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Periadriatic foredeep (onshore Albania) is developed as dextral pull-apart basin

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Abstract

The Periadriatic Foredeep onshore Albania is the only Foredeep basin located in the frontal part of the Albanides orogeny bordering eastward the Adriatic Foreland. The recent neotectonic investigations and previously published ones prove the formation of Periadriatic Foredeep as a dextral pull-apart basin in the Middle Miocene (Serravallian), subsequently to the main folding and thrusting of the Ionian Zone, through the strike-slip faulting mechanism. The two elements that commonly lead to the formation of the Periadriatic Foredeep Pull-apart Basin are the cross-basin strike-slip faults of Drini Bay-Lezha and Vlora-Bishqemi, and the oblique normal faults of Durresi-Frakulla and Preza-Rova-Bishqemi. The infill consists of the Serravallian to Pliocene molasses succession up to 6 km in thickness. The Periadriatic Foredeep Basin is located between the South Adriatic and Tirana Marginal Basins. The development of the Periadriatic Foredeep finally led to the different evolution of both the Periadriatic and Tirana depressions with different structures and mineral resources. The Periadriatic Depression structure is built by an NNW trending narrow anticline and wide syncline lines. From southwest to the northeast, these lines are distinguished: Frakulla-Durresi anticlinal line, Myzeqe syncline, Lushnja-Golem Kavaja anticlinal line, Erzeni i poshtem syncline, and Preza monocline. The Myzeqe and Erzeni i poshtem depocenters are separated by the intrabasinal Mliku-Shkoza high. The Divjaka gas field and Patosi, Marinza, and Kuçova oil fields are well known in the Periadriatic Depression. The Tirana Depression is developed from the Tirana marginal basin eastward bordering the Periadriatic Foredeep. It is characterized by the prevailing continental and shallow-marine Miocene sediments (with coal-bearing fields in Tortonian and Messinian deposits) that formed a wide northeast verging asymmetrical syncline due to the Preza-Rova-Bishqemi backthrust. The Tirana Depression overlies *the Kruja Zone substratum to the north of Tirana, and partly, the Ionian Zone substratum to the south of Tirana along its western limb to the east of the Rova anticline backthrust. Deformation of orogenic crust at the Albanides-Adria collision zone during Tertiary occurred and occurs into both levels: i) a basal fold-and-thrust system in the Ionian Zone, that accommodated an increasing amount of SW directed shortening, and ii) a structurally higher system of thrust faulting affecting the overlying structure of the Periadriatic Depression, that underwent a strong structural rearrangement.*

Keywords: *Periadriatic Foredeep, Albania, Pull-apart Basin, Periadriatic, and Tirana Depressions.*

ΠΕΡΙΛΗΨΗ

Το Περιαδριατικό Προβύθισμα της παράκτιας Αλβανίας είναι το μόνο Προβύθισμα που βρίσκεται στο μετωπικό τμήμα της οροσειράς των Αλβανίδων, οι οποίες οριοθετούν προς τα ανατολικά την Αδριατική Προχώρα. Οι πρόσφατες νεοτεκτονικές έρευνες και οι δημοσιευμένες εργασίες αποδεικνύουν ότι το Περιαδριατικό Προβύθισμα αποτελεί μία δεξιόστροφη pull-apart λεκάνη που σχηματίστηκε στο Μέσο Μειόκαινο (Σεραβάλλιο), μέσω ενός μηχανισμού οριζοντιολισθητικής διάρρηξης, μετά την κύρια πτύχωση - επώθηση της Ιονίου Ζώνης. Τα δύο στοιχεία που κατά κύριο λόγο συντέλεσαν στον σχηματισμό της pull-apart λεκάνης του Περιαδριατικού Προβυθίσματος είναι τα εγκάρσια ρήγματα οριζόντιας ολίσθησης του κόλπου Drini-Lezha και Vlora-Bishqemi και τα πλαγιοκανονικά ρήγματα Durresi-Frakulla και Preza-Rova-Bishqemi. Το υλικό πλήρωσης της λεκάνης περιλαμβάνει τις μολασσικές αποθέσεις Σερραβάλλιου - Πλειόκαινου πάχους έως 6 km. Η Λεκάνη του Περιαδριατικού Προβυθίσματος βρίσκεται μεταξύ των περιθωριακών λεκανών της Νότιας Αδριατικής και των Τιράνων. Η διαμόρφωση του Περιαδριατικού Προβυθίσματος οδήγησε τελικά στη διαφορετική εξέλιξη του Περιαδριατικού Βυθίσματος και του Βυθίσματος των Τιράνων, τα οποία παρουσιάζουν διαφορετικές δομές και διαφορετικούς ορυκτούς πόρους. Το Περιαδριατικό Βύθισμα δομείται από εναλλαγές στενών αντικλίνων με σύγκλινα μεγάλου εύρους και ΒΒΔ διεύθυνσης. Από τα νοτιοδυτικά προς τα βορειοανατολικά διακρίνονται οι εξής μεγα-δομές: αντίκλινο Frakulla-Durresi, σύγκλινο Myzeqe, αντίκλινο Lushnja-Golem Kavaja, σύγκλινο Erzeni i poshtem και μονόκλινο Preza. Τα κέντρα απόθεσης Myzeqe και Erzeni i poshtem χωρίζονται από το ύψωμα Mliku-Shkoza. Το κοίτασμα φυσικού αερίου Divjaka και τα κοιτάσματα πετρελαίου Patosi, Marinza και Kuçova του Περιαδριατικού Βυθίσματος είναι πολύ καλά μελετημένα. Το Βύθισμα των Τιράνων

αναπτύσσεται ανατολικά από την περιθωριακή λεκάνη των Τιράνων και οριοθετεί το Περιαδριατικό Προβύθισμα. Χαρακτηρίζεται από τα κυρίαρχα ηπειρωτικά και νηρητικά θαλάσσια ιζήματα του Μειόκαινου (με λιγνιτοφόρα πεδία σε αποθέσεις Τορτόνιας και Μεσσήνιας ηλικίας) που σχημάτισαν ένα ευρύ ασύμμετρο σύγκλινο με φορά προς βορειοανατολικά λόγω της αντιθετικής επώθησης Preza-Rova-Bishqemi. Το Βύθισμα των Τιράνων έχει ως υπόβαθρο τη Ζώνη Kruja (Γαβρόβου) στα βόρεια των Τιράνων, και εν μέρει, την Ιόνια Ζώνη, στα νότια των Τιράνων, στα ανατολικά της αντιθετικής επώθησης του αντικλίνου Rova, κατά μήκος του δυτικού σκέλους της. Η παραμόρφωση του φλοιού του ορογενούς στη ζώνη σύγκρουσης Αλβανίδων-Αδρίας κατά τη διάρκεια του Τριτογενούς έλαβε χώρα και συνεχίζει να εκδηλώνεται σε δύο επίπεδα: i) στο σύστημα πτύχωσης - επώθησης στην Ιόνια Ζώνη πάνω στο υπόβαθρο-βάση, μέσω του οποίου συντελέστηκε μια αυξανόμενη βράχυνση προς ΝΔ και ii) σε ένα τεκτονικά ανώτερο σύστημα ανάστροφων ρηγμάτων που επηρεάζει το τεκτονικά υπερκείμενο Περιαδριατικό Βύθισμα, το οποίο υπέστη ισχυρή τεκτονική αναδιάταξη.

Λέξεις – Κλειδιά: *Περιαδριατικό προβύθισμα, Αλβανία, Λεκάνη pull-apart, Περιαδριατικό Βύθισμα και Βύθισμα Τιράνων*

1. INTRODUCTION

The Periadriatic Foredeep comprising the hilly and plain terrains of the western lowland of Albania originated in Middle Miocene, since the Serravallian, subsequently to the main folding and thrusting of the Ionian Zone. The Periadriatic Foredeep is distinguished by Mishunina and Ivanova (1957), who considered it as a small part of the Periadriatic Zone taking place in most of the Adriatic Sea. The Periadriatic Foredeep was established in the Middle Miocene (Helvetian) with its centre lying in the Erzeni i poshtem network and developed during the Upper Miocene and Pliocene when it formed its fold and thrust structure. The Middle Miocene deposits surround the Periadriatic and Tirana depressions (Mishunina and Ivanova, 1957). The NNE trending Drini Bay-Lezha strike-slip fault bordering the Periadriatic Basin from NW was reported by neotectonic studies and has been concluded with the compilation of the Neotectonic Map of Albania on a scale of 1: 200.000 (Aliaj et al., 1995, published in 2018) and its explanatory text (Aliaj et al., 1996). The NNE trending Vlora-Bishqemi strike-slip fault bordering the Periadriatic Foredeep from SW is determined only from recent studies (Handy et al., 2019; Aliaj, 2021).

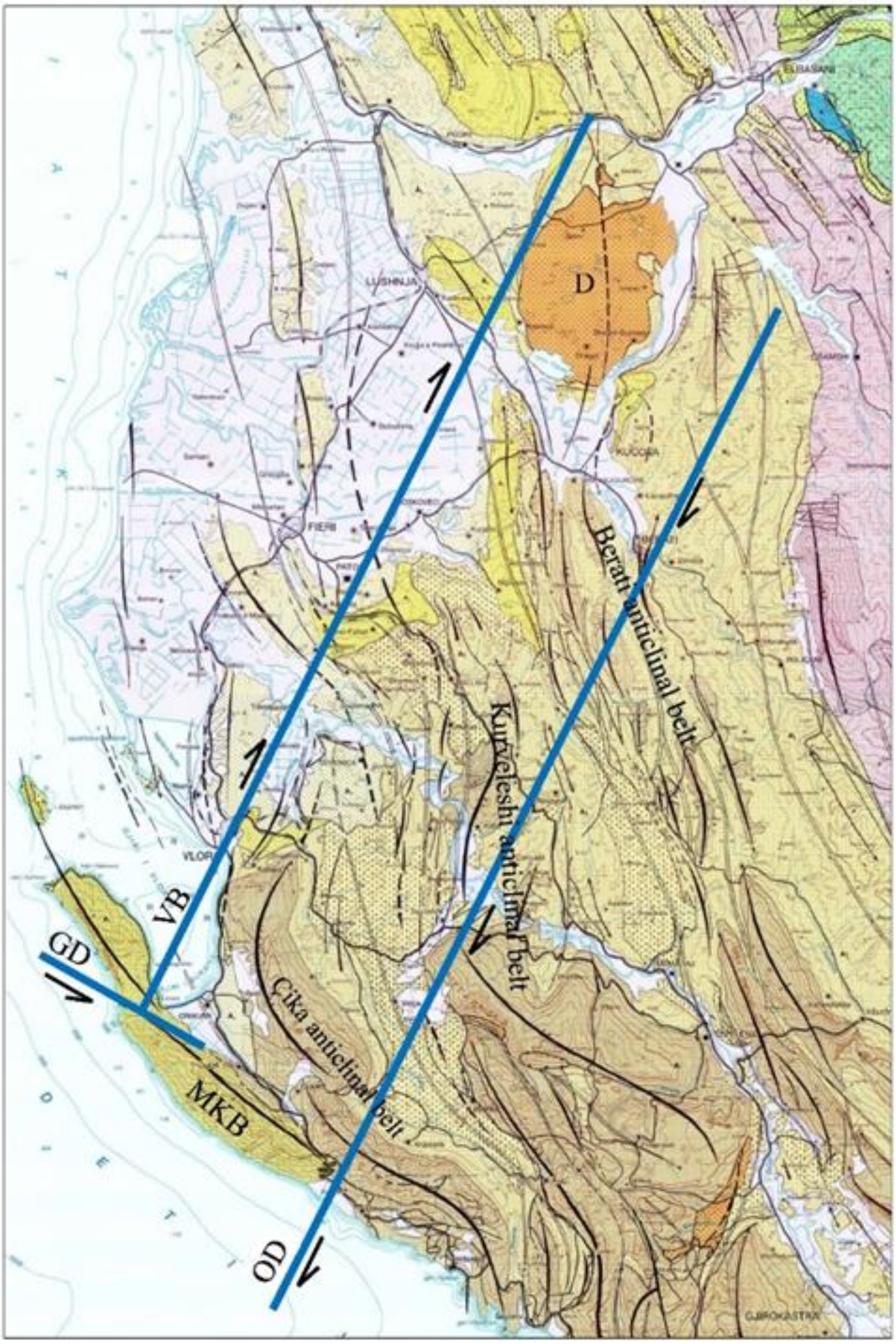


Fig. 1: Tectonic Map of Mali i Kanalit Block - Dumre diapir dextral strike-slip fault zone NNE trending in transpression that crosses the Albanides Collision Zone in NE-SW compression (after Aliaj, 2021). Map based on the Tectonic Map of Albania on a scale of 1:200,000 (after Shallo et al., 1999). VB-Vlora-Bishqemi strike-slip fault, OD-Othoni Island-Dhermi strike-slip fault, D-Dumre diapir. 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 back thrusts towards NNE the Çika anticlinal belt of Ionian Zone.

Aliaj (2021) paid much attention to the Vlora-Elbasani-Dibra transversal fault zone that crosses from south-west to northeast and the Albanides collision zone from the Vlora area up to the Dumre diapir, and then, from the Elbasani Quaternary graben to Dibra area, the internal Albanides extensional zone. The geological and neotectonic investigations as well as the focal mechanism solutions of earthquakes that occurred along the Vlora-Elbasani-Dibra fault zone indicate that the fault is divided into two distinct zones: a) Mali i Kanalit Block - Dumre diapir strike-slip zone NNE trending in transpression, and b) the Elbasan-Dibra normal fault zone NE trending in transtension. The Mali i Kanalit Block-Dumre diapir strike-slip offsets dextrally and to SW along the folds and thrusts of the Çika, Kurveleshi, d Berati anticlinal belts of Ionian zone delineating by this way to the North boundary the Çika, Kurveleshi and Berati anticlinal belts of Ionian zone, and the southern boundary of Periadriatic Depression (Aliaj, 2021; see Figs. 1 and 2).

The Mali i Kanalit Block-Dumre diapir transfer fault zone consists of two dextral strike-slip faults: i) the northwestern one, named the Vlora-Bishqemi strike-slip (VB), which forms the southern boundary of Periadriatic Basin, starts at Gjiri i Ariut- Dukat i Ri sinistral strike-slip (GD) and follows NNE in Vlora City, near Patosi town, west border of Dumre diapir up to Bishqemi village north of Dumre diapir, dislocating (cutting) from the south the Panaja, Frakulla, and Lushnja anticlines, and ii) the south-eastern one, named the Othoni Island-Dhermi strike-slip (OD) follows NNE in the west of Shkoza village, near Berati town up to the offset of Devolli river to the east of Dumre diapir, separating the north-west trending Lefkas-Corfu segment from the generally north-south trending Vlora-Dhermi segment of the Albanides orogenic frontal thrust (Aliaj, 2021, see Figs. 1 and 2). The Periadriatic Foredeep (PA) is located between the NNE trending Drini Bay-Lezha (DL) and Vlora-Bishqemi (VB) strike-slip faults that led to its development as a pull-apart basin (Aliaj, 2021, see Fig. 2).

This study aims to review the neotectonic structure of the Periadriatic Foredeep based on recent neotectonic investigations (Aliaj, 2021; Handy et al., 2019) and on previous publications (Skrami and Aliaj, 1995; Skrami 2001; Aliaj et al., 1995 *published in 2018*; Aliaj et al., 1996; Aliaj, 1988, 1998, 2000a, 2000b, 2006, 2012; Gelati et al., 1999) to propose a new geological interpretation for its formation as a pull-apart basin.

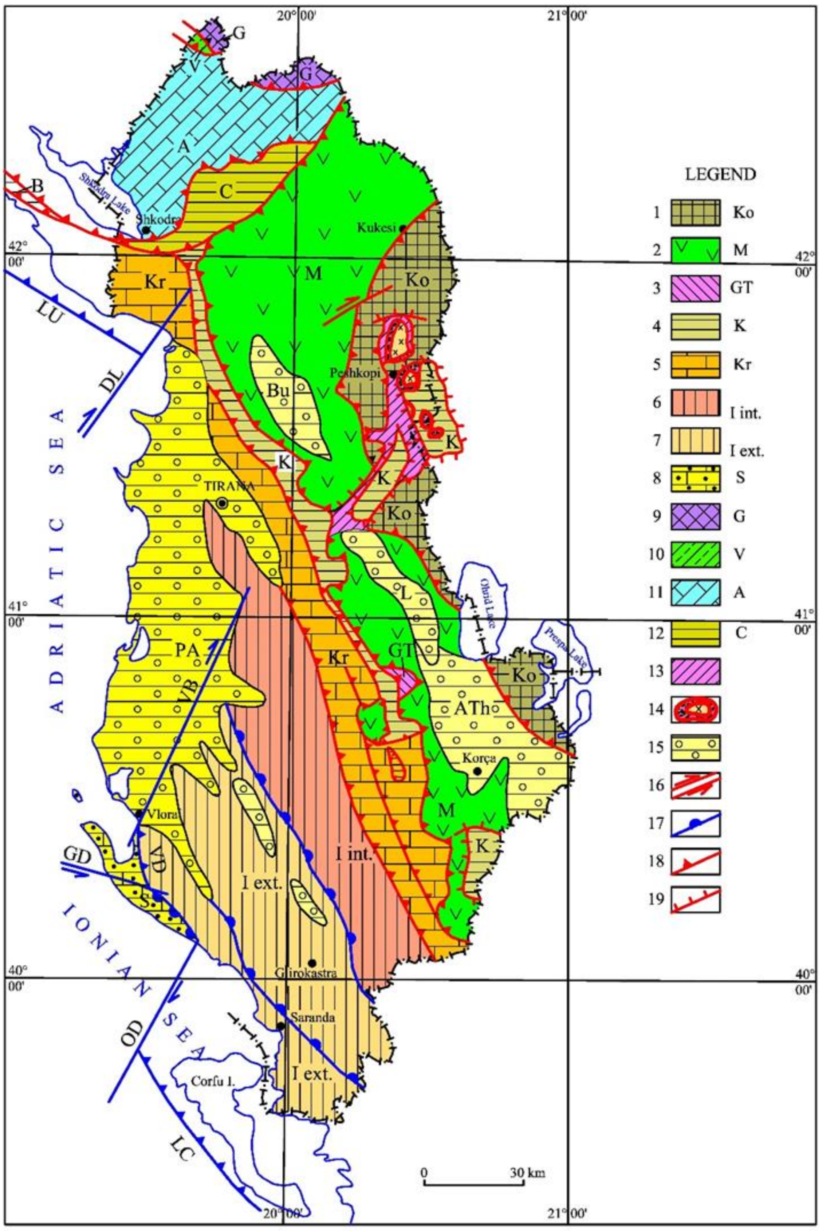


Fig. 2: Tectonic Map of Albania shows the Drini Bay-Lezha (DL) and Vlora-Bishqemi (VB) strike-slip faults in blue colour that led to the development of the Periadriatic Foredeep (PA) as well as the active Albanides collision zone thrust faults (modified from Aliaj, 2021). OD- Dhermi-Othoni Island dextral strike-slip fault that separates the Albanides – Hellenides segments: VD- Vlora-Dhermi segment from LC- Lefkas-Corfu one. LU-Lezha-Ulqini segment belongs to the Dinarides. The GD- Gjiri i Ariut - Dukat i Ri and OD -Othoni Island-Dhermi strike-slip faults bound the Sazani Zone Mali i Kanalit Block that backthrusts towards NNE the Ionian Zone Çika anticlinal belt. 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- Molasses basins: ATh-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.

2. GEOLOGICAL SETTING

In Albania and Greece, along the southern convergent margin of the Eurasia Plate, two segments are distinguished. A northern segment of the margin belongs to the Adriatic continental collision, and a southern one belongs to the Aegean (Hellenic) Arc related to active oceanic subduction. The Adriatic-Eurasian collision 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 (Louvari et al. 1999; Aliaj, 2006, see Fig. 3).

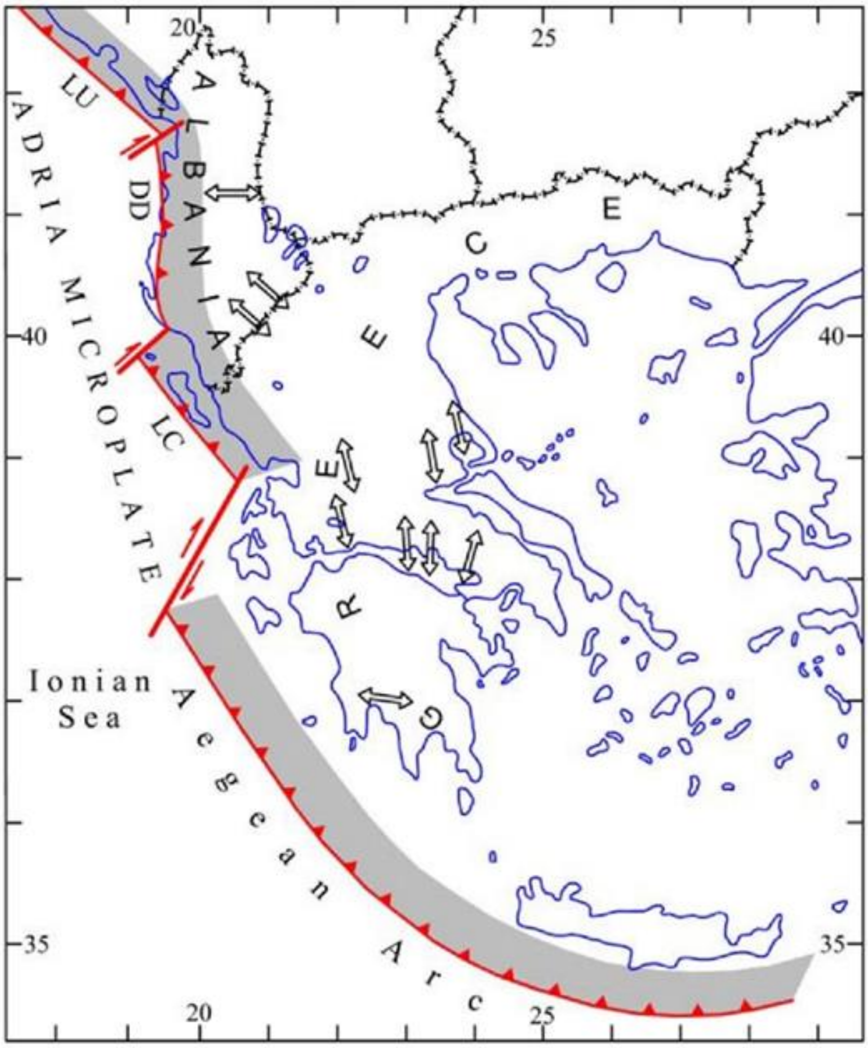


Fig. 3: Southern convergent margin of Eurasia Plate: Adriatic collision and Aegean Arc (modified from Aliaj 2006 with separation of two segments in the Albanides collision zone). Segments of Albanides – Hellenides collision zone are noted by capital letters: LC- Lefkas-Corfu, and DD- Dhermi-Durres. LU- Lezha-Ulqini segment belongs to the Dinarides. Divergent arrows indicate extension direction.

The Albanides is divided into the external collision domain which is in compression and is characterized by reverse faulting, and the internal domain which is in extension and is characterized by normal faulting. The Albanides (frontal part of the Eurasian plate) collides with Adria Microplate that is fragmented into two sub-plates: The Apulian platform from Sazani Island to the south, and the Albanian basin (= South Adriatic basin) to the north of it (Aliaj, 2006; Aliaj et al., 2018).

The Albanides orogenic frontal thrust is divided into the north-west trending Lefkas-Corfu segment (also belonging to the Hellenides; Killias, 2021), and generally, north-south trending Durres-Frakulla and Vlora-Dhermi segments separated by the Vlora-Bishqemi strike-slip fault (see Fig. 2). The present fold-thrust structure of Periadriatic Foredeep is due to two main compressional phases: the at Miocene-Pliocene boundary, and in the early Pleistocene which led to the final strong deformation of the Mio-Pliocene structures in the Periadriatic Basin and into the separation of two depressions: Tirana Depression located in the east and the Periadriatic Depression located in the western lowland of Albania. The compressional deformations are active present days (Aliaj, 1998; Skrami and Aliaj, 1995).

We concentrate our study on the pull-apart formation of the Periadriatic Foredeep (Albania onshore) which is located at the frontal part of the Albanides orogeny. The first scientific and systematic investigations about the neotectonic structure of Albania, performed during 1992-1995, are concluded with a compilation of the Neotectonic Map of Albania on a scale of 1:200.000 (Aliaj et al., 1995, *published in 2018*) and its explanatory text (Aliaj et al., 1996). The orogenic frontal thrust of the Albanides is well marked on the Map of Neotectonic Zonation of Albania (see Fig. 4). Based on seismic explorations carried out in Albania by foreign companies after 1990 (Aliaj et al., 1996; Meço et al., 2000; Skrami, 2001), the convergence boundary between the Albanian orogeny and the Adria microplate is fixed generally in the Ionian and Adriatic coasts. The Albanian orogenic thrust front is cut and displaced by the Othoni Island-Dhermi, the north of Sazani Island, and the Gjiri i Drinit-Lezha transversals of strike-slip type, which further divided it into some separate segments.

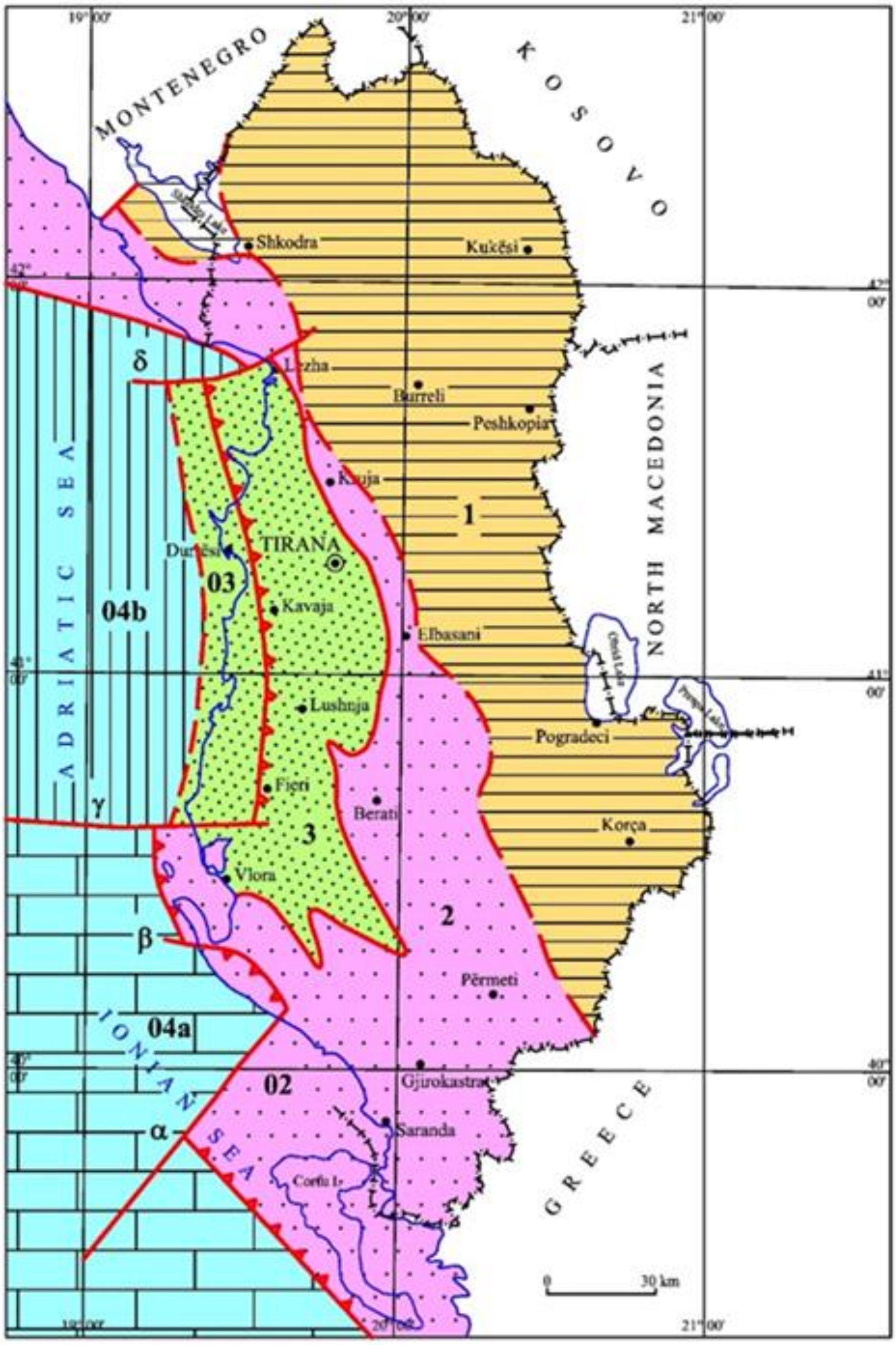


Fig. 4: Map of the neotectonic (Pliocene-Quaternary) zonation of Albania (and Corfu Island of Greece) shows the large neotectonic units of Albania (after Aliaj et al., 1995, *published in 2018*). The orogen front from south to north is cut and displaced by the Othoni Island-Dhermi (α), the Gjiri i Ariut-Dukat (β), the north of Sazani Island (γ), and the Gjiri i Drinit-Lezha (δ) transversals. The large neotectonic units of Albania shown by numbers are the following: 1: The internal area affected by extensional tectonics since Pliocene, 2: the external area affected by compressional pre-Pliocene tectonics, 3: the Peri-Adriatic 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).

The following segments of the Albanides – Hellenides orogenic thrust front are distinguished (see Fig. 4): 1) The NW-trending Lefkas-Corfu offshore segment to the SW of the Othoni Island-Dhermi strike-slip, 2) the NW-trending Karaburuni-Sazani Island offshore segment between the Gjiri i Ariut-Dukat and the north of Sazani Island strike-slips that thrusts the Apulian platform, and 3) the ~N-trending Frakulla-Durresi mainly onshore segment to the north of Sazani Island strike-slip that thrusts the Albanian Basin (= South Adriatic Basin). The WNW-trending Lezha-Ulqini offshore segment belongs to the Dinarides frontal thrust. The Othoni Island-Dhermi and the Gjiri i Ariut-Dukat strike-slips bound Mali i Kanalit Block that backthrusts towards NNE, the Ionian Zone Çika anticlinal belt. The W-E trending north of Sazani Island transversal separates the Apulian platform to the south from the Albanian Basin to the north of it.

Aliaj (2006) paid much attention to the Albanian Orogen: Convergence zone between Eurasia and the Adria Microplate. In Albania and Greece, along the southern convergent margin of the Eurasia Plate, we distinguish 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 (see Fig. 5). The Albanian orogenic thrust front is cut and displaced by the Othoni Island-Dhermi, the north of Sazani Island, and the Gjiri i Drinit-Lezha transversals of strike-slip type, which divide into some separate segments (see Fig. 5). Here, the N-trending Frakulla-Durresi mainly onshore segment makes up the orogenic front deeply buried beneath the Periadriatic Foredeep.

The continuation of the north of Sazani Island transversal fault (see Figs 4 and 5) into the Periadriatic Depression, as it was detected by seismic surveys, follows the Vjosa river towards SW, where it shows the passing from the Apulian platform to the Albanian Basin (South Adriatic basin) (Aliaj, 2006, see Fig. 7). Handy et al. (2019), are the pilot scholars who informed about the so-called Elbasan-Vlora 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-Vlora Transfer Zones (see Fig. 6).

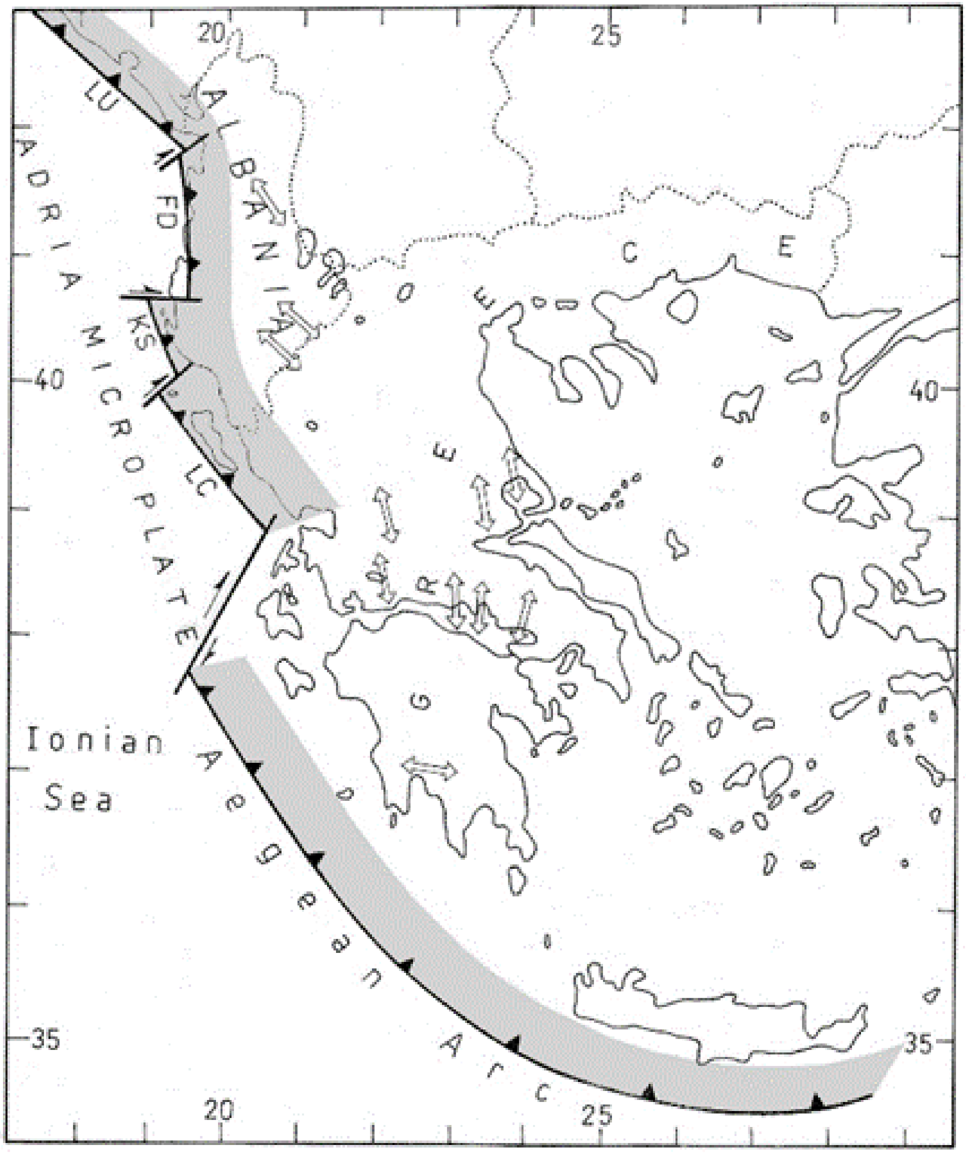


Fig. 5: Southern convergent margin of Eurasia plate: Adriatic collision and Aegean Arc (after Aliaj, 2006). Segments of Adriatic collision frontal thrust are noted by capital letters, as follows: LC- Lefkas-Corfu, KS-Karaburuni-Sazani Island, FD-Frakulla-Durresi, and LU-Lezha-Ulqini.

The Vlora-Bishqemi strike-slip fault, which forms the southern boundary of the Periadriatic Depression, dissects (cuts) from the south of the Panaja, Frakulla, and Lushnja anticlines (Aliaj 1988, see Fig. 7). The same anticlinal structures are dissected by the Transfer Fault forming the southern boundary of the Periadriatic Depression, marked on the tectonic map of the Elbasan-Vlora Transfer Zone (Handy et al., 2019; see Fig. 6).

Gelati et al. (1997) studied extensively the Tirana Depression, analyzing the stratigraphic record of Neogene events on some important stratigraphic sections mainly south of Tirana on both the eastern and western limbs of a wide syncline. They argued that the geological evolution of the Tirana Depression was different from that of the Periadriatic Depression.

The Late Serravallian - Tortonian slope extends in the direction of the inner margin of the Periadriatic foredeep, as the mudstone facies (upper lithozone) of the Preze homocline show. This large depositional slope connected the Periadriatic foredeep with the Tirana Depression and shows a widespread regressive trend, evolving to shallow-marine conditions. The Tirana Depression structure is connected to the east-verging thrusting of the Paper-Rova anticline-Preze Homocline. These structures may be interpreted as back thrusts if compared to the main vergency of the Dinaric structures (Gelati et al., 1997). Such a lineament, we named the Preza-Rova-Bishqemi backthrust, which has been a synsedimentary normal fault since the foundation of the Periadriatic Foredeep (see Fig 7).

The Preza-Rova-Bishqemi backthrust separates the Tirana Depression to the east from the Periadriatic Depression to the west. The Tirana Depression is developed with a different structural plan overlying the Kruja Zone substratum to the north of Tirana and partly the Ionian Zone substratum to the south of Tirana along its western limb to the east of Paper-Rova anticline backthrust.

The recent neotectonic studies (Handy et al., 2019; Aliaj, 2021), as well as the study about the Tirana Depression (Gelati et al.,1999), show that the Periadriatic Foredeep, which is located between the Drini Bay-Lezha and Vlora-Bishqemi strike-slip zones, was initially developed as a pull-apart basin and afterward the activation of the Preza-Rova-Bishqemi backthrust separated the Periadriatic Depression (PAD) from the Tirana Depression (TD).

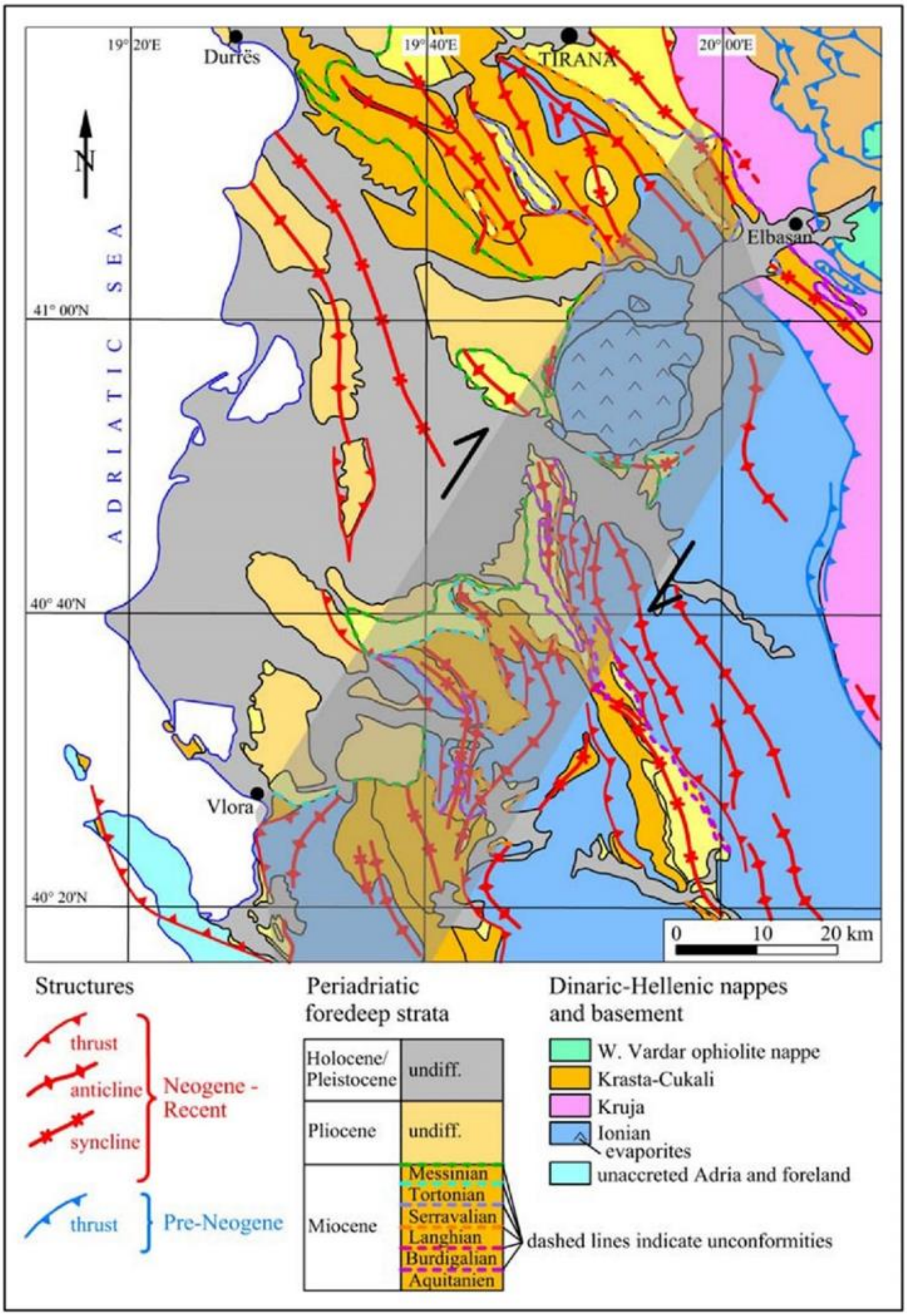


Fig. 6: Tectonic map of the Elbasan-Vlora Transfer Zone (grey shaded area) dextrally offsetting the Neogene thrust front. Map based on 1:200,000 Geological Map of Albania (Xhomo et al., 1999) and own observations (after Handy et al., 2019).

The Neotectonic Map of Albania on a scale of 1: 1,000,000 shows in blue colour the structural elements that shape the Periadriatic Depression (PAD) with two depocenters, and Tirana Depression (TD), as well as the active Albanides frontal thrust (see Fig. 7). The structural elements that led to the formation of the Periadriatic Foredeep are (i) the

DL-Drini Bay-Lezha and (ii) VB-Vlora-Bishqemi strike-slips and (iii) the DF- Durres-Frakulla and (iv) PRB-Preza-Rova-Bishqemi basin sidewall faults with latter two activated in present-days as thrusts or backthrusts. The frontal thrust segments of the Albanides fold-and-thrust belt (Aliaj and Kodra, 2016) are dissected (cut) by the NNE-trending Drini Bay-Lezha, Vlora-Bishqemi, and Othoni Island-Dhermi transversal strike-slip faults.

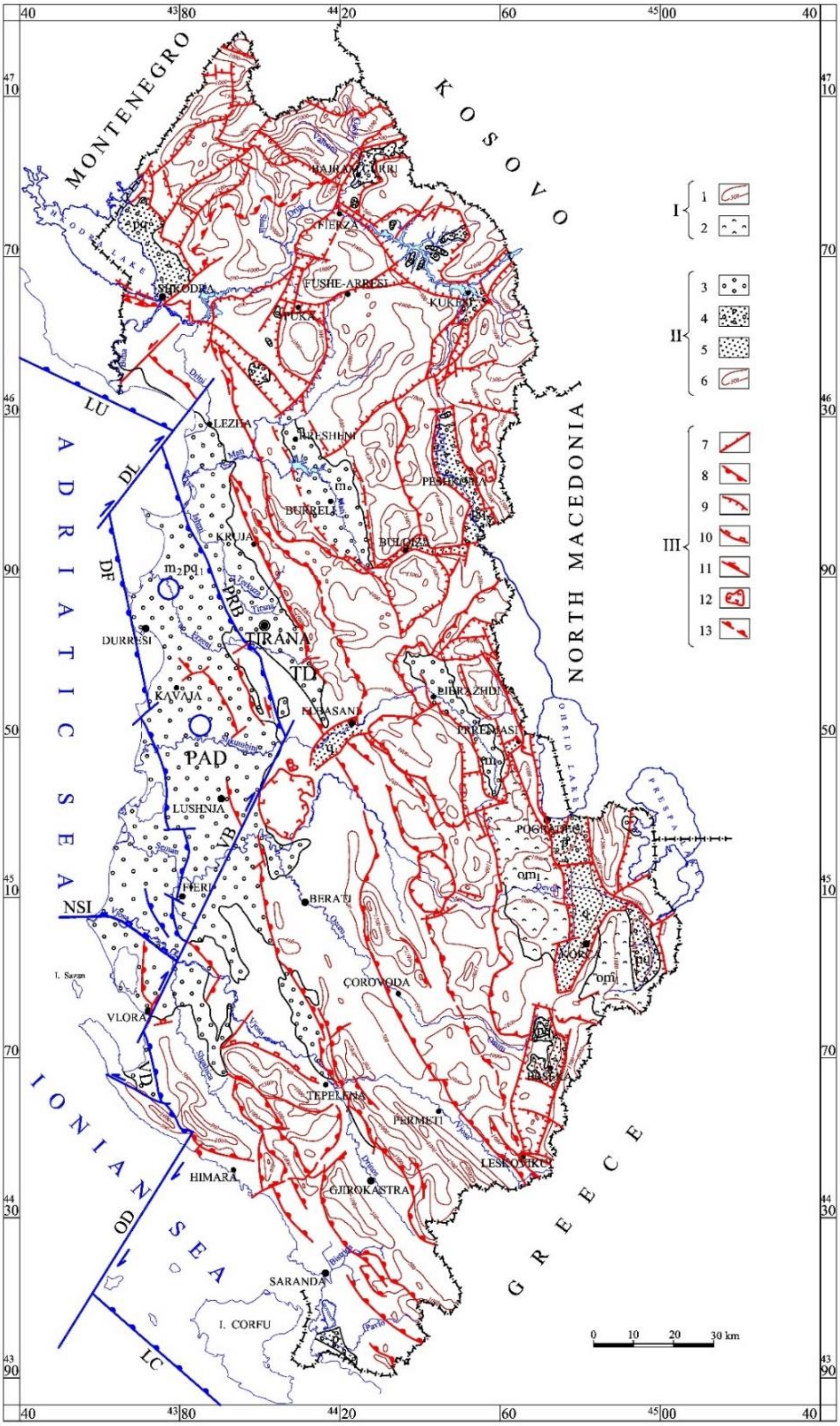
Caption of Fig. 7 (next page):

Fig. 7: Neotectonic Map of Albania on a scale of 1:1,000,000 shows in blue colour the structural elements that shape the Periadriatic Depression (PAD) with two depocenters, and Tirana Depression (TD), as well as the active Albanides frontal thrust (modified from Aliaj, 1988). The main elements of the Periadriatic Basin are the DL-Drini Bay-Lezha and VB-Vlora-Bishqemi strike-slip faults, and the DF- Durres-Frakulla and PRB-Preza-Rova-Bishqemi basin sidewall faults. The active Albanides – Hellenides frontal thrust consists of the following segments: DF-Durres-Frakulla, VD-Vlora-Dhermi, and LC-Lefkas-Corfu segments, which are dissected (cut) by the DL-Drin Bay-Lezha, VB-Vlora-Bishqemi and OD-Othoni Island-Dhermi strike-slip faults. The LU-Lezha-Ulqini segment belongs to the Dinarides. The north of Sazani Island transversal fault (NSI) shown in blue colour marks the boundary between the Apulian platform and the South Adriatic basin.

I. Regions subjected to uplifting tendency during the neotectonic period: 1. Regions subjected to uplifting typically from the Middle Miocene, but more strongly after the beginning of the Pliocene, with isolines of neotectonic deformations in m. 2. Oligocene to Lower Miocene molasse basins which underwent uplifting from the Middle Miocene, with isolines of neotectonic deformations in m.

II. Regions subjected to subsiding tendency during the neotectonic period: 3. Miocene (from Middle Miocene) molasse basins subjected to uplifting in post-Miocene time (m), Miocene (from Middle Miocene) to Pliocene molasse basins subjected to uplifting at the beginning of the Quaternary (m_2pq_1). 4. Pliocene marine or lake basins (p) subjected to uplifting in Quaternary; Pliocene to Lower Pleistocene Lake basins (pq_1) subjected to uplifting from Middle Pleistocene; Subsiding Pliocene to Quaternary depressions (PQ). 5. Subsiding Quaternary depressions (q). 6. Isolines of Pliocene floors in some depressions.

III. Structural active elements and others: 7. Nappe boundaries deformed by normal faults during the neotectonic period, 8. Reverse faults-thrusts, 9. Normal faults, 10. Flexures and faults detected by seismic exploration, 11. Strike-slips, 12. Active evaporite dome, 13. Inactive thrusts.


MONTENEGRO
KOSOVO
NORTH MACEDONIA
GREECE
ADRIATIC SEA
IONIAN SEA
SHKODRA
TIRANA
DURRESI
KAVAJA
LUSHNJA
FIERI
BERATI
VLORA
HIMARA
SARANDA
GJIROKASTRA
TEPELENA
PERMETI
LESKOVIKU
ÇOROVODA
ELBASANI
LIBRAZHDI
PRRENJASI
POGRADECI
KRUJA
LEZHA
BURRELI
RRESHENI
PESHKOPIA
BULQIZA
KUKESI
FUSHE-ARRESI
PUKA
FIERZA
BAJRAM CURRI
I. CORFU
I. Sazan
PAD
TD
PRB
VB
DF
DL
LU
NSI
VD
OD
LC
0 10 20 30 km

3. EVOLUTION OF THE PERIADRIATIC FOREDEEP AS A PULL-APART BASIN

In a pull-apart basin, there are at least two elements that commonly develop during the formation of the basin: basin sidewall faults (BSF) and cross-basin strike-slip faults (CSF). In a transtensional setting, the occurrence of en-echelon BSF has been proposed to be the primary character of the basin (Wu et al., 2009, 2012). The two main elements that define the formation of the Periadriatic Foredeep Pull-apart Basin are the Drini Bay-Lezha (DL) and Vlora-Bishqemi (VB) cross-basin strike-slip faults, and the Durresi-Frakulla (DF) and Preza-Rova-Bishqemi (PB) basin sidewall oblique normal faults (see Fig. 8).

The pull-apart basin has dual depocenters separated by an interbasin high. Dual depocenters are developed in both transtensional and pure strike-slip, pull-apart basin models. Furthermore, the development of a dual depocenter in the pull-apart basin appears to be greatly enhanced in a transtensional pull-apart basin setting (Wu et al., 2009, 2012). This morphology of dual depocenters might have developed because the area of maximum extension occurred at the junction of the principal displacement zone (PDZ) with the stepover.

The dual depocenters in Periadriatic Depression shown in Fig. 7 (modified by Aliaj, 1988) are well evidenced on the Neotectonic Map of Albania on the scale of 1: 200.000 (Aliaj et al., 1995; published 2018) by the deepest depocentres of Pliocene sediments, as follows: (i) the Myzeqe depocenter of 3000 m depth between Kryevidhi structure and the Thartori (Mliku) height (see Fig. 14), and (ii) the Erzeni i poshtem depocenter of more than 2000 m depth in the east of Shkoza height (see Fig. 15). The interbasin Thartori (Mliku)-Shkoza height separates the Myzeqe depocenter to the west and the Erzeni i poshtem depocenter to the east (Figs. 16 and 17).

The sedimentation in the Periadriatic Depression was controlled by intense syn-sedimentary tectonics (Aliaj, 1987). The en-echelon basin margin normal fault system formed since the Middle Miocene (Serravalian time) is generated due to the two oblique normal faults: (i) the NNW trending west dipping Preza-Rova-Bishqemi normal fault which is the eastern boundary of the Periadriatic Foredeep and in present-days acts as backthrust, and (i) the east-dipping Durresi-Frakulla (DF) normal fault, in present-days acts as the frontal blind thrust of the Albanides orogen (Aliaj, 2020).

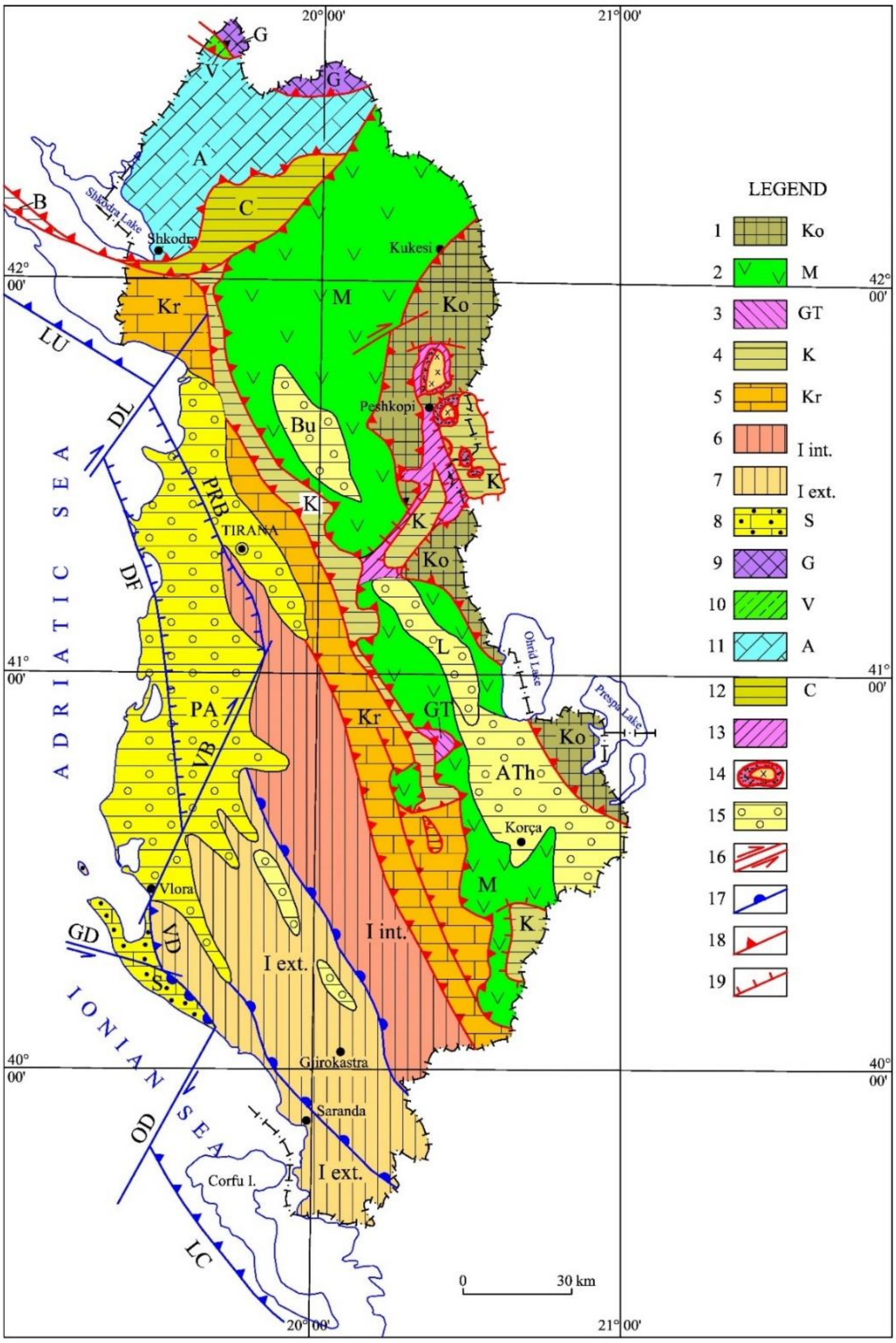


Fig. 8: Tectonic Map of Albania shows two elements in blue colour that commonly develop the formation of the Periadriatic Basin: (a) The Durresi-Frakulla (DF) and Preza-Rova-Bishqemi (PRB) sidewall oblique normal faults, and (b) the Drini Bay-Lezha (DL) and Vlora-Bishqemi (VB) cross-basin vertical strike-slip faults, as well as the active Albanides collision thrust faults (modified from Aliaj, 2021). 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- Molasses basins: ATh-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.

The Periadriatic Basin is installed between the South Adriatic Basin and Tirana marginal basin, where it takes a graben shape delimited by the Durresi-Frakulla and Preza-Rova-Bishqemi normal faults (see Fig. 9).

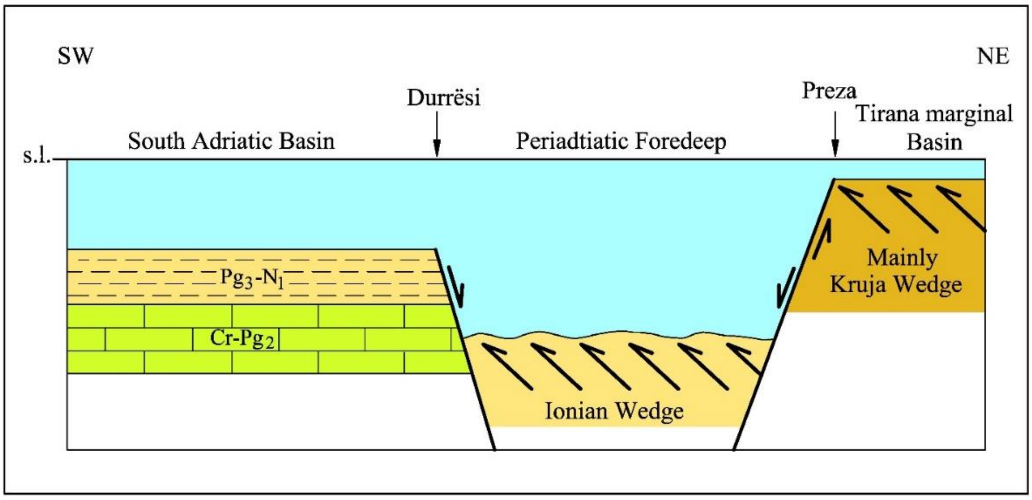


Fig. 9: Conceptual model of the Periadriatic Foredeep in the Middle Miocene within a graben structure between the South Adriatic Basin and Tirana marginal Basin. $Cr\text{-}Pg_2$: carbonates and $Pg_3\text{-}N_1$: siliciclastics.

The stratigraphic analysis of the basin was based on the recognition of tectonostratigraphic units bounded at the base and top by tectonically-induced unconformities, i.e., the allogroups are high-rank and large-scale stratigraphic units. Allogroup boundaries are produced by high-magnitude tectonic phases and are usually related to the creation of a new foredeep depocenter. Allogroup boundaries also correspond to abrupt changes in the gross distribution of depositional systems (Ghielmi et al., 2008). The Miocene-Pliocene-early Pleistocene infill of the Periadriatic Depression is subdivided into three allogroups: Serravallian-early Messinian allogroup, Late Messinian allogroup, and Pliocene-early Pleistocene allogroup that are delimited at the bottom by the pre-Serravallian compressional phase and separated by the intra-Messinian and Miocene-Pliocene boundary compressional phases. The Pliocene-early Pleistocene allogroup bounds at the top by the end of the early Pleistocene tectonic phase that finally shaped the tectonic structure of the Periadriatic and Tirana depressions. The last tectonic phase occurred between 1 and 0.7 Ma, and this compression has been observed to be decreased until today (Sorel et al., 1992; Sorel, 1989; Aliaj, 2012).

The sedimentation of the Serravallian-early Messinian allogroup is characterized by the sharp lithofacies changes from the coarser-grained facies along the eastern margin to the finer-grained basin facies to the west with the dominance of axial infilling in the

Myzeqe depocenter. Such facial changes are also observed in the sedimentation of the late Messinian allogroup.

The structural evolution and the geometry and kinematics of the Albanian nappe pile during the Tertiary, from the orogeny-making stage up to the post-nappe stacking collapse are envisaged by Kilias et al. (2001). All the external zones are included in the lower plate, while the internal units of the Korabi with Mirdita one on its top in the upper plate. Four main sets of structures that were formed into the Albanian nappe pile are due to D_1-D_4 deformational events during the Tertiary: D_1 compressional event occurred during the Eocene-Oligocene, D_2 extensional event took place during Oligocene-Miocene, D_3 compressional event occurred in the Middle-Late Miocene and D_4 extensional event from Miocene onward. The two plates collided during the Eocene-Oligocene. The extensional tectonics and continental uplift during the Oligocene-Miocene have a critical role in shaping the present structure of the Albanian orogenic belt. The structural analysis shows the role and importance of extensional-compressional tectonics in the Tertiary structural evolution of the Albanides.

4. PERIADRIATIC DEPRESSION

The Periadriatic Basin is installed over the fold and thrust Ionian and Kruja zones with a different structural plan. To the west of the Periadriatic Basin, extends the South Adriatic Basin with an inherited structure consisting of basin Cretaceous-Eocene carbonates, the same as the Ionian Zone, and the successive Oligocene-Mio-Plio-Quaternary terrigenous accumulations. The Periadriatic Depression consisting of several anticlines and synclines was formed by two marine cycles: a) Middle and Upper Miocene, and b) Pliocene cycles. The Quaternary sediments usually overlie folded Mio-Pliocene molasses horizontally and discordantly (Figs. 10 and 15). It was observed that during Middle Miocene (Serravallian), the sharp lithofacies changed from sandstone facies containing *Ammonia beccarii* in the eastern part of the Periadriatic Foredeep Basin (at Kavaja anticline, Peza syncline, and monocline of Preza) to the clayey-sandstone one westwards with the predominance of the planktonic foraminifera.

Serravallian sediments include clays and sandstones with lithothamnium limestone, especially in the lower part of the section (Prillo et al. 1996). They have been assigned to the *Orbulina universa* and *Globorotalia mayeri* zones. The lithothamnium within organogenic limestones is predominant in the Tirana syncline. To the west, they are mostly made up of clays and siltstones with rare alternations of sandstones and limestones. In the upper part of the section, more sandstones occur at the transition to the Tortonian. Two different lithological facies occur in Tortonian sediments of Periadriatic Depression: the first is clayey with rare sandstones and lithothamnium limestones that are encountered westwards, while the second is a massive sandstone facies with clayey strata, wherein *Ammonia beccarii* flourishes on eastern basin margin.

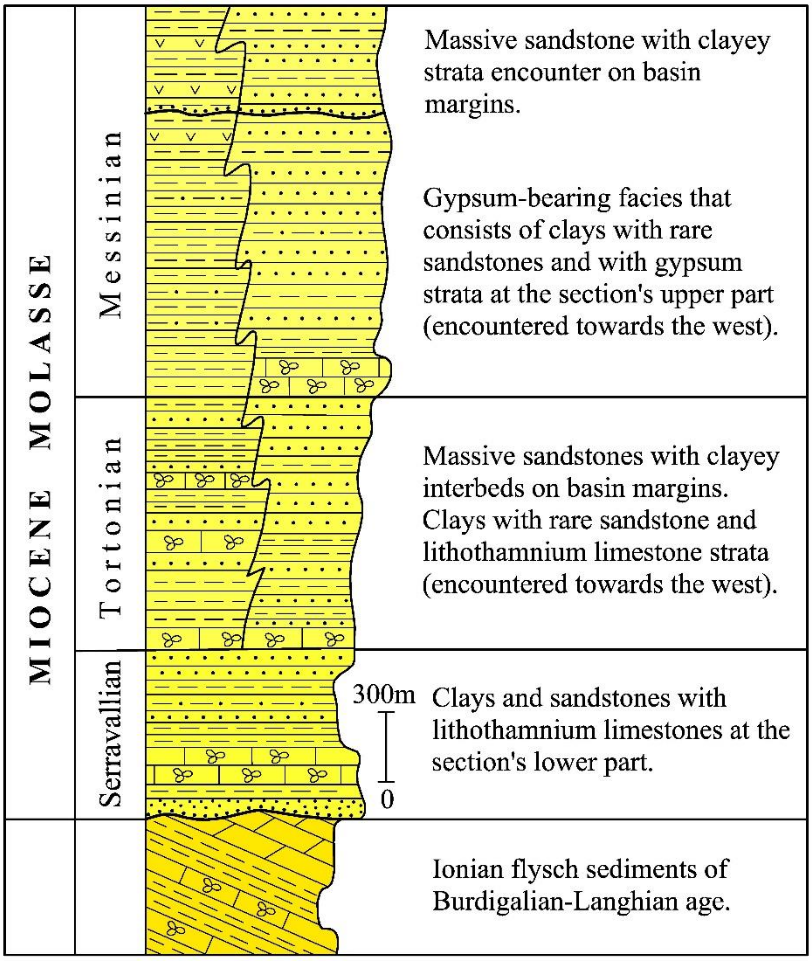


Fig. 10: Generalized stratigraphical section of Middle up to Upper Miocene molasse in the Periadriatic Basin (modified from Aliaj 2000a). The intra-Messinian compressional tectonic phase is marked on it too.

The Messinian stage includes very thick molasse deposits characterized by two different lithological facies, namely gypsiferous facies in clays with siltstones and sandstones, and other non-gypsiferous ones made of alternating sandstones and siltstones with clays on eastern margins (Pashko 1970, 1973; Prillo et al., 1996). The Messinian non-gypsiferous facies is characterized by coal-bearing formations that occur in Tirana Depression with many coal mines (Dimo et al. 1989), and in the Erzeni area with Manza coal mine, which belongs to the Periadriatic Depression (Xhomo et al., 2002). The paralic coal-bearing deposits are formed in lagoonal basin margins (Dimo et al., 1989; Meço et al., 2000).

The Kavaja section (south of Durresi) in the Periadriatic Depression represents the most continuous and complete sequence of the Messinian succession from the onset of the Messinian salinity crisis up to Pliocene marine sedimentation unconformity (Pashko, 1973, Pashko et al., 2017; Pashko and Aliaj, 2020). A salt unit about 32 m thick, found in the Kavaja section is unconformable by a conglomeratic layer that is 1.0-1.5 m thick (Fig. 11). This important erosional surface corresponds to the Messinian erosional surface (MES) that separates two main evaporitic successions and shows a significant intra-Messinian tectonic phase (Roveri et al., 2008).

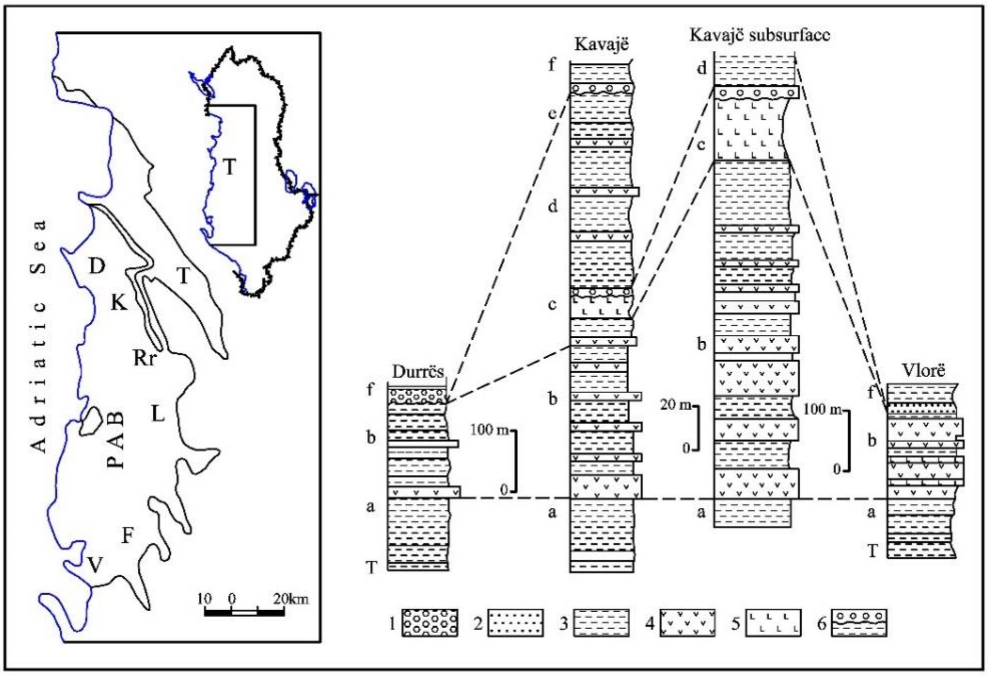


Fig. 11: Stratigraphic Column of Kavajë gypsum-bearing Section and its correlation with Durrës and Vlorë gypsum-bearing sections (after Pashko et al., 2017). T- Tortonian, a- Under-Gypsum Marls, b- Gips-Sharre Gypsum, c- Salt Unit, d- Mushnik Gypsum, e- Over-Gypsum Marls, f- Pliocene. 1- Conglomerates, 2- Sandstones, 3- Clays, Marls, 4- Gypsum, 5- Salt, 6- Unconformity. PAB- Preadriatic Basin, D- Durrës, K- Kavajë, Rr- Rrogozhinë, L- Lushnjë, F- Fier, V- Vlorë, and T- Tiranë.

The stratigraphic model of the Messinian Salinity Crisis (MSC) of the Sicilian Messinian succession and its correlation with the deep Mediterranean basin shows the evaporite 'trilogy' (Lower Evaporites, Salt, and Upper Evaporites). The sudden reopening of the Atlantic gateways marks the MSC ends at the base of the Pliocene (Roveri et al., 2008); it was associated with the Pliocene deep water marine transgression that covered the land to the east and north of the Periadriatic Basin up to the east of Shkodra Lake (Aliaj et al., 2018).

Four structural unconformities expressing the compressional phases are recognized in outcrops and on seismic lines across the Periadriatic Depression: (i) end Langhian or pre-Serravallian, (ii) intra-Messinian, (iii) Miocene-Pliocene boundary, and (iv) early Pleistocene compressional phases. The strongest last phase led to the final shaping of the Mio-Pliocene structures, and further, the separation of two depressions: The Tirana Depression located in the east, and the Periadriatic Depression located in the western lowland of Albania. The compressional deformations follow in the present day. The pre-Serravallian or end Langhian (pre-molasses) compressional phase has caused the folding and thrusting of the external Ionian zone (Çika and Kurveleshi anticlinal belts), simultaneously leading to the formation of Lezha-Drin Bay and the Vlora-Bishqemi dextral transfer zones, that led to the Periadriatic Basin set up as a dextral pull-apart basin. The Serravallian deposits overly unconformably the Burdigalian Flysch of the Ionian zone in the Hekali section, where they are characterized by Lithothamnium limestones intercalated with clays at the base passing upwards into the clayey packet (see Fig. 12).

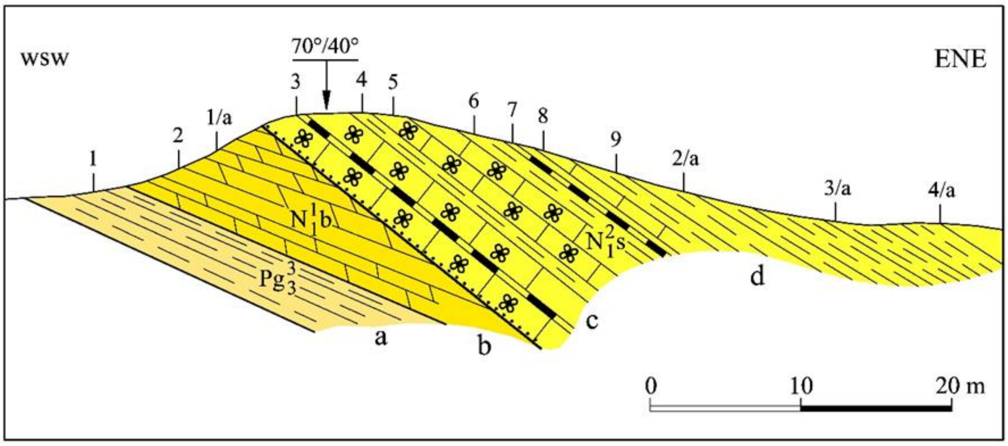


Fig. 12: The Hekali geological section shows the angular unconformity between the Serravallian molasse and Burdigalian flysch (after Aliaj et al., 1996). **a-** Clayey packet, sample 1 Lower Oligocene age (*G. ciperoensis* zone); **b-** Marl and sandstone, samples 2 and 1/a Burdigalian age (*G. scitula/G. acrostoma* zone); **c-** Lithotamnium limestone with clayey sublayers, samples 4-8 Serravallian age (*O. universa* zone); **d-** Clayey packet, samples 9, 2/a-4/a Serravallian age (*G. mayeri* zone).

The Pliocene molasse is placed over the Miocene molasse with angular unconformity, as a result of the transgression which is evident in the Povelça seismic line (Fig. 13) and Karpen (Shijak) geological section (Fig. 14). Drilling data show that the *Sphaerodinellopsis* zone of Lower Pliocene overlies the *Globorotalia conomiozea* zone of Lower Messinian and testifies that the compressional phase has occurred at Miocene-Pliocene boundary, probably at the end of Late Miocene (Aliaj et al. 1996).

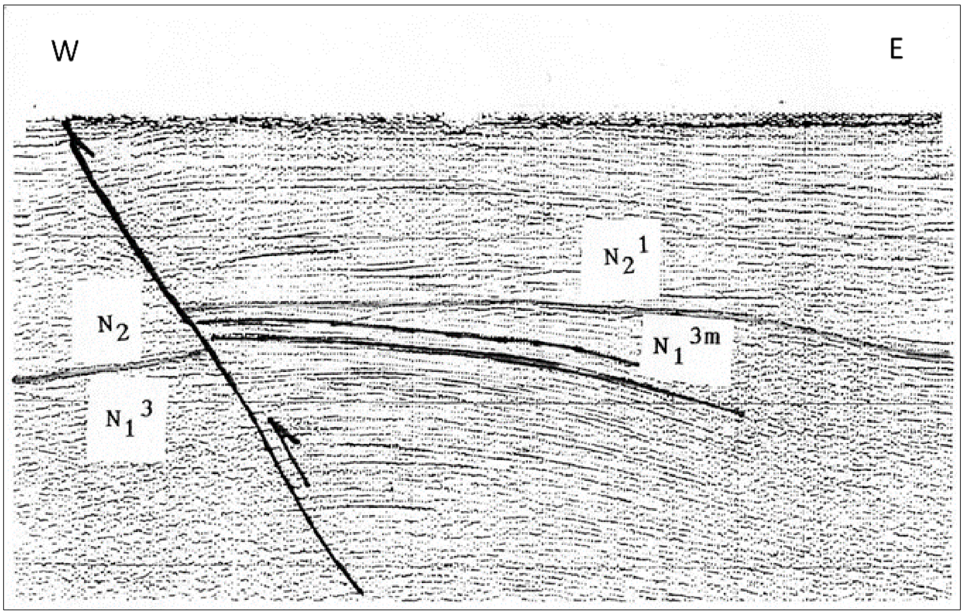


Fig. 13: Seismic Section through the buried Povelça structure shows the angular unconformity between the Lower Pliocene and the Upper Miocene (Lower Messinian) sediments (after Skrami and Aliaj, 1995).

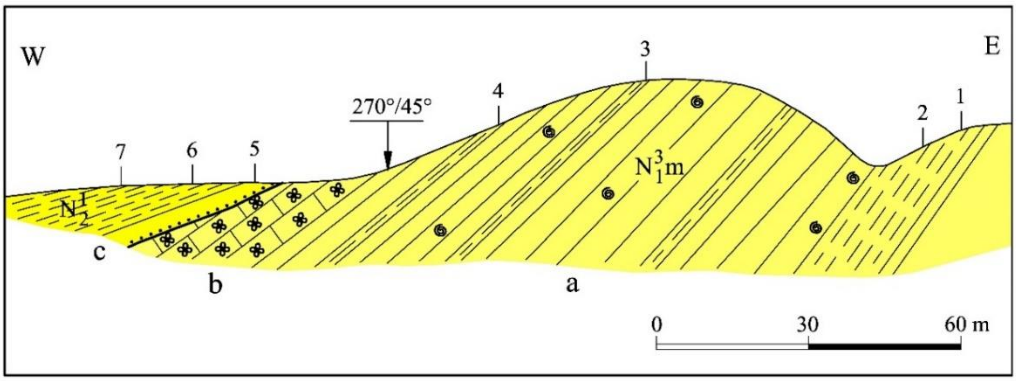


Fig. 14: The Karpen (Shijak) geological section shows the angular unconformity between the Lower Pliocene and Messinian molasse deposits (after Aliaj et al., 1996). **a-** massive sandstone with clayey sublayers, samples 1-4 Messinian age (*A. latiseptata* and *L. Hodenica* zone); **b-** organogenic limestone; c- Clayey packet, samples 5-7 Lower Pliocene age (*G. margaritae* zone).

The Pliocene sediments are divisible into two formations (Dalipi et al., 1974; Dalipi, 1977; Prillo et al., 1996) and these are: (1) The Helmesi clayey Formation, and (2) The Rrogozhina sandstone-conglomerate Formation (Fig. 15). The Helmesi Formation is named after Helmesi village in the Kavaja district, where the section is both full and typical. It belongs to the transgressive Pliocene molasses cycle. The following four planktonic biozones have been identified which include (from bottom to top): (a) flourishing zone with Sphaeroidinellopsis, (b) Globorotalia magaritae zone, (c) Glorotalia puncticulata zone, and d) Globorotalia crassaformis zone. The first three zones confirm the Lower Pliocene age while the fourth one verifies the Middle Pliocene age. The Helmesi Formation everywhere transgressively overlies underlying Miocene molasses sediments of the Periadriatic Depression (see Fig. 15). Generally, the transgressive base of Pliocene sediments is represented by conglomerates passing up into sandstones or just by sandstones. It is followed by clays which range from a few m to between 50 and 100 m in thickness. All the Lower Pliocene sections occur towards the central and western parts of the Periadriatic Basin.

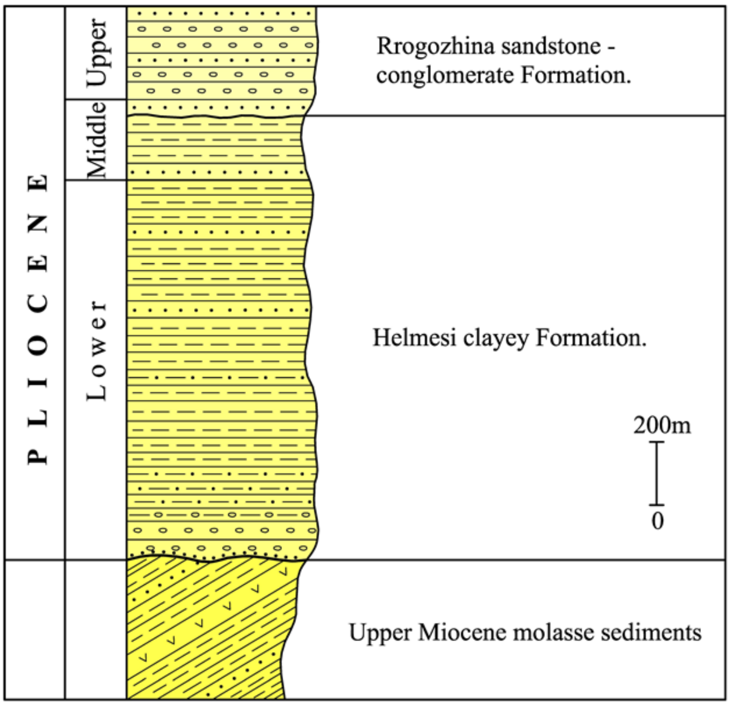


Fig. 15: Generalized stratigraphical section of Pliocene molasse in the Periadriatic Basin (modified from Aliaj, 2000a).

The Middle Pliocene sediments of the Globorotalia crassaformis Zone are usually covered by the sandstone-conglomerate facies of the Rrogozhina Formation. The Rrogozhina Formation is named after the town of Rrogozhina, where the Pliocene sandstone-conglomerate facies is successively placed on clayey facies of the Helmesi Formation. The section is complete and typical and belongs to the regressive cycle of Pliocene molasse. The sediments of the Rrogozhina Formation contain benthonic foraminifera, mostly Ammonia beccarii pinuseptata. The Middle Pliocene upper part of the Helmesi Formation is transgressively overlain by the Rrogozhina Formation (Xhomo et al., 2005).

The Quaternary sediments (marine and continental ones) overlay with unconformity on the folded Mio-Pliocene structures of the Periadriatic Depression. This compressional phase at the Lower Pleistocene has caused the final strong deformation of Mio-Pliocene structures in the Periadriatic Basin. North of the Durresi offshore, the seismic line shows the Durresi backthrust dislocating marine Quaternary sediments lying horizontally on the folded Mio-Pliocene molasses of the Periadriatic Depression demonstrating that compressional deformations are still active to date (Bega, 1985, 2020).

The last phase was associated with an uplifting of several hundred metres of the external Aegean Arc. The uplifted structures are covered by continental slope ‘breccia’, considered of the Middle Pleistocene age. In NW Greece and Albania, the slope breccias are attributed to the end of the Lower Pleistocene or the start of the Middle Pleistocene, between 1 and 0.8 Ma. More moderated compressional deformations continue after the last compressional phase (Sorel et al., 1992). The Quaternary lithified slope breccia outcrops along the Kruja, Radhima, and elsewhere. The Middle Pleistocene south-west low-dipping slope breccia in Radhima village are discordantly overlying the Jurassic limestones of Tragjasi anticline as well as the Pliocene molasses (Aliaj, 2001). The terrace age of the river valleys in Albania shows that they are formed from the Middle Pleistocene (180,000 years) to historic times (700 years). The terraces age of river valleys of Albania is determined from the novel ^{14}C dating and in situ produced $_{10}Be$ dating. At Vjosa and Osum river valleys, a total of nine terrace levels were identified to be formed from the Middle Pleistocene (180,000 years) to historic times (700 years). And these are developed since Marine Isotope Stage 6 (MIS 6) up to historic times (Carcaillet et al., 2009; Koçi, 2008).

The Periadriatic Depression structure is built by NNW trending narrow anticline and wide syncline lines. From southwest to the northeast are distinguished: Frakulla-Durresi anticlinal line, Myzeqe syncline, Lushnja-Golem Kavaja anticlinal line, Erzeni i poshtem syncline, and Preza monocline (Figs. 16 and 17). The positive structures are well expressed on the topography except for the Povelça-Semani anticline, which is buried under Quaternary deposits; so, the anticlines build hills, while the synclines are buried under the Holocene plains. Deformation of orogenic crust at the Albanides-Adria collision zone during Tertiary occurred and occurs into both levels: i) a basal fold-and-thrust system in the Ionian Zone, that accommodated an increasing amount of SW directed shortening, and ii) a structurally higher system of thrust faulting affecting the overlying structure of the Periadriatic Depression, that underwent a strong structural rearrangement (Aliaj, 2020, Fig. 17).

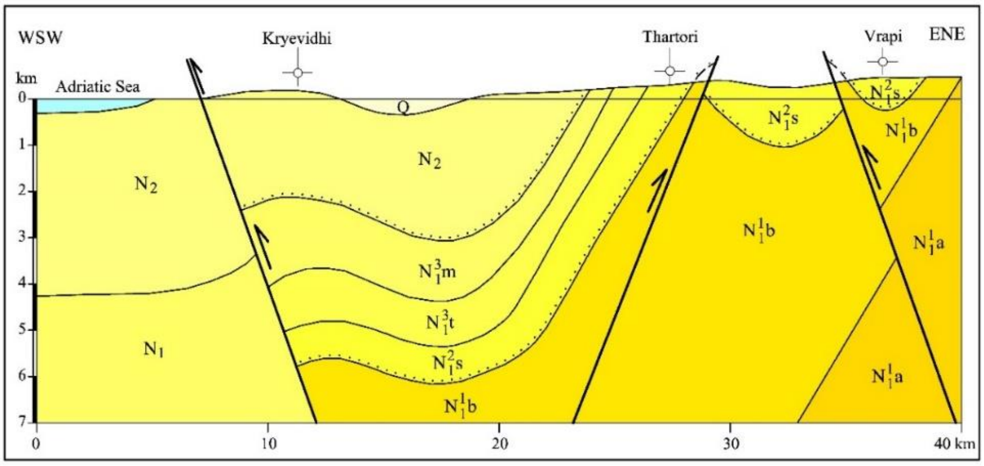


Fig.16: The Kryevidhi-Vrapi geological section shows the Periadritic Depression structure with its deepest Myzeqe depocenter of the Middle Miocene-Pliocene molasses that is located to the west of the Thartori-Mliku high.

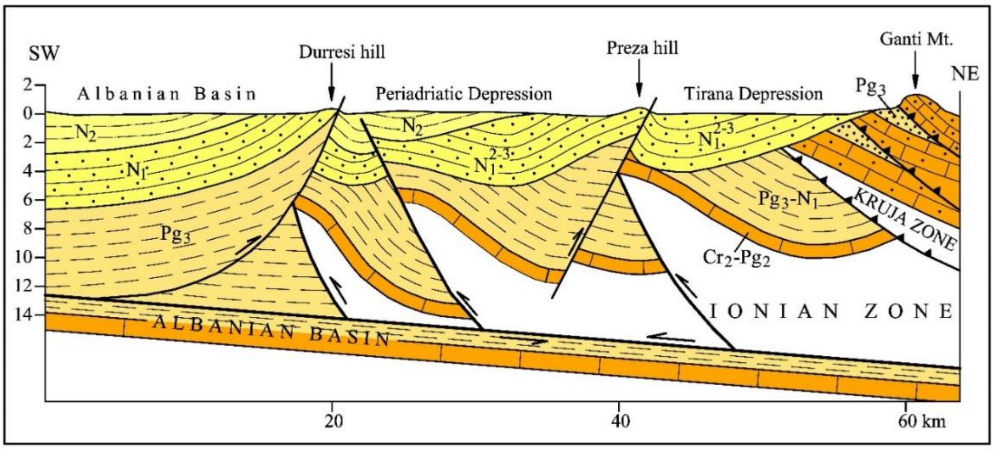


Fig. 17: Geological cross-section through the Durresi hill-Preza hill-Ganti Mt. showing the collision between the Albanian Basin and the Ionian Zone blind thrust-bounded imbricates which are unconformably overlain by the Middle Miocene-Pliocene molasse of Periadriatic and Tirana depressions (after Aliaj, 2020).

The Pliocene deposits outcropping in the anticlinal structures of the Periadriatic Basin overly on the deeper Miocene sediments as drilling data proved. The Upper Miocene sediments, which belong to the Adria Microplate, outcrop into the Durres-Bisht Palla anticline (Bega, 1995; Aliaj, 1996). The Mio-Pliocene anticlines of the Periadriatic Depression are formed due to the thrust or backthrust faults, that are evidenced during seismic explorations (Aliaj et al., 1996; Skrami and Aliaj, 1995). They are named over-fault anticlines (Aliaj, 1988) or determined as folds “placed in narrow zones of some big faults found under the Neogene cover” (Biçoku, 1964). The Frakulla-Divjaka Mio-Pliocene anticlines represent the “flower” structure of the “palm tree” type (Skrami and Aliaj, 1995; Aliaj, 1998). In general, thrusts and backthrusts have originated from the inversion of syn-sedimentary normal faults due to the post-Pliocene regional compression (Aliaj, 1988).

Some small strike-slip faults have displaced the Ardenica-Divjaka-Kryevidhi-Durresi anticlinal line. They include: the left-lateral strike-slip faults between Ardenica and Divjaka-Kryevidhi anticlines and those between Kryevidhi and Durresi anticlines; the Durresi anticline starts at the northernmost end of the Kryevidhi anticline. Southwards, the Ardenica anticline has been displaced from the Panaja-Frakulla anticlinal line by a right-lateral strike slip (Aliaj et al. 1995, 1996; Aliaj, 1998). Only the Frakulla anticline has been cut on both sides by thrust faults of the "flower" structure of the "palm tree" type (Bega, 1995, 2020). Rakipi and Mesonjesi et al. (1995) focused on the location of the gas fields in the Periadriatic Foredeep. The stratigraphy and tectonics of gas fields that were discovered in some anticlinal structures of the Periadriatic Foredeep like Divjaka, Frakulla, Panaja, Povelça, and Durresi are studied in detail. The gas-bearing sandstone beds are encountered in all stratigraphic sections of the Periadriatic Foredeep from Serravallian to Pliocene deposits. Gas-bearing of the Divjaka gas field belongs to the Tortonian deposit, while that of the Divjaka-Ballaj gas field belongs to the Pliocene deposits (Fig. 18). The anticline of the Divjaka gas field as the unique focus of compelled data is an integral part of the Southern Adriatic Depression, which comprises Middle Miocene to Pliocene deposits. Two levels of natural gas were discovered: the first level is located in the Pliocene deposits, while the second one belongs to the Tortonian and Messinian sandstone bodies, named the "Divjaka suite" (Prifti et al., 2010). Reservoir in some oil fields in the central part of Albania is related to Miocene deltaic sandstones with porosities ranging between 10-30% and permeability's 200-2000 md (millidarcy), such as in Marinza, Patosi, and Kuçova fields. Reservoir in the gas fields of Peri-Adriatik Depression is related to molasse sandstones of Late Miocene, Tortonian-Messinian in age or in turbidite sandstones of Pliocene age, with porosities ranging between 12 - 37% (see Fig. 16, AKBN.al.org., 2014).

The Messinian non-gypsiferous facies in Erzeni area of Periadriatic Depression is characterized by Manza coal-bearing field (Xhomo et al., 2002).

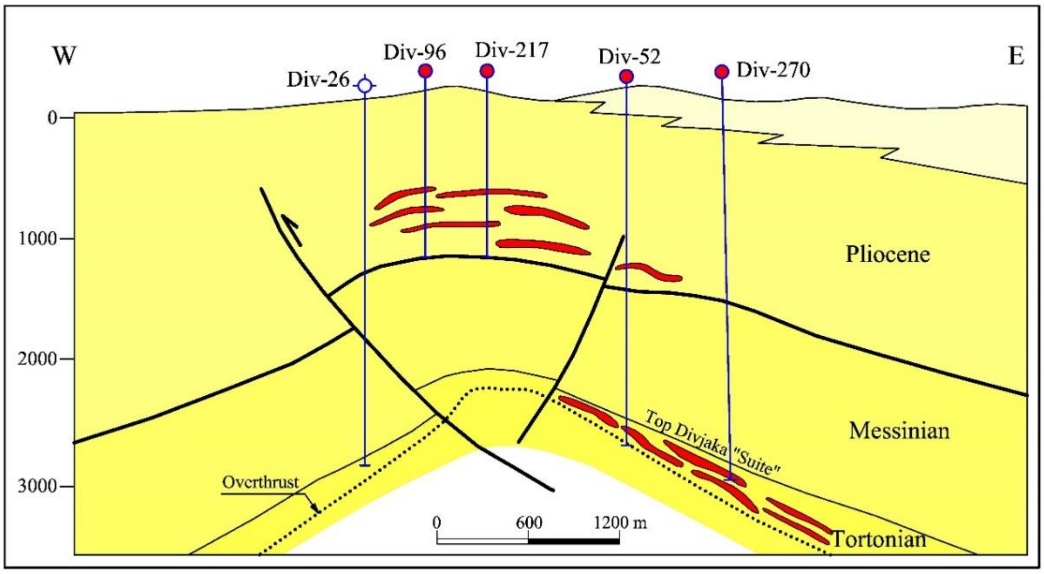


Fig. 18: Geological cross section through the Divjaka gasfield (after AKBN.al.org., 2014).

5. TIRANA DEPRESSION

The development of the Periadriatic Basin leads to the separation of two depressions: the Tirana Depression located in the east and the Periadriatic Depression located in the western lowland of Albania. The Tirana Depression is built by the Middle-Upper Miocene-Pliocene molasses that formed the northeast verging asymmetrical syncline structure. The Miocene molasse with the Serravallian one at its base is unconformably overlying the Lower Oligocene Flysch deposits of the Kruja Zone along the eastern limb of the Tirana syncline (Brari and Zall-Herri sections (Fig. 19) as well as on Burdigalian marls of the Ionian Zone to the south of Tirana along the western limb of Tirana syncline (Mulleti and Petrela sections; Fig. 20). The Pliocene molasse outcrops in the Thumane and Mamuras area, where it transgressively overlies the Cretaceous limestones of Kruja Zone as well as the Miocene molasse of the eastern limb of Tirana syncline; northwards, in Laçi-Lezha area buried under Quaternary deposits, it transgressively overlies the Late Miocene molasse (Xhomo et al., 2002).

The Pliocene marine transgression extends towards the north and northeast, outside of Periadriatic Basin, transgressively and with unconformity overlying the substratum of the Albanian Alps Zone at Shkodra and Kopliku areas, as well as the Mirdita Zone at Kashnjeti and Lezha areas (Aliaj et al., 1996). The Serravallian molasse made up of the lithothamnium limestones is studied in Zall-Herri, Brari, and Mulleti sections. The Tortonian molasses, characterized by claystone passing into claystone-sandstone intercalations is studied in Mulleti and Petrela sections.

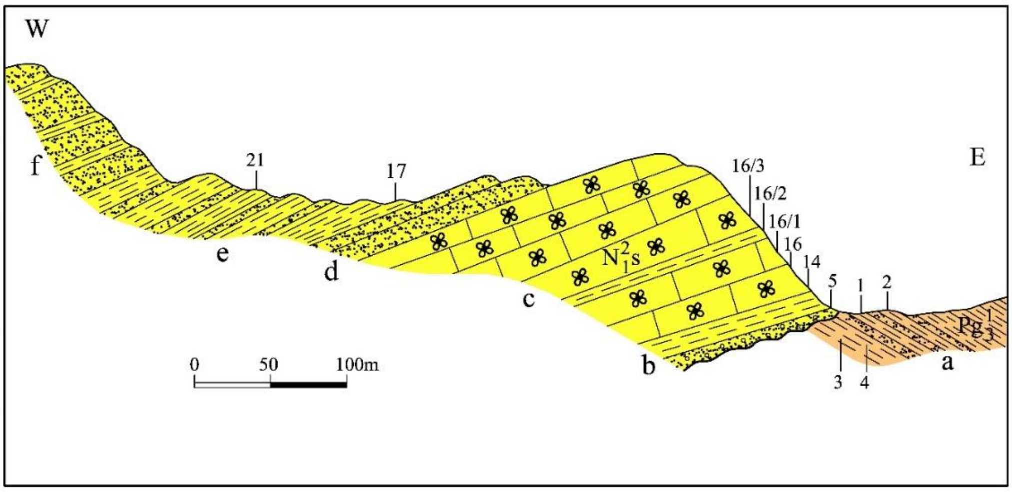


Fig. 19: The Brari geological section (eastern part of Tirana depression) shows the angular unconformity between the Serravalian molasse and Lower Oligocene flysch (after Aliaj et al., 1996). a- Oligocene flysch, clays with sandstone layers, samples 1-4 Lower Oligocene age (G. ampliapertura); b- Clays with limestone lenses, a conglomerate layer at the base; c- Lithotamnic limestone with clayey sublayers, sample 16/2 Serravallian age (G. mayeri zone); d- Sandstone; e- Clays with rare sandstone layers; f- Sandstone with clayey layers.

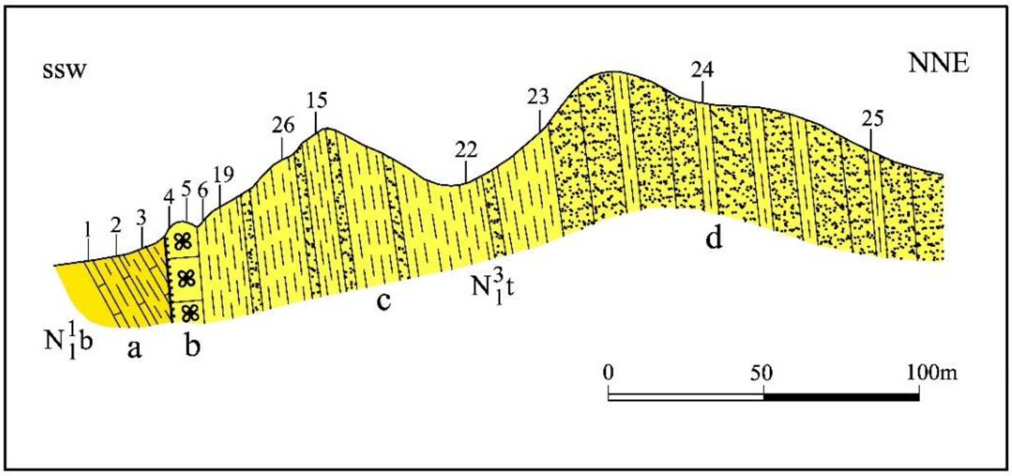


Fig. 20: Mulleti geological section (western part of Tirana depression) shows unconformity between the Serravallian-Tortonian mollase and Burdigalian sediments (after Aliaj et al., 1996). a. marls and clays, samples 1-3 Burdigalian age (G. acrostoma/G.scitula); b. Lithothamnium limestones, samples 4-5 age nondetermined; c. Clays with thin sandstone layers, samples 6-9 Tortonian age (G. menardi s.l. zone), samples 10-15 Tortonian age (G. acostaensis zone), samples 16-22 Tortonian age (G. obliquus extremus zone); d. thick-layer sandstones with thin clayey layers, age non-determined.

The presence of the Messinian molasse in the Tirana Depression is marked in the Geological map of Albania, scale 1: 200,000 (Biçoku et al., 1967). The Messinian non-gypsiferous facies in Tirana Depression is characterized by coal-bearing formations with many coal fields. In Tirana Depression, there are Mamli, Skuterra, and Mezezi coal-bearing formations. The Skuterra formation includes the Krraba, Mushqeta, and Priska coal fields, and the Mezezi formation encompasses the Mezezi and Valias coal fields. All coals in Tirana Depression are formed in paralic basins (Dimo et al., 1989; Burri & Turku, 1998). The paralic coal-bearing deposits are formed in lagoonal pre-coastal basin margins (Dimo et al., 1989; Meço et al, 2000). The Messinian coal-bearing facies is identified in Iba and Mezezi formations.

The Tirana Depression bounded from the west by the Preza-Rova-Bishqemi backthrust is characterized by the prevailing continental and shallow-marine sediments that are quite different from the deep-marine sediments of the Periadriatic Depression in the west. Gelati et al. (1997), focused on Tirana Depression, analysing the stratigraphic record of Neogene events in it, based on some significant stratigraphic sections that were examined mainly south of Tirana on the eastern and western limbs of a wide syncline. They argued that the geological evolution of the Tirana Depression was different from that of the Periadriatic Depression. They pointed out the following: (i) The Tirana Depression is located in the eastern and inner part of the Periadriatic Depression. There, it forms an elongated NW-SE oriented structural element, 60 km in length, located between the front of west-verging Dinaric structures and the east-verging Paper Rova anticline-Preza homoclinic alignment, which acted as a backthrust till post-Pliocene age.

(ii) Two Lithothamnium levels, uppermost Langhian and Serravallian, were used as markers. The generalized occurrence of planktonic Foraminifera-bearing mudstones, uppermost Serravallian-Tortonian in age, is interpreted as significant. The Langhian and Serravallian unconformities, recorded at the base of the Lithothamnium limestone levels, are considered of regional importance.

(iii) Continental and shallow marine sediments are largely prevailing. Deep-marine sediments are limited to the Oligocene-earliest Miocene and Serravallian-Tononian p.p and crop out only along the western margin of the Tirana Depression. The sequence was compared with the Langhian-Tortonian foredeep succession of the Preze homocline, which belongs to the Periadriatic Depression. The late Oligocene-Tortonian evolution of the Tirana Depression, which has frequently been reported simply as the "Mollase" basin, appears to be considerably different from the adjacent Periadriatic foredeep basin (Fig. 21). The Late Serravallian - Tortonian slope developed in the direction of the inner margin of the Periadriatic foredeep, as the mudstone facies (upper lithozone) of the Preze homocline shows (Fig. 19). This large depositional slope connected the Periadriatic foredeep to the Tirana Depression and shows a widespread regressive trend, evolving to shallow-marine conditions.

The Tirana Depression structure is connected to the east-verging thrusting of the Paper-Rova anticline-Preze Homocline alignment. These structures may be interpreted as backthrusts when compared to the main vergency of the Dinaric structures (Gelati et al., 1997). The Preza-Rova-Bishqemi backthrust is one of them, which has acted as a syn-sedimentary normal fault during the foundation of the Periadriatic Foredeep. The Preza-Rova-Bishqemi backthrust separates the Tirana Depression in the east from the Periadriatic Depression in its west. The Tirana Depression overly the Kruja Zone substratum to the north of Tirana and partly the Ionian Zone substratum to the south of Tirana along its western limb to the east of the Rova anticline backthrust (Fig. 22). To the south of Tirana, the Tirana Depression also may be outlined by field data and is a wide northeast verging asymmetrical syncline. The high dipping (locally 80°) western limb is bounded by the NW-SE oriented Paper-Rova anticline with Oligocene rocks at the hinge zone (Gelati et al., 1997).

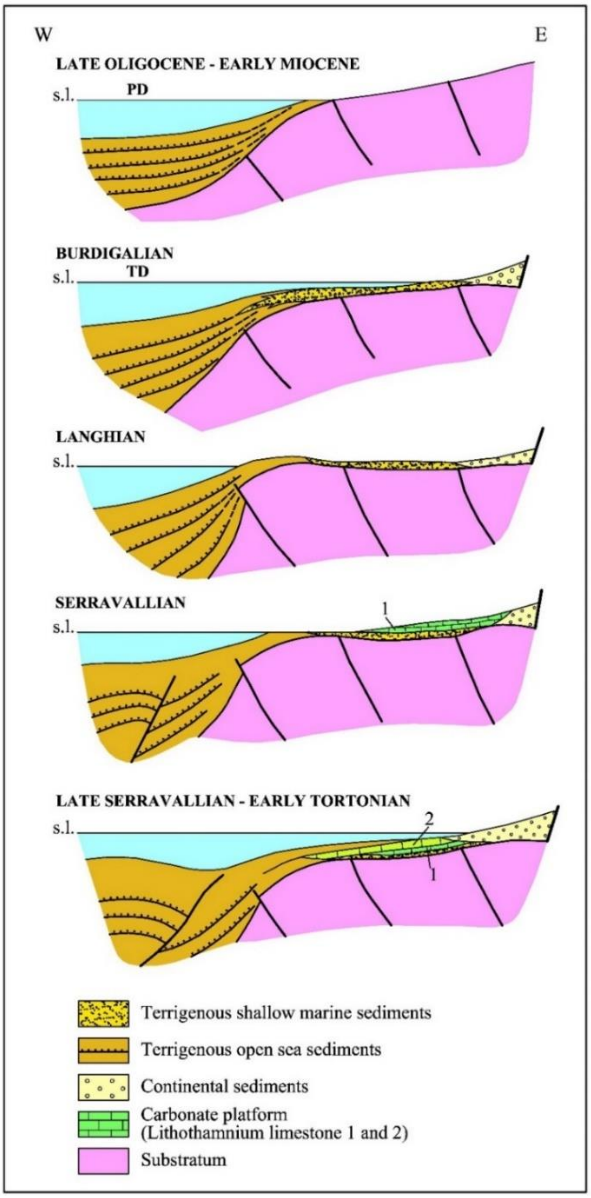


Fig. 21: Conceptual model for the late Oligocene-late Miocene evolution of the Tirana Depression (after Gelati et al., 1997).

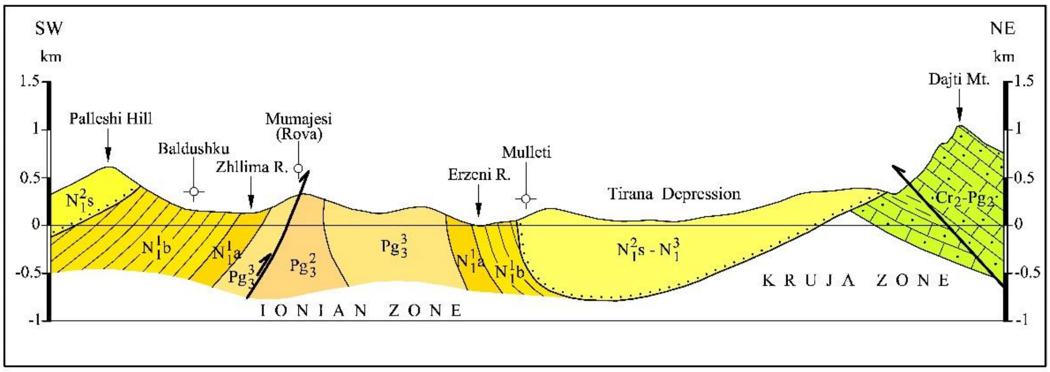


Fig. 22: Baldushku-Dajti Mt. geological section showing the northeast verging asymmetrical syncline structure of Tirana Depression that is conditioned by the Rova anticline backthrust.

6. CONCLUSIONS

Based on the recent neotectonic investigations and previously published articles concerning the dextral pull-apart formation of the Periadriatic Foredeep (onshore Albania), the development of which led to the separation of the Periadriatic and Tirana depressions with different evolution, its structure and mineral resources, the following conclusions are drawn:

1. The Periadriatic Foredeep onshore Albania is the only Foredeep basin located in the frontal part of the Albanides orogeny bordering eastward the Adriatic Foreland. The recent neotectonic investigations and former ones prove the formation of Periadriatic Foredeep as a dextral pull-apart basin in the Middle Miocene (Serravallian), consequent to the main folding and thrusting of the Ionian Zone, through the strike-slip faulting mechanism. The two elements that commonly caused the formation of the Periadriatic Foredeep Pull-apart Basin are the cross-basin strike-slip faults of Drini Bay-Lezha and Vlora-Bishqemi and the oblique normal faults of Durresi-Frakulla and Preza-Rova-Bishqemi basin (sidewall oblique normal faults). The infill consists of the Serravallian to Pliocene molasse succession up to 6 km in thickness.

2. The Periadriatic Basin was formed between the South Adriatic Basin and Tirana marginal basin, where it attains a graben shape delimited by the Durresi-Frakulla and Preza-Rova-Bishqemi normal faults.

3. The fold-and-thrust structure of the Periadriatic Foredeep is formed due to four compressional phases: the pre-Serravallian, the intra-Messinian, the Miocene-Pliocene boundary, and the early Pleistocene, the strongest one, and the one that led to the formation of two depressions with different evolution, structure and mineral resources: Tirana Depression in the east, and the Periadriatic Depression in the west, separated by Preza-Rova-Bishqemi backthrust.

4. The Periadriatic Depression filled with Miocene-Pliocene molasse succession is characterized by sharp lithofacies changes from the coarser-grained facies along its eastern margin to the finer-grained basin facies to the west with the dominance of axial infilling in the Myzeqe depocenter.

5. The Periadriatic Depression structure is formed by NNW trending narrow anticlinal and wide synclinal lines. From southwest to the northeast region, they are distinguished: Frakulla-Kryevidhi-Durresi anticlinal line, Myzeqe syncline, Lushnja-Golem Kavaja anticlinal line, Erzeni i poshtem syncline, and Preza monocline. The Mio-Pliocene anticlines are superimposed on thrusts or backthrusts, some of them have flower structures of the "palm tree" type. Some thrust and backthrust faults originated from the inversion of syn-sedimentary normal faults during the post-Pliocene regional compression, and the others originated from the Albanides-Adria collision (Durresi and Ardenica backthrusts). The Patosi, Marinza, and Kuçova oil fields in Miocene molasses as well as the Divjaka gas field in Tortonian and Pliocene deposits are well known for the Periadriatic Depression.

6. The two depocenters of the Periadriatic Depression are separated by the interbasin Thartori (Mliku) -Shkoza high: the Myzeqe depocenter between Kryevidhi anticline and Thartori (Mliku) high, and the Erzeni i poshtem depocenter in the east of Shkoza high. The depocenters migrated in the south-north direction from the Myzeqe depocenter in the south and to the Erzeni i poshtem one in the north.

7. The Tirana Depression has developed from the Tirana marginal basin eastwards bordering the Periadriatic Foredeep. It is characterized by the prevailing continental and shallow-marine Miocene sediments (with coal-bearing fields in Tortonian and Messinian deposits) that formed a wide northeast verging asymmetrical syncline that is further conditioned by the Preza-Rova-Bishqemi backthrust. The Pliocene molasse transgressively overlies the Late Miocene molasses in both Laçi and Lezha areas, while in Thumane and Mamurras areas, it transgressively overlies the Cretaceous limestones of the Kruja Zone.

8. The Tirana Depression overlies the Kruja Zone substratum to the north of Tirana and partly the Ionian Zone substratum to the south of Tirana along its western limb to the east of the Rova anticline backthrust.

9. Deformation of orogenic crust at the Albanides-Adria collision zone during Tertiary occurred and occurs into both levels: i) a basal fold-and-thrust system in the Ionian Zone that accommodated an increasing amount of SW directed shortening, and ii)

a structurally higher system of thrust faulting affecting the overlying structure of the Periadriatic Depression that underwent a strong structural rearrangement.

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