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PRESENT DAY MOVEMENTS OF THE EXTERNAL ALBANIDES, BASED ON GPS DATA, IN RELATION TO THE REGIONAL GEODYNAMICS

Abstract

From the geological point of view, Albanides are part of the folded Mediterranean Alpin belt. It extends to the south in Dinarides and Helenides, along the eastern coasts of the Adriatic and Ionian Sea. From this region further east, through the Aegean Sea, they contionues in Taurides. As the whole, these units are associated in the Dinarides-Albanides-Helenides-Taurides arc. Its western outline takes place in a confrontation againts the Adria micro plate. Nowadays, the movement of the Adria micro plate is crucial to through light into the geodynamic evolution, stress build mechanism and consequently strain accommodation in the western folded flank of the Dinarides-Albanides-Helenides-Taurides chain as well as the whole Mediterranean. After the GPS deployment in Southeastern Europe, aiming the monitoring of the geodynamic movements along the Adria conturs against the African and Eurasia major plates, a number of 6 permanet GPS stations were also deployed in Albania within the Nato "Science for Peace" program. Furthemore, a network of repeated stations was built, during a 6 years period, starting from the year 2000. Based on Albanian GNSS data the overall geodynamics of the Albanian crust and the surrounding region is pointed out. This paper aims to describe these results within the most comprehensive description of the local and regional tectonics.

Keywords: geodynamic; frontal collision, GNSS; Adria microplate.

1. Adria regional geodynamics

The tectonic evolution of the Europe and Mediterranean has been strongly affected by the Adria micro plate movement, which represent a continental lithospheric unit which cover the eastern Italy, the Po river plateau and the Adriatic Sea, in the western side of Dinarides. Its movements have caused the convergence between African and Eurasian major plates (figure 1). The time history of the crustal deformations in the central Mediterranean point out a co-movement of the Adria until late Miocene, as part of the African plate. The Anatolo-Aegean-Balkan system [9], pushed the southern part of Adria, due to its movement towards west, leading to its detachment from the African plate. After this tectonic event, Adria undergone a counter clockwise rotation in relation to the Eurasian plate, inducing a strong compressional regime in the central Mediterranean [2]. As the result of its collision with the southern Apennines, during the late Pliocene to the upper Pleistocene, its clockwise rotation refered to the African and Eurasian plates, slowed down [2]. Present day movement of Adria is an important factor in the Mediterranean, as the main source of the tectonic stress accumulation and the cause of numerous earthquakes in the confining regions. Taking into account the present movement of Adria thoroughly ones can understand its connection to the African and Eurasian major units, and explane the geodynamic of the collision area between these tectonic plates as well as the central Mediterranean tectonic processes.

The displacement of Dinarides, Albaniades and Hellenides is directed towards the Adria micro plate, thereby Dinarides and Hellenides are positioned diametrically opposite in a converging direction to the Appenines. The orogenic compressional movements in the folded belts surrounding the Adria micro plate, are expressed by thrusting folds and tectonic nappes (figure 2-b), [1]. Likewise, along the contact areas where the displacement between these tectonic plates occurre, folding takes place along with the arise of tectonic stress. The stress field is continuously intensified up to a critical point beyond which new faults are created and the existing ones are activated [6]. As the consequence the borders of the Adria microplate are distinct for a high seismicity (figure 2-a, 2-b). Seismological and geological studies shows that the tectonic characteristics of Adria, are dominated by the continental collision between the African and Eurasia plates (figure 2-b). The epicenters of earthquakes in the Adriatic region are mainly concentrated along the coastline area (figure 1-a).

The passage between the Gargano region and the central Dinarides is expressed by a highly active tectonics. The majority of earthquakes within these areas, are located in the Appennines (Italy), in the central Dinarides, from the northeastern Italy up to Slovenia, along the west coasts, Serbia, Montenegro, Albania and Greece (figure 2-a), [2][6].

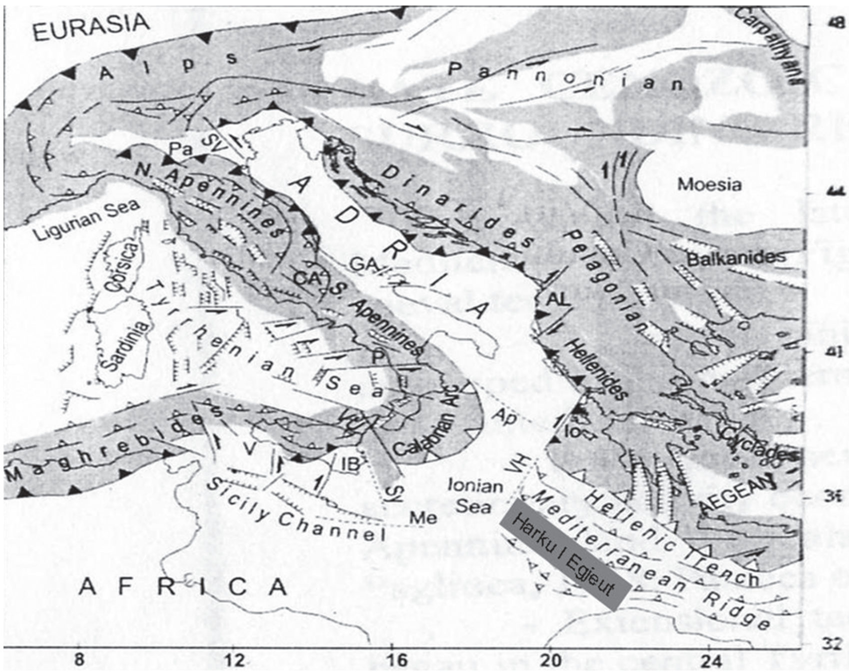

Figure 1. The schematic view of the tectonic pattern of the Mediterranean, where the Aegean Sea region is showing up along with the eastern edge of the Adria micro plate.

In the southern part of the Hellenides, the Aegean arc which in contrast to the Adriatic collision, in the Hellenides and Dinarides, shows different geological and geophysical characteristics, comparable to those of an Island arc [8].

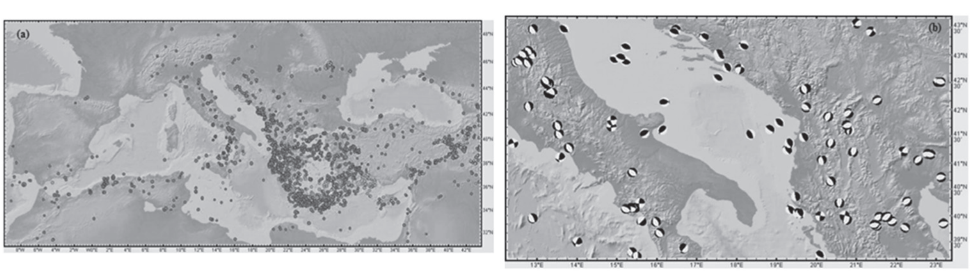

Figure 2. a) the earthquake (M>4.0), are distributed along the Adria and southern Balkan contures, according to the ISC catalogue for the last 33 years; b) the distribution of the focal mechanism solutions of the earthquakes affected the Mediterranean region according to Global Centroid Moment Tensor (CMT).

The oceanic subduction zone sinks towards the Hellenides at nearly 180 km, directed northeast. The Ciclades volcanic and the southern Aegean sedimentary arc, outline the Aegean arc [1]. The Aegean arc is positioned in the middle of the Arabian-African collision on the south, Eurasia to the east and the Adriatic collision on the west. The transition from the Aegean oceanic subduction zone to the Adriatic collision zone (continental subduction zone), is accomodated through a dextral transform fault, oriented NNE, in the western flank of the Kefalonia-Lefkada islands [11].

Taking into account the described tectonic pattern, Albanian territory is situated in the region of the majore tectonic units confrontation, being affected by the corresponding geodynamics. Actually the geodynamics of this region is properly monitored and measured in quantitative terms by mean of a number of GPS stations, functioning so far in the region. Part of this network is also the Albanian GNSS, since 2000.

2. GPS network configuration in Albania and recorded data

The regional geodynamics of Adria, as well as the its borders relation to the major African and Eurasian plates, is monitored so far by a number of GPS stations deployed all over the South-Eastern Europe. Jointly to this regional network, a number of local permanent GPS stations have been installed in Albania, aiming the monitoring of the present day geodynamics and tectonic movements of the Albanian orogene. GPS stations have been installed in stable basement sites regarding the local geological conditions found in Albania, taking into account also the majore tectonic division inside the country.

They are spread to monitor the entire territory, namely in Tirana, Shkodra, Peshkopia, Berati, Saranda and Maliqi (figure 3-a), thus configuring the Albanian GNSS permanent network. In addition to permanent GPS stations, a secondary GPS network composited by 47 periodic stations is built as well, with points uniformly distributed with the priority to the most distinct tectonic nodes [5]. During a 5 years period, each year a GPS measurement campaign has been organized utilizing these predefined periodic points, measuring at least 48 hours per point.

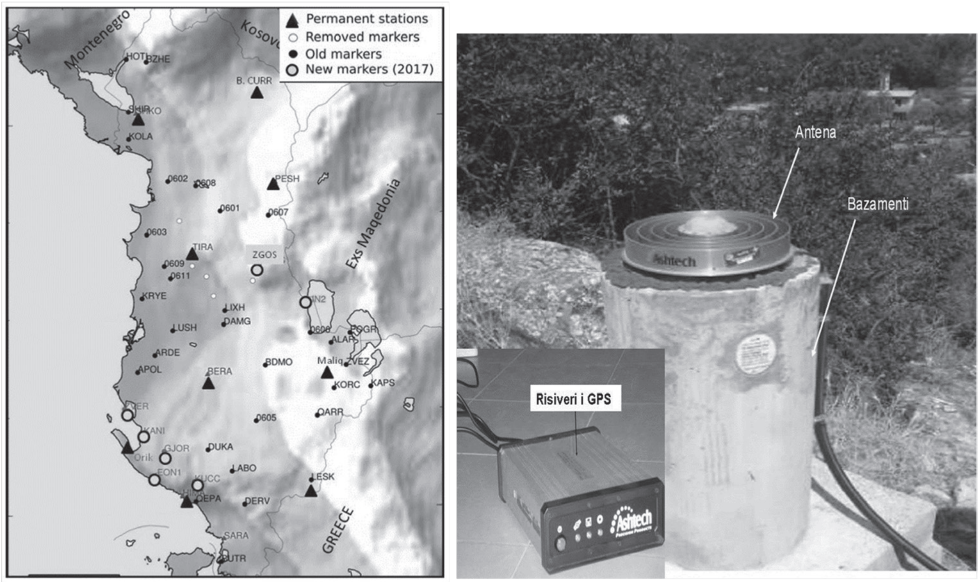

Figure 3. a) the map of the Albanian National GNSS b) photo of a permanent GPS station and respective instrumentation.

The GPS receivers, being compound by the outdor and indoor equipment, are of the Ashtech and Topcom types. These instruments records the position in each point every 30 sec, within a very small error range. GPS antennas are placed in open places to better lock to the satellites, having a clear sight to the sky. To properly measure the correct position in each site, GPS antenna should receive a strong enough signal by at least 6 satellites instantly. The angle of the receiver antenna to the horizon accomplishes values> 12^0. All the selected sites were build according to the international standards, constructing their basements on a strong rocky formation, as far as possible to the other sources of electromagnetic signal transmition such as television or mobile antennas. Meanwhile, for the secondary GPS stations, their banchmarks have been strongly receseed into basement rocks to be ready for periodic measurements, upon the installation of portable GPS units [6]. Achieved data have been processed abroad according to the eastablished working packages of the corresponding NATO Project, within the framework of the "Science for Piece" program. Obtained results are very interesting from the geodynamic point of view and the present day tectonic movements of the Albanian crust, giving a clear view of the actual tectonic stresses build up in Albania and surrounding region, as well.

3. GPS data interpretation and results

From regional data, obtained from GPS measurements in the Southwestern Balkan, results that the northernmost edge of the Adria microplate undergoes a counter clockwise rotation, reflecting a north-south overall compression. This compressional field changes direction to northwest-southeast in Friuli region, along the Dinarides coastline to the north of Dubrovniku. This dynamics is well evidenced by the strain rate tensor inversion as well as the focal mechanism of earthquakes (figure 2-b), [5]. Deformations are present not only along the coastal regions but also in the whole Dinarides.

Measurments obtained by the two GPS stations, in Dubrovniku and Matera, revealed a shortening (compression) by a rate of 1.9 mm/year. As well as between Dubrovnik and Sarajevo stations, along the inner Dinarides, where shortening happens by a rate of 2.5 mm/year. This displacements have been noticed also by the dense Croatian GPS network [4]. An enormous change is observed between the Dinarides and the northern Albanides. Dubrovnik GPS station undergoes a northward displacement referring to the Eurasian structure, whilst the GPS stations in external Albanides, namely Shkodra, Tirana and Saranda, show a westward displacement tendency (figure 4).

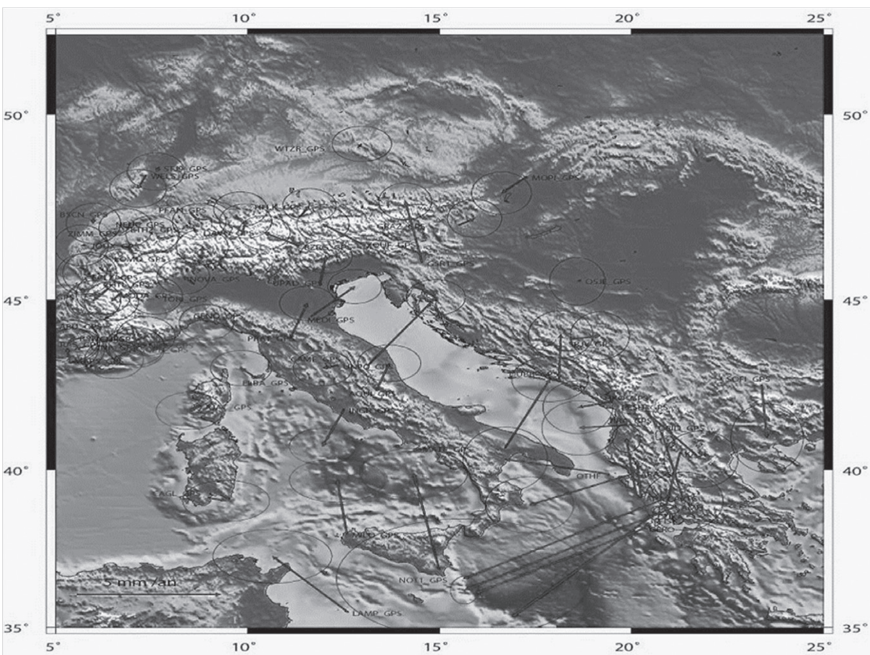

Figure 4. a) Crust displacement recorded by permanent GPS stations deployed along the borders of the Adria microplate, referring to the Eurasian plate (cortesy to F. Jouanne et al., 2008).

The strain rate tensor inversion clearly support these deformations. Dubrovnik station undergoes a 1.25 mm/year of displacement rate, along the eastward component, and 2.78 mm/year along the northward component, as comparing to Shkodra station. If the relative movement between both stations would be attributed to a single fault line, then the most probable fault to confine Dinarides and Albanides is the Shkoder-Peja tectonic fault [5&13]. According to this hypotheses, this fault is characterized by a dextral strike-slip displacement by a rate of 3 mm/year. During the Neogene, this fault has been the major border between Dinarides, which undergone an average rotation, Albanides and the northwestern Hellenides, affected by two subsequent rotations.

In order to test the existence of the present rotation of Albanides and northern Hellenides, a clockwise rotation pole is determined in reference to Eurasia, in the externalAlbanides. Based on the measurements, a rotation pole is found between the southern external Albania, refering to the Eurasia, for which the rotation angle, measured at Matera station, is $-0.776^0 \pm 1.22$”. Incremental shortening rate along the Adriatic, between the northwestern and southwestern Albania, is an evidence of a counter clockwise rotation of the southern Adriatic foreseeing an increment of the relative displacement along the Adriatic from north to south, and a clockwise rotation of the Albanian crust having the same direction and relative displacement norm. In this reference frame of Albania, a very important residual displacement in the inner Albanides, leads to important conclusions regarding the existence of considerable deformations in this region [5][10].

4. External Albanides tectonic ovements

External Albanides, which comprise Kruja, Ionian and Sazani tectonic units, have been affected by an important pre-Pliocene compression and also by a significant post-Pliocene shortening in the Periadriatic foredeep. They are structured by NNW-SSE to NW-SE thrusts, backthrusts and folds and by transversal faults with a NE-SW to nearly E-W orientation. Numerous focal mechanism solutions of shallow earthquakes demonstrate an ongoing horizontal compression (thrust faulting) dominating along the Adriatic collision (figure 2-b). Active tectonics is expressed by important historical earthquakes, as shown by the repeated historic destructions of Durresi (177 B.C, 334 or 345 A.C., 506, 1273, 1279, 1869, 1870, 1926 Ms 6.2), Apollonia (II-III BC, 217 AD), the 1920 Tepelena(Ms6.4) earthquake, the 1962 (Ms 6.0) Fieri earthquake and the 1979 Montenegro earthquake (M 6.9), [14].

As above shown, GPS results supports the occurrence of south-westward motion of points located in external Albanides relative to Apulia (figure 5). It is possible to distinguish a moderate deformation across the inland part of the periadriatic foredeep (2 mm/year at the latitude of Tirana between TIRA and KRYE stations), and an important shortening across Adriatic Sea increasing from north to south of Albania [5]. From north to south, displacement rates of points located in the external Albanides presents changes in directions and norm. In the northern Albanides, between the Shkodra-Peja fault zone and Lezha fault, where displacements are normal to the fold's axis, an ongoing shortening of 3.0 (+/-1.7) mm/year,is suggested as observed by a rapid change between the western GPS points and the other points of this area, which direction is also compatible with focal mechanisms. In the central, external Albanides, between the Lezha fault and the Vlora Bay, displacement rates reveal the occurrence of an ongoing shortening, partly offshore [2.3 (+/-1.3) mm/year] and partly onshore [1.7 (+/-1.3) mm/year], [4]

Between central and southern Albanides a major change occur in displacement direction and also in the norm of displacement as well. This change is evident near the Vlora town affected by earthquakes in 1601, 1833, 1862, 1865 and 1866 in an area characterized by an intense seismicity with focal mechanisms showing the occurrence of both thrust and dextral strike-slip events, witha direction parallel to the Llogara Pass Fault (Othoni Island-Dhermi pass Fault), (figure 5). GPS points suggests the existence of a 4.5 mm/year dextral strike-slip displacement rate along this major fault accomodating the tectonic contact between the Apulian plateforme and Albanides.

In the southern, external Albanides, an ongoing deformation occurred off-shore (4.9 mm/year +/- 0.3), referring to the SARA permanent station with the Apulia fixed reference frame) [5]. Displacement rates do not allow identifying an E-W extension component that could be related to the quaternary graben system south of Saranda.

The NE-SW Vlora-Elbasani-Dibra (VED), transversal fault zone, cuts through all the Albanides [7]. It is underlined from south-west to north-east by the Lushnja flexure, the Dumrea diapire, the Elbasani depression, marked by important quaternary infills [10], and the transversal structure of Labinoti, continuing further, in Macedonia.

The current tectonics, along this structure, is expressed by an alignment of important historical seismicity comprising 15 historical and instrumental earthquakes ($M_s > 6$). This active faults zone is also underlined by the NEE-SW alignment of the sftershock cluster consecutive to the September 1, 1959 and November 30, 1967 earthquakes respectively, located on the south-western and north-eastern edges, respectively, of this fault zone [14].

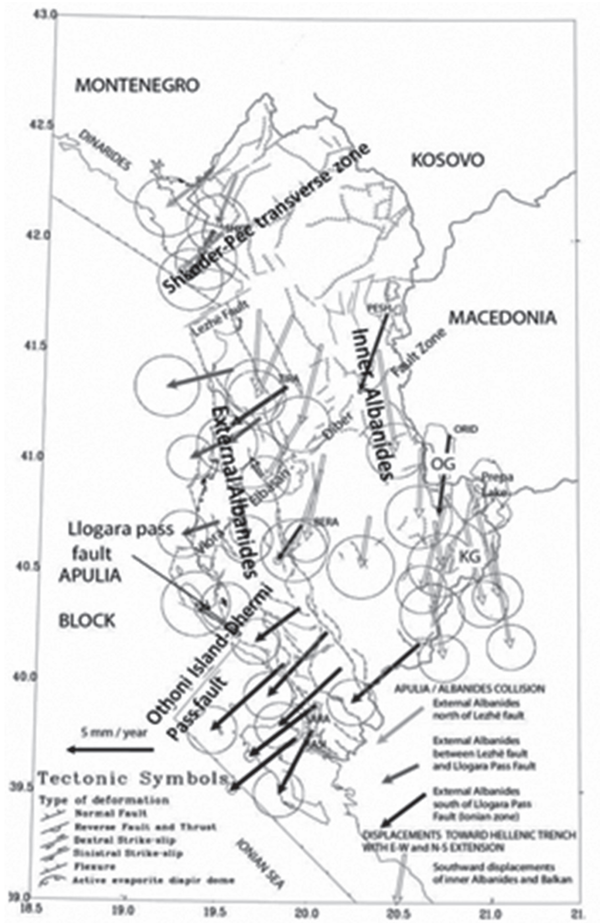

Figure 5. a) Map of the displacement of different sectors in Albania vs Apulian block (cortesy to F. Jouanne et al., 2012).

The current tectonics of this fault zone is expressed by an extension regime, measured in both sides of the Elbasani graben, whereas no relative displacements are recorded in both sides of the fault zone, in its southwestern edge (figure 5). It is then highly probable that this fault is mainly active in the Elbasani area and in its eastern edge, as shown by the 1967 Dibra earthquake [14]. Relative displacements across the fault zone indicate that this fault is almost normal which is in good agreement with the focal mechanism solution for the Dibra earthquake [14], as well as with the observed surface trace during the field work aftermath the earthquake occurence.

In the Apulia and Eurasia fixed reference frame, inner Albanides points present south-westward displacements reaching 2 mm/year north of the Elbasani-

Dibra fault (according to Peshkopia GPS permanent station), and up to 4 mm/year for points located south of the fault zone. External-Inner Albanides boundary (figure 4), appears to be the western boundary of the active tectonics, expressed by E-W and N-S extension in Bulgaria [6], Macedonia, Albania and northern Greece and in the Corinth Gulf [3][9]. In the Orhid-Korca graben system, current displacements (figure 5), indicates a moderate E-W extension across the Orhid graben that change to a N-S or multidirectional extension in the Korca graben. This highlights the rapid change between early quaternary E-W extension and the late N-S one, as described by [12], which may also be explained by a current multidirectional extension identical to the present-day deformation. Historical seismicity (figure 1), clearly indicate that this deformation is released during earthquakes with magnitudes M $\geq$ 6.

4. Conclusions

The Albanian territory is part of the folded Alpine belt, which geological structure lays between the Dinarides in the north and the Hellenides in the south. The Alpine belt is the result of the collision between the major tectonic plates, namely Eurasia and African one. The folded Dinarides-Albanides-Hellenides belt moves convergently aside the Adria microplate. The convergent compressional movements between the folded orogene surrounding the Adria microplate, are expressed by thrusted folds and tectonic nappes, which often are related to the new tectonic faults and reactivation of the existed ones. The vast borders of the Adria microplate are pronounced for the high seismicity. Based on the GPS data in the Balkan region, it results that the Dalmatian coastal region moves towards the Adria microplates by a rate of 2 mm/year. As well it is observed that the northern Balkan is rotated in a counter clockwise direction. Based on the GPS measurements in the Albanian territory it results that the Albanian crust is shortening in the north-south direction as well as in the east-west one. This results are achieved by comparing data recorded by Matera GPS station in Italy and Ohrid GPS station in Macedonia.

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