GEOLOGIA • 2006 • Tom 32 • Zeszyt 1 • 47–63

BLUESCHISTS IN THE CRETACEOUS EXOTIC CONGLOMERATES OF THE KLAPE UNIT (PIENINY KLIPPEN BELT, WESTERN CARPATHIANS): THEIR GENETIC TYPES AND IMPLICATIONS FOR SOURCE AREA

Łupki glaukofanowe w kredowych zlepieńcach egzotykowych jednostki klapskiej (pieniński pas skałkowy, Karpaty Zachodnie): ich typy genetyczne i implikacje dla obszaru źródłowego

Peter IVAN[1], Milan SÝKORA[2] & Rastislav DEMKO[3]

[1]Comenius University; Department of Geochemistry, Mlynská dolina G, 842 15 Bratislava, Slovak Republic; e-mail: ivan@nic.fns.uniba.sk
[2]Comenius University; Department of Geology and Paleontology, Mlynská dolina G, 842 15 Bratislava, Slovak Republic; e-mail: sykora@fns.uniba.sk
[3]Slovak Geological Survey; Kynceľovská 10, 974 01 Banská Bystrica, Slovak Republic; e0mail: demka@gessrbb.sk

Abstract: In the Klape Unit of the Pieniny Klippen Belt the Albian conglomerates with clasts of exotic carbonates, clastic sediments and also volcanic and plutonic rocks are relatively widespread. In the small area near the town Považská Bystrica also scarce blueschist clasts of variegated petrographic types have been found. Three groups of starting rocks can be discerned for blueschists: pelagic sediments, metamorphic rocks (amphibolites, gneisses) and volcanic rocks. Based on immobile trace element (HFSE, REE) distribution two petrogenetic types of volcanic rocks have been identified: basalts with BABB signature and calc-alkaline basaltic andesites to rhyolites. Source of these rocks was probably a nappe stack located in the Carpathian interior and created in the Late Jurassic time as a result of subduction of the oceanic crust and adjacent volcanic arc and followed by collision during the Meliata Ocean closure.

Key words: Western Carpathians, Albian, exotic conglomerates, blueschists, volcanics, geochemistry

Treść: Albskie zlepieńce jednostki klapskiej pienińskiego pasa skałkowego zawierające egzotyki skał węglanowych, klastycznych, jak również wulkanicznych i plutonicznych są szeroko rozprzestrzenione. Na małym obszarze w okolicy Považskiej Bystricy (Słowacja zachodnia) w kilku stanowiskach znaleziono rzadkie egzotyki zróżnicowanych petrograficznie łupków glaukofanowych. Wyróżniono trzy grupy pierwotnych utworów przekształconych w te łupki: osady pelagiczne, skały metamorficzne (amfibolity, gnejsy) i skały wulkaniczne. W oparciu o niestabilne pierwiastki śladowe (HFSE, REE) zidentyfikowano dwa typy petrogenetyczne skał wulkanicznych: bazalty o cechach bazaltów obszarów zaułkowych (BABB) oraz wapniowo-alkaliczne andezyty i ryolity bazaltowe. Obszarem źródłowym tych skał były prawdopodobnie spłaszczowinowane jednostki zlokalizowane w obrębie Karpat wewnętrznych, powstałe w późnej jurze jako rezultat subdukcji skorupy oceanicznej i utworzonego w związku z tym łuku wulkanicznego, w następstwie kolizji podczas zamykania się oceanu Meliaty.

Słowa kluczowe: Karpaty Zachodnie, alb, zlepieńce egzotykowe, łupki glaukofanowe, utwory wulkaniczne, geochemia

INTRODUCTION

Comprehensive geological studies of the recycled orogenic material piled up in sedimentary basins seems to be an important tool for the reconstruction of the geological structure of destructed parts of the orogenic belts. Among various sedimentary rock types the conglomerates represent the most suitable rock type for such study due to biggest piece of accessible information.

Conglomerates of various age have been studied in the Western Carpathians as a source of information concerning ancient geological structure, but most intensive effort has been concentrated on Cretaceous conglomerates of the Pieniny Klippen Belt and their analogues between Tatric and Fatric Unit rocks and content of exotic clasts (Mišík & Sýkora 1981, Mišík *et al.* 1981, 1991a, b, Burtan *et al.*, 1984, Šímová 1985, Birkenmajer & Wieser 1990 and references herein). Exotic material is represented by various rocks types – sedimentary, magmatic and metamorphic. One of the most peculiar rock type is represented by high-pressure/low temperature (HP/LT) metamorphosed rocks – blueschists. Blueschist facies rocks are generally accepted as an unambiguous indicator of destructive lithospheric plate margin related to subduction of oceanic or marginal basin crust. Blueschists in the Cretaceous conglomerates seem to be not only important witness of ancient geodynamic processes but can significantly contribute to our knowledge on position and geological structure of the conglomerate source area.

The aim of this paper is to summarise new data concerning the genetical types of blueschists which were found as a relatively scarce component of the exotic material in the Cretaceous conglomerates in the Klape Unit of the Pieniny Klippen Belt and use them to give some constraints on source area of conglomerates.

GEOLOGICAL SETTING

The Pieniny Klippen Belt (PKB) is a narrow décollement thrust system located at the sutured transpressive boundary between Outer and Central Western Carpathians. It consists mostly of Cretaceous flysh sequences associated with inliers of Mesozoic limestones.

Ihe PKB in its western part generally divided into three units:

1) Czorsztyn-Pieniny,
2) Klape,
3) Manín.

They represent tectonically separated sheets differ in lithology (Fig. 1). Conglomerates with exotic clasts, composed of rocks unknown from adjacent units of central Western Carpathians, have been found in all these units, but they are most widespread in the Klape Unit. Huge Cretaceous wild flysch complexes of the Klape Unit were formed during three distinct sedimentary megacycles. The first and third megacycles are considered as to be prograding, second one as retrograding. Thick prisms of Albian conglomerates with exotic clasts were deposited during the first megacycle (Fig. 2) as components of prograding fans with clearly expressed proximality. Sedimentological studies indicate SSE to E (in present-day coordinates) supply of clastic material and relatively steep dips of fans (Marschalko & Rakús 1997).

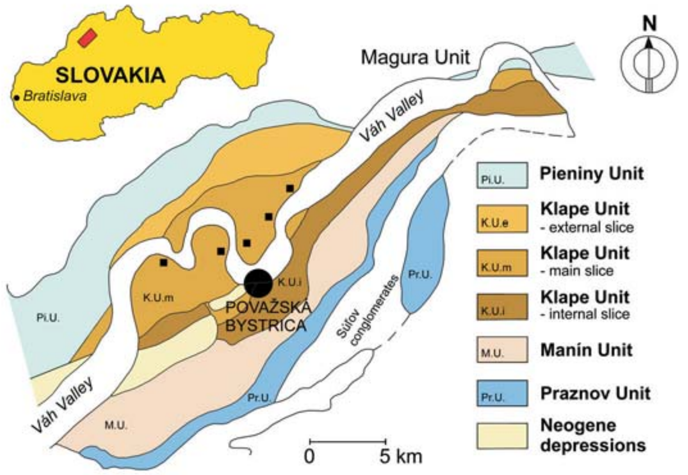

Fig. 1. Sketch map of arrangement of tectonic units of the Pieniny Klippen Belt in the neighbourhood of the town Považská Bystrica. Main localities of conglomerates with blueschist clasts are labeled by squares (after Marschalko & Rakús 1997, modified)

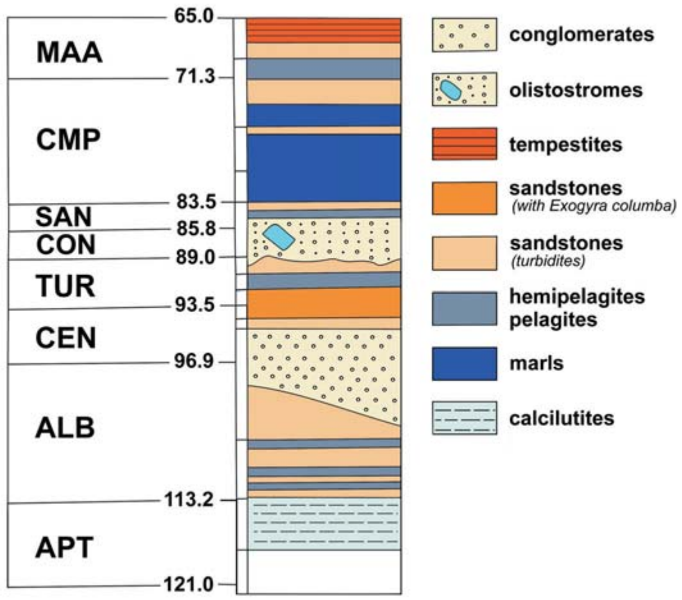

Fig. 2. Lithostratigraphy of the Cretaceous flysch complexes of the Klape Unit (Pieniny Klippen Belt) (after Marschalko & Rakús 1997)

Coniacian to Santonian conglomerates with exotics are related to the second megacycle. In the adjacent units flysch cycle appears at higher stratigraphic levels only. The Manín Unit comprise thin beds of conglomerates Cenomanian to Turonian in age, whereas conglomerates in the Pieniny Unit belong to the Coniacian to Santonian stratigraphic level (Rakús & Marschalko 1997). Clasts in conglomerates are well-rounded disregarding variable hardness of them, poorly sorted and average size of clasts varies in the range of several decimetres to metres in majority of outcrops.

Variegated rock types (more than 100) form clasts in Cretaceous exotic conglomerates of the PKB. Dominating rock types include mainly carbonates (*ca* 50%), volcanic rocks (*ca* 20%), clastic sediments (*ca* 15%) and cherts (*ca* 5%). Composition of clasts vary with stratigraphic level and also among tectonic segments and units (Mišík & Sýkora 1981, Marschalko 1986). Most of carbonate clasts are Triassic (more than 30%), Jurassic and Cretaceous carbonates seem to be some less frequent.

Based on the metamorphic alteration four groups of exotic rocks have been discerned:

1) practically unmetamorphosed rocks (mainly Triassic to Cretaceous sediments),
2) low pressure/low temperature (LP/LT),
3) high pressure/low temperature (HP/LT),
4) medium pressure/medium temperature (MP/MT) metamorphosed rocks.

LP/LT metamorphic conditions seem to be typical for most clasts of igneous rocks represented by plutonic (S- and A-types of granitoids) and volcanic varieties (calc-alkaline volcanics and volcaniclastics of wide compositional range from basalts to rhyolites). Clasts of MP/MT metamorphosed rocks (gneisses, orthogneisses and migmatites) has been found in negligible amounts.

Occurrences of HP/LT metamorphosed rocks (blueschists) are strictly related to the beds of the first megacycle conglomerates in the several kilometres long segment of the Klape Unit in the close surroundings of the Považská Bystrica town (Upohlav conglomerates; Fig. 1). Total content of blueschist clasts do not exceed 1%, their size vary in the range less than 1 cm up to 40 cm.

PETROGRAPHY

Original textures of the blueschist rocks despite their intensive metamorphic transformation are mostly preserved although in the phantom, palimpsest or mimetic forms. More than 150 samples of HP/LT metamorphosed rocks have been microscopically studied to identify their starting rocks (protolith).

Three groups of blueschists can be divided based on their protolith:

1) sedimentary rocks,
2) metamorphic rocks,
3) volcanic rocks.

Blueschists formed by metamorphic transformation of volcanic rocks are clearly dominated.

Blueschists created by transformation of sedimentary rocks (i) are represented mostly by very fine laminated rocks composed of alternating quartz and garnet + Na-amphibole or garnet + Na-amphibole + magnetite/haematite lamines as a rule no more than one milimeter thick. Deep sea pelagic cherts with thin layers of disintegrated and altered basaltic material seem to be most probable starting rocks here. Also HP/LT metamorphosed chert of Na-amphibole-quartz composition with preserved phantoms of elliptic radiolaria sections has been found. Blueschists formed at the expense of metamorphic rocks (ii) are represented mostly by amphibolites overprinted with various intensity by HP/LT metamorphic stage. Some amphibolites seem to be retrogressed to greenschist facies conditions before high-pressure overprint. Oriented nematogranoblastic texture is typical. Green Ca-amphibole (magnesiohornblende) relics are rimmed by pale violet or blue Na-amphibole, former plagioclase was transformed to lawsonite, ilmenite to titanite. Actinolite, chlorite, pumpellyite, epidote and carbonate occur mostly in samples experienced greenschist retrogression. Relatively coarse-grained blueschists with textures identical to above-mentioned rocks and white mica-Na-amphibole (idioblasts up to 3–4 mm) lawsonite composition are supposed to be amphibolites fully transformed by blueschist overprint. Except amphibolites also gneisses could had been starting rocks for one blueschist sample with gneissic texture and epidote--garnet-Na-Ca-amphibole-quartz composition.

Majority of blueschists from the Cretaceous exotic conglomerates of the Klape Unit were formed by HP/LT metamorphic transformation of volcanic and volcaniclastic rocks (iii). As will be proven below two groups of these starting rocks can be discerned based on their geochemical signature: volcanic rocks of back-arc basin basalt type (BABB) and calc-alkaline (CA) volcanic and volcaniclastic rocks. Differences in petrography exist between these two groups. Typical lawsonite-, epidote- and also garnet-bearing blueschists or transitional rocks to low-temperature eclogites make up the former group. Na-pyroxene, Na-amphibole, lawsonite, pumpellyite and leucoxene is most common mineral assemblage for lawsonite blueschists. Association of Na-amphibole, epidote/zoisite, albite, chlorite, white mica, carbonate and also Ca-amphibole (actinolite) seems to be typical for epidote blueschists. Garnet and Na-amphibole dominate in garnet blueschists, whereas albite, chlorite, carbonate and ore mineral are presented in subordinate amounts. Rare Na-amphibole dominated blueschists containing big idioblasts (up to 1 mm) of garnet and Na-pyroxene together with some epidote, albite and leucoxenized ilmenite could represent transitional rock types to low-temperature eclogites. Despite of metamorphic transformation relic magmatic textures are usually well-preserved, moreover also relic magmatic pyroxenes has been found in some samples. Originally glassy, variolitic, intersertal, ophitic, doleritic and gabbro-doleritic magmatic textures have been identified, so various types of effusive basalts and subvolcanic dolerites or gabbrodolerites were starting rocks of this group of blueschists.

Blueschists included in the second group display unusual starting rocks. They were formed by metamorphic transformation of calc-alkaline effusive and extrusive volcanics of wide compositional range which vary from basaltic andesites and andesites trough dacites up to rhyolites. Such rock association seems to be worldwide uniqueness among blueschist terrains. Original magmatic textures of these rocks are partly preserved although they were modified in some cases due to intensive alteration (propylitization, alkali metasomatism) preceded blueschist metamorphic stage. Intergranular, porphyric or intersertal textures as well has been identified in HP/LT metamorphosed basaltic andesites and andesites. Magmatic plagioclase phenocrysts were replaced by fine-grained aggregate of white mica, mafic phenocrysts sometimes by dimmed brownish-coloured mineral with composition similar to Na-pyroxene. Matrix was transformed to aggregate of randomly oriented columnar Na-amphibole with some alkali feldspar, quartz, chlorite and leucoxenized ilmenite. Effusive or extrusive dacites seem to be most widespread protolith for blueschists of this group. Vitritic, perlitic, vitrophyric, crystallovitroclastic or eutaxitic textures have been found in these rocks. Alkali feldspar, Na-amphibole, quartz, chlorite, ± jadeite ± lawsonite ± white mica and ore mineral is typical mineral association. Original plagioclase and hornblende phenocrysts were replaced by white mica-chlorite or albite aggregates. Long columnar Na-amphibole crystals followed structures of devitrified volcanic glass, especially dendritic crystallites. Relic vitritic, perlitic, less eutaxitic textures are typical for HP/LT metamorphosed rhyolites. Sporadic small quartz phenocryst relics have only been found in these rocks, relics of feldspar phenocrysts occur in subordinate amounts. Quartz and alkali feldspar represent main mineral phases of devitrified glassy matrix together with small dendritic crystals of iron oxides. Needles of Na-amphibole are concentrated as a rule at the border of devitrification centres.

GEOCHEMISTRY

Major and trace elements including REE have been studied in the blueschists transformed from volcanic and volcaniclastic rocks as well as in amphibolites overprinted by HP/LT metamorphic stage. Selected analyses of these rocks are shown in Table 1 (see the attached interleaf). Analyses of analogical rocks from the Meliatic Unit, as a potential source rocks, were added for comparison.

Variability in the major element distribution of studied rocks is fully in agreement with their petrography. An alkali element mobility test using diagram by Hughes (1972, not shown) indicates that original magmatic distribution was more or less transformed by sodic (rarely also potassic) metasomatism. Hence the common SiO_2 *vs*. Na_2O+K_2O (TAS) diagram could be hardly used to verification of petrographic types of blueschist starting rocks. Diagrams Zr/TiO_2 *vs*. SiO_2 (Fig. 3) and Nb/Y *vs*. Zr/TiO_2 (Winchester & Floyd 1977) based on relatively immobile elements were applied instead of its. Both diagrams support microscopic identification of the blueschist volcanic protolith as varying from basalts to rhyolites.

As follows from them and FeO^t/MgO *vs*. SiO_2 diagram (Miyashiro 1974, not shown) as well, two petrogenetic series can be discerned here:

1) tholeiitic, represented by basaltic rocks only,
2) calc-alkaline including volcanic rocks from basaltic to rhyolitic compositions with dacites as dominating rock type.

More detailed identification concerning to geochemical type of volcanic rocks, their geodynamic setting of generation and magma evolution follow from trace element distribution study concentrated on elements immobile in metamorphic processes (REE, HFSE). Differences among blueschists with various volcanic starting rocks can be demonstrated on chondrite normalized REE patterns for selected rocks (Figs 4–6) and Hf/3-Th-Ta discriminant diagram (Fig. 7).

Table 1

Representative analyses of blueschists with volcanic starting rocks forming clasts in the Cretaceous conglomerates of the Klape Unit (Pieniny Klippen Belt) and their analogues from the Bôrka Nappe (Meliatic Unit, Inner Western Carpathians). Also one analysis of the LP/LT metamorphosed rhyolite is added for comparison. For explanations of abbreviations and analytical methods see note under the Table

Sample	1	2	3	4	5	6	7	8	9
	VPO-17	VPO-25	FBO-12	VVS-16	VPO-19	VHA-14	VPO-266	VPO-134	VPO-631
Unit	KU	KU	BN	BN	KU	BN	KU	KU	KU
Type	BABB	BABB	BABB	BABB	ABO	ABO	CAD	CAR	CARlp
SiO_2	46.18	50.39	48.03	48.64	44.31	47.93	66.48	71.40	75.90
TiO_2	2.35	1.40	3.23	1.62	1.44	1.68	0.72	0.49	0.10
Al_2O_3	13.91	14.57	13.00	15.03	13.65	15.86	12.56	12.93	11.42
Fe_2O_3	3.26	1.84	7.61	3.73	3.88	4.93	1.81	1.95	1.21
FeO	9.45	8.30	6.38	6.39	8.38	5.54	3.49	2.72	0.36
MnO	0.18	0.25	0.17	0.17	0.17	0.14	0.08	0.09	0.01
MgO	6.29	7.86	5.06	6.69	9.20	5.95	1.70	0.62	0.59
CaO	8.97	5.75	8.66	10.37	9.36	8.45	2.60	1.63	0.67
Na_2O	3.62	4.51	3.13	3.64	2.12	4.02	4.16	6.08	1.33
K_2O	0.15	0.10	1.23	0.56	0.75	0.03	1.56	0.17	6.87
P_2O_5	0.25	0.17	0.35	0.17	0.12	0.17	0.21	0.10	0.01
H_2O^-	0.36	0.62	0.04	0.09	0.66	0.22	0.36	0.14	0.09
CO_2	1.93	1.08	0.60	0.52	2.02	1.64			
LOI	3.63	3.48	2.14	1.92	4.82	3.90	3.53	0.93	1.14
Total	100.53	100.32	99.63	99.54	100.88	100.46	99.26	99.25	99.70
Rb	12.4	17.6	21.8	38	19.5		46	6	236
Ba	36	18	92	43	96	13	188	82	205
Th	1.4	0.5	2.05		0.45	0.38	11.33	14.05	22.29
Nb	6	3	6	1	5	4	24	20	19
Ta	0.37	0.25	0.4	0.12	0.24	0.31			1.34
Hf	4.6	3.4	6.1	2.65	2.55	2.95	7.08	4.88	8.43
Zr	146	104	212	102	76	102	669	604	190
Y	40	31	58	30	24	38	93	85	38.9
Cr	246	252	28.6	191	310	184			6.4
Co	43	49	25.9	45.5	47.5	45			0.59
Ni									19
Sc	42	40.5	36	46	44.5	37	15.3	15.7	5.05
V	309	256	467	280	254	302	12	<5	<5
La	9.4	4.1	11.5	3.9	18.2	99.5	48.5	62	47.8
Ce	27.5	15.3	33	14.3	16.3	56.5	86.4	106.2	88.9
Pr							14.7	17.1	
Nd	21.3	14	28.3	13.2	10.2	14.8	56.1	64.7	40.7
Sm	6.2	3.9	8.9	4.2	3.2	4	12.6	15.1	7.6
Eu	1.85	1.15	2.65	1.45	1.1	1.55	2.16	2.41	0.24
Gd	8.8	4.7	11.6	4.8	4.3		10.42	13.08	8.1
Tb	1.40	0.84	1.70	0.79	0.73	1.00	2.11	2.61	1.15
Dy							13.06	16.45	
Ho			2.55				2.67	3.33	1.64
Er							7.8	9.26	
Tm	0.78	0.54	1	0.66	0.42		1.09	1.24	0.71
Yb	5	4	6.3	3	3.1	3.8	7.5	7.74	4.85
Lu	0.81	0.77	1.05	0.38	0.57	0.61	1.06	1.06	0.80

Explanations: KU – Klape Unit, BN – Bôrka Nappe, BABB – blueschist with the back-arc basin basalt protolith, ABO – amphibolite with blueschist facies overprint, CAD – blueschist with the calc-alkaline dacite protolith, CAR – blueschist with the calc-alkaline rhyolite protolith, CARlp – LP/LT metamorphosed rhyolite.

Note: Analyses of major element and Zr, Y, Nb, Ba and V were performed by ICP OES in laboratories EL Ltd., Spišská Nová Ves. Other elements were analysed by INAA method in the Institute of Nuclear Physics of the Czech Academy of Sciences, with exception of analyses 7 and 8 which were performed by ICP MS in the Institute of Geochemistry and Raw Material of Charles University, Prague.

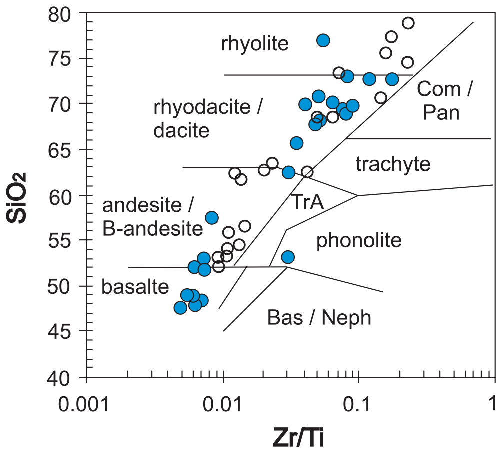

Fig. 3. Diagram Zr/Ti *vs*. SiO_2 (Winchester & Floyd 1977) for HP/LT (filled circles) and LP/LT (open circles) metamorphosed volcanic rocks forming clasts in the Cretaceous exotic conglomerates of the Klape Unit. Explanations: B – andesite – basaltic andesite, Bas/Neph – basanite/nephelinite, TrA – trachyandesite, Com/Pan – comendite/pantellerite

Flat REE patterns with some medium REE enrichment and small negative Eu anomaly seems to be typical for blueschists with tholeiitic basalt protolith and they are almost indentical with pattern of selected HP/LT metamorphosed basalts from the Bôrka Nappe (Meliatic Unit of the Inner Western Carpathians; Fig. 4).

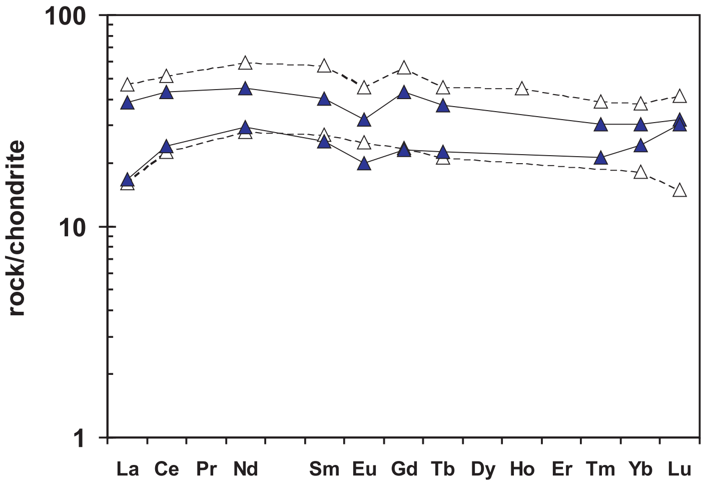

Fig. 4. Chondrite normalized REE pattern for the BABB-type blueschists from the Klape Unit (filled triangles). Analogical rocks from the Bôrka Nappe (Meliatic Unit) are added for comparison (open triangles); normalization after Evensen *et al*. (1978)

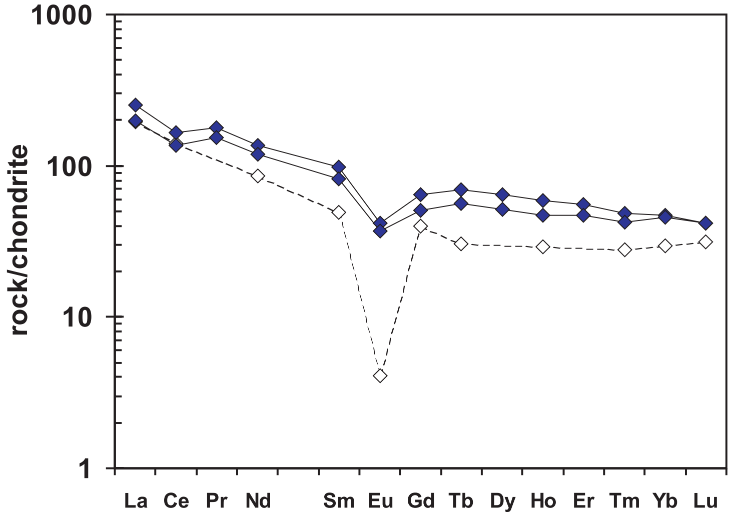

Fig. 5. Chondrite normalized REE patterns for HP/LT metamorphosed dacite and rhyolite (filled diamonds) from the Cretaceous conglomerates of the Klape Unit. Pattern for a typical LP/LT rhyolite (open diamonds) from the same conglomerates is added for comparison; normalization after Evensen *et al*. (1978)

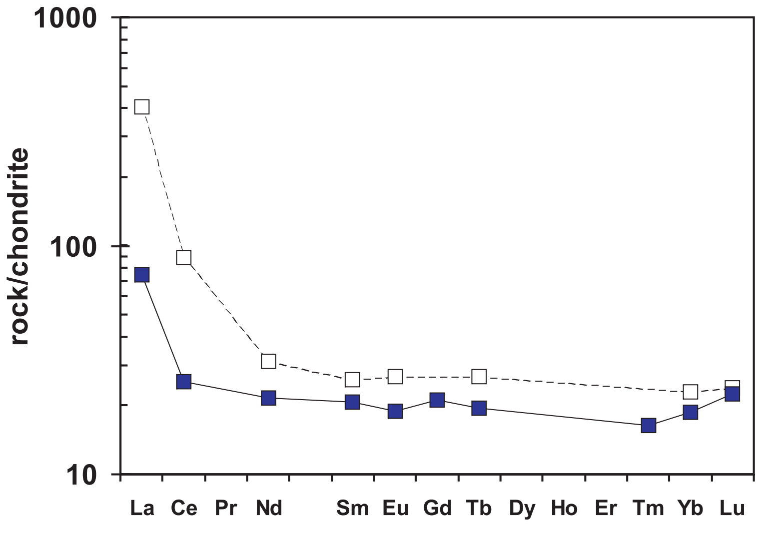

Fig. 6. Chondrite normalized patterns for the amphibolite with blueschist facies overprint from the Cretaceous conglomerates of the Klape Unit (filled squares) and their analogue from the Bôrka Nappe (open squares); normalization after Evensen *et al*. (1978)

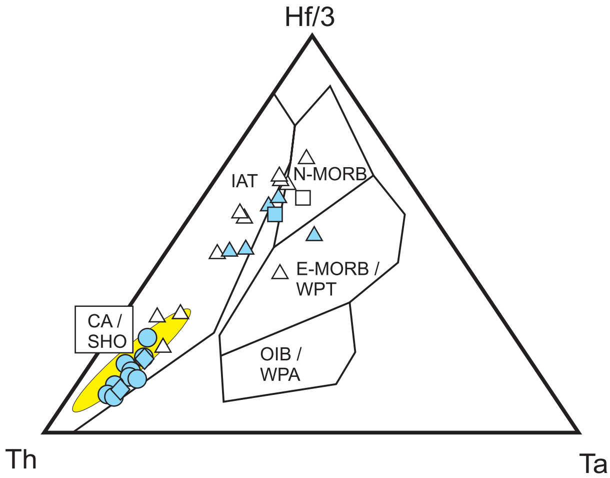

Fig. 7. Hf/3-Th-Ta discriminant diagram (Wood 1980) for the blueschists with volcanic starting rocks from the Cretaceous conglomerates of the Klape Unit (filled symbols) compared to their analogues from the Bôrka Nappe of the Meliatic Unit (opens symbols). Shaded field represents positions of LP/LT volcanic rocks from conglomerates of the Klape Unit. Explanations: triangles – basalts, diamonds – andesites, circles – dacites and rhyolites, squares – amphibolites with blueschist facies overprint, CA/SHO – calc-alkaline/shoshonite volcanics, IAT – island arc tholeiites, OIB/WPA – oceanic island basalts/within-plate alkali basalts, E-MORB/WPT – enriched mid-ocean ridge basalts/within-plate tholeiites, N-MORB – normal mid-ocean ridge basalts

Very similar patters display also basalts from some recent back-arc basins (BABB type – *cf*. Fryer *et al.* 1990, Hawkins *et al.* 1990, Falloon *et al.* 1992, Gribble *et al.* 1996, 1998). Negative Eu anomaly in both samples from the exotic conglomerates indicate their fractionated character (removing of plagioclase) but fractionation mechanism as a whole was different (various total REE enrichment). Similarity of these rocks to the BABBs is supported also by Hf/3-Th-Ta diagram (Fig. 7), where they are plotted on the boundary between N-MORB and IAT fields – i.e. in the area typical for this type of basalts.

Most of chondrite normalized patterns of blueschists with calc-alkaline volcanic protolith display generally similar shape from basaltic andesites to rhyolites with increasing of total REE content. Differentiated LREE/HREE enrichment with small negative Eu-anomaly is typical (Fig. 5). In the Hf/3-Th-Ta diagram all samples of this type of blueschists are plotted in the calc-alkaline field following trend typical for magmatic arc setting (Fig. 7) and different from extensional continental interior setting (*cf*. Rollinson 1993). As follows from Zr *vs*. Nb diagram (Fig. 8) HP/LT metamorphosed dacites to rhyolites from the exotic conglomerates of the Klape Unit were generated in a suprasubduction setting and their position seems to be transitional between subalkaline and peralkaline rhyolites. Surprisingly these rocks differ in some trace element characteristics from their LP/LT metamorphosed analogues occurring in the same conglomerates. Lower Th/Yb, Ta/Yb or La_n/Yb_n ratios and higher concentrations of Zr, Yb and Zr/Y ratio are typical. LP/LT calc-alkaline volcanic rocks display less fractionated HREE and more pronounced negative Eu-anomaly in rhyolites (Fig. 5).

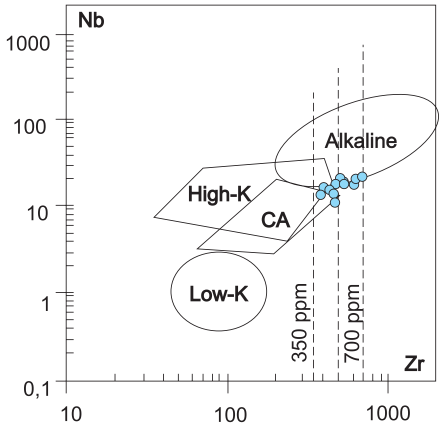

Fig. 8. HP/LT metamorphosed dacites and rhyolites from the Cretaceous conglomerates of the Klape Unit in Zr *vs*. Nb discriminant diagram by Leat *et al*. (1986). Explanations: low-K, CA and high-K – field for low-, medium- and high-kalium calc-alkaline rhyolites, alkaline – field for alkaline rhyolites. Boundaries 300 and 700 ppm Zr – most subalkaline rhyolites have < 300 ppm Zr with rare examples having up to 700 ppm Zr. Probably all peralkaline rocks have > 350 ppm Zr and most have > 700 ppm Zr

Preliminary geochemical study of amphibolites overprinted by HP/LT metamorphic stage indicate that these rocks seem to be geochemically close to the N-MORB type of basalts. Chondrite normalized REE pattern is flat in shape but with extraordinary enrichment in La and Ce. The cause of such enrichment is unclear. Curiously enough an analogue of this rock inclusive of La-Ce enrichment has been found in the Bôrka Nappe of the Meliatic Unit (Inner Western Carpathians; Fig. 6).

DISCUSSION

An important feature of the blueschist facies metamorphism is preservation not only pre-metamorphic trace element distribution (immobile elements as REE, HFSE and some others) but frequently also relics of pre-metamorphic minerals and textures. That is why the identification of starting rock types for blueschists seems to be fully reliable for majority of these rocks.

Despite the scarcity of blueschist clasts (less than 1%) in the Cretaceous exotic conglomerates of the Klape Unit in the neighbourhood of the town Považská Bystrica, our petrographical and geochemical studies convincingly demonstrate their considerable genetic variability. All of three main genetic groups of blueschists – i.e. metamorphosed sedimentary, volcanic and metamorphic rocks include many rocks types and varieties differing in their starting rocks. Among metamorphosed sedimentary rocks prevail fine laminated pelagic sediments of deep-see provenance. Alternating layers of disintegrated and altered basic volcanic material, cherts and maybe also carbonates and Fe-Mn oxides composed originally these sediments. Radiolaritic chert seems to be also a product of the same sedimentary environment.

Two genetic groups of HP/LT metamorphosed volcanic rocks seem to be clearly defined and segregated by their distinct petrographic and geochemical features. They are represented by:

1) blueschists with BABB signature,
2) blueschists formed from calc-alkaline volcanic rocks.

Preserved relics of primary magmatic textures indicate that basaltic lava flows and subvolcanic doleritic bodies must have been starting rocks of the former group. Relic glassy, variolitic or intersertal textures point to submarine environment of basaltic lava effusions. Distribution of major and trace elements relatively immobile in metamorphic processes clearly point to their tholeiitic character and proximity to BABBs (Figs 4, 7). Evolution of basaltic magma to the Fe-Ti enriched type is documented by composition of some dolerites. It seems to be probable that basalts and dolerites with BABB signature were genetically related to above mentioned deep-sea sediments and they originally built up together the upper part of oceanic crust in an immature back-arc basin. Recrystallization in the blueschist facies conditions indicate that this basinal crust experienced subduction followed by exhumation during their geological history. *P*, *T* – values of metamorphic alteration was estimated by Faryad (1997) as 310–360°C at 7–9.5 kbar for pumpellite-, 325–375°C at 9–11.5 kbar for lawsonite- and 360–420°C at 10.5–12.5 kbar for the omphacite-bearing blueschists. Relatively wide temperature and pressure ranges in variable blueschist types were probably caused by various depths of their exhumation from subducting slab with a progressively evolving high-pressure metamorphism.

The second genetic group displays extremely rare starting rocks for blueschists - calc-alkaline volcanics. Although chemical composition of these rocks were modified by alkali (mostly sodic) metasomatism, their original petrographic types have been identified using preserved relics of magmatic textures and diagrams by Winchester & Floyd (1977; Fig. 3) based on immobile trace element distribution. They were originally represented by volcanic rocks varied in wide compositional range from basaltic andesites to rhyolites but silicic members, dacites and rhyolites, were dominated. Not only the fully crystallized effusive rocks with prevailing porphyric or intergranular textures but also widespread volcanic glasses (including perlitic varieties) and extrusive tuffs or ignimbrites have been found among blueschist clasts of this group. Although rhyolites metamorphosed in blueschist facies conditions have been found at some localities (e.g. Tribuzio & Giacomini 2002), such various types of calc-alkaline intermedial and silicic volcanics inclusive of perlitic glass have never been described yet. Finding of ignimbrites seems to be an important evidence for subaeral environment of the volcanic activity. Calc-alkaline affinity of these metamorphosed volcanic rocks seems to be reliable proven by testing in several discrimination diagrams based on immobile trace element distribution as is documented by diagrams Nb/Y *vs*. Zr/Ti (Winchester & Floyd 1977) or Hf/3-Th-Ta (Wood 1980; Fig. 7) as examples. The identical affinity as this group of blueschists display also clasts of LP/LT metamorphosed basic to silicic volcanic rocks from the same conglomerates. Similarly to their high-pressure metamorphosed analogues they are thought to be produced in the volcanic arc setting mostly at subaeral stratovolcanoes, because of extrusive varieties inclusive ignimbrites have also been found here (Ivan *et al.* 1999). On the other hand there are also some differences in trace element distribution between both groups most evident in the case of silicic volcanics. Generally higher Zr, Nb and Yb contents, less fractionated LREE/ HREE, less pronounced negative Eu-anomaly in blueschist facies rhyolites (Fig. 5) probably reflect some differences in source composition, but some exceptions exist in both groups. To summarize all petrographic and geochemical features of all calc-alkaline volcanics from the Cretaceous exotic conglomerates of the Klape Unit it can be concluded that they were generated in the magmatic arc related to a mature island arc or active continental margin. Observed geochemical differences between HP/LT and LP/LT metamorphosed types could be probably ascribed to their production in various segments, centers and/or in different stages of arc evolution (*cf*. Thorpe *et al.* 1993). As Zr *vs*. Nb diagram indicates (Fig. 8) a trend to intraplate peralkaline signature could be seen in HP/LT metamorphosed silicic volcanics. Spatially separated origin of these rocks seems to be support also by their metamorphic history. Only segment with domination of such rock types was involved in subduction zone and underwent HP/LT metamorphism. *P*, *T* – conditions of these metamorphism was not exactly estimated yet, but they appear to be generally comparable to those in BABB-type volcanics.

Starting rocks for HP/LT metamorphosed amphibolites were probably basaltic rocks with N-MORB signature. Despite this fact these rocks do not display any genetic relations to BABB-type blueschists except last HP/LT stage of their metamorphic evolution. Their petrographic features, multistage metamorphic evolution and possible relations to similarly metamorphosed gneisses clasts allow comparison to analogical rocks in crystalline complexes of Central or Inner Western Carpathians, especially to amphibolites from the Meliatic or Gemeric Unit which are supposed to be originally related to the arc lower crust (Ivan 1994, 2002).

Identification of various genetic types of blueschists in the exotic conglomerates of the Klape Unit shed also new light on the problem of the original position and sedimentary material source of this unit, which are still a matter of controversy.

There are two concept of the location of the sedimentation area for the Klape Unit (together with adjacent the Manín Unit):

1) position between the Klippen Belt and the Tatric Unit (e.g. Andrusov 1972, Mišík 1996, Rakús & Marschalko 1997),
2) position southward of the Tatric Unit (e.g. Maheľ 1978, Plašienka 1995, Plašienka *et al*. 1997).

According to sedimentological studies of Marschalko (1986) the conglomerate source area must have been an extended, tectonically complicated mountain system with dynamic relief built up by various tectonic units including also obducted ophiolite formation.

Two concept of location of this area has been proposed:

1) the source area termed as "exotic cordillera" or "Andrusov Ridge" and situated between the Klape Unit and the front of Central Western Carpathians (e.g. Birkenmajer 1988, Mišík & Marschalko 1988, Oszczypko *et al.* 2004);
2) the source area located southward in the Carpathian interior and represented probably by a wide actively shortened and uplifted orogenic belt build up by exotic ultragemeric units related to the Meliata Ocean suture (Plašienka 1995, 1996, Rakús & Marschalko 1997).

Results of petrographical and geochemical studies of blueschists mentioned above seem to support the latter concept.

The Triassic-Jurassic Meliata Ocean was probably opened as a back-arc basin inboard of the Permian magmatic arc, the vestiges of which are traceable in the nappe piles on both sides of the Inner and Central Carpathian boundary (Ivan 2002). Closing of this ocean in the Middle to Late Jurassic time (Kozur 1991) and related subduction of its crust are documented also by blueschist facies rocks preserved in the Bôrka Nappe of the ultragemeric Meliatic Unit. Blueschists of the oceanic origin (relics of oceanic floor) as well as of non-oceanic origin (relics of adjacent arc margin) have been found in the Bôrka Nappe (Ivan 2002). Among oceanic crust relics also rocks representing originally pelagic sediments and BABB-type basalts very similar to those in exotic conglomerates have been found here (Fig. 4). Also amphibolites with HP/LT metamorphic overprint seem to be the same type (Fig. 6). Close genetic relation between blueschists of both occurrences could be also supported by their almost identical $^{40}Ar/^{39}Ar$ ages – 155.4 ± 0.6 Ma for the Klape Unit (Dal Piaz *et al.* 1995) and 152–155 Ma for the Bôrka Nappe (Faryad & Henjes-Kunst 1997).

Although calc-alkaline basic rocks with blueschist facies overprint have also been found in the Bôrka Nappe (Ivan 2002), they do not appear to be directly related to those from the exotic conglomerates, because of serious differences in geochemistry, lithology and metamorphic evolution exist here. Despite this fact they bear together evidence that not only the oceanic crust but also adjacent arc crust must had been pulled down into subduction zone during the Meliata Ocean closing maybe by similar mechanism as proposed by Chemenda *et al.* (1996) for continental subduction. Permian to Lower Triassic arc volcanic complexes partly preserved in the present-day nappe stucture of the Northern Veporic, Hronic and Gemeric units seem to be most probable source of calc-alkaline basalts to rhyolites in the exotic conglomerates of the Klape Unit regardless their further metamorphic evolution path. It follows from the cognate to indentical petrografical and geochemical features of all these rocks (Ivan *et al.* 2002) as well as from our preliminary results of U-Pb dating on monazite for rhyolite clasts. Such interpretation is supported also by the Permian age of A-type granites occurring in exotic conglomerates and in the Veporic or Gemeric Units as well (Uher & Pushkarev 1994). Although modern data are missing here, dacites and rhyolites with relatively high Zr contents similar to their high-pressure metamorphosed analogues from the Klape Unit are known from the Permian Krompachy Group in the northern part of Gemeric Unit (Rojkovič & Vozár 1972).

CONCLUSIONS

Geochemical and petrological studies concerning blueschist facies clasts from the Cretaceous exotic conglomerates of the Klape Unit in the neighbourhood of the town Považská Bystrica led us to following conclusions:

- Pelagic deep-sea sediments, volcanic and volcanoclastic rocks, amphibolites and gneisses represent starting rocks of blueschists.
- Based on relatively immobile trace element (REE, HFSE) distribution two different petrogenetic groups in the volcanic protolith of blueschists have been discerned: BABB-type and calc-alkaline type.

– Protolith of BABB-type blueschists was generated in the back-arc basin setting as an upper part of its oceanic crust composed of basalts, dolerites and gabbrodolerites.
– Starting rocks of the calc-alkaline type blueschists varied from basaltic andesites to rhyolites and were produced in a subaeral volcanic arc situated in island arc or active continental margin settings.
– Metamorphic transformation in the blueschist facies conditions was probably caused by back-arc basin closing during of which not only oceanic crust but also adjacent arc crust must had been subducted.
– Source area of blueschist clasts was situated southwards in the Carpathian interior and was probably related to a nappe stack formed as a result of the Meliata Ocean closing in the Late Jurassic time (*ca* 155 Ma) as it was originally proposed by Plašienka (1995). Potential source units are still preserved in the present-day geological structure building up some parts of the Bôrka Nappe (Meliatic Unit).

Research of exotic blueschist clasts from the Pieniny Klippen Belt has been supported by VEGA grants 1/9213/02 and 1/2025/05. Autors are grateful to Michal Krobicki and Jan Golonka (Akademia Górniczo-Hutnicza, Kraków, Poland) for constructive comments and reviews, which greatly improved the manuscript.

REFERENCES

Andrusov D., 1972. Sur l´ampleure de la nappe du Manín (Zones des klippes pienines, Carpathes occidentales, Slovaquie). *Geol. Zbor. Slov. Akad. Vied*, 32, 2, 227–235.

Birkenmajer K., 1988: Exotic Andrusov Ridge: its role in plate-tectonic evolution of the West Carpathian foldbelt. *Stud. Geol. Pol*., 91, 7–37.

Birkenmajer K. & Wieser T., 1990. Exotic rock fragments from Upper Cretaceous deposits near Jaworki, Pieniny Klippen Belt (Carpathians, Poland). *Stud. Geol. Pol.*, 97, 7–67 (In Polish).

Burtan J., Chowaniec J. & Golonka J., 1984. Preliminary results of studies on exotic carbonate rocks in the western part of the Polish Flysch Carpathians. *Biul. Inst. Geol.*, 346, 147–159 (In Polish).

Chemenda A.I., Mattauer M. & Bokum A., 1996. Continental subduction and mechanism for exhumation of high-pressure metamorphic rocks: new model and field data from Oman. *Earth Planet. Sci. Lett.*, 143, 172–182.

Dal Piaz G.V., Martin S., Villa I.M., Gosso G. & Marschalko R., 1995. Late Jurassic blueschist pebbels from the Western Carpathian orogenic wedge and paleostructural implications for Western Tethys evolution. *Tectonics*, 14, 874–885.

Evensen N.M., Hamilton P.J. & O´Nions R.K., 1978. Rare earth abundances in chondritic meteorites. *Geochim. Cosmochim. Acta*, 42, 1199–1212.

Falloon T.J., Malahoff A., Zonenshain L.P. & Bogdanov Y., 1992. Petrology and geochemistry of back-arc basin basalts from Lau Basin spreading ridges at 15, 18 and 19-degrees S. *Mineral. Petrology*, 47, 1–35.

Faryad S.W., 1997. Petrological model for blueschist facies metamorphism in the Pieniny Klippen Belt. In: Grecula P., Hovorka D. & Putiš M. (eds), Geological evolution of the Western Carpathians. *Mineralia slov. – Monograph*., 155–162.

Faryad S.W. & Henjes-Kunst F., 1997. Petrologic and geochronologic constraints on the tectonometamorphic evolution of the Meliata Unit blueschists, Western Carpathians. In: Grecula P., Hovorka D. & Putiš M. (eds), Geological evolution of the Western Carpathians. *Mineralia slov. – Monograph*., 145–154.

Fryer P., Taylor B., Langmuir C.H. & Hochstaedter A.G., 1990. Petrology and geochemistry of lavas from Sumisu and Torishima backarc rifts. *Earth Planet. Sci. Lett*., 100, 161–178.

Gribble R.F., Stern R.J., Bloomer S.H., Stuben D., O´Hearn T. & Newman S., 1996. MORB mantle and subduction components interact to generate basalts in the Southern Mariana Trough back-arc basin. *Geochim. Cosmochim. Acta*, 60, 2153–2166.

Gribble R.F., Stern R.J., Newman S., Bloomer S.H. & O´Hearn T., 1998. Chemical and isotopic composition of lavas from the northern Mariana Trough: Implications for magmagenesis in back-arc basins. *J. Petrology*, 39, 125–154.

Hawkins J.W., Lonsdale P.F., MacDougall J.D. & Volpe A.M., 1990. Petrology of the axial ridge of the Mariana Trough backarc spreading centre. *Earth Planet. Sci. Lett.*, 100, 226–250.

Hughes C.J., 1972. Spilites, keratophyres and the igneous spectrum. *Geol. Mag*., 109, 513–527.

Ivan P., 1994. Early Paleozoic of Gemeric unit (Inner Western Carpathians): Geodynamic setting as inferred from metabasalt geochemistry data. *Mitt. Osterr. Geol. Gesell.*, 86, 23–31.

Ivan P., 2002. Relics of the Meliata Ocean crust: Geodynamic implications of mineralogical, petrological and geochemical proxies. *Geologica Carpath*., 53, 4, 245–256.

Ivan P., Demko R., Rojkovič I. & Vozár J., 2002. Geochemistry and geodynamic setting of the Permian volcanism in the Western Carpathians: a review. In: Proceed. XVII. Congr. Carpath. Balcan Geol. Assoc., Bratislava, *Geologica Carpath*., 53, electr. ver., 1–7.

Ivan P., Demko R. & Sýkora M., 1999. Calc-alkaline basalts and basaltic andesites in the Cretaceous conglomerate of the Klape Unit (Pieniny Klippen Belt) – problem of the source area and its geodynamic setting. In: Ďurža O. & Rapant S. (eds), *Geochémia 1999*, Konf. Symp. Sem., Št. Geol. Úst. D. Štúra, Bratislava, 115–119 (In Slovak).

Ivan P. & Kronome B., 1996. Protolith and geodynamic setting of the HP/LT metamorphosed basic rocks from the northern margin of the Bôrka Nappe (Meliatic Unit, Inner Western Carpathians). *Slovak Geol. Mag.*, 3–4/96, 331–334.

Ivan P. & Kronome B., 1996. Pre-metamorphic character and geodynamic setting of high--pressure metamorphosed basic rocks of the Meliata Unit at localities Radzim, Bôrka, Hačava a Rudník. *Mineralia slov.*, 28, 1, 26–37 (In Slovak).

Kozur H., 1991. The evolution of the Meliata-Hallstatt ocean and its significance for the early evolution of the Eastern Alps and Western Carpathians. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, 87, 109–135.

Leat P.T., Jackson S.E., Thorpe R.S. & Stillman C.J., 1986. Geochemistry of bimodal basalt-subalkaline/peralkaline rhyolite provinces within the Southern British Caledonides. *J. Geol. Soc.*, 143, 259–273.

Maheľ M., 1978. Manín tectonic unit, relations of the Klippen Belt and central Western Carpathians. *Geol. Zbor. Geologica Carpath.*, 29, 2, 197–214.

Marschalko R., 1986. Evolution and geotectonic significance of the Klippen Belt Cretaceous flysch in the Carpathian Megastructure. Bratislava, Veda, 130–137 (English summary of Slovak text).

Marschalko R. & Rakús M., 1997. Development of the Cretaceous flysh in the Klape Unit and the recyclity problem of the clastic material. In: Plašienka D., Hók J., Vozár J. & Elečko M. (eds), Alpine evolution of the Western Carpathians and related areas, 71–78, D. Štúr Publ., Bratislava.

Mišík M., 1996. About sedimentary area of the Klape Unit. *Mineralia slov*., 28, 73–75 (In Slovak).

Mišík M., Jablonský J., Mock R. & Sýkora M., 1981. Konglomerate mit exotischen Material in dem Alb der Zentralen Westkarpathen – paläogeographische and tektonische Interpretation. *Acta geol. geogr. Univ. Com*., 37, 5–55.

Mišík M. & Marschalko R., 1988. Exotic conglomerates in flysh sequences, examples from the Western Carpathians. In: Rakús M., Dercourt J. & Nairn A.E.M. (eds.), *Evolution of the northern margin of Tethys*, 147–164, vol. 1, Paris, Mém. Soc. Géol. France, nouv. Sér. 154.

Mišík M. & Sýkora M., 1981. The Pieniny exotic ridge reconstructed from carbonate pebbles of the Cretaceous conglomerates from the Klippen Belt and Manín Unit. *Západ. Karpaty, Sér. Geol.*, 7, 7–111 (In Slovak).

Mišík M., Sýkora M., & Jablonský J., 1991a. Strihovce conglomerates and South-Magura exotic ridge (West Carpathians). *Západ. Karpaty, Sér. Geol*., 14, 59–69 (English summary of Slovak text).

Mišík M., Sýkora M., Mock R. & Jablonský J., 1991b. Paleogene Proč conglomerates of the Klippen Belt in the West Carpathians. Materials from the Neopieninic exotic ridge. *Acta geol. geogr. Univ. Com., Geol.*, 46, 9–101.

Miyashiro A., 1974. Volcanic rock series in island arcs and active continental margins. *Amer. J. Sci.*, 274, 321–355.

Oszczypko N., Malata E., Švábenická L., Golonka J. & Marko F., 2004. Jurassic-Cretaceous controversies in the Western Carpathians Flysch: the “black flysch” case study. *Cretaceous Res.*, 25, 89–113.

Plašienka D., 1995. Mesozoic evolution of Tatric units in the Malé Karpaty and Považský Inovec Mts.: Implications for the position of the Klape and related units in Western Slovakia. *Geologica Carpath.*, 46, 101–112.

Plašienka D., 1996. Cryptic ridges or collisional orogenic belts. *Mineralia slov.*, 28, 75–79 (In Slovak).

Plašienka D., Havrila M., Michalík J., Putiš M. & Reháková D., 1997. Nappe structure of the western part of the central Carpathians. In: Plašienka D., Hók J., Vozár J. & Elečko M. (eds), Alpine evolution of the Western Carpathians and related areas, 139–161, D. Štúr Publ., Bratislava.

Rojkovič I. & Vozár J., 1972. Contribution to the relationship of the Permian volcanism in the northern Gemerides and Choč Unit. *Geol. Zbor. Geologica carpath.*, 23, 7, 87–98.

Rollinson H., 1993. *Using geochemical data: Evaluation, presentation, interpretation*. Longmans Harlow, 1–352

Rakús M. & Marschalko R., 1997. Position of the Manín, Drietoma and Klape Units at the boundary of the central and outer Carpathians. In: Plašienka D., Hók J., Vozár J. & Elečko M. (eds), Alpine evolution of the Western Carpathians and related areas, 79–97, D. Štúr Publ., Bratislava.

Šímová M., 1985. Magmatic rocks from the Cretaceous conglomerates of the western part of the Pieniny Klippen belt and Manín Belt. *Západ. Karpaty, Sér. Mineral., Petrogr., Geoch., Metalog.*, 10, 9–110 (In Slovak).

Thorpe R.S., Leat P.T., Mann A.C., Howells M.F., Reedman A.J. & Campbell S.D.G., 1993. Magmatic evolution of the Ordovician Snowdon Volcanic Centre, North Wales (UK). *J. Petrology*, 34, 711–741.

Tribuzio R. & Giacomini F., 2002. Blueschist facies metamorphism of peralkaline rhyolites from the Tenda crystalline massif (northern Corsica): evidence for involvement in the Alpine subduction event? *J. metamorph. Geol.*, 20, 513–526.

Uher P. & Pushkarev Y., 1994. Granitic pebbles of the Cretaceous flysh of the Pieniny Klippen Belt, Western Carpathians: U/Pb zircon ages. *Geologica Carpath*., 45, 375–378.

Winchester J.A. & Floyd P.A., 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chem. Geol.*, 20, 325–343.

Wood D.A., 1980. The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary Volcanic Province. *Earth Planet. Sci. Lett*., 50, 11–30.