STUDIA UBB GEOGRAPHIA, LXII, 1, 2017 (p. 5-27)
(RECOMMENDED CITATION)
DOI:10.24193/subbgeogr.2017.1.01

TECTONIC AND STRUCTURAL RELATIONSHIPS IN SILVANIA MOUNTAINS

I. A. IRIMUŞ[1], CORINA BOGDAN[1]

ABSTRACT. – Tectonic and Structural Relationships in Silvania Mountains. The structural landforms were defined by the fault systems present in the area, as dislocations following the Alpine orogenic system, which imposed the subaerial and submerged dynamics of the landforms, coordinating in this way the modeling systems with the geological time scale, on the basis of complex tectonic and structural, morphotectonic and morphoselection relationships between the geologic structure, the tectonic factors and the external geodynamic agents. The Meseș hemi-anticline is different from the horst of Plopiş as well as Șimleu and Coșeiu Hillocks due to the dynamics, intensity and magnitude of the faulting phenomenon which controlled the sedimentation process and the placement of eruptive bodies. The morphoselection relationships, in which the main role belonged to the selective erosion, facilitated the development of three types of structural (tabular, monoclinal and folded) landforms.

Keywords: *Silvania Mountains, tectonics, collisional chain, geomorphologic structure, relationships.*

1. INTRODUCTION

Silvania Mountains appear as an unusual mountainous segment in comparison with other Carpathian units considering the spatial and morphological aspects as well as the structure and the petrographic composition. They border Silvania Hills to the North, Almaş-Agriji Basin to the East, Vad-Borod Basin, Piatra Craiului Mountains, Vlădeasa Mountains and Gilău Mountains to the South and Plopiş and Oradea Hills to the West.

They are considered by geologists an **Alpine collisional chain**, where, although one can see the marks of a Hercynian orogeny, Variscan remnants incorporated into alpine nappes structures have left *islands of crystalline schists* in the North-Western part of the Transylvanian Basin (*Șimleu Uplifting,* as named

[1] *Babeș-Bolyai University, Doctoral School of Geography, 5-7 Clinicilor Street, Cluj-Napoca, Romania, e-mails: aurel.irimus@ubbcluj.ro; bogdan.corina@ymail.com.*

by geologists or the *Intra-Carpathian Yoke* as called by geographers). Their position, location (fig. 1) and integration into the Alpine-Carpathian system was and remains one of the most controversial issues of the Romanian school of geomorphology and geology.

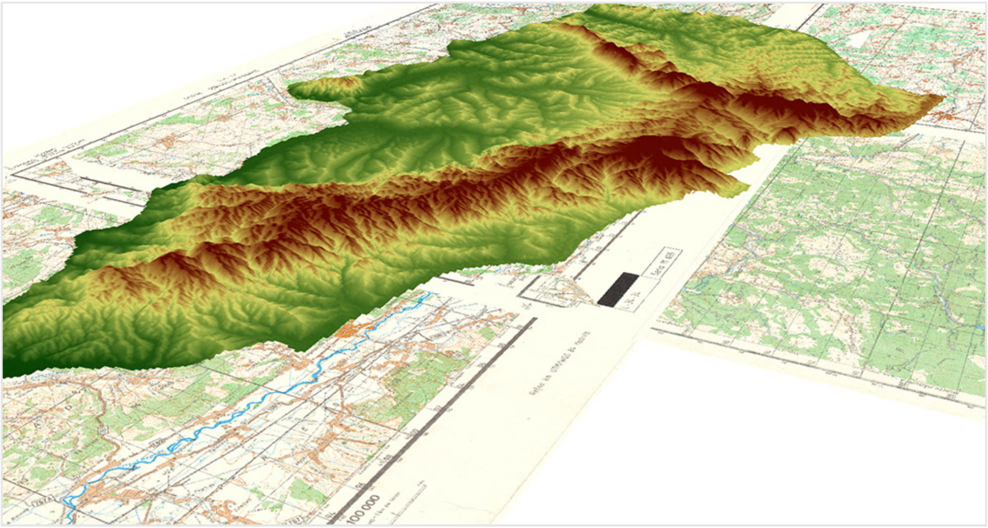

Fig. 1. Silvania Mountains – 3D perspective

Silvania Mountains, considered an **Alpine-type orogenic** unit, submitted to fragmentation and unevenness, were involved into the tectostructural Tertiary movements. The specialized geological and geomorphological literature refers to this unusual unit as follows: Intra-Carpathian Yoke, mountainous Carpathian subunit, complex structural block "Șimleu Uplifting", Silvania Belt, crystalline islands in the North of the Transylvanian Basin, hidden mountains of Northern Transylvania, Preluca-Gilău Island, Preluca Range, Tisia Range, Northern Transylvania Chain, median range, Silvania – Someşan Hills, district of regional Alpine metamorphism. According to geologists, Silvania Mountains would have been part of an immense crystalline Hercynian range during the ***Paleozoic***: ***the Transylvanian-Pannonian Range*** or ***Tisia***.

The Tertiary paleogeographic evolution of Silvania Mountains (fig. 2) emphasized a complex structure, with crystalline seed stripping, brought to the surface due to erosion under the layers of Tertiary sedimentary strata (**Paleogene** on the East side, towards the Transylvanian Basin and **Neogene** towards Silvania Basin and the Western Hills). **A palympsestic morphology unique within the Romanian territory** was outlined in this way (fig. 3).

Fig. 2. Silvania Mountains – panorama from Almaş-Agrij and Șimleu Basins

According to the latest geological research, Silvania Mountains are considered Variscan remnants incorporated into alpine nappes structures. These remnants represent the testimonies of a grandiose **Hercynian chain** that still has unusual fragments (Plopiş Mountains, Meseş Mountains, Şimleu and Chilioara/Coșeiu Hillocks) within the geomorphological landscape of North-Western Romania, as a trace of a vast crystalline area, part of the Preapulian craton and Tisia-Dacia Microplate respectively.

2. DATA AND METHODS

The Hercynian origin of these mountains and the fact that they were not involved in the metamorphism of the Alpine orogeny or the statement that there are no longer Hercynian mountains in Romania and the entire territory would have regenerated during the Alpine orogeny led us to the geomorphological argumentation of a middle position based on the reconstitution of tectonic and structural events related to the modifications of Silvania mountainous space from the point of view of topography and morphology.

3. DISCUSSION AND RESULTS

3.1 The regional tectonic evolution and the geodynamic setting

The geodynamic evolution of the Central Mediterranean, through the opening and the subsequent consumption of the Tethys Ocean crust (Paleotethys and Neotethys) and of some smaller back-arc basins behind their subduction zone, formed the *Alpine orogenic system* to which Silvania Mountains belong too. Its geodynamic evolution is reflected due to the complex Mesozoic–Tertiary interaction between the African-Arabian plate and the European one through the triggering of deformation processes starting with Lower Miocene.

The subunits of the Central Mediterranean: the Pelagian Block (the Strait of Sicily), the Ionic Block and the Apulian Block are important for the Carpathian geodynamics and mainly for Silvania Mountains geodynamics. The geological data confirm the fact that Alcapa and Tisia originated from the Northern margin of the Apulian Block (Săndulescu, 1994; Schmid et al., 2008). The opening of the North Atlantic triggered complex processes of rifting in the area of North Africa which led to the fragmentation of the African margin in minor plates, followed by their successive collision with Southern Europe. This movement is responsible for the *compressive deformations* that had a fundamental role in the formation of the Alpine orogeny. The cause of the compression processes was the detachment of the Carnian Plate from Europe. The closures occurring on its margins led to the compressive deformations in the Alps and the Carpathians. The collision, due to which the alpine nappes in the Western margin of Carnian were formed, is emphasized during Paleocene by the thrust and the generation of nappes in the Alps, in the Carpathians and Silvania Mountains.

On the basis of paleomagnetic, paleobiogeographic and structural data, the Alpine-Carpathian region consists of three continental blocks or microplates: **Alcapa**, **Tisia-Dacia** and **Adria** while the ***intra-Carpathian basement*** is also made of three microplates: **Alcapa**, **Tisia** and **Dacia** (Balla, 1984, Csontos et al., 1992, Schmid et al., 2008). The Alcapa microplate is located in the North of the Pannonian Basin while Tisia and Dacia successively developed in the South of the Pannonian Basin including Apuseni Mountains and the Transylvanian Basin, the two being separated by Alcapa through a major fault with transcrustal character: *Mid-Hungarian Line* (Csontos, Nagymarosy, 1998) active since the Cretaceous and responsible for numerous deformations (Csontos et al., 1992, 2002).

Tisia and Dacia represent two microplates with different geological histories during the Mesozoic era according to paleomagnetic data (Pătrașcu et al., 1994). The movements of these plates are connected to the major convergence between Africa and Europe, a convergence oriented from North to South during the Tertiary (Csontos, 1995). These two microplates collided during Late Cretaceous and thus the **Tisia-Dacia Microplate** was born, a geodynamic reality confirmed by the crustal increase in thickness in the contact area of these two blocks and the tectonic formation of the nappe systems in Apuseni Mountains (Balintoni, 1997, Dallemeyer et al., 1999). The role of these two microplates in the Carpathian geodynamics is relevant and is highlighted by the existence of numerous geological and geophysical studies, undertaken over time by Balla (1987); Ratschbacher et al. (1991); Csontos et al. (1992), Horvath (1993); Royden (1993); Csontos (1995); Nemčok et al. (1998); Fodor et al. (1999); Huismans et al. (2001); Sperner et al. (2002), Seghedi (2005). These authors state that the formation of the Carpathian arc during Tertiary is the result of subduction towards West of a closed basin surrounded to the North and East by the East-European plate and to the South by the Moesian plate. Following the collision of these two continental blocks (Alcapa and Tisia) with the European foreland, the arc structure of the **fold-thrust type belt** of the Carpathians appeared during Late Negeone because of the movement towards East of the Tisia-Dacia block mainly due to the convergence of the Adriatic plate and to the withdrawal of the oceanic plate (Linzer at al., 1998).

The Romanian Carpathians represent a compressive belt with a structure similar to an arc. The deformation age leading to the thrusting of the Carpathian nappes over the foreland coincides with the moment of collision and became increasingly smaller, as the collision extended towards South along the Carpathians. Thus, within the Western segment, the age of collision is Karpatian 17 my (Royden et al., 1982 and Săndulescu, 1988). Royden et al. (1982), Csontos et al. (1992) and Meulenkamp et al. (1996) admit the existence of a progression of deformations along the nappe system from West to East. From Eocene until Early Miocene (32-24 my) important processes of compression took place on NNE-SSW direction, accompanied by extension processes ESE-WNW, which assembled the blocks inside the intra-Carpathian area (Sperner et al., 2002), and in particular those of Silvania Mountains as indicated in the DEM (fig. 3) (Mac, Irimuș, 2000). During the Middle Miocene (24-16.5 my) the regional tectonics were dominated by a translation towards East and concomitant rotations, but also by the opposite directions of Alcapa and Tisia blocks, rotation completed through their collision with the European plate and the triggering of a *strike-slip* regime along the Northern margin of the Alcapa block. Therefore both microplates have suffered counterclockwise rotations and important translations proven by paleomagnetic data (Marton et al., 1992, Pătraşcu et al., 1994, Panaiotu, 1998, etc).

The kinematics of the Carpathians is linked to the evolution of the Eastern Alps. They appeared due to a strong collision while the Carpathians are the result of a low intensity collision through retrograde subduction linked in this way to the orogenic collapse of Eastern Alps (Royden, 1993). Other possible causes of the tectonic forces responsible for these compressions are the slab-pull processes which led to roll-back processes of the plate along the subduction zone of the Carpathians (Royden, 1993). The asthenospheric flow directed towards East determined the rotation of the subduction zone, together with a translation movement of the lithospheric plates (Doglioni et al., 1999). The movement of these plates towards East has been influenced by the existence of the oceanic subduction in the External Carpathians during the Early Miocene through the consumption of the basin with oceanic crust in front of the European Plate, approximately 500 km wide (Csontos, 1995), under the Tisia-Dacia microplates.

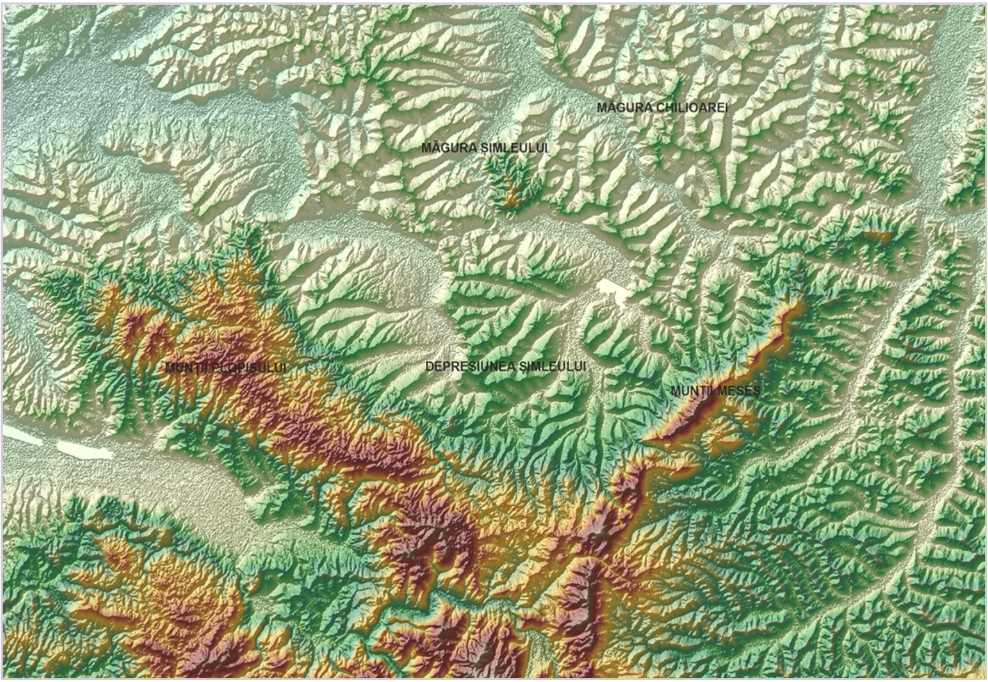

Fig. 3. Silvania Mountains (Plopiș, Meseș, Șimleu Hillock, Chilioara Hillock) in a DEM perspective

The withdrawal of the subduction zone led to an increase in the movement of the microplates towards East and North-East (Royden, Burchfiel, 1989, Royden, 1993). Therefore, during the Late Miocene, the compression forces in the Carpathian-Pannonian area determined the contraction processes, respectively *crustal shortening* (~ 300 Km) within the Carpathian plates (Tari et al., 1992).

In contrast with the crustal shortening of the Carpathian arc, the South of the Pannonian Basin indicates an extensional regional movement ~ 230 km during the Neogene (Tari et al.,1995) of back-arc type. Royden (1988) explains the back-arc extensions within the Panonnian Basin on the account of the withdrawal of the subduction (soft subduction) characteristic to situations where the subduction rate is higher than the convergence rate of the plates. Based on the above, the deformation during Middle Miocene-Pliocene was induced by the retrograde subduction of the oceanic plate between the European and Moesian plate and because of the movement towards East of the Tisia-Dacia block, which will result in the closure of the oceanic basin and the collision of the Tisia-Dacia block with the foreland of the European and Moesian plates which led to the arc structure of the Carpathians while the retrograde subduction from East to West produced the calc-alkaline volcanism. Konecny et al. (2002) proposed a model of the geodynamic evolution of the Carpathian arc and of the Pannonian Basin during the Neogene.

The structural evolution (fig. 4) is like an interconnected system consisting of four main elements: Alpine obduction and the development of compressive orogenic centers due to the movement of the Adriatic plate, a lateral extrusion of the Alcapa lithosphere due to alpine collision; a gravitational subduction of an oceanic lithosphere in the area of the Carpathian arc and a back-arc extension due to the diapiric elevation of the asthenospheric mantle. The low depth of the lithosphere-asthenosphere limit under the Pannonian Basin indicates an asthenopheric elevation during Tertiary.

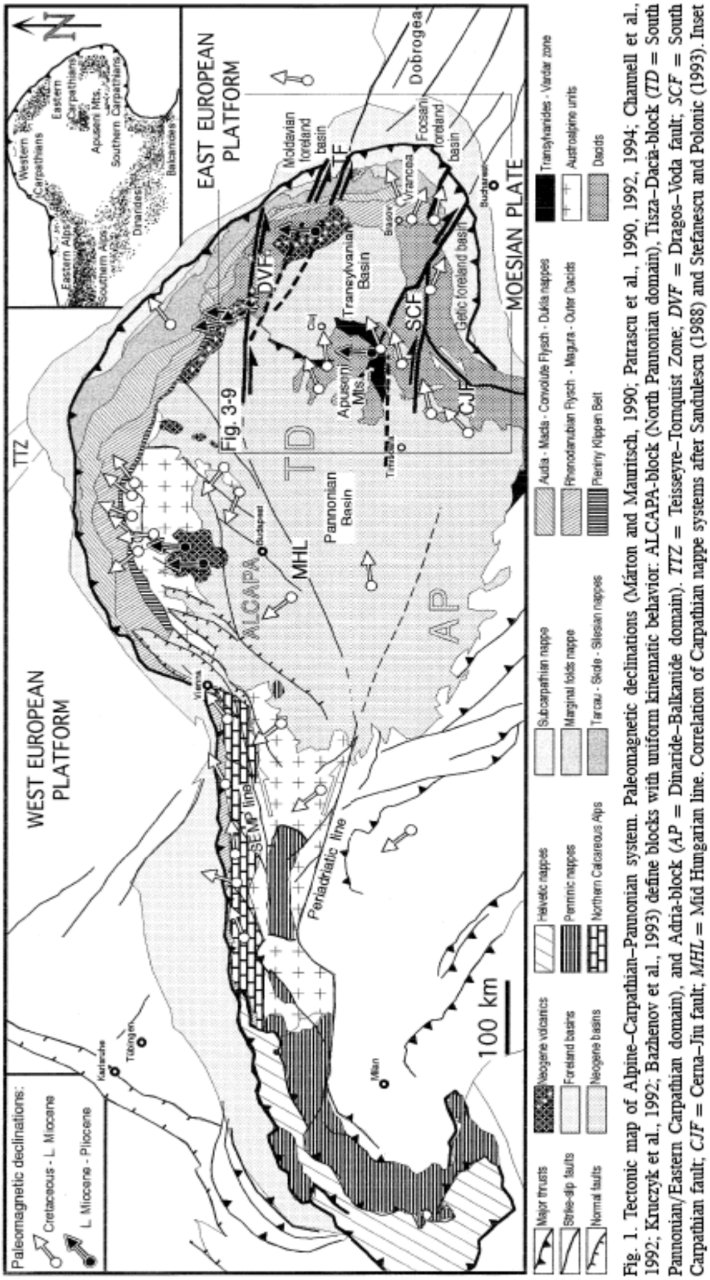

Fig. 4. The tectonic map of the Alpine-Carpathian-Pannonian system
(source: Linzer et al., 1998)

3.2 Tisia-Dacia Microplate and the tectonic and structural implications for Silvania Mountains geodynamics

Silvania Mountains, as an **Alpine collisional chain,** are the result of a complex geodynamics, on one hand a Hercynian one and on the other hand mostly Alpine, being part of the continental margin of the Apulian or Adrian microplate. In Romania, it has different names within the geological literature: **Preapulian Craton, Austro-Bihorean Block, Tisia-Dacia Microplate, Intra-Carpathian Microplate** (Zugrăvescu and Polonic, 1997) and more recently it received the name of **Interalpine Microplate** (Beșuțiu, 2001). We use the name of Tisia-Dacia. The spatial delimitation of these two cratons (Tisia and Dacia) is needed for a better understanding of the structural constitution of the nappe system in the Apuseni Mountains and their structural relevance for the geodynamics of Silvania Mountains. The Preapulian Craton *bordered* Tethys to the North (divided into the Transylvanian, Penninic, Liguro-Piedmontese areas) and the Pannonian sphenochasm to the South (which includes the Apusenides, Mecsek-Villany area, Zemplin block, Western Carpathians and Austro-Alpine domain). The Getic Craton, according to Săndulescu (1984), Froitzheim et al. (1995), Marchant & Stampfli (1995) would represent a link between the external Dacian rift and the Valais rift, therefore, according to this perspective, it includes the area bounded on the West by the North Transylvanian Fault, the Szolnok block, the basement of Măgura flysch and the Brianconnais domain. We mention the rotation of the Tisia around a pole situated in South-Eastern Serbia, rotation completed by its Tertiary movement still heading NE (Pătrașcu et al.,1994) which determined the shearing of the Southern margin of Penninic Tethys and the formation of nappes from the Biharia system (derived from the Southern part of the active margin of Transylvanian Tethys) while the Codru nappes were detached from the passive margin of the Meliata-Hallstatt ocean, placement completed during the Late Cretaceous (Kovac et al., 1994).

During the Late Cretaceous, the Preapulian Craton was located between the Penninic Tethys to the North and Meliata-Hallstatt Ocean to the South. The **Apuseni Mountains,** mainly **Silvania Mountains**, were **part of the Tisia-Dacia Microplate** within the Austroalpine-Carpathian system and included the Bihor Autochthonous unit, the Codru nappe system –cover nappes, Biharia nappe system – basement nappe and the Transylvanide Nappes – obduction nappes (Săndulescu, 1984) that originated from the major Tethysian lithosphere. The pre-collisional tectonic setting of the latter was that of an island arch accompanied by a marginal basin according to Nicolae (1995) which moved under the Pre-Apulian Plate. The nappes system from the Apuseni Mountains appeared during three tectogeneses: Cretaceous tectogenesis, Pre-Gosau tectogenesis and Laramian tectogenesis. In this context, the Alpine geosynclinal of Silvania Mountains was installed on the peneplenized area of the Hercynian structures that formed the Tisia microplate.

The ancient cratons Tisia and Dacia (the current Tisia-Dacia microplate) were part of an intense collision during the Alpine orogeny. According to Royden (1993), during the **Cretaceous tectogenesis**, the tectonic regime at the convergent contact between the Pre-Apulian plate and Getic plate was of *advanced subductional type* (Balintoni, 1994). The Pre-Apulian craton was submitted to compression and shortening, therefore the crystalline basement was strongly deformed, setting the **Apusenide** as cover and basement antithetic nappes, reality confirmed by the mylonites in Meseş Mountains. As a result of disjunctive movements due to the Alpine orogeney, certain parts of the ancient Tisia craton were isolated as peaks and hummocks like those in Silvania Mountains which highlight Șimleu Basin (Plopiș, Meseș, Șimleu and Chilioara/ Coșeiu Hillocks) being incorporated as Variscan remnants in these structures of alpine nappes. Stan and Puște (2001) take into account data from Balintoni (1997) and Pană, Balintoni (2000) in the context of the Paleozoic development of the Alps proposed by von Raumer (1998). They consider that the Apuseni Mountains and the Biharia nappes were formed within the extensional regime of the Alps during Paleozoic, due to subduction, being also formed the Biharia protolith, model supported by radioactive dating U/Pb on granitoids that indicate an age of about 500 My (Pană, 1998). According to them, in Ordovician the Gondwana blocks started moving towards North colliding with Laurussia or with blocks annexed to Laurussia, the end of collision occurring during the Middle Devonian. The Devonian oblique convergence formed in the Alps the nappes of the *pre-Variscan suture* and now, in the Apuseni Mountains, the *Biharia arc* was caught between the granite–gneiss Northern terrains (Someș) and gneiss-carbonate Southern terrains (Baia de Arieș).

In the collision area between the Biharia arc and the Someș Northern terrain, the crustal thickness led to melting which generated the 400 my Codru migmatites according to Dallmayer et al. (1999). The Someş lithogroup has a tectonic accretionary prism setting (where one can also find oceanic crust lame) with strong input from the arc (Biharia volcanic arc; Biharia remnants of an island arc, which marked a suture between the Someş lithogroup and Baia de Arieș lithogroup approximately 400 my ago). The K-Ar ages for metamorphites in Romania (Soroiu et al., 1982, Mânzatu et al., 1975, Pavelescu et al., 1976, Ignat et al., 1982, Ichim et al., 1984, Soroiu et al., 1985, Strutinski & Soroiu, 1985) indicate that in the Upper Paleozoic, the Preapulin and Getic cratons were located in Southern Europe, heavily affected by the Variscan events. As a result, they were involved in a subsidence partially caused by Variscan molasse according to Argyriadis (1975).

After this, a series of basinal sequences appeared at the beginning of the collisional period during the Lower Late Cretaceous. The downward (digging-in) and then upward movement – exhumation is confirmed by the *collapse of the Variscan orogeny of Tisia and the disinterment of metamorphites at average crustal depths*. The main type in these cases is the **blasto-kinematic metamorphism**, which resulted in the development of **schistuous metamorphites** from **Șimleu Uplifting** and **Silvania Belt**, crystalline remnants of **Tisia, the ancient crystalline craton**.

In this geodynamic context, the Șimleu Basin, from a geological and structural point of view, represents one of the five basins formed by the collapse of the crystalline basement of the Tisia Craton. During the Alpine orogeny, the area was affected by vertical, predominantly disjunctive, movements, which fragmented the ancient craton in a series of *smaller blocks*. The predominance of the disjunctive tectonic style since the Mesozoic intensified in the Late Cretaceous and it is noticed during Tertiary, due to the sinking of large blocks maintaining in their physiognomy the descending direction of movement, therefore the crystalline was affected by the deep rifts that have caused the unevenness of blocks in Silvania Mountains. In Romania, one can no longer discuss about Hercynian chains, but Variscan remnants incorporated into alpine nappe structures.

3.3 The structural landforms of Silvania Mountains

The structural landforms of Silvania Mountains are conditioned by *the systems of faults* present in the area which determined the tectonic fragmentation and led to a *horst- graben* system. The formation of these structures is the result of Neogene extensional development of neighboring Transylvanian and Pannonian Basins (Fodor et al., 1999) as well as of translational post-Eocene movements (towards North) and a large clockwise rotation of the Tisia block with an angle between 90º and 120º around the Moesian Plate on the basis of a compressive tectonic (NNE-SSW) and extensional regime (E-W), fact confirmed by the movement of cortical faults of strike-slip type which contributed to the structural geodynamics of Silvania Mountains (Pătrașcu et al., 1994; Csontos, 1995; Panaiotu, 1998; Seghedi et al., 1998; Roșu et al., 2000). The current aspect of Silvania Mountains is due to three major tectonic events: the first event refers to the Paleogene – Neogene deformation fields, which affected the rotation of the Carpathian nappe system (in particular, those of the Apuseni) around the Moesian Plate; a reorientation of the deformation field during the Middle Miocene, which was caused by the retrograde subduction towards East, therefore a new fault system pushed the Carpathian nappes in the E-SE direction; the last and the most recent event consisted of a reorientation of the deformation field during the Pliocene-Middle Miocene, characterized by fanwise directions of compression, as those from Silvania Mountains, as it is noticed in the DEM model. Silvania Mountains branch out of North Apuseni as an *independent chain* from the point of view of direction and structure, with an island and V-shaped configuration.

The post-tectonic movements have fragmented this chain compressing it towards the Getic craton located in the basement of the Transylvanian Basin. Approaching an argument of the magnitude of the tectonic and structural relationships within Silvania Mountains implies referring to the Paleogene and Neogene sediments, to the bedded character of the deposits, to the position ratios between the rock masses, deformations, fractures and schistosity plans as structural factors.

Silvania Mountains present structural landforms (fig. 5) conditioned by the fault systems, which have determined a *dynamics of the subaerial and submerged landforms*, coordinating in this way the modeling systems with the geological time scale. The Sub-Hercynian (Mediterranean) diastrophism, but especially the Laramian one, are responsible for the fragmentation and dismantling of *Gilău-Plopiş-Meseş-Preluca Island* into **horsts and grabens**, reactivating old fault lines or generating new ones. The geologic basement of Plopiș Mountains and Meseș Mountains is implicitly represented by the Bihor Autochthonous, characterized by two crystalline series, Someş and Arada, and a sedimentary suite (Permian, Triassic, Cretaceous), divided into horsts and grabens, as a result of diastrophism during the Cretaceous until the Pliocene and which affected both the crystalline basement and the sedimentary cover.

Fig. 5. The geomorphological maps of Silvania Mountains


I.ELEMENTE GEOLOGICE SI STRUCTURALE.
ELEMENTI GEOLOGICI E STRUTTURALI.
(I). 1.LITOLOGIA SUBSTRATULUI.
LITOLOGIA DEL SUBSTRATO.
Roci metamorfice sistoase.Rocce metamorfiche scistose.
Seria de Meses (Paleozoic Inferior- Precambrian).
Seria de Somes (Precambrian Superior).
Roci vulcanice efuzive.Rocce vulcaniche effusive.
Magmatite neogene-dacite si andezite.
Magmatite Senonian-Paleocene (dacite).
Roci silicioase.Rocce Silicee.
Camplian Inferior-Werfenian (gresii silicioase).
Roci predominant calcaroase.Rocce prevalentemente calcaree.
Priabonian.
Roci predominant dolomitice. Rocce prevalentemente dolomitiche.
Priabonian.
Roci predominant argiloase .Rocce prevalentemente argillitiche.
Oligocen-Miocen Inferior, Stratele de Moigrad (Chattian-Rupelian).
Roci marnoase.Rocce marnose.
Pannonian (Malvensian),Lutetian.Badenian.Sarmatian.Miocen.
Pietrisuri si conglomerate.Ghiaie sciolte e conglomerati.
Pleistocen Inferior.
Contact litologic.Contatto litlogico.
III. FORME, PROCESE SI DEPOZITE DE VERSANT
DATORATE GRAVITATIEI.
FORME, PROCESSI E DEPOSITI DI VERSANTE
DOVUTI ALLA GRAVITA.
(III). 1.FORME DE EROZIUNE.
FORME DI EROSIONE.
Alunecari de teren.Frane.
Fenomene de creep. Fenomeni di creep.
Suprafete cu forme de curgere concentrata
(ravene si torenti).Superficie con forme di dilavamento
concentrato (ravene e torenti).
(III).2.FORME DE ACUMULARE.
FORME DI DEPOSITO.
Con detritic activ. Cono detrittico attivo.
Con detritic inactiv. Cono detrittico inattivo.
Depozite eluviale.Depositi eluviali.
(IV).2. FORME DE ACUMULARE.
FORME DI DEPOSITO.
Depozite aluvionale recente.Depositi alluvionali recenti.
Holocen.
Depozite aluvionale terasate, terase.Depositi alluvionali terrazzati.
Pleistocen.
Depozite coluviale. Depositi colluviali.
Cuaternar.
Curgeri noroioase. Depositi di debris flow.
Con aluvial si torential activ. Conoide alluvio torrentizio attivo.
Con aluvial si torential inactiv. Conoide alluvio-torrentizioinattivo.
VII. FORME RELICTE, SUPRAFETE DE NIVELARE
SI FORME ASOCIATE CU O GENEZA COMPLEXA.
FORME RELITTE, SUPERFICI DI SPIANAMENTO
E FORME ASSOCIATE TALORA
DI GENESI COMPLESSA.
Suprafata de nivelare I Pria - Merisor(800-1000m).
La superficie di spianamento Pria- Merisor (800- 1000m).
Suprafata de nivelare II Talhareasa -Secatura (650-750m).
La superficie di spianamento II,Secatura- Talhareasa(650- 750m).
Martori de eroziune.Testimoni di erosione
(I). 2.ELEMENTE TECTONICE.ELEMENTI TETTONICI.
Falie. Faglia
II.FORME STRUCTURALE SI VULCANICE.
FORME STRUTTURALI E VULCANICHE.
(II). 1. FORME STRUCTURALE. FORME STRUTTURALI.
Fronturi de cuesta. Orlo di cuesta.
Front de suprafata structurala. Orlo di scarpata strutturale.
Inseuare.Sella.
(II). 2.FORME VULCANICE. FORME VULCANICHE.
Neck vulcanic.Neck vulcanico.
Con polifazic. Cono poligenico.
Dyke. Dicco.
IV.FORME SI DEPOZITE FLUVIALE DE VERSANT
DATORATE SCURGERII.
FORME E DEPOSITI FLUVIALI DI VERSANTE
DOVUTI AL DILAVAMENTO.
(IV).1. FORME DE EROZIUNE.
FORME DI EROSIONE.
Curs de apa permanent.
Traccia di corso di acqua estinto.
Vai fluviale de tip V. Vallecola a V.
Vai cu fund concav.
Vallecola a fondo concavo.
Front de terasa aluvionala.
Orlo di terazzo alluvionale.
Suprafete cu forme de curgere difuze.
Superficie con forme di dilavamento diffuso.
V.FORME SI DEPOZITE DE ORIGINE CARSTICA
(V).1. FORME DE EROZIUNE.
FORME DI EROSIONE.
Dolina cartografiabila. Dolina.
VI.FORME SI DEPOZITE DE ORIGINE PERIGLACIARA.
FORME E DEPOSITI DI ORIGINE PERIGLACIALE.
Panza de grohotis.Falda di detrito.
VIII.FORME, DEPOZITE SI ACTIVITATI ANTROPICE.
FORME , DEPOSITI E ATTIVITA ANTROPICHE.
Mina, galerii de excavare antropica.
Cava, imbocco di galleria di scavo antropico.
Suprafete de excavare antropica.
Superficie di sbancamento.

The border and basement formations are made of crystalline schists, mesometamorphic schists (Someş crystalline) and epimetamorphic (Green schist facies), with a discrepancy in metamorphic grade over the Someş crystalline. These are followed by pre-Neogene sedimentary deposits (the Lower Triassic, the Upper Cretaceous and the Danian-Paleocene) and Neogene sedimentary deposits (filler sediments of the Şimleu Basin, respectively Badenian, Sarmatian, Panonnian, Pontian and Quaternary) laid down during three sedimentation cycles. The position and the structural ratio of Silvania Mountains with the neighboring units, as well as the presence of remnants from the ancient mountainous chain, indicate a well-individualized geographical region, on crystalline basement, strongly fragmented and marked by levels towards West. As previously mentioned, the formation of the horst and grabens systems of Silvania Mountains is due to the strike-slipe tectonics.

The tectonic structure, Carei-Preluca fault, continues in Hungary through the sinestral shear zone, Mid Hungarian Line, which is connected towards East to the fault system in the North of the Transylvanian Basin (Dragoş Vodă, Bogdan Vodă and North Transylvanian faults), where the paleostress measurements indicate sinestral lateral movements with associated tectonic structures. The Tisia-Dacia block moves towards East along the Mid Hungarian Line shear zone (Carei – Preluca – North Transylvanian System). The tectonic and structural relationships within Silvania Mountains are defined by two types of relationships: morphotectonic ones and morphoselective ones, with reference to the fault systems present in the region.

3.4 Morphotectonic relationships in Silvania Mountains

The geological structure played a significant role in the morphology of Silvania Mountains through the complex systems of faults in the area which imposed the modeling and the evolution of the structural landforms. The evolution of Silvania Mountains morphology was conditioned by the strong rectangular fragmentation of the Tisia block (according to Păucă, 1964) and its following vertical movements through the formation of the horsts-grabens system as a result of diastrophic processes. Silvania Mountains comprise *Plopiş Mountains, Meseș Mountains, Şimleu Hillock* and *Coșeiu Hillock,* and there are complex tectonic and structural relationships between these subunits.

The asymmetric crystalline horst of Plopiş Mountains, the Western side of Silvania Mountains, spreads over 37 km and has an island configuration, respectively a general NW-SE orientation of the tops (in line with the Carpathian direction), being surrounded by a fault with Pannonian direction (NE-SW) and of secondary faults on the N-S and W-E direction. The age of the main and secondary faults within Plopiş is Laramian, because of the banatites laid down on them (Patrulius, 1972, Bleahu 1976, Păucă, 1964). These fault systems gave the dynamics of the relief. The Mesozoic sedimentation processes within Plopiş Mountains did not take place in its current area, thus there are two hypotheses: during the Upper Triassic and the Jurassic, the Plopiş functioned as a horst, only in subaerial regime, although towards the South, in Pădurea Craiului Mountains, the Jurassic series is complete (in the geological literature, it is mentioned a mainland located in the North of Bihor Platform); during the Upper Triassic and Jurassic, the alternation of *ascending and descending movements on fault lines* from the Northern platform of the Tethys is the result of the *Eokimmeric* and *Neokimmeric phases*, followed by the Austrian phase, which determined the removal of sediments of the same age through erosion. To these we also add the lack of nappe structures in the Plopiș Mountains. The subcrustal dynamics of the *Plopiş subcrustal block* confirms the fact that they would have detached from *Muntele Mare crustal block* (Socolescu, Airinei, Ciocârdel, Popescu, 1975), in the shape of crustal scales or transition masses linked to the Bihor-Olt fracture and the Mureş geosynclinal. The research in Geophysics confirms the *disordered tectonic block structures* which crop out from the Neogene and the small crystalline formations in Silvania Mountains. The presence on the isostatic map of an important point, spreading towards West, from Telciu-Răzoare-Jibou until the Meseș Mountains, due to the rotation of blocks and crustal scales towards West, around an area in the North of Borşa, surrounding and compressing, with the blocks from the Apuseni Mountains, the area under the Transylvanian Basin, is a proven fact. Within Plopiş, there are transversal fault systems which have equidistant fractures, being crossed by vertical and subvertical faults, the most important being the *Aleuș-Pandorac fault* (NE-SW) and *Plopiş-Vuica fault* (NE-SW).

The dominant note of the structural morphology in the Plopiş Mountains is given by Măgura Synclinorium. *Meseș Mountains*, as part of the Eastern Silvania Mountains, represent a *hemi-anticline* with the eastern flank oriented SW-NE, having a length of around 35 km and a width of 2-5 km. The *tectonic phenomena* in Meseș Mountains (Szadeczky-Kardoss, 1925-1926) are represented by folding (in what concerns the metamorphism) due to *ante-Permian folding* and *mesozonal* and *kata metamorphism* (indicated by the diaftorites of the first crystalline series and the imprisonment of ancient crystalline schists of Verucano conglomerate, less metamorphosed). In agreement with the authors, the Mesozoic strata were folded and metamorphosed especially in the epizone, reality confirmed the Permian conglomerate and the Guttenstein limestone – epizone crystalline schists folded between other crystalline schists of Meseş Mountains. In what concerns the Upper Cretaceous sediments, they are not metamorphosed, therefore the discrepancy between the Upper Cretaceous basement and the Eocene strata confirms the existence of a folding period at the end of Cretaceous, with a maximum folding of intra and post Mediterranean age, with a SW-NE direction, causing a *strong folding of the Meseş*. The arguments for this hypothesis are the Eocene and Oligocene basements folded together and the conformity between Oligocene and Lower Mediterranean. The main direction of Alpine folding of the Cretaceous and Tertiary in the Meseş is NE-SW and the *faults and dislocations* specific to this area represent dislocations following the Alpine orogenic system, being parallel to the main NE-SW direction. As opposed to the Plopiş Mountains, there are fragments of nappe structures belonging to *Gârda Nappe* according to Horvath (1982) and Balintoni (1985).

The *Meseș hemi-anticline* is different from the horst of Plopiş due to the *dynamics, intensity* and *magnitude of the faulting phenomenon*, as three major faults are noticed: Moigrad fault, Meseș fault and Benesat-Cuceu-Moigrad fault. *The Moigrad fault* is a deep faulting zone, characterized by a pronounced instability, which determined a powerful subsidence and the control of sedimentation, as well as the placement of magmatic rocks in the area. It also has a thrust character, being known as the *Meseș overthrust line*. The Paleogene strata are overthrown and overlapped by crystalline. The fault was active especially during the Miocene. It is accompanied by numerous perpendicular or parallel secondary faults that affect the sedimentary deposits and the crystalline structures, in the shape of a *transverse fracture system.*

The Meseş Mountains highlight the tectonic and structural relationships between the basement (in this case the fault systems) and the external modeling agents. The linear erosion of the transversal water streams (Poicu, Poniţa, Ragu Valley) determined a modeling of the fault fronts in the shape of trapezoidal and triangular facets, in particular in Meseş, near Grebeni Peak, Măgura Priei Peak, Tabla sub Pietre Peak, Citera Poniţa Peak, Găsin Hill, Ragu Peak and Gruiu Peak, unlike in Plopiș, Șimleu Hillock and Coșeiu Hillock (fig. 6). The fault fronts in the Meseş and Plopiș were submitted to dismantlement through areal and linear erosion and sedimentation, therefore lower landforms appeared in comparison with the initial placement where the faulting phenomenon took place, as shown in this transversal profile on SW-NE direction over the southern Meseş, in Ciucea-Buciumi sector (fig. 6). In Meseş Mountains, as a result of faulting processes, the slopes sectioned by faults have detritus nappes at Stâna, Fetindia, Carpeni, Meseşenii de Sus, Tabla sub Pietre, Hodin Tableland, unlike in Plopiș.

Another structural feature of Meseş as opposed to Plopiş is the presence of fault valleys (Poicu and Ragu Valley) due to tectonic disorders which determined a process of mechanical fragmentation of the rock, in line with the fault planes. These cataclastic strips can be areas of major erodability, where a flowing channel can be installed in the shape of a fluvial valley resulting in this way “transversal valleys on faults” such as Poniţa Valley and Ragu Valley, which drain their waters along fault lines.

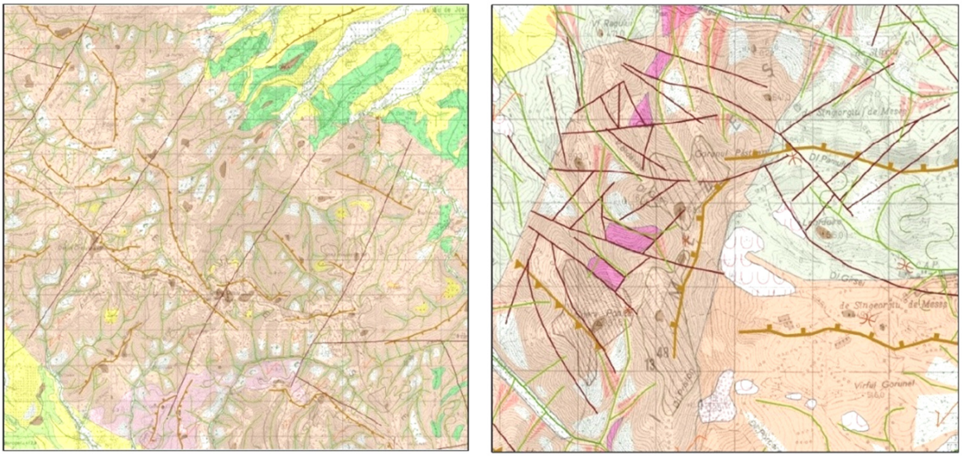

Fig. 6. Fault systems in the Meseş and Plopiş Mountains

At the contact of **Benesat-Cuceu-Moigrad** fault with Moigrad faulting zone, a series of eruptive bodies of microgabbro and andesites (Moigrad Hillock) have been placed, unlike in Plopiş, where there are no explicit marks of magmatic activity due to the presence of faults. Instead, in Plopiş, the NE-SW local fault systems, which flank on both sides the Plopiș summit and their tectonic basement, were formed on the old shoreline, especially on the Northern side. Therefore, coastal platforms composed of submontane deposits were left in the overall morphology as erosion marks, discordantly sitting over the crystalline. Regarding the morphotectonic attributes of the two hillocks, Șimleu and Coșeiu, we have found the following. *Șimleu Hillock* presents itself in the shape of a crystalline island (the crystalline schists from its composition belong to the Someș Series), composed of two terrigene complexes (the lower one made of quartzites, schists and muscovite and biotite paragnaises of Șimleu and the upper one of quartzites, schists and mica-schists of Cehei) separated by an acid magmatogenic complex.

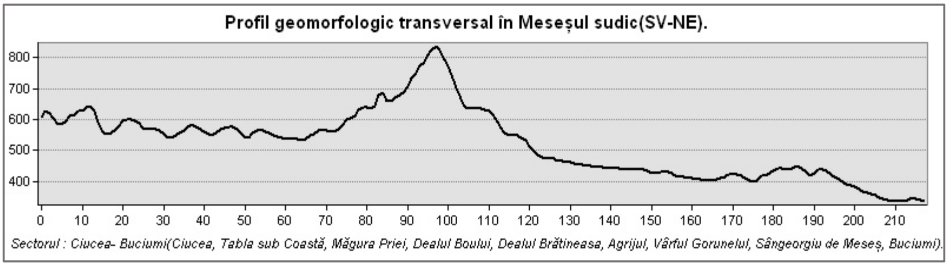

Fig. 7. Transversal geomorphological section across Meseş Mountains

The metamorphic processes have been defined by three Blastese phases (according to Kalmar, 1996): a progressive phase of high temperature and low pressure, a regressive phase – in the green schists facies, as in Plopiș and Meseș, and a new progressive phase – which has three schistosity surfaces as well as two fissure systems. The age of the metamorphism is Hercynian or older, and the K-Ar age values of around 100 my are due to the thermic front of the Middle Cretaceous, during the collision between the Tisia and Dacia domains.

On the basis of some local references (gneiss, biotite quartzite and graphite quartzite), the structure of the range was deciphered, being made of a succession of E-W faulted folds, some of them with the tectonic shank thinned away, with narrow milonitic areas. Over the surface of the crystalline, one can recognize the remnants of an ancient alteration crust, on which small areas of Paleogene (Jibou Formation), Badenian and Panonnian deposits can be found. Considering the faults bordering this crystalline island, the Șimleu-Bădăcin fault (with a SW-NE orientation) in the South-Eastern part of the range is relevant. The crystalline schists near it have a fall close to 90° and come into contact with Badenian and Pontian sediments. The crystalline schists in Măgura Șimleului are covered by Danian-Paleocene deposits. In what concerns Coșeiu Hillock, with an ENE direction from the Şimleu crystalline, it spreads near Coşeiu village, in the shape of a small crystalline island, with an area of around 2 km and a WNW-ESE orientation, falling towards ENE. Coșeiu Hillock represents a bigger crystalline block, under Tertiary sediments (Badenian and Sarmatian), being partially brought to surface by erosion processes. A complex system of faults, with SW-NE and E-W orientation, separates towards East the Hăghișa crystalline from the Șimleu Basin; these faults can also be seen near Chilioara and Guruslău villages. To the North of Chilioara, along the fault, volcanic events with explosive character took place. Their marks are the Dacitic agglomerate in Lighet Hill and, in this respect, Chilioara is similar to Meseş. Păucă (1964) asserts that this eruption center provided the cineretic material between the Badenian and Sarmatian sediments. To the North of Archid, near Coșeiu Valley, the crystalline can be seen emphasizing a lift of the basement in the direction of Codru Range.

3.5. Morphoselective relationships

The role of the geological factor in the erosion modeling can also be that of passive control of landforms, because structural and lithological discontinuities present in the rocks exposed to erosion facilitate the selectivity of the erosion processes (fig.7). In this respect, we can speak of morphoselection and tectonic and structural relationships between the tectonic process intensity and the competence of rocks in Silvania Mountains, which favored the development of three types of structural landforms: on folded structures, on consistent horizontal structures and on monoclinal structures.

The relief of consistent horizontal structures is characteristic to Şimleu Basin. The composition of the basement in mesozone rocks and the rarity of Paleo-Mesozoic sediments confirm the fact that during the pre-Badenian the region was submitted to ascending processes and intense erosion. The crystalline islands of Silvania Mountains have an advanced evolution, and the tectonic and structural relationships of the crystalline with the discordant sediments is reflected from a structural point of view by ancient erosion surfaces, whose presence can be noticed at different altitudes.

The Danian – Paleocene erosion surface, *Pria-Merişor* (Savu, 1965), located at 800-1000 m (it is located at lower altitudes in Şimleu Hillock, while it is buried in Coşeiu Hillock) and *Secătura –Tâlhăreasa* (Pop, 1964), more recent and strongly fragmented (650 - 750 m), are both important and are intersected by faults. The alternance between the hard rocks from the basement and the soft ones from the sedimentary cover, on fault lines, facilitated the modeling of some structural surfaces, asymmetric valleys, border cuestas, exhumed peneplains (Paleogene in Plopiş) and contact basins. The exhumed peneplains, with some exceptions, maintain their initial physiognomy here and there and, subject to erosion, they are modeled as border glacis, abrasion-accumulation surfaces, submontane accumulation glacis.

The contact basins stretch between the border cuesta and the old range border. Contact erosive basins (Pria, Poniţa, Hurezu Mic and Meseşeni in Meseş, Tusa, Preoteasa, Plopiş, Halmăşd and Cerişa in Plopiş) developed as a result of the structural contact between the crystalline and the sedimentary rocks, on the fault lines of Şimleu Basin and the Meseş hemianticline. *The landscape of the monoclines* of Silvania Mountains formed on complex tectonic and structural relationships between the geological structure (the unconformities between the strata with different dips and resistance to shaping) and the external agents (the drainage network). Against the negative movements of the sinking blocks of Silvania Mountains, the westerly rivers get in regressively. These rivers disarranged the old artery, through consecutive disturbances. Thus, the current network (Barcău, Crasna, Crişul Repede and Zalău), which affects the monoclinal structure both in depth and sideways, formed during the Middle Quaternary. By the way the valleys affect the monoclinal structure, one finds consequent, subsequent and obsequent streams in Silvania Mountains.

The landscape of folded structures represents a different type of tectonic deformation formed against complex tectonic and structural relationships between the structure and the tectonic processes (ascending, descending movements, basculations, inflections) *as folds* (depth and surface folds), as a result of the upright movements of the Tisia block. Silvania Mountains appeared in a sedimentation basin (*the Transylvanian lagoon*), independently located, in the North-West of Transylvania, subject to the repeated transsgresions of the Paratethys. Thus, the sedimentary deposits of Meseş Mountains display strongly reshaped terrigenous sediments that underwent an advanced alteration and a long transportation process. These sediments display a high degree of erosion (red shales). The Meseş Mountains Eocene was formed following the erosion of rocks from the neighboring crystalline mountains. Thus, the Eocene deposits were folded as anticlines and synclines. The NW-SE orientation of Silvania Mountains is the main tectonic orientation of NW Transylvania, being emphasized by the two rows of crystalline mountains that separate the Transylvanian Basin from the Pannonian Basin (the first - Plopiș Mountains, Meseş Mountains, the second one - Șimleu Hillock and Bâcu Mountains). The Pontian sediments of the central areas of Şimleu Basin cover the Miocene sediments, and in the border areas they stretch unconformably over the crystalline. As a result of the rigid crystalline basement proximity to the top, these deposits of the higher structural sub-stage display simple tectonics. Mostly, they find themselves in their initial position, with a monoclinal succession with a fall less than 12º and small ridges under the form of *large upwarping folds* due to *transverse fault lines* in the basement of the area. They display different fall directions, as a result of the upright displacement of the blocks. Thus, they produced lateral compressions as secondary tangential movements that led to the disarrangement of strata and their large upwarping under the form of synclines and anticlines, located between the crystalline of Meseş Range and the crystalline of Hăghișa, Zalău syncline, Dobrin - Panic anticline, Crișeni and Aghireș – Panic brachianticlines respectively.

4. CONCLUSIONS

The article aims at highlighting the active and passive role of the geological factor in establishing tectonic and structural relationships in Silvania Mountains. The research began with a restructuring of Silvania Mountains paleodynamics and tectonic evolution *as an Alpine collisional chain*, result of a complex geodynamics, Hercynian on the one hand, mainly Alpine on the other, integrated to the Tisia-Dacia microplate and reduced to these *islands of crystalline schists* (nowadays, Variscan remnants incorporated into the structures of Alpine nappes of the North Apuseni Mountains), against an Alpine disjunctive tectonic style to which the block or craton of Tisia was subject.

The geodynamics of Silvania Mountains and inferientially their structural landmarks are due to the Neogene development of the neighboring Transylvanian and Pannonian Basins, to the post-Eocene translational movements (towards North) and to the large clockwise rotation of the Tisia block around the Moesian plate, against a tight (NNE-SSW) and extensional (E-W) tectonic regime. This is reaffirmed by the *strike-slip type* fault movements of Silvania Mountains.

Silvania Mountains branch out of the North Apuseni Mountains like an *independent chain* as orientation and structure, with an island and V-shaped configuration as a result of the new orientation of the deformations specific to the Middle Miocene-Pliocene, marked by fanwise directions of compression. The emergence of Silvania Mountains system of horsts and grabens is due to the *strike-slip* **type tectonics**, favoured by *Carei-Preluca fault*, through which the Tisia-Dacia Block moves towards East, along the shearing area of the *Mid Hungarian Line* (Carei – Preluca - the North Transylvanian System).

REFERENCES

1. Argyriadis, S. (1975). *Mesogeepermiene chaine herciniene et cassure tethysiene*. Bull. Soc. Geo. France (7), XVII, 156-57.
2. Balintoni, I. (1994). *Structure of the Apuseni Mountains*, Rom. J. Tect. Reg. Geol. 75/2 (ALCAPA II Field Guide Book), 9–14.
3. Balintoni, I., Vlad, S. (1998). *Tertiary magmatism in the Apuseni Mountains and related tectonic setting.* Studia Univ. Babeș-Bolyai, Geologia IX, 1-11.
4. Balintoni, I. (1997). *Geotectonica Terenurilor Metamorfice din Romania*. Edit. Carpatica, Cluj-Napoca, Romania, 176 pp.
5. Balla, Z., (1984). *The Carpathian loop and the Pannonian basin: a kinematic analysis*. Geophys. Trans. 30, 313–353.
6. Clichici, O. (1973). *Stratigrafia Neogenului din estul Bazinului Șimleu*, Edit. Academiei Republicii Socialiste Romania, Bucharest, p. 14-70.
7. Csontos, L. (1995). *Tertiary tectonic evolution of the Intra-Carpathian area: a review*, Acta Vulcanologica, 7 (2), 1-13.
8. Csontos, L. & Nagymarosy, A. (1998). *The Mid-Hungarian line: a zone of repeated tectonic inversions.* Tectonophysics, 297, 51–71.
9. Csontos, L., Márton, E., Worum, G., Benkovics, I. (2002). *Geodynamics of SW-Pannonian inselberg (Mecsek and Villany Mts., SW Hungary): inference from complex structural analysis,* EGU Muller Special Pub. Ser., 3, 1-19.
10. Dallmeyer, R.D., Pană, D.I., Neubauer, F., Erdmer, P. (1999). *Tectonothermal evolution of the Apuseni Mountains, Romania: resolution of Variscan versus Alpine events with 40Ar/39Ar ages*, J. Geol., 107, 329–352.
11. Doglioni, C., Harabaglia, P., Merlini, S., Mongelli, F., Peccerillo, A., Piromallo, C. (1999). *Orogens and slabs vs their direction of subduction*, Earth Science Reviews, 45, 167-208.
12. Fodor, L., Csontos, L., Bada, G., Gyorfi, I., Benkovics, L. (1999). *Tertiary tectonic evolution of the Pannonian Basin system and neighbouring orogens; a new synthesis of palaeostress data*, in Durand, B., Jolivet, L., Horvath, F., Seranne, M. (eds.) *The Mediterranean basins; Tertiary extension within the Alpine Orogen*, Geol. Soc. Spec. Publ., 156, 295-334.

13. Horváth, F. (1993). *Towards a mechanical model for the formation of the Pannonian basin*, Tectonophysics, 226, 333-357.
14. Huismans, R.S., Podladchikov, Y.Y., Cloetingh, S. (2001). *Dynamic modeling of the transition from passive to active rifting, application to the Pannonian Basin*, Tectonics, 20, 1021-1039.
15. Kalmár, J. (1996). *Geology of Szilágysomlyói Măgura*, Földtani Közlöny, 126/1,41-65, Budapest.
16. Konecny, V., Kovac, M., Lexa, J., Sefara, J. (2002). *Neogene evolution of the Carpatho-Pannonian region: an interplay of subduction and black-arc diapiric uprise in the mantle*, EGU Stephan Mueller Special Publication Series, 1, 105-123, European Geosciences Union 2002.
17. Linzer, H.-G., Frisch W., Zweigel P., Girbacea, R., Hann, H.-P., Moser, F. (1998). *Kinematics evolution of the Romanian Carpathians*, Tectonophysics, 297, 133-156.
18. Mac, I., Irimuș, I.A. (2000). *Geomorphological homologies in the mountainous ranges situated in the north-western and south-eastern part of the Transylvanian Basin*, in Bălteanu, D., Ielenicz, M., Popescu, N. (eds.) *Geomorphology of The Carpatho-Balcan region*, Edit. Corint, Bucharest.
19. Meulenkamp, J.E., Kovac, M. and Cicha, I. (1996). *On late Oligocene to Pliocene depocenter migration and the evolution of the Carpathian-Pliocene system*, Tectonophysics, 266, 301–317.
20. Nemčok M., Pospisil L., Lexa J., Donelik R.A. (1998). *Tertiary subduction and slab breakoff model of the Carpathian Pannonian region*, Tectonophysics, 295, 307-340.
21. Nicolae, I. (1995). *Tectonic setting of the ophiolites from the South Apuseni Mountains: Magmatic Arc and Marginal Basin*. Rom. J. Tect. Reg. Geol. 76, p. 27-39.
22. Panaiotu, C. (1998). *Paleomagnetic constraints on the geodynamic history of Romania*. In: Reports on Geodesy. Monograph of Southern Carpathians. CEI CERGOP Study Group No 8, Geotectonic Analysis of the Region of Central Europe. Warsaw Univ. of Technology / Inst of Geodesy & Geodetic Astronomy No 7 (37), 205-216.
23. Panaiotu, C. (1999). *Paleomagnetic studies in Romania; Tectonophysics implications* (in Romanian). PhD thesis, University of Bucharest, 265 pp.
24. Pană, D., Balintoni, I. (2000). *Igneous protoliths of the Biharia lithotectonic assemblage timing of intrusion, geochemical considerations, tectonic setting*, Studia Univ. Babeş-Bolyai, Geologia, XLV, 1, 3-22, Cluj-Napoca.
25. Pană, D. (1998). *Petrogenesis and Tectonics of the Basement Rocks of the Apuseni Mountains: Significance for the Alpine Tectonics of the Carpatian-Pannonian Region,* PhD. Thesis, Univ of Alberta, Canada.
26. Pătraşcu, St., Panaiotu, C., Şeclăman, M., Panaiotu, C.E. (1994). *Timing of rotational motion of Apuseni Mountains (Romania): paleomagnetic data from Tertiary magmatic rocks*, Tectonophysics, 233, 163–176.
27. Păucă, M., Clemens, A. (1964). *Vârsta pietrișurilor piemontane din regiunea de sud a Bazinului Silvaniei,* D . S. Com. Geol., L. ,1.
28. Ratschbacher, L., Frisch, W., Linzer, H.G. & Merle, O. (1991). *Lateral extrusion in the Eastern Alps; Part 2, Structural analysis*, Tectonics, 10, 257– 271.

29. Rădulescu, D. (1984). *Continuity, periodicity and episodicity in magma genesis processes associated to the closing of the Alpine Ocean in the Carpathian Area*, An. Inst. Geo. Geofiz., LXIV, 103-110.
30. Roșu, E., Seghedi, I., Downes, H., Alderton, D.H.M., Szakács, A., Pécskay, Z., Panaiotu, C., Panaiotu, C.E., Nedelcu, L. (2004). *Extension-related Miocene calc-alkaline magmatism in the Apuseni Mountains, Romania: origin of magmas*, Swiss Bulletin of Mineralogy and Petrology, 84/1-2,153-172.
31. Roșu, E., Panaiotu, C., Pécskay, Z., Panaiotu, C.E. and Ivășcanu, P.M. (2000). *Neogene Magmatism in the Apuseni Mountains, Romania. Evolution and geochemical features*, An. Inst. Geol. Rom., 72, 71–72.
32. Royden, L.H. (1993). *The tectonic expression slab pull at continental convergence boundaries*, Tectonics, 12, 2, 303–325.
33. Săndulescu, M. (1994). *Overview of Romanian Geology*, in ALCAPA II field guide book. Romanian J. of Tectonics and Reg. Geol., 75 (suppl. 2): 3-15.
34. Săndulescu, M. (1984). *Geotectonica României*, Edit. Tehnică, Bucharest, 366 pp.
35. Săndulescu, M. (1988). *Cenozoic Tectonic History of the Carpathians*., in: Royden LH, Horváth F (eds.), *The Pannonian Basin; a study in basin evolution*. AAPG Mem, 45, 17-26.
36. Schmid, S., Bernoulli, D., Fügenschuh, B., Maţenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K. (2008). *The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units*, Swiss Journal of Geosciences: doi: 10.1007/s00015-008-1247-3, 139-183.
37. Seghedi, I., Balintoni, I., Szakács, A. (1998). *Interplay of tectonics and Neogene post-collisional magmatism in the Intracarpathian area*, Lithos, 45, 483-499.
38. Socolescu, M., Airinei, S., Ciocârdel, R., Popescu, P. (1975). *Fizica și structura scoarţei terestre din România,* Edit. Tehnică, Bucharest.
39. Soroiu, M., Balintoni, I., Vodă, Al. (1985). *A model of the Basement of the Transylvanian Basin as revealed by K-Ar Dating*, Rev. Roum. Geol., Gephys., Geogr., Geophys., 29, 29-35, Romanian Academy, Bucharest.
40. Sperner, B. Ratschbacher, L. & Nemcok, M. (2002). *Interplay between subduction retreat and lateral extrusion: tectonics of the Western Carpathians*, Tectonics, 21/6, I-1 to I–24, 1051, doi:10.1029/2001TC901028.
41. Stan Rodica & Puște, A. (2001). *Un posibil model de evoluţie al Munţilor Apuseni și al sistemului Pânzelor de Biharia,* Studia Univ. Babeş-Bolyai, Geologia, XLVI,1.
42. Strutinski, C., Soroiu, M. (1985). *K-Ar Ages on Rock-Forming Minerals from the Basement of the Southern Pannonian Basin*, Studia Univ. Babeş-Bolyai, Geologia, LV,1.
43. Szadeczky-Kardoss, E. (1925-1926). *Munţii Ascunşi ai seriei cristaline mai vechi (seria I), din nord-vestul Ardealului*, D.S ale Şed. Inst.Geol.Rom, XIV, Bucureşti.
44. Zugrăvescu, D., Polonic, G. (1997). *Geodynamic compartments and present-day stress state on the Romanian territory*, Rev. Roum. Géophys., 41, 3-24.