Geophysical outlook on structure of the Albanides

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Abstract: *The Albanides represent the assemblage of the geological structures in the territory of Albania. This paper presents a review of the existing seismological, reflection seismic, gravity, magnetic, electrical, and geothermal information, and relates them to the geological structure of the Albanides. Two major paleogeographic domains form the Albanides. The Internal Albanides belong to the Subpelagonian Trough. The External Albanides develop out of the Western passive margin and continental shelf of the Adriatic plate. Regional gravity anomalies are attributed to the depth variation of the Moho discontinuity, and the block structure setting of the crust. The Albanides are interrupted by a system of longitudinal fractures in NW - SE direction and transversal fractures. Intensive Bouguer anomalies and turbulent magnetic field with weak anomalies characterize the ophiolithic belt of the Internal Albanides. These data favor the allochton character of ophiolites. The Internal and the External Albanides show a nape character. A common feature of Ionian and Kruja structural belts in External Albanides is their Westward thrusting. Two tectonic styles are observed in the Ionian zone, namely duplex and imbricate tectonics. Miocene and Pliocene molasses of Peri-Adriatic Depression cover the Western part of Ionian zone.*

Key words: *Albanides, Mediterranean Folded Belt, Geophysics.*

INTRODUCTION

Integrated regional geophysical studies have been performed for exploration of the Albanides, both on land and in the Adriatic Sea Continental Shelf. Seismological studies, gravity and magnetic surveys, reflection seismics, geothermal studies, radiometric investigations, vertical electric soundings and well logging are combined in this geophysical investigation. Here, only selected geophysical data are presented.

The Albanides, together with Dinarides to the North and Hellenides to the South, form the Southern branch of the Mediterranean Alpine Belt (Fig. 1), (Aubouen and Ndojaj, 1964; Aubouen, 1973; Biçoku and Papa, 1965; Biçoku, 2000; Bushati, 1988; Frasheri et al., 1999; I.G.S., 1983, 1985; Meço and Aliaj, 2000; Melo, 1986; Papa, 1970). This paper presents the outcome of the seismological, reflection seismics, gravity, magnetic, electrical, and geothermal surveys for Albanides, in the framework of geophysical and geological observations.

Two major paleogeographic domains form the Albanides: the Internal Albanides and the External Albanides (Fig. 2).

The Internal Albanides are of Triassic and Jurassic age (Kodra, 1987) and belong to the Subpelagonian Trough. They are characterized by the presence of the immense and intensively tectonized ophiolithic belt which expands from E to W as overthrust. There are two viewpoints about the placement of the ophiolites: The allochthon character of the ophiolithic nappe (Auboin, 1973; Cadet et al., 1980; Çollaku et al., 1992; Frasheri et al., 1995, 1996; Frasheri, 2000; Hoxha and Bushati, 1996; Hoxha, 2000; Hoxha and Avxhiu, 2000; Lubonja et al., 1968; Langora et al., 1983; Melo, 1986; Papa, 1993; Qirinxhi, 1970; Veizaj and Frasheri, 1996) and autochthon ophiolitic belt (Beccaluva et al., 1994; Gjata and Kodra, 1999, 2000; Kane et al., 1999; Kodra, 1987, 1978; Kodra et al., 1996, 2000; Robertson and Shallo, 2000; Shallo et al., 1989).

The External Albanides develop off the Western passive margin and continental shelf of the Adriatic plate. They are regular structural belts associated with overthrusting.

Geophysical data indicate that the Earth crust becomes thicker from Adriatic Sea towards Albanides (Bare et al., 1996; Dalipi, 1985, 1987; Dhima et al., 1996; Guri and Guri, 1996; Mëhillka et al., 1996, 1999; Nishani, 1985; Papa and Kondo, 1968; Seitaj et al., 1996; Valbona and Misha, 1987; Velaj, 1995; Xhufi and Canaj, 1999).

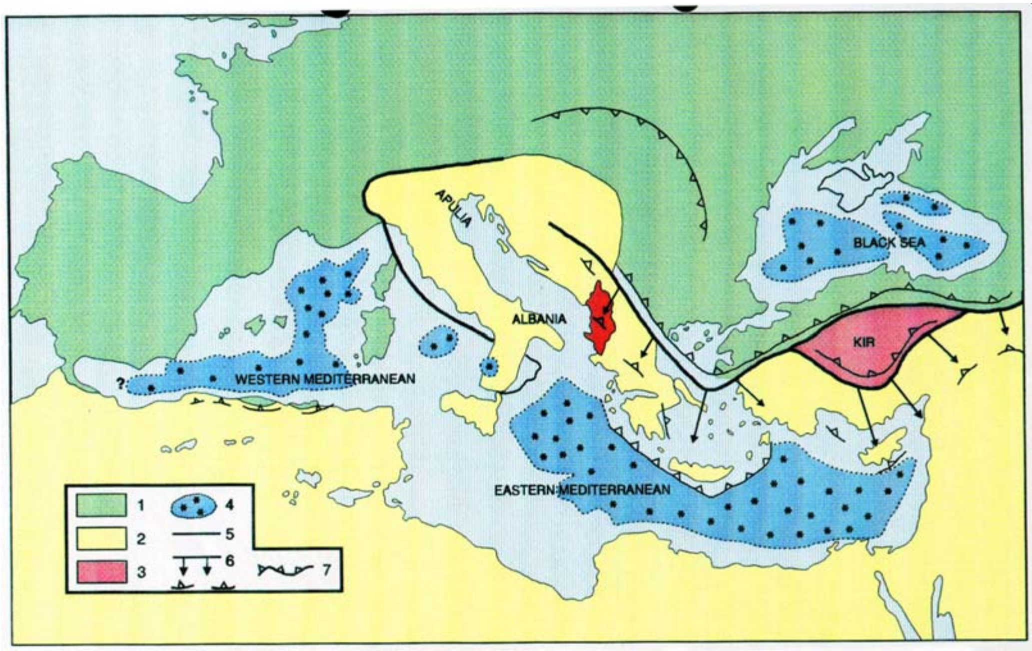


FIG. 1. Schematic Map of African Plate subduction under the Eurasia (After Ricou, 1986). Legend explanation: 1- Euro-Asiatic Continent; 2- African continent; 3- Kishir block; 4- Present Oceanic Basins; 5- Boundaries of Mesozoic Oceans; 6- Boundaries of Mesozoic Ocean and the Main Ophiolithic Nappes; 7- Troughs of present and past subduction.

The thickness of the sedimentary basin is 8-9 km near the Adriatic seashore and reaches 15 km in the Northwestern regions of Albania (Fig. 3) (Frasheri et al., 1998, 2000; Koçiu, 1987; Veizaj, 1995; Veizaj and Frasheri, 1996). The depth of the Moho discontinuity is 40 -50 km. The maximum thickness of the crust is observed at NW Albania. The regional gravity anomalies are attributed to the Moho undulations and the block structure of the crust. The latter is in accordance with the results from seismological studies (Figs. 3 and 4). Very deep faults in the NW-SE direction separate the tectonic zones. This tectonic setting of the deep crust in Albanides is also responsible for the scattering of the magnetic fields.

According to geological data, regional geophysical studies and based on structural criteria the Albanides consist of the zones shown on Table 1 (Fig. 2).

Intensive Bouguer anomalies and very turbulent magnetic field with weak anomalies (Bushati, 1988, 1997) (Figs. 5, 6 and 7), characterize the Mirdita ophiolithic belt of the Internal Albanides. According to these data, Kukes ultrabasic massif to the NE of the ophiolithic belt exhibits a maximum thickness of 14 km (Figs. 8, 10, 11 and 12). Towards West and Southeast, its thickness is reduced to 2 km. This supports the allochthon character of the ophiolithic belt and the overthrusting character of its Western contact, under which the formations of Krasta-Cukal zone, External Albanides are laid. The nape character between the Internal and the External Albanides develops in the W-SW direction. The splitting of the gravity and the magnetic anomalies in the central region of the Internal Albanides, at Shengjergji flysch corridor, is attributed to the presence of Diber -Elbasan - Vlora fault. This fault plays a significant role in the geology of Albanides (Figs. 4, 5, 6 and 7).

A common feature of the Ionian and Kruja belts in External Albanides is their Westward thrusting (Figs. 8, 10, 11 and 12). The presence of the Triassic evaporites sheet under the carbonates helped this thrusting process. According to the integrated geological-geophysical studies and deep wells, there are two tectonic styles, namely the Ionian and the duplex imbricate. Traverse faults separate the Ionian basin in several blocks. Additionally, the Southern Adriatic basin (limestone formations) is partly extended under the Sazani, Ionian and Kruja zones.

Peri-Adriatic Miocene and Pliocene deposits cover the Sazani, Ionian and partly Kruja tectonic zones. These Neogene molasses are placed transgressively over the older ones on top of the Ionian zone limestone (Fig. 20). The post-orogenic molasse deposits cover transgressively Mirdita and partially Krasta – Cukali tectonic zones in Korça and Burreli basins.

Table 1: The tectonic zones in Albania.

In Albanides	*equivalent in Hellenides*	*in Dinarides*
Internal Albanides		
Korabi	Pelagonian	Golia
Mirdita	Subpelagonian	Serbian
Gashi		Durmitor
External Albanides		
Albanian Alps	Parnas	High karst
Krasta-Cukali	Pindos	Budva
Kruja	Gavrovo	Dalmatian
Ionian	Ionian	
Sazani	Preapulian	
Peri Adriatic Depression		

EARTH CRUST

Seismological, gravity and magnetic data probed the crust (Figs. 2, 3, 4, 8 and 21) (Aliaj, 1987; Arapi, 1982; Bushati, 1988, 1997; Chiappini et al., 1996; Duka and Bushati, 1997; Frasheri et al., 1999; 2000; Koçiu, 1989; Langora et al., 1983; Lubonja et al., 1968; Lulo and Bushati, 2000; Sulstarova, 1987; Veizaj, 1995; Veizaj and Frasheri, 1996). The P-wave velocity in the deeper sedimentary crust ranges from 5.9 to 6.2-km/s, indicating more consolidated rocks (consolidated crust, Fig. 3). The regional gravity anomaly in Albanides is attributed to the Moho discontinuity undulations. The Bouguer gravity increases from Albanides to the Adriatic Sea Shelf (Figs. 5, 8 and 21). The geological-geophysical profiles Albanid-1 and Albanid-2 (Figs. 8 and 21) indicate that the depth to the Moho is minimum in the Adriatic sea region. The Moho discontinuity plunges from 25 km in the central part of the Adriatic Sea (Finetti and Morelli, 1972) to 43- 52 km at the Eastern Albanides. According to the interpretation of the regional magnetic anomalies, the top of the crystal basement plunges towards seashore and central Albania (Figs. 8 and 24).

In the Albanides there are four small Bouguer anomalies: two maximums and two minimums (Figs. 5 and 6). The first gravity maximum is observed over the Northeastern part of Mirdita and Korabi tectonic zones.

The second maximum, located at Vlora district to the Southwest of Albania, exhibits a strike which is sub-transversal to the geological structures of the Ionian tectonic zone. These regional gravity maximums indicate a crust thinning toward the Mirdita tectonic zone in Vlora district (Figs. 8 and 21). The same feature is observed in the Hellenides South of Mirdita ophiolithic belt (Cadet et al., 1980). The main gravity minimum extends from Southeast to the Northwest Albania. Another minimum is present at Alps tectonic zone.

These anomalies are attributed to the depth fluctuation of the Moho discontinuity and reveal a block setting of the crust, which is in accordance with the results of seismological studies (Fig. 2).

This tectonic setting of the deep crust in Albanides causes scattering of the magnetic fields (Fig. 7).

Geothermal energy of the Albanides is linked to deep faults. According to the geothermometer data, the water temperature reaches 220-270^{o}C at depth 12 – 13 km.

Earth crust setting of the Albanides controls the distribution of the geothermal energy. In the Heat Flow Density Map of Albania, the geothermal gradient varies from 15-21.3 mK/m in Pre-Adriatic Depression (Fig. 9) (Çermak et al., 1996; Frasheri 1993, 2000; Frasheri et al., 1995, 1996, 1999). According to the modeling results, the gradient decreases at depth greater then 20 Km (top of the crystal basement). In the ophiolithic belt (Northeast and Southeast Inner Albanides), the geothermal gradient reaches 36 mK/m. Lower gradient values are observed at depth greater than 12 Km (top of the Triassic salt deposits) (Fig. 8). On Albanid-1 and Albanid-2 profiles, the temperatures in the ophiolithic belt are higher than the ones in the sedimentary basin at the same depth.

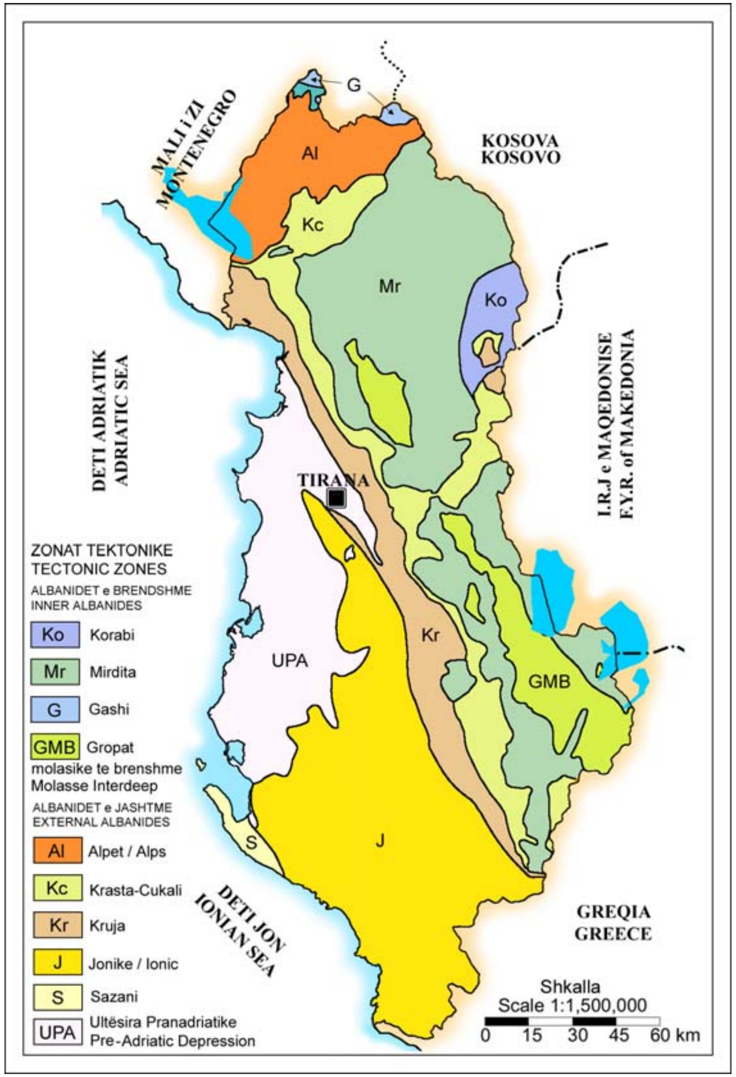


FIG. 2. Schematic Tectonic Map of Albania. (After Tectonic Map of Republic of Albania, at scale 1:200.000, 1985).

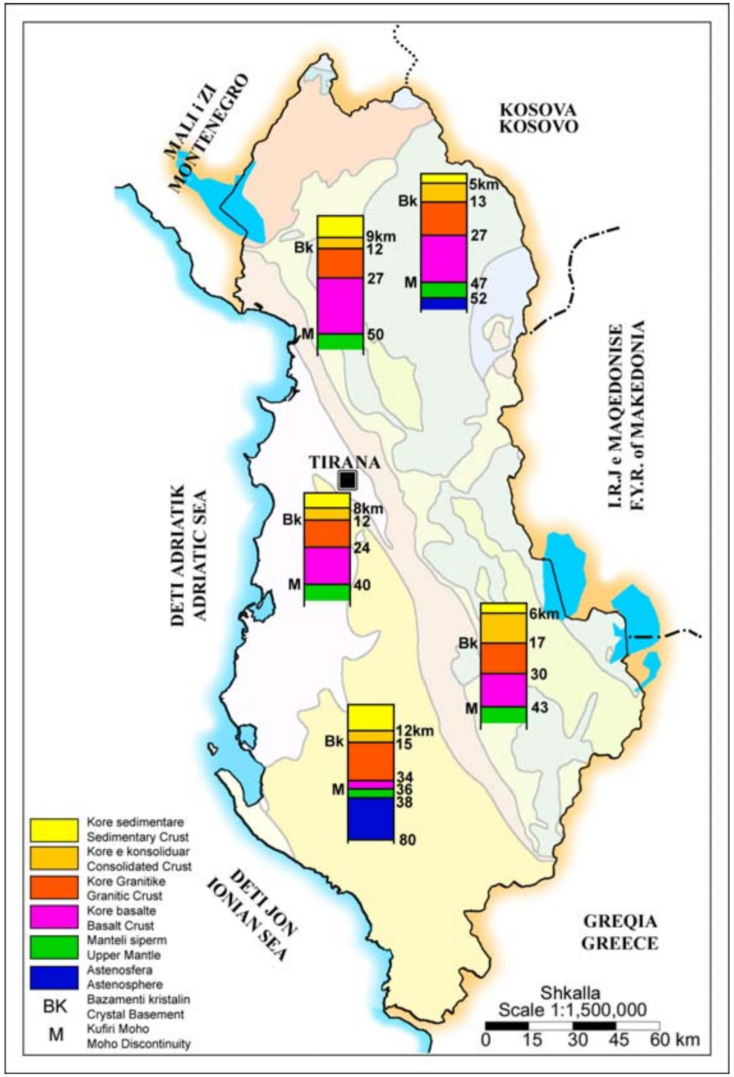


FIG. 3. Geologic structure of Earth's Crust and Upper mantle based on seismological studies (data taken from Koçiu, 1989). The numbers given in the columns express depths.

The Heat Flow Density Map (Fig. 9) reveals two characteristic features:

Firstly, the maximum value of the heat flow in the External Albanides is 42 mW/m^2. At the Eastern part of Albania, heat flow density values of 60 mW/m^2 are recorded. Since, the radiogenic heat from the ophiolites is very low, the higher heat flow in the ophiolithic belt is linked to deeper heat sources. According to the Albanid-1 profile, the granites of the crystal basement represent the potential heat source.

Secondly, in the ophiolithic belt there are hearths of higher heat flow density. Under the ophiolithic belt, the Moho depth decreases. Heat flow anomalies are controlled by deep transverse faults. These faults are associated with the geothermal fields. According to different geothermometers, the estimated aquifer temperature ranges from 144 to 270^{o}C. Based on geothermal modeling, thermal waters can rise from 8-12 km deep, where temperature reaches 220^{o}C.

These arguments favor the block character of the crystal basement. The depth of these blocks is small in Mirdita tectonic zone. Local heat hearths show the existence of transverse faults through which there is very high heat flow.

INTERNAL ALBANIDES

The tectonic zones of the Internal Albanides cover the Eastern part of Albania.

1. KORABI zone (K) is related to the Pelagonian zone in Hellenides and the Golia zone in Dinarides. In Korabi zone the Bouguer anomaly is normal (Fig. 4). The contact between Korabi and Mirdita zone coincides with the Ohrid-Qarishte-Qafe Murre-Kukes deep seismogenic structure.

This zone consists of the oldest formations of Albania, such as sandstones, schistose-conglomerate and metamorphic limestone of Silurian, Devonian and Carboniferous age, as well as sandstone-conglomerate and anhydrite of lower Permian-Cretaceous age. There are also volcanic and subvolcanic rocks of basic and acidic-alkaline content. In the Korabi zone, folds, thrust faults and cover rocks are present.

2. MIRDITA zone is related to the Subpelagonian zone in Hellenides and the Serbian zone in Dinarides. This wide belt extends from NW to SE., Three tectonic units were formed in Mirdita zone during different orogenic phases. The lower tectonic unit consists of ophiolites. Intensive Bouguer anomalies and turbulent magnetic field with weak anomalies characterize the ophiolithic belt of the Internal Albanides (Figs. 5, 6, 7, 8, 10, 11, 12 and 13).

There are three features in this anomalous belt:

- Firstly, this zone is divided in two parts, North and South of Shengjergji flysch corridor.
- Secondly, there are five gravity maximums (up to 105 mgal), along the anomalous chain from Tropoja-Kukesi ultrabasic massif in the North-East Albania to the Morava massif at South-East. In its Northern part, the anomalous belt takes a 60^o to 70^o turn to the North-East reaching the Dinarides ophiolithic belt.
- Thirdly, higher gravity anomalies are present in the Eastern belt over the ultrabasic massif. To the South, the ophiolithic belt exhibits limited thickness and it keeps developing Southwards in the Hellenides.

The Falko-Tirana-Bulqiza profile traverses all the tectonic zones of the Albanides (Figs. 8 and 13). Along this profile the maximum thickness of the Bulqiza ultrabasic massif is about 6 km. Two VES indicate that the Eastern part of this massif is dipping to the West. The abundance of high resistivity zones in these soundings indicates that the ultramaphic rocks are located at depths greater than 2500 m (Fig. 13).

The splitting of the gravity and the magnetic anomalies in the Shengjergji flysch corridor is caused by the presence of Diber -Elbasan - Vlora transverse fault, which has played a significant role in the geology of the Albanides. In Shengjergji flysch corridor, the absence of magnetic anomalies indicates that there are no ultrabasic rocks to the East of massif margins and under the flysch deposits (Fig. 14). The Bouguer anomaly in this region is due to the presence of a limestone anticline covered by the flysch. From vertical electrical soundings revealed the thickness of flysch deposits ranges from 2000 to 2500 m.

The thickness of the ophiolithic belt becomes 14 km in its Northeastern extreme (Kukes ultramaphic belt). Towards West and Southeast its thickness reduces to 2 km (Fig. 10). The Northwestern sector of the ophiolithic belt extends to the East of Shkodra (Figs. 10, 11 and 12). The intensity of gravity and magnetic anomalies increases from seashore towards the East. The gravity anomaly over the Gomsiqe ultrabasic massif is 12 mgal. It is four times smaller than the anomalies in the Eastern belt of ultramaphic massif. This indicates that the ophiolithic belt is thinner to the West.

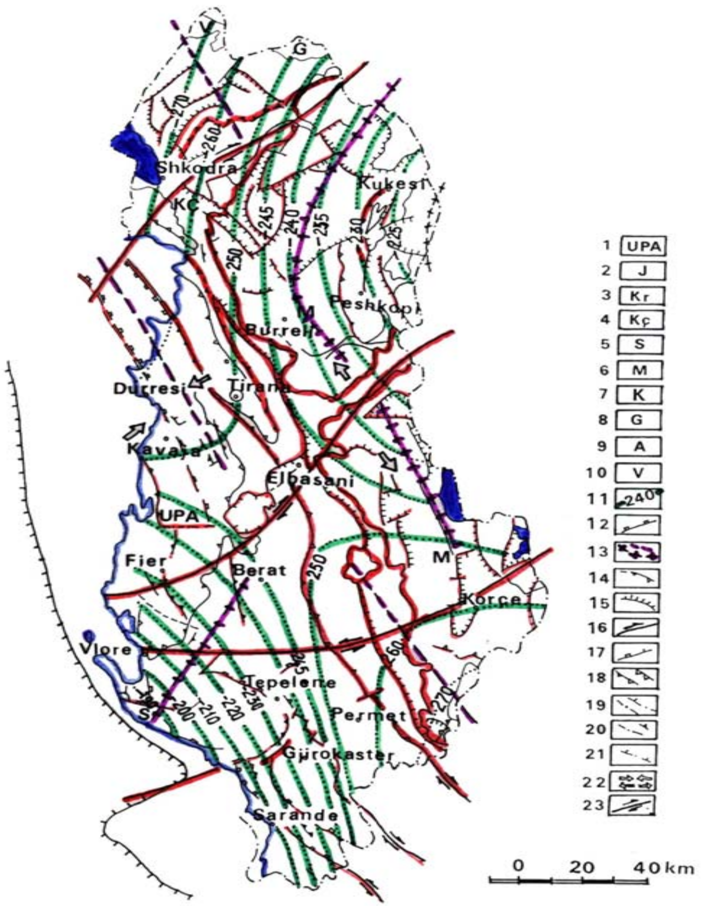


FIG. 5. The Complex Tectonic Map and Bouguer Anomaly map in the Albanides (3rd degree trend).

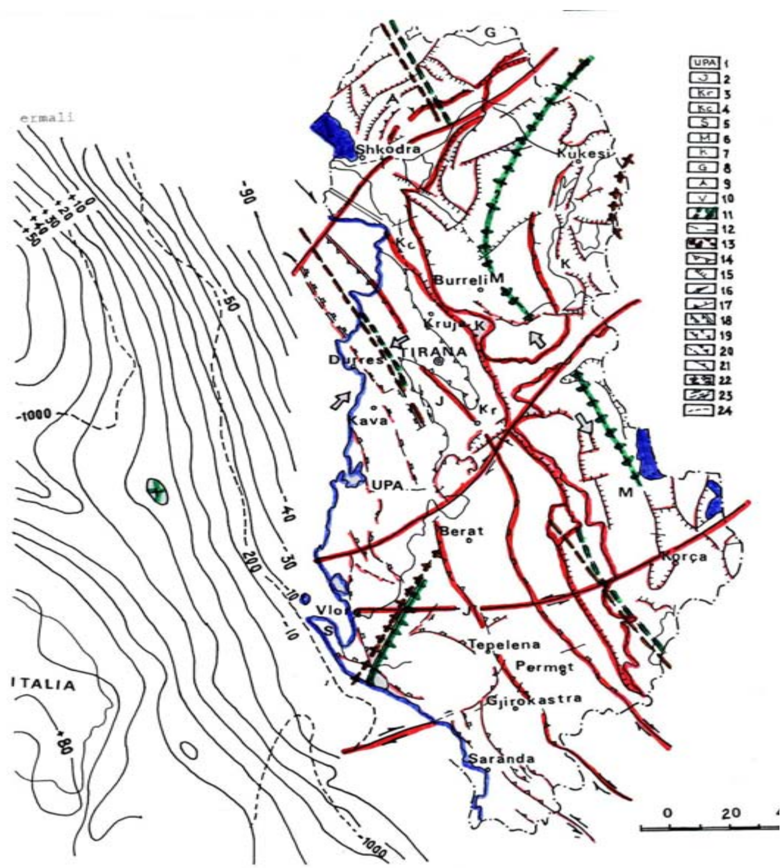


FIG. 6. The Complex Tectonic Map and axes of the Bouguer anomaly in the Albanides and in theAdriatic Sea continental plate.

Explanation of the legend for Figs. 5 and 6

1-Peri-Adriatic Depression; 2- Ionian zone; 3- Kruja zone; 4- Krasta-Cukali zone; 5- Sazani zone; 6- Mirdita zone; 7- Korabi zone; 8- Gashi zone; 9- Albanian Alps zone; 10- Vermoshi zone; 11- The axes of the Bouguer Residual Anomalies, positive (a) and negative (b); 12- Isoanomals of the Bouguer Anomaly in the Adriatic and Ionian Sea (after Morelli C et al. 1969); 13- The axes of the up-left and down-left of the Mante; 14- Boundary of the Peri-Adriatic Depression with angular discordance; 15- Normal fault; 16- Pressure; 17- Limit of deformed envelopment during the neotectonic period; 18- Overthrust; 19- Flexure; 20- Flexure and faults based on geophysical data; 21- Inactive overthrust; 22- Compression (a) and (b) extension zones; 23- Seismogenic deep uplift; 24- Isobaths of the water depth, in meters.

The magnetic anomaly present in the profile, shows that here the ophiolites contact dips to the East with an angle about 45°. This interpretation supports the argument that Mirdita zone covers the formations of Krasta-Cukal zone at the Western contact of the Mirdita ophiolithic belt. The seismological studies do not support the presence of any deep fracture.

VES carried out in Burreli indicate that the thickness of the neogene molasses is approximately 1500 m in the Northern part of the basin (Fig. 15). A high resistivity layer under the neogene formations is attributed to the ophiolites. The thickness of the 100 Ohmm resistivity layer under the ophiolites is 500 m. This layer corresponds to Triassic limestone. The seismic profile through this basin shows that the layer under neogene deposits without internal reflections, is attributed to the ophiolithic formation. Under this layer, the section exhibits many horizontal seismic reflections, which implies the presence of stratified formations (Fig. 16). At greater depths seismological data indicate a P-wave velocity reversal in Mirdita zone (Fig. 17).

These observations indicate that the ophiolithic belt of the Albanides is genetically unique and tectonically split into two sub-belts. Geophysical data give the arguments for the overthrust character of ophiolithic belt.

3. GASHI zone (G). Beyond its border it continues into the Durmitori zone of the Dinarides. This zone includes metamorphic rocks, terrigeneous rocks, limestone, metamorphic volcanites, basic intermediate and acidic rocks.

EXTERNAL ALBANIDES

The tectonic zones of the External Albanides are present in Western Albania.

1. ALPS zone (A) is related to the Parnas zone of the Hellenides and the High Karst one of the Dinarides. In this zone the oldest rocks are the Permian sandstones and the conglomerates. In general, Alps consist of limestone monoclines, combined with smaller anticlines. A regional gravity minimum is observed in the Alps zone. Local gravity maximums are present over the carbonate structures (Fig. 18).

2.KRASTA-CUKALI zone (K-C) is related to the Pindos zone of the Hellenides and the Budva zone of the Dinarides. Krasta subzone is a narrow belt from Shkodra city, Northwest Albania to Leskovik city Southeast Albania. This zone is located between the Internal and External Albanides. The profile in Figure 18 crosses the Northwestern margin of ophiolithic belt, the Cukali zone and reaches to the Albanian Alps. The Shkoder–Peje transverse fault interrupts this profile. Residual Bouguer anomaly increases to the Southeast along this profile. This increase is attributed to:

Firstly, the increased thickness of the Triassic to Cretaceous limestone formations in Cukali and Mirdita zones towards their contact with Alps.

Secondly, the existence of ophiolites covered by Cukali formations.

Thirdly, the presence of higher density Paleozoic formations.

3. KRUJA zone (K) continues to the North as Dalmate zone of the Dinarides and to the South as Gavrovo zone of the Hellenides. The reflector at 2.3-2.5 s, partially parallel to the shallower ones, is attributed to the top of the limestone (Fig. 19). The reflector 1-1 is attributed to the top of J-C salts which are placed on top of the flysch. The seismic section shows a deep regional overthrust feature. In this case, the 2-2 reflection originates from the top of the flysch. Thus, carbonate structures underneath the flysch show perspectives for oil and gas.

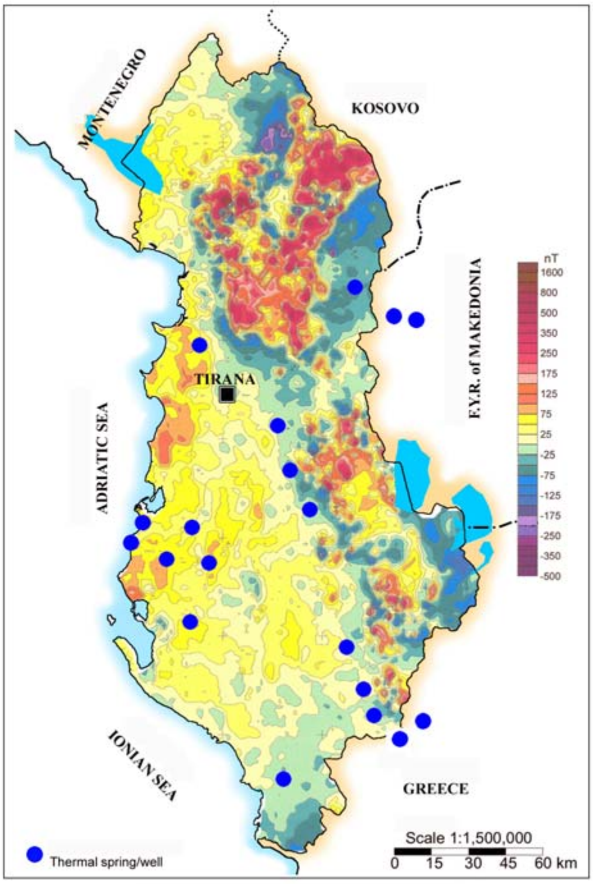


FIG. 7. Total Magnetic Field map of Albania (After Bushati, 1987).

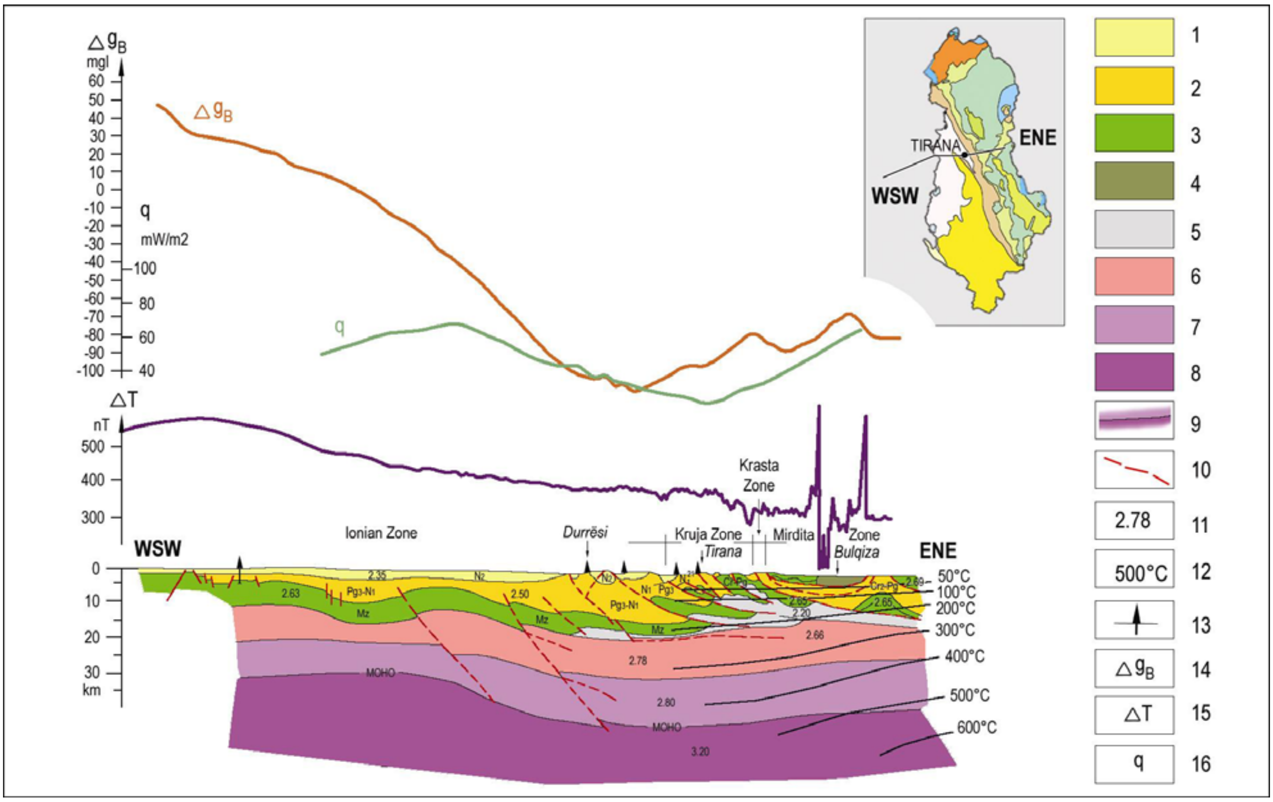


Fig. 8. Geological-geophysical profile Albanid-2: Falco Adriatic Sea- Durres-Tirana- Peshkopi (The gravity data for the Adriatic Sea after Richetti, 1980).

Legend: 1. Pliocene Substratum; 2- Substratum of Serravalian Molasses-Paleogenic flysch (Pg_3) over the limestone; 3- Lower - Middle Paleogene (Pg_{1-2}) - Triassic carbonatic facies; 4- Ultrabasic rocks; 5- Permian evaporites; 6- Crystal basement; 7. The basalt Earth Crust 8. Mantle; 9- Moho Discontinuity; 10. Uplift; 11- Density value of the rocks, in g/cm^3; 12- Temperature, in ^{o}C; 13. Deep wells; 14. Δg_B- Bouguer Gravity Anomaly; 15. Total Magnetic Field Anomaly; 16. Q- Heat Flow Density.

4. IONIAN zone (Io) in the Southwest Albania continues in Greece. It is the largest zone of External Albanides which has been developed as a deep pelagic trough since upper Triassic (Figs. 20.a, b and c). The Permian- Triassic evaporites are the oldest rocks of this zone. This formation is covered by thick deposits of upper Triassic- lower Jurassic dolomitic limestone and Jurassic-Cretaceous-Paleogene pelagic cherty limestone. Limestones are covered by Paleogene flysch, Aquitanian flyschoidal formations and a thin layer of Burdigalian-Helvetian and partially of Serravalian- Tortonian formations, which mainly fill the synclinal belts. Burdigalian deposits are placed in angle discordance over anticline belts. This indicates a two-stage structure.

Liassing rifting affected External Albanides including Ionian zone. In the latter, three tectonic blocks were formed which correspond to the following structural belts:

a. Berati anticline belt, in the eastern margin of the zone.

b. Kurveleshi anticline belt, in the central part, according to evidence from reflection seismics which image the carbonates.

c. Çika anticline belt, which represents the Western edge of the Ionian zone.

By combining the geological-geophysical data many anticlines were delineated in the carbonate deposits within these tectonic belts. Longitudinal faults affect the Western flanks of these structures.

The Berati anticline belt

The seismic acquisition on this belt was performed by different techniques. The time sections are very complicated. Occasionally, some reflections from the top of the limestones are recorded in certain lines, especially in the centre and to the West, probably because limestones in this zone are deep and faulted. According to the seismic data, limestones in the centre are markedly broken.

This conclusion is well supported by deep wells, drilled in Sqepur- Bistrovica area.

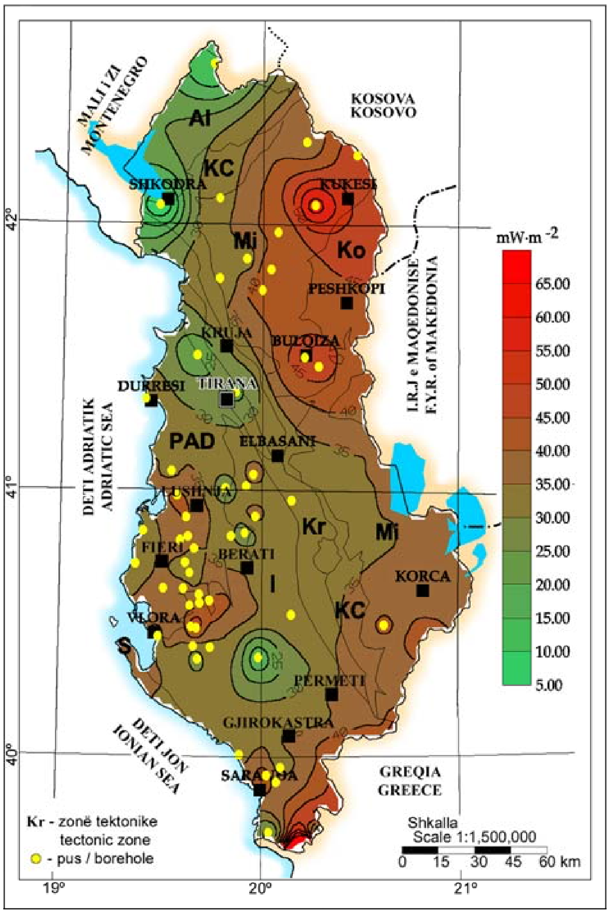


Fig. 9. Heat Flow Density Map of Albania (After Frashëri et al., 1995).

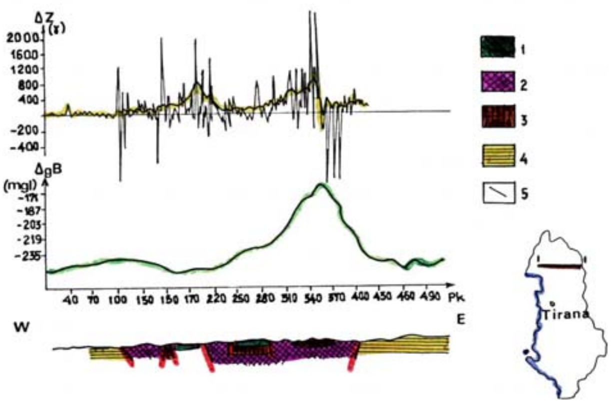


Fig. 10. Geological-geophysical Shkodër-Kukës profile.

Legend: 1-Effusive rocks; 2- Ultrabasic rocks; 3-Gabbro; 4- Sedimentary formation; 5- Disjunctive tectonic.

Kurveleshi anticline belt

Here, we refer mainly to carbonate formations. The Kurveleshi belt consists of structures associated with developed tectonics and thrusting (5-10 km horizontal displacement) to the West, as well as diapirism to the east. The regional seismic section II-II, which crosses the Ionian zone, from West to east, clearly depicts perspective oil and gas-bearing structures.

Çika anticline belt

Çika anticline belt is constructed mainly by prolonged structures associated with evaporates outcropping in Xara, Fterra, Çika etc. Seismic surveys in this belt date back to the start of oil exploration in Albania and still continue today. Earlier one fold coverage acquisition techniques have been replaced in the last years by multiple fold coverage ones. Two main tectonic styles characterize the Ionian zone: Duplex tectonic and imbricate tectonic styles. The back thrust faults have been caused by retrotectonic phenomena. The geodynamics of the Ionian zone is related to the evolution of the transversal faults. These faults divided the Ionian basin in several blocks, since lower and middle Jurassic rifting. The periodical tectonic movement of the transverse faults has played an important role to this overthrusting phenomenon.

The regional seismic sections clearly show that during the structuring process of the Ionian zone, (upper Oligocene to Langhian), the Sazani zone as well as the underlying of Southern Adriatic basin limestone were formed (Figs. 22 and 23).

5. SAZANI zone is the continuation of the Apulian platform. It consists of a thick Cretaceous-Eocene limestone and dolomite formation. Marly deposits of Burdigalian age are placed transgressively over carbonate formations (Fig. 22).

The interpretation of the recent geological, seismic and gravity data provides a new structural model. The External Albanides are in compression tectonic regime since upper Jurassic-Cretaceous periods. Only to the West, the Apulian zone and the South Adriatic basin exhibit continuous extension. South-Eastern External Albanides are characterized by a great Southwestward overthrust of the anticline chains and transverse faults.

Evaporites represent the lubrication substratum during this overthrusting movement. Regional back thrusting is also observed in the Ionian and Sazani zones. These structural-tectonic models indicate the interference of South-Westward over thrusting with secondary and more recent North-Westwards overthrusting.

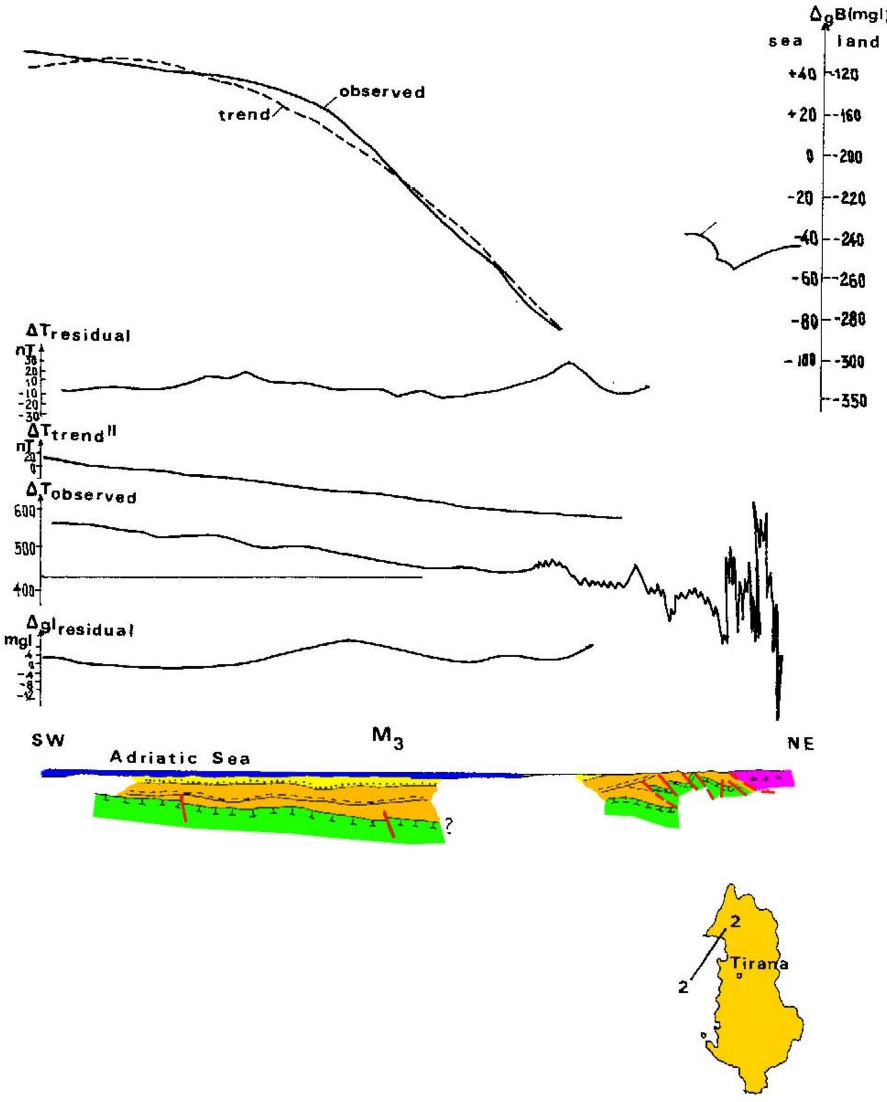


Fig. 11. Geological- geophysical profile: Adriatic Sea- Vrith.

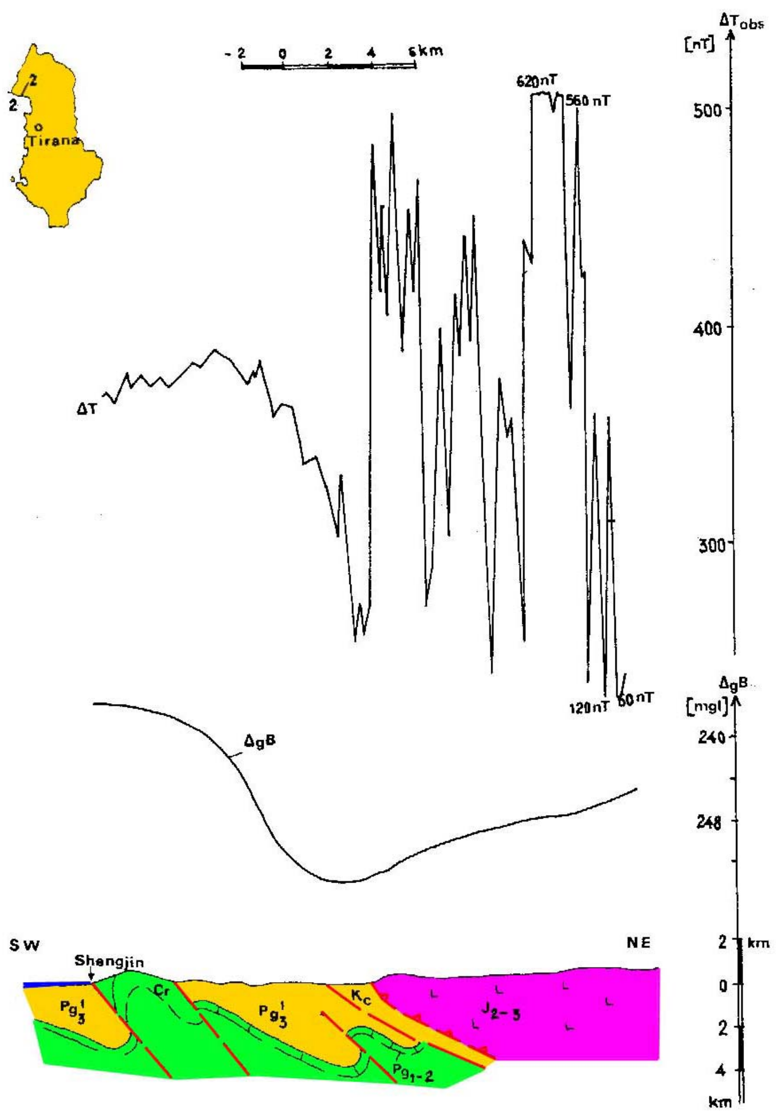


Fig. 12. Geological-geophysical profile: Shëngjin- Vrith.

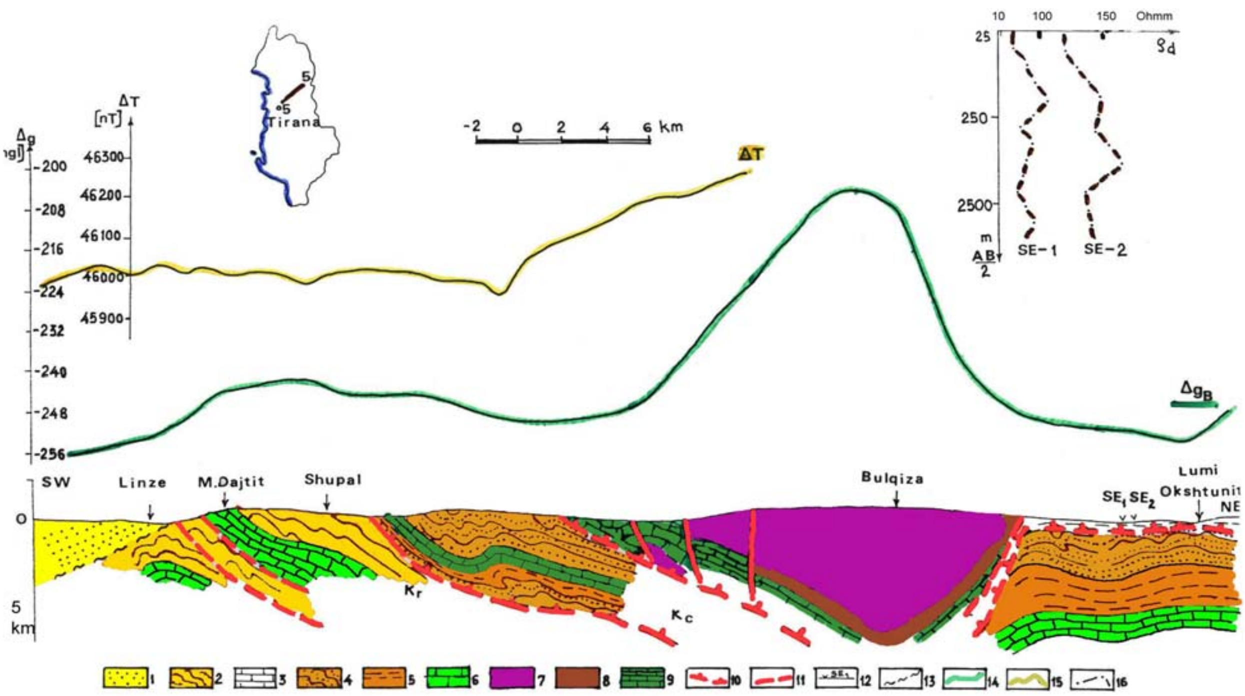


Fig. 13. Geological-geophysical profile: Tirana- Bulqizë- Shupenzë.

Legend: 1-Terrigeneous Tortonian formations; 2- Paleogene flysch formations; 3- Upper Cretaceous-Paleogene Limestone; 4- Titonian- lower Cretaceous flysch formations; 5- Upper Triassic- lower Triassic limestone; 6- Radiolaritic limestone with silic radiolarities; 7- Ultrabasic rocks; 8- Effusive rocks; 9- Limestone with siliceous of middle Triassic- lower Jurassic; 10- Overthrust plane; 11- Uplift tectonic; 12- Electrical sounding centers; 13- Unconformity; 14- Bouguer anomaly; 15- Magnetic anomaly; 16- Electrical sounding resistivity curve.

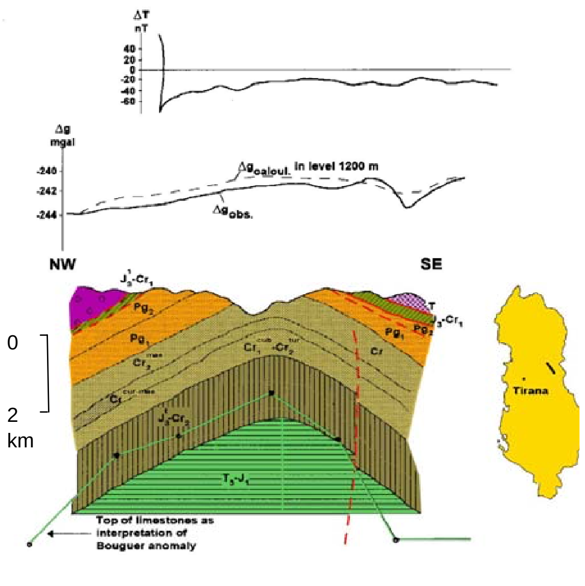
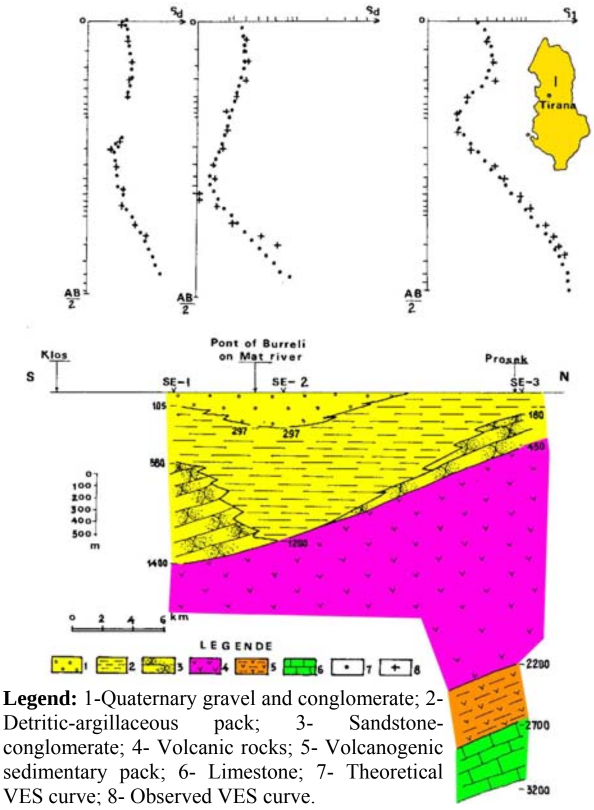


Fig. 14. Geological-geophysical profile through Peleogene and Cretaceous flysch exposures (Okshtun window).

Abbreviations: T- Triassic; J- Jurassic, Cr- Cretaceous, Pg- Paleogene.



Legend: 1-Quaternary gravel and conglomerate; 2- Detritic-argillaceous pack; 3- Sandstone-conglomerate; 4- Volcanic rocks; 5- Volcanogenic sedimentary pack; 6- Limestone; 7- Theoretical VES curve; 8- Observed VES curve.

Fig. 15. Geoelectrical profile: Klos-Prosek over the Burreli Neogenes.

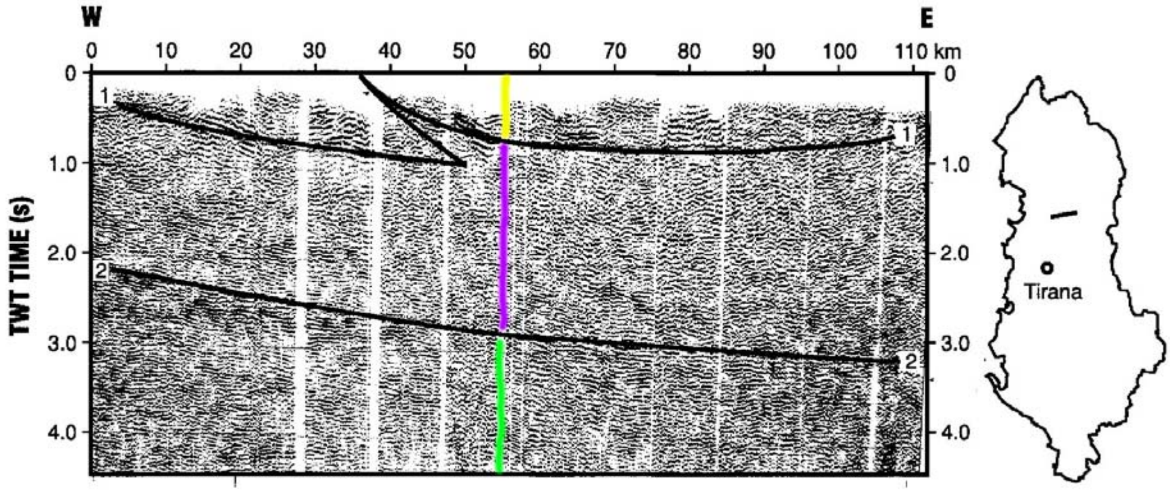


Fig. 16. Seismic reflection line in the Burreli Neogenes.

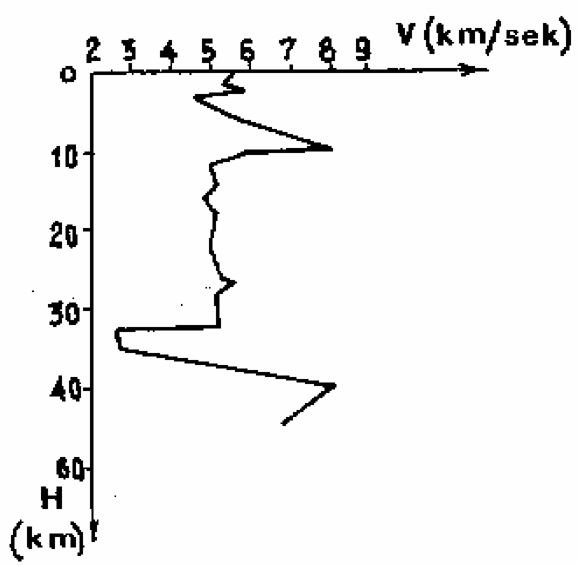


Fig. 17. Seismic P wave velocity reversal deduced from seismological data (Koçiu, 1989).

6. PERI-ADRIATIC DEPRESSION

Overlying Peri-Adriatic Depression covers the Ionian, Sazani and partly Kruja tectonic zones. This is a depression filled with middle Miocene and Pliocene molasses, which are mainly covered by Quaternary deposits (Figs. 8, 20, 21 and 24). Tortonian- Messinian- Pliocene molasses consist of a considerable number of sandy-clay mega-sequences. From SE to NW, the thickness of the molasses increases, reaching 5000 m. Sandstone-clay deposits of Serravalian and Tortonian age are placed transgressively over the oldest ones, including limestone formations and they create a two-stage structure (Figs. 20 and 24).

In the Ionian, Kruja and Sazani zones, the thrusting and back thrusting degree of the structures and structural chains increased during the molasses cycle. This phenomenon often led to the formation of tectonic blocks within the carbonate section, and to the partial or complete development of the anticline structures.

The Albanian sedimentary basin extends even in the Adriatic shelf where local Bouguer and magnetic anomalies are observed (Figs. 8 and 14) (Richetti, 1980). These local gravity maximums coincide with magnetic field minimums. Some researches have reached to the conclusion that the Apulian platform is tectonically quiet.

PALEOMAGNETIC REVIEW ON DYNAMIC EVOLUTION OF ALBANIDES

The dynamic evolution of the Albanides is recorded in the paleomagnetic data, collected from the paleomagnetic studies in Albania (Frasheri and Bushati 1995, Frasheri et al., 1995; Kane et al., 1999; Kissel et al., 1992, 1994, 1995; Mauritsch et al., 1991, 1994; Mauritsch, 2000).

Paleomagnetic studies show that the Ionian and Kruja zones encountered a joint 45^o-50^o clockwise rotation, during and after Eocene-Oligocene periods. This is the outcome of two distinct 25^o rotations in the middle Miocene up to Plio-Pleistocene. Ionian and Kruja zones as well as the zones the central and Northern Albania divided by Vlora- Elbasan- Diber encountered similar rotations. Thus, the evolution of the External Albanides from upper Eocene up to present is probably continuous (Fig. 25).

The upper Miocene formations in the Peri-Adriatic Depression indicate that the External Albanides encountered a 10-15^o clockwise rotation between Oligocene and upper Miocene. Also, Pliocene clays at the Central Albania indicate a 10^o rotation of the External Albanides during the upper Miocene and lower-middle Pliocene. Additionally, a clockwise rotation of the External and Internal Albanides has been evidenced. This rotation is younger than Tortonian, compared to the general apparent polar displacement path from the Africa and Eurasia (Figs. 26 and 27). Renz and Kakariq Eocene limestone anticlines in the Shkoder-Peje transverse zone, exhibit a 31^o rotation. Consequently, the declination of these two anticlines is smaller than the declination of the Eocene limestone in the Central Albania (18^o). These two anticlines undertook two distinct rotations. One rotation is clockwise (50^o) which is typical for External Albanides. The second rotation is counterclockwise (25^o).

Limestone samples from Albanian Alps at Selca area, North of the Shkoder-Peje transverse, indicate a 20^o counterclockwise rotation which is the case for South Dinarides.

Similar counterclockwise rotation is also recorded on Jurassic limestone present at the South shore of Shkodra lake. This indicates that both formations belong to the same tectonic zone. Shkoder-Peje transverse area has great tectonic influence over Cukali subzone, where rotation changes from counterclockwise to clockwise be observed in very short distances. In the North-Western edge of the Mirdita zone, at the Komani ophiolithic belt, declinations show the clockwise rotation of the effusive and sedimentary rocks.

Thus, Shkoder-Peje lineament defines a transition zone which separates the Albanian Alps and the Dinarides (counterclockwise rotation), from Albanides and Hellenides (clockwise rotation).

Magneto-biostratigraphic studies performed at Kçira area in Mirdita zone, show alternation of normal and inverse magnetization in the Spathian-Anisian section. Kçira Pole presents affinity with Western Gondwana after restoration for the Neogenes (Muttoni et al., 1996).

Samples from the ophiolithic belt in Internal Albanides (Qafëzezi South of Korça district through Kalimashi area in Kukësi ultrabasic massif NE Albania) exhibit the same declination as the ones from the Hellenides ophiolithic belt.

CONCLUSIONS

1. Albanides, the assemblage of geologic structures, which extend in the Albanian territory, between the Dinarides and the Hellenides consist of two major Internal Albanides and the External Albanides.

2. Earth Crust of the Albanides exhibits a block structure controlled by a system of NW-SE longitudinal faults as well as transverse ones. Some of these faults separate even the tectonic zones and are linked to the geothermal fields of the Albanides.

3. The Mirdita ophiolithic complex causes a gravity anomaly chain and a turbulent magnetic field of relatively low intensity. This geophysical evidence supports the allochthon character of ophiolithic belt. According to the gravity data the thickness of the ophiolithic belt varies from 6 to 14 km to the East (ultrabasic massifs), while it is less than 2 km to the West.

4. The tectonic zones of the External Albanides are in compression tectonic regime since the upper Jurassic-Cretaceous. The Western part of external Albanides, the Apulian zone and the South Adriatic basin are in continuous extension.

5. The geophysical data show that the orogene front of the Albanides is in the Adriatic Sea. The Ionian and Sazani zones in the Adriatic Sea Shelf extend over the Apulian platform.

6. The Internal and the External Albanides have a Southwestward nappe character.

7. Paleomagnetic studies have demonstrated that assemblage of the Albanides margin encountered a clockwise rotation of about 45^o, after upper Oligocene. This rotation happened in two phases. This is also the case for the Western margin of the Hellenides. Shkoder-Peje transverse fault represents a transition zone between the clockwise rotation of the Albanides and Hellenides and the counterclockwise one of the Dinarides. For the rotation pole located at Shkoder-Peje transverse fault in Southern Albania, the horizontal displacement is about 173 Km.

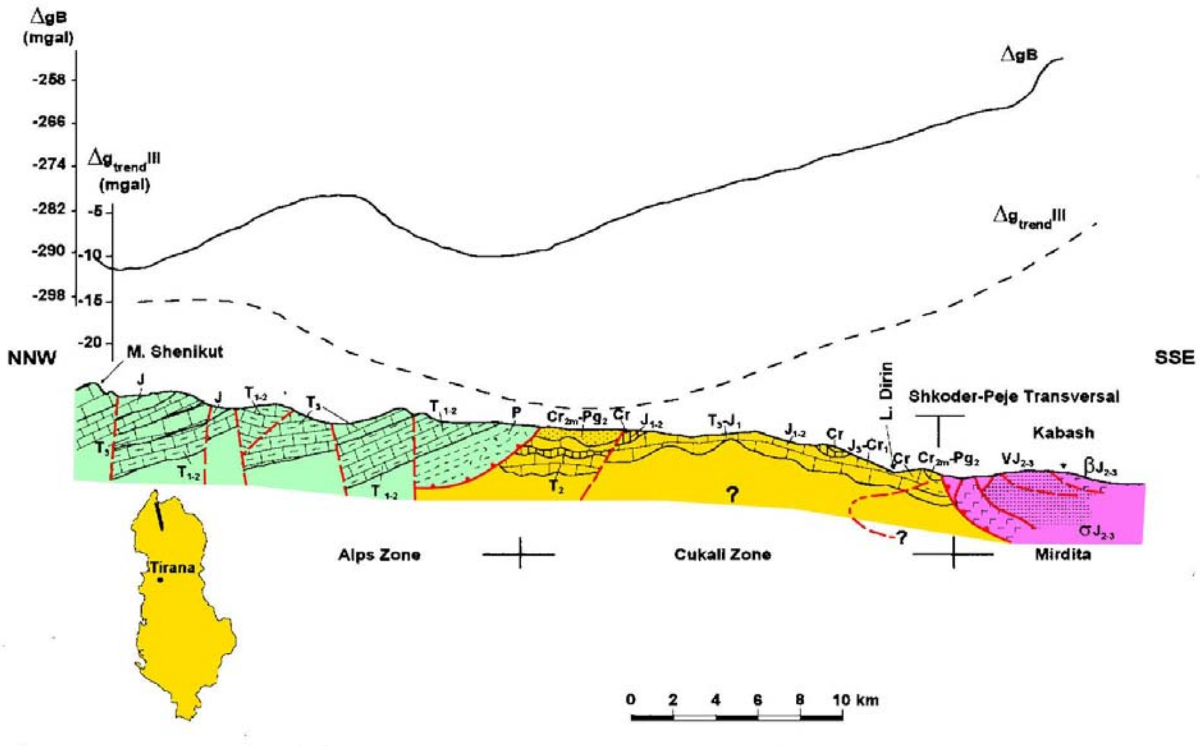


Fig. 18. Geological-geophysical profile: Alps-Cukali-Mirdita zones, over the Shkodër- Pejë Transverse.
Legend: as in Fig. 14.

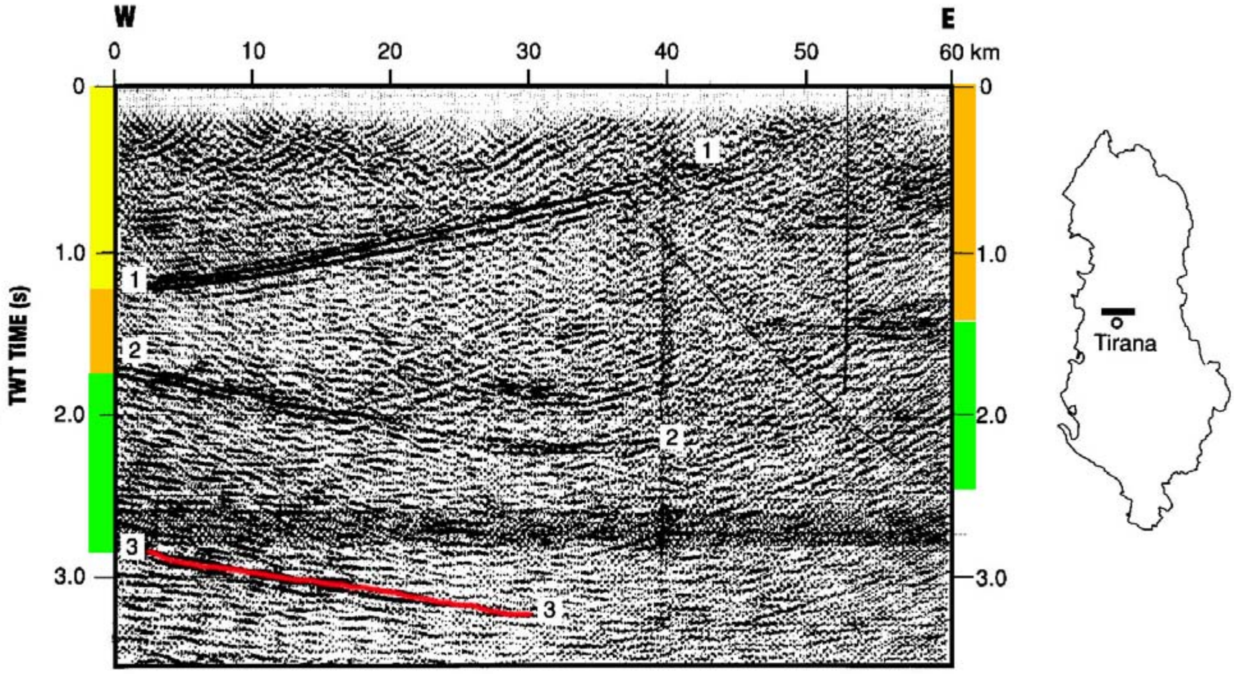


Fig. 19. Reflection seismic line in the Tirana Neogene Depression.

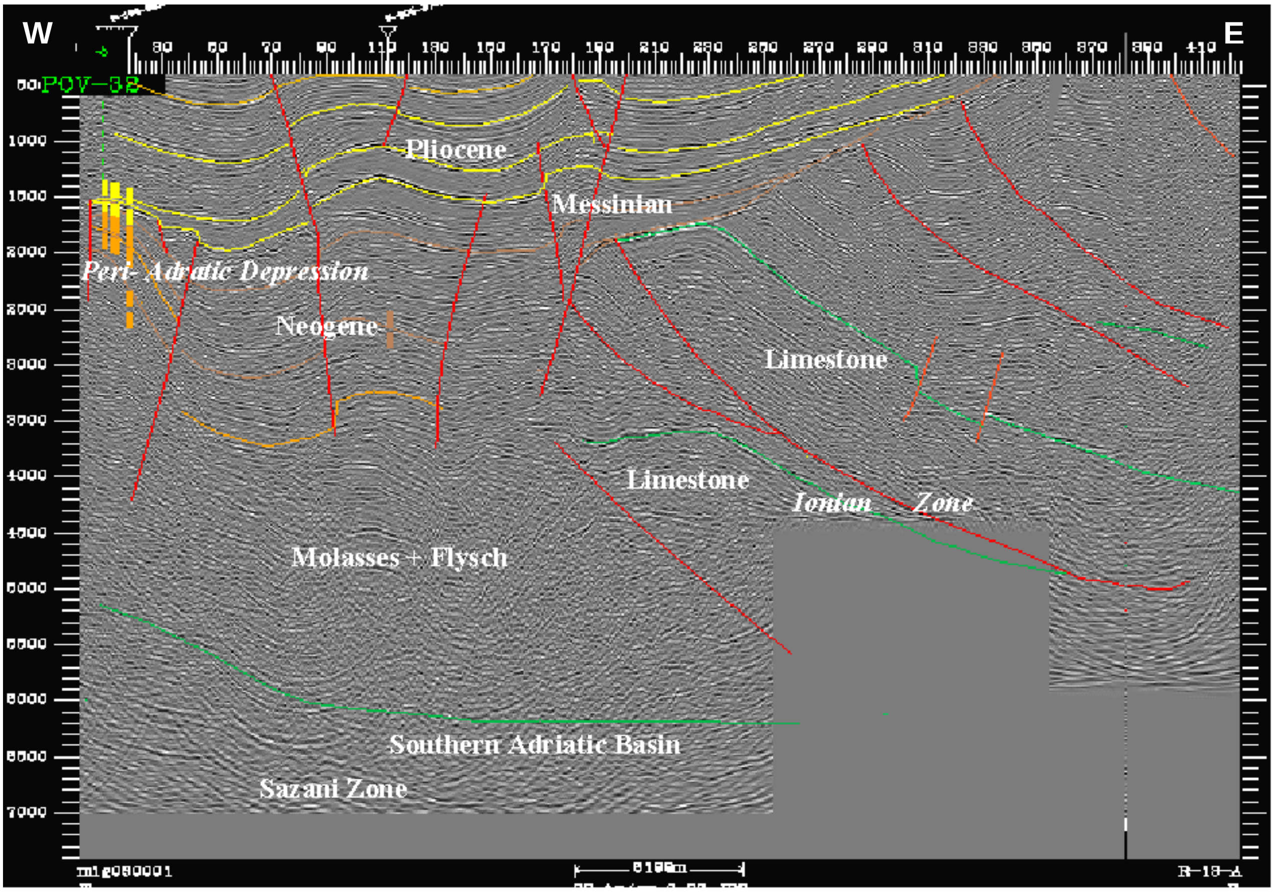


Fig. 20. Regional seismic reflection line in Ionian and Peri-Adriatic Depression. The vertical axis denotes two way travel time in ms (maximum time 7500 ms). The length of the line is approximately 35000 m.

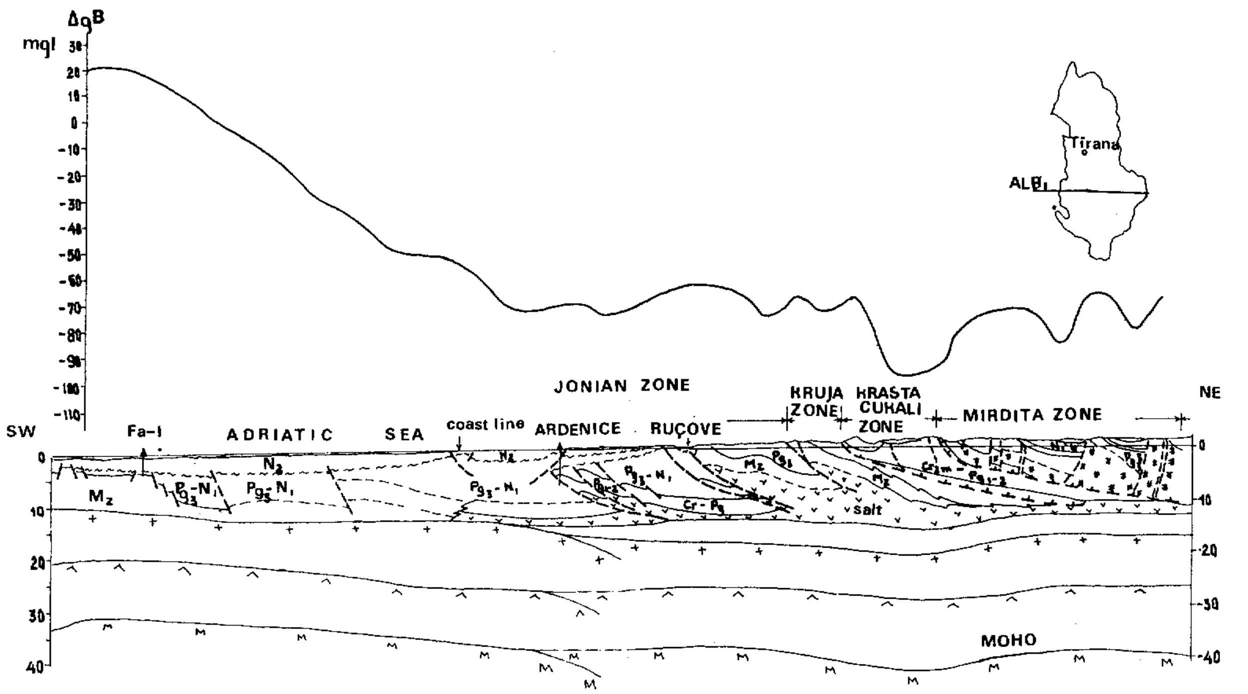


Fig. 21. Geological-geophysical profile Albanid-1: Falco Adriatic Sea- Seman-Kuçovë- Bilisht (The gravity data for the Adriatic Sea after Richetti, 1980).

Legend: as in the Fig. 14.

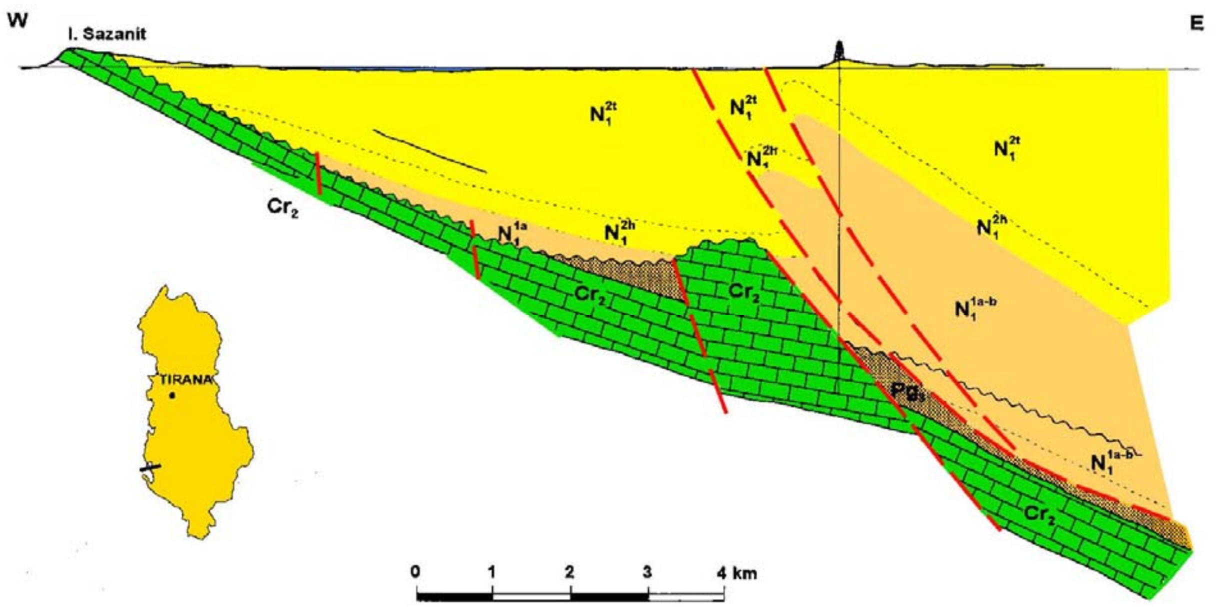


Fig. 22. Geological profile of Sazani-Zvërnec in Vlora district. Legend as in Fig. 14.

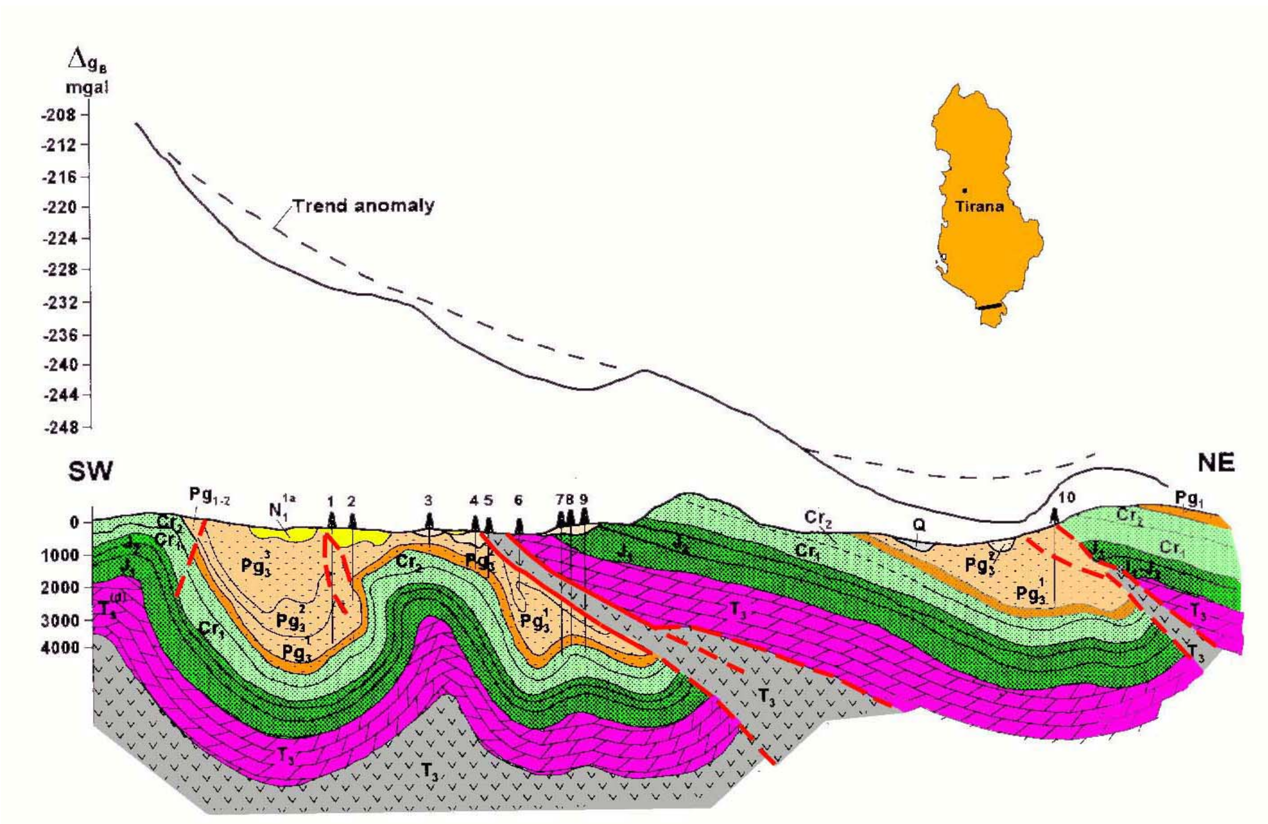


Fig. 23. Geological-geophysical profile: Saranda-Gjirokastra region.

Legend: as in Fig. 14.

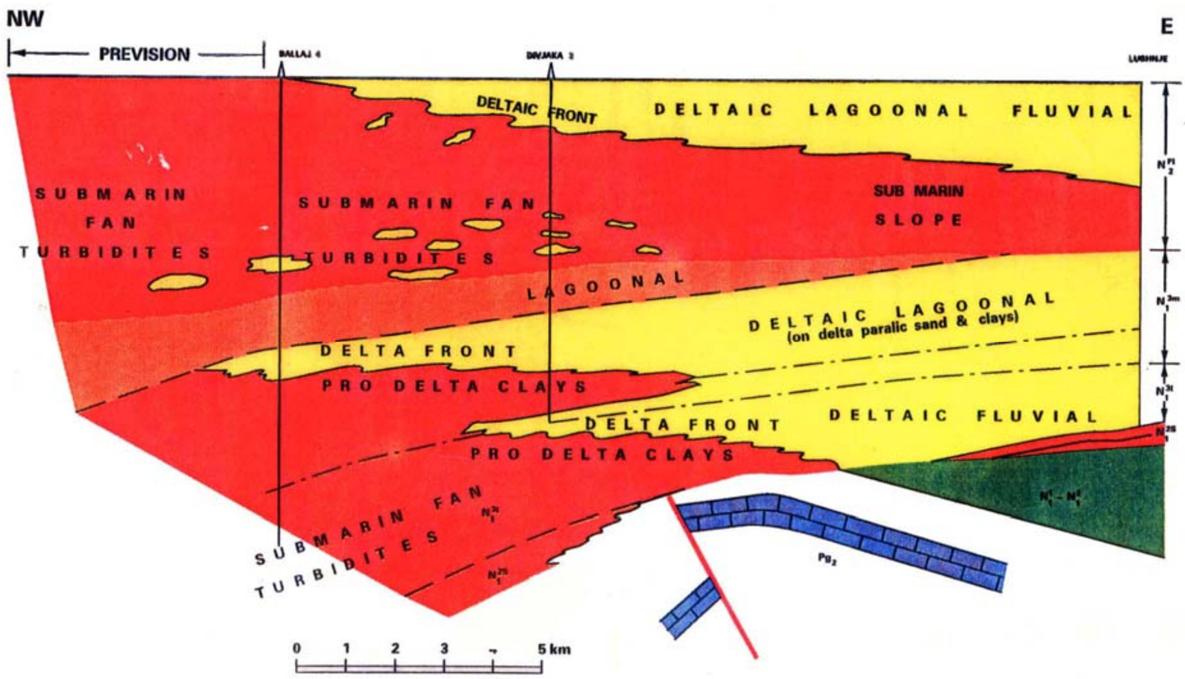


Fig. 24. Geological profile: Divjaka brachi anticline in Peri-Adriatic Depression.

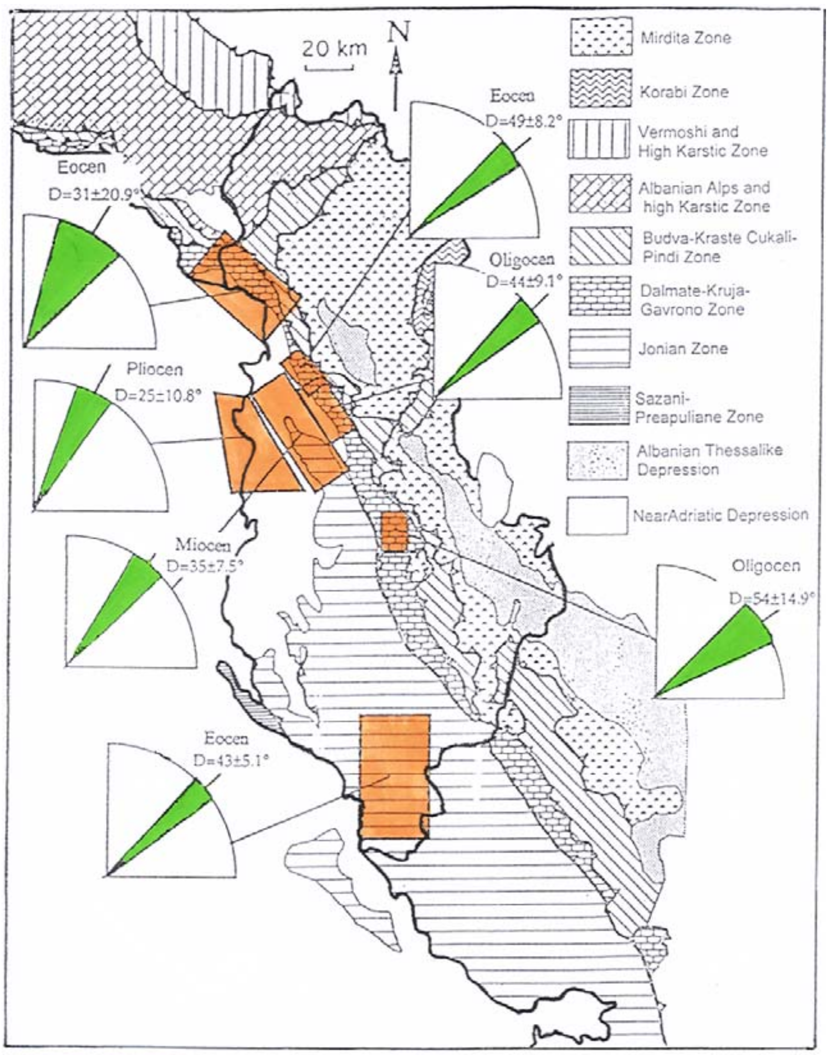


Fig. 25. Paleomagnetic Declinations Map of the External Albanides (After Kisel et al., 1994).

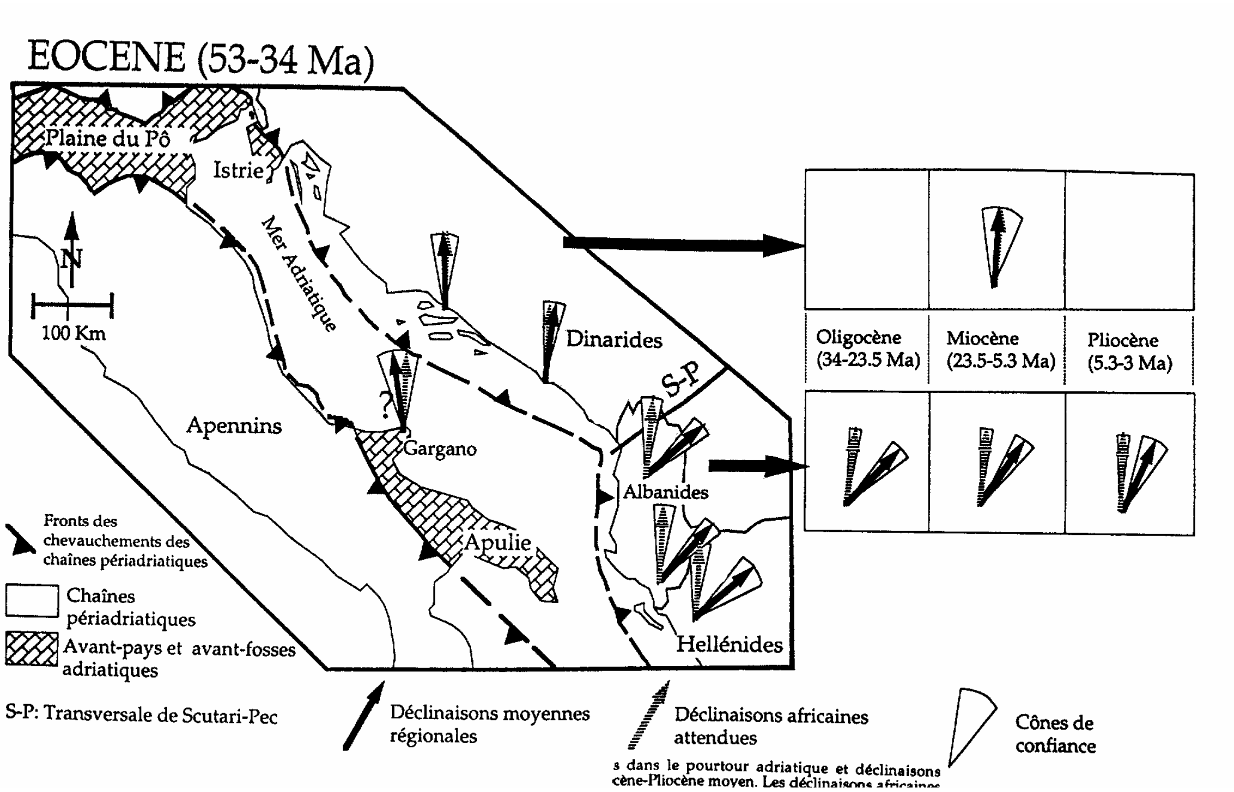


Fig. 26. Regional Paleomagnetic Declinations around Adriatic Sea and expected paleomagnetic declination for Africa during the Eocene-middle Pliocene period (After Speranza, 1995).

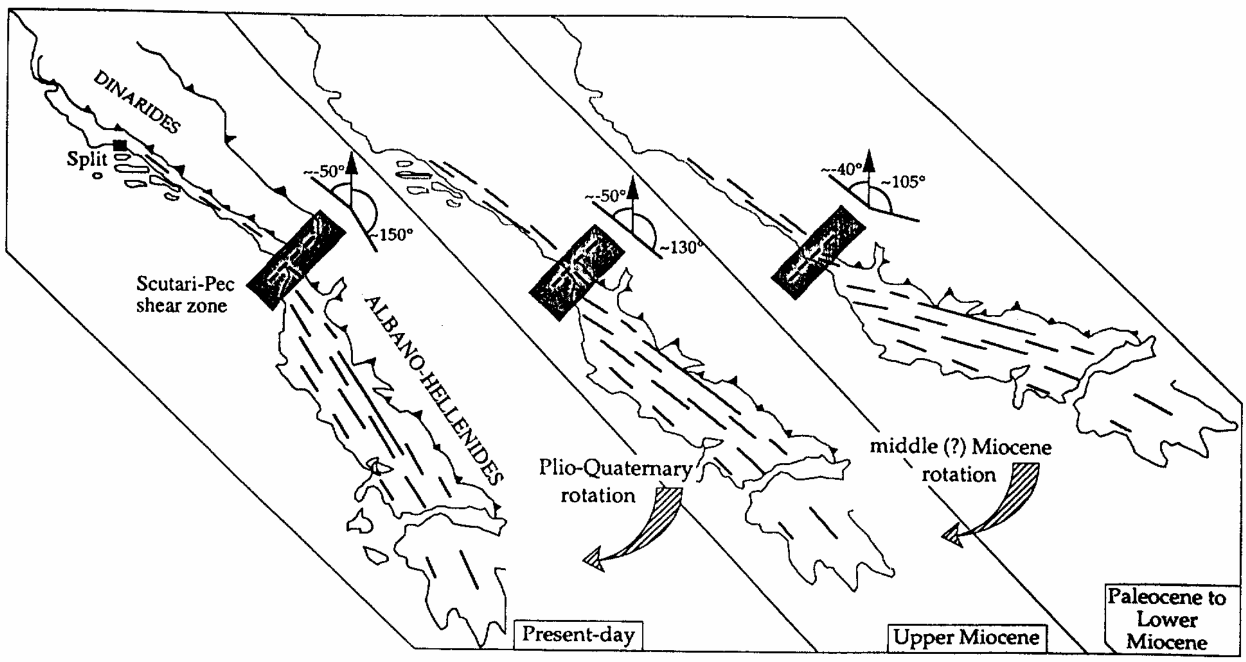


Fig. 27. Schematic evolution of the orientation of Albanides-Hellenides and Dinaride structures during the Cenozoic era, (After Speranza, 1995).

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