EVIDENCE OF RIFT MAGMATISM FROM PRELIMINARY PETROLOGICAL DATA ON LOWER TRIASSIC MAFIC ROCKS FROM THE NORTH DOBROGEA OROGEN (ROMANIA)

Emilio Saccani*, Antoneta Seghedi** and Ionel Nicolae***

* Dipartimento di Scienze della Terra, Università di Ferrara, Italy.
** Institutul de Geologie si Geofizica, Bucuresti, Romania.
*** Institutul de Geodinamica al Academiei Romane, Bucuresti, Romania.

Corresponding Author: Emilio Saccani, e-mail e.saccani@unife.it

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ABSTRACT

The Cimmerian orogenic belt of North Dobrogea (East Romania) is located in the Carpathian foreland between the Moesian and Scythian Platforms. In the absence of reliable geochemical data on the different magmatic rock-types, various geodynamic models have been suggested for the Triassic-Jurassic evolution of this belt. Geochemical studies on mafic dykes emplaced in different Hercynian basement rocks, as well as on the Early-Middle Triassic Niculitel Formation basalts have been performed in order to provide new constraints for the geotectonic setting of this belt.

A Perm–Triassic phase of crustal thinning of the Hercynian basement is suggested by the still poorly known alkaline magmatism. The Triassic magmatic history involves intrusion of tholeiitic dykes in the Hercynian basement of the Macin Zone, and extrusion of pillow basalts (Niculitel Formation) that most likely occurred above the carbonate compensation depth in a rifted basin with a thinned crust, as suggested by facies characteristics of carbonate rocks interbedded with basalts. This basin could have corresponded either to an aborted rift, or to a passive margin related to back-arc opening.

Our data indicate that the Macin and Niculitel basalts originated in an extensional tectonic setting in which the transition from alkaline to E-MORB magma types and their petrogenetic features is essential for the identification of the Triassic magma types and their petrogenetic features is essential for the reconstruction of the tectonic evolution of the North Dobrogea Orogen during that time. In the hypothesis of the aborted rift, an evolution of the mantle sources, starting with a predominating plume activity followed by an uprise of the primitive asthenospheric mantle, can be postulated for the North Dobrogea Triassic basalts. By contrast, in the back-arc basin model, the plume activity may have played a major role in weakening the lithosphere and preparing the back-arc spreading.

The close geochemical similarities between basalts from North Dobrogea and basalts from various ophiolitic complexes and oceanic ridges do not necessarily imply that North Dobrogea Triassic basalts represent an ophiolitic sequence or, in other words, the hypothesized uprise of asthenospheric primitive mantle does not imply an oceanic spreading steady-state.

Our data indicate that the Macin and Niculitel basalts originated in an extensional tectonic setting in which the transition from alkaline to E-MORB magmatism was a consequence of the mantle plume evolution through time.

INTRODUCTION

The North Dobrogea Orogen (Fig.1a) is the westernmost end of a Cimmerian orogenic belt, which extends eastwards up to the Asian Cimmerides (Sandulescu, 1984; Sengor, 1984). This orogen has been interpreted as: (1) a short-lived failed rift, representing the abandoned branch of the Carpathian triple junction (Vlad, 1978); and (2) a fragment of a former back-arc basin formed above a north-dipping Triassic subduction zone, active during the closure of the Paleo-Tethys ocean (Stampflí and Marchant, 1995; Ustaömer and Robertson, 1997; Banks, 1997; Banks and Robinson, 1997; Stampflí et al., 2001).

The North Dobrogea Orogen is characterized by the widespread occurrence of Upper Permian - Upper Triassic (and subordinate Jurassic) volcanic and subvolcanic rocks possibly formed during an intraplate rifting stage (Seghedi, 2001; Nikishin et al., 2002). The controversial geodynamic interpretations of the evolution of this orogenic belt are in part a consequence of a still-poor knowledge of the magmatic history and petrogenesis of Upper Permian-Triassic rocks. In particular, one of the most controversial points concerns the occurrence of ophiolitic rocks in the Cimmerides (Yilmaz and Sengor, 1984).

Previous geochemical works (Nicolae and Seghedi, 1996; Seghedi, 2001) report the occurrence of (1) dyke swarms cross cutting the Paleozoic basement of the Macin Zone and including Upper Permian alkaline rocks and Triassic tholeiitic basalts; (2) Lower-Middle Triassic mid-ocean ridge basalts (MORB) forming the Niculitel Formation. Nonetheless, the petrological characterization of these magmatic series is usually inadequate. The identification of the Triassic magma types and their petrogenetic features is essential for providing new constraints for the reconstruction of the tectonic evolution of the North Dobrogea Orogen during that time.

The aim of this paper is thus to present preliminary geochemical results and petrological interpretation on a highly selected set of magmatic rocks from the Niculitel Formation and Macin Zone in order to provide a valuable base for further petrological and geological studies.

GEOLOGICAL SETTING AND PERMIAN TO JURASSIC MAGMATIC EPISODES

Geological setting of North Dobrogea

The North Dobrogea is the part of the Cimmerian orogenic belt exposed west of the Black Sea in the Carpathian
foreland (Fig. 1a). The North Dobrogea Orogen joins the Scythian (to the north) and Moesian (to the south) Platforms along two major crustal faults: the Sfantu Gheorghe and the Peceneaga-Camena Faults, respectively (Fig. 1b). During the Mesozoic, both Peceneaga-Camena and Sfantu-Gheorghe faults were active as strike-slip faults, accommodating transpression or transtension; latest Cretaceous-Paleogene reactivation of the Peceneaga-Camena Fault as a pure reverse fault is indicated by palaeostress reconstructions (Hippolyte, 2002). The North Dobrogea consists of two main tectonic zones, separated by the Luncavita-Consul Fault (Fig.1b): (1) the Macin Zone, largely consisting of Palaeozoic formations and (2) the Tulcea Zone, where mainly Mesozoic formations (including limestones, cherty limestones, marls, and siliciclastic turbidites) are exposed. The Luncavita-Consul Fault is a reverse fault along which the strongly uplifted metamorphic basement of the Macin Zone joins Lower Triassic formations of the Tulcea Zone. The formation of the North Dobrogea Orogen is related to two deformation phases occurred during the Late Triassic and Late Jurassic (early and late Cimmerian phases); these phases are also observed all along the Cimmerides.

During the Late Carnian, inversion of the North Dobrogea basin commenced, as indicated by the deposition of siliciclastic turbidites resting unconformably on Niculitel basalts and Anisian-Ladinian pelagic limestones. Inversion movements persisted during the Early and Middle Jurassic times, as indicated by the overall upward coarsening and eastward propagation of the turbiditic fan complexes (Gradinaru, 1988). Inversion movements were apparently interrupted during Oxfordian-Kimmeridgian times, as suggested by the re-establishment of a carbonate dominated depositional regime in the remnant North Dobrogea basin and on the adjacent platforms (Seghedi, 2001). Kimmeridgian transtensional activity along the Peceneaga-Camena fault probably controlled the extrusion of basalts and rhyolitic air-fall tuffs (Gradinaru, 1988). Although in the stratigraphic record of North Dobrogea the Tithonian to Albian times correspond to a regional break in sedimentation, the occurrence of late Cimmerian inversion movements during the Berriasian-Aptian is indicated by the destruction of the late Jurassic carbonate platform and shedding of clastics and Aptian kaolinites onto the Predobrogea Depression and South Dobrogea platform (Seghedi, 2001). The Cimmerian structure of North Dobrogea involves several NW-SE trending units, oblique to the bordering faults, interpreted either as nappes (Sandulescu, 1980; 1984; Visarion et al., 1990), or as high-angle thrusts (Vlad, 1978; Baltres, 1993; Seghedi et al., 1990). The thrust and fold model is based on borehole data that established the presence of a system of northeast-
vergent imbricate high-angle thrust-sheets which involve Mesozoic sediments and the Hercynian basement (Baltres, 1993). Such thrusts in the central part of the Macin Zone, in combination with local south-verging conjugate reverse faults north of the Peceneaga-Camena Fault, accommodated the uplift of the Hercynian basement. The structural style changes toward the north-east in the Tulcea unit to recumbent and ultimately to upright folds, which are basement cored. The intensity of deformation decreases further to the east in the Tulcea unit, giving way to open folds in areas where Upper Triassic carbonates directly overlie the basement or thin Scythian clastic (Baltres, 1993).

Upper Cretaceous shallow marine deposits (Babadag Basin), which formed in a shelf environment during the opening of the Western Black Sea Basin, seal all the Cimmerian structures. This narrow Cimmerian belt is superimposed on remnants of the Hercynian orogenic belt that forms the suture between the Gondwana-derived Moesian Platform and the East European Craton (Sandulescu, 1984; Nikishin et al., 1996; Yanev, 1996; 1997; Tari et al., 1997). The Hercynian basement of North Dobrogea consists of metamorphic rocks, Paleozoic sediments and a Carboniferous–Early Permian volcano-plutonic calc-alkaline association. The Mesozoic successions, developed in Alpine facies, are carbonate-dominated from Scythian to Ladinian, and siliciclastic from Late Carnian to Scythian to Ladinian, and siliciclastic from Late Carnian to Scythian and K-Ar age range between 275 and 290 Ma (Minzatu et al., 1975). Geophysical data indicate that below the Upper Camelifar and the Quaternary sediments this lineament of alkaline rocks continues towards SE up to Camena. At Camena only rhyolitic rocks occur, forming a northern lineament of lava flows and subvolcanic bodies and a southern lineament with only pyroclastic sediments (Seghedi et al., 1992). The Camenia rhylolites are interbedded with Scythian (Spathian) red clastics (Seghedi, 2001 and references therein).

**Permo-Triassic volcanism**

Geological relationships indicate that in North Dobrogea volcanism was active from Late Permian to Anisian, with a later pulse of bimodal, basalt-rhyolite volcanism during Late Jurassic. The earliest volcanic products (Permian to early Scythian) are alkaline and form two narrow lineaments parallel to the bordering strike-slip faults. A bimodal basalt-trachyte volcanism started in the Scythian, emplacing dyke-swarms in the strongly sheared Hercynian basement rocks of the central part of the Macin Zone (Seghedi, 2001). From late Scythian to Anisian the volcanism was dominantly basaltic.

**Alkali volcanism.** - South of the Sfantul Gheorghe Fault, a NW oriented dyke-swarm (Fig. 1c) is known from outcrops and boreholes (Seghedi A. et al., 1994; Seghedi I. et al., 1994; Seghedi and Oaie, 1995). The dykes are emplaced in Paleozoic sequences and form a 16 km wide belt. Petrographical features indicate that they belong to the bimodal basalt-trachyte association (Seghedi I. et al., 1994). Based on field evidence and correlation with the volcanism from the Scythian plate, an Upper Permian emplacement age is attributed to the dykes. Crosscutting relationships show that dykes are emplaced in the Silurian–Devonian series of the Tulcea Zone. Stratigraphic relationships indicate that dykes are unconformably overlain by Lower Triassic conglomerates (Mirauta, 1966). Geochemical data show an alkaline geochemical signature of the dyke swarms (Seghedi I. et al., 1994). Trachyte petrogenesis indicates magma generation at great depths and under high-pressure conditions (Seghedi et al., 1992; Seghedi and Szakacs, 1994).

Along the southern margin of the Macin Zone, alkaline volcanics and subvolcanic bodies are exposed in three areas north of the Peceneaga-Camena Fault: Turcoaia, Carjelari and Camena (Fig. 1c); a suite of riebeckite and aegirine-bearing granites are emplaced in the Paleozoic formations from Turcoaia to Carjelari. The subvolcanic bodies are associated with riebeckite-bearing rhyolites. The Late Permian age of the intrusives is indicated by field relations: the Iacobdeal Massif intrudes the Carboniferous–Early Permian clastics of the Carapelit Formation. Recent Ar-Ar geochronology yielded a Late Permian cooling age of 245-243 Ma for the Iacobdeal Massif (Teleman and Bilal, 2001) and K-Ar age range between 275 and 290 Ma (Minzatu et al., 1975). Geophysical data indicate that below the Upper Cretaceous and Quaternary sediments this lineament of alkaline rocks continues towards SE up to Camena. At Camena only rhyolitic rocks occur, forming a northern lineament of lava flows and subvolcanic bodies and a southern lineament with only pyroclastic sediments (Seghedi et al., 1992). The Camenia rhyolites are interbedded with Scythian (Spathian) red clastics (Seghedi, 2001 and references therein).

**Bimodal dykes in the Macin Zone.** - A suite of NW–SE trending dyke-swarms of the basalt-rhyolite bimodal association (Fig. 1c) is found in the Hercynian basement exposed in the western part of North Dobrogea (Seghedi, 1985; Nicolae and Seghedi, 1996). The dykes intrude all the Paleozoic formations, including the Hercynian massifs. Few basic dykes are intruded in the Turcoaia Massif. Based on geochemical characteristics, the dyke-swarm was interpreted to represent the feeder channels of the rhyolitic and basaltic volcanism of the Tulcea Zone (Nicolae and Seghedi, 1996).

**Triassic volcanism of the Tulcea Zone.** - Explosive sub-aerial rhyolitic volcanism in the Tulcea Zone (Fig. 1c) developed during the early Scythian (early Spathian) and produced pyroclastic flows and cinder tuffs, interbedded with continental red volcaniclastic-epiclastic sequences (Seghedi et al., 1990; 1992). The Upper Scythian products of sub-aerial rhyolitic volcanism are interbedded as tuffs in the calcareous turbidites of the Somova Formation, or overlie the Spathian limestone turbidites as thick, submarine pyroclastic flows (Seghedi et al., 1990).

The products of basic volcanism are included in the Niculitel Formation (Baltres, 1993), which largely consists of submarine basaltic flows, often developed in pillow-lava facies, as well as volcanic breccias, basaltic agglomerates, tuffs and sills of dolerites and gabbro-dolerites intercalated between the flows (Savu, 1986; Savu et al., 1980; 1988). Debris-flow, turbiditic and pelagic limestones are also interbedded in the basaltic rocks (Baltres, 1993). The late Scythian (late Spathian) to Middle Anisian age for Niculitel Formation is determined on the basis of ammonites, forams and conodonts found within the red or cherty limestones interbedded with the basaltic flows (Mirauta, 1982; Baltres, 1993).

**Jurassic volcanism**

Basaltic pillow lavas are exposed at the top of the Oxfordian–Kimmeridgian Baspunar Formation, which surface along the southern part of the Peceneaga-Camena Fault (Fig. 1c). This Unit mainly consists of marls rich in sponge spicules (Gradinaru, 1981). Rhyolitic tuffs are interbedded in the shallow marine, carbonate platform limestones of the Carjelari Formation (Gradinaru, 1981). This Upper Jurassic volcanism is interpreted as the bimodal volcanism precursor to the extension and crustal separation in the Western Black Sea basin (Gradinaru, 1981; 1988).
**SELECTION OF SAMPLES AND ANALYTICAL METHODS**

Five samples of mafic rocks from pillow lavas of the Niculitel Formation and dykes of the Macin Zone were selected for major oxide and trace element analyses. The selection of highly representative samples for the chemical analyses carried out in this work has been made by taking into account the compositional variation of similar basaltic rocks reported in Nicolae and Seghedi (1996), as exemplified in Fig. 2. In this figure it can be observed that both Macin and Niculitel selected basalts cover the range of variation of their equivalents reported in literature.

Major elements and Pb, Zn, Ni, Co, Cr, V, Rb, Sr, Ba, Nb, Zr, Y were determined by X-ray fluorescence spectrometry (XRF) on pressed powder pellets using an ARL Advant-XP spectrometer, following the full matrix correction method proposed by Lachance and Trail (1966). Accuracy is generally lower than 2% for major oxides and less than 5% for trace element determinations, whereas the detection limits for trace elements range from 1 to 2 ppm. Replicate analyses on trace elements gave a precision lower than 5%.

Volatiles were determined as loss on ignition (L.O.I.) at 1000°C. REE, Sc, Nb, Ta, Th, Hf, and U contents were determined by inductively coupled plasma-mass spectrometry (ICP-MS) using a VG Elemental Plasma Quad PQ2 Plus. Accuracy and detection limits were calculated by analyzing a number of international standards as unknown. Accuracy varies from 1% to 8%, while detection limits are (in ppm): Sc = 0.29; Nb, Hf, Ta = 0.02; REE <0.14; Th, U = 0.01. All analyses were performed at the Department of Earth Sciences of the University of Ferrara. Results are presented in Table 1.

**PETROGRAPHY**

All the analyzed samples have been variably transformed under low- and very low-grade metamorphic conditions and/or by alteration processes that drastically obliterated the original mineralogical assemblages. The main mineralogical substitutions include calcite and clay minerals pseudomorph after plagioclase, chlorite and clay minerals after pyroxenes and/or vitrophyric groundmass. Prehnite and pumpellyite, mostly occurring as thin, millimeters-thick veinlets and subordinately as cavity fillings are found in basaltic lavas. Nonetheless, in all samples the original igneous textures are preserved.

Mafic dykes and lava flows from Macin Zone and Niculitel Formation, respectively, are represented by basalts, which display textures ranging from aphyric to porphyritic. In porphyritic varieties, phenocrysts are represented by plagioclase (ranging from 5 to 40%) settled in microcrystalline to vitrophyric groundmass. In sample DO1 microphenocrysts of clinopyroxene (10%) can be observed. Groundmass is characterized by opthic to sub-opthic textures with

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Table 1 - Major (as wt%) and trace element (as ppm) compositions for Triassic basalts from the North Dobrogea Orogen

<table>
<thead>
<tr>
<th>Sample</th>
<th>Macin Zone</th>
<th>Niculitel Formation</th>
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<tr>
<td>Sample</td>
<td>DO1</td>
<td>DO2</td>
</tr>
<tr>
<td>SiO₂ (%)</td>
<td>43.75</td>
<td>46.56</td>
</tr>
<tr>
<td>TiO₂ (%)</td>
<td>1.21</td>
<td>1.54</td>
</tr>
<tr>
<td>Al₂O₃ (%)</td>
<td>14.07</td>
<td>15.00</td>
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<tr>
<td>Fe₂O₃ (%)</td>
<td>3.14</td>
<td>4.13</td>
</tr>
<tr>
<td>MgO (%)</td>
<td>15.04</td>
<td>12.14</td>
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<tr>
<td>CaO (%)</td>
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<td>12.14</td>
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<tr>
<td>Na₂O (%)</td>
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<td>K₂O (%)</td>
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<td>P₂O₅ (%)</td>
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<td>L.O.I (%)</td>
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<td>Total (%)</td>
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<td>L.O.I (%)</td>
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<td>4.27</td>
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<td>Total (%)</td>
<td>99.91</td>
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Mg# = molar proportions of 100*(Mg/Mg+Fe); Fe₂O₃ = FeO*0.15. Normalization values for REE ratios are from Sun and McDonough (1989).

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Fig. 2 - Ti vs. Zr diagram (modified after Pearce, 1982) for Triassic basalts from the North Dobrogea Orogen. Black symbols: samples studied in this paper; grey symbols: data from Nicolae and Seghedi (1996).
small laths of plagioclase, interstitial clinopyroxene and an-
hemical opaque minerals. Sample DO2 is characterized by a
course-grained doleritic texture.

**GEOCHEMISTRY**

The mafic rocks from both Niculitel Formation and
Macin Zone studied in this paper are exclusively represent-
ied by basalts with SiO₂ ranging from 43.75 wt% to 47.44
wt%. Variable contents in Na₂O, K₂O, Rb, Sr, and Ba
(Table 1) are related to the high degrees of alteration gener-
ally displayed by these rocks. Moreover, the contents of
L.O.I. (2.07 - 4.48 wt%) and the scattered contents of CaO
with respect to SiO₂ are related to the presence of secondary
calcite.

All samples display relatively high TiO₂ contents (1.21 -
2.06 wt%) and a clear sub-alkaline character (Fig. 3); nonethe-
less, various chemical differences between Macin
and Niculitel basalts can be observed. These are illustrated
in the variation diagrams of Fig. 4. Dykes from Macin Zone
are characterized by lower Zr, TiO₂, P₂O₅, V, Sc, Nb, Th,
and Y with respect to basalts from Niculitel Formation,
though all these elements (except Th) show variable in-
crease with increasing Zr in both series. In Macin dykes, Zr
displays a sharp positive correlation with Al₂O₃ and a nega-
tive correlation with Ni and Th (Fig. 4). By contrast, in Ni-
culitel basalts Al₂O₃ decreases while Ni and Th increase
with increasing Zr contents.

The Ti/V ratios range from 43 to 46 (Table 1) that are
values shared by mid-ocean ridge and within-plate tholeiitic
basalts (Shervais, 1982).

In the N-MORB-normalized (Sun and McDonough,
1989) spiderdiagrams of Fig. 5, samples from Niculitel For-
mation are characterized by trends generally decreasing
from Th to Yb, which are very similar to that of E-MORB.

By contrast, samples from Macin Zone exhibit relative Th-
U-Ta and Nb negative anomalies. The K positive spike ob-
served in all samples (Fig. 5) reflects the effect of alteration
processes, as also suggested by the absence of Th enrich-
ment (Table 1, Fig. 5).

The chondrite-normalized (Sun and McDonough, 1989)
rare earth element (REE) patterns shown by Niculitel basalts
(Fig. 6) exhibit slightly decreasing trends from light REE
(LREE) to heavy REE (HREE), as exemplified by the
La₉/Sm₉ and La₉/Yb₉ ratios ranging from 1.3 to 1.5 and
from 2.2 to 2.8, respectively (Table 1). LREE abundances
are 35 - 50 times chondritic, while HREE are 17-25 times chondritic, indicating a marked heavy to light REE fractionation. Samples from the Macin Zone are characterized by moderate LREE depletions (Fig. 6) with respect to medium REE (LaN /Sm N = 0.8 - 1.0). This aspect may reflect LREE depletion of the mantle source(s) or LREE leaching occurred during the alteration processes. Abundances for REE are 20-30 and 12-20 times chondritic for LREE and HREE, respectively.

TEKTONIC AND PETROGENETIC INTERPRETATION

The Th-Ta-Hf/3 discrimination diagram of Fig. 7 (Wood, 1980) is used as a base for the tectono-genetic interpretation of the basaltic rocks from the North Dobrogea Orogen. In this diagram, dykes from the Macin Zone plot in the N-MORB field, whereas basalts from the Niculitel Formation plot across the boundary between the N-MORB and E-MORB/within-plate tholeiite fields. Accordingly, the Th/Ta ratios (<1.5: Table 1) are typical of anorogenic settings (Cabanis and Lécolle, 1989) for both basaltic series.

Niculitel basalts display incompatible element distributions (Fig. 5) included between those of E-MORB (Sun and McDonough, 1989) and plume-MORB (P-MORB) (Shilling et al., 1983), whereas REE patterns (Fig. 6) are similar to that of E-MORB (Le Roex, 1987). Macin dykes also show E-MORB-type high field strength element and REE patterns (Figs. 5, 6); nevertheless, they are characterized by marked Th-U-Ta and Nb depletion if compared to typical E-MORB composition (Fig. 5).

These features suggest that Niculitel and Macin basalts both originated from variably enriched MORB-type sources, though the degree of enrichment was relatively lower for Macin dykes.

In the Th/Yb ratio vs. Ta/Yb ratio diagram of Fig. 8, both basaltic series plot in the MORB-OIB array, suggesting that any chemical contribution from the continental crust should be excluded. Fig. 8 also confirms the less enriched character of the Macin dykes with respect to Niculitel basalts. In addition, Macin basalts show Th/Yb and Ta/Yb ratios similar to those of the transitional MORBs of the Balagne-Nebbio Nappe from Alpine Corsica (Venturelli et al., 1979; Saccani et al., 2000; Saccani, 2003), as well as to those of Jurassic MORBs from the South Apuseni Mountains (Saccani et al., 2001). By contrast, Niculitel basalts have elemental ratios similar to those of rift-related basalts from the Toccone and Volparone Breccias of Alpine Corsica (Marroni et al., 2001), and within-plate tholeiites (Thompson et al., 1983).

The Y/Nb ratio vs. Zr/Nb ratio diagram of Fig. 9 is used for depicting the influence of a plume source on MORB composition. Ratios of highly incompatible trace elements, such as those listed above, are indeed generally poorly influenced by small extents of fractional crystallization and are thought to reflect either the source characteristics or the degree of partial melting (Saunders et al., 1988). Basalts from the Niculitel Formation plot on the mixing line between OIB source and depleted N-MORB source components (Sun and McDonough, 1989). They also plot close to the E-MORB composition (Sun and McDonough, 1989), and to the field...
of within-plate tholeiites from the Paraná basin, which were interpreted by Fodor et al. (1985) as being strongly influenced by a plume source component active before continental break-up. By contrast, elemental ratios for the Macin dykes indicate a lower influence from an OIB source component with respect to the Niculitel basalts (Fig. 9).

Alternatively, the Macin and Niculitel basalts may have derived from a common mantle source, where the former represent melts derived from lower degree of partial melting with respect to those of the Niculitel Formation. However, the differences in the Th/Ta and Th/Tb ratios of the two basalitic series (Table 1) suggests that Macin and Niculitel basalts likely represent melts derived from compositionally distinct mantle sources.

The possible mantle source of Macin and Niculitel basaltic types is modelled in the (Dy/Yb)\textsubscript{N} vs. (Ce/Yb)\textsubscript{N} ratios diagram, where, according to Haase and Dewey (1996), melting models for a plume source, a depleted MORB source and a mixed MORB-plume source are shown (Fig. 10). Both Niculitel Formation and Macin Zone basalts are consistent with low degrees of partial melting of mantle sources ranging from a theoretical mixed plume - MORB mantle source to a depleted MORB mantle source. In addition, basalts from both series exhibit very little difference in their (Dy/Yb)\textsubscript{N} vs. (Ce/Yb)\textsubscript{N} ratios; however, in accordance with previous conclusions, the influence of plume component seems to be less in Macin dykes than in Niculitel basalts.

In short, from these observations we can deduce that Niculitel basalts show E-MORB affinity and possibly represent melts derived from depleted N-MORB-type mantle sources strongly metasomatized by OIB-type components, whereas the influence of such metasomatizing components is significantly lower in the Macin dykes.
DISCUSSION

Different authors have proposed various interpretations of the geodynamic evolution of the North Dobrogea Orogen. This orogenic belt was formerly interpreted as an intracratonic fold belt by Dumitrescu and Sandulescu (1968). Subsequently, Vlad (1978) suggested that it represents a short-lived aborted rift, corresponding to the abandoned branch of the Carpathian triple junction. Eventually, the North Dobrogea Orogen was interpreted by Gradinaru (1981; 1988) as a Middle Cretaceous transpressional strike-slip belt. However, this scenario is not consistent with any geological and seismic evidence. In the Middle Cretaceous the entire area of the Black Sea was actually affected by extension and rifting (Finetti et al., 1988; Görür, 1988; 1997; Banks and Robinson, 1997; Yilmaz et al., 1997; Nikishin et al., 2002). Paleostratigraphic evidence also indicates that during Aptian-Coniacian the Dobrogea was affected by SE trending extension (Hippolyte, 2002). Recent works suggest that the North Dobrogea Orogen represents a fragment of a back-arc basin formed above a north-dipping Triassic subduction zone, active during the closure of the Paleo-Tethys ocean (Stampfli and Marchant, 1995; Ustaömer and Robertson, 1997; Banks, 1997; Banks and Robinson, 1997; Stampfli et al., 2001).

The Niculitel basalts from North Dobrogea can be correlated with basalts of the Küre ophiolitic complex from the Central Pontides (Ustaömer and Robertson, 1997). The age of the Küre ophiolites is still controversial (Carboniferous - Jurassic: Yilmaz et al., 1997; Triassic - Jurassic: Ustaömer and Robertson, 1997, or Carboniferous: Kozur et al., 1999). However, the model of Kozur and Stampfli (2000), postulating a late Scythian opening and latest Middle Jurassic closing of the Küre Ocean is consistent with the geological evidence for the North Dobrogea basin. In addition, the Jurassic turbidites from North Dobrogea (Nalbant Formation) were often correlated to the Tavric Flysch of South Crimea (Sandulescu, 1984; Nikishin et al., 2001). Geological, stratigraphic and structural data suggest that the Küre Complex (Küre Nappe) from Central Pontides is the southern counterpart of the Tavric Flysch from Crimea, which was brought to its present position consequently to the rifting and opening of the Western Black Sea basin (Ustaömer and Robertson, 1997; Robinson and Kerusov, 1997). The Küre Nappe consists of a Middle Triassic-Lower Jurassic deep-water flyschoid association (Akgöl Formation) overlying an ophiolitic complex, which represents the remnant of the Paleotethys Ocean (Yilmaz et al., 1997, and references therein). The Küre complex shows a blueschist facies metamorphism, while only prehnite-pumpellyite, sub-greenschist facies metamorphism affected the Niculitel basalts. Ustaömer and Robertson (1997) correlate the Küre ophiolites with the Niculitel basalts and suggest that during Paleozoic-Middle Jurassic times North Dobrogea was located adjacent to Kokaeli Peninsula from the Pontides, and that it was translated into its present position during Late Jurassic-Early Cretaceous. In this scenario, prior to the opening of the Western Black Sea basin, the Central Pontides (Sinop Peninsula) would be restored to south Crimea.

Although the oblique-slip tectonics along the Peceneaga-Camena Fault is important for sedimentation and deformation in North Dobrogea, the mechanism and timing of basin opening and closure still remain unsolved. To this purpose, the Lower-Middle Triassic magmatism analyzed in this paper is aimed to constrain the early phases of basin formation. Several magmatic episodes now recorded in North Dobrogea terranes occurred from Late Permian to Middle Triassic. Syenites, rhyolites, and associated co-genetic granites, cropping out north of the Peceneaga-Camena Fault (Fig. 1c), were emplaced during Late Permian. $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios, ranging from 0.707 to 0.708, indicate a crustal magma source for these rocks (Pop et al., 1985). In particular, Seghedi et al. (1992) refer the genesis of granites to crustal anatexis in a continental within-plate tectonic setting probably related to the formation of a thermal dome in the upper mantle. The Permo-Triassic alkaline magmatism, although still poorly known, is reasonably associated with a phase of crustal thinning (Seghedi, 2001). During Early - Middle Triassic, tholeiitic dykes were intruded in the Hercynian basement rocks of the Macin Zone, whereas pillow basalts of the Niculitel Formation were extruded in a basin above the carbonate compensation depth, possibly a rifted basin with a thinned crust, as suggested by facies characteristics of the carbonate rocks that are interbedded with basalts (Seghedi, 2001). This basin could have corresponded either to an aborted rift, as suggested by Vlad (1978), or a passive margin flanking a branch of the evolving Meliata-Karakaya Ocean (Stampfli et al., 2001).

Basalts from the Niculitel Formation have been interpreted as an ophiolitic sequence and genetic relationships with the Macin dykes were suggested for their common MORB geochemistry (Nicolaes and Seghedi, 1996). However, though basalts from the Niculitel Formation have E-MORB composition, this Unit does not display a typical ophiolitic stratigraphy, due to the lack of mantle tectonites and/or mafic-ultramafic cumulates (Cioflica et al., 1980; Savu, 1986).

The highly selected data presented in this paper indicate that Macin and Niculitel basalts have many geochemical similarities. Both are derived from a MORB-type asthenospheric mantle source variably influenced by a plume-type component. Macin dykes result to be less enriched in OIB components with respect to the Niculitel basalts, suggesting that the plume source has affected the magma composition at a minor extent (Figs. 8, 9). Nonetheless, a common geo-dynamic setting of formation can be postulated for the two basaltic series, and their chemical differences can reasonably be related to local variations of the influence of the plume component on the MORB source. Modern analogues are found in the South West Indian (Le Roex et al., 1983) and American-Antarctic Ridges (Le Roex et al., 1985), where the chemical composition of basalts range from pure plume-type (Bouvet mantle plume) ocean island basalts (OIBs) to pure MORBs (Fig. 9).

According to the hypothesis of the aborted rift suggested by Vlad (1978), an evolution of the mantle sources of North Dobrogea Triassic basalts starting with a predominating plume activity followed by the uprising of primitive asthenospheric mantle can be postulated. By contrast, according to the hypothesis of arc-back-arc formed during the northward subduction of the Paleo-Tethys below the Scythian Platform (Stampfli and Marchant, 1995; Ustaömer and Robertson, 1997; Banks, 1997; Banks and Robinson, 1997; Stampfli et al., 2001), the plume activity may have played a major role in weakening the lithosphere and preparing the back-arc spreading.

The close geochemical similarities between the Macin and Niculitel basalts and those from other ophiolitic complexes and oceanic ridges (Figs. 6, 8, 9) do not necessarily imply that North Dobrogea Triassic basalts represent an ophiolitic sequence or, in other words, the hypothesized up-
rise of the asthenospheric primitive mantle does not imply an oceanic spreading steady-state. In any case, the Macin and Niculitel basalts originated in an extensional tectonic setting in which the transition from alkaline to E-MORB magmatism was a consequence of mantle plume evolution through time. This conclusion is in agreement with the Permain-Triassic general geodynamic framework of the Eurasian Plate that was characterized by extensive mantle plume activity associated with widespread development of rift systems (Nikishin et al., 2002).

CONCLUSIONS

The North Dobrogea is a Cimmerian orogenic belt located between the Moesian and Scythian platforms. Two main hypothesis for its original geodynamic setting have been previously postulated: 1) an aborted rift (Vlad, 1978); and 2) a Triassic back-arc basin connected with the closure of the Paleo-Tethys Ocean (Stampfl et al., 2001 and references therein). This belt is characterized by the widespread occurrence of Upper Permain - Jurassic magmatic activities (Seghedi, 2001, and references therein).

In this paper, Triassic volcanic basalts from the Niculitel Formation and basaltic dykes from the Macin Zone, selected on the bases of previously published data (Nicolae and Seghedi, 1996), are analyzed in detail in order to constrain their tectono-magmatic significance. These two basaltic series display many geochemical similarities and are derived from a MORB-type asthenospheric mantle source variably enriched by a plume-type geochemical component. Consequently, Macin and Niculitel basalts share a common geodynamic setting of formation and are compatible with a genesis in a rifting setting characterized by earlier plume activity, corresponding to the formation of Permo-Triassic alkaline volcanics (Seghedi, 2001), followed by uprising of MORB-type asthenospheric mantle, which variably interacted with the plume source.

The preliminary conclusions presented in this paper are limited to Lower Triassic mafic volcanics and subvolcanics. Further studies on petrogenetic characteristics and possible relationships between the various North Dobrogea volcanics and dykes should be carried out to depict the tectono-magmatic evolution of the southern edge of the East European craton from Late Permain to Triassic.

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