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GENERALIZED GEOPHYSICAL OVERVIEW ON SHKODËR-PEJË DEEP TRANSVERSAL FRACTURE

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Abstract

The article presents an attempt to generalize the complex of geophysical data: Gravity, Magnetic, Paleomagnetic, Geothermal, Seismological and Remote Sensing of Cukali tectonic subzone, where it crosses the deep transversal fracture Shkodër – Pejë, as well as marine seismic data, and hydrological observations on the shelf of the Southern Adriatic Basin. Analyses of the results of these studies are based on regional geological setting data.

Regional geological-tectonic setting of Shkodër-Pejë sector of Mediterranean Alpine Folded Belt, presents the existence of this important disjunctive deep tectonics element. The geological surveys and detailed mapping at the scale 1:25.000 up to regional ones at the scale 1:200.000, does not have traced at the Earth's surface the outcrop of this thrust. Consequently, have brought about the different concepts on it: "scharung" (1901), "deviation" (1920—1930), "an accident" (1960), "transform transversal fault" (1970-2012), "transverse fault" (1990-2012), "deep transversal fracture" (2012), and to silence about its existence, even to denial of its presence. These changes in the course of a century, not just in terms of use, were related to different geological schools over the geological setting of the Albanides. This transformation of concepts, unfortunately even in our days in some studies, related to the fact that the geological hypothesis or theories about the geological-tectonic setting of the region, were formed solely on the basis of surface geological surveys, which undertake to presented geological setting to the Moho Discontinuity without geophysical data, as necessary to known the depth.

During the last two decades, the Shkodër-Pejë region was involved in geophysical surveys polygons. Gravity Bouguer Anomaly Map, Magnetic Anomaly Map, Paleomagnetic Studies, Heat Flow Density Map, analyze of the satellite imagery, have provided important information about tectonic setting in the depth of the region. This information, interpreted in complex with the existing geological-tectonic data has cast light on the depth of the area, where it crosses the transverse Shkodër-Pejë. They argued that it represent a deep transverse vertical fracture, which affects the Moho Discontinuity. Its amplitude at those levels is about 4 km. It decreases toward the Earth's surface, until extinguished in some segments. This fracture represent a wide belt, was also interrupted by the deep regional or lowest order longitudinal thrusts.

Key Words: Mediterranean Alpine Folded Belt, Shkodër - Pejë transversal, geophysical anomalies, deep fracture.

1. Introduction as a historic review

Hellenides-Albanides-Dinarides, branch of the Mediterranean Alpine Folded Belt, are interrupted by a deep transversal tectonic fracture in the Shkodër-Pejë segments. This fracture is correlated with contact between Eurasian and African Plates in Drini Bay in Adriatic Sea (Fig. 1-a). It has been Svijich Jovan who described this fracture, calling “scharung”, for the first time in his book “Die Dinarics Albanische scharung-sitzba”, 1901 [Cvijich, 1901]. Later, during the first half of last century, this “scharung” is called as “deviation” by many Austrian, French, German, Italian, and Serbian researches, as Kosmat F. (1924), Koberh L. (1929), Nopca F. (1929), Bourcart J. (1919, 1925), Novack E. (1929), Zuber S. (1940) et al., have mentioned also Shkodër-Pejë zone, which differs clearly in tectonic and geological maps of Europe (Fig. 1-b, 1-c, 1-d).

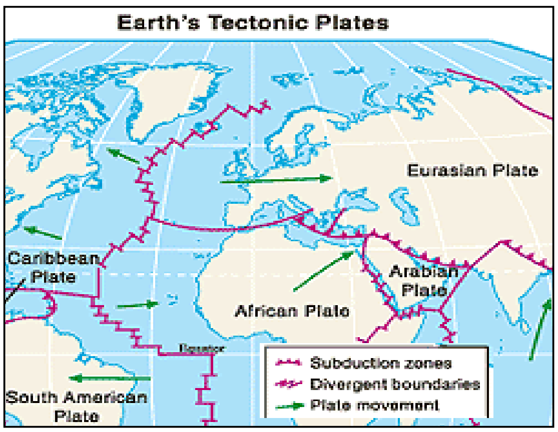

Fig. 1. Shkodër-Pejë deep transversal fracture belt according to the geophysical data:
Fig. 1-a: Earth’s Tectonic Plates Map;
Fig. 1-b: Western Balkans Tectonic Maps [International Tectonic Map of Europe, at scale 1:5.000.000].

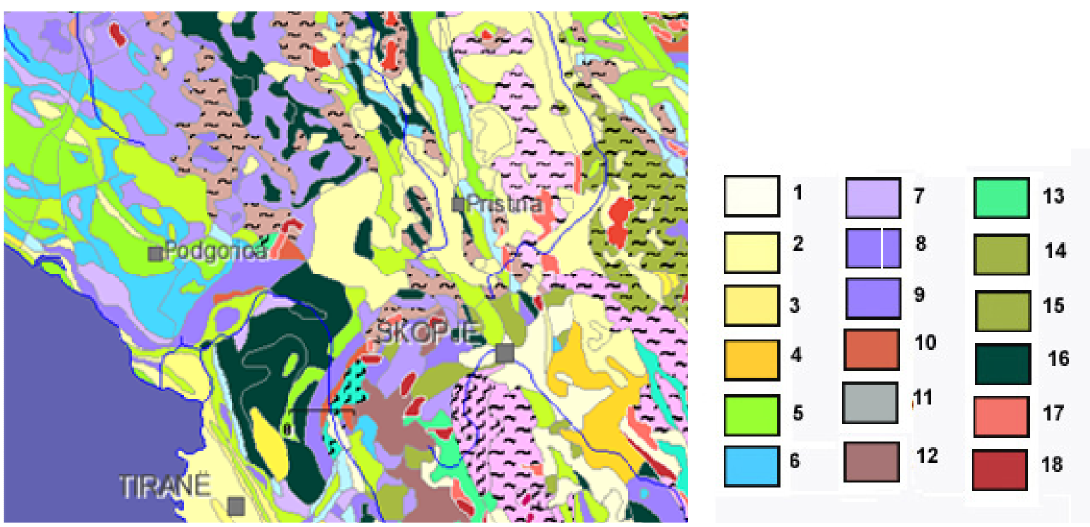

Fig. 1- c: Regional Geological settings of central part of western Balkan Peninsula [Geological Map of Europe, http://www.bgr.de/igme5000/igme_frame.php].
1- Quaternary; 2- Neogene; 3- Oligocene; 4- Paleocene-Eocene; 5- Cretaceous; 6- Jurassic; 7 - Alpine, 8 - Triassic; 9 - Mesozoic; 10 - Permian; 11- Carboniferous- Permian; 12- Devonian; 13- Silurian; 14- Cambrian; 15- Palaeozoic; 16- Ophiolite complex; 17 - Palaeozoic plutonite; 18- Mesozoic plutonite.

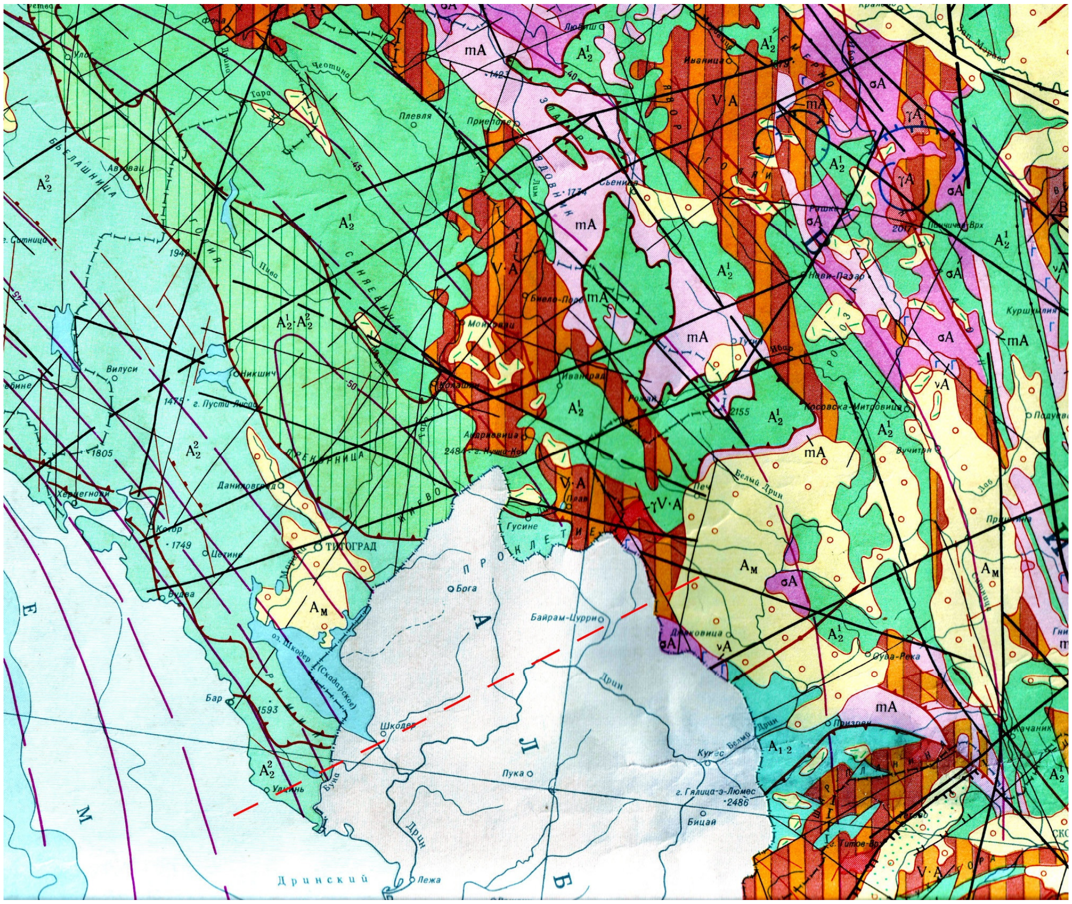

Fig. 1.d. Cosmotectonic Map of European Countries, SEV and SFRJ members, at the scale 1: 1.000.000 (Union Aerogeologia- Geological production for regional studies of geological setting of country territory, 1987)

__________ Lineaments interpreted not so unique (hidden fractures, planetary fissures, flexures)

\- - - - - - Shkodër-Pejë deep fracture according to the geophysical data.

In the second half of the 20th century, the French geologist Aubouin J. and Albanian geologist Ndoja I. Gj. have called the Shkodër-Pejë fracture as "accident" [Aubouin J. & Ndoja I.Gj. 1964]. Later, Aubouin J. has considered "ancient transform fault" the Shkodër-Pejë transversal, and as an "element inherits of the Tethyan Ocean paleogeography" [Aubouin J. et al. 1970]. Like a "Faille transversale Scutari-Pec" was presented by Çollaku A. & Cadet J.P. (1991).

After these, for almost several decades in Albanian geological studies, this fracture had not been mentioned, because the Albanides geological setting and its geologic history (palaeogeographic and tectonic) had been based on geosyncline's theory [Geology of Albania, 1970].

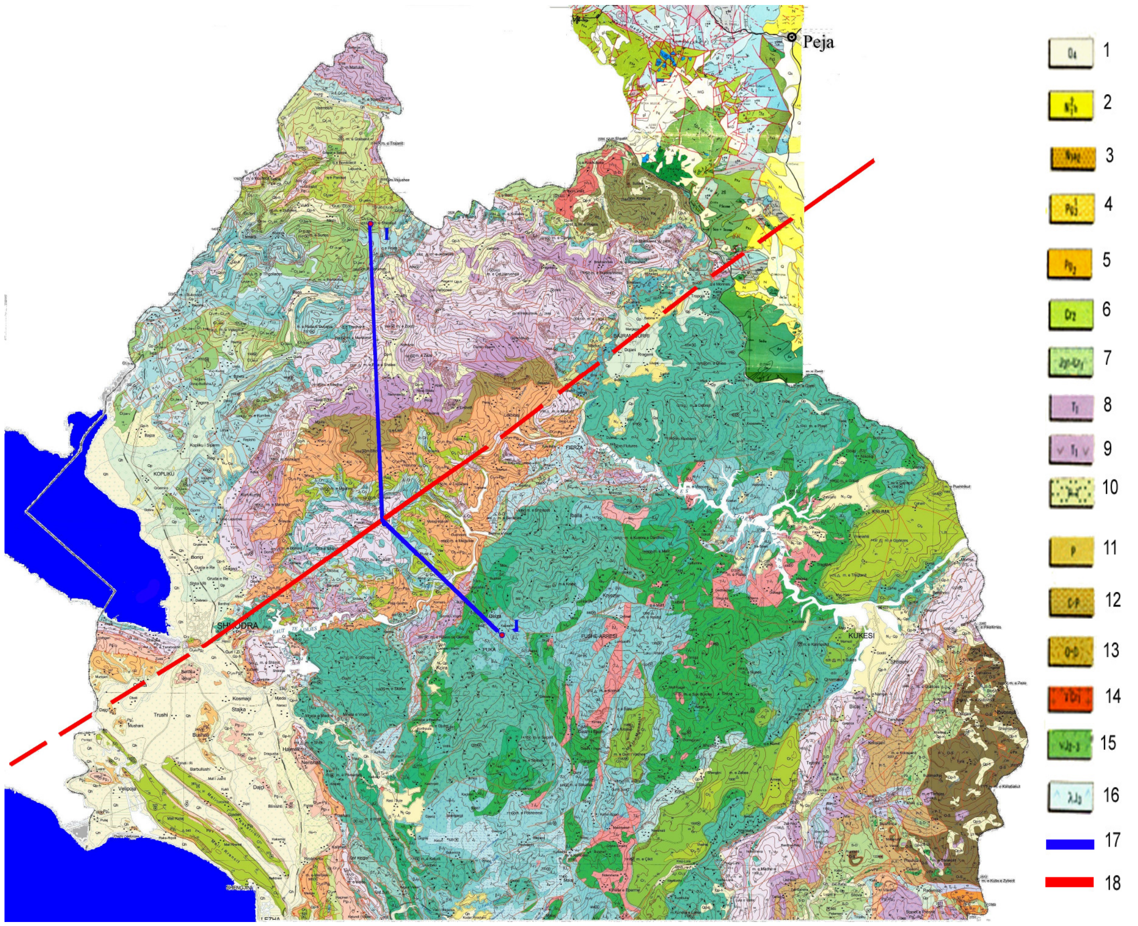

Fig. 1-d: Geological Map of Northern region of Albania, at scale 1:200.000, (Xhomo A. et al. 2002), and neigbor area from the Geological Map of Kosova.
1-Quaternary; 2- Neogene, molasse, 3- Lower Neogene-marlstone and flyschoid formation; 4- Oligocene, flysch formation; 5- Eocene-Paleocene, limestone; 6-Cretaceous- carbonate formation; 7- Jurassic- carbonate formation, melange; 8- Triassic- carbonate – terrigene formations; 9- Lower Triassic- volcanite formation; 10- Permian-Triassic- evaporate formation, gypsum; 11- Permian- limestone, sandstone, conglomerate, schist; 12- Carboniferous-Permian- sandstone, conglomerate, schist; 13- Ordovician-Devonian- limestone, schist; 14- Plagiogranite, granodiorite; 15- Ophiolite complex; 16- Jurassic- splitite, keratophyre – diabase 17- Gephysical inversion line; 18- Shkodër-Pejë deep tranversal fracture according to the gravity Bouguer anomaly inversion.

Later, seismological studies argued the presence of an active fault zone according to the well known Shkodër-Pejë direction [Aliaj Sh. 1999, Muço B. et al. 2001, and Sulstarova E. et al. 1972]. The authors of the Geologic Map of Albania [Geology of Albania, 1970] and latter Papa A., Xhomo A., et al. have analyzed Shkodër-Pejë transversal and its role in Albanides (Papa A. et al. 1985, 1991).

They mentioned it as a transversal zone, which represents an area where there are rapid paleogeographic transitions, with the presence of a talus, connecting the Albanian Alps Ridge with the Krasta-Cukali Groove. They wrote, also, that this area marks the southern paleogeographic closure of the Albanian Alps Ridge, constituting the paleotectonic etape, the natural boundary between the northern and southern Albanides. Melo V. wrote "…in the Southern side of the thrust, which some described as transform fault, lies Mirdita tectonic zone of Albanides [Melo V. 1986]. Shkodër-Pejë thrust as a transform-transversal fault is considered also by many authors, mainly by the autoctonists, which accepted the formation of ophiolitic belt as a result of the Mirdita Ocean opening [Kodra A. et al. 1994, Melo V. et al. 1991]. Shkodër-Pejë "scharung" is considered a real tectonic regional element, because the area of the Albanian Alps, with compelling scientific basis, so far not yet found in southern Albanides, according to the Peza L. et al. (1971). According to Aliaj Sh. "…the Shkodër-Pejë transverse fault dividing Dinarides from the Hellenides" [Aliaj Sh., 1999, 2006]. Some geologists did not mention this fracture among those who analyze their books became [Vranaj A. et. al. 1997]. Shehu V. has written "so called Shkodër-Pejë transversal" and denied its existence, accepted that this tectonic line represents simply the border of the northwest front of the Mirdita's zone [Shehu V., 1967].

During the last quarter century, the geophysical studies, and remote sensing that were carried out have a cast light on the Shkodër-Pejë fracture, giving new evidences on its structure. In satellite images, Chorowicz J. has observed some tectonic lineaments along the Shkodër-Pejë transversal zone [Chorowicz J. et al. 1981]. In the paper, related to the study region, are presented and analyzed the offshore geophysical exploration results at Montenegro Adriatic shelf and littoral [Dragasević T., 1983], and remote sensing surveys (Frashëri N. 2012).

Is important to show that the existence of Shkodër – Pejë thrust and its position cannot being observed and mapped during geological field surveys, even at the 1:25.000 scale [Qirinxhi A., et al. 1983]. Qirinxhi A. confirmed that in the field they were not capable to distinguish the tectonic borders between the Paleozoic (of Albanian Alps tectonic zone) and Paleogenic black schists (of Cukali tectonic zone). Because the tectonic border between them does not represent the Scutari-Pec fracture, about this fracture they had not discussed. Later, during the Symposium "Thrust Tectonics in Albania", they sustained that Shkodër-Pejë fracture does not exist on the surface but, perhaps, exist in the depth [Qirinxhi A. et al. 1991].

The above interpretations regarding the Shkodër-Pejë fracture also have resulted in alternative of the geological opinion concerning its position. Some authors, who admit the opening of the Mirdita Ocean and interpreted this transversal as oceanic transform fracture. After them, Shkodër-Pejë transform fault is represented by the north-western front of the ophiolitic belt [Xhomo A. et al. 2002]. After some other authors, this transversal is represented by the northern border of Cukali subzone as natural geological border between Alps Zone and Cukali ones [Papa A. et al. 1991].

2. Methodology of Study

Already avalaible are the results of integrated surveys and studies, which include Shkodër-Pejë fracture zone [Frashëri A. et al 2009].

Geologic-tectonic settings of Shkodër-Pejë region is included in the regional Geological Maps of Albania, by Nopça F. (1929), Novack E. (1929), and Zuber S. (1940), in the Geological Maps of Albania at the scale 1:200.000 (1967, 1983, 2002), and in the Tectonics Map at the scale 1:200.000 (1984), Neotectonics Maps of Albania, and seismicity studies [Sulstarova E. et al. 2011]. Detailled geological setting of the Kiraj-Ndreaj-Brashtë in Cukali zone was presented in the Geological Map at the scale 1:25.000 [Qirinxhi A. et al. 1983].

The seismicity of Albania was study by analyze of the historical and instrumental data, and the distribution in time and space of the seismic activity in Albania and surrounding areas. The study covers a period of about 2000 years. During the period about half a century have been compilated the catalogues of Earthquakes in Albania up to 2005, and Atlas of the Isoseismic Maps for 198 earthquakes occurred in Albania and nearby during 1800-1990 [Sulstarova A., et al. 2011]. Present-day stress field in Albania was study based on the earthquakes focal mechanism solutions in the complex with structural analysis of the faults from Middle Pleistocene up to our time, and neotectonic analyze [Aliaj A. 1988, Sulstarova E.1986, Tagari Dh.1993, Muço B., 1994]. The seismic hazard estimation of Albanian territory, which presents a part of the seismological studies, is accompanied and with important geological information to investigated the Earth Crust structure of Albanides.

Have been compilated the Map of Gravity Bouguer Anomalies of Albania [Bushati S., 1988] and Map of Total Magnetic Vector (T) of Albania [Bushati S., 1998] at the scales 1:200.000. For the Shkodër - Pejë area have been observed also two detailled profiles (Fig. 1-b). Gravity and magnetic surveys were accompanied with density and magnetic properties of the rock detailled studies (Qirinxhi A. et al. 1983).

The dynamic evolution of the Albanides is recorded in the paleomagnetic data, collected from the paleomagnetic studies in Albania during 1991-1995: Frashëri A. and Bushati S., 1995; Kissel C. et al., 1992, 1994, 1995; and Mauritsch H.J., Scholge R., Bushati S., 1991, 1994; [Frashëri A. and Bushati S. 1995, Kissel C. et al, 1995, Mauritsch H.J., et al. 1995, Speranza F. 1995].

Geophysical investigation has provided some information related to the crystal basement of Albanides (Aliaj Sh. 2006; Frashëri A. et al. 1991, 2004, 2010; Bushati S. 1988, 1998; Koçiu S. 1989). In particular, was analyzed the propagation of the Earth Thermal Field. This analysis has been performed according the Heat Flow Density Map, based on the temperature records in boreholes at Ragami in Tropoja region, and Palaj-Karmë zone [Frashëri A. et al. 2004].

Remote sensing based on Landsat and Modis data was used to identify some regional geological features and analyse the ground temperatures.

The ofshore area of Drini Bay, at the south-western edge of Shkodër - Pejë fracture zone, is included in the contour of the polygone of offshore geothermal studies in South Adriatic Sea. Was observed marine currents, waves, water salinity and temperature at various depth, as well as Earth Heat Flow Density at the sea bottom (Frashëri A. et al. 2011, Geothermal Atlas of Europe, 1992).

3. Results and discussion

Complex methods used for studies also in northern Albania and in the Adriatic Sea have brough the new information of great value for the Albanides depth, and which throw light on the Shkodra - Peja fracture zone. Follow separately analyze for results from each used method, and in the end will be presented their generalization.

Geophysical investigation results show that crystal basement of Albanides has a blocks character (Fig. 2) (Bushati S., 1988, 1998, Koçiu S., 1989, Frashëri A. et al. 1991, 2010). Thickness of the location of these blocks is shallower in Mirdita Tectonic Zone. The crust construction and their dynamics are reflected in the geological setting of the Albanides tectonic zones, and their tectonic styles. Block structure controlled by a system of NW-SE longitudinal faults as well as transverse ones.

Local heat hearths put in evidence the transversal faults. Geothermal energy is related with a great heat flow through these fractures (Fig. 3) [Frashëri A. et al. 2004].

The Shkodër-Pejë deep fracture represents one of deep thrusts, which transversally divides Albanides in two parts (Fig. 3, 4). In northern part are including western-northern edge of Kruja tectonic zone, northern part of Cukali zone, Albanian Alps and Gashi zones, which follow by the Dinarides tectonic zones: Budva, High Karst, Dalmate, Durmitor, Serbian, and Golia zone. In the southern part of the Albanides, represented by Sazani, Ionian, southern part of Cukali zone, Krasta-Cukali, Mirdita and Korabi tectonic zones, which follows by the Hellenides. This deep fracture generally considered a multi phase's transversal tectonic faults zone, with a north-eastern extension of about 30°. Consequently, Shkodër-Pejë deep fracture divides two big areas with different geological settings and developing geological history, but not only in the continent, also to the orogenic front in the Adriatic Shelf.

The Albanian orogenic thrust front is cut and displaced by the Othoni Island-Dhërmi, the north of Sazani Island, and the Gjiri i Drinit-Lezha strike-slip faults, which divide the orogen into separate segments showing diachronous development (Fig. 5) [Aliaj Sh., 2006]. The orogenic front, north of the Drini Bay-Lezha town strike-slip fault, in the Adriatic offshore, belongs to the Kruja Zone. The buried orogenic front, north-west-trending here, is expressed by the Kruja Zone thrusting over the Albanian Basin. The external margin of the fold and thrust belt in Albania was thrust on the Adria microplate, partly over the Apulian Platform and partly over the Albanian Basin [Aliaj Sh., 2006]. During the Tertiary phase, this strike-slip fault functioned as a right pushing, being shifted towardsthe south-western inner zones [Sulstarova E. et al. 2011]. Ophiolitic Belt of the Mirdita Tectonic Zone is displaced more than 100 km south - west, and touching the outer zones. During Pliocene - Quaternary was processed with the normal disjunctive, mainly along north - western border of Mirdita Tectonic Zone. In outer zones, at the transversal Drini Bay - Lezha Town, cut and displaced front thrust of the orogen [Sulstarova E. et al. 2011].

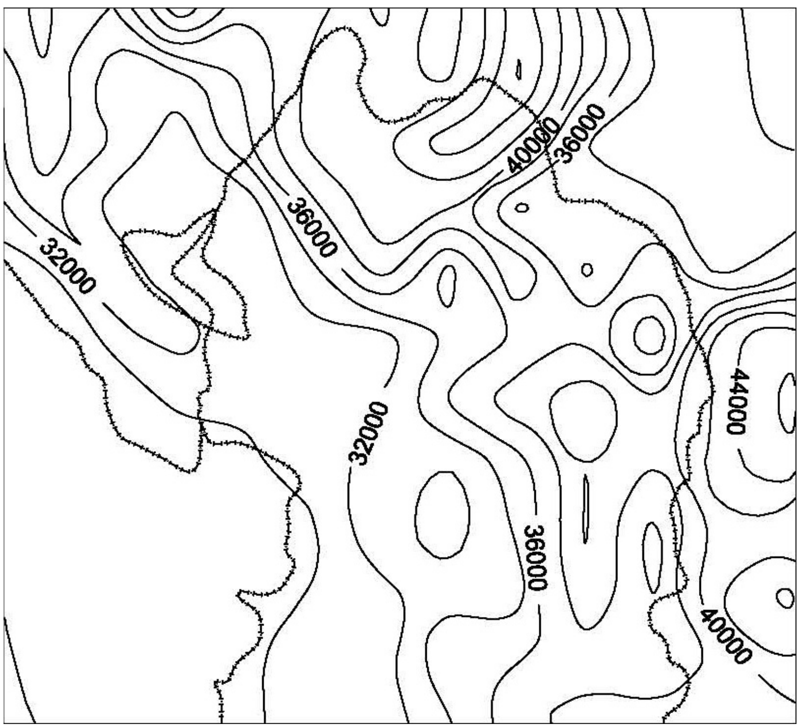

Fig. 2. Map of the Moho Discontinuity depth calculated by the Geiss relation [Koçiu S. 1989] using the Gravity Map of Albania [Bushati S. 1988].

Fig. 3. Tectonic scheme of the Albanides [Xhomo A. et al. 2002].
G-Gashi zone; MOJ- Mirdita ophiolites; MOT-T2-J3 Ophiolites (Efusive-sedimentary formation): Ko, Ko1, Ko2-subzones of Korabi zone; MK4 Gjallica subzone; Ao, A1, A2 sobzones of Alps zone; K-C1- Cukali subzone; K-C2- Krasta subzone; Kr1- Dajti subzone of Kruja zone.
1. The trace of the deep transversal thrust Shkodër-Pejë after gravity inversion,
2- Thermal anomaly axis of the Heat Flow Density value mW/m2 ;
3- Strike-slip faults Gjiri Drinit-Lezhë.

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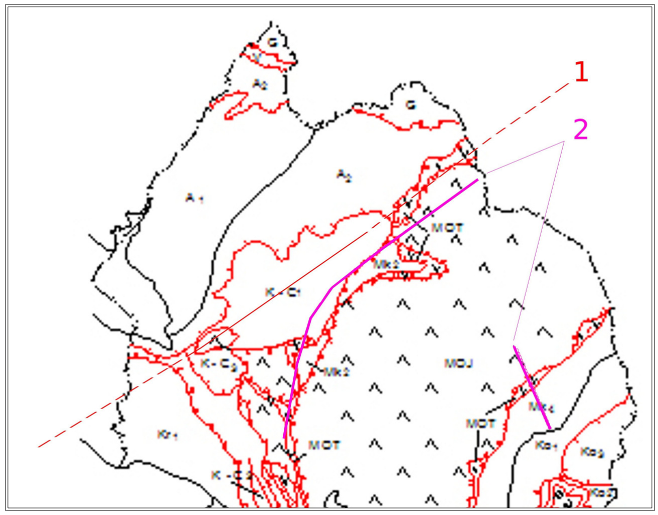

Offshore seismic surveying at the Montenegrin Adriatic shelf and deep wells [Dragasević T. 1983, Picha F.J. 2002] very well have enlightened geological setting at the depth on the western edge of Shkodër-Pejë deep thrust in the Adriatic shelf (Fig. 6, 7). Deep fractures in this region represent a wide zone with the presence of different fault branches, arising out of the common trunk that comes from deep.

Onshore geological surveys from Adriatic coast line-Shkodër-Cukal-Tropoja have mapping two regional disjunctive tectonics in northern southern borders of Cukali subzone, divided this subzone from Alps zone and Mirdita zone, respectively (Fig. 4).

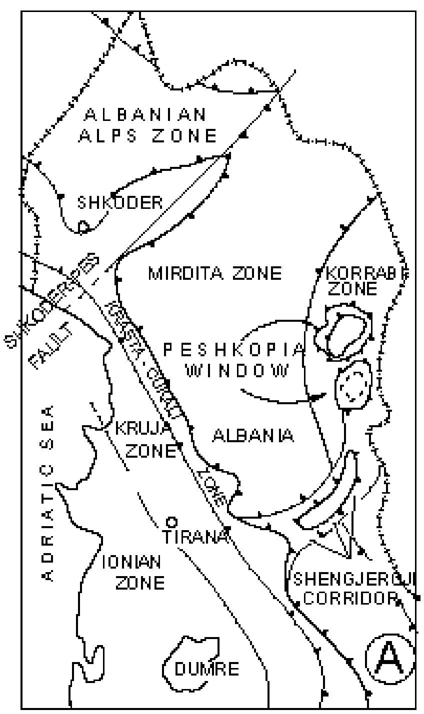

Fig. 4. Shkodër-Pejë deep transversal fault [Collage A. & Cadet J.P., 1991]

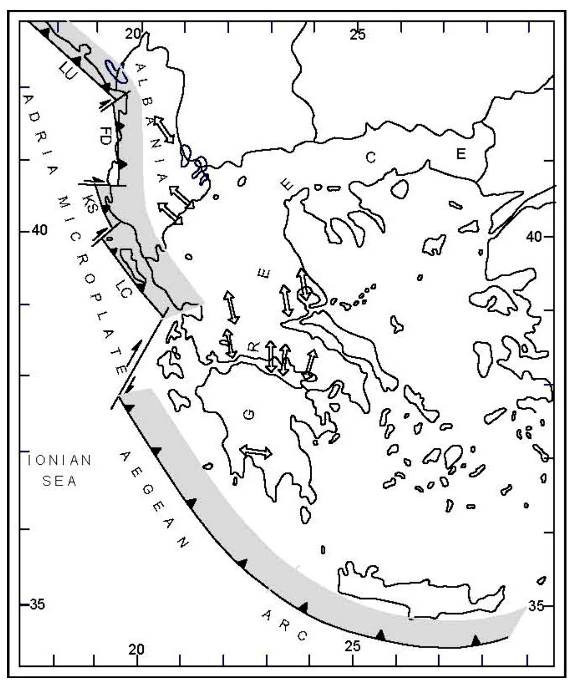

Fig. 5. Southern convergent margine of Eurasia plate: Adriatique collision and Aegean Arc [Aliaj Sh., 2006].Convergent margine segments: LU- Lezha-Ulqin; FD- Frakull-Durrës; KS-Karaburun- Sazani Island; LK-Lefkas-Corfu Island.

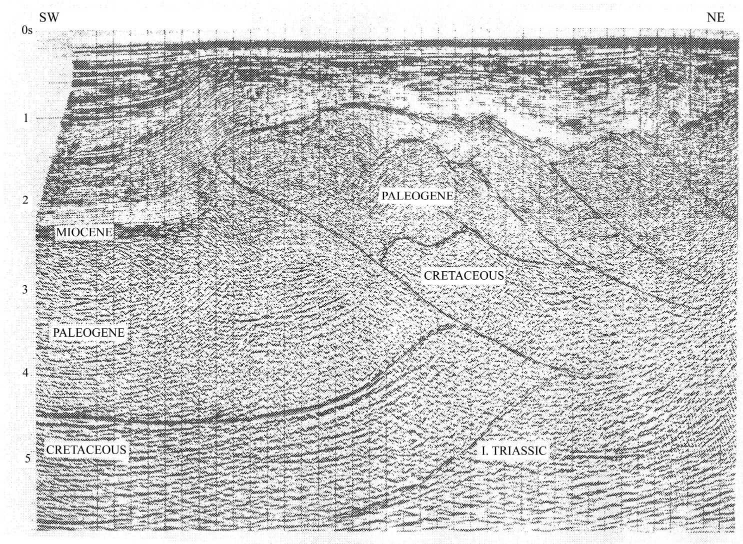

Fig. 6. Seismic section through area of Boka Kotorska perpendicular to the coastline [Dragasevic, 1983], showing the over thrusting of the buried orogen front over the South Adriatic Basin

Intensively folded structure of the Cukali subzone has northwest-southeast strike. They are cut transversally by Albanian Alps zone, at the north, and Mirdita zone at the south. Cukali zone, itself, is suppressed as an accordion -by these mentioned above two zones, during their overthrusting toward west and southwest. According to the estimation by the palinspatic opening of the Cukali folds, result that the displacement of its northwest edge toward the west-southwest is at least xxx km. After this geological mapping, in the Cukali subzone (sensu stricto), had not been observed any evidences of disjunctive tectonics of the Shkodër-Pejë tranversal fault [Qirinxhi A. et al. 1983].

From surface geological data, ranging from the Permian rocks of Albanian Alps tectonic zone, the Upper Triassic - Maastrichtian- Paleocene - Eocene rocks in Cukali subzone, and also from all magmatic and sedimentary rocks that spread of the Mirdita zone at the surface, had not been deduced any arguments which can help to accept the presence at the surface of the Shkodër-Pejë transversal fault. There are not any phenomenon of their influence for paleogeographic and paleotectonic of these zones [Qirinxhi A. et al. 1983].

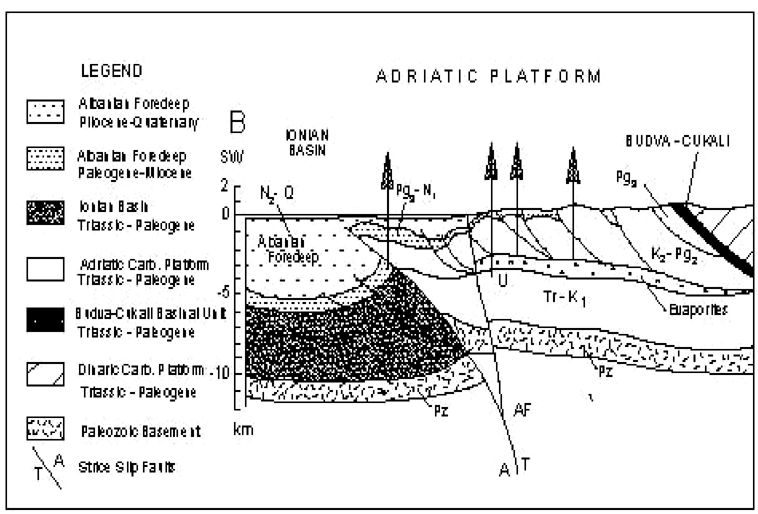

Fig. 7. Cross section BB’, interpreted from wells and seismic lines, shows the relation between the frontal zone of the thinned thrust belt, consisting of a series of shallow anticlines, apparently detached within the evaporitic horizon, dissected by the younger strike-slip fault, also shown the juxtaposition of the deep side of the Pliocene-Quaternary Albanian fore deep toward the Adriatic strike-slip fault system [Pica F.J., 2002]. AF - Adriatic strike-slip fault system; U - Lucan deep structure; A/T direction of strike-slip motion: A- away; T- toward.

In contrast with surface geological surveys, the gravity and magnetic surveys, seismological, and geothermal studies have provided information on the presence of this regional transversal deep thrust, and consequences of its action for geological history of the Albanides setting, which will analyzed below.

In these conditions the alternatives of characterisation of this transversal fault as a transform tranversal fault, aligned with the overthrust tectonic in the northern boundary of the Mirdita zone [Kodra A. et al. 1994, Xhomo A. et al. 2002], or as a tectonique border between Cukali and Alps zone as natural geological border between them [Papa A. et al. 1991] have not support by geophysical and remote sensing data.

3.2. Gravity and Magnetic field scattering

Scattering of gravity and magnetic fields have very well contoured Inner Albanides, particularly the ophiolitic belt (Fig. 8, 9). Bouguer gravity anomaly and magnetic ones have common peculiarities: a) epicenters are located over the eastern belt of the ophiolites; b) Ophiolitic belt represented in two parts: northern and southern, separated by flyschoid corridor; c) gravity and magnetic anomalies are very intensive, compared with Internal Albanides. These pecularities and anomaly configuration have argued the nape character of the ophiolitic belt [Frashëri A. et al. 1991, 2010].

According the gravity and magnetic surveing (Bushati S. 1987), Alps zone represented by a minimum of Bouguer gravity anomaly in general, with particularly a small amplitude anomaly in southern part of the Alp's zone (Fig. 8). In the northern direction there are observed the trend of the increasing of the intensivity of magnetic anomaly. This pecularity of the magnetic anomaly express overthrust character of the Albanian Alps, too. Over the Cukali subzone is observed a linear upward trend of the intensity of the Bouguer anomaly toward the Mirdita zone (Fig. 8, 10). This trend's anomaly can explained by the presence of the vertical deep tectonic thrust.

After the inversion model, thrust level resulted with amplitude about 4km in the Moho Discontinuity (Fig. 10). Thrust amplitude toward the Earth's surface is gradually reduced and, until the surface of the Earth, is almost extinguished, also according to the geological mapping. This deep thrust represents Shkodër - Pejë fracture. By analogy with the deep strike-fault in the Adrietic Shelf Crust (Fig. 7) and this, Shkodër - Pejë deep fracture, at the depth expected to be composed by several branches, occupying a wide zone of their influence and action.

3.3. Paleomagnetic surveys - an important indicator of the presence of Shkodër - Pejë deep fracture and its geodynamic evolution role in Alpine Mediterranean Foldet Belt Hellenide-Albanides-Dynarides

Dynamic evolution of the Northern Albanides has its reflection in paleomagnetic data, collected from the paleomagnetic studies in Albania, which were performed during 90 years, performed by Mauritsch H.J. et al. (1991-1995), Kissel C. et al. (1992-), Muttoni G. et al (1940), Frashëri A. and Bushati S. (1995) [Frashëri A. et al., 1995; Kissel C. et al., 1995; Mauritsch H.J. et al., 1995, 2006, Mauritsch H.J. 2000, Muttoni G. et al. 1994, Speranca F. 1995].

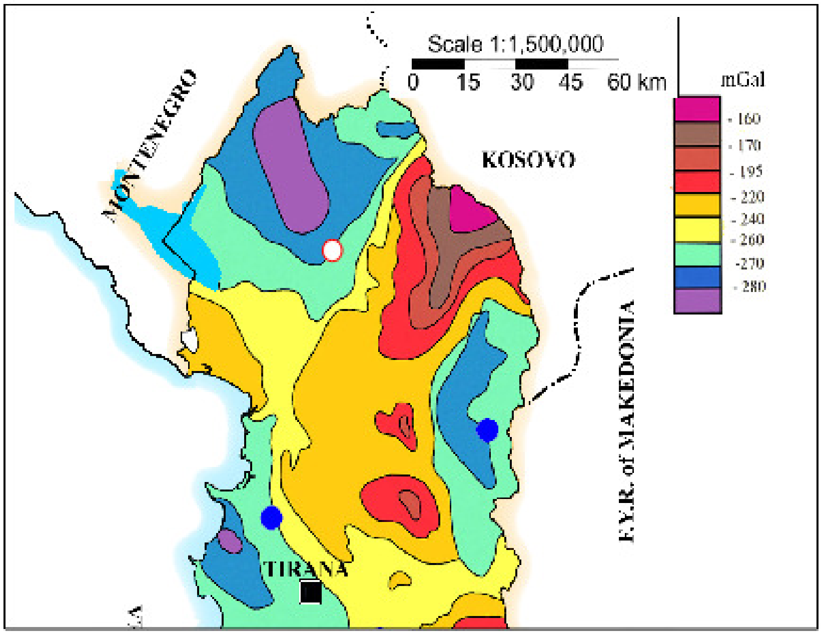

Fig. 8. Gravity Bouguer Anomaly Map of Albania [Bushati S. 1988]

Paleomagnetic studies shows that Ionic and Kruja tectonic zones, located at southern side of the Shkodër - Pejë transversal, have support a joint clockwise rotation, with an angle 45-50^o during and after Eocene-Oligocene period. This rotation has been realized through two phases, by 25^o every phase in the middle Miocene up to Plio-Pleistocen. Ionic and Kruja zones don't have any different rotation between each other. Clockwise rotation for 40^o-45^o since Early-Middle Miocene is observed at Kçira site. For this rotation, the Kçira pole acquires a West Gondwana affinity [Mutoni G. et al. 1996]. A large Neogene clockwise rotation, D=40^o, I=3.8^o, is observed also in the Mirdita zone of Inner Albanides, at southern Albania, northern of Albanian-Greek border [Mauritsch et al., 1994].

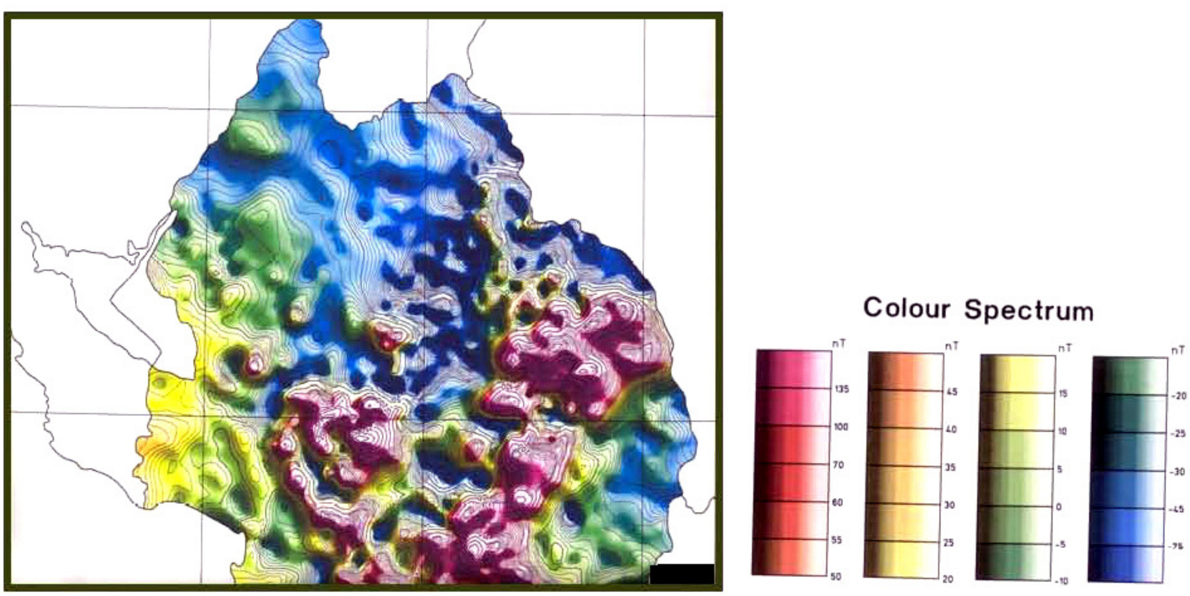

Fig. 9. Magnetic Anomaly Map of Albania [Bushati S. 1998]

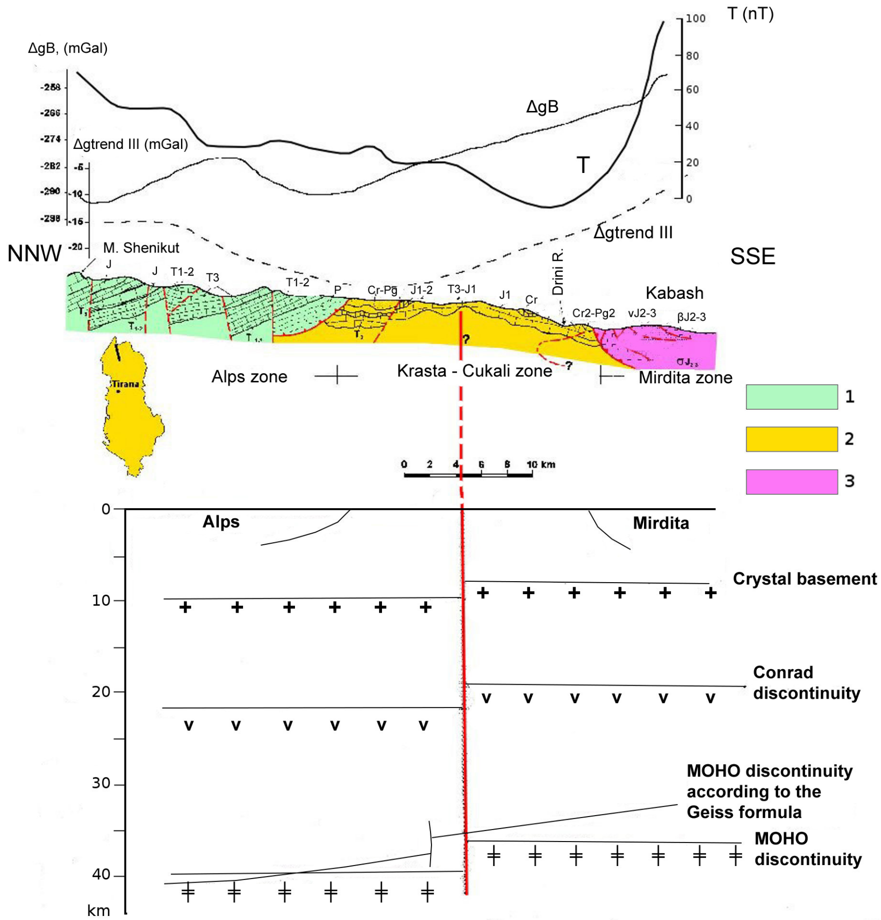

Fig. 10. Gravity Bouguer Anomaly (Δg) and Magnetic Anomaly (T) profile I-I, Mountain Sheniku at the Albanian Alps-Kabash in Mirdita zone, and gravity inversion results.

Eocene limestone anticlines of the Renz and Kakariq area, which are located in southern side of the Shkodër - Pejë transversal zone, have a rotation about 31^{o}. Consequently, these two anticlines have a declination with 18^{o} smaller than the declination of the Eocene limestone in the Central Albania. These two anticlines maybe have superposition of two rotations with inverse sense: clockwise rotation of 50^{o}, which has been subdued all External Albanides structures and local counterclockwise rotation by 25^{o}, which has rotated only these two anticlines that have a Dinaride strike.

At the Komani area, in the southern side of Shkodër - Pejë transvesal, at north-western edge of the ophiolitic belt of Mirdita zone, have been observed declinations, which show the 82^{o}-140^{o} clockwise rotation of the Jurassic limestone. The same 28^{o}-57^{o} clockwise rotation is observed for ultrabasic rocks of western edge of the Gomsiqe massive, at south-western direction from Komani (Fig. 11).

Gabro massive at Bozhaj, southern of Korça city have a magnetization vector with declination Do=282^{o} and inclination Io=60.9^{o}, the same direction as in the Khalkidhiki in Greece (D=240^{o}-312^{o} and I=30^{o}-68^{o}), which have demonstrated an Upper Cretaceous anti-clockwise rotation, and Upper Tertiary clockwise rotation of the Khalkidhiki [Feinberg H. et al. 1996].

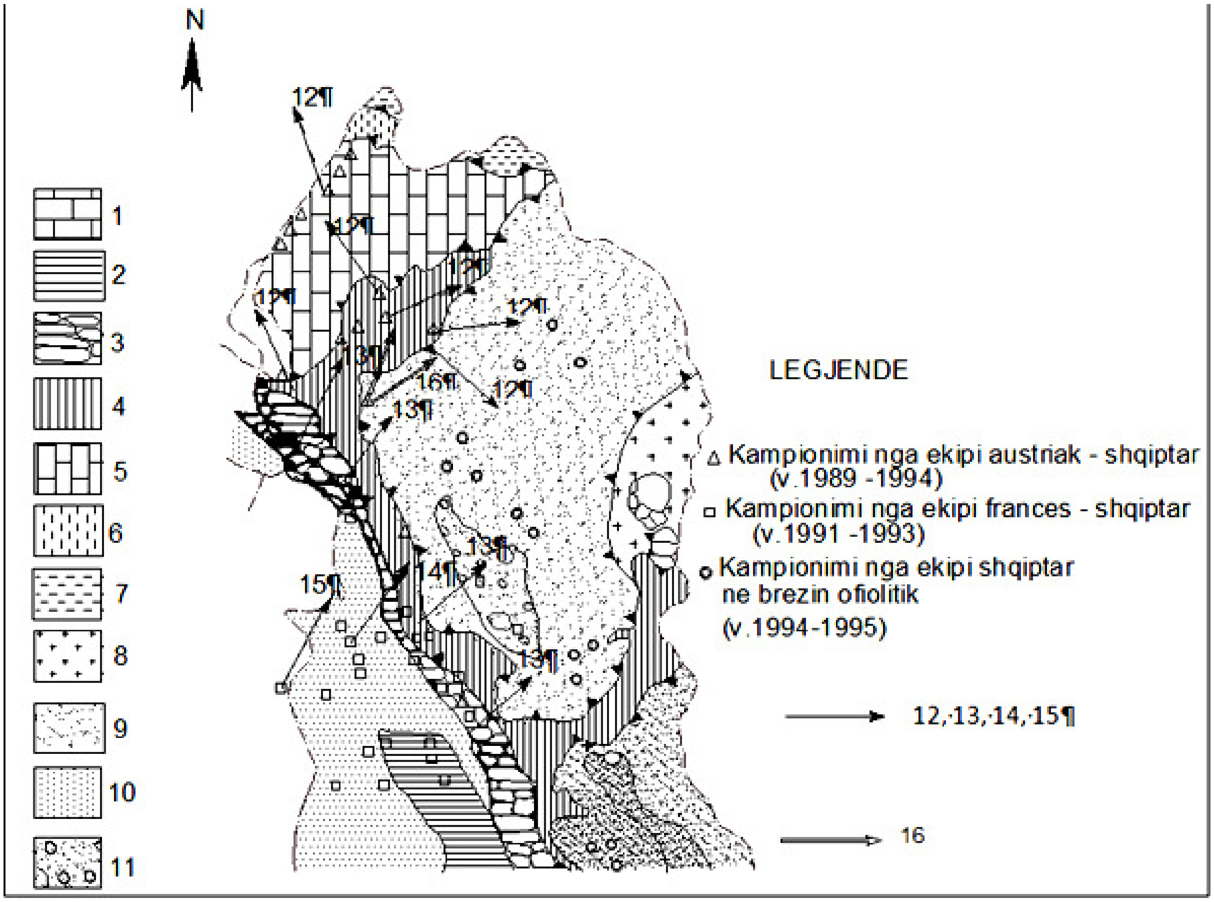

Fig. 11. Scheme of the paleomagnetic echantionage in Northern Albania, during 1989-1994.

1-Sazani Zone; 2-Ionian Zone; 3-Kruja Zone; 4-Krasta-Cukali Zone; 5- Albanian Alps Zone; 6-Vermoshi Zone; 7- Gashi Zone; 8-Korabi Zone; 9-Mirdita Zone; 10- Periadriatic Depression; 11-Mollasic depressions; 12- Jurasic limestone; 13- Upper Cretaceous-Eocene limestone: 14- Middle Neogene molasses: 15- Pliocene formation: 16- Ophiolite.

Limestone samples from Albanian Alps at Selca area, in the north of Shkodër - Pejë transversal, shows a counterclockwise rotation for 20^o in relation with present north, the same value as in southern Dinaride’s structures. The analogue counterclockwise rotation as in Selca area, have also Jurassic limestone at southern Shkodra lakeshore. This fact shows that both these sections appertain to the same tectonic zone, in northern of Shkodër-Pejë transversal area.

The Kotori to the Split area, which belongs to the Dinarides in Dalmatia in the North is almost immovable for the time period being studies starting from the Eocene onwards. Dinaride’s orogen in the north are characterized by the regional direction f the structures N12^o, unlike the Albanides orogen structures with a direction N150^o, as in southern Hellenides [Kissel C., 1994; Mauritch H.J. et al 1993, 1995, 2006; Mauritch H.J. 2000]. Paleomagnetic studies in the external Dinarides have shown that this orogen has no any significant counter-clockwise rotation in relation to Africa, ranking from the Eocene, such small rotation that is observed in limestone of the Albanian Alps to the southern shore of Shkodra Lake.

Paleomagnetic directions demonstrate a strong tectonic disturbance in the Central part of Shkodër - Pejë zone. In the Jurassic limestone of the northern side of Cukali subzone, about 4 km northwest of Prekali village, is observed a country-clockwise rotation for about 45^o. Only in less than 2 km south, a 60° clockwise rotation is observed. Such result attests to the strong tectonic influence in transversal thrust zone.

Paleomagnetic studies have demonstrated that Shkodër - Pejë belt presents a transition zone between counter-clockwise rotation in the north, and clockwise rotation in the south sides (Fig. 11, 12). Consequently has a great tectonic influence over Cukali subzone. Thus, Shkodër-Pejë lineament, defines a transition zone which separates the Albanian Alps and the Dinarides (counterclockwise rotation), from Albanides and Hellenides (clockwise rotation).

For the rotation pole located at Shkodër - Pejë transversal thrust, Southern Albania has undergone a horizontal displacement is about 173 Km [Speranza F., 1995].

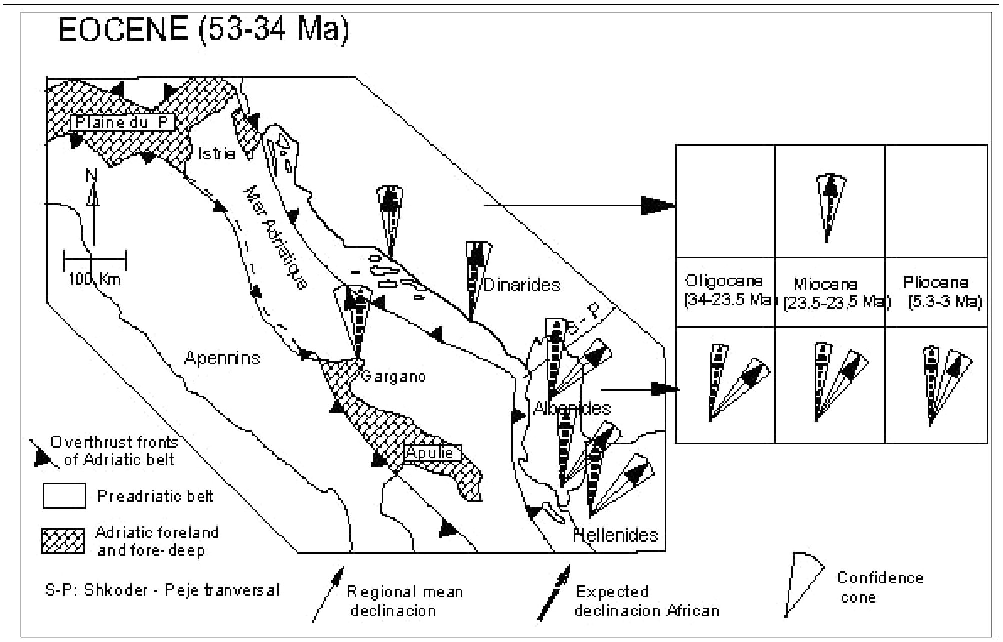

Fig. 12. Regional Paleomagnetic Declinations around Adriatic Sea and expected paleomagnetic declination for Africa during the Eocene-middle Pliocene period (Speranza, 1995).

3.4. Seismological pecularities related to Shkodra-Peja seismoactive tranversal fault zone

Seismological studies carried during the last half of century in Albania have mapping seismoactive longitudinal and transversal deep tectonic fault zones of the Albanides (Fig. 13 and 14).

Among them is situated the Shkodër - Pejë transversal fault zone, which represent a seismoactive transversal normal fault zone There are systematic misallocations of the earthquakes (between zones 4-5, fig. 13-a, or one Nr. 4 in fig. 13-b), with strong lateral velocity contrasts, with a difference across the fault about 3-7%. It is well delineated also by present-days seismic activity. His more intensive activity, after relatively strong earthquakes, it appears in zones where interrupted by longitudinal faults. The following earhtquakes have been recorded in the Shkodra-Peja fault zone: Peja, Io=VIII, Febryary 11, 1662; Shkodra, Io=VIII, July 3, 1855, and 1 June 1905; Trush-Shkodra M=5,5, August 27, 1948; Ulqini, 1444, and M=5,5, November 3, 1968. During the period 1976 - 1992, in some segments of the fault zone, were evident lots of micro and small earthquakes with a magnitude $Ms \leq 5.0$, mainly as clusters of earthquakes (Muço B., 1984; 1991, Sulstarova S. et al. 2011). The expected seismic potential of this seismogene zone is of a Mmax=5,5 to 6,0 [Sulstarova S. et al. 2011].

Shkodër - Pejë transversal fault zone divided in two segments the northern part of the Ionian-Adriatic thrust fault zone, which presented the longest fault zone along the Adriatic and Ionian coasts:

a) Lezha town in Albania - Ulqini in Montenegro coastline Northern segment, WNW trending. This segment is more than 200 km long, including Northern side of Kruja tectonic zone in Albanides and Southern part of Dalmatian zone in Montenegro.

b) Lezha town-Vlora city, with an N to NNW trending. This segment, which is situated along Periadriatic Depression and stroked by Adriatic coastline, is about 130 km long.

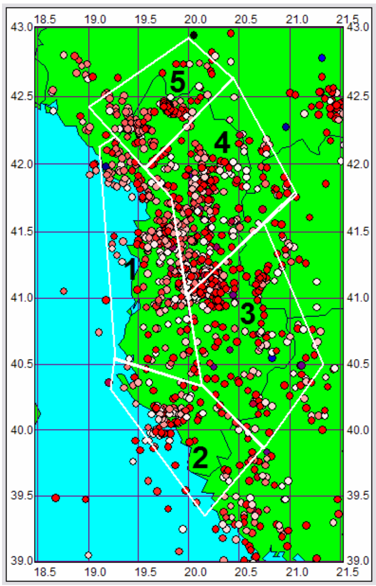

Fig13-a. The map of seismogenic zone and the earthquakes epicenter, occurred in the period of time 2002-2006, where the models of velocity of the Earth crust are calculated [Aliaj Sh. 2000]

Fig. 13-b. Map of the seismoactive zones in Albania, with maximal Albania [Aliaj Sh. 1988].

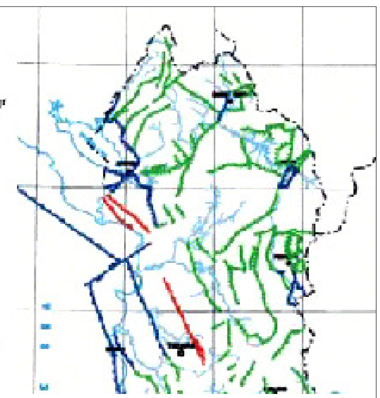

Figure 14. Map of active fault zones in Albania [Aliaj Sh. 2000]

Based on focal mechanism solution, results that in Northern littoral side of the Shkodër- Pejë fault zone, the compression strain has a P=16^0 NE-W strike, and 10^0 plunge, while the axis of expansion T = 124^0 and 79^0 dep. In the Southern side of the Shkodër- Pejë fault zone, the compression strain has a P=274^0 E-W strike, and 10^0 deep, and the axis of expansion T = 164^0 SE-NW and 64^0 deep (Sulstarova, 1988, Tagari (1993). In the internal area, region Vau i Dejes-Pukë-Tropojë, the tensional stress regime has a NWN extending (Muço B. 1994, Sulstarova 1988). Axis of expansion have a strike direction NNE T=140, and compression axis SSE-NNW P=152^0 and 74^0 dep. The focal mechanism solution of November 21, 1985 earthquake with Mw=5,6, generated from Lezha strike-slip, shows that this fault acts as a dextral transpression strike-slip stress axis P-207^o/30^o and T-94^0/33^0 [Muço B. 1994, Aliaj Sh. 2000]. This fault there presents the SW edge of Shkodra - Peja transversal fault zone in the internal domain of compressional regime. The existence of Lezha transversal as a important element, that cut and transfer the orogen front is testified not only from geologic-geophysical and seismological data, but also from GPS ones [Sulstarova et al, 2011].

Offshore geophysical explorations have discovered a deep fractures zone in the Adriatic Sea between Buna River discharge and Kotorri Estuary, about 15-20 km from coastline, with the NW strike direction. In this Adriatic ofshore area, near Albanian-Montenegrin border, at the northern side of the Shkodra - Peja fault zone, was located focus of earthquake, 15 April 1979. According to the scattering of his aftershocks, the focal dimensions are: longue 70 km and width 25 km. Focal zone, as a narrow belt, has a NW-SE strike direction from Ulqini city to Kotorri Estuary (Sulstarova E. et al. 2011). Thrust fault plane has a NW 500 strike direction, with NE 160 plunge, while slip vector has a NE 48^o direction, slipping angle $\lambda = + 16^0$, axis of the stress P=46^o SW with 28^o deep, and T=52^0 VL and 62^0 deep [Sulstarova E., 1983; Sulstarova E. et al. 2011].

The analyze of the seismic P waves velocities (Vp) and ratio Vp/Vs show that exist a difference 0,12-0.46 k/s between upper part of the Earth Crust (0-30 km) in the both side of the Shkodra-Peja fault zone [Ormëni Rr., 2010]. Such difference presents a 1,9-8,5 % of the Vp size. At the greatest depths, 30-45 km the difference is insignificant.

The stress field, the fault system and the spatial distribution of the seismic activity shows that the Albanian territory and the surrounding areas is constructed by many blocks which move relatively to each other due to the collision of two great plates, the Eurasia and African ones, in the region of the Adriatic promontory of African plate [Sulstarova et al. 2011].

All seismological features indicated above argues that Shkodra-Peja transversal present a deep fracture, a relatively wide active fault zone that separates the paleogeographic units with different geological settings, and dynamic of their developments.

3.5. Heat Flow density anomalies

Geothermal studies at Northern Albania have been performed in 19 boreholes and in one deep well. As for the whole territory of Albanides, even in northern their part extends Heat Flow Density anomaly. Their axes are presented in Fig. 3. There are there heat hearths. Two of them, in Ragami in Tropoja and Karma-Palaj are located in the unic axis, which extends from northeast to southwest, over the overthrust tectonics in the northern border of the ophiolitic belt. Thirty axes is located in Keçel village in eastern site of the Kukesi ultrabasic massif. The heat flow density values are up to 60-70 mW/m^2. Radiogenic heat generation of the ophiolites is very low. In these conditions, increasing of the heat flow in the ophiolitic belt is linked with heat flow transmitting from the depth. Ophiolitic belt Heat Flow Density highest value can be explained by the small thickness of the geological section down to the top of crystalline basement, and MOHO discontinuity. The granites of the crystalline basement, with the radiogenic heat generation, represent the heat source. Heat flow anomalies are conditioned by intensive heat transmitting through deep and transversal fractures. Distance between trace of the Shkodër - Pejë thrust and thermal anomaly axis is 9 km. Thermal anomaly is located on the mounted side of the fracture, where the crystalline basement top is located in lower depth than on the sitting side of the fracture.

By comparing these characteristic of the thermal field and zone geological setting with structure of the strike-fault system in southwestern side of the Shkodër - Pejë transversal in Adriatic Shelf, we assume that this thermal anomaly associated with the branches of transversal fracture.

3.6. Offshore geothermal information

Heat flow density anomaly in the Adriatic See shelf, has been presented "Geothermal Atlas of Europe", 1992, (Fig. 15). The thermal anomaly over the Adriatic Shelf, with epicenter in Drini Bay is linked with Adriatic strike-slip fault system. In the same time, this thermal anomaly epicenter is located over the prolongation into Albanian Adriatic Shelf of Shkodër - Pejë transversal deep fracture. These facts show that the Shkodër - Pejë transversal deep thrust continues even in the Adriatic Shelf, where interrupted with Adriatic longitudinal strike-slip fault system. Over their intersection node is located thermal anomaly, which is linked with heat flow from Crystalline Basement through these deep fractures.

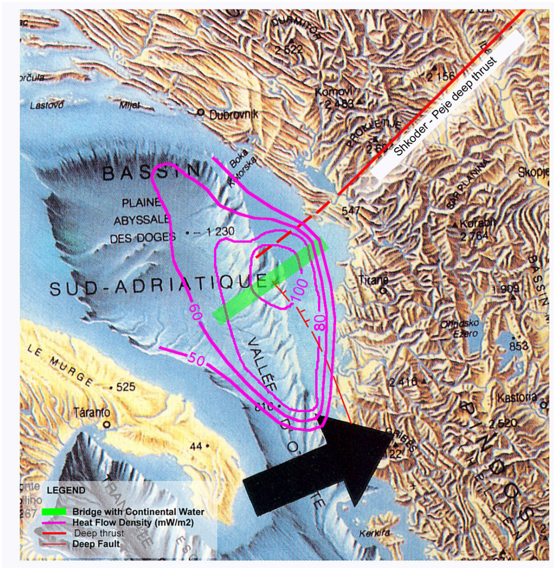

Fig. 15. Adriatic Heat Flow Density Anomaly [Geothermal Atlas of Europe, 1992] (a), and correlation of the thermal anomaly with trace of the Shkodër-Pejë transversal deep fracture (b).

3.5. Remote sensing and GIS information

First study by Landsat imagery, conducted Chorowich J., Cadet J.P. and Stephan J.F. [Chorowich J. et al. 1981], for disjunctive tectonics in Northern Albania, include Shkodër - Pejë transversal fault. In fig 16 are presented a sketch of thrust tectonic in Northern Albania, which differenced clearly main segments of Shkodër - Pejë transversal fault.

Fig. 16. Major tectonic accidents in northern and southern side of the Shkodër-Pejë transversal accodin to the landsat data [Chorowich J. et al. 1981]

Based on GIS and seismological investigations are determined velocities of microplates movement in Adriatiuc Sea. Nubia (Africa) microplate is moving NW with respect to Eurasia with a velocity of 6 mm/yr, while the Adria microplate moves NE at a rate of 4-5 mm/yr (Fig. 18) [Battaglia M. et al. 2004]. For Nocquet J.M., Adriatic is an independent microplate within Nubia – Eurasia plate boundary one [Nocquet J.M. et al. 2001]. Oldov et al. (2002) propose that Adria is divided by Gargano-Dubrovnic fault in two blocks. Northern Adria has little or no motion relative to Europe and its part of Alpine collage of Southern Europe. Southern Adria is moving with Nubia and is continuous from Sicily to Apulia, [Oldov J.S. et al. 2002].

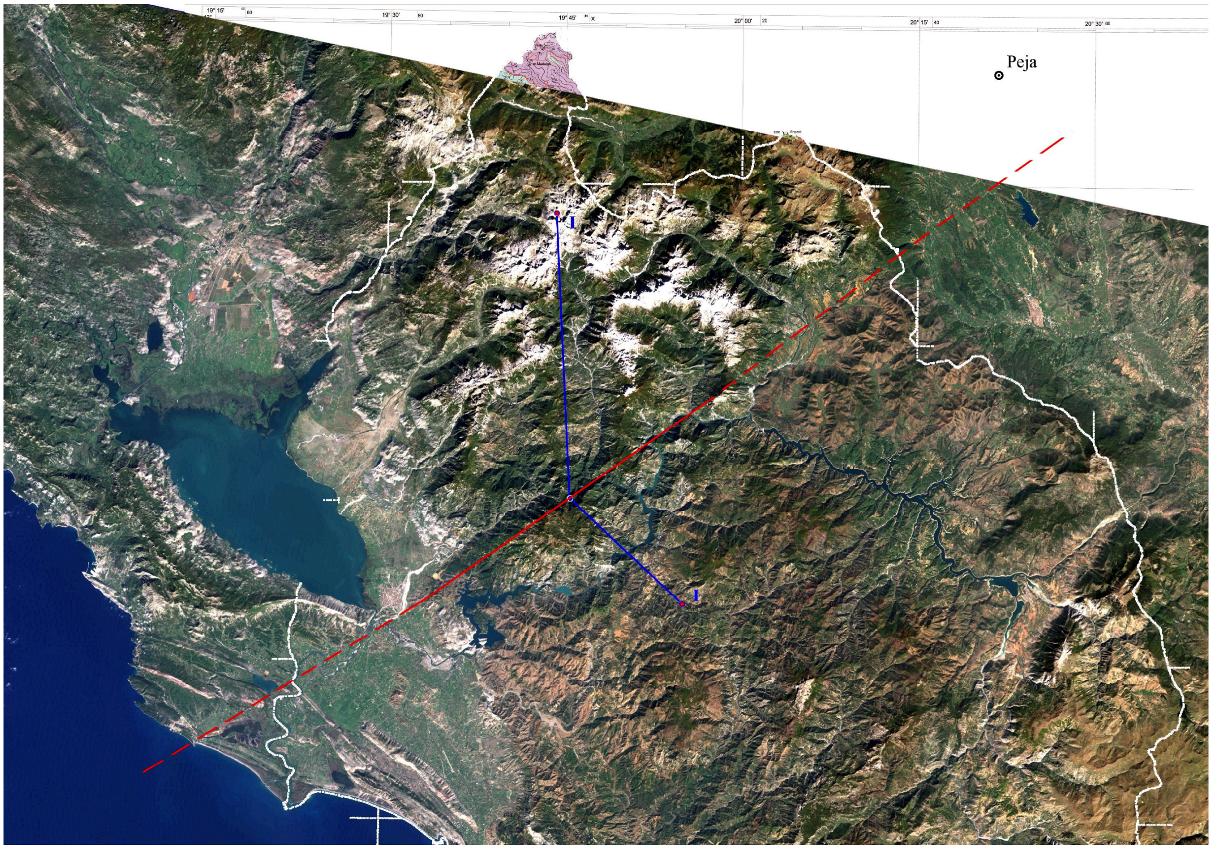

Fig. 17. Satelite image of Shkodër-Pejë transversal fault at Northern Albania.

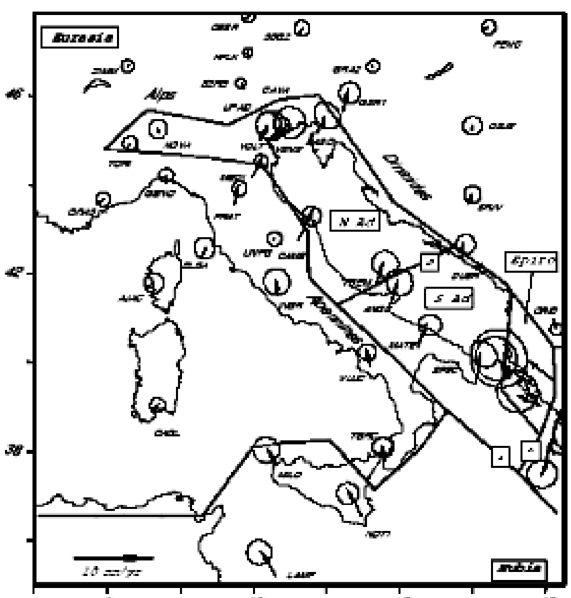

Fig. 18. Location of the segments (solid lines) and blocks used to model the Adriatic Region. [NAd] North Adria, [Sad] South Adria, [G] Gargano-Dubrovnik fault zone, [K] Kefallinic fault zone, [A] Apulia escarpment. GIS velocities and their 95 confidence ellipses. The grey dots indicate the location of the shallow seismicity from 1975 to 2000 (M>3.5) [Battaglia M., et al. 2004].

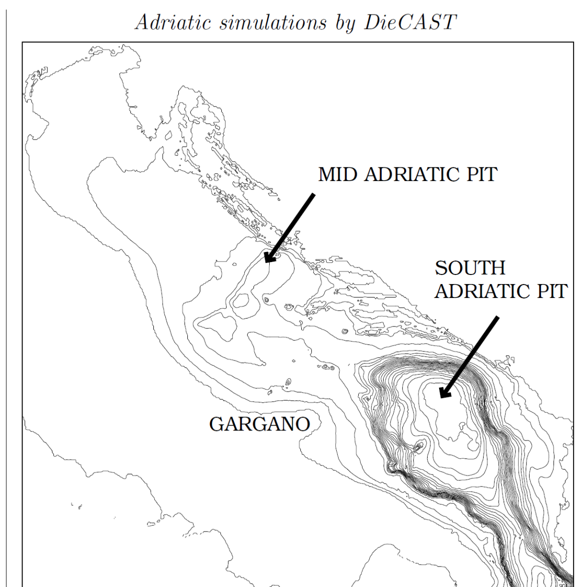

Figure 19. Contour plot of the bathymetry of the Adriatic Sea with horizontal resolution of 1 min. The Mid Adriatic Pit is the relatively deep region which nearly transects the Adriatic. The contour interval is 50 m. [Dietrich D., et al., 2002].

In the frame of these interpretation data is necessary to discussed also the position of NW edge of Otranto Street, which is located in the direction of the Shkodër-Pejë deep transversal fault in the eastern Adriatic Shelf, that result parallel with Gargano – Dubrovnic fault zone (Fig. 19).

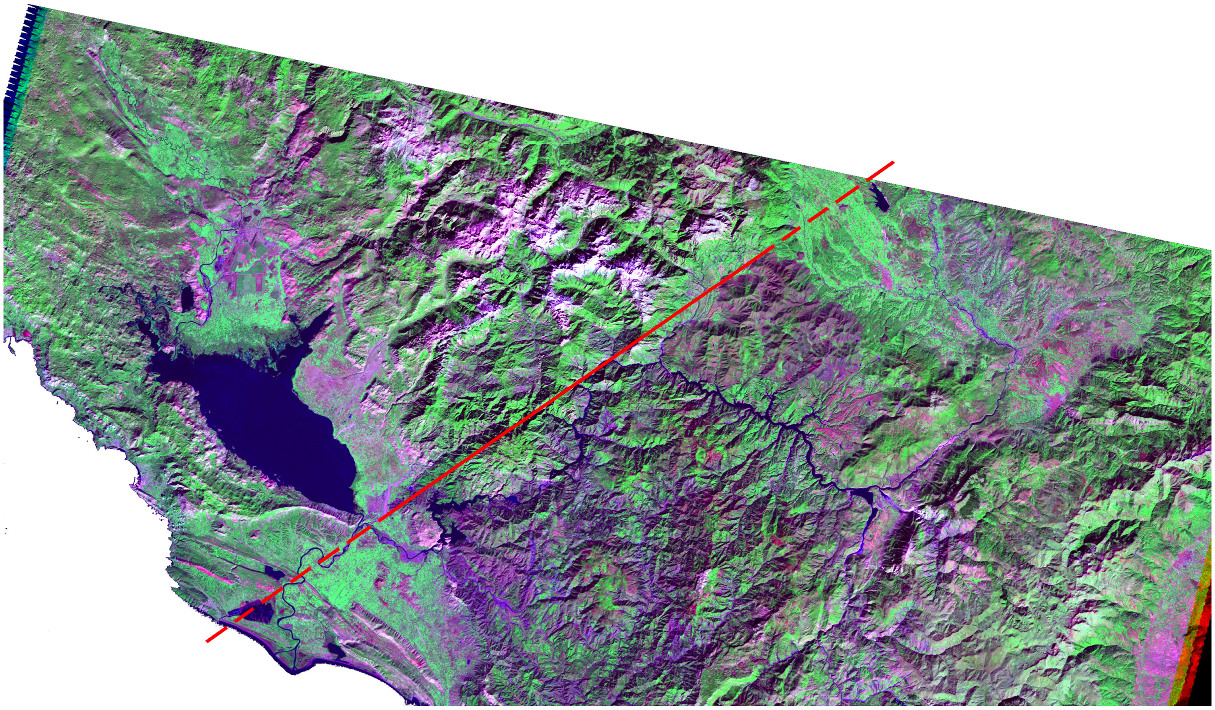

Fig. 20. Combination of Landsat bands 7 ~ Red, 4 ~ Green, 2 ~ Blue.
Green areas represent the vegetation coverage.

Usage of satellite imagery for identification of geological structures resulted difficult because of two factors: vegetation coverage of the area and soil coverage of rocks. Nevertheless in different band combinations from Landsat it is possible to distinguish two areas separated during the same delineation of Shkodra – Peja fault (Figure 20 represents in false colors the area from Landsat7 images with the band 7 as Red, band 4 as Green and band 2 as Blue).

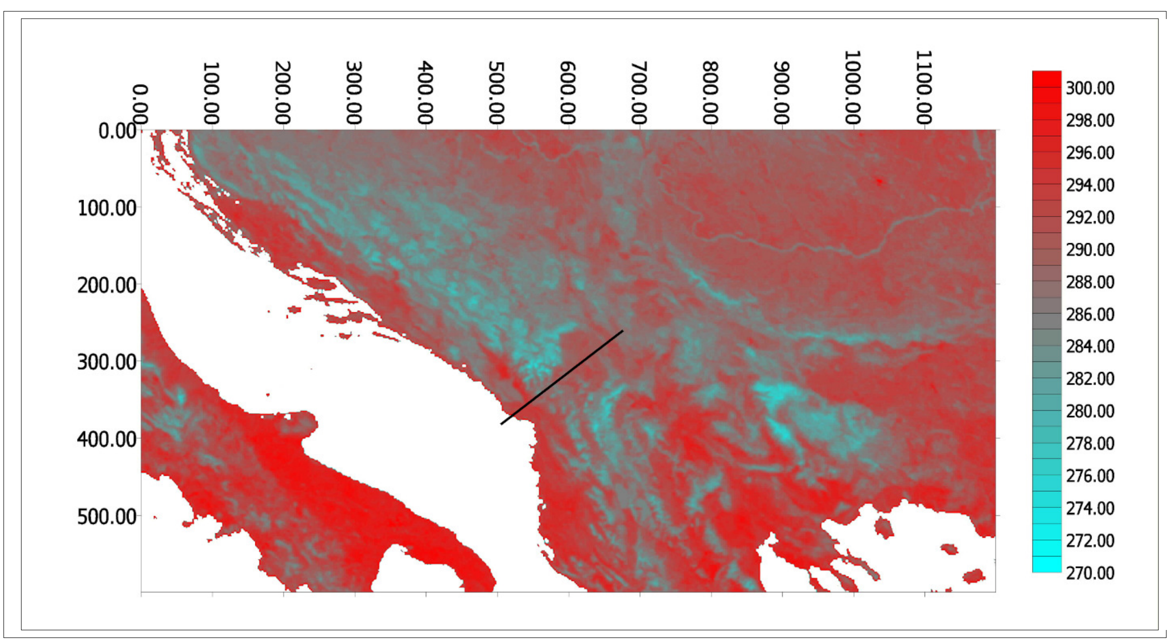

Fig. 21-a. Average of daily ground temperature for the period 2004 – 2006 from MODIS images

Analysis of ground temperature from MODIS images was done calculating the average for day and night temperatures from 24 images spanned in the period 2004 – 2006. In these images it is visible a “bridge” of relatively higher temperature delineated between Shkodra and Peja (Fig. 21).

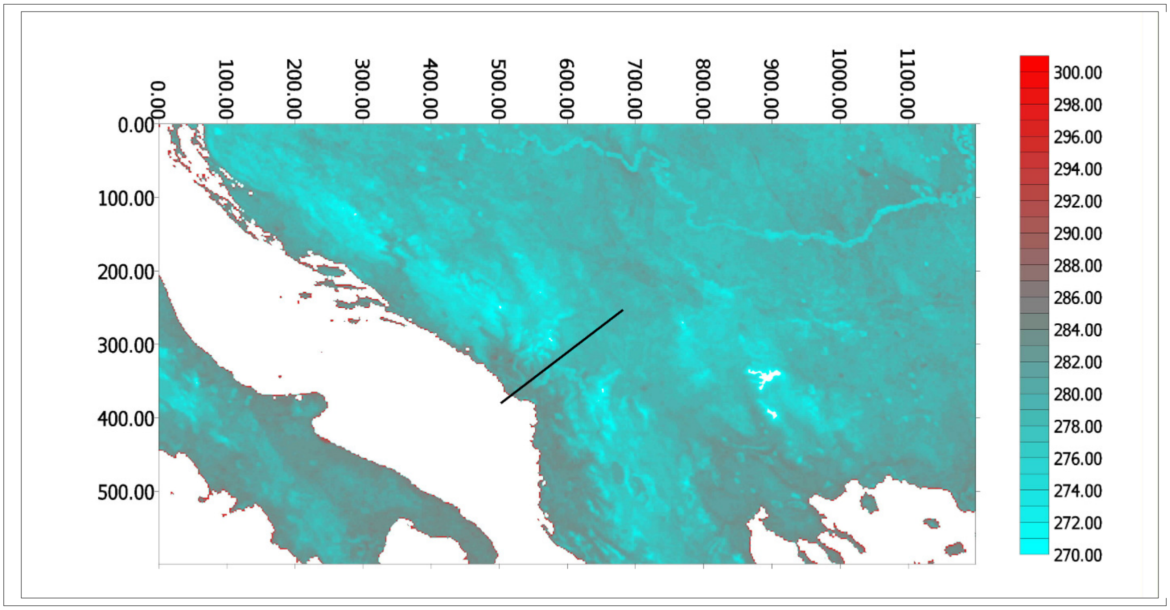

Fig. 21-b. Average of night ground temperature for the period 2004 – 2006 from MODIS images

At the end of our analysis on the Skoder-Peje transversal thrust we find reasonable to confront our results with new reference of the model for European crust, EuCRUST-07 (Mahdala Tesaauro et al. 2008). As is evident from Fig. 22 , which represents map of Moho depth, is very clear existence of the transversal Shkodër-Pejë belt with reduced Moho depth, which is a determining argument for the presence and nature of its.

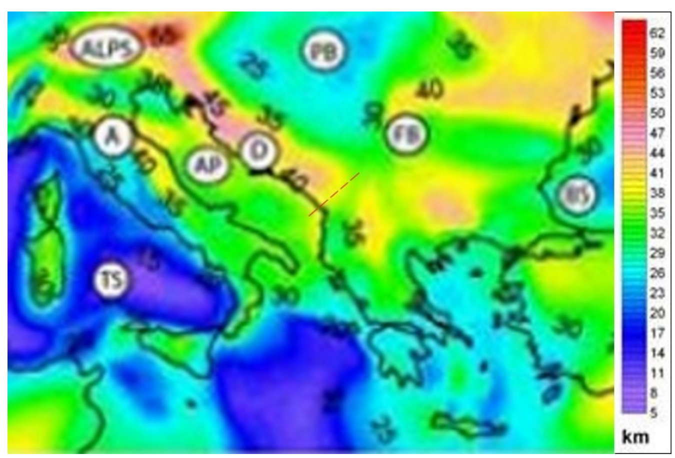

Fig. 22. Moho depth (km), EuCRUST-07: A new reference for the European crust (Teasuro M. et al. 2008)

4. Conlusions

1. Earth Crust of the Albanides exhibits a block structure controlled by a system of NW-SE longitudinal faults as well as transverse ones. The blocks have different thickness.
2. According to the gravity data inversion, Shkodër-Pejë zone present a vertical deep transversal fracture, which separate two Earth crust blocks. Fracture interrupts the MOHO Discontinuity with amplitude about 4 km that decrease towards the Earth surface. This fracture represents a

seismically active belt. Based on satellite image, this vertical fracture outcropped through Cukali subzone.

3. 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. Shkodër-Pejë transverse fault represents a transition zone between the clockwise rotation of the Albanides and Hellenides and the counterclockwise of Albanian Alps on e and Dinarides. For the rotation pole located at Shkodër-Pejë transverse fault, the horizontal displacement is about 173 Km in Southern Albanian border.

4. Continuation of Shkodër-Pejë fracture in the Albanian Adriatic Shelf in Drini Bay passes over the epicenter of Heat Flow. This correlation argues relation of the geothermal anomaly with depth fractures of the Earth Crust in Adriatic Shelf.

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