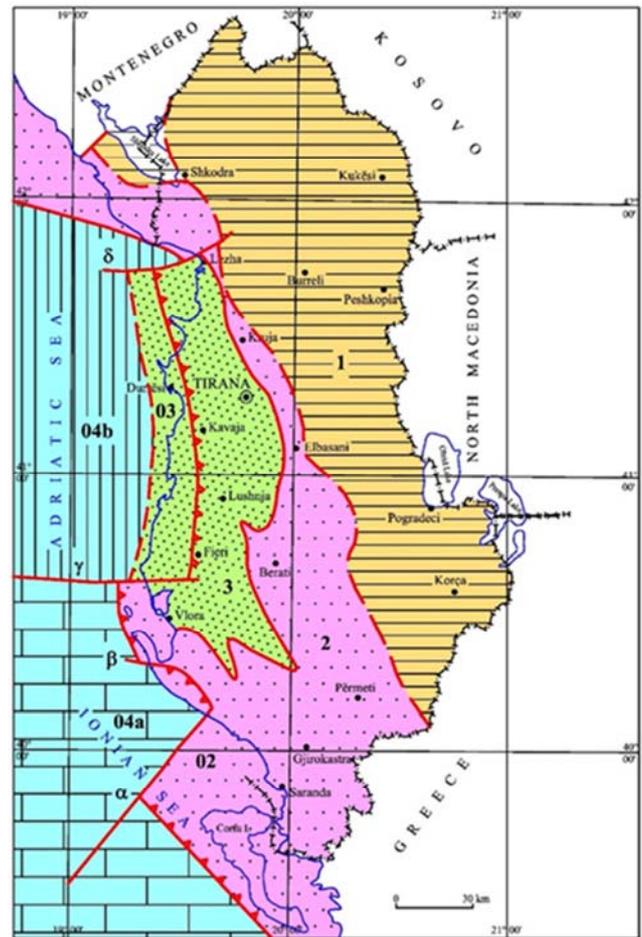
The Othoni Island-Dhermi dextral strike-slip fault has been proven from seismic explorations carried out in Ionian Sea waters by foreign companies and has been represented by Aliaj et al. [14] into the neotectonic map of Albania in scale 1:200.000 (1995, published 2018), and by Aliaj [15] into its explanatory text (1996). It has been marked by an abrupt passage from continental shelf in the south to Ionian offshore bathyal depths towards the north that follows the Palasa stream north-east trending. A thin imbricated section of Ionian Zone which was largely displaced south-west for about 45 km has been shown in Figure 2.

The last investigations about the stratigraphy and tectonic evolution of Late Miocene-Quaternary basins in Eastern Albania as well as the relief formation and thermochronological data show that the Late Miocene-Quaternary period which led to the recent geological structure of Albania and its rapid relief formation, can be accepted as 'Neotectonic period' [33].

The Othoni Island-Dhermi dextral strike-slip fault separates the north-west trending Lefkas-Corfu segment from the generally north-south trending Dhermi-Durres segment. Jouanne et al. [27] offered the new informations from the current velocities of external Albanides which are the expression of the ongoing collision between Apulia microplate and the deformed Balkan area, especially concerning the Othoni Island-Dhermi strike-slip fault, as follows: "The increase of shortening rate across the Adriatic occurs between the north-western and south-western Albania from 3.2 mm/year at SHKO to 4.9 mm/year at SARA. Major changes in velocities field reflect the location of major transverse zones: Shkodra-Peja fault zone, the Lezha fault and the Othoni Island-Dhermi Pass Fault between the Ionian zone and the Sazani zone.

GPS results demonstrate a southwestward motion of points located in external Albanides relative to Apulia with important north to south increase of their velocities, which arrive the maximum velocity of greater than 5 mm/year south of the dextral Othoni Island-Dhermi transfer fault. This fault is identified as a major seismogenic source underlined by the earthquake of November 21, 1930 at LLogora pass (south of

Vlora) and many destructive earthquakes that heavily hit the Vlora town".



**Figure 2.** Map of neotectonic (Pliocene-Quaternary) zonation of Albania [3, 5, 6, 12, 14, 15]. The orogen front from south to north is cut and displaced by the Othoni Island-Dhermi ( $\alpha$ ), the Gjiri i Ariut-Dukat ( $\beta$ ), the north of Sazani Island ( $\gamma$ ), and the Gjiri i Drinit-Lezha ( $\delta$ ) transversals. The large neotectonic units of Albania are represented by numbers: 1: Internal area affected by extensional tectonics since Pliocene, 2: External area affected by compressional pre-Pliocene tectonics, 3: Periadriatic Foredeep strongly affected by post-Pliocene compressional tectonics (03: its offshore sectors), 04: Pliocene-Quaternary Foreland in Adriatic and Ionian offshore (04a: Apulian platform. 04b: Albanian Basin).

#### 3.2. GPS Results Demonstrate That Elbasani-Dibra Fault Zone Is Mainly Affected by an Extensional Displacement and Does Not Extend Till Vlora [27]

Jouanne al. [27] offered very useful data from the results of GPS measurements carried out in the Albanides fold and thrust belt, and especially for the Vlora-Elbasani-Dibra fault zone, as follows: "The GPS results demonstrate the occurrence of the south-westward motion of points located in the external Albanides relative to Apulia. From the north to south, displacements rates of points in the external Albanides present changes in directions and norms. Current displacements of the external Albanides are the expression of the ongoing collision between Adria microplate and the Albanian orogen, frontal part of the Euroasia deformed plate, occurred in compressive regime. The major changes in displacement field are the reflection of main Shkodra-Peja

transversal, near Lezha, and Vlorë-Tepelena one, near Vlorë. To the east of external Albanides, the southward displacements take place in the inner Albanides under conditions of present-days extensional regime.

The current tectonics of the Elbasani-Dibrë fault zone is expressed by the extension measured between both sides of the Elbasani graben as shown by the strain rate tensors derived from permanent (P4, P5 and P6) GPS network, whereas no relative displacements are recorded in both sides of southwestern end of this fault zone. It is then highly probable that this fault zone is mainly active in the Elbasani area and in its eastern end as is shown by the 1967 Dibrë earthquake [39]. Strain rate tensors (P4, P5 and P6) across the fault zone indicate that this fault zone is mainly normal with extension directions  $\sim$  W-E (WNW-ESE). It is important to note the very good agreement between the extension direction deduced from strain rate tensor and focal mechanisms of the November 1967 [39] and the September 2009 earthquakes [28]. The Elbasani-Dibrë fault zone is mainly affected by an extensional displacement and does not extend till Vlorë.

The continuation of this fault zone in Macedonia is also marked by a noticeable increase of southward displacements. It is suggested that this fault zone is a major limit in current deformation of the western Balkan. It is important to state that this transverse zone is the most seismoactive one in Albania and in western Balkan too”.

### 3.3. The Elbasan-Vlorë Transfer Zone Offsets the Kruja and Ionian Nappes Dextrally and to SW [26]

Handy et al. [26] are the first scholars who informed the so-called Elbasan-Vlorë transfer zone as a dextral strike-slip fault zone and pointed out that Periadriatic Foredeep is offset dextrally along the NE-SW-striking zones, here named the Lezha and Elbasan-Vlorë Transfer Zones.

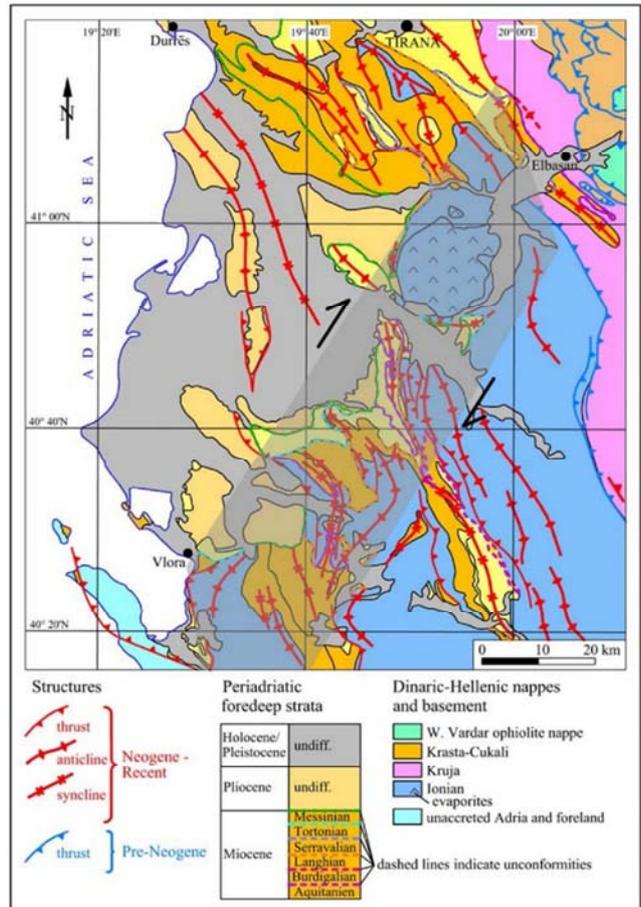
Handy et al. [26] in reference to the Elbasan-Vlorë transfer zone pointed out as follows: “The mountain range forming the eastern morphological boundary of the Tirana Basin is the site of Neogene thrusting and folding. The Neogene thrust front in northern Albania is offset dextrally along two NE-SW-striking zones, here named the Lezha and Elbasan-Vlorë Transfer Zones.

From the Lezha Transfer Zone to the SE and all the way along the morphological front of the mountain belt to Tirana, the Neogene thrusts imbricate Mesozoic-Paleogene strata of the Kruja Nappe. Between Tirana and Elbasan, the late Neogene thrusts are transitional along strike to open folds as shortening is transferred progressively across strike into Miocene sediments of the Periadriatic Foredeep. This is manifested by steepened Miocene strata, backfolds, and locally even overturned thrusts that affect Miocene and even Pliocene basin fill.

The Elbasan-Vlorë Transfer Zone offsets the Kruja and Ionian Nappes dextrally and to the SW. In map view, this transfer zone is marked by dextrally dragged folds and thrusts as well as thrusts that steepen and offset all Neogene basal unconformities and is shown in Figure 3.

Taken together, the deformed unconformities indicate that the Elbasan-Vlorë Transfer Zone has been active since

at least middle Miocene time. A salt diapir in the middle of the zone comprises Permo-Triassic salt from the decollement horizon of the Ionian thrust sheets. Miocene transfer faulting evidently exerted a control on the locus of diapirism, though final emplacement of the diapir is recent, as indicated by tilted Pleistocene beds in the outer limb of its rim syncline”.



**Figure 3.** Tectonic map of the Elbasan-Vlorë Transfer Zone (gray shaded area) dextrally offsetting the Neogene thrust front. Map based on 1:200,000 Geological Map of Albania [46] and our own observations [26].

### 3.4. Tectonic Map of Southern Albania Scale 1: 200,000 Shows the Excellent Offset of Çika, Kurveleshi and Berati Anticlinal Belts Within Vlorë-Dumrë Area [42]

The Southern Albania map view shows the excellent offset of Çika, Kurveleshi and Berati anticlinal belts of the Ionian Zone from their NW-SE direction to the N-S one within Vlorë-Dumrë area. The marked strong offset of the Çika, Kurveleshi and Berati anticlinal belts occurs within the Mali i Kanalit Block-Dumrë diapir strike-slip zone. This has been shown in Figure 6.

The dextrally dragged to southwest folds and thrusts of Çika and Kurveleshi anticlinal belts since the Middle Miocene offset is due to the NE-SW oblique compression from Albanides collision zone. It is important to note that Albanides collision zone locating to north-west of Mali i Kanalit-Dumrë diapir strike-slip fault zone is in generally E-W to ENE-WSW oblique compression.

### 3.5. Oil-field Structure of Kurveleshi and Berati Anticlinal Belts Offsets from Generally NW-SE Direction to N-S Direction Within Vlora-Dumre Area [44, 45]

Velaj [44, 45] is a well-known scholar for the geological studies in Ionian Zone that contains many oil fields structures. He paid much attention to tectonic style and oil-field perspective of the Kurveleshi and Berati anticlinal belts of Ionian Zone and describes in details their structural characteristics.

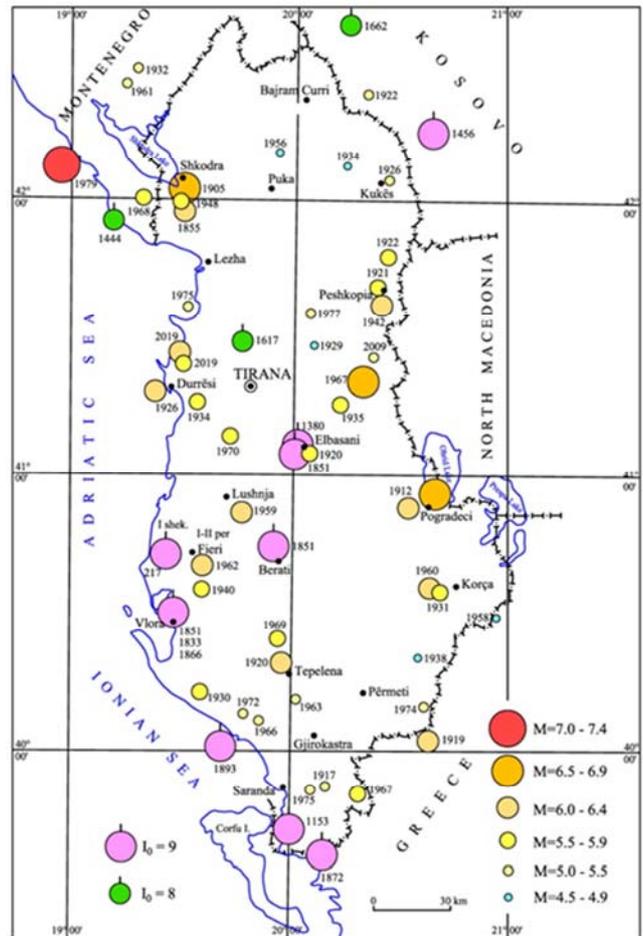
Velaj [44, 45] concerning the peculiarities of Kurveleshi and Berati anticlinal belts pointed out as follows: “The Berati anticlinal belt is differentiated into two sectors: the southern sector, to the south of Kiqoku pass, characterized by the large anticlinal structures having NW-SE trending, and the northern sector, to the north of Kiqoku pass, where the structures are smaller having gradually a meridional direction. Currently, the more interesting opportunity lies in the subthrusts beneath the Berati thrust belt. Actually, the Berati subthrust is in the process of being the subject of a seismic survey and exploration drilling where a new oil field was discovered in the subthrust of the Berati anticlinal belt, with drilling of the Shpiragu-2 well. The Kuçova, Shpiragu and Molishti oil fields of Berati anticlinal belt take place into the northern sector of it where the structures have gradually a meridional direction [44].

The Kurveleshi anticlinal belt is divided into two parts: the southern part from Sevasteri pass to the south, where predominate the large in size anticlinal structures having a generally NW-SE direction, and the northern pass, to the north of Sevasteri pass, where the anticlinal structures generally small to medium in size take immediately a northern direction. The Pekishti, Patos-Marinza, Visoka, Ballshi, Cakrani, Gorishti, Karbunara, and Amonica oil fields are located on the northern part of Kurveleshi anticlinal belt where the anticlinal structures have a northern direction [45]”.

From the above treated geological data is obtained the following conclusion: The oil fields located on the northern part of Kurveleshi and Berati anticlinal belts and having a generally northern direction structure are included within the structure of the Mali i Kanalit Mt Block- Dumre Diapir strike-slip fault zone NNE trending in transpression.

## 4. Seismic Activity of Vlora-Elbasani-Dibra Fault Zone

The seismicity of Albania is characterized by micro-seismicity, small and medium size earthquakes and a few large events as shown by the occurrence of 7 earthquakes with  $M_s$  magnitudes exceeding 6 from the last century to the present [1, 9, 10, 12, 16, 18, 30]. The  $M_s > 6$  earthquakes are: 1905, Shkoder earthquake  $M_s=6.6$ , 1911 Ohrid lake earthquake  $M_s=6.7$ , 1920 Tepelena earthquake  $M_s=6.4$ , 1926 Durres earthquake  $M_s=6.2$ , 1967 Diber earthquake  $M_s=6.6$ , 1979 Montenegro earthquake  $M_s=6.9$ , and 2019 Durres earthquake  $M_w=6.4$  (Figure 4).



**Figure 4.** Map of earthquake epicenters in Albania (modified from Aliaj [1]) shows that the Vlora-Elbasani-Dibra transverse earthquake belt is well marked.

Most of the strong earthquakes have occurred along three following well-defined seismic belts (see Figure 4): a) the Ionian-Adriatic coastal earthquake belt, NW-SE trending, along the eastern margin of the Adria microplate; b) the Drini (Peshkopi-Korça) seismic belt in the interior of the country, N-S trending, and c) the Vlora- Elbasani-Dibra transverse earthquake belt (trending SW to NE), which cuts through the Drini seismic belt [9, 39].

The Vlora-Elbasani-Dibra seismogenic fault zone is expressed by an alignment of important historical and instrumental seismicity with 15  $M_s > 6$  earthquakes. The Vlora, Berati and Elbasani were struck by following strong earthquakes: Berati on July 6, 1356 ( $I_{max}=VIII-IX$ ), Elbasani on 1380 ( $I_{max}=IX$ ), Berati on march 1551 ( $I_{max}=IX$ ), Vlora on June 16, 1601 ( $I_{max}=IX$ ) and on January 1, 1833 ( $I_{max}=IX$ ), Elbasani on September 5, 1843 ( $I_{max}=IX$ ), Berati on 1848 ( $I_{max}=VIII-IX$ ), Elbasani on January 20, 1851 ( $I_{max}=VIII-IX$ ), Vlora on October 12, 1851 ( $I_{max}=IX$ ), Berati on October 17, 1851 ( $I_{max}=IX$ ), Elbasani on October 20, 1851 ( $I_{max}=VIII$ ), Berati on December 29, 1851 ( $I_{max}=VIII$ ), Vlora on November 4, 1862 ( $I_{max}=VIII$ ) and on January 2, 1866 ( $I_{max}=IX$ ), Elbasani on August 16, 1907 ( $I_{max}=VIII-IX$ ) and on December 18, 1920 with  $M_s=5.6$  ( $I_{max}=VIII$ ), and Llogora pass (south of Vlora) on November 21, 1930. The

Vlora-Berati-Elbasani segment of this fault zone during the year 1851 has been activated along all its length [38, 40, 41].

Some other internal areas of the country were struck by the following strong earthquakes: Çermenika on March 31, 1935 with  $M_s=5.7$  ( $I_{max}=VIII$ ), Dibra on November 30, 1967 with  $M_s=6.6$  ( $I_{max}=IX$ ) and Dibra on September 6, 2009 with  $M_w=5.4$ .

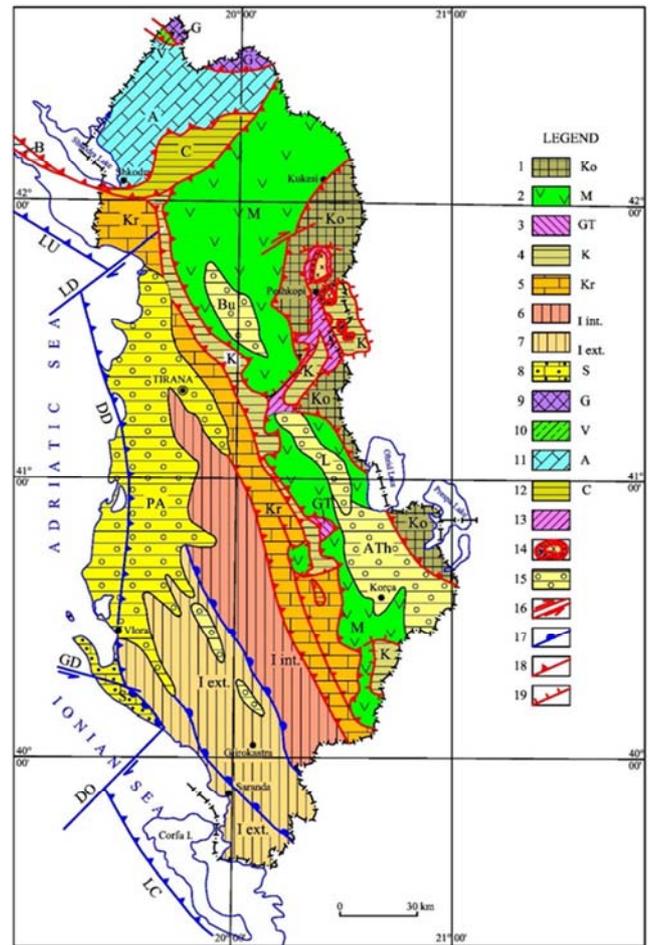
## 5. Mali i Kanalit Block-Dumre Diapir Strike-slip Fault Zone NNE Trending in Transpression

The convergent boundary between the Albanides and Adria Microplate is now well constrained to be located in the Adriatic and Ionian coasts. The inferred and reviewed geological data show that the Albanides orogenic frontal thrust, cut and displaced by the southwest-northeast trending Lezha-Drini Bay and Dhermi-Othoni Island dextral transfer faults, is divided into the north-west trending Lefkas-Corfu segment, and the generally north-south trending Dhermi-Durres segment, shown in Figure 5.

The thrust front of Dhermi-Durres segment investigated in details starts from Dhermi-Othoni Island dextral strike-slip passing underneath the backthrust of Mali i Kanalit Block [11], and follows the contact between Sazani and Ionian tectonic units up to Vlora city and then from Panaja through Frakulla to Durresi anticlinal line of quasi-northern extension which is deeply buried under Middle Miocene molasses of the Periadriatic Foredeep basin. The orogenic front in the Adriatic offshore to the south of the Drini Bay-Lezha dextral strike-slip fault passes along the Ionian Zone and to the north of it along the Kruja Zone that belongs to the Dinarides sensu strict [18].

The Mali i Kanalit Block of Sazani Zone backthrusting towards the NNE the Çika anticlinal belt of Ionian Zone is characterized by a flower-structure fault of "Palm tree" type revealed by seismic explorations in Ionian offshore [11]. It shows that Mali i Kanalit mountain block occurs in transpressional deformation due to the NE-SW oblique compression from Albanides collision zone (Figure 5).

The Mali i Kanalit Block - Dumre Diapir dextral strike-slip fault zone NNE trending in transpression is well marked on Tectonic Map of Albania in scale 1:200,000 [42] which is shown in Figure 6. The Mali i Kanalit Block - Dumre diapir strike-slip fault zone in transpression NNE trending offsets dextrally and to SW the folds and thrusts of the Çika, Kurveleshi and Berati anticlinal belts of Ionian Zone. In the map view it is marked by dextrally dragged folds and thrusts steepened into the Çika, Kurveleshi and Berati anticlinal belts of Ionian Zone, that are shown in Figure 6. The Albanides collision zone in NE-SW oblique compression has led to the offset of the dextrally dragged to southwest folds and thrusts steepened into the Çika, Kurveleshi and Berati anticlinal belts of Ionian zone.



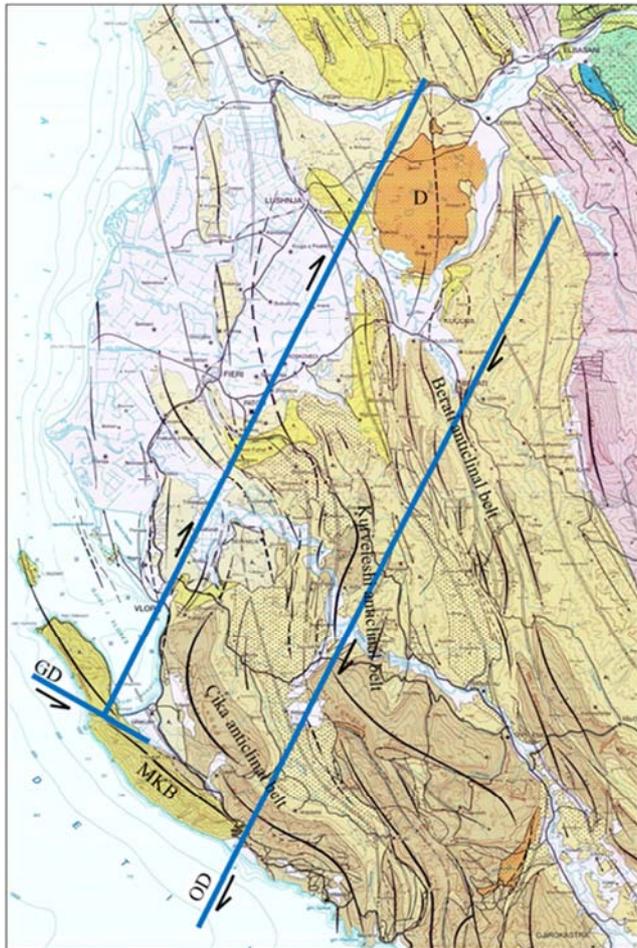
**Figure 5.** Tectonic Map of Albania shows in blue color the active Albanides collision thrust faults (modified from Aliaj [13]). Tectonostratigraphic units: 1- Korabi, 2- Mirdita, 3- Guri i Topit, 4- Krasta, 5- Kruja, 6- Internal Ionian, 7- External Ionian, 8- Sazani, 9- Gashi, 10- Vermoshi, 12- Cukali. 13- Upper Jurassic-Lower Cretaceous marly flysch underlying Korabi nappes, 14- Kruja zone evaporite dome surrounded by the Upper Eocene-Lower Oligocene flysch. 15- Molassic basins: Atho- Albanian-Thessalian, L- Librazhdi, Bu- Burreli and PA- Periadriatic basins. 16- Dextral and sinistral strike slip faults, 17- Reverse fault, 18- Thrust, 19- Normal fault. LD- Lezha-Drini Bay and DO- Dhermi - Othoni Island dextral strike slip faults that separate the Albanides segments: LC- Lefkas-Corfu and DD- Dhermi-Durres from the Dinarides: LU- Lezha-Ulqini segment. The GD- Gjiri i Ariut - Dukati i Ri and DO - Dhermi-Othoni Island strike slip faults bound the Mali i Kanalit Block of Sazani Zone that backthrusts towards NNE the Çika anticlinal belt of Ionian Zone.

The Neogene offset of the Çika, Kurveleshi and Berati anticlinal belts from generally NW-SE trending to near N-S trending has led to thrusts steepening and turning into high-angle strike-slip faults due to the Albanides collision zone in NE-SW oblique compression. Such abrupt structural changes are well marked on Tectonic Map of Albania in scale 1:200,000 [42] shown in Figure 6.

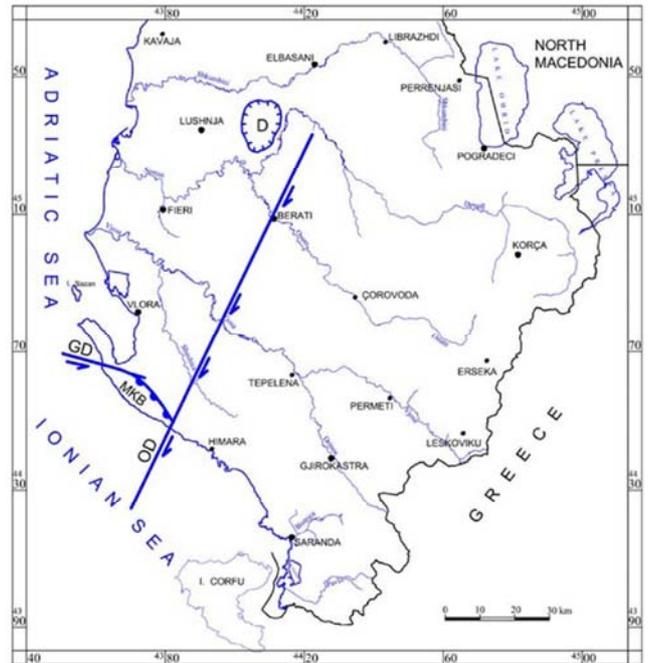
The terraces age of river valleys of Albania is determined from the new  $^{14}C$  dating and in situ produced  $^{10}Be$  dating. At Vjose and Osum river valleys there are identified 9 terrace levels formed from Middle Pleistocene (180,000 years) to historic times (700 years) [29]. The identified nine preserved terrace units are developed since Marine Isotope Stage 6 (MIS 6) up to historic times [22].

The Othoni Island-Dhermi dextral strike-slip fault offsets

the dextrally dragged Devolli (to the east of Dumre diapir), Osumi (near to Berati town), and Vjosa (west of Shkoza village) rivers valleys that were formed from Middle Pleistocene to historic times, shown in Figure 7. Devolli river should have been connected with Shkumbini river, the nearest to it, but in fact it is connected with the Osumi river through a strong SW offset due to its drag from the Othoni Island-Dhermi dextral strike-slip fault.



**Figure 6.** Tectonic Map of the Mali i Kanalit Block - Dumre diapir dextral strike-slip fault zone NNE trending in transpression that crosses the Albanides collision zone in NE-SW compression. Map based on Tectonic Map of Albania in scale 1:200,000 [42]. The GD- Gjiri i Ariut - Dukat i Ri and OD - Othoni Island-Dhermi strike slip faults bound the Sazani Zone Mali i Kanalit Block (MKB) that backthrusts towards NNE the Çika anticlinal belt of Ionian Zone. D-Dumre diapir. The marked Çika, Kurveleshi and Berati anticlinal belts show their strong offset within the Mali i Kanalit Block-Dumre diapir strike-slip zone.



**Figure 7.** The offset of Devolli (to the east of Dumre diapir), Osumi (near to Berati town), and Vjosa (west of Shkoza village) river's valleys is due to the dextrally dragged Othoni Island-Dhermi strike-slip fault. D- Dumre diapir, OD-Othoni Island-Dhermi dextral strike-slip fault and GD-Gjiri i Ariut-Dukat i Ri sinistral strike-slip fault bound the MKB-Mali i Kanalit Block backthrusting the Çika anticlinal belt of Ionian Zone.

The Othoni Island-Dhermi dextral strike-slip fault, that reaches the maximum velocity of greater than 5 mm/year south of it, is the only leading fault, that shaped the Mali i Kanalit Block-Dumre diapir dextral strike-slip fault zone in transpression under conditions of NE-SW compression from Albanides collision zone.

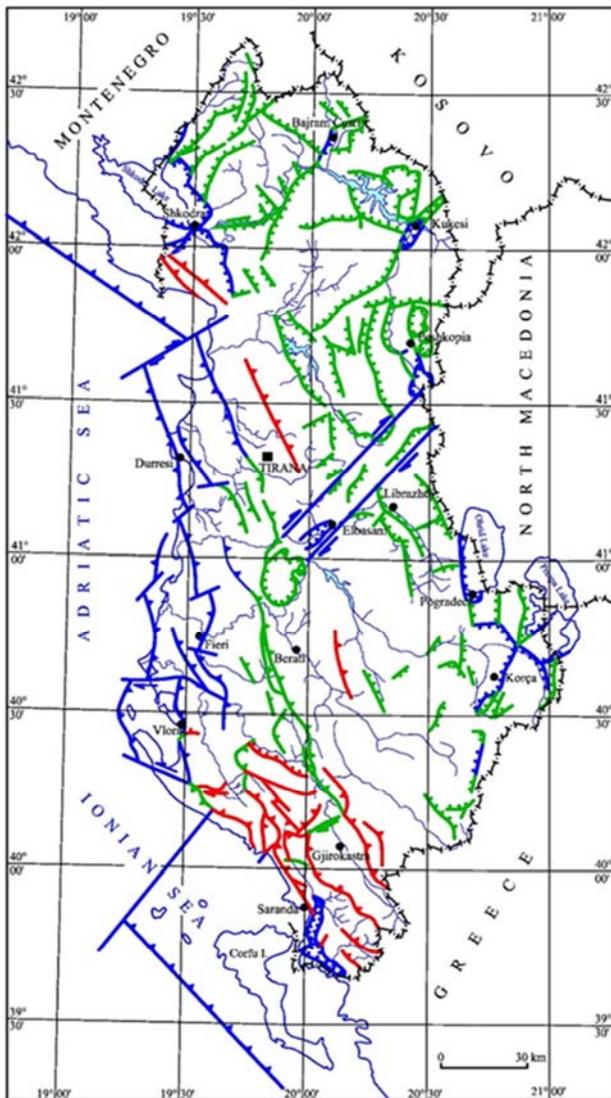
## 6. Focal Mechanism Solutions of Earthquakes That Occurred on the Vlores-Elbasani-Dibra Fault Zone

The focal mechanism solutions for the earthquakes that occurred into the Vlores-Elbasani-Dibra Fault Zone testify its division into two distinct fault zones: a) Mali i Kanalit Block - Dumre Diapir dextral strike-slip fault zone NNE trending in transpression that crosses the Albanides Collision Zone in SW-NE compression, and b) Elbasani-Dibra normal fault zone NE trending in transtension that crosses the internal Albanides area in E-W to ENE-WSW extension (see Table 1).

**Table 1.** Focal mechanism solutions of earthquakes that occurred along the Vlores-Elbasani-Dibra Seismogenic Transversal Fault Zone.

No	Date	Coordinates	H km	Mw	Plane 1 Str/dip	Plane 2 Str/dip	P axis Az dip	T axis Az dip	Fault type	References
1	17 08 1959	40.90 19.80	24	5.8	105/80	10/66	145/10	51/24	SS	[35]
2	01 09 1959	40.85 19.90	25	6.2	72/36	164/86	281/34	41/36	SS	[35]
3	07 10 1959	41.00 19.80	25	5.7	67/64	340/88	292/16	28/20	SS	[35]
4	30 11 1967	41.35 20.40	10	6.6	42/50	265/50	248/66	335/01	Nss	[35]
	30 11 1967	41.41 20.44	21	6.9	26/50	265/58	231/56	327/4	Nss	[32]
	30 11 1967	41.41 20.44	9	6.2	190/43	7/47	242/88	98/2	N	[21]
5	25 07 1968	40.95 20.09	23	4.9	319/76	66/41	20/21	268/45	Rss	[32]
6	08 04 1969	40.67 19.77	17	5.0	169/60	69/72	121/8	26/35	SS	[32]
7	20 10 1974	39.57 18.83	7	5.2	110/78	17/77	63/0	334/18	SS	[32]

No	Date	Coordinates	H km	Mw	Plane 1 Str/dip	Plane 2 Str/dip	P axis Az dip	T axis Az dip	Fault type	References
8	23 11 1974	39.74 18.94	49	5.1	306/49	47/73	170/18	275/38	SS	[32]
9	21 10 1979	41.14 19.94	26	5.3	161/83	255/58	212/17	114/27	SS	[32]
10	28 02 1982	41.28 20.44	10	5.1	54/58	172/52	19/53	114/4	N	[32]
11	16 11 1982	40.82 19.58	21	5.6	336/49	79/75	202/16	306/41	SSr	[32]
12	15 03 1986	41.15 20.17	7	5.2	200/47	308/72	174/45	68/15	Nss	[32]
13	17 03 1989	41.22 20.01	23	5.0	77/52	260/38	336/83	167/7	N	[32]
14	26 04 1990	40.96 19.97	21	4.9	161/52	280/53	128/53	221/2	N	[32]
15	06 09 2009	41.46 20.41	6	5.4	194/45	25/46	14/84	110/1	N	[28]



**Figure 8.** The Elbasan-Dibra normal fault zone NE trending having dextral strike-slip motions shown in blue color. Map based on the Map of active faults in Albania [8]. Blue lines correspond to faults activated during Middle Pleistocene-Holocene (or Quaternary), the green lines to faults activated during Pliocene-Lower Pleistocene and the red lines to faults activated during Pre-Pliocene period.

**6.1. Focal Mechanism Solutions of Earthquakes Occurred on the Mali i Kanalit Block – Dumre Diapir Dextral Strike-slip Fault Zone NNE Trending in Transpression**

The focal mechanism solutions of earthquake series of August-October 1959 in Lushnja area show that it was generated from a strike-slip fault in transpression: the

foreshock of August 17, 1959 (5.8) from a strike-slip fault with P axis 145/10 and T axis 51/24; the main shock of September 1, 1959 (6.2) from a strike-slip fault with P axis 281/34 and T axis 41/36; and the aftershock of October 7, 1959 (5.7) from a strike-slip fault with P axis 292/16 and T axis 28/20 (see Table 1).

It is necessary to note that the macroseismic epicenter of the main shock of September 1, 1959, which is called the Lushnja earthquake, was situated nearby to southwestern part of Dumre diapir.

Focal mechanism solutions of the July 25, 1968 earthquake (M=4.9) with epicenter nearby to north-eastern part of Dumre diapir show that it was generated from a reverse fault offset into strike-slip with P axis 20/21 and T axis 268/45.

The earthquake of April 8, 1969 (M= 5.0) with epicenter in south-west of Berati town, at the frontal thrust of Berati anticlinal belt, was generated from a strike-slip fault with P axis 121/8 and T axis 26/35.

The earthquake of October 21, 1979 (M=5.3) with epicenter nearby to the north of Dumre diapir was generated from a strike-slip fault with P axis 212/17 and T axis 114/27.

The earthquake of November 16, 1982 (M=5.6) with epicenter to frontal thrust of Berati anticlinal belt, to west of Kuçova town, was generated from a reverse fault offsetting into strike-slip with P axis 202/16 and T axis 306/41.

The focal mechanism solutions of the earthquakes with epicentres from north of Dumre diapir to Kuçova and Berati towns, that were taking place into the northern part of the Berati anticlinal belt, show that they were generated from strike slip faults in transpression.

From the focal mechanism solutions of the earthquakes of October 20, 1974 and of November 23, 1974 with epicenters near Otranto Strait, south-west of Vlora Bay as well as south-west of Dhermi-Ishulli Othon dextral strike-slip fault, the following results were obtained [32]. The earthquake of October 20, 1974 (M= 5.2) was generated from a strike-slip fault with P axis 63/0 and T axis 334/18, and the earthquake of November 23, 1974 (M= 5.1) from a strike-slip fault with P axis 170/18 and T axis 275/38. The fault plane solutions of both earthquakes testify that the Otaoni Island-Dhermi strike-slip fault area is acting as a dextral strike-slip fault [7].

**November 21, 1930 and September 1, 1959 Earthquakes That Occurred on the Mali i Kanalit Block - Dumre Diapir Dextral Strike-slip Fault Zone**

The earthquake of November 21, 1930. On November 21, 1930 at 02 h 00 min (GMT) in Llogara Pass of Çika mountain (Vlore) a very strong earthquake occurred, which destroyed totally the villages of Dukat, Terbaç, Palase and Dhermi (Gjolekaj & Vretkaj quarters). It also destroyed partially the villages of Smokthine, Velçe, Brataj, Vranisht, Lepenice,

Tragias. The earthquake caused 30 deaths and over 100 injured. Many domestic animals were lost. The damage of dwelling houses was observed over the area, from Vlora (North) to Tepelena (East) and to Fterra (South) [18].

The Austrian geologist Ernest Nowack described one of the most interesting phenomena. "In one case we observed at Llogara Pass, that during the first shock, a big crack was opened on hard rocks of the width of 1 m and of the length of 1 km. This crack followed the crest of the Pass in some places both banks of this crack were almost vertical ones and have an amplitude of 20 cm. Impression is of a compression without vertical throw" [18]. Without any doubt in this case, we are dealing here with a primary phenomenon which reflects dislocations in the focus.

This earthquake was followed by a great number of aftershocks, some of which of high intensity; aftershocks continued for about one year and ended with a strong shock of September 23, 1931 of 13h 38min with intensity 8-9 degrees ( $M=5.0$ ). Its VIII intensity isoseist has a NNE extending from Uji i Ftohte to Kote [38], which is the same with that of the main shock of November 21, 1930 ( $M=5.8$ ,  $I_0=IX$ ).

The Dukat, Terbaç, Palase and Dhermi (Gjolekaj & Vretkaj quarters) villages that were totally destroyed by the earthquake of November 21, 1930 are a direct testimony for the activation of Othoni Island-Dhermi strike-slip fault which is in good agreement with the data of isoseimal map [18]. The axis line of pleistoseists with IX and VIII intensities has a  $20^{\circ}$ - $25^{\circ}$  NNE striking that dextrally and southward offsets the Vjosa river valley, and towards the SSW agrees fully with Othoni Island-Dhermi dextral strike-slip fault. The November 21, 1930 earthquake occurred on Othoni Island-Dhermi dextral strike-slip fault.

GPS results demonstrate a southwestward motion of points located in external Albanides relative to Apulia with significant increase of their velocities from north to south, which reach the maximum of greater than 5 mm/year south of the dextral Othoni Island-Dhermi transfer fault. This fault is identified as a major seismogenic source underlined by the earthquake of November 21, 1930 at Llogara pass (south of Vlora) and many destructive earthquakes that heavily hit the Vlora town [27].

The present-day greatest velocity evidenced to the south of Othoni Island-Dhermi dextral strike slip fault agrees well with south-west large displacement for about 45 km of the Ionian Zone frontal thrust [12].

The earthquake of September 1, 1959. At 11h 37m (GMT) of September 1, 1959 an earthquake of magnitude  $M_s=6.2$  hit the villages close to Kuçi bridge (Lushnje district) and towns of Lushnja, Fieri, Rogozhine, Peqin, Kuçove and Berat. In the epicentral area of this earthquake (villages Ngurez e Vogel, Arapaj (Lushnje), Strume, Çukas, Kurjan dam (Fieri), Kozare (Kuçove), Çiflik-Poshnje, Pashalli (Berat)) a lot of dynamic soil instabilities due mainly to the liquefaction phenomena, were observed [18].

In a particular site, nearby to Ura e Kuçit bridge, traces of seismic fault of strike-slip dextral movement were observed; strike direction of the fault  $NE 70^{\circ}$ . Before the main shock, some strong foreshocks were recorded and observed as those of August 17, at 04h 29m,  $M=5.8$ ; August 17, at 01h 33m,

$M=4.5$ . Despite of the large energy of the first earthquake ( $M=5.8$ ), it did not cause large damage. Its intensity was no more than 7 degrees in Lushnja town. The earthquake of September 1, 1959 was followed by a large number of aftershocks among which two had the magnitude higher than 5.0: September 3, 1959  $M=4.5$ ,  $I_0=6$  degrees; October 5, 1959 ( $M=5.1$ ,  $I_0=7$  degrees); October 7, 1959 ( $M=5.5$ ,  $I_0=7-8$  degrees).

The space distribution of aftershocks of the earthquake of September 1, 1959 appears as ellipses with long axis strike to NE. The focal mechanism solutions of August 17, 1959 foreshock, September 1, 1959 main shock and October 7, 1959 aftershock show that they were generated from a strike-slip fault (see Table 1).

## 6.2. Focal Mechanism Solutions of Earthquakes Occurred on the Elbasan-Dibra Normal Fault Zone NE Trending in Transtension

The focal mechanism solutions of earthquakes that occurred on Elbasan-Dibra fault zone show that they were generated from normal faults [35, 36, 41] (see Table 1). The focal mechanism solution of the November 30, 1967 earthquake ( $M=6.6$ ) with epicenter at Golloborda horst, show that it was generated from a normal fault with dextral strike-slip motions. The most important phenomenon was observed in the epicentral zone of November 30, 1967 earthquake: a 10 km long surface rupture appeared from Pervalla Pass to Sebisht village in the direction  $40^{\circ}$  NE, where the southeastern block dipped with an amplitude of vertical displacement of 50 cm. Diagonal fissures of the dilatational type appearing in crosswise direction of this fault that were observed in some places are a good testimony for dextral strike-slip movements along it [41]. This was a normal fault with small dextral strike-slip component [40, 41] (Figure 8).

The focal mechanism solution of the November 30, 1967 earthquake ( $M=6.6$ ) re-estimated by Sulstarova et al. [35] shows that the earthquake was generated from a normal fault with small strike-slip component; P axis 248/66 and T axis 335/01 in NW-SE extension [41]. The other focal mechanism solutions for this earthquake show that it was generated from a normal fault in W-E extension; P axis 242/88 and T axis 98/2 [21], or from a normal fault with small strike-slip component in NW-SE extension; P axis 231/56 and T axis 327/4 [32].

The aftershock distribution of the November 30, 1967 earthquake shows  $40^{\circ}$  north-east striking of its long axis [41]. It fully agrees with the strike direction of the surface rupture caused by this earthquake.

The focal mechanism solution of February 28, 1982 earthquake ( $M=5.1$ ) with epicenter near to SE of Golloborda Krasta flysch horst structure shows its generation from a normal fault in WNW-ESE extension; P axis 19/53 and T axis 114/4. The focal mechanism solution of the March 15, 1986 earthquake ( $M=5.2$ ) with epicenter at Labinoti area shows that it was generated from a normal fault with strike-slip component; P axis 174/45 and T axis 68/15 in ENE-WSW extension. The focal mechanism solution of the March 17, 1989 earthquake ( $M=5.0$ ) with epicenter in north of Elbasani town shows its generation from a normal fault in NNW-SSE extension; P axis 336/83 and T axis 167/7.

The focal mechanism solution of the April 26, 1990 ( $M=4.9$ ) earthquake with epicenter in west of Elbasani town shows that it was generated from a normal fault in SW-NE extension; P axis 128/53 and T axis 221/2. The focal mechanism solution of the September 6, 2009 earthquake ( $M=5.4$ ) with epicenter to east of Bulqiza ophiolites in northern part of Golloborda Krasta flysch horst shows that it was generated from a normal fault roughly in W-E extension; P axis 14/84 and T axis 110/1 [28].

The aftershock distribution of the November 30, 1967 earthquake and the strike direction of the surface rupture caused by this earthquake fully agrees with the NE trending of Elbasani-Dibrë normal fault zone.

The 40° NE trending of the Elbasani-Dibrë normal fault zone from Elbasani Quaternary graben to Golloborda horst is shown in Figure 8 as a transtensional dextral strike-slip normal fault zone due to the internal Albanides area in E-W to ENE-WSW extension.

The Elbasani-Dibrë normal fault zone NE trending cuts through the Drini (Korçë-Peshkopi) normal fault zone N-S up to NNW-SSE trending [4]. The focal mechanism solutions of some earthquakes show that they were generated from the Elbasani-Dibrë transversal normal fault zone NE trending that has dextral strike-slip motions. The internal Albanides area in E-W to ENE-WSW oblique extension has led to transtensional dextral strike-slip movements into the Elbasani-Dibrë normal fault zone NE trending.

## 7. Conclusions

1. The seismicity of Albania is characterized by micro-seismicity, small and medium size earthquakes and a few large events as shown by the occurrence of 7 earthquakes with  $M_s$  magnitudes exceeding 6 from the last century to present. Most of the strong earthquakes have occurred along three following well-defined seismic belts: a) the Ionian-Adriatic coastal earthquake belt, NW-SE trending, along the eastern margin of the Adria microplate; b) the Drini (Peshkopi-Korçë) seismic belt in the interior of the country, N-S trending, and c) the Vlorë-Elbasani-Dibrë transverse earthquake belt (trending SW to NE), which cuts through the Drini seismic belt. The Vlorë-Elbasani-Dibrë seismogenic fault zone is expressed by an alignment of important historical and instrumental seismicity with 15  $M_s > 6$  earthquakes. The Vlorë-Berati-Elbasani segment of this fault zone during the year 1851 has been activated along all its length. Some other internal areas of the country were struck by following strong earthquakes: Çermenika on March 31, 1935 with  $M_s=5.7$  ( $I_{max}=VIII$ ), Lushnjë on September 1, 1959 with  $M_s=6.2$ , and Dibrë on November 30, 1967 with  $M_s=6.6$  ( $I_{max}=IX$ ) and Dibrë on September 6, 2009 with  $M_w=5.4$ .
2. The Vlorë-Elbasani-Dibrë transversal fault zone crosses from south-west to northeast the Albanides collision zone starting from Vlorë area to the Dumre diapir and continuing from the Elbasani Quaternary graben to Dibrë area, within the internal Albanides extensional zone. The geological and neotectonic investigations as well as the focal mechanism solutions of the earthquakes that occurred along the Vlorë-Elbasani-Dibrë fault zone prove its division into two distinct fault zones: a) the Mali i Kanalit Block - Dumre diapir dextral strike-slip fault zone NNE trending in transpression, and b) the Elbasani-Dibrë normal fault zone NE trending in transtension. The Elbasani-Dibrë normal fault zone NE trending consists of fragmentary normal faults cutting across the Krujë and Krasta zones and separating the Mirdita ophiolites into two main segments. It follows the Elbasani Quaternary graben, the Labinoti transverse structures, the Golloborda transverse horst, the Tetovë Quaternary graben in Macedonia and Morava e Binçes Quaternary graben in Kosova. Its fragmentary continuation is more than 200 km long starting from Elbasani to Gjiçani in Kosova.
3. The Mali i Kanalit Block-Dumre diapir strike-slip fault zone NNE trending in transpression offsets dextrally and to SW the folds and thrusts of Çika, Kurvelesh and Berati anticlinal belts of Ionian Zone. In the map view it is marked by dextrally dragged folds and thrusts that steepen into the Çika, Kurvelesh and Berati anticlinal belts of Ionian Zone. The Neogene (mainly since Middle Miocene) offset of the Çika, Kurvelesh and Berati anticlinal belts from generally NW-SE trending to near N-S one has led to thrusts steepening and turning into high-angle strike-slip faults due to NE-SW oblique compression from the Albanides collision zone. The Othoni Island-Dhermi dextral strike-slip fault offsets the dextrally dragged Devolli (to the east of Dumre diapir), Osumi (near to Berati town), and Vjosa (west of Shkoza village) river's valleys that were formed from the Middle Pleistocene (180,000 years) to historic times. The Othoni Island-Dhermi dextral strike-slip fault, that reaches the maximum velocity of greater than 5 mm/year to the south of it, is the only leading fault that shaped the Mali i Kanalit Block-Dumre diapir dextral strike-slip fault zone in transpression under conditions of NE-SW oblique compression from the Albanides collision zone.
4. The focal mechanism solutions of earthquakes that occurred on the Mali i Kanalit Mt Block – Dumre diapir dextral strike-slip fault zone NNE trending, show that they were generated from strike-slip faults in transpression. The focal mechanism solutions of the earthquake series of the August-October 1959, the July 25, 1968 ( $M=4.9$ ), the April 8, 1969 ( $M=5.0$ ), the October 21, 1979 ( $M=5.3$ ) and the November 16, 1982 ( $M=5.6$ ) with epicentres from north of Dumre diapir up to Kuçovë and Berati area, show that they were generated from the strike-slip faults in transpressional motions. The Albanides collision zone in NE-SW oblique compression has led to transpressional dextral strike-slip movements into the Mali i Kanalit Block - Dumre diapir dextral strike-slip fault zone NNE trending.
5. Focal mechanism solutions of earthquakes that occurred on the Elbasani-Dibrë normal fault zone NE trending in transtension show that they were generated from normal faults with dextral strike-slip motions. The focal mechanism solution of the November 30, 1967 earthquake ( $M=6.6$ ) with epicenter at Golloborda horst,

and of the March 15, 1986 earthquake (M=5.2) with epicenter at Labinoti area, show that they were generated from particular normal faults with dextral strike-slip movements. The most important phenomenon that was observed in the epicentral zone of the November 30, 1967 earthquake (M=6.6) was a 10 km long surface normal fault rupture appearing from Pervalla pass to Sebisht village in the direction 40° NE. Diagonal fissures of the dilatational type appearing in crosswise direction of this fault observed in some places, are good evidence for dextral strike-slip movements. The focal mechanism solution of the February 28, 1982 (M=5.1), 1989 (M=5.0), the April 26, 1990 (M=4.9), and the September 6, 2009 (M=5.4) earthquakes with epicentres from Golloborda flysch horst to around Elbasani town, show that they were generated from normal faults. The internal Albanides area in E-W to ENE-WSW oblique extension has led to transtensional dextral strike-slip movements into the Elbasan-Dibra normal fault zone NE trending.

6. The oil fields located on the northern part of Kurveleshi and Berati anticlinal belts and having a generally northern direction structure are included within the structure of the Mali i Kanalit Mt Block- Dumre diapir strike-slip fault zone NNE trending in transpression.

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