Per. Mineral. (2002), *71*, 2, 127-135 http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment, Archaeometry* and *Cultural Heritage*

Detrital high pressure – low temperature minerals in Lower Eocene deep-sea turbidites of the Julian Alps (NE Italy)

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Submitted, March 2002 - Accepted, May 2002

ABSTRACT. — Detrital amphiboles (actinolite, Mg-hornblende, barroisite and glaucophane) associated with pyroxenes (omphacite) have been found in Lower Eocene (about 52Ma) deep-sea turbidite of the Julian Alps. The occurrences of these minerals are commonly related to the erosion of high pressure - low temperature metavolcanics in green – blue schist and eclogitic facies. It is suggested that these detrital minerals belong to limited metamorphic bodies exhumed at about 56Ma during a phase of Dinarides uplift.

RIASSUNTO. — In alcune torbiditi di mare profondo dell'Eocene inf (ca. 52 Ma) affioranti nelle Alpi Giulie sono stati ritrovati degli anfiboli detritici (actinolite, Mg-orneblenda, barroisite e glaucofane) associati con pirosseni onfacitici. Il ritrovamento di tali minerali è generalmente legato all'erosione di rocce vulcaniche di alta pressione e bassa temperatura metamorfosate in facies di scisti blu – verdi ed eclogitica. Si suppone che i minerali detritici provengano da corpi metamorfici, di limitata estensione, esumati a circa 56 Ma durante una fase dell'uplift delle Dinaridi.

KEY WORDS: *Ca-Na amphiboles, omphacite, Julian Alps, Dinarides uplift.*

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INTRODUCTION

The presence of high pressure – low temperature (HP-LT) metamorphism in the northern part of the Vardar zone has been documented in the area of Fruška Gora (Serbia) where epidote-bearing segment of blue facies occurs (Milovanovic *et al.*, 1995). Geochemical investigations indicate a primary alkaline character of the crossite schist, which suggests a volcanic arc or mid ocean ridge basalt tectonic setting. The mineral assemblage of the crossite schists observed in the region is mainly composed of crossite, albite, epidote and phengite. The metamorphism of the subducted slab occurred in the Barremian – Aptian (123 ± 5 My). Pebbles containing this paragenesis occur in Late Cretaceous conglomerates of the same area (Pamic, 1993). No glaucophane-bearing blueschist facies rocks are present in the area between the eastern Alps and the Dinarides.

Several studies have evidenced the importance of detrital glaucophane to recognise HP – LT metamorphic source rocks and, as a consequence, these result important to understand the geodynamic evolution of convergent margin (Mange-Rajetzki and Oberhänsli, 1982; Winkler and Bernoulli, 1986; Dal Piaz *et al.*, 1995; Faupl *et al.*, 1996; Gansslosser *et al.*, 1996; von Eynatten and Gaupp, 1999).

In the Eastern Alps detrital blue amphiboles were recognised only in the Cretaceous sediments of the Northern Calcareous Alps and an Alpine blueschist metamorphic origin was proposed (Winkler, 1996; von Eynatten and Gaupp, 1999). To our knowledge no Na-pyroxene crystals were found in the same areas.

This paper highlights the first evidence of actinolite, Mg-hornblende, barroisite, glaucophane and omphacite in a Lower Eocene deep-sea turbidite of the Julian Alps (SE Alps; NE Italy). The aim of this study was to analyse these minerals, discuss their possible paragenesis and infer some hypothesis on their provenance and geodynamical evolution of the area.

Geological setting

The Julian Basin (or Slovenian Basin; NW Slovenia and NE Italy) during Cretaceous time was a narrow, elongated sedimentary basin limited by a carbonate platform along its southern border and connected with the Bosnia trough to the southeast. Turbidite deposition began during the Senonian p.p. (Ogorelec *et al.*, 1976). The Campanian-Maastrichtian boundary represents the climax of the evolution of the basin due to the beginning of the alpine compressional phase. In this period, flysch reach great thickness in the easternmost sector. During the Paleocene the trough became narrower and infilling continued with siliciclastic turbidites and carbonate megabeds particularly frequent and thick during the Early Ypresian. As a consequence of the Laramian phase the depth of the Julian Basin began to decrease. To the SE, during the Late Ypresian, a situation of terrigenous platform progressively influenced by one or more deltas is outlined (Tunis and Venturini, 1987).

The collected turbidites are from different outcrops from Italy and Slovenia. The first series is from the Cormons Flysch Unit (Ypresian; *Morozovella Formosa* zone; Tunis and Venturini, 1989) and was taken in the Mt Candia area where the outcrops consist of deep-sea turbidites (Fig. 1). The second series was taken in the nearby Slovenia (near Hlevnik) where the Medana Beds outcrop. Tunis and Pirini (1987) suggest that the Medana Beds are coeval with the Cormons Flysch Unit.

Sample description and analytical procedure

The rocks here studied are classified as lithic graywackes. Quartz and calcite are the main mineral phases followed by feldspars and clay minerals in order of abundance. In the heavy mineral assemblage Cr-spinel, garnet, pyrite and ZTR group minerals were recognised together with several anhedral grains of blue amphiboles and pyroxenes. Note that, in the Julian Basin, amphiboles and pyroxenes were recognised only in turbidites from Early Eocene samples of Mt. Candia (Italy) and Hlevnik (Slovenia). These minerals were magnetically separated from crushed sandstones (63-125 μm fraction) and were specifically looked for in larger fractions. Successively they were handpicked and mounted in epoxy resin. Polished grain mounts were analysed using a CAMECA SX50 electron microprobe at 15kV accelerating voltage, 10 nA beam current, 8 μm beam size of the University of Tasmania. Two spot analyses were performed on each crystal showing no differences. Results are considered accurate to within 1-2 % for major and 5 % for minor elements.

Chemistry of Cr-spinels and of some silicate inclusions present in them has been described by Lenaz *et al.* (2000). Pyrite crystals have been described by Lenaz and Billiato (2000).

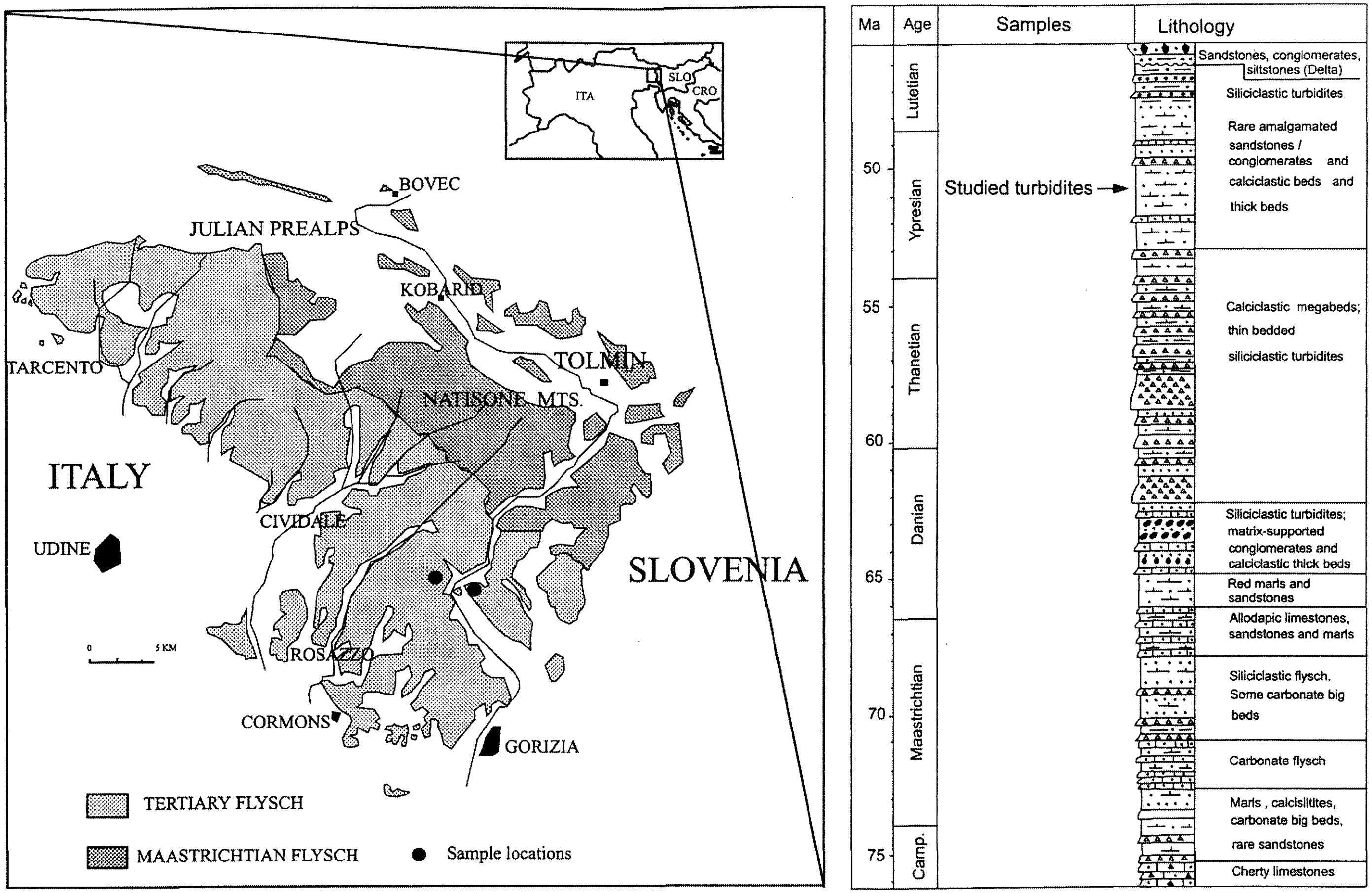

Fig. 1 – The Slovenian Basin: sample location and stratigraphic column

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As regards the amphiboles, the chemical analyses were calculated on the basis of 23 oxygens. The Fe^{3+} content was calculated according to stoichiometry (Papike *et al.*, 1974). The amphibole grains show important differences in sodium and calcium content and, according to Leake (1997), Mg-hornblende, actinolite, barroisite and glaucophane are present (Fig. 2).

Mg-Hornblende: differences has been encountered mainly in Al^{VI} (0.377 vs 0.609 a.f.u.), total Fe (1.814 vs 1.153) and Mg (2.775 vs 3.227) content. As a consequence the Mg/(Mg+Fe^{2+}) ratio ranges from 0.67 to 0.78, respectively.

Actinolite: differences has been encountered mainly in total Fe (1.498 vs 1.280) and Mg (3.307 vs 3.528) content. The Mg/(Mg+Fe^{2+}) ratio ranges from 0.73 to 0.75, respectively.

Barroisite: differences has been encountered mainly in Al^{VI} (0.613 to 0.979 a.f.u.), total Fe (1.058 to 1.361) and Mg (2.621 to 3.119) content. As a consequence the Mg/(Mg+Fe^{2+}) ratio ranges from 0.68 to 0.79.

Glaucophane: the two samples show very little differences in chemical analyses. As a result there is little variation only in the Mg/(Mg+Fe^{2+}) ratio ranging from 0.76 to 0.71, respectively.

As regards the clinopyroxenes, the chemical analyses were calculated on the basis of 6 oxygens. All the analysed clinopyroxenes have been classified as omphacites (Clarke and Papike, 1968). The jadeite content is about 47 mole % for all the studied grains. Fe^{3+} was estimated from the structural formula (Papike *et al.*, 1974). All the analysed pyroxenes show little differences mainly represented in the total Fe (0.145 to 0.183 a.f.u.) and Mg (0.414 to 0.449) content.

DISCUSSION AND CONCLUSIONS

Paragenesis

As concern the possible paragenesis, the green calcic amphiboles (actinolite and Mg-hornblende) are most probably derived from low to medium grade metamorphic rocks (metavolcanics in greenschist facies rocks). In basic rocks the change from actinolite to hornblende with advancing metamorphism appears to be abrupt even if sometimes they could coexist. The sharp change in compositions is considered the usual relationship from regionally metamorphosed rocks of basic and intermediate compositions, from the greenschist to granulite facies.

Barroisite is the ultra-high pressure type of hornblende and could be representative of B-type eclogites (Coleman *et al.*, 1965). It is generally considered as a marker of a retrogressive metamorphism.

Na-amphiboles are representative of HP metamorphic rocks in the blueschist facies.

Omphacites are related to subsolidus recrystallisation of basic igneous rocks at high pressure and temperature with $P_{H_2O} \ll P_{tot}$ (eclogitic facies).

It is possible that eclogites and blueschist coexist in the same lithologic sequence. Gomez-Pugnaire *et al.* (1997) show that in the Nerkau complex (Russia) two types of eclogites can be distinguished:

(1) glaucophane-free eclogites, consisting of garnet + omphacite + barroisite + calcic amphibole + albite + epidote + rutile + titanite + quartz. This assemblage was overprinted by another consisting of barroisite/Mg-hornblende + albite + epidote, which developed under albite – bearing greenschist conditions;

(2) Paragonite – glaucophane – bearing eclogites consisting of omphacite + garnet + glaucophane + barroisite + actinolite + paragonite + albite + epidote + titanite or rutile + quartz. The blueschist surrounding the eclogites consist of garnet + glaucophane + or barroisite + phengite + or paragonite + chlorite + albite + quartz + titanite + or rutile + or ilmenite.

The two types of eclogites were stable between 450 and 490° C and minimum pressures of 10 to 11 kbar. In the case of blueschist, coexisting glaucophane and garnet are stable at similar metamorphic conditions. The final retrogressive transition to greenschist

TABLE 1

Microprobe analyses of amphiboles (a-q) and Na-pyroxenes (r-u). A-b: actinolite; c-d: Mg-hornblende; e-o: barroisite; p-q: glaucophane; r-u: omphacite.

Sample	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
SiO_2	52.95	53.89	51.45	52.02	51.73	51.86	51.47	49.51	52.50	51.57	52.08	51.41	51.65	49.04	51.76
Al_2O_3	3.66	3.00	5.63	7.64	10.51	7.69	10.37	10.61	7.76	9.78	8.41	9.99	10.28	9.72	9.18
TiO_2	0.04	0.07	0.10	0.10	0.14	0.17	0.12	1.87	0.15	0.12	0.11	0.10	0.13	0.14	0.15
MgO	15.52	16.63	12.91	15.35	14.12	14.80	14.01	13.04	14.75	13.72	14.89	12.37	13.79	12.58	13.92
Fe_2O_3	2.74	1.00	4.33	2.64	2.89	2.78	2.70	1.21	1.07	2.97	2.14	3.37	2.67	3.41	2.28
FeO	10.08	9.85	11.14	7.40	6.43	8.03	7.13	9.00	8.93	7.83	7.45	8.58	7.19	10.10	8.16
MnO	0.07	0.11	0.19	0.00	0.02	0.04	0.04	0.06	0.03	0.07	0.08	0.07	0.01	0.07	0.05
CaO	11.58	12.24	10.02	9.65	7.53	9.59	7.98	8.11	9.43	8.22	8.95	7.19	7.79	9.15	8.32
K_2O	1.38	1.06	2.13	2.92	4.22	2.84	4.05	3.85	3.13	3.79	3.40	4.05	3.96	3.51	3.74
Na_2O	0.11	0.07	0.11	0.20	0.22	0.22	0.22	0.35	0.12	0.19	0.16	0.15	0.19	0.31	0.17
S	98.12	97.92	98.01	97.91	97.81	98.02	98.09	97.61	97.87	98.27	97.67	97.29	97.66	98.03	97.73
Si	7.566	7.669	7.420	7.338	7.244	7.332	7.218	7.046	7.415	7.249	7.344	7.309	7.263	7.050	7.312
Al^{IV}	0.434	0.331	0.580	0.662	0.756	0.668	0.782	0.954	0.585	0.751	0.656	0.694	0.737	0.950	0.688
	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.183	0.172	0.377	0.609	0.978	0.613	0.932	0.825	0.707	0.869	0.742	0.979	0.967	0.697	0.840
Ti	0.004	0.007	0.011	0.011	0.015	0.018	0.013	0.200	0.016	0.013	0.012	0.011	0.014	0.015	0.016
Fe^{3+}	0.294	0.107	0.470	0.280	0.305	0.296	0.285	0.130	0.114	0.315	0.227	0.361	0.282	0.369	0.242
Fe^{2+}	1.204	1.173	1.344	0.873	0.753	0.949	0.836	1.071	1.054	0.921	0.879	1.020	0.846	1.214	0.964
Mn	0.008	0.013	0.023	0.000	0.002	0.005	0.005	0.007	0.004	0.008	0.010	0.008	0.001	0.009	0.006
Mg	3.307	3.528	2.775	3.227	2.947	3.119	2.929	2.767	3.105	2.874	3.130	2.621	2.890	2.696	2.932
Oct	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Ca	1.773	1.866	1.548	1.459	1.130	1.453	1.199	1.237	1.427	1.238	1.352	1.095	1.174	1.409	1.259
Na_{M4}	0.227	0.134	0.452	0.541	0.870	0.547	0.801	0.763	0.573	0.762	0.648	0.905	0.826	0.591	0.741
Oct + M4	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000
K	0.020	0.013	0.020	0.036	0.039	0.040	0.039	0.064	0.022	0.034	0.029	0.027	0.034	0.057	0.031
Na_A	0.155	0.159	0.144	0.257	0.275	0.231	0.300	0.299	0.284	0.271	0.282	0.211	0.253	0.388	0.284
Σ	15.175	15.172	15.164	15.293	15.314	15.271	15.339	15.363	15.306	15.305	15.301	15.238	15.287	15.445	15.315

TABLE 1: *Continued*

Sample	p	q		r	s	t	u
SiO_2	57.38	56.91		55.51	55.86	55.77	55.66
Al_2O_3	11.93	12.06		10.05	10.44	10.12	10.00
TiO_2	0.02	0.02		0.05	0.06	0.05	0.03
MgO	11.50	10.58		7.78	8.51	8.31	8.07
Fe_2O_3	1.96	1.68		2.43	2.25	2.42	2.53
FeO	6.38	7.82		3.95	2.88	3.21	3.71
MnO	0.00	0.05		0.04	0.03	0.00	0.03
CaO	1.47	1.43		14.02	14.18	14.24	14.30
K_2O	6.85	6.66		n.d.	n.d.	n.d.	n.d.
Na_2O	0.02	0.05		6.60	6.60	6.57	6.50
Σ	97.51	97.26		100.42	100.81	100.69	100.82
Si	7.819	7.817	Si	1.983	1.977	1.981	1.980
Al^{IV}	0.181	0.183	Al^{IV}	0.017	0.023	0.019	0.020
	8.000	8.000		2.000	2.000	2.000	2.000
Al^{VI}	1.734	1.770	Al^{VI}	0.406	0.413	0.404	0.399
Ti	0.002	0.002	Ti	0.001	0.002	0.001	0.001
Fe^{3+}	0.201	0.174	Fe^{3+}	0.065	0.060	0.065	0.068
Fe^{2+}	0.727	0.898	Fe^{2+}	0.118	0.085	0.095	0.110
Mn	0.000	0.006	Mn	0.001	0.001	0.000	0.001
Mg	2.336	2.166	Mg	0.414	0.449	0.440	0.428
Oct	5.000	5.017		1.005	1.010	1.005	1.007
Ca	0.215	0.210	Ca	0.537	0.538	0.542	0.545
Na_{M4}	1.785	1.774	Na	0.458	0.452	0.453	0.448
Oct + M4	7.000	7.000		0.995	0.990	0.995	0.993
K	0.003	0.009	Σ	4.000	4.000	4.000	4.000
Na_A	0.024	0.000	Wo	50.20	50.16	50.30	50.31
			En	38.76	41.89	40.84	39.51
Σ	15.027	15.009	Fs	11.03	7.95	8.85	10.18
			Jd	47.28	47.42	47.03	46.76

took place at pressure below 9 kbar and temperature around 480° C. This results in an almost isothermal decompressional path.

Lombardo *et al.* (2000) showed an example from glaucophane and barroisite-bearing eclogites from the Upper Kaghan nappe in the Higher Himalayan Crystallines of the Pakistan Himalaya. The metamorphic peak assemblage is garnet - omphacite - rutile - quartz in glaucophane eclogite and garnet - omphacite - zoisite - rutile + or - kyanite + or - phengite + or - ankerite in barroisite eclogite. Most samples contain a significant amount of amphibole, white mica and quartz. White mica may be present either as part of the peak assemblage (phengite) or as a retrogressive

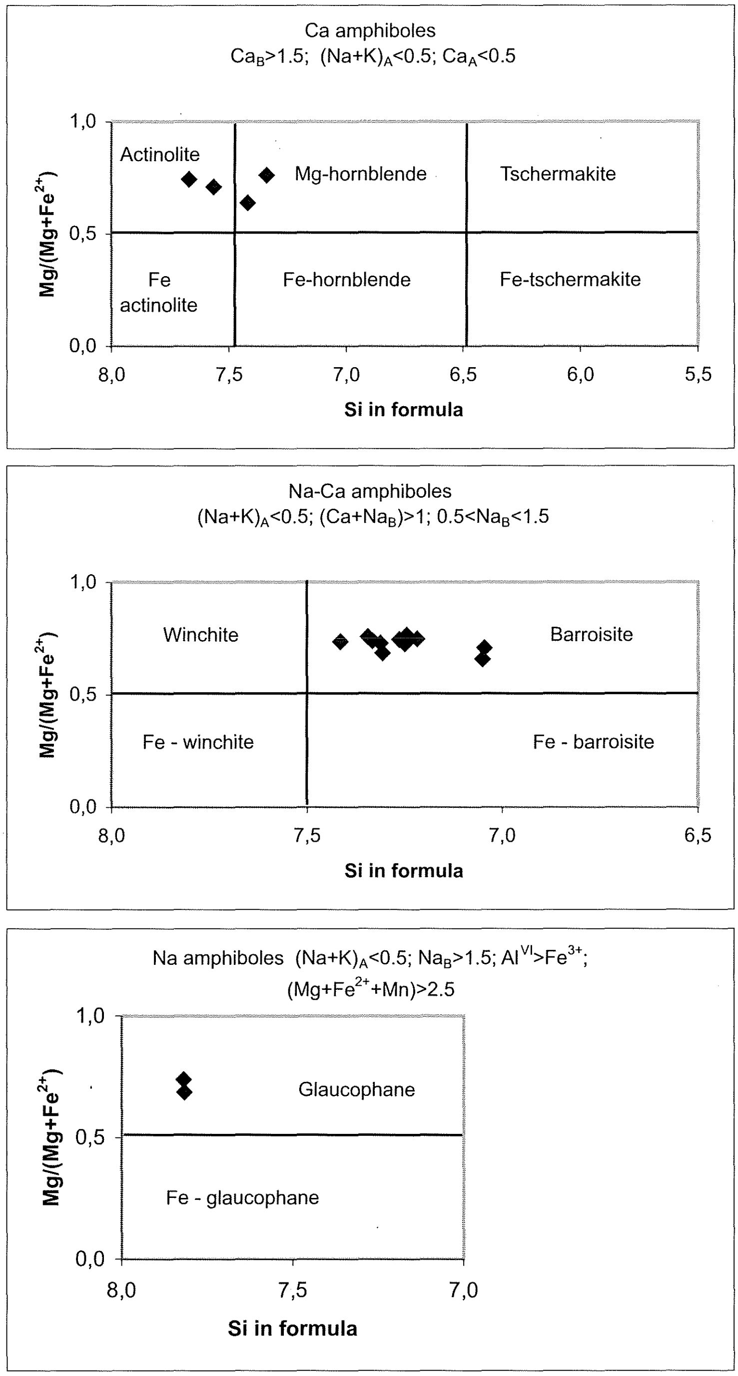

Fig. 2: Classification of the amphiboles according to Leake et al. (1997)

phase after kyanite (paragonite). Amphibole is later than the metamorphic peak assemblage and is barroisite in most samples. Peak metamorphic conditions in the barroisite eclogites have been estimated at about 610° C and 24 kbar from Fe/Mg partition in garnet-omphacite pairs, and from the garnet-omphacite-phengite barometer.

According to Godard *et al.* (1981), the following reaction is possible: omphacite + garnet + quartz + $H_2O \rightarrow$ glaucophane + grossular s.s. + paragonite. The appearance of glaucophane can be explained as the beginning of a retrometamorphic evolution from the stable physical conditions of the primary eclogite paragenesis, while barroisite could be related to a greenschist facies overprint.

Provenance and geodynamical implications

The occurrence of oceanic material in the sediments of the Julian Basin is documented by abundant Cr-spinels related to a suprasubduction zone (Lenaz *et al.*, 2000) during the whole sedimentation. In the same level, a spinel with silicate inclusion showing evidences of mixing between eclogite-derived dacitic magmas and mantle peridotites has been found (Lenaz *et al.*, 2000). These minerals are supposed to be supplied from the Internal Dinarides where ophiolitic bodies outcrop. Initial subduction processes during the Late Jurassic/Early Cretaceous, taking place along the northern Tethyan margin, were accompanied by ophiolites obduction over the Apulian passive margin. This subduction initiated the gradual closure and the development of a magmatic arc located north of the obducted ophiolites. A Late Cretaceous-Paleogene flysch sequence accumulated in the trench associated with the magmatic arc (Pamic, 1998). This sedimentary unit of the Northern Dinarides contains pre-Upper Cretaceous blueschist olistoliths and blocks (Mayer and Lugovic, 1992; Pamic, 1993). Persisting subduction processes along this arc-trench system caused continuous magmatic activity during the Late Cretaceous and the Paleogene.

The lack of detrital amphiboles and omphacites in the Maastrichtian to Upper Paleocene sediments as well as in Middle Eocene samples seems to be rather important. The first and last appearance of detrital blue amphiboles and omphacites during the Ypresian (Lower Eocene) gives important constraints about the state of uplift of HP metamorphic and the onset of exhumation of eclogites. According to Gomez-Pugnaire *et al.* (1997) and Lombardo *et al.* (2000) we can suppose the existence of an eclogitic facies (omphacite-barroisite or omphacite – glaucophane – barroisite - actinolite bearing) overprinted by barroisite/Mg-hornblende + albite + epidote assemblage, developed under albite – bearing greenschist conditions. It is possible that the subducted slab that gave origin to this eclogitic rocks is different from the slab that originated the crossite schist in Fruška Gora.

Lawrence *et al.*, (1995) suggested that at about 56Ma a major uplift affected the Dinarides. The studied sample has a stratigraphic age of about 52Ma. It should be concluded that, possibly during the upper Paleocene uplift, scattered and limited eclogitic rocks were exhumed. Erosion and deposition of this material happened later, during the Ypresian.

ACKNOWLEDGMENTS

DL thanks Dr. V.S. Kamenetsky for chemical analyses at Hobart University, Prof. G.Tunis for help with stratigraphic interpretations and Dr. G. Cargnel for help in sampling. The authors would like to thanks Dr. Andreozzi and an anonymous reviewer for helpful suggestions. This work was supported with MURST and University grants to FP (Crystal chemistry of mineral species: use of advanced techniques for a modern systematic; Cristallochimica delle specie minerali: uso di tecniche avanzate per una moderna sistematica; COFIN 1999).

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