Triassic MORB magmatism in the Southern Mirdita zone(Albania)

TRIASSIC MORB MAGMATISM IN THE SOUTHERN MIRDITA ZONE (ALBANIA)

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ABSTRACT

In southern Albania the Mirdita Ophiolitic nappe is characterized by subophiolitic complexes in which remnants of volcanic ophiolite sequences of Triassic age have been identified, either as rare blocks of variable dimension in the Rubik Complex, or as a thin tectonic unit (the Porava Unit), sited immediately under the main ophiolitic masses of the Eastern Ophiolite Belt. In this paper the results of petrological investigations on basalts and biostratigraphical studies on associated radiolarian cherts included in these subophiolitic complexes units are presented.

Biostratigraphical investigations indicate that cherts have ages ranging from Middle to Late Triassic. The associated basalts are represented by both high-Ti mid-ocean ridge basalts (MORB) and alkaline ocean island basalts (OIB). MORB rocks mainly consist of basalts and ferrobasalts with a mild enrichment in low field strength elements and flat rare earth element patterns and, subordinately, by basalts strongly depleted in incompatible elements and light rare earth elements. The chemistry of slightly enriched MORB is consistent with a generation in a mid-ocean ridge setting, from somewhat enriched sub-oceanic mantle source(s), whereas depleted MORB generated from a primitive MOR-type mantle source. The OIB rocks imply a generation in a within-plate oceanic setting from a mantle source enriched by plume chemical components.

Basalts and associated cherts from southern Albania subophiolitic mélanges represent remnants of a Triassic oceanic lithosphere, which testify for the existence, from northern Albania to southern Greece, of a Middle to Late Triassic oceanic basin located between the Adria and Eurasia plates.

The occurrence in the Rubik Complex and Porava Unit of MOR basalts generated from differently enriched sources, as well as of alkaline OIBs, suggests that the early stage of oceanic spreading was variably associated with a plume activity.

INTRODUCTION

The Dinaric-Hellenic belt is characterized by the occurrence of a wide, huge ophiolitic nappe, regarded as one of the best preserved examples of fossil oceanic crust in the whole Mediterranean area.

The Dinaric-Hellenic ophiolites have been generally divided into two belts, the western and the eastern ones, corresponding to distinct tectonic units, each showing sequences of Jurassic age, but with different geological, geochemical and petrological features (e.g. Beccaluva et al, 1994 and Bortolotti et al., 2002). These rocks have been deeply investigated mainly in northern Albania and Greece, where nice and well exposed sequences can be found. Recently, remnants of ophiolite sequences of Triassic age have been identified in the subophiolite mélanges, either as rare blocks of variable dimension, or as tectonic slice underlying the ophiolitic belts (Bortolotti et al., 2004a and references therein; 2005). However, little data are available on these sequences.

This paper focuses on the results of petrological investigation on the basalts and biostratigraphical studies of associated cherts found at the base of the ophiolitic belts in southern Albania. We present our interpretation of the collected data and discuss the related geodynamic implications.

GEOLOGICAL OUTLINE

The north-south trending belt extending from Greece to Serbia, across Albania, Montenegro and Croatia, is a collisional mountain chain originated from the Mesozoic to Tertiary convergence between the Adria and Eurasia plates.

This convergence resulted in the squeezing of the oceanic basin located between the Adria and Eurasia continental margins and the subsequent continental collision. According to some authors this oceanic domain belonging to the Tethyan realm, consisted of a single, wide basin (Vardar, see Bortolotti and Principi, 2005, and references therein), whereas other authors suggested more than one basin (Pindos and Vardar oceanic basins, see Robertson and Shallo, 2000, and references therein). Despite the different interpretations, the existence of oceanic lithosphere is documented by the ophiolitic sequences now thrust to the west onto the Adria continental crust from the Northern Dinarides in Croatia, through Albania, to the southern Hellenides in the Argolis Peninsula. The ophiolites are present, all along this orogenic system, in four different tectonic settings (Bortolotti et al., 2004 and references therein):

1- as fragments of disrupted ophiolitic successions included as blocks of very variable dimensions (from millimetric to pluridecametric) in the widespread (subophiolitic) mélanges lying on top of the calcareous successions of the Adria plate continental margin. In Albania this mélange is known as Rubik Complex, whereas in Greece it is reported with different names (e.g., Avdella Mélange, Koziakas Mélange, Agoriani Mélange, Fourka Subunit).

2- as thin disrupted tectonic units comprising MOR basalts with some serpentinite slivers at the base; they are interposed between the mélange and the overlying large ophiolite units. The cherts found at the top of the basalts generally show a Middle to Late Triassic age. These tectonic units have been called "Porava Unit" in northern Mirdita, Albania (Bortolotti et al., 2004a), "Fourka Subunit" in the Othris region, Greece, and "Migdalitsa Ophiolitic Complex" in the Argolis Peninsula, Greece (Bortolotti et al., 2002; 2003; 2004b). In this paper, this unit is reported as Porava Unit.

3- The Middle to Upper Jurassic Western Ophiolite belt, not everywhere present, of which a reconstructed stratigraphy includes, from bottom to top: metamorphic sole, lherzolitic mantle tectonites, mafic-ultramafic cumulates, a discontinuous sheeted dyke complex and a volcanic sequence (Beccaluva et al., 1994; Shallo, 1994; Bortolotti et al., 1996; 2004b; Saccani et al., 2004). The volcanic as well as the intrusive sequence show high-Ti (mid-oceanic ridge basalt, MORB) affinity but a volcanic sequence showing IAT and MOR-IAT intermediate geochemical features has been found, directly overlying the more typical MORB sequences (Bortolotti et al., 1996).

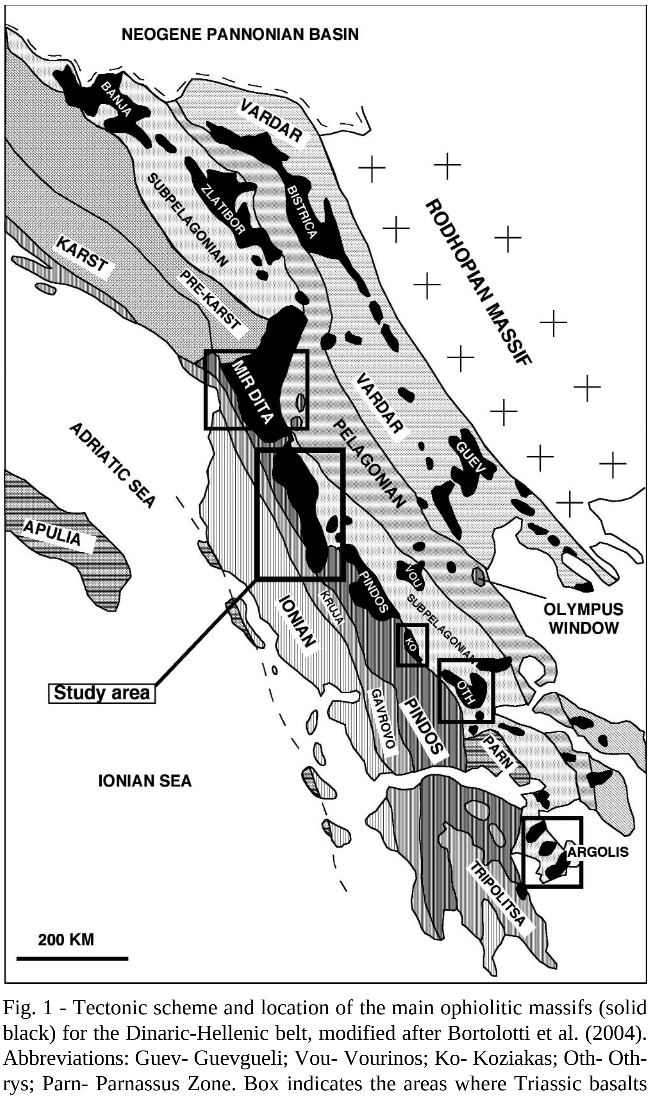

Fig. 1 - Tectonic scheme and location of the main ophiolitic massifs (solid black) for the Dinaric-Hellenic belt, modified after Bortolotti et al. (2004). Abbreviations: Guev- Guevgueli; Vou- Vourinos; Ko- Koziakas; Oth- Othrys; Parn- Parnassus Zone. Box indicates the areas where Triassic basalts have been recognized.

4- The Middle to Upper Jurassic Eastern Ophiolite belt consisting of a very thick ophiolite sequence, up to 10 km, which comprises mantle harzburgites, ultramafic and mafic cumulates and, at the top, a sheeted dyke complex followed by a volcanic section. According to the geochemical data, the ophiolites from the Eastern unit show low-Ti affinity (Beccaluva et al. 1994; Shallo, 1994; Saccani et als. 2004), suggesting an origin in a supra-subduction zone (SSZ) setting.

Our working group is involved in the investigations on the Triassic ophiolitic basalts found in both the subophiolite mélange and in the Porava Unit

We summarize here the results of our previous works:

Argolis. In this area, either at the top or in the upper part of the subophiolite Mélange covering the Pelagonian formations (continental realm of the Adria mesoplate), the Migdalitsa Ophiolitic Complex (= Porava Unit), comprising MOR basalts with some serpentinite slivers at the base and cherty intercalations, furnished radiolarian assemblages of Middle to Late Triassic and also of Liassic age (Bortolotti et al., 2003; 2004b; Saccani et al., 2004).

Othris. In the basaltic Fourka Subunit (= Porava Unit), interposed between the subophiolitic Agoriani Mélange and the Ophiolitic Unit, two sections of basalts with MORB affinity are associated to thin chert levels which yielded radiolarian assemblages of Triassic and Late Triassic age (Photiades et al., 2003; Bortolotti et al., 2005).

Koziakas. In this area, the volcanites of the subophiolitic mélange were studied by Saccani et al. (2003), who found MORB, transitional to alkaline rocks and boninites. Chert intercalations gave Triassic and Jurassic ages. Pomonis et al. (2005) separated the mélange from the overlying massive and pillow basalts, which can be correlated to the Porava Unit. The field evidence suggests that the Triassic fossils come from the cherts of this unit (Bortolotti and Principi, 2005).

Northern Mirdita. In this area, on top of the formations pertaining to the Adria mesoplate, the tectono-sedimentary subophiolite mélange, called by Bortolotti et al. (1996; 2004b; 2005) Rubik Complex, is tectonically covered by a thin tectonic unit called by Bortolotti et al. (2004a) Porava Unit. This unit comprises MOR basalts with cherts at their top, which furnished ages ranging from Middle to Late Triassic. The Porava Unit is in turn tectonically covered by peridotites of both the Western and Eastern Ophiolite Belts.

For completing our studies in the ophiolite sequences of Albania, we sampled the basalts and the cherts at their top, in the Porava Unit cropping out in southern Mirdita.

GEOLOGICAL OUTLINE OF THE STUDY AREA

We focused on the Triassic basalts and related sedimentary cover of the Mirdita Ophiolitic Nappe, South Albania. The Mirdita ophiolitic nappe is constituted by a stack of tectonic units, which lies at the top of the Krasta-Cukali Unit to the west, and on the Pelagonian Units, to the east (Figs. 1 and 2). Differently from Northern Albania, in the study area the outcrops of the Mirdita Ophiolitic nappe are discontinuous and extensively covered by Upper Tertiary transgressive “molasse” deposits of the Meso-Hellenic trough.

The ophiolitic nappe consists of four tectonic units, from the base upwards they are (Bortolotti et al., 1996; 2004b; 2005):

a- Rubik Complex: a tectono-sedimentary mélange where huge masses of carbonate rocks derived from a continental margin, are associated to slices of serpentinised peridotites and sedimentary breccias. The breccias include carbonate and ophiolitic clasts in a very abundant shaly and subordinately serpentinitic matrix.

b- Porava Unit: a tectonic unit consisting of Triassic basalts with thin levels of cherts intercalated in the volcanites or at its top.

c- Western Ophiolite belt: a thick ophiolite sequence which, from bottom upwards consists of mantle lherzolites, ultramafic-mafic cumulates covered by MOR and MOR-IAT intermediate basalts with thin levels of Middle Jurassic cherts at the top.

d- Eastern Ophiolite belt: a very thick ophiolite consisting of mantle harzburgites, ultramafic and mafic cumulates and, at the top a SSZ volcanic section (basalts, basaltic andesites, andesites, dacites and rhyolites). The chert levels found either intercalated or at the top of the volcanites have the same age of the cherts at the top of the Western belt.

The two ophiolite belts are unconformably covered by the Simoni Mélange, which grades upwards to the Tithonian - upper Valanginian Firza Flysch. The Barremian-Senonian shallow water carbonate sequence unconformably overlies the ophiolite sequence -from peridotites to volcanics- of the Eastern belt.

The studied samples have been collected in both the Rubik Complex and Porava Unit. We report here below the biostratigraphic, petrographic and geochemical results.

SAMPLE LOCATION AND BIOSTRATIGRAPHY

The basalts and radiolarian cherts of the Porava Unit have been collected in four zones of southern Albania (Fig. 2): a- Miraka, b- Sheh-Polisi, c-Zereci, d- Barmashi

The locations of the samples and the results of radiolarian biostratigraphy study are herein described.

For *Paroertlispongus mostleri* (Kozur) and *Paroertlispongus multispinosus* Kozur and Mostler, we consider the range reported in Kozur (1996) and Kozur et al. (1996). For the other taxa we adopted the stratigraphic distribution of Tekin (1999).

a- Miraka

At the western base of the harzburgitic massif of Miraka, immediately to the north of the Elbasani - Librazhdi road (N41° 10’ 597; E020°18’ 229), a level of boudinaged metamorphic sole, with few meters thick cataclasite and ultracataclasite bands, crops out. Below the sole, the Rubik Complex includes at its top, blocks of very weathered basalts with some thin lenses of cherts: these blocks can be interpreted as a very tectonised level of Porava Unit. We sampled one of these cherts (04AL1), but it was impossible to find fresh basalts.

The age of the cherts is Middle Triassic (latest Anisian - early Ladinian) for the presence of *Paroertlispongus mostleri* (Kozur).

b- Sheh-Polisi

On the left side of the Shkumbini River, between Librazhdi and Elbasan, near Sheh-Polisi, the Porava Unit, here some hundred meters thick, crops out at the base of a 40 to 150 meters thick metamorphic sole (amphibolites with scarce micaschists).

We collected samples in three different chert intercalations in the pillow basalts:

1- near the base of the Porava Unit: the basalt 04AL15; the cherts 04AL16, 04AL17, 04AL18, 04AL19, 04AL20.

The age of sample 04AL16 is Middle? Triassic for the presence of *Tetrapaurinella* sp. and *Tiborella* sp. cf. *T. florida* (Nakaseko & Nishimura); the age of sample 04AL19 is Late Triassic (latest Carnian - early Norian) for the presence of *Capnodoce anapetes* De Wever, *Capnucosphaera theloides* De Wever and *Xiphoteca rugosa* Bragin.

2- a few meters upwards: the basalts 04AL22B, 04AL22C; the cherts 04AL23, 04AL24, 04AL25. The age of sample 04AL23 is Late Triassic (middle Carnian - early Norian) for the presence of *Capnucosphaera* sp. cf. *C. concava* De Wever, *Capnucosphaera* sp. cf. *C. crassa*, *Spongostylus carnicus* Kozur and Mostler and *Spongostylus tortilis* Kozur and Mostler.

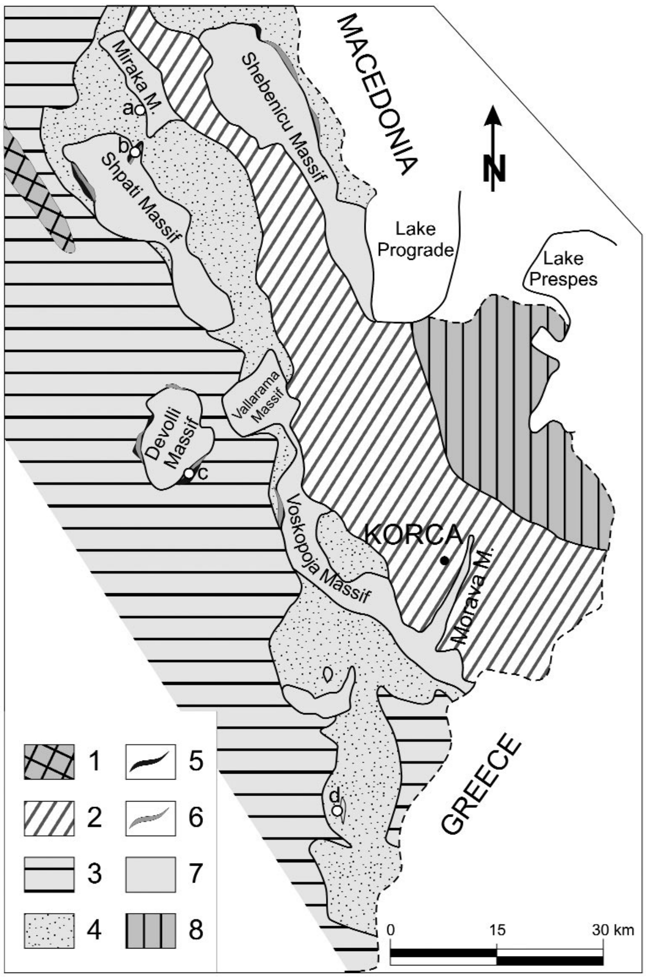

Fig. 2 - Schematic geologic setting of the south-eastern Albania (modified from Robertson and Shallo, 2000). 1- Lower Miocene - Quaternary Periadriatic Basin. 2- Middle Eocene - Upper Miocene Mesohellenic basin; 3- Krasta-Cukali Unit. Mirdita Ophiolitic Nappe (4- Rubik Complex; 5- Porava Unit; 6- Metamorphic Soles; 7- Harzburgite massifs). 8- Pelagonian Units.

In sample 04AL25 the presence of *Capnucosphaera deweveri* Kozur and Mostler, *Spongostylus carnicus* Kozur and Mostler and *Xiphoteca rugosa* Bragin also indicates a Late Triassic age (latest Carnian - early Norian).

3- south of the Dipolisi village, some hundred meters upwards (N41° 07” 318; E020° 14’ 714), in the same very thick basalt outcrop, a section in a level of cherts, 2 meters thick (04V5, 04V6, 04V7), intercalated in the basalts (04V8), ~14 meters under the tectonic contact with the metamorphic sole (Fig. 3a).

The presence of *Capnuchosphaera* sp. indicates a Late Triassic (early Carnian - late Norian) age for sample 04V5.

The age of sample 04V7 is Late Triassic (early Carnian - early Norian) for the presence of *Capnuchosphaera* sp., *Dumitricasphaera* (?) sp. cf. *D.* (?) *planustyla* Lahm and *Spongostylus tortilis* Kozur and Mostler.

c- Zereci

Below the southeastern side of the harzburgitic massif of Devolli and its metamorphic sole, at about 80 m thick, the Porava Unit crops out about 500 meters to the northwest of the village of Zereci (N40° 42’ 482; E020° 20’ 979). We sampled a plurimetric level of cherts (04V1) intercalated in the pillow basalts, and the surrounding basalts (04V1B).

The age of the cherts is Late Triassic (early Carnian - early Norian) for the presence of *Capnodoce* sp., *Capnucosphaera deweveri* Kozur and Mostler, *Capnucosphaera theloides* De Wever and *Capnucosphaera* sp. cf. *C. triassica* De Wever.

d- Barmashi

At about 500 meters to the northwest of the village of Barmashi (N40° 16’ 832; E020° 36’ 315), under a 100 to 150 meters thick metamorphic sole, which constitutes the base of a harzburgite sliver, a small outcrop of the Porava Unit is present. We sampled a thin sequence (Fig. 3b) at the contact between the pillow basalts (04V4, 2 meters under the contact) and the overlying cherts (04V2 and 04V3, 150 and 160 cm over the contact, respectively,).

The age of the cherts is Middle Triassic (latest Anisian - early Ladinian) for the presence of *Paroertlispongus mostleri* (Kozur), *Paroertlispongus multispinosus* Kozur and Mostler in the sample 04V2 and *Paroertlispongus mostleri* (Kozur), *Paroertlispongus multispinosus* Kozur and Mostler, *Pseudostylosphaera* (?) sp. cf. *P.* (?) *magnispinosa* Yeh in the sample 04V3.

PETROGRAPHY

All samples have been severely affected by ocean-floor hydrothermal alteration processes, which resulted in an intensive recrystallization of the primary igneous phases; nonetheless the primary igneous textures are still preserved. The main mineralogical transformations include the replacement of plagioclase by clay minerals and the transformation of clinopyroxene into chlorite. Only sample 04V1B displays partial replacement of clinopyroxene by brown amphibole.

Samples 04AL15, 04AL22B, 04AL22C (Sheh-Polisi), and 04V4 (Barmashi) display coarse-grained aphyric textures with groundmasses ranging from sub-ophitic to intergranular. All these rocks are characterized by euhedral plagioclase and anhedral to interstitial clinopyroxene. Sample 04AL15 contains a significant amount of opaque minerals, which often display skeletal textures. Sample 04AL22B includes about 10% of euhedral, fresh olivine crystals.

Sample 04V8 (Sheh-Polisi) displays hyalophitic texture in which only small laths of plagioclase can be recognized. The volcanic glass is replaced by a cryptocrystalline assemblage of clay minerals and chlorite. This sample is characterized by veins filled by calcite and calcite-chlorite assemblages.

Sample 04V1B (Zereci) is slightly porphyritic (PI<10) with plagioclase microphenocrysts settled in a sub-ophitic to intergranular, coarse-grained groundmass. Groundmass mineral assemblage includes euhedral plagioclase and anhedral to interstitial clinopyroxene, as well as minor interstitial opaque minerals.

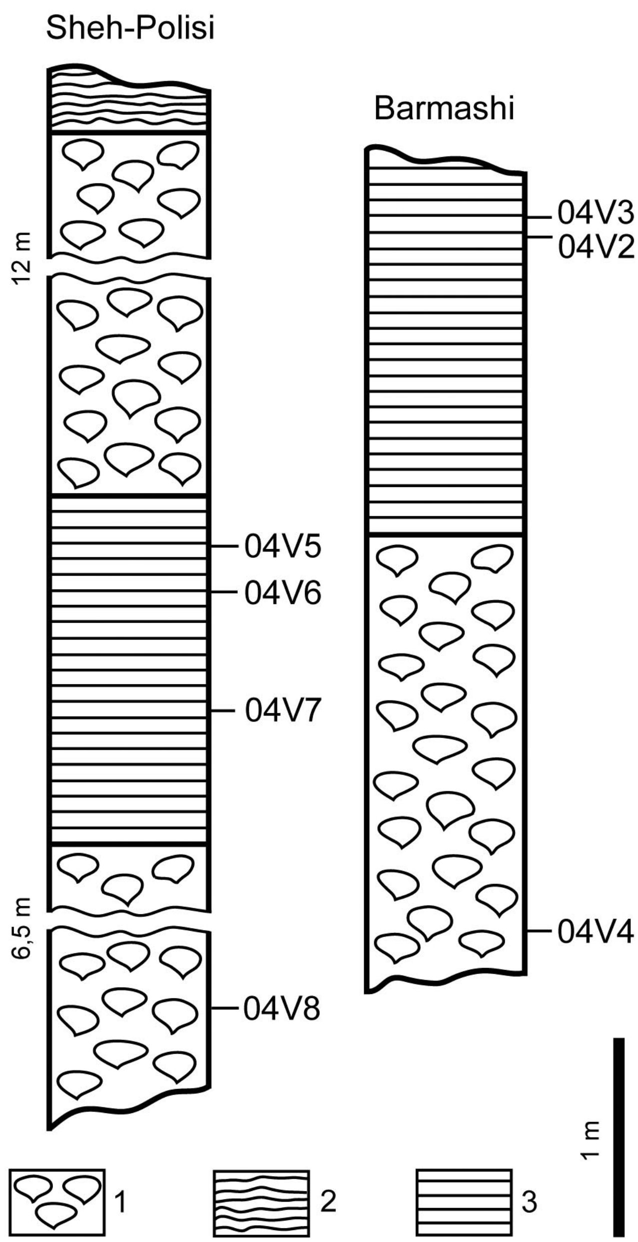

Fig. 3 - Columnar sections of the Sheh-Polisi and Barmashi sampled sections. 1- pillow lavas; 2- metamorphic sole; 3- radiolarites.

GEOCHEMISTRY

Analytical Methods

Bulk-rock major and trace element analyses were obtained by X-ray fluorescence (XRF) with an ARL Advant-XP automated spectrometer using the matrix correction methods proposed by Lachance and Trail (1966). Accuracy and detection limits were determined using a set of international standards run as unknown. Accuracy is better than 3% for Si, Ti, Ca, K and 7% for Al, Mn, Mg, Na, P, and better than 6% for trace elements, with the exception of Ba (8%); detection limits for trace elements are: Zn, Cu, Ga, Ba = 5 ppm; Ni, Co, Cr, V, Rb = 1 ppm; Sr, Zr, Y = 2 ppm. The precision of XRF analyses (determined by replicate analyses) was less than 5% for all elements. Rare earth elements (REE), Sc, Nb, Ta, Th, Hf, and U were determined by inductively coupled plasma-mass spectrometry (ICP-MS) using a VG Elemental Plasma Quad PQ2 Plus. 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.

Geochemistry and tectono-magmatic interpretation

One of the main objectives of this chapter is to evaluate the chemical nature of basalts, which are unequivocally associated with radiolarian cherts. The chemistry of volcanic rocks may be related to different source characteristics, associated in turn with distinct tectono-magmatic settings of formation. The discussion will therefore be focused on the possible tectonic setting of formation of the analyzed basalts in order to constraint the age of development of the different tectonic settings inside the Mirdita oceanic basin.

The geochemical and petrogenetic interpretation of the rocks studied in this paper is mainly based on those elements which are considered to be immobile during ocean-floor alteration processes (e.g., Pearce and Norry, 1979; Shervais, 1982). These elements are high field strength elements (HFSE), such as Zr, Y, Nb, Ti, P; rare earth elements (REE); and transition metals (e.g., V, Cr, Co, Ni). The geochemical data (Table 1) indicate that the analysed basalts belong to three chemically different groups.

Samples **04AL15, 04AL22B, 04AL22C** (Sheh-Polisi), **and 04V4** (Barmashi) are basaltic in composition and are characterized by relatively high TiO_2 (1.32 to 1.84 wt%), P_2O_5 (0.12 - 0.25 wt%), Zr (86-141 ppm), and Y (31-46 ppm) contents. The generally high MgO and CaO contents, coupled with high Mg# (Table 1), indicate a rather primitive nature of samples 04Al22B, 04AL22C, and 04V4. By contrast, sample 04AL15 displays a rather fractionated nature, having the highest TiO_2, FeO, P_2O_5, V, Zr, and Y associated with the lowest Mg#. In particular, the high FeO_t content (14.21 wt%) point to a ferrobasaltic composition. In spite of the primitive nature of basalts, Ni, Co, and Cr concentrations are generally lower than expected in similar rocks. The relative distribution of incompatible element concentrations (Fig. 4) indicates that all these rocks share affinities with high-Ti ocean-floor basalts. In particular, HFSE exhibit rather flat patterns ranging from 1 to 2 times typical normal-MORB (N-MORB) of Sun and McDonough (1989). Low field strength elements (LFSE) show slightly enriched patterns that resemble that of typical enriched-MORB (E-MORB), and range in concentration from 2 to 4 times N-MORB (Fig. 4). REE concentrations display rather flat patterns (Fig. 5), which are consistent with N-MORB compositions, as they have a very mild light REE (LREE) depletion

Table 1 - Major and trace element composition of volcanic rocks from the Rubik Complex and Porava Unit from southern Albania.

Locality	Sheh Polisi	Sheh Polisi	Sheh Polisi	Barmashi	Sheh Polisi	Zereci
Sample	04AL15	04AL22B	04AL22C	04V4	04V8	04V1B
Rock	Fe-Bas	Bas	Bas	Bas	Bas	Bas
Type	MORB	MORB	MORB	MORB	MORB	OIB
XRF Analyses:						
SiO_2	46.55	47.71	47.62	50.23	42.28	48.67
TiO_2	1.84	1.32	1.43	1.34	0.81	2.41
Al_2O_3	15.13	17.99	17.21	15.85	16.13	15.78
Fe_2O_3	1.82	1.25	1.46	1.18	0.99	1.14
FeO	12.15	8.34	9.73	7.84	6.57	7.61
MnO	0.34	0.19	0.20	0.14	0.12	0.16
MgO	6.22	7.83	7.84	7.96	8.24	5.41
CaO	9.01	8.07	7.18	10.54	13.02	7.43
Na_2O	3.72	2.97	3.20	3.30	2.97	2.72
K_2O	0.03	1.26	0.91	0.34	0.74	3.11
P_2O_5	0.25	0.23	0.25	0.12	0.03	0.63
L.O.I.	2.59	3.70	2.88	2.04	7.93	4.60
Total	99.65	100.84	99.90	100.87	99.83	99.67
Mg#	47.7	62.6	58.9	64.4	69.1	55.9
Zn	80	65	66	67	40	67
Cu	89	97	108	127	89	35
Ga	10	9	8	7	5	20
Ni	32	56	56	73	162	19
Co	46	41	39	43	37	15
Cr	82	222	266	200	159	93
V	387	290	287	288	166	215
Rb	4	14	6	8	13	100
Ba	80	183	147	157	163	698
Sr	143	221	230	215	406	476
Zr	141	107	121	86	45	222
Y	46	36	39	31	21	25
ICP-MS Analyses:						
Sc	40.1	39.5	39.4	37.8	30.5	18.2
La	5.61	4.65	5.25	3.79	1.14	75.4
Ce	15.8	13.6	15.0	10.8	4.33	135
Pr	2.32	2.01	2.21	1.63	0.82	12.5
Nd	12.2	10.4	11.4	8.20	4.53	42.5
Sm	3.73	3.22	3.51	2.57	1.60	7.69
Eu	1.34	1.15	1.23	0.99	0.68	2.02
Gd	5.19	4.54	4.86	3.50	2.35	5.64
Tb	0.95	0.79	0.87	0.63	0.45	0.94
Dy	6.23	5.25	5.79	4.03	2.95	5.02
Ho	1.42	1.17	1.29	0.90	0.69	0.96
Er	4.21	3.47	3.71	2.59	2.01	2.48
Tm	0.64	0.55	0.57	0.38	0.33	0.35
Yb	4.24	3.69	3.80	2.64	2.16	2.09
Lu	0.56	0.48	0.50	0.34	0.29	0.26
Nb	5.66	4.67	5.16	3.91	0.55	110
Hf	3.35	2.82	3.17	2.17	1.29	6.60
Ta	0.42	0.31	0.30	0.27	0.07	6.72
Th	0.50	0.45	0.49	0.35	0.06	13.5
U	0.17	0.15	0.16	0.17	0.02	2.49
Ti/V	29	28	31	28	32	71
Nb/Y	0.12	0.13	0.13	0.12	0.03	4.38
Th/Ta	1.18	1.44	1.62	1.31	0.84	2.00
Th/Tb	0.52	0.57	0.56	0.56	0.13	14.33
Ce/Y	0.34	0.38	0.38	0.35	0.21	5.39
Ta/Hf	0.13	0.11	0.09	0.12	0.05	1.02
$(La/Sm)_N$	0.97	0.93	0.97	0.95	0.46	6.33
$(La/Yb)_N$	0.95	0.90	0.99	1.03	0.38	25.95

Fe_2O_3 = FeO x 0.15; Mg# = 100 x Mg/($MgFe^2$), where Mg = MgO/40 and Fe = FeO/72. Normalizing values for REE ratios are from Sun and McDonough (1989). Abbreviations: Fe-Bas = ferrobasalt; Bas = basalt; MORB = mid-ocean ridge basalt; OIB = ocean island basalt.

with respect to medium REE (La_N/Sm_N = 0.93-0.97) and heavy REE (La_N/Yb_N = 0.90-1.03). The overall enrichment for heavy REE (HREE) is in the range 13 to 25 times chondrite (Fig. 5). The Ti/V ratios of these basalts range from 28 to 31 (Table 1), which are values typical for basalts generated at mid-ocean ridge settings (Shervais, 1982). A similar conclusion is obtained in the discrimination diagram of Fig. 6 (Wood, 1980).

In summary, the overall geochemical features of samples 04AL15, 04AL22B, 04AL22C, and 04V4 suggest melt generation in a mid-ocean ridge tectonic setting. In agreement with Pearce and Norry (1979), in the Zr/Y versus Zr plot of Fig. 7 the partial melting path of high-Ti basalts intersects the path of slightly enriched mantle source. Ratios of highly incompatible trace elements, such as Ce/Y are generally little influenced by small extents of fractional crystallization and are expected to reflect the source characteristics. Ce/Y ratios in typical normal and enriched-type MORBs are 0.37 and 0.68, respectively (Sun and McDonough, 1989). Ce/Y ratios of these basalts range from 0.44 to 0.73 (Table 1), suggesting that they most likely consist of N-MORBs generated from slightly enriched mantle sources. The very low depletion of LREE with respect to HREE, further supports this conclusion.

Th/Tb and Ta/Yb ratios, which are in the MORB-OIB array between the compositions of typical N- and E-MORBs (Fig. 8), also suggest that these basaltic rocks originated from slightly enriched sources. Nonetheless, they plot in the compositional field of N-MORBs from various sub-ophiolitic mélange units from the Albanide-Hellenide ophiolites (Fig. 8; Saccani and Photiades, 2005).

Basalt 04V8 (Sheh-Polisi) displays a chemical composition which is, for most of the elements, quite similar to those of the basaltic rocks previously described. However, this basalt differs from those rocks in having comparatively lower TiO_2 (0.81 wt%), P_2O_5 (0.03 wt%), Zr (45 ppm), and Y (21 ppm) contents, coupled with a high Mg# (69.1). Moreover, Th, U, Ta, Nb, La, Ce and HFSE (Fig. 4) are strongly depleted with respect to the typical N-MORB composition (Sun and McDonough, 1989). Their abundance ranges from 0.2 to 0.8 times N-MORB. REE concentrations (Fig. 5) are characterized by a strong LREE depletion with respect to medium (La_N/Sm_N = 0.46) and HREE (La_N/Yb_N = 0.38), as well as an overall enrichment in HREE of about 12 times chondrite (Fig. 5). The Ti/V ratio (Table 1) and the discrimination diagram of Fig. 6 indicate a clear MORB affinity for this rock.

The depletion of Th, U, Ta, Nb, LREE, and HFSE with respect to the N-MORB composition (Fig. 7), as well as the low Zr/Y ratio (Fig. 7) observed in basalt 04V8 suggest genesis from a mantle source depleted in incompatible elements. This conclusion is also supported by very low incompatible elements ratios, such as Nb/Y, Th/Ta, Ce/Y, and Ta/Hf (Table 1), as well as Th/Yb and Ta/Yb ratios (Fig. 8).

Basalt 04V1B (Zereci) displays high TiO_2, P_2O_5, Th, Nb, La, Ce, and Zr contents, as well as high Nb/Y and Zr/Y ratios (Table 1), which testify for the alkaline character of this rock. The incompatible elements abundances (Fig. 4) are characterized by a regularly decreasing pattern from Rb to Y and a generalized enrichment with respect to N-MORB (Sun and McDonough, 1989), particularly evident for the large ion lithophile elements (LILE), which range from 200 to 50 times N-MORB. The pattern of incompatible elements

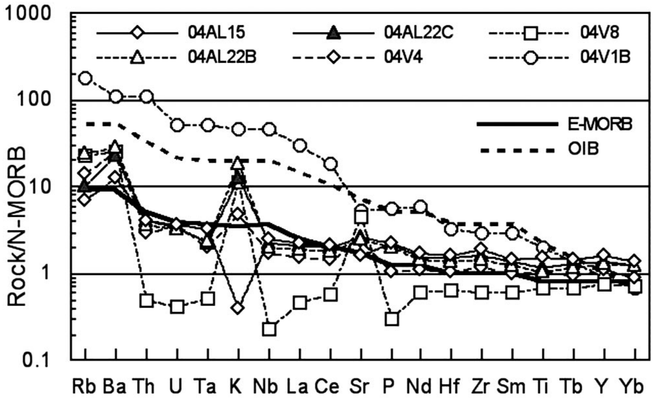

Fig. 4 - N-MORB (Sun and McDonough, 1989) normalized incompatible element abundance patterns for volcanic rocks from the Rubik Complex and Porava Unit from southern Albania. Compositions of typical alkaline ocean island basalt (OIB) and enriched-MORB (E-MORB) are reported for comparison. OIB and E-MORB are from (Sun and McDonough, 1989).

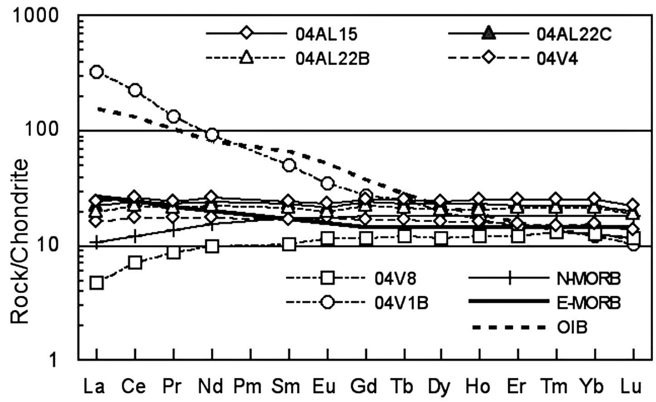

Fig. 5 - Chondrite (Sun and McDonough, 1989) normalized incompatible element abundance patterns for volcanic rocks from the Rubik Complex and Porava Unit from southern Albania. Compositions of typical alkaline ocean island basalt (OIB), normal-MORB (N-MORB), and enriched-MORB (E-MORB) are reported for comparison (data from Sun and McDonough, 1989).

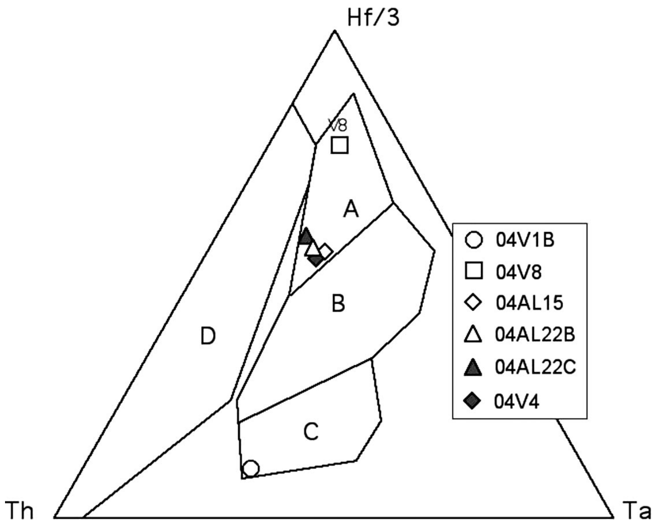

Fig. 6 - Th, Ta, Hf/3 discrimination diagram for volcanic rocks from the Rubik Complex and Porava Unit from southern Albania. Modified after Wood (1980). A: normal-type MORBs, B: enriched-type MORBs and within-plate tholeiites, C: alkaline within-plate basalts, D: volcanic arc basalts.

of this basalt displays strong similarities with the pattern of typical ocean islands basalt (OIB) of Sun and McDonough (1989). The pattern of REE is characterized by a strong enrichment in LREE with respect to HREE (Fig. 5), which is a typical feature of alkaline within-plate alkaline OIBs (Frey and Clague, 1983; Le Roex, 1983). Accordingly, in the discrimination diagram of Fig. 6, this rock plots in the field for alkaline within-plate basalts. The Zr/Y ratio (Fig. 7) is also in the typical range of values for within-plate ocean island basalts (Pearce, 1982) and indicates genesis from an enriched mantle source associated with mantle plumes. The significantly high contents of Th, U, Ta, Nb, and LREE, as well as the ratios of highly incompatible elements, such as, Nb/Y, Ce/Y (Table 1) and Ta/Yb, Th/Yb (Fig. 8) ratios, are in agreement with this conclusion.

The overall geochemical characteristics suggest that basalt 04V1B represents seamount material originated in an intra-plate oceanic setting.

Similar alkaline volcanic rocks, some of which dated as Triassic, are documented in several localities of the Hellenides (Pe-Piper and Piper, 2002, and references therein) and are also common in many mélange terranes along the Albanide-Hellenide ophiolitic belts (Saccani and Photiades, 2005, and references therein).

CONCLUSIONS

The collected data suggest that the Rubik Complex and the Porava Unit in southern Albania are characterized by the occurrence of MOR and OIB basalts covered by cherts ranging in age from Middle to Late Triassic. MOR volcanics are mainly represented by basalts and ferrobasalts showing a mild enrichment in LFSE and flat REE patterns (Figs. 4, 5). The chemistry of these rocks is consistent with a generation in a mid-ocean ridge setting from a slightly enriched sub-oceanic mantle source(s). Incompatible element ratios, such as Zr/Y Th/Yb, and Ta/Yb (Figs. 7, 8) also support this conclusion. Subordinately, MOR volcanics are represented by basalts strongly depleted in incompatible elements and LREE (Figs. 4, 5). These rocks were most likely generated from a depleted MOR-type mantle source, as also evidenced by the Zr/Y and Th/Yb, Ta/Yb ratios (Figs. 7, 8). The OIB rocks are represented by alkaline basalts generated in a within-plate oceanic setting from a mantle source enriched by plume chemical components.

These new data confirm that from northern Albania to southern Greece a continuous belt of Triassic oceanic lithosphere remnants occurs. This implies the existence of a Middle to Late Triassic oceanic basin located between the Adria and Eurasia plates and characterized by MORB magmatism. This conclusion agrees very well with the reconstructions proposed by Bortolotti et al. (2004a; 2004b; 2005) and Bortolotti and Principi (2005), where the occurrence of an oceanic basin already opened between the Adria and Eurasia Plates in Middle Triassic time is postulated. In these reconstructions, the oceanic basin developed after a Lower Triassic rifting stage, which evidence is preserved in the rift basins accompanied by magmatism on the Adria continental area (Bortolotti and Principi, 2005), and in carbonate slices of the Rubik Complex, where a pelagic succession of Triassic age is recognised. The occurrence in the Rubik Complex and Porava Unit of southern Albania of different MOR basalts showing different enrichments in incompatible elements, as well as of alkaline OIBs suggests that the oceanic spreading was most likely associated with mantle sources characterized by variable degree of enrichments from a plume component. Saccani and Photiades (2005) have postulated that the early stages of oceanic spreading were associated with plume activity, while the steady-state phases of oceanization only involved sub-oceanic primitive mantle sources. The data presented in this paper are in good agreement with this interpretation. The phase of spreading continued from Middle to Late Triassic according to the age of the radiolarites associated to MOR basalts in the Rubik Com-

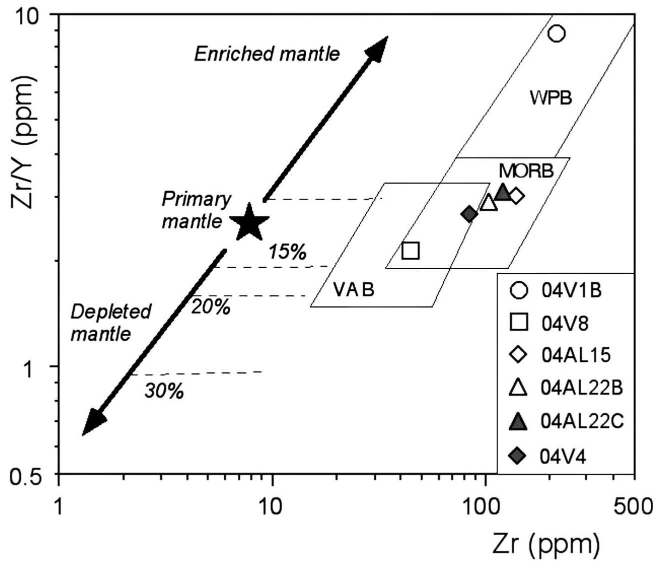

Fig. 7 - Zr/Y vs. Zr discrimination diagram for volcanic rocks from the Rubik Complex and Porava Unit from southern Albania. Modified after Pearce and Norry (1979). VAB: volcanic-arc basalts, MORB: mid-ocean ridge basalts, WPB: within-plate basalts.

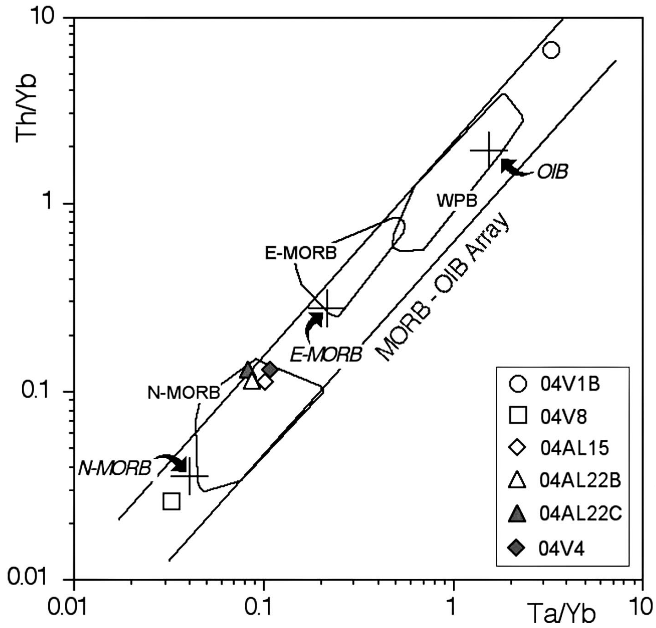

Fig. 8 - Th/Yb vs. Ta/Yb diagram Th/Yb vs. Ta/Yb diagram for volcanic rocks from the Rubik Complex and Porava Unit from southern Albania. Modified after Pearce (1983). Compositions (crosses) of Modern normal mid-ocean ridge basalt (N-MORB), enriched mid-ocean ridge basalt (E-MORB) and within-plate ocean island basalt (OIB) are from Sun and McDonough (1989). Compositional fields of Triassic E-MORBs and within-plate basalts (WPB), as well as Triassic and Jurassic N-MORBs from various sub-ophiolitic mélange units from the Albanide-Hellenide belt (Saccani and Photiades, 2005) are reported for comparison.

plex as well as in the Porava Unit. Subsequently, in Early Jurassic time, the oceanic basin was affected by convergence, with the development of a subduction zone, responsible for the SSZ-related magmatic sequences found in the Western and Eastern ophiolitic belts.

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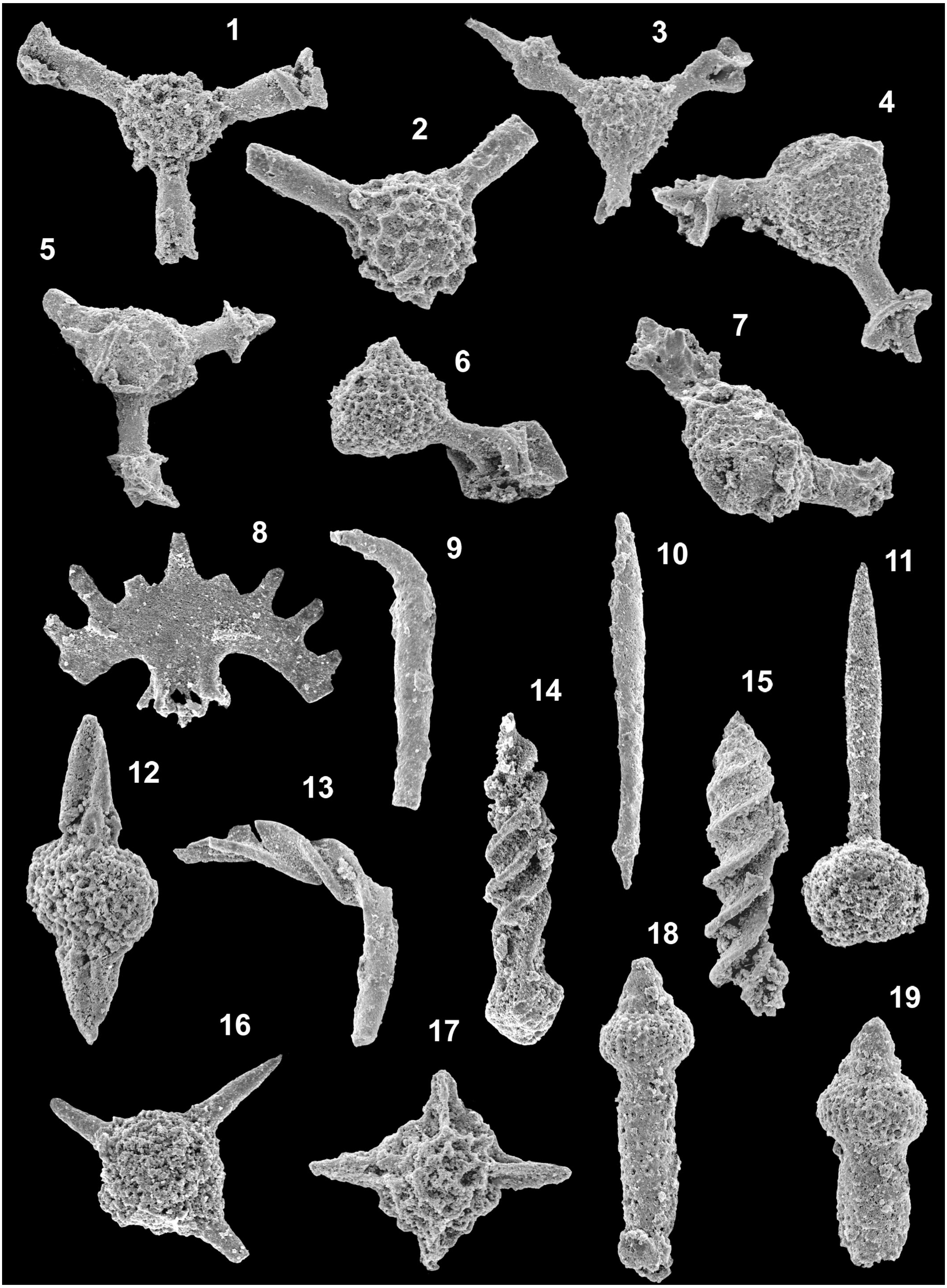
Plate 1 - 1 - *Capnodoce anapetes* De Wever, 04AL19, x215. 2 - *Capnodoce* sp., 04V1, x300. 3 - *Capnuchosphaera deweveri* Kozur & Mostler, 04V1, x220. 4 - *Capnuchosphaera theloides* De Wever, 04AL19, x200. 5 - *Capnuchosphaera theloides* De Wever, 04V1, x170. 6 - *Capnuchosphaera* sp. cf. *C. triassica* De Wever, 04V1, x245. 7 - *Capnuchosphaera* sp. 04V5, x200. 8 - *Dumitricasphaera* (?) sp. cf. *D.* (?) *planustyla* Lahm, 04V7, x270. 9 - *Paroetlispongus mostleri* (Kozur), 04V2, x240. 10 - *Paroetlispongus multispinosus* Kozur & Mostler, 04V2, x290. 11 - *Paroetlispongus multispinosus* Kozur & Mostler, 04V3, x185. 12 - *Pseudostylosphaera* (?) *sp. cf. P.* (?) *magnispinosa* Yeh, 04V3, x270. 13 - *Spongostylus carnicus* Kozur & Mostler, 04Al23, x220. 14 - *Spongostylus tortilis* Kozur & Mostler, 04V7, x220. 15 - *Spongostylus tortilis* Kozur & Mostler, 04AL23, x250. 16 - *Tetrapaurinella* sp., 04AL16, x270. 17 - *Tiborella* sp. cf. *T. florida* Nakaseko & Nishimura, 04AL16, x270. 18 - *Xiphoteca rugosa* Bragin, 04AL19, x240. 19 - *Xiphoteca rugosa* Bragin, 04AL25, x250.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