THE PERMIAN SYSTEM IN ROMANIA

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Key words – Permian; sedimentology; paleontology; magmatism; tectonics; Romania.

Abstract – Permian deposits from major tectonic units in Romania (South Carpathians, East Carpathians, Apuseni Mountains, North Dobrogea, Moesian and Scythian Platforms) are mainly developed in continental facies, with molassic characteristics. Red beds are the dominant facies, but basal black and grey shaly deposits are present in the South Carpathians and Apuseni Mountains. In all areas, sedimentation took place mostly in alluvial fan, fluvial and lacustrine systems. Shallow-marine carbonate platform conditions were restricted to the northern part of the Moesian Platform in the Early Permian. Evaporites are associated with the red beds only within the platforms.

The sedimentary record of most basins includes volcano-sedimentary sequences. The Permian volcanism was bimodal, with an alkaline signature in the Apuseni Mountains, North Dobrogea and Scythian Platform. The basalt-rhyolite bimodal association typically occurs in the South Carpathians, Apuseni Mountains and the Moesian Platform, while the basalt-trachyte association is found in North Dobrogea and the Scythian Platform.

The South Carpathians (Getic Nappe and Danubian units) yielded by far the most fossiliferous Permian deposits in Romania, the fossil remains being represented by flora (compressed macroflora, microflora), and fresh water fauna (ganoid fishes, ostracods, bivalves). The Apuseni Mountains include deposits yielding flora (silicified woods, microflora), while the North Dobrogea has yielded no fossils to date. The Moesian and Scythian Platforms include faunal remains, but palynological evidence was also found in the latter.

An extensional tectonic setting, related to Late? Permian rifting, is suggested by both field evidence and the geochemistry of the volcanic rocks from the South Carpathians, Apuseni Mountains, Moesian and Scythian Platforms. Typical rift basins are those from the platforms. For North Dobrogea, magmatic associations illustrate the transition from a compressional, post-collisional setting in the Early Permian to a transtensional setting in the Late Permian, related to the tectonic collapse of the Hercynian crust.

Parole chiave – Permiano; sedimentologia; paleontologia; magmatismo; tettonica; Romania.

Riassunto – I depositi permiani delle maggiori unità tettoniche della Romania (Carpazi meridionali, Carpazi orientali, Monti Apuseni, Dobrogea settentrionale, Piattaforme Moesia e Scitica) sono rappresentati essenzialmente da facies continentali con caratteristiche di molasse. I *red beds* corrispondono alla facies dominante, ma peliti (*shales*) di color nero affiorano altresì, in posizione sottostante, nei Carpazi meridionali e nei Monti Apuseni. In tutte le sopra citate aree, la sedimentazione si espresse principalmente in sistemi di coni alluvionali, fluviali e lacustri. Condizioni di piattaforma carbonatica di mare basso furono limitate alla parte settentrionale della Piattaforma Moesia, nel corso del Permiano inferiore. Evaporiti si trovano associate a *red beds* solo all'interno delle piattaforme. Il record sedimentario della maggior parte dei bacini include sequenze vulcano-sedimentarie. Il vulcanismo permiano fu bimodale, con un marchio di natura alcalina nei Monti Apuseni, nella Dobrogea settentrionale e nella Piattaforma Scitica. L'associazione bimodale basalto/riolite ricorre tipicamente nei Carpazi meridionali, nei Monti Apuseni e nella Piattaforma Moesia, mentre l'associazione basalto-trachite è presente in Dobrogea meridionale e nella Piattaforma Scitica.

I Carpazi meridionali (Falda Getica e unità Danubiche) comprendono di gran lunga i maggiori depositi fossiliferi della Romania, con resti fossili rappresentati da flore (macroflore limitate, microflora) e faune (pesci ganoidi, ostracodi, bivalvi). I Monti Apuseni includono depositi a flore (legni silicizzati, microflora), mentre la Dobrugea settentrionale non ha ancora dato fossili utili per eventuali datazioni. Le Piattaforme Moesia e Scitica contengono resti faunistici; tuttavia, nella seconda di esse è stata anche riscontrata la presenza di elementi palinologici.

Un assetto tettonico estensionale riferito al *rifting* permiano è suggerito da evidenze di campagna e dalla geochimica delle rocce vulcaniche provenienti dai Carpazi meridionali, dai Monti Apuseni, e dalle Piattaforme Moesia e Scitica. Bacini tipici di *rift* sono quelli di piattaforma. Per quanto riguarda la Dobrogea settentrionale, le associazioni magmatiche segnano la transizione da un assetto compressionale e post-collisionale, durante il Permiano inferiore, ad un assetto transtensivo, riferito al collasso tettonico della crosta ercinica, nel corso del Permiano superiore.

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INTRODUCTION

In Romania, Permian deposits are exposed in the Alpine belts (East and South Carpathians, Apuseni Mountains and North Dobrogea orogen), but they are also known from boreholes in the Moesian and Scythian Platforms (Fig. 1). In the East Carpathians, scarce terrigenous sediments overlain by Lower Triassic sandstones are ascribed to the Permian within the Bucovinian, Sub-Bucovinian and Infra-Bucovinian Nappes. In the South Carpathians the Permian deposits are recorded in both the Getic and Danubian Nappe systems. The Permian occurrences are confined to the central part of the Apuseni Mountains (Codru and Biharia Nappe systems and Bihor "autochthonous" unit of the Codru Moma, Bihor and Padurea Craiului Mountains).

The Permian sedimentation took place in several basins in the South Carpathians – Resita and Pui (Getic Nappe), Sirinia and Presacina (Danubian units) (Codarcea, 1940; Raileanu, 1953; Stilla & Luta, 1968). Small patches of thin Permian red beds, mostly fanglomerates, initially described as "Verrucano" facies, are scattered locally in the area of the Danubian Window and in the Godeanu outlier of the Getic Nappe (Gherasi, 1937; Pavelescu, 1953).

The Resita Basin exposes the sedimentary cover of the Getic Nappe in the westernmost part of the South Carpathians (Banat region). It is a north-south elongated basin, faulted and folded longitudinally, its deposits belonging to a Variscan (Westphalian A?-B-Lower Permian - "Autunian") and an Alpine cycle (Hettangian-Albian). The Pui area is located within the Hateg Depression (central South Carpathians), which is dominated by Mesozoic and Tertiary deposits.

The Sirinia Basin represents the cover of the Upper Danubian units and lies in the southwesternmost Carpathians (Banat region), mainly within the Almaj Mountains. It is a north-south oriented basin, located eastwards of and parallel to the Resita Basin. The Presacina Basin, oriented north-south, lies eastwards of the Sirinia Basin. Both Danubian basins include products of two main cycles, a Variscan and an Alpine cycle.

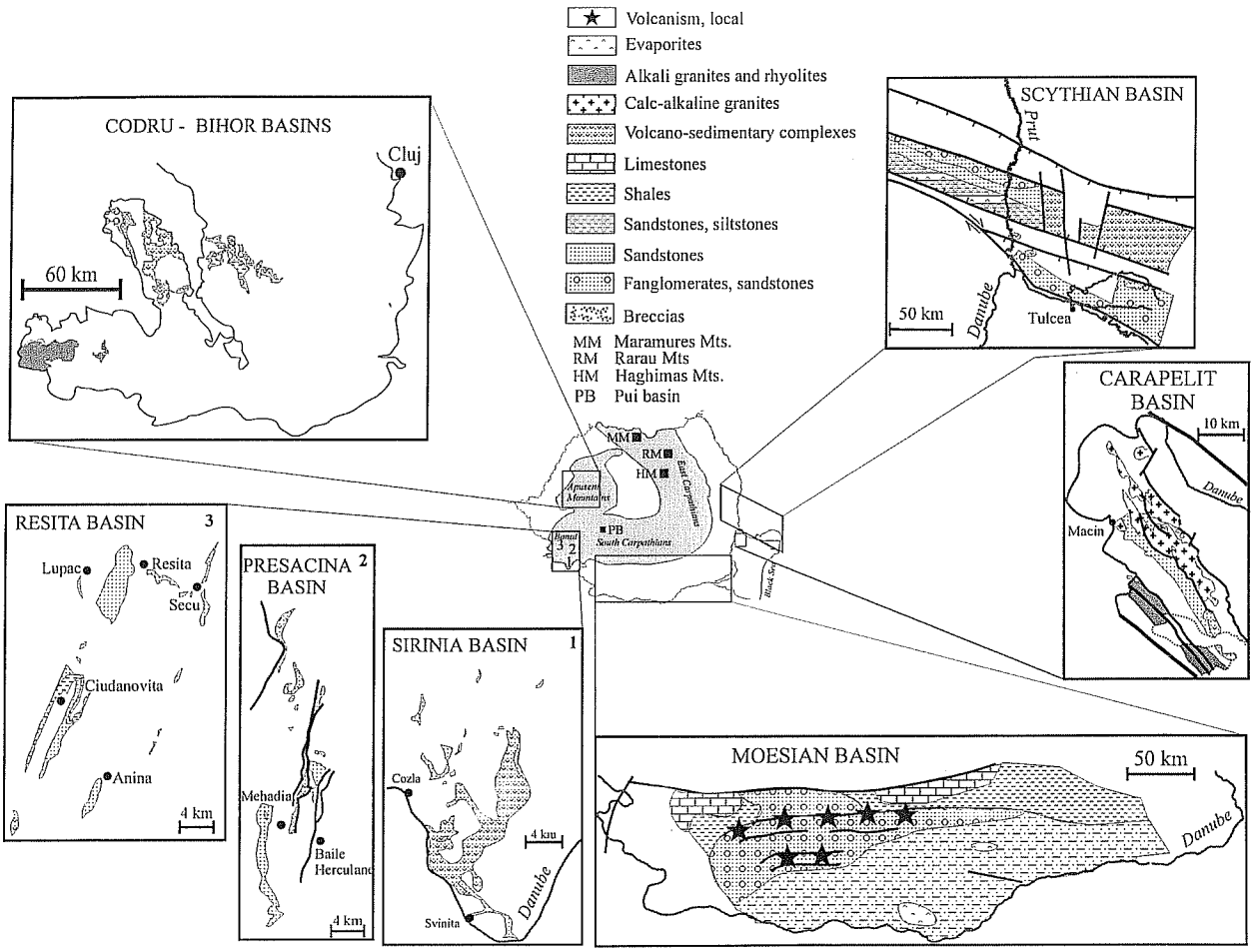

Fig. 1 – Location map and distribution of Permian deposits in Romania.

The Permian of the Apuseni Mountains is known in the Codru Nappe System (Dieva, Moma, Finis and Codru Nappes) of the Codru Moma Mountains, as well as in the Biharia Nappe System (Garda and Arieseni Nappes) and the Bihor Unit (Bihor "Autochthonous") of the Bihor and Padurea Craiului Mountains (Bleahu, 1963; Istocescu *et al.*, 1970; Patrulius, 1972; Bordea & Bordea, 1982; Bleahu *et al.*, 1985; Dimitrescu, 1988). Recent studies (Bordea & Bordea, 1993) revealed the presence of the Lower Permian bioturbated sandstones in the Highis Mountains (south-western part of the Apuseni Mountains).

In North Dobrogea, Permo-Carboniferous continental sedimentation took place in largely E-W oriented, narrow piggyback basins related to back-arc thrusting (Seghedi & Oaie, 1995 a). The NW-SE elongation of the outcrop area of Carapelit Formation (Fig. 1) is the result of subsequent deformation, and preservation of the Upper Paleozoic sediments in the core of a Kimmerian syncline.

An E-W oriented rift basin controlled the Permian sedimentation in the northern part of the Moesian Platform. This was located south of an elongated basement high (Craiova - Bals - Optasi rise) (Paraschiv, 1979), which probably represented a rift shoulder. Other part of the Permian basin occurred in the southern part of the Romanian Moesian Platform and continued southwards into the present-day Bulgarian territory.

The Scythian Basin, bordered and fragmented by major faults, is oriented WNW-ESE and includes the Aluat-Sarata and Lower Danube sub-basins (Neaga & Moroz, 1987), separated by tectonic ridges or push-ups.

STRATIGRAPHY

Coarse-grained sediments (Haghimas Breccias) in the Bucovinian Nappe of the East Carpathians, consisting mainly of unsorted clasts of metamorphic rocks, were ascribed to the Permian in Rarau and Haghimas Mountains, based on palynological associations (Muresan, 1970). In the Bucovinian and Sub-Bucovinian Nappes from the Maramures Mountains, the Haghimas Breccia directly overlies the metamorphic basement and is unconformably overlain by red Permian siliciclastics; based on field relations, an Upper Carboniferous and possibly Lower Permian age was ascribed to these rocks, overlain in turn by Lower Triassic sediments (Sandulescu *et al.*, 1989). A Permian age was assigned to the red sandstones and conglomerates from the Infrabucovinian Nappes in the same area, by lithological correlation with the Rozis series from Ukraine (Sandulescu, 1985).

The Variscan molasse deposits of the Resita Basin are subdivided into the Upper Carboniferous ("Westphalian A?-B" – "Stephanian") Resita Formation and the Lower Permian ("Autunian") Ciudanovita Formation (Bucur, 1991); the latter consists of lower black deposits (the Gîrliste Member) overlain by red beds (the Lisava Member) (Fig. 2). The Ciudanovita Formation lies conformably (west-

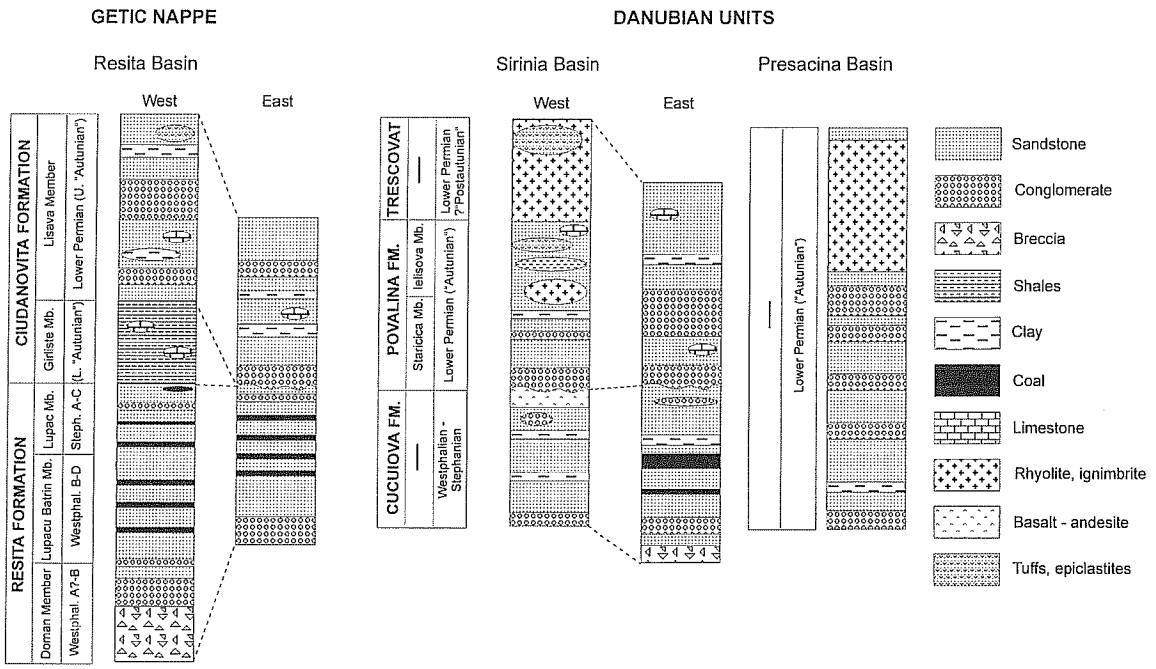

Fig. 2 – Variscan molasse deposits of the South Carpathians. Data compiled from Raileanu (1953), Nastaseanu *et al.* (1981), Stanoiu & Stan (1986) and Stanoiu *et al.* (1996).

wards) or unconformably (eastwards) on the Upper Carboniferous deposits of the Resita Formation, and it is unconformably overlain by the Lower Jurassic deposits of the Steierdorf Formation (the first unit of the Alpine cycle). The typical molasse characteristics suggest that the continental deposits of the Ciudanovita Formation accumulated in an intramontane depression. During Late Carboniferous and Early Permian times, the lateral shift of the depositional centre of the basin explains the numerous heteropic, partially juxtaposed Upper Paleozoic sequences in the Resita Basin (Stanoiu *et al.*, 1996). The Gîrliste Member is the lowest sequence of the Lower Permian, dominated by lacustrine deposits. Its thickness (150-300m) decreases from the west (Lupac, Ciudanovita and Jitin areas) to the east, disappearing in the Secu area. This member consists of black pelites with sandstone and freshwater limestone interlayers; rare microconglomerates or thin coal layers also occur. The Lisava Member is represented by red beds (red, green and grey sandstones, clays, conglomerates), with freshwater limestone interbeds; rare volcanic tuff and tuffite interlayers occur westwards in Lupac area. Its thickness varies between 1000-1500m. The paleontological data recorded within the middle part of the succession indicate an upper Lower Permian ("Autunian") age, but there are no markers for younger ages ("Saxonian"-"Thuringian"?) recorded for the uppermost sequences of the Lisava Member (Antonescu, 1980).

Below the Lower Jurassic deposits in the Pui area, scarce outcrops of grey sandstones recovered close to the Cioclovina Cave yielded palynological assemblages ascribed to the Lower Permian (Stilla & Luta, 1968; Stilla, 1980).

The Variscan cycle of the Sirinia Basin (Fig. 2) is represented by "Westphalian-Stephanian" clastics overlain by

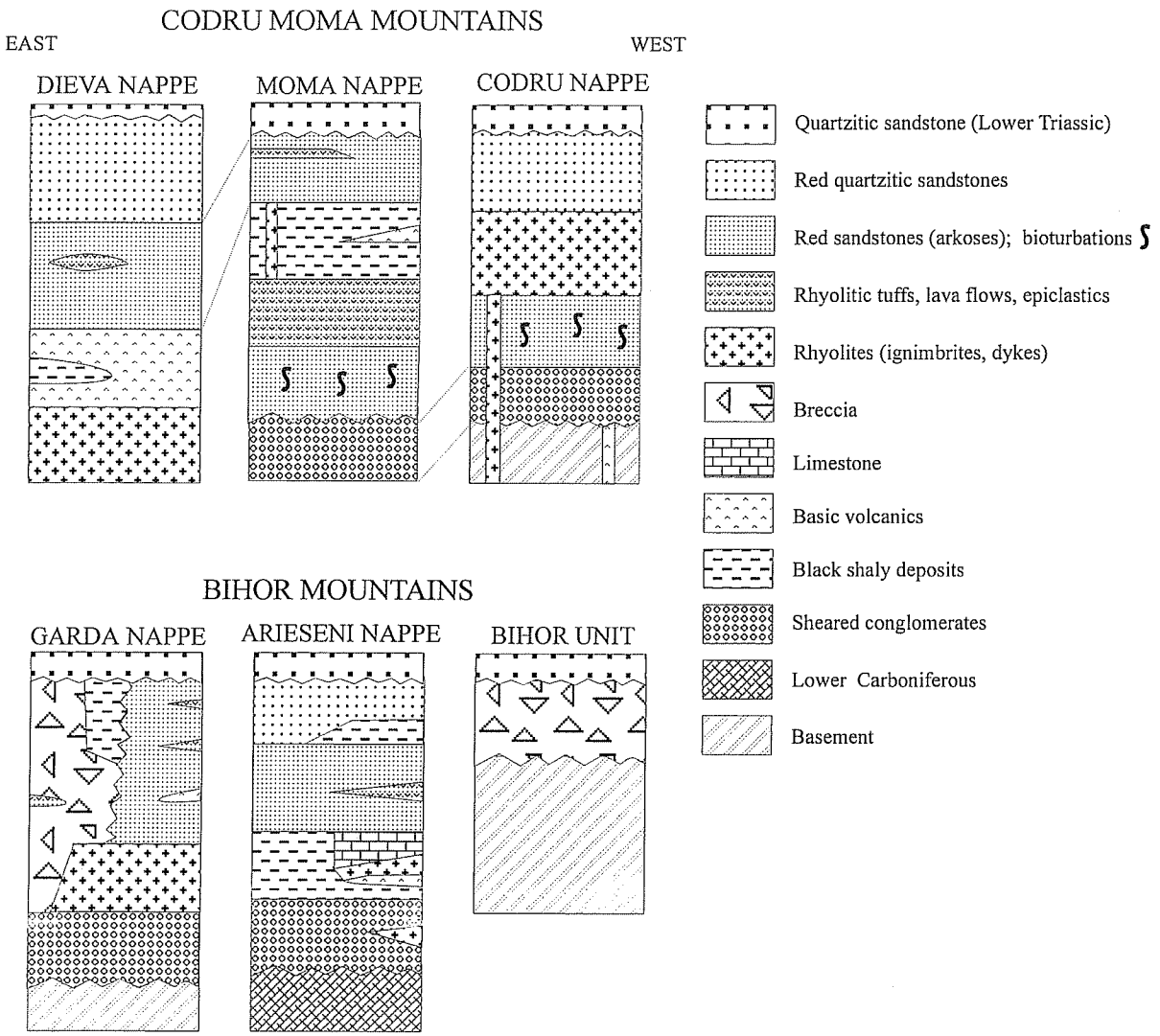

Fig. 3 – Permian logs of the Apuseni Mountains, after Bleahu *et al.* (1979, 1981, 1985) and Dimitrescu *et al.* (1977).

the Lower Permian sediments of the Povalina Formation; this Permian sequence unconformably rests on the lower-middle "Stephanian" deposits, upper "Stephanian" being absent. The Povalina Formation includes black and grey shales (Staricica Member) overlain by red beds (Ielisova Member) (Stanoiu & Stan, 1986). The Ielisova Member conformably overlies the Staricica Member in the central areas of the basin, and unconformably rests on the basement towards the marginal parts of the basin, mainly eastwards (Stanoiu *et al.*, 1996). The red beds are dominated by thick volcano sedimentary sequences, with local lacustrine limestones (Raileanu, 1953). Paleosol layers with caliche concretions often occur in the red bed sequence. The volcano-sedimentary dominance is very strong within the western part of the Sirinia Basin, while to the east the sedimentation is more terrigenous. The black fine clastics of the Staricica Member are thin and fossiliferous.

Within the Presacina Basin, the Lower Permian deposits show both terrigenous (red beds) and volcaniclastic deposits (Codarcea, 1940; Nastaseanu *et al.*, 1973; Nastaseanu, 1975, 1987) (Fig. 2).

Volcaniclastic, volcanic and terrigenous Permian sequences are exposed in various units of the central Apuseni Mountains (Fig. 3). The discovery of Lower Permian ("Autunian") rocks is based on geometric and facies criteria; a possible "Saxonian" or even younger Permian age is indicated by silicified wood remains. The basal phyllitic sequence of the Permian corresponds to the black bituminous pelites and is overlain by red beds with tuffaceous interbeds. To the east, in the Bihor Mountains, the Lower Permian consists of sheared conglomerates; the Upper Permian sequence starts either with ignimbritic rhyolites, or with breccias and fanglomerates sourced from the nearby metamorphic basement. The fanglomerates interfinger with coarse sandstones or fine shale sequences, as well as with ignimbritic rhyolites and occasionally with basalts.

The stratigraphy of the Permo-Carboniferous continental deposits (Carapelit Formation) of North Dobrogea includes a lower member of grey alluvial fan - alluvial plain sediments (loosely ascribed to the Carboniferous), unconformably overlying older metamorphic basement or Silurian-Lower Devonian sediments; the succession continues upsequence with red beds (0-900 m thick), overlain in turn by an upper volcanosedimentary member (Oaie, 1986; Seghedi & Oaie, 1986, 1995 b; Seghedi *et al.*, 1987) (Fig. 4).

In both the Moesian and Scythian Platforms, the Permian overlies older Paleozoic sequences (Fig. 5); the Permo-Triassic boundary is often difficult to trace, since both Permian and Triassic sediments show Germanic facies development. Evaporites occur in red beds devoid of carbonate sediments, suggesting a desert or coastal sabkha environment. In the Moesian Platform, red continental deposits prevail, but recent micropaleontological evidence suggests the presence of shallow-marine, Lower Permian carbonate facies in some parts of the platform (Pana, 1997) (Figs 1, 5). The red beds are interbedded with products of bimodal volcanism, with rhyolitic and basaltic rocks prevailing in the Moesian Platform, and the basalt-trachyte association well represented in the eastern part of the Scythian Platform.

PALEONTOLOGICAL DATA

Paleontological data were recorded for the Resita and Pui basins of the Getic Nappe, the Sirinia Basin of the Danubian units, the Codru-Biharia Nappes of the Apuseni Mountains, and the Moesian and Scythian Platforms. No paleontologi-

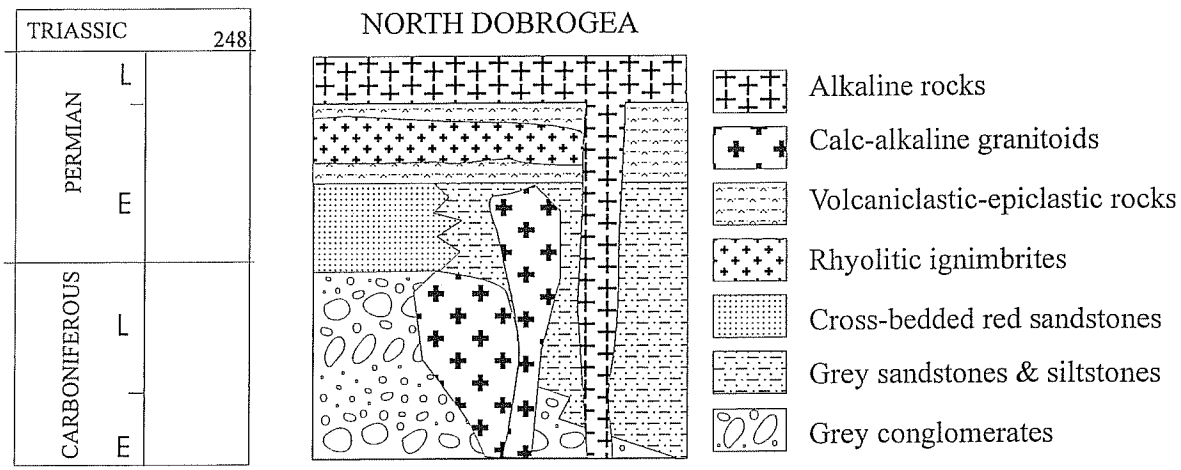

Fig. 4 – Log of the Carapelit Formation, North Dobrogea.

cal evidence has been recorded so far for the Presacina Danubian Basin of the South Carpathians, the Bihor Autochthon or the Carapelit Basin in North Dobrogea.

The first paleobotanical data from the Resita Basin were recorded by Stur (1870) and Telegd (1890), citing various Permian and Upper Carboniferous megaflora taxa. These taxa were later cited by Schreter (1910), Bitoianu (1973, 1974, 1987, 1988), Antonescu & Nastaseanu (1976) and Dragastan *et al.* (1997). Popa (1999) undertook a taxonomic revision and has established for the first time the majority of the Permian megaflora taxa of the Ciudanovita Formation: *Calamites* sp., *Annularia* cf. *stellata*, *Annularia* cf. *sphenophylloides*, *Asterophyllites longifolius*, *Sphenophyllum oblongifolium*, *Autunia conferta*, *Autunia naumannii*, *Arnhardtia scheibei*, *Lodevia suberosa*, *Gracilopteris bergeronii*, *Rhachyphyllum schenkii*, *Neuropteris* cf. *cordata*, *Neuropteris* sp., *Odontopteris* sp., *Pecopteris polymorpha*, ?*Linopteris* sp., *Cyclopteris* sp., *Pecopteris* cf. *polymorpha*, *Taeniopteris* sp., *Alethopteris zeilleri*, *Cordaites principalis*, *Walchia piniformis*, *Ernestiodendron filiciformis*, ?*Otovicia* sp., *Carpolithes* sp. *A* and *Carpolithes* sp. *B*. For the Gîrliste Member, the paleoflora are diverse and well preserved, represented by pteridophytes, pteridosperms and conifers, recording some Late Stephanian taxa as well as Early Permian taxa. For the Lisava Member, the diversity of the flora decreases substantially, with only Walchiaceae conifers occurring.

The palynological associations of the Permian deposits of the Resita Basin (Beju, 1970; Antonescu, 1980; Antonescu & Nastaseanu, 1976), record an early assemblage with *Florinites*, within the lowermost part of the Gîrliste Member (black sediments), and an upper assemblage with *Potonieisporites*, in the upper part of the Gîrliste Member and within the Lisava Member (red beds).

The first assemblage, with *Florinites*, is dominated by *Florinites* div. sp. (*F. circularis*, *F.* cf. *junior*, *F.* sp., 60-90% of the assemblage), followed by *Potonieisporites novicus* and *P. bharadwaji* (8-15%) or *Reticulatisporites facetus*, *Platysaccus papillionis*, *Alisporites* div. sp. (*A. aequus*, *A. saarensis*, *A.* sp.), *Pityosporites* sp., with less than 1-2% (Beju, 1970, in the Gîrliste area). Antonescu & Nastaseanu (1976) cited the same assemblage from Vidra Valley (Gîrliste Member), correlating the zone with the zone A1 of Doubinger (1974). They also cited S. Luta (in Antonescu & Nastaseanu, 1976) who described a Lower Permian assemblage with *Urospora kosankei*, *Raistrikia microhorrida*, *Complexisporites chaloneri*, *Cordaitina rotata*, *C. uralensis*, *Florinites similis*, *F. volans*, *P. novicus*, *Vittatina simplex* and *Guthorlisporites verus* from the Secu-Lupac area.

The second assemblage, dominated by *Potonieisporites* div. sp. (*P. novicus*, *P. bharadwaji*, 30-70%), is also represented by *Florinites* div. sp. (*F. circularis*, *F.* cf. *junior*, *F.* sp., 15-30%), *Platisaccus papillionis*, *Alisporites* div. sp. (*A. aequus*, *A. saarensis*, *A.* sp., 3-10%), *Pityosporites* sp. (3-8%) and *Striatoabietites* sp. (Beju, 1970, in the Gîrliste zone). To this assemblage was added *Crucisaccites* sp. and *Vesicaspora wilsonii* by Antonescu & Nastaseanu (1976, from Vidra Valley), these authors correlating the assemblage with the zone A2 of Doubinger, and later, (Antonescu, 1980) *Leiotriletes* sp., *Verrucosisporites* sp., cf. *Concetricisporites* sp., *Halletheca reticulata* and cf. *Schopfipollenites* sp. in samples from the Jitin-Ciudanovita Veche Valleys. These assemblages were described from the basal or terminal sequences of the Gîrliste Member. Furthermore, from the median sequence of the Lisava Member (within the Permian red beds) Antonescu & Nastaseanu (1976) identified an assemblage with cf. *Punc-*

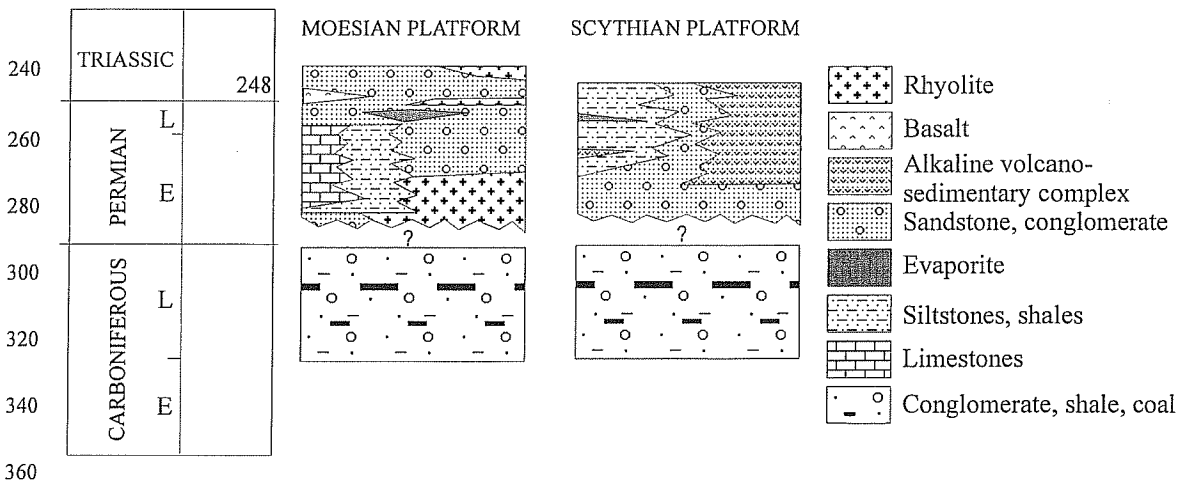

Fig. 5 – Paleozoic deposits of the Moesian and Scythian Platforms, compiled from Paraschiv (1979), Pana (1997) and Neaga & Moroz (1987).

tatisporites sp., *Granulatisporites* sp., *Lophotriletes* sp., cf. *Reticulisporites* sp., cf. *Neoraistrikia* sp., *Knoxisporites* sp., ?*Speciosporites* sp., *Guthorlisporites* sp., *Potonieisporites* div. sp. (*P. novicus*, *P. bharadwaji*, *P.* cf. *microdens*, *P. neglectus*), *Florinites* sp., *Crucisaccites* sp., *Vittatina costabilis*, *Protohaploxypinus*, *Striatopodocarpites* sp., *Hamiapollenites* sp., *Ginkgocycadophytus* sp., cf. *Gardenasporites* sp., *Platysaccus* sp., *Alisporites* cf. *aequus* and *Vesicaspora wilsonii*. This is the uppermost palynological assemblage described within the red beds facies and it is considered Lower Permian ("Autunian") in age (zone A2 *sensu* Doubinger, 1974). In a paper discussing the age of the red beds of the Resita Basin, Antonescu (1980) attributed at least an Early Autunian age to the microflora from the basal sequences, but not excluding younger ages (Late Autunian?) for the upper sequences of the red beds, which lack paleontological evidence.

The fauna of the Resita Basin includes fish remains as *Palaeoniscus duvernoy* (Eufrosin, 1957) and the bivalves *Carbonicola carbonaria* and *Anthracomya* cf. *thuringensis*.

At Cioclovina, in the Pui area, Stilla & Luta (1968) mentioned and figured *Azonomonoletes vulgaris*, *Leiotriletes gulaferus*, *Punctatisporites* sp., *P. obliquus*, *P. spathulatus*, *Azonotriletes* cf. *tuberculatus*, *A. microrugosus*, *A.* cf. *rezistens*, *Laevigatisporites* sp., *Pemphygaletes minor*, *Reticulatosporites facetus*, *Punctatisporites marattioides*, *Cyclogranisporites leopoldi*, *Cycadopites* sp., *Vitrisporites* cf. *signatus*, *Ephedripites primus* and *Pityosporites* sp. This assemblage was considered Early Permian in age.

The megaflora of the Povalina Formation in the Sirinia Basin was cited by Telegd (1890) and Raileanu (1953). As their material is not yet revised, their lists include old designations (*Hymenophyllites semiallatus*, *Odontopteris obtusiloba*, etc.); however, *Walchia piniformis* and *Cordaites principalis* were mentioned.

Antonescu (1980) recognised from Sirinia well no. 22766/586 (Berzasca area), within the Povalina Formation, a palynological assemblage with *Leiotriletes* sp., *Dictyophyllidites* sp., *Calamospora breviradiata*, *C. mutabilis*, *Granulatisporites* sp. 1, 2, *Nigrisporites nigritellus*, *Punctatisporites obliquus*, *P.* sp., *Cyclogranisporites* cf. *palaeophytus*, *C.* sp., *Lophotriletes scotii*, *Knoxisporites* cf. *glomus*, *Crassispora* cf. *kosankei*, *Laevigatisporites* cf. *vulgaris*. *L. desmoinesensis*, *Spinosporites exiguus*, *Florinites* spp., cf. *Potonieisporites* sp., *Vittatina* sp., *Vesicaspora wilsonii* and *Ginkgocycadophytus* sp. The assemblage is dominated by *Laevigatisporites* and *Punctatisporites obliquus*, and it is considered Late Stephanian - Early Permian in age.

Faunal remains from the Sirinia Basin consist of the fresh-water bivalves *Carbonicola carbonaria*, *Anthracomya thuringensis* and the ostracod *Estheria* sp. (Raileanu, 1953).

The megaflora recorded for the Codru-Biharia Nappe System are very scarce, represented only by rare rachises, which are impossible to identify. Silicified woods, collected from the red bed sequences, were described by Arabu (1941) as *Dadoxylon* sp. Matyasi (1998) recorded silicified wood fragments identified by Popa (thanks to J. Galtier from Montpellier, France) as *Dadoxylon* of type III *sensu* Doubinger & Marguerier, 1975; they may represent a marker for a possible Late Permian age for the above-mentioned red-beds.

The palynological assemblage identified in the Codru Nappe (at Scarisoara) is represented by *Calamospora microrugosa*, *Turrisporites pyramidalis*, *Verrucosporites* sp., *Florinites* sp., *Cycadopites* sp., *Vittatina* sp., *Azonotriletes* cf. *nodosus*, *Zonotriletes* cf. *anubilus*, *Azonoletes similis*, *Stenozites compactus* and *S.* cf. *bulbiferus* (Visarion & Dimitrescu, 1971). This assemblage is related to a Late Carboniferous - Early Permian time interval.

The presence of ichnogenous *Planolites* is suggested to support an Early Permian age of the bioturbated sandstones from the Apuseni Mountains, as this ichnogenus is confined to the Lower Permian (Rotliegendes) from the Thuringerwald, in Germany, and widespread within coeval formations in continental facies from the Sudets (Poland) and West Carpathians (Slovakia) (Brustur, 1986, 1997). Moreover, identification of the resting trace of a primitiv aquatic amphibian of *Diplocaulus* type (*Hermundurichnus patruliusi*) within the bioturbated sandstones from the Finis Nappe (Padurea Craiului Mountains) enables their correlation with the Lower Permian from Thuringerwald (Brustur, 1997).

Within the central-eastern part of the Moesian Platform, paleontological data from wells Ileana, Hirlesti, Peretu, Peris and Amara indicate Early Permian marine environments (Pana, 1997). The author described Permian species of several foraminifer groups: Textulariina, Miliolina, Lagenina, Stafellidae (nine species), Ozowainellidae (six species), Schubertalidae (three species), Neoschwageridae, Earlandinidae, Nodosinellidae, Corallinellidae, Dagmaritinae, Louizettitinae. *Medlicottia* sp. was also cited. Among the conodonts, *Gnathodus defectus* and *Spathognathodus whitei* were identified in the Lower Permian, and *Anchirognathus typicalis*, *Neospathodus divergens* and *N. profundis* in the Upper Permian (Pana, 1997). As for ostracods, Pana found *Healdia* aff. *axensis*, *Coronakirbia fimbriata* for the Lower Permian and *Permiana oblonga* for the Upper Permian, among many other ostracod species (*Sishaella*, *Bythocypris*, *Tomiella*, *Iniella*, *Kirkybia*, etc.).

Paleontological and palynological studies of the red beds from the Scythian Platform identified a phyllopode association with *Pseudoestheria*, as well as spores indicating a Permian age (Kaptan & Safarov, 1965, 1966). Geochronological data show ages of 290-248 Ma for the associated

volcanic rocks (Neaga & Moroz, 1987). However, as they are K-Ar ages, they represent cooling ages.

SEDIMENTOLOGY

Sedimentological studies on the Permian deposits of the South Carpathians and Apuseni Mountains are still in progress. The red-bed sequences from the Resita Basin (Lisava Member) and the Bihor Mountains show frequent cross-bedding, and their depositional features generally indicate alluvial to fluvial environments. The Lower Permian sequence of the Resita Basin coarsens upwards (Stanoiu *et al.*, 1996).

In North Dobrogea, the lower terrigenous members in-

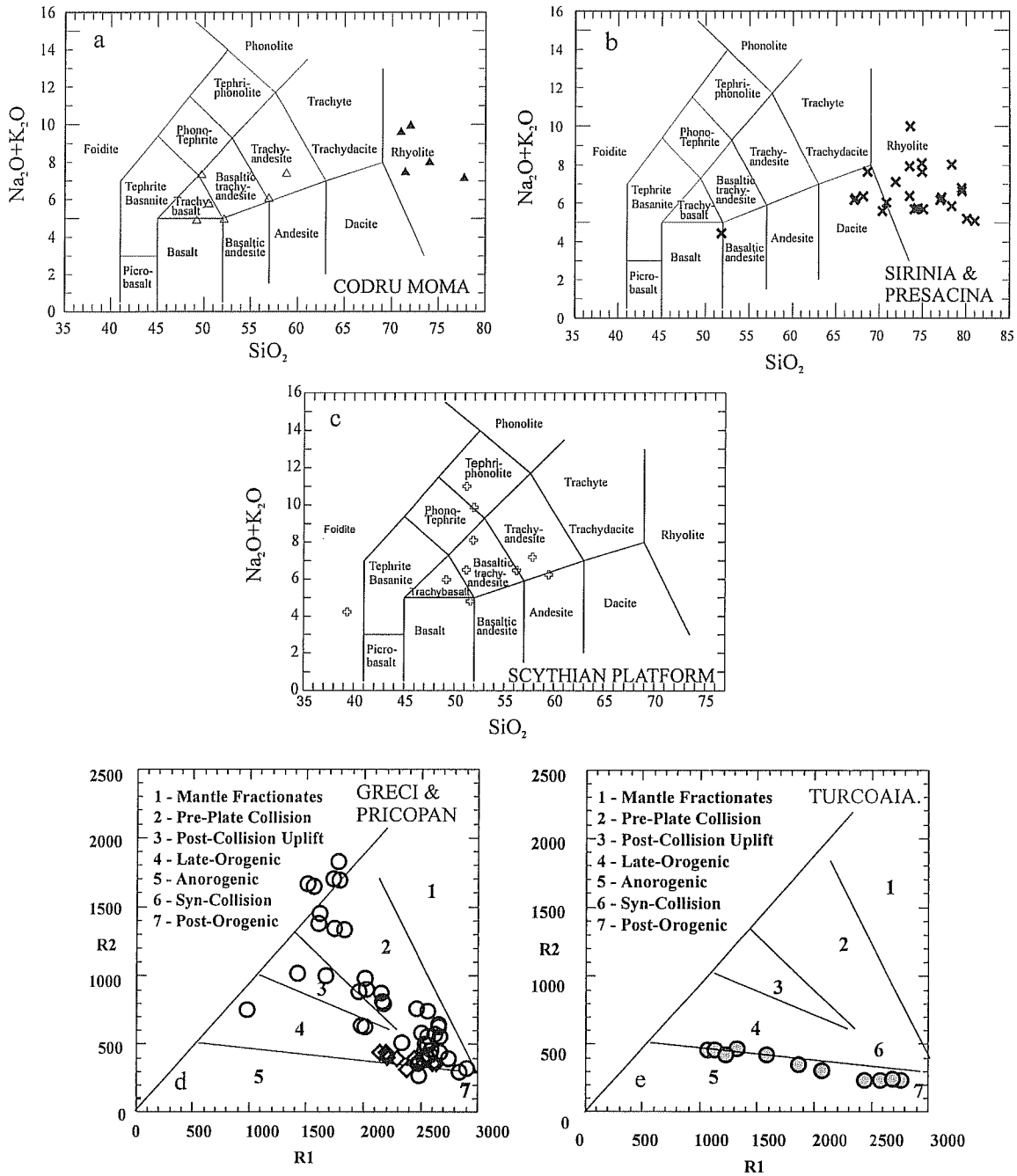

Fig. 6 – TAS diagrams for South Carpathian (Banat), Apuseni Mountain and Scythian Platform volcanics. Data compiled from papers of Stan (1984, 1987), Stan & Udrescu (1980), Stan *et al.*, (1986 a, b), Moroz *et al.* (1996) and unpublished data of the authors. Multication discriminant diagrams of Greci and Turcoaia massifs from North Dobrogea (modified from Tatu, 1999 and Tatu & Seghedi, 1999).

clude alluvial-fans to alluvial plain clastic wedges, with fanglomerates dominating the coarse members and sandstone-siltstone cycles in the flood-plain deposits (Seghedi & Oaie, 1986). Red beds make up a thick, upward-coarsening sequence, deposited by a sandy braided river with fluctuating discharge, showing upward progradation of coarse, longitudinal bar deposits over sand dunes with planar cross-beds (Oaie, 1986). Sandstone petrography suggests that the onset of red-bed deposition was related to a major climatic change, switching from a warm and humid climate which prevailed during alluvial fan sedimentation, to an arid, dry climate, controlling red-bed accumulation. The thick volcaniclastic successions from the upper part of the Carapelit Formation consist of superimposed cycles of pyroclastic deposits and coarse rhyolitic epiclastic sequences. Volcaniclastic rocks are dominated by large volumes of ignimbritic rhyolites (up to 1000 m in thickness), interbedded with airfall tuffs and base surge deposits, displaying the geometry of superimposed flow units (Seghedi *et al.*, 1987). Vertical facies associations suggest that the style of deposition was controlled by intermittent volcanic eruptions. Sedimentological, petrographical and mineralogical evidence reveals that accumulation of the Carapelit Formation was controlled by two major factors: a tectonically active source area, supplying metamorphic rocks, granites and earlier Paleozoic sediments and an active volcanic source, delivering large amounts of feldspars (mostly plagioclase feldspars) and volcanic lithoclasts (Seghedi & Oaie, 1986, 1994; Oaie, 1986; Seghedi *et al.*, 1987).

In the eastern part of the Aluat-Sarata half-graben from the Scythian Platform, several fining-upwards cycles are superimposed in the 1685 m-thick column of Permian volcanosedimentary sequences pierced by borehole 1 Furmanovka (Moroz, 1984; Neaga & Moroz, 1987). In the western part of the half-graben, the distribution of the coarse fanglomerates suggests sedimentation controlled by activity along the northern boundary fault (Fig. 1). Fanglomerates interfinger and grade upwards to a finegrained sequence of siltstones and mudstones, with thin, discontinuous layers of gypsum and anhydrite.

MAGMATISM

Permian magmatism was characterised by bimodal volcanism in the South Carpathians and Apuseni Mountains, as well as in both the Moesian and Scythian Platforms; volcanosedimentary sequences are typically developed in most areas, with the exception of the Resita Basin, where minor volcanism occurred. Granite intrusions took place only in the southern part of the Apuseni Mountains (Highis massif) (Tatu, 1998). In North Dobrogea a volcano-plutonic association with calcalkaline geochemistry is well represented, and the transition to alkaline magmatism probably occurred in the Late Permian, reflecting a change in geotectonic setting from compression to transtension.

Acid, rhyolitic volcanic and volcaniclastic deposits prevail in the Permian of the Danubian units (Banat). Rhyolitic and dacitic volcanics and volcaniclastic-epiclastic successions are variously interbedded with continental red beds, while thick bodies of ignimbritic rhyolites occur at the top of the Danubian sequences (Stanoiu & Stan, 1986; Stan *et al.*, 1986 a, b). The thickness of the volcanic sequences increases westwards. The volcanism was bimodal (Fig. 6 a), as basic dykes intrude the red beds in some areas (Pop, 1997), and basic flows are exposed below red beds from the right bank of the Danube (Serbia) (Grubic *et al.*, 1997). Trachytic rocks occur southward (A. Grubic, oral comm., 1997). An intraplate setting is suggested for these rocks, based on geochemical data.

In the Codru Moma Mountains (western Apuseni), the volumes of both ignimbritic rhyolites and basic rocks decrease eastwards (Dimitrescu *et al.*, 1977; Bleahu *et al.*, 1979, 1981, 1985). Thin dykes and elongate rhyolitic bodies cutting the older basement (Bleahu *et al.*, 1984) suggest that volcanic centres, aligned in a NNW-SSE direction, were located along the present western border of the massif. Several basic dykes, elongated in the same direction, may represent the feeder channels for the basic flows interbedded in the middle part of the Permian sequence. In the Bihor Mountains, the ignimbrite eruptions took place in the upper part of the Permian sequence (Dimitrescu *et al.*, 1977). These acid rocks, mostly rhyolites, occur as pyroclastic flows and lava flows, but also as tuffs (Dimitrescu *et al.*, 1973; Dimitrescu, 1975; Stan, 1983, 1984, 1987). Basic volcanic rocks include basalts and basaltic andesites as pillow lavas, minor pyroclastic sequences and dykes (Bleahu *et al.*, 1979, 1981,1985; Stan, 1987). Chemical analyses of the volcanic rocks reveal both the bimodality and the alkaline features of the basic rocks; the latter plot in the trachybasalt-trachyandesite field of the TAS diagram (Fig. 6 b). The bimodal character of the volcanism is explained by having two distinct magma sources (Stan, 1987).

In North Dobrogea, the volcano-plutonic association with a calcalkaline geochemistry is related to crustal convergence at the end of the Hercynian Orogeny. For the volcanosedimentary member of the Carapelit Formation, overall volcanological features indicate that the calcalkaline volcanism was subaerial, with calderas and plinian eruptions, and that volcanic products accumulated in both subaerial and subaqueous environments (fluvial and lacustrine) (Seghedi *et al.*, 1987).

Field relationships indicate that two major phases of granite emplacement occurred in North Dobrogea, one

preceding and the other post-dating the deposition of the Carapelit Formation or at least its lower and middle members (Rotman, 1917; Mirauta & Mirauta, 1962). However, the age of the granites is not well constrained, since no reliable geochronological data exist. Younger generation intrusives thought to have been emplaced during the Early Permian represent a highly differentiated I-type calcalkaline suite, ranging from dioritic and gabbroic facies to leucogranites, but dominated by biotite-hornblende granodiorites and tonalites (Seghedi *et al.*, 1994 a). The suite of the Greci Massif was emplaced in lower members of the Carapelit Formation as high level, high temperature intrusives, with both cross-cutting and partly conformable contacts, producing large contact-metamorphic aureoles and local garnet-pyroxene skarns. Rocks are rich in xenoliths of hornfels inferred to have been country rocks, as well as in various types of cognate xenoliths. The discriminant multicationic diagram (Fig. 6 d) suggests a mantle source for the basic end members and a deep or mid-crustal conditions for the genesis of granitic magma, as well as a syncollisional geotectonic setting (Tatu & Seghedi, 1999).

In the Late Permian, products of alkaline, intraplate volcanism were emplaced along the crustal faults bordering North Dobrogea. They form both subvolcanic bodies (granites, syenites, rhyolites of the Turcoaia – Cîrjelari lineament) in the south and basalt-trachyte dyke swarms in the north (Fig. 7) (Seghedi *et al.*, 1994 b; Tatu & Teleman, 1997). For the Turcoaia massif, a crustal magma source is indicated by the $^{87}Sr/^{86}Sr$ values (Pop *et al.*, 1985), suggesting that crustal anatexis occurred in a continental, intraplate tectonic setting (Fig. 6 e) (Tatu, 1999). The geochemistry of Permian magmatic rocks suggests that this transition from calcalkaline to alkaline magmatism reflected a change in tectonic setting from compressional to (trans)tensional.

In the Moesian Platform, volcanic products belonging to a bimodal basalt-rhyolite association, interbedded at various levels of the Permo-Triassic sequence (Savu & Paraschiv, 1985) are obviously related to several episodes of extension and rifting of the Moesian Platform.

Products of a typical continental within-plate bimodal volcanism of the alkali basalt-trachyte association accumulated in the two major half-grabens from the Scythian Platform (Aluat and Sarata – Tuzla). Alkaline basalt flows, trachytes, rhyolites and various pyroclastic and epiclastic products make up volcanic-volcaniclastic sequences that are up to 300 m thick, interbedded with thick, synrifting continental clastics. The Permian volcanism was subaerial and effusive, displaying a subalkaline geochemical signature (Moroz, 1984; Neaga & Moroz, 1987). Trachy-

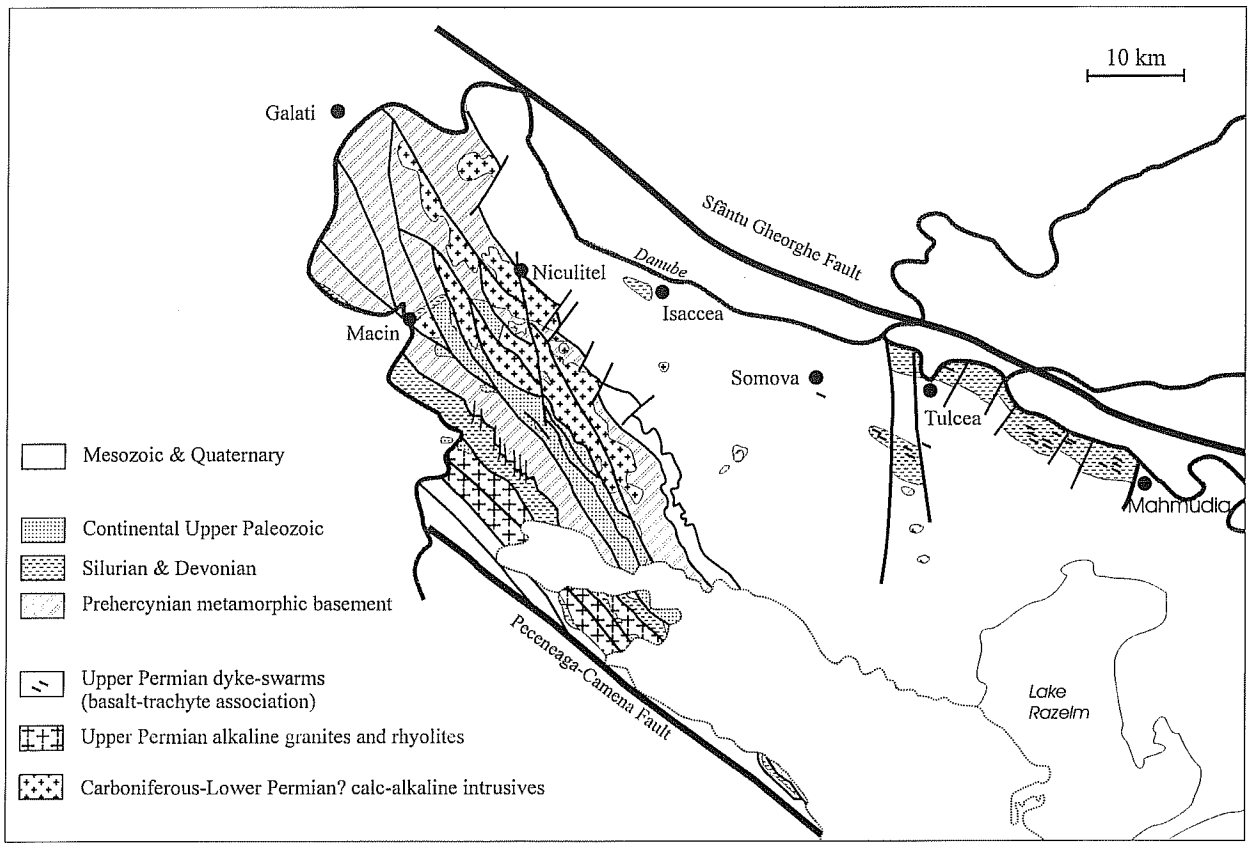

Fig. 7 – Simplified geological map showing the distribution of Permian magmatic rocks in North Dobrogea (subcrop map, base of the Quaternary); modified after Seghedi (1999).

basalts and trachyandesites prevail, most rocks showing a shoshonitic affinity (Fig. 6 c). Geochemical data suggest a great inhomogeneity of samples compared with the Codru-Moma volcanics. However, the intraplate setting is quite clear from the geological evidence.

CONCLUSIONS

The Permian deposits of Romania are mainly developed in continental facies, with molassic characteristics. The sedimentary record of most basins includes volcanosedimentary sequences. Red beds are the dominant facies, but the lower black shaly member of the Permian is present in the South Carpathians and Apuseni Mountains. Evaporitic sediments are associated with the red beds in both the Moesian and Scythian Platforms. In all areas, sedimentation took place mostly in alluvial fan, fluvial and lacustrine systems. Only in the northern part of the Moesian Platform do shallow-marine limestones occur. The South Carpathians (Getic Nappe and Danubian units) yield by far the most fossiliferous Permian deposits in Romania, the fossil remains being represented by both flora (compressed macroflora, microflora) and fauna (ganoid fishes, ostracods, bivalves). The Apuseni Mountains include deposits yielding flora (silicified woods, microflora), while North Dobrogea has no fossils recorded so far. The Moesian and Scythian Platforms include faunal remains.

The Permian volcanism was bimodal. The basalt-rhyolite association typically occurs in the South Carpathians, the Apuseni Mountains and the Moesian Platform, while the basalt-trachyte association is found in North Dobrogea and the Scythian Platform.

An extensional tectonic setting, related to Late? Permian rifting, is suggested by both field evidence and geochemical features of the magmatic rocks from the South Carpathians, Apuseni Mountains, Moesian and Scythian Platforms. For North Dobrogea, both magmatic associations and their geochemical features illustrate a transition from a calcalkaline post-collisional setting to a transtensional setting related to the collapse of the overthickened Hercynian crust, which was displaced along major wrench faults.

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