Tectonic style and hydrocarbon evaluation of duplex Kruja zone in Albania

T. Velaj

PRELIMINARY COMMUNICATION

Albania belongs to the Dinaric-Albanid-Hellenides arch of alpine orogeny. There are four main geological units (Fig. 2): autochthonous foreland, foredeep basin, inner and external Albanides. The Kruja zone is included in the External Albanides.

The Kruja thrustbelt consists of a succession of tectonic duplexes. From tectonic point of view this zone represents orogen, but with shallow water carbonates facies. It is represented by some anticlinal structural lines which are tectonically faulted in their western flank. Western edge of this zone is complex due to regional overthrust faults, which have caused their overthrusting above the South Adriatic basin with amplitude of about 70-100 km. A folded zone with high perspective plays must have developed, which is an analogue scenario as the Apennines overthrust in Italy. The stratigraphic section of the Kruja zone comprises: Upper Cretaceous to Paleocene-Eocene platform carbonate sequences; the Oligocene-Aquitaine deposits are represented by flysch-flyschoidal sandstone-clays-silts with underwater slumping horizons and organogenic-clastic limestones; nonconformity Tortonian -Pliocene molasses deposits.

From petroleum point of view, numerous surface oil seeps occurred there along the Neogene nonconformity in Tirana piggyback basin. The seeps confirm the existence of a currently active petroleum system in this area, but no commercial hydrocarbon accumulation has yet been found. Many exploration wells with target being carbonate structures and Neogenic sandstones have been drilled in this zone. In the Kruja zone, the source rocks horizons were proved to be related to Upper Cretaceous deposits. Oil and gas accumulations in Albania occur both in carbonate (Cr_2 –Pg_2) and clastic reservoirs (N_1^{3t} – N_2^P).

Key words: Albanides, Kruja zone, Tirana piggyback basin

1. INTRODUCTION

The Abanides are located between the Dinarides in the north and Hellenides in the south. This range is included in north-eastern edge of the African plate, which has already undergone orogeny, (Fig. 1).[6]

There are three main geological units on Albanian territory. (Fig. 2):

1. The autochthonous foreland Apulian platform (Sazani zone in Albania) has the form of a regional monocline, folded in its eastern part and unfolded in its western one (Fig. 3, 6, 7, 8). It is extended to Adriatic and Ionian Sea (offshore) and partly onshore under Periadriatic (PAD) depression and South Adriatic basin. It is an autochthonous unit and is partly underthrusted by the orogenic units (Ionian and Kruja zone).The Sazani zone is characterized by slope to platform carbonate facies (Cr1 - Pg2), with thick sequences of well -bedded ruddist-bearing Cretaceous biocalcarenites. Unconformable Burdigalian ($N1^{1b}$) (Fig. 2) clastic confirm relatively late flexural subsidence for Sazani zone.

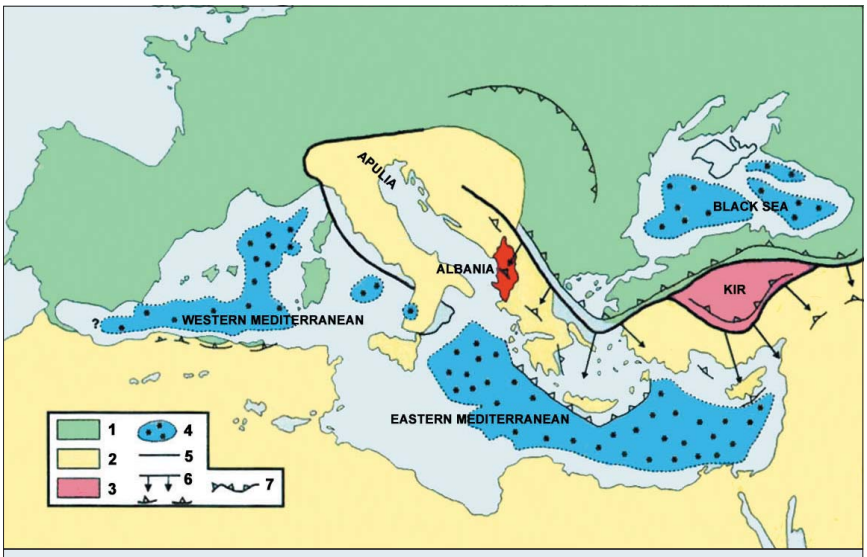

Fig. 1. Schematic map of African plate subduction under Eurasia (after Ricou, 1986)
LEGEND: 1 - Euro-Asiatic Continent; 2 - African continent; 3 - Kishir block; 4 - Present Oceanic Basins; 5 - Boundaries of Mesozoic Oceans; 6 - Boundaries of Mesozoic Ocean and the Main Ophiolithic Nappes; 7 - Troughs of present and past subduction.

Sl. 1. Shematska karta podvlačenja Afričke ploče pod Euroaziju (prema Ricou,1986.)
LEGENDA: 1 - Euro-Azijski kontinent; 2 - Afrički kontinent; 3 Kishir blok ; 4 - Današnji oceanski bazeni ; 5 - Granice mezozojskih oceana ; 6 - Granice mezozojskog oceana i glavni ofiolitski pokrov, 7 - Trogovi sadašnjih i prošlih podvlačenja

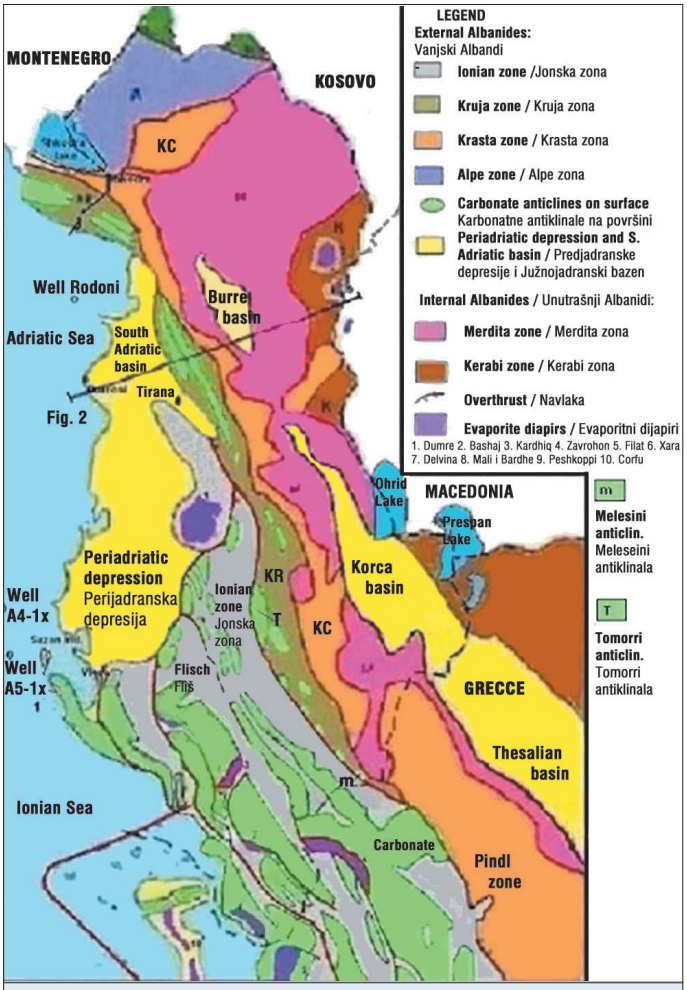

Fig. 2. Tectonic map of Albanides and carbonate structures in Ionian and Kruja zones
Sl. 2 . Tektonska karta Albanida i karbonatne strukture Jonske i Kruja zone

2. Albanide orogen that is divided into two parts:

a) Internal Albanides with two tectonic zones: Korabi (Pelagonia in Greece; Golia in Serbia) and Mirdita (Subpelagonia in Greece; Serbian in Serbia), which are characterized by the presence of ophiolites (Upper Jurassic), many folding phases (Upper Jurassic, Eocene etc.) and a total allochtony (Fig. 3).

b) External Albanides include the tectonic zones : Sazani zone (Preapulian zone in Greece and Italy), Ionian (Ionian in Greece), Kruja (Gavrovo in Greece, Dalmatian in Montenegro), Krasta-Cukali (Budva in Montenegro, Pindi in Greece), and Albanian Alps (High Karst in Montenegro, Parnaso- Kiona in Greece). There is an overthrusting of all the tectonic zones westward, which partly mask each other. The overthrusting scale may be over 50 - 100 km. (Fig. 3).[11] The overthrusting of tectonic zones of orogenetic front above the western autochthon (Apulian platform and South Adriatic basin) has masked the structures with large dimension and high perspective (Fig. 3,6,7).

3. The Periadriatic depression represents the basin between the External Albanides orogenetic belts and Apulian platform (Sazani zone in Albania).

The whole post carbonatic deposition is represented by a terrigenous sedimentation (Molasses of Serravalian-Tortonian-Messinian-Pliocene). Its positioning and distribution were definitely performed in a basin, included in South Adriatic basin. The basin overlies Ionian zone in south-east and the Kruja zone to the far east (Fig. 4). From south-east to north-east, the thickness of the molasses increases, reaching 5 000 - 7 000 m in north of Rodoni area (offshore). By the time that the South Adriatic basin deposits were formed and folded, the adjacent carbonatic structures of the Kruja zone, as a result of intensive submerging of the South Adriatic basin, were "absorbed" towards the north-east and were rotated anti-clockwise, increasing their tectonic complexity degree and replacement in the west. One of the consequences of the movement of orogenetic

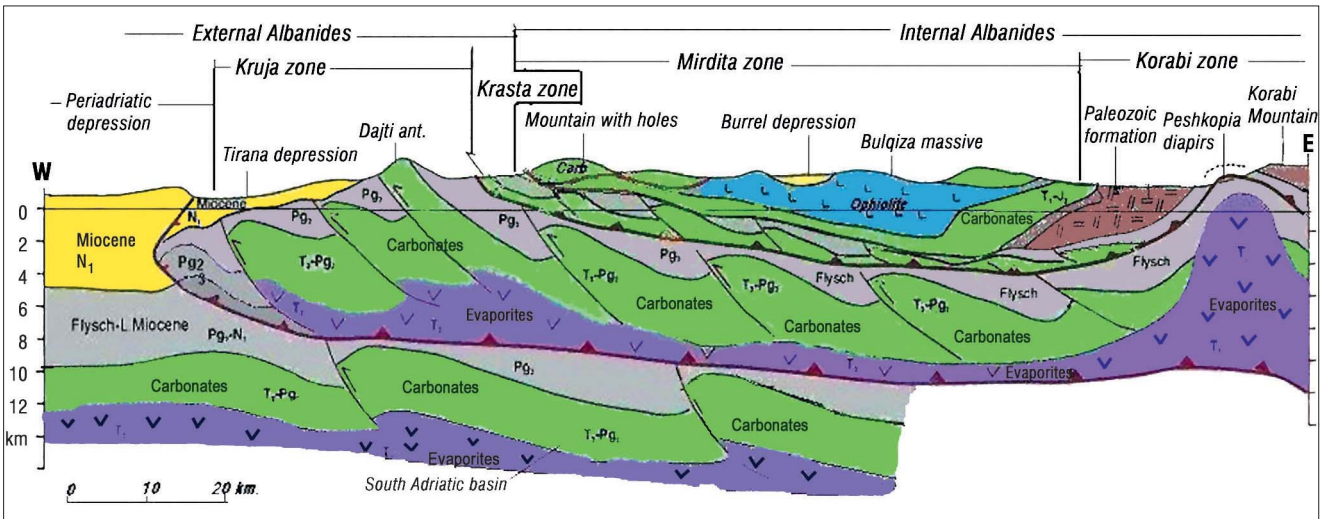

Fig. 3. Schematic geological cross-section through the Albanides and South Adriatic basin
Sl. 3. Shematski geološki profil kroz Albanide i Južnojadranski bazen

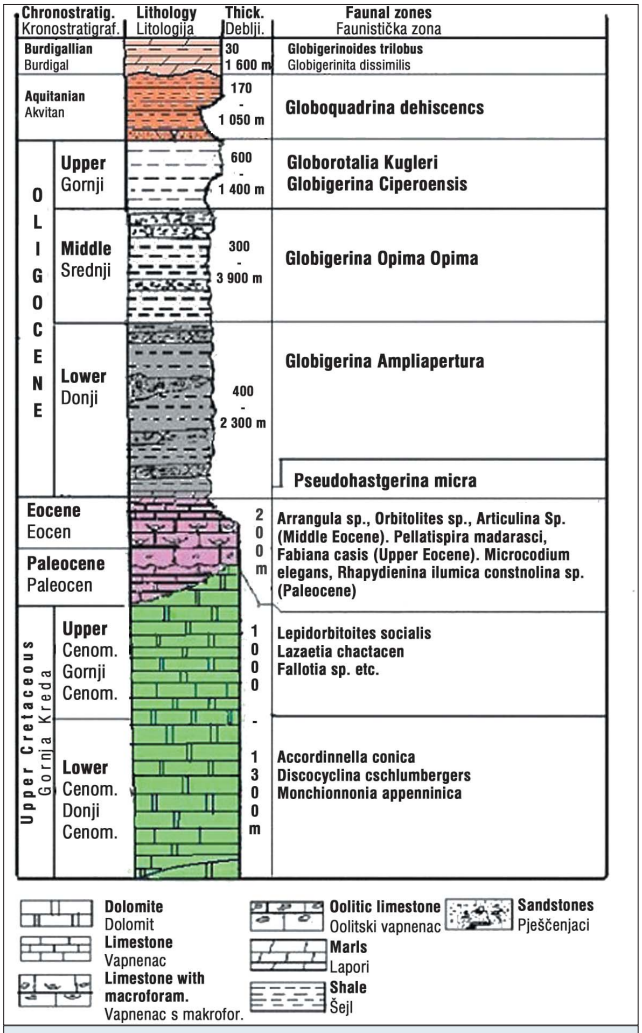

Fig. 4. Lithological and stratigraphic section of the Kruja zone
Sl. 4. Geološki i stratigrafski presjek Kruja zone

front at the same time with sedimentation ($N1^{3t}$ - $N2^{p}$) has caused the formation of a regional backthrust tectonic incident in the eastern edge of South Adriatic basin (Figs. 3,6,7,8) and secondary folding in flysch deposits (Rova, Papri, Fortuzaj).

2. GEOLOGICAL SETTING

The Kruja zone is included in the External Albanides (Fig. 2) and is overthrusted westward in the South Adriatic basin, Periadriatic depression and Ionian zone (Fig. 3). Also it is largely masked by Krasta tectonic zone (Fig. 3). It is composed mainly of carbonate deposits (Cr_2-Pg_2) of neritic facies, which changes to mixed facies (pelagic and neritic) westward (Ishmi anticlinale) and southward.

(Melesini anticlinal) (Fig. 2,3). From tectonic point of view, it represents an orogenic unit which is analogous in south (Greece) Gavrovo zone and northward (Montenegro) to Dalmatian one.

According to geological data, the Ionian zone does not have continuation in north of Dumrea region (Fig. 2).

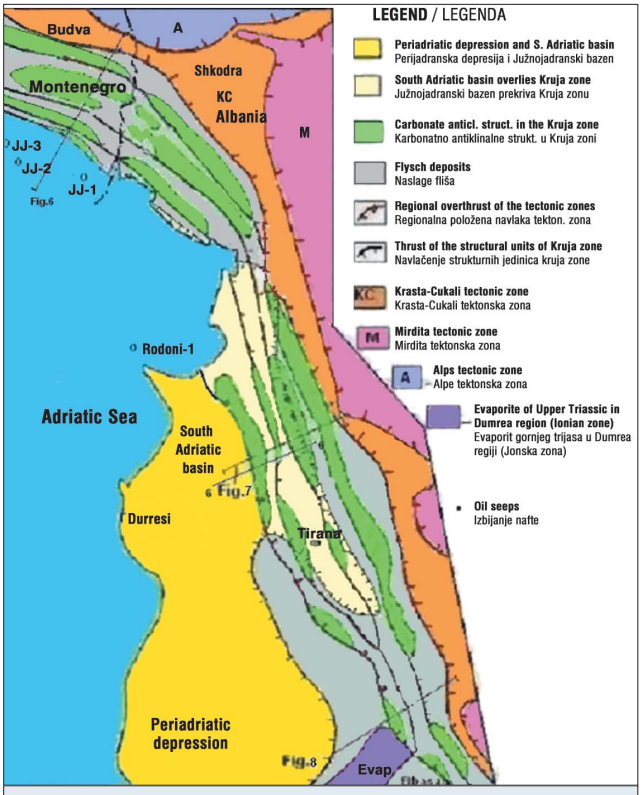

Fig. 5. Tectonic map of Kruja tectonic zone
Sl. 5. Tektonska karta Kruja zone

3. REGIONAL GEOLOGICAL TECTONICS FEATURE OF KRUJA ZONE

It consists of the succession of tectonic duplexes which might have been detached along intro-Cretaceous (Cr_1) decollement level probably consisting of evaporites, known to occur in Montenegro. The stratigraphic section of Kruja Zone comprises (Fig. 3):

1. Upper Cretaceous to Paleocene-Eocene neritic carbonate sequences related to shallow-water. They consist of dolomites, limestones with rudistes etc, detritus limestones, rich in miliolides and textularides with frequent hiatus, emersions; erosional surface and even bauxite horizons. The deposit of carbonates facies changes toward west (Ishmi) and south (Tomorri ant.) into mixed (neritic and pelagic one). More to the south (Melesini ant.) (Fig. 2) the carbonates are completely basin facies. There are different ideas about the age for the evaporite facies encountered by drilling in the Dalmatian zone (Montenegro):

a) It belongs to Lower Cretaceous[2] but without biostratigraphic data.

b) It belongs to Upper Triassic[11], these kinds of rocks are not encountered in Albania region at present.

2. The Oligocene flysch sequence confirms the development of a Paleogene foredeep basin, sourced by the erosion of early emplacement of tectonic units in the east which inducted a coeval flexure of Kruja zone. The Kruja

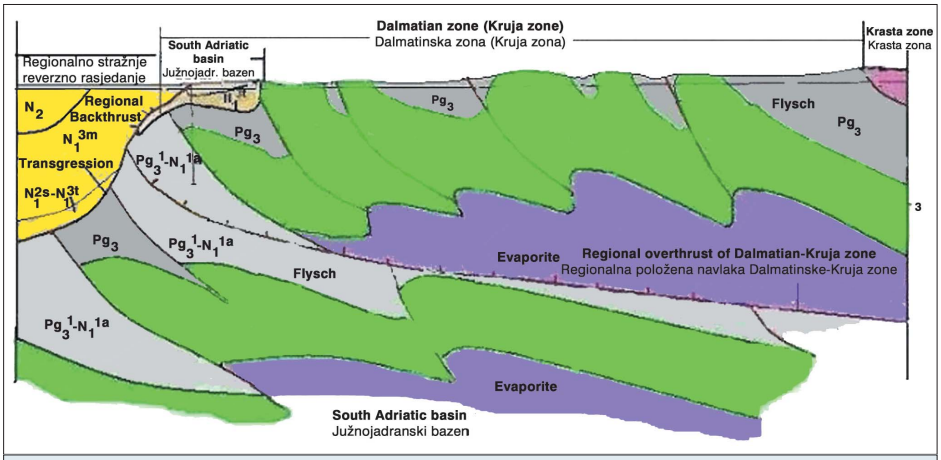

Fig. 6. Schematic geological cross-section in Ulcinj region (Montenegro)
Sl. 6. Shematski geološki profil u području Ulcinja (Crna Gora)

region in the Lower Oligocene was filled with flysch deposits reaching a thickness of 3 000 to 4 000 m. The Oligocene-Aquitanian is represented by intercalations of flysch-flyschoidal sandstone-clays-silts with underwater slumping horizons and olistoliths of organogenic-clastic limestones (Cr_2-Pg^{1+2}), which became thicker and coarser eastward and upward (Fig. 4).

3. Unconformity of Tortonian molasse deposits which lies on the top of the major structures and locally seals off the thrust contact between successive duplexes, is composed of Mesozoic carbonates and Oligocene flysch (Fig. 5,6,7,8). They represent a Neogenic piggyback basin (Tirana depression) between the west-verging overthrust of the Dajti units and regional east-verging backthrust involving the Pliocene terrigenous fill of the Periadriatic Depression.[7] The Western flank of Tirana piggyback basin is composed of a range of hills with very steep slopes and geological strata with 90° dip (Fig. 7).

In Montenegro, this zone belongs to Lower and Upper Cretaceous (carbonate and anhydride rocks), Eocene (clastic and carbonates), Oligocene-Miocene and Pliocene (flysch and molasses clastics).[2]

From tectonic point of view, the Kruja zone is represented by developed tectonics and it is composed of some structural lines which are faulted in western flank and complicated by a regional fault with amplitude around 70 - 100 km westward. This fault, which is of overthrust type, separates Kruja zone from South Adriatic basin (Fig. 5), masking perspective structures.

Thrust and overthrust faults occurred during the collision stage (J_3-$N1^{2S}$), and they acquired their more or less conclusive form in Kruja tectonic zone (Fig. 3,6,7,8). The tectonic faults developed together with sedimentation and fold-formation processes. The fact that the neogenic piggyback basins ($N1^{3t}$–N^{2p}) are not touched by tectonic faults of carbonate structures (Fig. 3, 6, 7, 8) shows that they have completed their tectonic activity before Serravalian ($N\ 1^{2S}$).

The westward thrust processes of all the structural units of Kruja zone continued in the post collision phase (N_1^{2S}- Q). This was in accordance with the formation of new fault planes (Fig. 6,7,8). As a result of this action, which continued with variable intensity in time and space, flysch deposits of the folded subthrust complex are "brought" in western margin of the thrust Kruja sheet, exposed in the form of rootless folding (Fig. 3,6,7,8). Their roots represent perspective structures of the subthrust (Fig. 6,7,8).

The tectonic of diverse structural units associated with them and with Tirana piggyback basin caused also the folding of neogenic deposits of South Adriatic basin. These folding are of SE-NW trend, showing similarity with the folding of carbonate structures, which gives evidence for their formation -mechanism from compressive regime of carbonate orogenetic front.[8] In the north part, from Elbasani northward, the Kruja zone consists of linear anticlines, which extend in form of structural range. From North (Ulcinj, Montenegro) toward south the structural ranges decreased, from five structural ranges

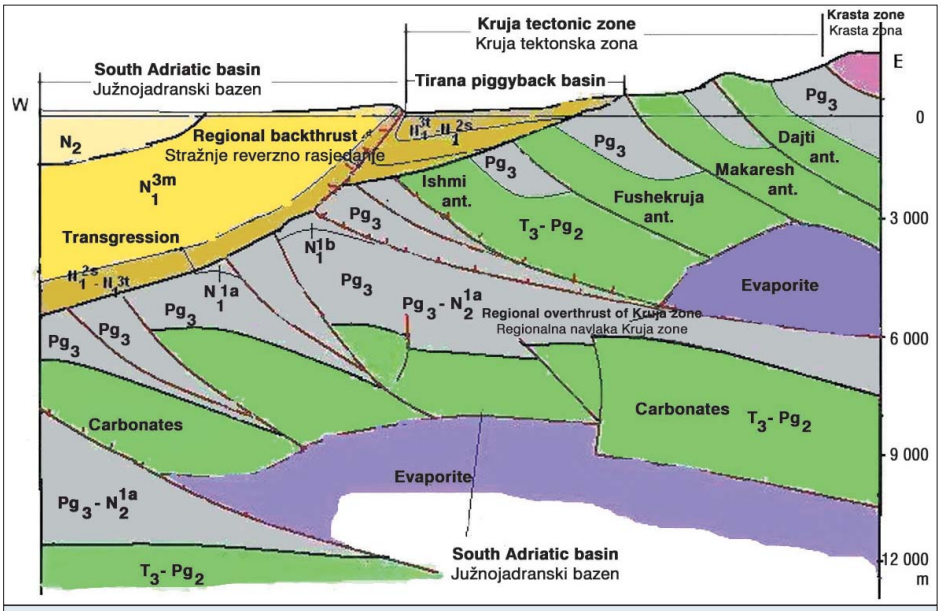

Fig. 7. Schematic geological cross-section in Ishmi area
Sl. 7. Shematski geološki profil područja Ishami

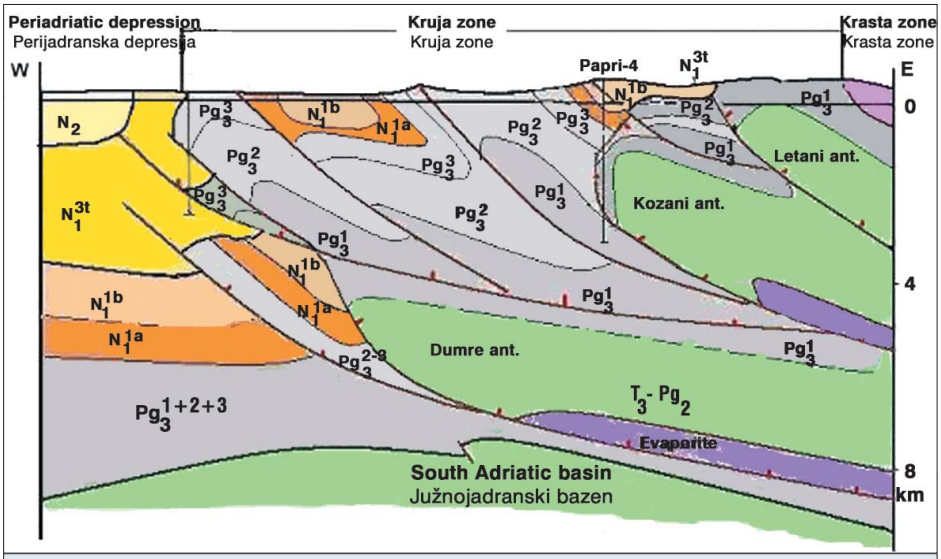

Fig. 8. Schematic geological cross-section in Kozani area
Sl. 8. Shematski geološki profil područja Kozani

(Ulcinj) to four in Ishmi region (Dajti, Makareshi, Fushekruja, Ishmi) continuing only with two structural ranges in Elbasani region (Dajti, Kozani) (Fig. 5).

They are tectonically interrupted by a regional overthrust fault, which has caused overthrusting of Kruja zone and underthrusting of Southern Adriatic basin (Fig. 4,6,7,8,9) with amplitude of about 70-100 km. The South Adriatic is basin represented by folds, with possible structural traps in limestone formations, with very high perspective for hydrocarbon exploration (Fig. 3,6,7). This overthrusting tectonic occurred during the orogenic processes starting in Oligocene to pre-Burdigalian age. During this time, as the result of the continuous development of movements toward the west, Kruja zone has folded and emerged. This global overthrusting occurred as a result of a tectonic plane that corresponds with sliding level of evaporites (Fig. 3,6,7).[14] The form of this regional overthrust is convex (SE-NW), which mostly advanced in the Ishmi zone (Fig. 5, 6). Several secondary faults can be distinguished between main faults (Fig. 6,7), complicating the seismic images with different diffraction waves. As a result, some positive structures in flysch deposits were created (Papri to Rodoni) (Fig. 5,7,8).

During the molasses cycle, the structures and structural ranges of Kruja zone have increased the thrusting scale as a result of powerful tectonic development. During this period, the Kruja zone moved creating a new tectonic regional fault. (Fig. 6,7,8). This phenomenon has often formed some tectonic blocks (inside the carbonatic section) of imbrication type.

Westward wedge-form movement of carbonate mass at the time when sedimentation occurred during the Upper Miocene-Pliocene(N_1^{3t}- N^{2p}), has caused the formation of a regional backthrust in the eastern margin of the Neogene deposits of the South Adriatic basin in contact with Tirana piggyback basin (Fig. 3,7). This backthrust has a regional character beginning in the south of Tirana area and continuing to the north in the western border of Dalmatian zone in Montenegro.[10] Lithofacies of South Adriatic basin became much more varied and complex as a result of Neogene activity. Rapidly, subsiding syntectonic foredeep basin began to develop in front of advancing thrust sheets. Widespread terrigeneous clastic deposition occurred in early Neogene and thick turbidites sequences filled the foredeeps. In late Neogene (Pliocene), after the main Miocene tectonic phase, the sedimentary fill was affected by thrusting and folding and a postorogenetic sequence several kilometers thick accumulated in localized areas. Synsedimentary tectonics and high sedimentation rate contributed to preservation of organic matter accumulating in marine sediments under largely oxidizing conditions. The large volume and wide geographic distribution of these rocks make them potential source bed of primary importance. About 80% of the gases in Pliocene reservoirs of the South Adriatic basin in Albania (Divjaka, Povelca, Frakulla, Kryevidh, Ballaj etc.) were generated by bacterial action on the immature organic rich shales associated with the reservoirs.[15] Some other tectonic events occurred during the developing of Kruja zone along the molasses cycle besides the phenomenon mentioned above:

a) Some tectonic faults in front of this big overthrust inside of flysch, flyschoidal and molassíc were created. According to the surface geology, in the western wedge of Kruja zone a narrow flysch belt was encountered, rather folded and associated with thrusting faults, which indicates the presence of underlying carbonate structures. However, this flysch has lost its relationship with carbonate roots (Fig. 3,6,7,8).

b) At the same time the Tirana piggyback depression is formed (from Tortonian to Pliocene deposits).The transgression phenomenon dips from south to northward with lot of pinch out in this thickness.[11]

c) In the southern part, from Elbasani to the south, Kruja zone consists of smaller structures and structural ranges which continue in two lines (Tomorri and Tervolli). In this region, the Kruja zone is divided from the Ionian zone by a tectonic fault of overthrust type with a throw smaller than that in the north (Fig. 2).

4. HYDROCARBON EXPLORATION

Although no commercial hydrocarbon accumulation has yet been found in the Kruja zone, numerous surface oil seeps have occurred there along the Neogene nonconformity (Thumane, Burizane etc.) in Tirana piggyback basin. The well JJ-1, on the northern margin of Albanian foredeep, in Montenegro offshore, has had gas show in Oligocene sequence (flysch). Also numerous oil seeps

have occurred in Cretaceous carbonate along the Dalmatian coast of Montenegro and the JJ-3 well (4 605 m deep) had good oil show within shallow water Eocene - Cretaceous carbonate sequence. Oil was found at a depth of 4 134 m and in total of 167 bbl/d (26.5 m^3/d) during one test. In spite of that, no commercial discoveries have been made to date in this region.[3] This is in contrast with the Apennic side (Italy), where significant oilfields have been found in both thrustbelt and platform subthrusts (Monte Alpi, Tempa Rosa, Rospo Mare, Aquila, Falco etc.).[1]

The exploration of the thrust sheet of Kruja zone was considered with high risk mainly due to structural conditions. The most of carbonate anticline structures are eroded in the top (Makaresh, Fushekruja, Ishmi, Kozani, Dajci etc.) and do not necessary seal for accumulation of hydrocarbons. Other negative factor is that all the anticline structures of Kruja zone are set up in structural line very prolonged without distinct periclines and of very small strike direction closure (Fig. 5). It is very important to underline that in future exploration effort in Kruja-Dalmatian thrust sheet needs to change towards the carbonate of the eastern part of South Adriatic basin (Fig. 6,7,8,9).

These seeps confirm the existence of a currently active petroleum system in this area. The source horizon is proved to be related to Upper Cretaceous deposits, which is most likely to be situated in oil window in nearby underthrust synclines. The analyses performed for this source rock horizon show that TOC ranges from 0.664 to 1.05. The Hydrogen Index Values (HI) as well as the maceral components show that the organic matter belongs to the type I/II able to generate liquid hydrocarbons. The vitrinat Reflectance = 0.338 to 0.403 show that the organic matter has just started maturation. Deeply buried Cretaceous source rocks (SR), analogue to those related to Southern Apennines discovery are modeled to generate the necessary light oil, trapped in fractured shallow water carbonates reservoirs and sealed by Oligocene flysch.[12] The flysch and flyschoides deposits of Kruja zone, based in the maceral components (where the oxidized and wooden components predominate) as well as on average value of HI= 71 mg Ho/gr. show that their organic matter is able to generate gases hydrocarbons.

The oil and gas accumulations occur both in carbonate and clastic reservoirs in Albania. Typically the carbonate reservoirs have low matrix porosity. However, their storage capacity is largely improved by the presence of open fractures. Some regional studies for the Kruja zone indicate that the carbonate reservoirs are of the same age as those of the Ionian zone: Upper Cretaceous-Paleocene-Eocene age. The analysis performed at the outcrops samples, shows that the open porosity is 5-8% and the fracture porosity is 1-3%.[12] Considering the fact that those reservoirs in Kruja zone belong to neritic platformic facies, good to excellent reservoir properties are expected to be found there. Although no oil has yet been produced from Cretaceous carbonate reservoir here, all the above data show that carbonate facies of the thrust sheet of Kruja zone has hydrocarbon potential. The big problem is the closure of the carbonate anticlinale structures, which is very small in the entire Kruja- Dalmatian thrust sheet. If in future, any carbonate structure with big closure in strike and dip direction are to be found, they will most probably be oilbearing.

The geochemical indexes of the organic matter for the Serravalian-Tortonian deposits in South Adriatic basin such as: HI 34.8 mg Hc/g,Vitrinnite Reflectance Ro = 0.330% as well as the oxidized and wooden composition, show that organic matter of these deposits is able to generate gas of biogenic and mixed origin. In some cases, in the organic matter of those deposits, a higher content of Liptinites of the continental origin is noticed, which is able to generate unsaturated liquid hydrocarbons (condensate). In geochemical indexes of Pliocene in South Adriatic basin, changes are noticed compared to Seravalian-Tortonian - Messinian ones. The changes consist of increase of the "Oxidized" composition and of the decrease of Liptinite composition. The organic matter of Pliocene deposits is able to generate dry methane gas of biogenic origin. The gas pools in all the fields in Albania (Divjaka, Frakull, Kryevidh, Povelce, Ballaj etc.) are related to sandstone reservoirs of Serravalian-Tortonian - Messinian to Pliocene inclusive.

A dense grid of seismic lines has been recorded over last years in these regions (from Papri in South until Shkodra in North).The interpretation of these seismic data clarified and solved certain geological problems, like structural form, tectonic style, relation between the Kruja orogen and South Adriatic basin etc.

We underline that in general at the seismic lines of the Kruja zone are distinguished from top to base (Fig. 9):

1. The first reflector 1-1 (around 1.4 sec. TwT) represents unconformity surface of Serravalian - Tortonian molasses deposits of Tirana piggyback basin (Fig. 9).

2. The second reflector 2-2 which is directly under the Tirana piggyback basin represents the top of limestones

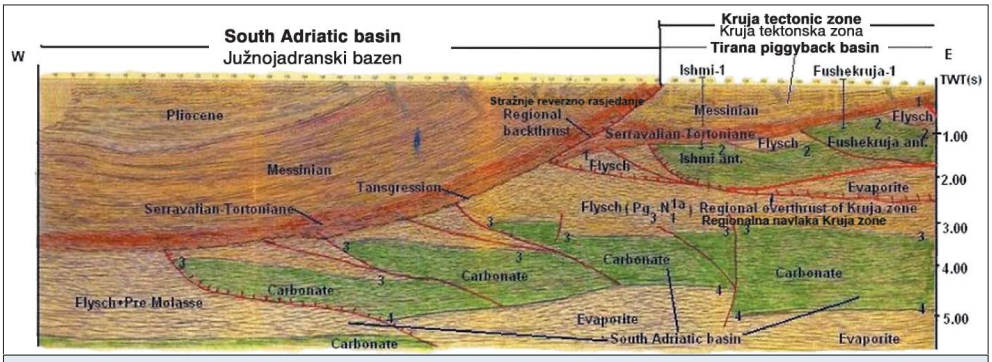

Fig. 9. Migrated seismic line 6-6 (according to geological cross-section in Ishmi area at Fig. 6)
Sl. 9. Migrirani seizmički profil 6-6 (prema geološkom profilu Ishimi područja na sl. 6).

of different anclinale structures of the Kruja zone (Ishmi, Fushekruja, Tirana, Makareshi, Lanabregas, Kozani, Letani etc) (Figs. 6,7,8,9). They have been tested by many exploration wells. The large scale of Kruja overthrust westward (Fig. 9) was confirmed.

3. The third reflector 3-3 (around 2.3- 2.5 sec. TwT) is interpreted to correspond with the carbonates of subthrust unit (South Adriatic basin), which is folded with big anticlinal structures with high perspective for hydrocarbon exploration (Figs. 6,7,8,9). It is comparable with Monte Alpi, Tempa Rosa etc. oilfield in Apulian platform subthrust reservoirs, discovered in the Southern Apennines (Italy)[1,5].

4. The fourth reflector 4-4 is interpreted to be the top of diapiric evaporites (Fig. 8). In the westward direction seismic lines show one succession of deposits from the top of carbonates until Pliocene (Fig. 9). from Serravalian and up (Tortonian, Messinian). These deposits in east border are set up with transgression (Fig. 9).

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Author:
Telo Velaj, 1575 W. Street Road # 336, Warminster. PA 18974.USA. E-mail: telovelaj@verizon.net