Crustal structure and evolution of the Carpathian-Western Black Sea areas

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The Carpathian and Balkan foldbelts are segments of the Tethyan chain, emplaced and deformed during the Mesozoic and Cenozoic. Their foreland, situated around the western Black Sea, consists of several platforms and the North Dobrogea-South Crimea Cimmerian Chain (Figure 1).

Tectonic setting

The foreland platforms on Romanian territory are of different ages. They include: (a) the East European Platform, with a Precambrian basement and a Vendian–Neogene platform cover; (b) the Moesian Platform, with a Precambrian basement and a Cambrian-Neogene platform cover and (c) the Scythian Platform, with a Caledono-Hercynian folded basement and an Upper Carboniferous-Neogene platform cover. The Cimmerian Chain outcrops in North Dobrogea and South Crimea; the connection between these two segments develops across the northwestern part of the Black Sea continental margin. Three tectonic units (nappes) with N-NE vergency were recognized in the North Dobrogea segment. The median one contains Triassic within-plate ophiolites and sedimentary rocks, while the two others involve pre-Triassic basement rocks and Triassic-Jurassic sedimentary forma-

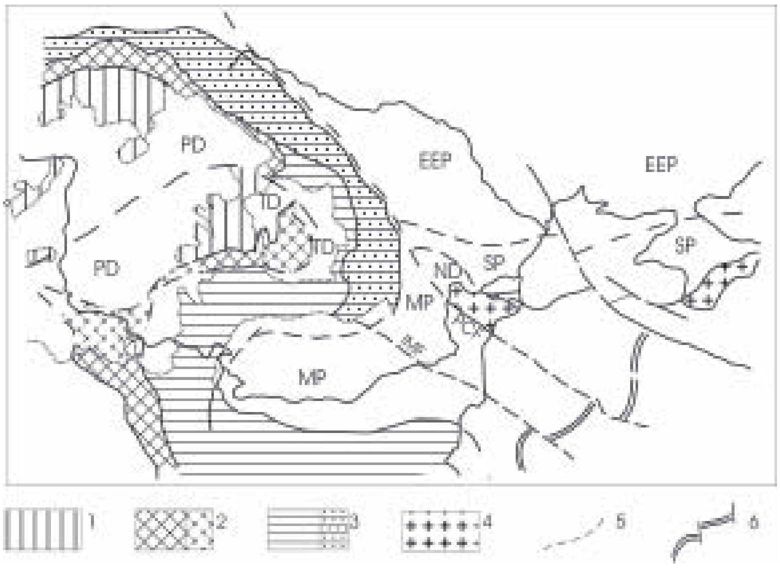

Figure 1 Tectonic sketch of the Carpathian-Western Black Sea areas: 1. Foreapulian units; 2. Main Tethyan Suture, a. covered by Neogene formations; 3. European continental margin units, a. cover flysch nappes; 4. North Dobrogea-South Crimea Cimmerides; 5. Transcrustal faults; 6. Boundary of the basaltic crust of the Western Black Sea; EEP—East European Platform, MP—Moesian Platform, SP—Scythian Platform, PD—Pannonian Depression, TD—Transylvanian Depression.

tions. The deformation of the Cimmerian Chain took place in two tectogenetic episodes: 1. End-Triassic and 2. End-Jurassic or lowermost Cretaceous. The Cimmerian Chain originated from an intracratonic rift (aulacogen) developed during the Triassic.

The Carpathian Mountains consist of tectonic units emerging from the deformed lithosphere of the Tethys Seaway (the Main Tethyan Suture) and from its deformed continental margins (Figures 1, 2 and 4). Relative to this suture, the deformed European continental margin is represented by South Carpathian and East Carpathian units as well as a part of the North Carpathian Flysch Zone. Within the European continental margin, a 'satellite' suture was recognized (Figure 2); there, the original basement of the sedimentary basins corresponding to the Flysch Zone units was 'consumed'. On the opposite side of the Main Suture are situated the units proceeding from the Foreapulian continental margin, represented by the Northern Apuseni Mountains–Central West Carpathian unit, their affiliated terrain below the Pannonian Depression and the Austro-Alpine units of the Eastern Alps.

Carpathian tectonic units were formed during two tectogenetic periods: 1. The Cretaceous (Dacidian) period, generating the major part of the Inner Carpathians and 2. The Miocene (Moldavidian) period, building the Outer Carpathians.

Crustal structure

Considering age and constitution, several types of crust may be distinguished in the foreland and in the Carpathian Chain.

East European Platform. The oldest crust belongs to the East European Platform and is Precambrian. It is 55 km thick in the Odessa region, western Ukraine and southeastern Poland. Certain crustal blocks, bounded by deep trans-crustal faults (generally oriented north-south) are significantly thinner (40 km) due to prolonged evolution of this crust and the close vicinity with the Tornquist-Teisseyre Zone, which runs along the western border of the platform.

Paleozoic Platforms. To the south and west of the East European Platform lies the continental crust of two Paleozoic platforms: (a) the Scythian and (b) the Central European. The crust thickness within these Paleozoic platforms is variable. The crust is 40–42 km thick between the Black Sea and the front of the East Carpathians as well as below the overthrusted cover nappes of the Flysch Zone of the Romanian East Carpathians and 60–65 km below the same nappes of the Ukrainian Carpathians (Figure 3). The two Paleozoic continental crusts, showing this significant difference in thickness, are separated by a NE-SW trending trans-crustal fault. This unusual thick crust in the Ukrainian and southeast Poland sectors of the Paleozoic platforms may be explained by the existence of a transitional layer between the crust and the upper mantle, which is 10–15 km thick and ex-

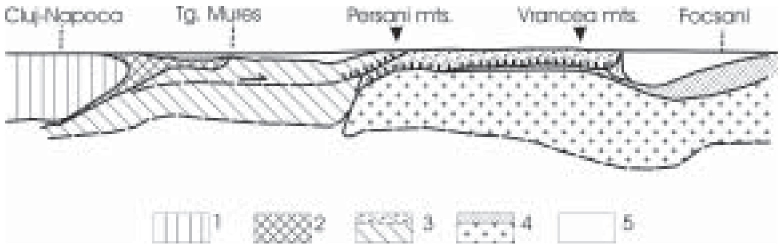

Figure 2 General cross-section of the Romanian Carpathians: 1. Foreapulian units; 2. Main Tethyan Suture; 3. European continental margin units, a. cover flysch nappes; 4. Underthrusted Foreland, a. basement, b. sedimentary cover; 5. Neogene molasse depressions.

hibits anomalous velocities (7.5–7.6 km/s). Additionally, crust thickened due to transpresive strike-slip displacements, which occurred along the Tornquist-Teisseyre Zone.

Moesian Platform. The southernmost of the Carpatho-Balkan foreland is the Moesian Platform. Although the Moesian basement is Precambrian, the corresponding crust is thinner than the crust of the East European Platform, with values between 30–35 km. A possible explanation may be found in the excessive thickness of the platform cover (Paleozoic and Mesozoic formations) which in some areas reach more than 8 km and generally, is at least 5 km thick. A general thinning of the Moesian crust took place in order to permit so much subsidence. A trans-crustal fault delimitates two major sectors of the platform: the Dobrogean and Wallachian-Prebalkan sectors separated by the Intramoesian Fault (Figure 1). Within the Wallachian-Prebalkan sector the crust shows a larger mobility (higher values of the geothermal field and a Triassic bimodal magmatism) and a lower crust (basaltic layer) with a high seismic 'transparency'. The crust corresponding to the North Dobrogea Orogen belongs to the underthrusted Scythian Platform (extending below the Tulcea

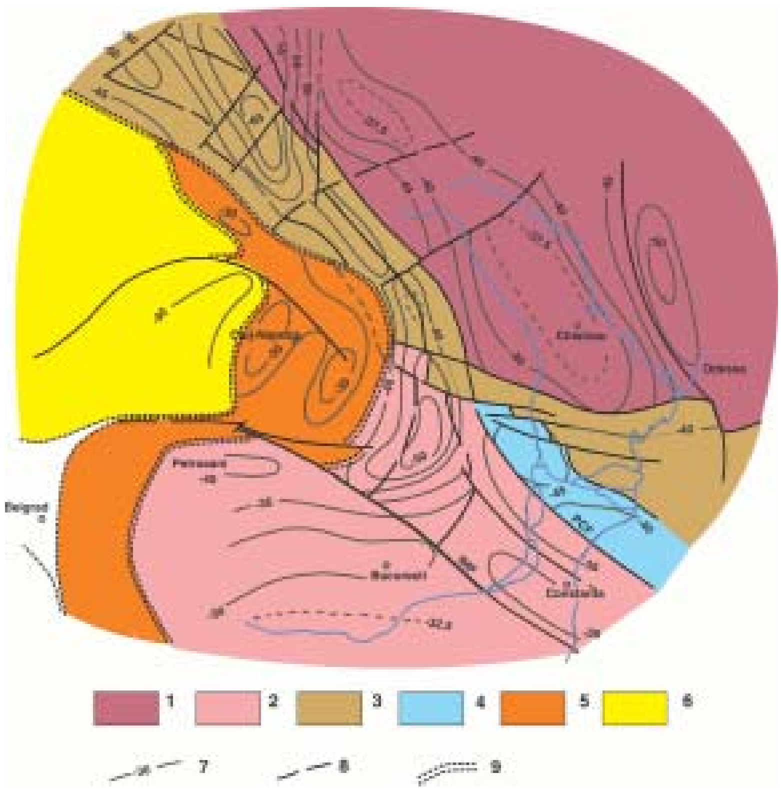

Figure 3 Types of crust within Romanian territory: 1. Precambrian East European Platform crust; 2. Precambrian Moesian crust; 3. Paleozoic Scythian crust; 4. Cimmerian North Dobrogea crust; 5. 'Transylvanian' type crust; 6. 'Pannonian' type crust; 7. Depths to Moho; 8. Main deep faults (mostly transcrustal); 9. Position of the suture zones at the Moho level.

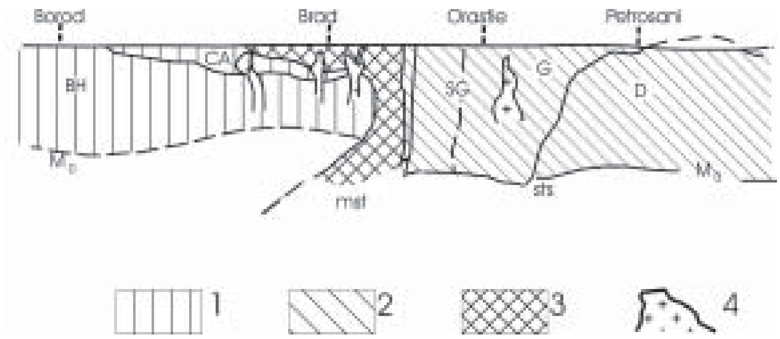

Figure 4 Structural cross-section Apuseni Mts—South Carpathians: 1. Foreapulian units; 2. Main Tethyan Suture; 3. European continental margin units; 4. Calk-alkaline magmatics; Bh—Bihor Unit, CA—Codru Arieseni units, SG—Supragetic Unit, G—Getic Unit, D—Danubian Unit, mts—Main Tethyan Suture, sts—'satellite' suture (Severin), Mo—Mohorovicic discontinuity.

Unit) and, north of the Peceneaga-Camena Fault, to the 'roots' of the orogen.

In the Carpathian domain three types of crust may be distinguished: (a) the underthrusted forelandic crust; (b) the 'Transylvanian' type-crust and (c) the 'Pannonian' type-crust. They are separated by sutures corresponding to former subduction zones, the Main Tethyan Suture and the Severin-Ceahlau 'satellite' suture (Figures 2 and 4). The subduction processes took place during the Middle and Upper Cretaceous and during the Miocene. The positions of paleosutures are supported by geophysical data (the differences of the crustal thickness, the positive heat-flow anomaly located along the 'satellite' suture and also the divergence directions of the Wiese vectors along the 'satellite' suture), as well as by geological data (the balance of the primary basements of the flysch troughs, the obduction nappes proceeding from the Main Suture, the tholeitic nature of the ophiolitic complexes of the Main Suture, etc).

(a) The underthrusted forelandic crust is situated below the cover nappes of the Flysch Zone (Figure 2). It belongs to the Moesian and Scythian Platforms. Its thickness is variable, with the largest values of 50–53 km in the bend area of the external Carpathians. In this area, known as the Focsani Depression, the sedimentary sequence is extremely thick: ca. 18 km. Consequently the continental crust situated below the depression shows relative thinning, when compared to other crustal segments.

(b) The 'Transylvanian'-type crust situated between the Main Suture and the 'satellite' suture (Figures 2, 3 and 4), is characterized by thicknesses of 30–35 km. The basaltic layer is normally developed, while the granitic layer shows a thinning below the central part of the Transylvanian Depression, where important Neogene subsidence took place. Below the Neogene basin depocenter, the basaltic layer is shallower and is well expressed on the geomagnetic field map.

(c) The 'Pannonian'-type crust has a thickness of 24–28 km and a thin (ca. 8 km) basaltic layer. In the Pannonian area the heat-flow anomaly is highly positive (probably due to the existence of a 'mantle diapir'), contrasting with the much colder 'Transylvanian' crust. In the eastern part of the Pannonian Depression, geophysical studies have suggested the existence of a 4 km thick transitional layer between the crust and the uppermost mantle.

The crust of the western basin of the Black Sea represents a peculiar situation. There, the crust of the continental margin gradually thins and passes, in the central area of the western Black Sea basin, to a crust exclusively represented by the basaltic layer which have thicknesses of 18–20 km. Transition to the basaltic crust is marked by an increase in the gravity anomaly.

Geodynamic history

Cratonization stage. The end-Proterozoic (Panafrican) cratonization is recognized in the whole platform area of the foreland and, as relicts, in the Carpathian. This huge cratonic area, preserved actually in the East European Platform, was split southwards and westwards by several Paleozoic mobile belts. A second large cratonization, post-Lower Carboniferous, occurred in the Carpathians area and its foreland, which were at that time parts of Pangea. These main episodes of general cratonization are materialized in two platform types: the Precambrian (East European and Moesian) and the Paleozoic (Scythian) platforms, respectively. In the Carpathian domain, remnants of older Dalslandian, Cadomian, Caledonian and Hercynian structures (continental crust with metamorphics and, sometimes, granitoids) are incorporated in the Alpine units.

Rifting stage. Earliest Mesozoic rifting occurred in the North Dobrogea-South Crimea aulacogen, a possible pull-apart basin connected with transtensive strike-slip movements. The rifting processes started in the Spathian and continued during

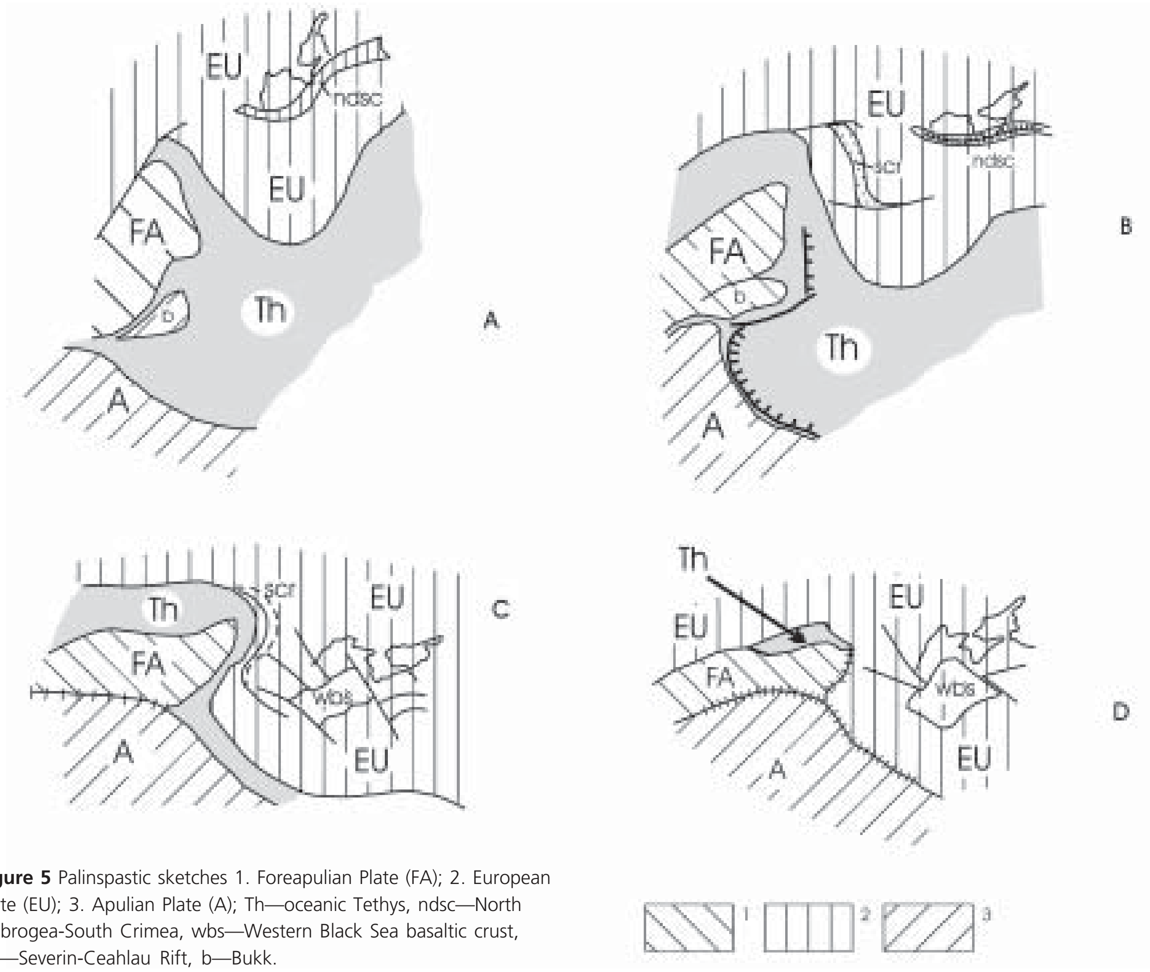

Figure 5 Palinspastic sketches 1. Foreapulian Plate (FA); 2. European Plate (EU); 3. Apulian Plate (A); Th—oceanic Tethys, ndsc—North Dobrogea-South Crimea, wbs—Western Black Sea basaltic crust, scr—Severin-Ceahlau Rift, b—Bukk.

the entire Triassic. In the Carpathian domain, the rifting preceding the Tethyan opening started in the Lower Triassic and was followed by Tethyan Sea spreading in the Middle Triassic. Triassic Tethyan spreading separated the European margin from the Foreapulian block (Figure 5a). The spreading processes continued during the Jurassic, propagating into the Pienidian domain and toward the Alps, separating the Foreapulian block entirely from the European Plate (Figures 5a and 5b). The opening of the Tethys Sea and Severin-Ceahlau intracontinental rift is followed by a compressional event, which created the North Dobrogea Orogen, as a result of the anticlockwise rotation of the Moesian Platform. Since the lowermost Cretaceous the North Dobrogea Orogen was integrated in the stable Carpathian foreland.

Compressional stage. The earliest crustal shortening in the Carpathian domain was recorded in latest Tithonian/lowermost Berriasian within the oceanic Tethys (Figure 5b). It generated subductions to which is associated a calk-alkaline magmatic arc, later assimilated in the structure of the South Apuseni Mountains.

The Mid-Cretaceous is the first major compressional period and has affected mostly the European continental margin and parts of the oceanic Tethys (Figure 5c). The Foreapulian block, comprising the North Apuseni Mountains, the central West Carpathians and Austro-Alpine units, was deformed in an intra-Turonian compressive event. The End of Cretaceous tectogeneses lead to the closure of a significant part of the oceanic Tethys, but only partial shortenings in the Pienidian domain (Figure 5d).

Starting with the Early Paleogene, the Pienidian trough (oceanic crust) and the north and east Carpathian Flysch Zone (thinned European crust) stayed mobile areas and received predominantly flysch (turbiditic) sediments. These sedimentary basins developed until the Lower Miocene, when a first Neogene (intra-Burdigalian) tectogenesis took place, emplacing the Pienidian units and the inner part of the Carpathian Flysch Zone. The external part of Carpathian Flysch Zone as well as the Subcarpathian foothills were built during two tectogenetic episodes (intra-Badenian and intra-Sarmatian).

The existing double-bend of the Carpathian foldbelt is the result of mutual interaction, during the Cretaceous and Miocene deformations, of the Moesian block, drifting westward, and the Foreapulian block, exercising eastward translations and clockwise rotations. The westward wandering of the Moesian Block relates to the opening of the Western Black Sea basin (Figures 5c and 5d), which started in Upper Aptian or Albian and continued during the Upper Cretaceous and Cenozoic.

The youngest deformations recorded in the Romanian Carpathians occur in the outermost part of the Carpathian Bend Area and are Lower Pleistocene age (the Wallachian 'phase'). The deformed area is delimited by two important trans-crustal faults: the Intramoesian Fault (left-lateral translations) and the Peceneaga-Camena Fault (right-lateral translations) (Figure 1). The thus defined foreland panel moved towards the Carpathians Bend Area generating the Pleistocene deformations. The translation of this foreland panel is still active now: the well-known Vrancea seismic zone is situated in the frame of this panel, in its lithosphere and astenosphere.

Volcanism. The subduction of the Tethyan oceanic lithosphere as well as the Severin-Ceahlau rift (thinned continental or oceanic crust) and of the Flysch Zone (thinned continental crust), generated several calk-alkaline magmatic arcs of Senonian-Paleogene age (in the North Apuseni Mountains and South Carpathians) and Neogene age (along the inner margin of the East and North Carpathians and in the Apuseni Mountains).

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