GEOLOGICA CARPATHICA, 45, 2, BRATISLAVA, APRIL 1994
71 - 82

A LATE CRETACEOUS TO PALEOGENE GEODYNAMIC MODEL FOR THE WESTERN CARPATHIANS IN POLAND

WILFRIED WINKLER[1] and ANDRZEJ SLACZKA[2]

[1]Geological Institute, Swiss Federal Institute of Technology, ETH-Zentrum, 8092 Zürich, Switzerland
[2]Institute of Geological Sciences, Jagiellonian University, ul. Oleandry, 30-036 Kraków, Poland

(Manuscript received September 22, 1993; accepted December 10, 1993)

Abstract: In the Western Carpathians there is no ophiolite-bearing suture zone known which could form evidence for the presence of an oceanic basement floored basin during the evolution of this mountain chain. From comparisons with the Eastern Alps and Eastern Carpathians the existence of one or several oceanic basins is infered. Actually, the pebble content in Slovakian flysch deposits strongly indicates that the suture was located at the transition between the Inner and Outer Carpathians. Along Alpine continental-oceanic convergence (subduction) zones it is generally observed that oceanic basement was uplifted or obducted. Such a process is documented in coeval marine (frequently turbiditic) sediments by the reworking of ophiolitic detritus (p. p. chromian spinel). We have applied this approach to locate the possible paleogeographic position of such convergence zone(s) by analyzing flysch sandstones for their heavy mineral content from the various paleogeographic domains. In an earlier work (Winkler & Slaczka 1992) we presented data mainly from the Silesian, Dukla and Magura Basin units and concluded that an ophiolite-bearing belt should have existed to the south of the Pieniny Klippen Belt domains. Here we present further data from Late Cretaceous to Eocene sandstones comprised in the Pieniny Klippen Belt, Grajcarek and southern Magura Basin units. After the main discriminating mineral species chromian spinel and garnet we can establish several sandstone groups which correlate with spatial provenance data in the literature. Chromian spinel was reworked in two main pulses: First, during the Late Cretaceous to the Pieniny Basin s. l. and second, after accretion of the Pieniny domain, during Paleocene and Eocene to the Grajcarek and Magura Basins. The ophiolitic and continental basement bearing source terrain was situated in the rear of the Pieniny Basin s. l. and it was brought to erosion from at least the Middle Cretaceous on. It represented probably a subduction related marginal thrusts belt heading the Apulian (Tatra) continental margin and corresponds to the "Exotic" ridge of earlier authors. The ophiolitic basement rocks included in the marginal thrust belt appear to have been derived from an oceanic domain situated to the south of the Pieniny realm and which was eliminated probably early during Late Cretaceous. This is supposed from facies relations present in the Czorsztyn Ridge and its southern slope series. We suggest that these domains formed a mobile foreland bulge which migrated northwards during Late Cretaceous due to continental collision between the Apulian and Eurasian plates to the south.

Key words: Western Carpathians, Late Cretaceous - Eocene, flysch deposits, source terrains, heavy minerals, geodynamics.

Introduction

A persisting problem in the geodynamic interpretation of the Western Carpathians in Poland is the lack of direct evidence for the formation of oceanic crust floored basins during stages of their orogenic evolution. Such earlier process should be manifested today at the Earth surface, after basin closure and nappe thrusting, by the presence of ophiolite-bearing suture zones. However, this information is not found in the actual nappe stack in the Northern and Inner Carpathians.

Based on comparisons with the Alps and Eastern Carpathians there are attempts to interpret the former presence of oceanic floored basins within the Northern Carpathian paleogeographic domain (Birkenmajer 1986; Debelmas & Sandulescu 1988; Oszczypko 1992). There, by correlations with the Eastern Alpine Penninic zone and the Poiana Botizei ophiolite zone in the Eastern Carpathians the main oceanic floored basin is thought to have been situated in the inner part of the Northern Carpathians, i. e. the Magura Basin domain. More agreement is probably to be found for the opinion that an oceanic basin should have existed to the south of the Pieniny paleogeographic domain. In this position, a supposedly convergence related obducted Late Cretaceous ophiolite and blueschist-bearing complex (Pieniny Exotic Ridge) was recognized for many years (Andrusov 1938; Mišík 1978; Mišík & Sýkora 1981; Marschalko 1986 amongst others). It is assumed that it supplied various convergence related flysch basins and was called the "Andrusov Ridge" by Birkenmajer (1988). The precise position of this hypothetical ridge with respect to the various basins, however, is disputed. According to most Slovak geologists it ought to have been situated between the Klape and Manín Basins (e. g. Mišík & Marschalko 1988) and after Birkenmajer (1988) it should have been situated between the Pieniny and Klape Basin. A discussion of possible correlations with Alpine units and positions of oceanic basins is to be found in Trümpy (1988).

The presence of ophiolite-bearing convergence complexes adjacent to sedimentary flysch basins can be recognized by heavy mineral analyses by detecting, in particular, chromian spinel. The chromian spinel is supplied in greater quantities from oceanic serpentinic rocks and additionally, probably blue amphiboles from high-pressure/low-temperature metamorphic rocks. Both rock types may have been obducted or uplifted during convergence (e. g. Pober & Faupl 1988; Winkler 1988). In the Northern Carpathians this approach was applied by Winkler & Slaczka (1992) to reveal the possible presence of a Late Cretaceous or Paleocene ophiolite-bearing paleo-suture zone along the southern border of the Magura Basin. Hitherto, the data obtained show that no comparable rocks were obducted there and the interpretation of an oceanic basement floored Magura Basin is questionable. The reworked chromite grains observed in Magura Basin sediments appeared to have been supplied from more internal sources situated to the south of the Pieniny Basin s. l. (Winkler & Slaczka 1992). For this reason we have extended sandstone sampling for heavy mineral analyses southward to the Grajcarek unit and the Pieniny Klippen Belt.

Geological setting

The Carpathians are a part of the Alpine-Carpathian orogenic system and in the area south of Kraków they are subdivided into the Inner (Internides) and Outer (Northern) Carpathians. Between them there occurs the narrow, strongly shortened individual tectonic unit, the Pieniny Klippen Belt (Fig. 1). Paleogeographically, the Northern Carpathian domain is correlated with Alpine flysch units originally located on the northern (Eurasian) margin of the Alpine-Carpathian Tethys realm. The Inner Carpathian units are correlated with Austroalpine units derived from the southern (Apulian) margin of the Tethys (e. g. Csontos et al. 1992). The Pieniny Klippen domain occupied a position in between, but the precise attribution to the northern or southern margin is debatable.

In the Northern Carpathians several tectono-sedimentary units are distinguished (see Fig. 2). They represent sedimentary basin fill sequences formerly situated between emergent source areas which disappeared during the Neogene overthrusting. From N to S these units are the Skole, Subsilesian, Silesian, Dukla-Foremagura and Magura Nappes (Ksiazkiewicz 1962; Birkenmajer 1977). The Grajcarek unit is distinguished at the transition from the Magura to the Pieniny unit. It can be also considered as the southernmost part of the Magura Basin fill.

The Pieniny Klippen Belt represents a composite unit of strongly folded Jurassic and Cretaceous sedimentary series which were supposedly underlain by continental basement to the north and probably by oceanic crust to the south. The latter is suggested from the deep-water nature of the sediment sequences originating from southern basin realms (Birkenmajer 1977, 1985). In the following, we shall subdivide the Pieniny Klippen zone in two genetic parts: the Czorsztyn Ridge and its southern slope to the north and the Pieniny Basin s. l. to the south. A more detailed paleogeographic model can

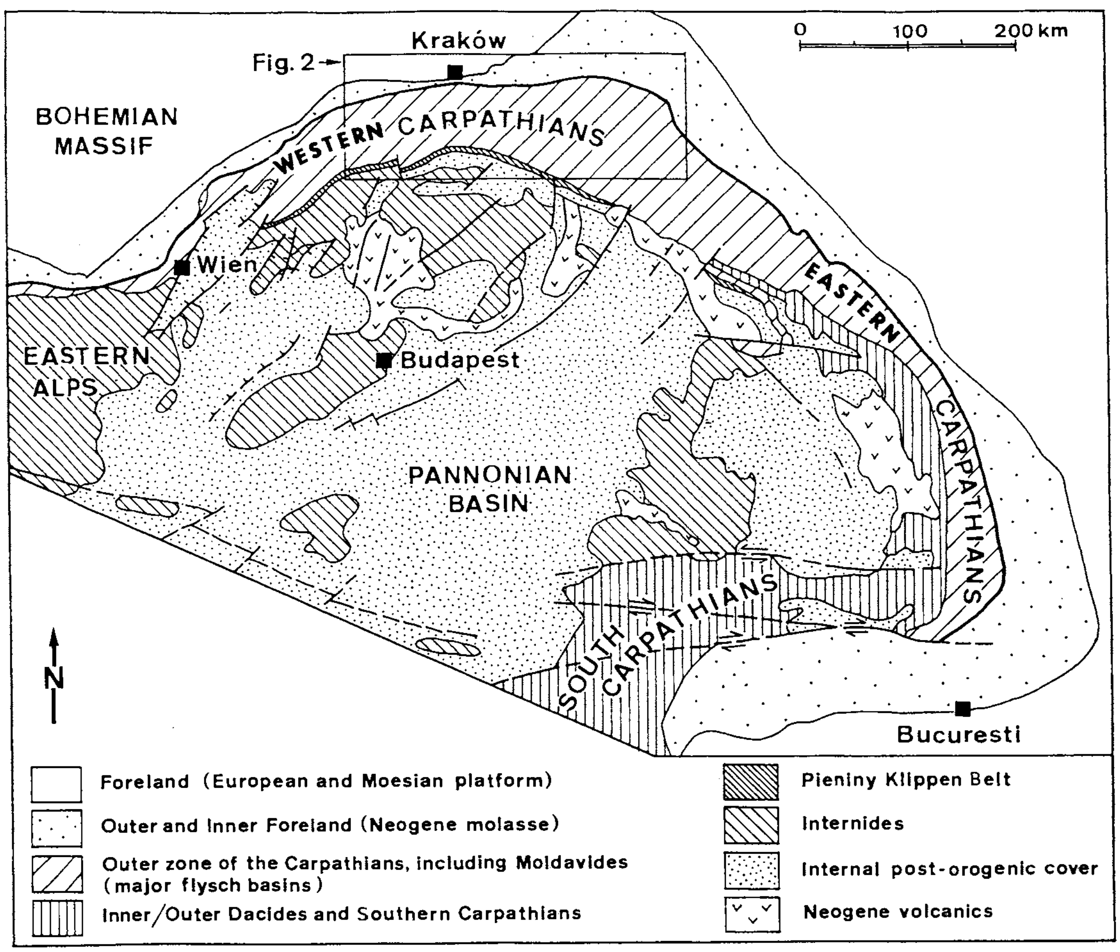

Fig. 1. Simplified tectonic map of the Carpathian arch and its relations to the Eastern Alps. Modified after Ksiazkiewicz (1977). Box indicates the area of present investigation in Fig. 2. The Outer Carpathian tectono-sedimentary units were deposited on the Eurasian margin, the Internides (Inner Carpathian units) on the Apulian margin of the Tethys.

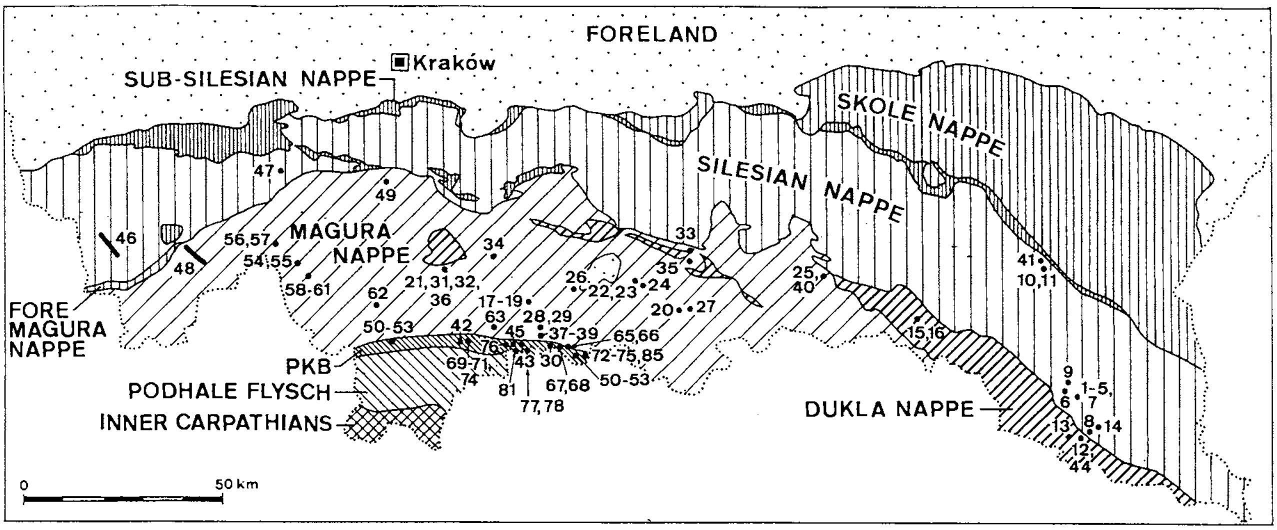

Fig. 2. Tectonic map of the Polish part of the Western Carpathians with the approximate location of the sampling points given in Tab. 2. The individual nappes represent tectono-sedimentary units which were sheared off from their basement during Neogene overthrusting. PKB = Pieniny Klippen Belt. The structural contact between the Tatric/Subtatric units and the Pieniny Klippen Belt is covered by the late orogenic Podhale Flysch.

be found in Birkenmajer (e. g. 1977, 1985). After a Late Cretaceous (Campanian) tectonic deformation the Pieniny Klippen Belt series were overlain discordantly by Maastrichtian clastic sediments. In western Slovakia SW of the Pieniny Klippen Belt the so-called Peri-Klippen zone can be distinguished, comprising the Klape and Manín (Basin) units (Mišík & Marschalko 1988). From pebble and heavy mineral anlyses it is suggested that the oceanic domain should have been situated between the Pieniny swell (Czorsztyn Ridge) to the north and the Inner Carpathian margin (Tatra units) to the south (e. g. Mišík & Marschalko 1988; Birkenmajer 1988).

The inner contact between the Pieniny Klippen Belt and the northernmost Tatric units (Subtatric nappes) is partly masked by the Upper Eocene to Oligocene Podhale Flysch series deposited in a late intra-orogenic basin. The Subtatric Nappe beneath, revealed in boreholes (Sokolowski 1973) represents distal parts of the Tatric (Apulian) continental margin.

Sampling, sample preparation and analysis

We have sampled in the various flysch formations taking into account their stratigraphic position and interpreted basin supply compiled in Ksiazkiewicz (1977), Birkenmajer (1985) and Oszczypko (1992). For a stratigraphic overview see Tab. 1. The sampling points are given in Tab. 2 and Fig. 2. The preparation of sandstones for heavy minerals was performed following standard methods described e. g. in Winkler (1988), Winkler & Slaczka

Table 1: Simplified Cretaceous to Tertiary stratigraphic scheme of the tectono-sedimentary units comprised in the Outer Polish Carpathians. Shaded fields indicate the lack of sedimentary record. It is emphasized that the stratigraphy of the Pieniny Basin s. l. and Czorsztyn Ridge domains are extremely simplified here.

tectonic units	PIENINY & CZORSTYN RIDGE	GRAJCAREK	MAGURA	DUKLA	SILESIAN
Miocene Early			Waksmund Beds		Upper Krosno Beds
Oligocene Late			?	Lower Krosno Beds Menilite Shales	
Oligocene Early			Magura Formation: Malcow Beds; Magura Sandstone (glauconitic)	Cergowa Beds Mszanka Sandstone	
Eocene Late	Magura Formation		Poprad Sandstone; Variegated Shales	Globigerina Marls Green Shales	
Eocene Early	?		Piwniczna Sandstone; Lacko Marls; Pariebiec Sst.; Beloweza Beds; Variegated Shales	Hieroglyphic Beds	Ciezkowice Sandstones
Paleocene		Jarmuta Formation	Szczawnica Beds; Inoceramian Beds	Majdan/Cisna Beds	Upper Istebna Beds
Senonian	Jarmuta Formation Sromowce Formation Pustelnia Marl Mbr.	Malinowa Shale Formation	?; Szczawina Beds Malinowa Shale Formation; Kanina Beds; Variegated Shales	Lupkow Beds	Lower Istebna Beds Godula Beds
Turonian Cenomanian	Jaworki Marl Formation	Hulina Formation			Green Radiolaritic Shale
Albian Aptian	Kapusnica Formation	Wronine Formation Kapusnica Fm.	Lgota Beds		Gaize Beds U. Lgota Beds L. Lgota Beds Verovice Shales
Barremian-Hauterivian Valanginian Berriasian Tithonian-L. Kimmeridgian	Pieniny Limestone Formation CZORSZTYN SLOPE & RIDGE	Pieniny Limestone Formation			Grodziszcze Beds Upper Cieszyn Beds Cieszyn Limestone Lower Cieszyn Beds

(1992). In each grain mount (grain size fraction 0.063 - 0.4 mm) at least 200 transparent heavy minerals were quantified. In the presence of a strongly dominating mineral species (usually garnet or apatite) up to 300 and 400 grains were counted. Diagenetic baryte is sometimes abundant and was disregarded.

The observed heavy mineral assemblages generally reflect the composition of basement rocks eroded in the source terrains, however, very stable mineral species (zircon, rutile, tourmaline, but also chromian spinel) supporting several erosion/sedimentation cycles can partly be drived from older siliciclastic series. The quantitative amount of the individual mineral species present in the turbiditic sandstone samples is additionaly governed by their specific density and mean grain size (depending on the primary grain size and the resistance to chemical and physical abrasion during transport) and hence, their hydrodynamic behaviour during gravity flow transport. Therefore, a ± large scatter in heavy mineral species abundance due to the average grain size and sorting degree of the sampled sandstones must be accepted.

Our following sample grouping is a supposed best fit with the structural and stratigraphic position data available in the Polish transsect of the Northern Carpathians and the Pieniny Klippen Belt. However, in few cases it does not match with the supposed provenance data and in addition, it arises that similar heavy mineral association can be provided by spatially separated source terrains (Winkler & Slaczka 1992).

Results

Outer Carpathian series

Our earlier data and comparisons with published data on heavy mineral assemblages and pebble analyses (Wieser 1985; Winkler & Slaczka 1992) revealed that the northerly situated source terrains (the Subsilesian and Silesian Ridges and the NW prolongation of the Marmaros Ridge) mainly consisted of granitic low-grade metamorphic and medium to high-grade metamorphic rocks and their sedimentary cover. They supplied mainly very stable minerals (zircon, tourmaline, rutile) and less stables as garnet and also staurolite to the basins (see groups Silesian I, II, Dukla I, II, and Magura III, IVb, IVc, VI in Tab. 3). The input of chromian spinel, if present at all, was always very low and can be derived from inclusions of small ultramafic bodies in the Hercynian basement (Wieser 1985) and/or intrabasinal reworking of material which was supplied contemporaneously from southern sources. The latter process should have been more important in the southern Magura Basin.

Higher amounts of chromian spinel were detected in the southern part of the Magura Basin (Winkler & Slaczka 1992, sample groups Magura I and Magura IVa) and in Pieniny Klippen Belt series sample (Jaworki and Sromowce Formations). There, the mineral assemblage points to the presence of non-metamorphic to low-grade metamorphic granitic crust, medium to high-grade metamorphic terrains and obducted Alpine oceanic crust probably situated along the southern margin of the Pieniny Klippen realm. We concluded that the Outer Carpathian basin and ridge realm occupied, with respect to a probable internal suture zone, the position of a deep marine continental basement floored foreland basin (Winkler & Slaczka 1992).

Inner Magura, Grajcarek and Pieniny series

The present work resulted partly in the extension of previous sample groups and partly in the establishment of new sample groups (for details it is refered to Tabs. 2 and 3). The variable amounts in chromian spinel and garnet mineral grains were found to be the best discriminating features, and their variations with respect to the very stable and other metamorphic minerals are shown in Fig. 3.

The earlier Magura I group is divided into Magura Ia (equivalent and extended Magura I group in Winkler & Slaczka 1992) and the new Magura Ib group. The latter contains between 10 and 18 % of chromian spinel in the bulk heavy mineral assemblage, but otherwise the composition is similar to Magura Ia. It is to be noted that the sample group Magura Ib comprises sandstones collected in the western Magura Nappe (Fig. 2, Tab. 2) situated in front of the Peri-Klippen Belt with the Klape and Manín units. Samples from Magura sandstones in the Grajcarek unit (Sztolnia creek section) correlate well with both the Magura Ia and Ib populations.

The groups Magura II and III distinguinshed in Winkler & Slaczka (1992) are supported now by additional samples. Both groups reveal variable amounts of garnet and stable minerals and rather low contents of chromite (0 - 4 %). The main discriminating feature is that the Magura III sandstones contain 1 to 10 % of staurolite. The earlier group Magura IVa (characterized by a high content of chromian spinel) was modified partly by removing the Jarmuta Fm. sample and by assigning it to the new Grajcarek supergroup. Other Magura groups in Winkler & Slaczka (1992) were not modified.

According to varying chromian spinel and garnet contents the samples from the Grajcarek tectono-sedimentary unit can be assembled into two groups. The first is a rather homogeneous group of Jarmuta Fm. sandstones which show partly high chromite and generally low to medium garnet contents. The second is a mixed group in which we assemble informally the supposed Jurassic Szlachtowa Fm. and the Turonian Malinowa Fm. Samples from the Malinowa Fm. are rich in garnet. In the Szlachtowa Fm. there is no or little chromite and a high content of garnet observed.

All Upper Cretaceous sandstone samples from various parts of the Pieniny Klippen Belt domain form a more or less consistent group. They reveal generally low garnet contents and partly the highest chromite contents observed in the present investigation (up to 27 % with a mean of 14 % in the bulk sample heavy mineral associations). It is noteworthy that the partly high chromite contents observed in this Pieniny sample group correlate with high chromite contents in groups Magura IVa, Ib, V and the Jarmuta Fm. representing latest Cretaceous to Eocene sandstones deposited discordantly in the remaining Pieniny Klippen domain after Late Cretaceous nappe formation and in front of it to the north (Grajcarek and southern Magura Basin, see Fig. 4).

Some samples were not included in the present grouping: An unusual heavy mineral composition was found in one sample taken in the Trawne Member (sample 3453) of the Pieniny Branisko Succesion. It contained 46 % of chloritoid. On the other hand, sample 3413 reveals an excessively high garnet content compared to other samples from the Sromowce Fm. from the Czorsztyn Succession. Mineralogically this sample would fit well with the Magura Ia group representing an important element of the Paleogene Magura Basin fill (see Fig. 3). Other individual samples were discussed in Winkler & Slaczka (1992).

Table 2: Sample numbers, locations, formation ages and literature data analyzed for the present paper. A more detailed discussion of the results from Silesian and Dukla units can be found in Winkler & Slaczka (1992). Serial numbers locate the sample points in Fig. 2.

Silesian-Dukla supergroup					
Silesian I	1.	3082	Jablonka creek, S of Baligrod	Grodziszcze Sst.	Barremian
	2.	3083	"	Lower Lgota Beds	Aptian
	3.	3084	"	Upper Lgota Beds	Albian
	4.	3085	"	Lower Istebna Beds	Late Senonian
	5.	3086	"	Lower Istebna Beds	Late Senonian
	6.	3087	Rabe, Old quarry	Upper Istebna Beds	Paleocene
	7.	3088	Jablonka creek	Ciezkowice Sst.	Paleocene
	8.	3089	Cisna creek, Cisna	Mszanka Sst.	Early Oligocene
Silesian II	9.	3081	Rabe creek, S Baligrod	Upper Cieszyn Beds	Valang.-Hauterivian
	10.	3079	Trepcza, N Sanok	Gaize Beds	Albian
	11.	3078	"	"	"
Dukla I	12.	3091	Wetlinka creek, Cisna	Cisna Beds	Paleocene
	13.	3093	Wetlinka creek, Zubracze	Majdan Beds	Paleocene
	14.	3090	Dolzyca near Cisna	Lower Krosno Beds	Middle Oligocene
Dukla II	15.	3076	Tylawa, Stasina	Mszanka Sst.	Early Oligocene
	16.	3077	"	"	"
Magura supergroup					
Magura Ia	17.	2955	Tylmanowa	Magura Fm.	Early Eocene
	18.	3063	"	"	"
	19.	3064	"	"	"
	20.	3071	Krzyzowka, N Krynica	"	Middle Eocene
	21.	3055	Konina creek, Koninki	"	"
	50.	3417	Sztolnia creek	Magura Fm.	Eocene
	51.	3418	"	"	"
	52.	3421	"	"	"
Magura Ib	53.	3419	"	"	"
	54.	3437	Krowiarka pass	Magura Sandstone	Late Eocene
	55.	3438	Krowiarka pass	Magura Sandstone	"
	56.	3439	Zawoja Wilczne	Hieroglyphic Beds	Middle Eocene
	57.	3440	Zawoja	Magura Sandstone	Late Eocene
Magura II	22.	3066	Labowa bridge	Beloweza Beds	Early Eocene
	23.	3067	"	"	"
	24.	3069	Kamienica creek, E Labowa	"	"
	58.	3435	Zubrzyca-Moniakow dwor	"	"
	59.	3436	"	"	"
Magura III	25.	3074	Folusz	Magura Sst.	Eocene - E. Oligocene
	26.	3065	Golkowice, Dunajec river	Lacko Marls	Middle Eocene
	27.	3072	Krzyzowka, N Krynica	"	"
	60.	3433	Zubrzyca-Moniakow dwor	"	"
	61.	3434	Zubrzyca-Moniakow dwor	"	"
	62.	3450	Pieniazkowice	Magura Sandstone	Late Eocene
	63.	3454	Huba	"	"
Magura IVa	28.	3061	Kroscienko Zawodzie	Szczawnica Fm.	L. Paleocene-E. Eocene
	29.	3062	"	"	"
	64.	3425	Dunajec river-Lakcica	"	"
Magura IVb	31.	3051	Koninki creek, Koninki	Basal Inoceram. Beds	Turonian
	32.	3054	"	Lower Inoceram. Beds	Early Senonian
	33.	2963	Biala river, Grybow	Inoceramian Beds	Late Senonian
Magura IVc	34.	3056	Szczawa, waterfall Huk	Inoceramian Beds	Late Senonian
	35.	3073	Biala river, Grybow	"	"
	36.	3052	Koninki creek, Koninki	Basal Inoceram. Beds	Turonian
Magura V	37.	3057	Kroscienko, Dunajec river	Lacko Marls	L. Paleocene - E. Eocene
	38.	3058	"	"	"
	39.	3059	"	"	"
Grajcarek supergroup					
Malinowa Fm.	65.	3410	Grajcarek river near Malinowa	Malinowa Shale Fm.	Turonian
	66.	3411	"	"	"
Jarmuta Fm.	30.	2961	Dunajec valley, Kroscienko	Jarmuta Fm.	Maastrichtian
	67.	3423	Szczawnica - Rzeznia	"	"
	68.	3424	"	"	"

Continuation of Tab. 2.

	69.	3428	Kalotow forest	"	Campanian - Maastricht.
	70.	3431	"	"	"
	71.	3432	Krempach village	"	"
Szlachtowa Fm.	43.	2962	Krupianka river, Jaworki	Szlachtowa Fm.	"Aalenian" flysch
	72.	3415	Sztolnia creek	"	"
	73.	3422	"	"	unknown age
	74.	3429	Kalotow forest	"	"
Pieniny supergroup					
Sromowce Fm.	42.	2960	road S Cisowiec	Sromowce Fm.	Santonian
	75.	3412	road to Homola	"	Coniacian - Santonian
	76.	3457	Sromowce wyzne	"	Early Santonian
Macelowa Fm.	77.	3455	Macelowa	Macelowa Mb.	Turonian
Sneznica Mb.	45.	3276	Sromowce (Katy)	Sneznica Mb.	L. Cenom. - E. Turonian
	78.	3456	Macelowa	"	Coniacian?
Trawne Mb.	79.	3451	Pasieczny	Trawne Member	Early Cenomanian
	80.	3452	Pasieczny	Trawne Member	Middle Cenomanian
Grobka Mb.	81.	3458	Grobka (Katy)	Grobka Member	Coniac. - Turonian?
Individual samples					
	40.	3075	Folusz	Magura Sst.	L. Eocene - E. Oligocene
	41.	3080	Miedzybrodzie, near Sanok	Grodziszcze Sst.	Hauteriv. - Barremian
	44.	3092	Solinka creek, Cisna	Cisna Beds	Paleocene
	82.	3413	river section near Homola	Sromowce Fm.	Coniac. - Santonian
	83.	3453	Pasieczny	Trawne Member	Cenomanian
Literature data					
Silesian III	46.	Wisla river section (KRYSOWSKA & UNRUG, 1967), Silesian unit			
	47.	Potrojna borehole (SZCZUROWSKA, 1985), Silesian unit			
Magura VIa	48.	section South of Zywiec (KRYSOWSKA & UNRUG, 1967), Magura unit			
Magura VIb	49.	Trzebunia borehole (SZCZUROWSKA, 1980), Magura unit			

Interpretation of the data and discussion

Our data obtained from the southern Magura, Grajcarek and Pieniny units are qualitatively in line with the data presented earlier and which are representative for the more external parts of the Outer Polish Carpathians (Winkler & Slaczka 1992). Here, in the southern tectono-sedimentary units, we can interprete three main trends:

Firstly, in the internal Carpathian flysch units staurolite grains represent again a very rare constituent. Higher staurolite amounts are only observed in the presently extended Magura III group and in the earlier established Dukla II group. It is assumed that these turbiditic sandstones were mostly supplied from northerly situated source terrains (the Silesian Ridge and a hypothetical ridge at the northern margin of the Magura Basin, see Fig. 5 in Winkler & Slaczka 1992).

Secondly, in following the palinspastic reconstructions of Ksiazkiewicz (1962), Oszczypko (1992) and others, turbiditic sandstones which are assumed to have been derived from southern source terrains contain definitively more chromian spinel grains. Their occurence shows a paleogeographical and time dependent bimodal distribution. Cenomanian to Santonian flysch series deposited in the Pieniny realm s. l. contain a higher mean amount of chromite compared to the coeval and younger (Turonian - Late Senonian) sediments in the Grajcarek and southern Magura Basin to the north of the Czorsztyn Ridge (Fig. 4). But there the mean amount of reworked chromian spinel is increased later during the Maastrichtian to Early Eocene. These two peaks are separated by the time period (Middle Senonian) which coincides with the supposed tectonic phase of closure of the Pieniny domain (see Birkenmajer 1988; Birkenmajer & Oszczypko 1989) followed by discordant and prograding deposition of chromite-rich sandstones of the Jarmuta and Magura Sandstone Formations in the remaining Pieniny, the Grajcarek and southern Magura realms.

Thirdly, high garnet contents are present mainly in Paleogene Magura and Beloweza Fm. sandstones (populations Magura Ia, Ib, II). It is to be remembered that the garnet-rich sandstones of group Magura III are supposed to have been derived from a northern source. This increasing garnet contents in younger flysch deposits (with the exclusion of the Szlachtowa and Malinowa Fms., see Fig. 3) probably reflects the continued uplift/exhumation of deeper continental crustal levels in the southern source terrains.

It remains open to explain the provenance of the siliciclastic continental basement material documented by the heavy minerals. Clastic pebble facies analysis in the Magura Basin (Oszczypko 1975; Oszczypko et al. 1992) indicate that the sedimentary lithic clasts were derived for a part from Triassic to Cretaceous sedimentary series correlatable with Apulian/Tatra platform and basin series. They include also conodont-bearing deep-marine Triassic carbonate clasts (Mišík & Marschalko 1988). This suggest that the coevally reworked siliciclastic continental basement detritus (heavy minerals p. p.) should have

Table 3: Heavy mineral data in frequency percent quantified in the sandstone samples listed in Tab. 2. In the case of less than 200 grains present in the investigated grain mounts, the corresponding total number of counted grains is indicated in parenthesis. Generally, the frequency percents given here are based on 250 - 400 grain counts.

Silesian, Dukla and Magura Basin sample groups

		tourm	zircon	rutile	br/an/ti	apatite	chromite	epidote	chloritoid	garnet	staurolite	kyan/sill
Silesian I	3082	36.4	29.4	25.7	6.5	0.5	0.0	0.9	0.0	0.5	0.0	0.0
	3083	31.4	42.6	21.9	2.9	0.0	0.0	0.0	0.0	1.2	0.0	0.0
	3084(28)	28.6	57.2	10.7	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3085	32.5	41.6	21.8	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
	3086(140)	50.0	27.8	15.0	6.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0
	3087	47.3	25.9	14.1	10.9	0.0	0.0	1.4	0.0	0.5	0.0	0.0
	3088	52.7	18.4	19.3	7.8	1.8	0.0	0.0	0.0	0.0	0.0	0.0
	3089	43.7	28.2	20.7	5.2	2.3	0.0	0.0	0.0	0.0	0.0	0.0
Silesian II	3081	31.0	22.0	33.5	2.5	0.0	2.0	0.0	0.0	8.5	0.5	0.0
	3079	17.4	27.6	19.1	3.8	0.0	1.7	0.0	0.0	28.0	2.4	0.0
	3078	17.0	32.2	22.6	3.0	1.7	0.0	0.0	0.0	19.6	3.9	0.0
Dukla I	3091	7.9	8.6	8.6	1.5	1.5	0.0	0.4	0.0	71.5	0.0	0.0
	3093	6.1	3.6	8.3	0.3	0.6	0.6	0.6	0.0	80.1	0.0	0.0
	3090	8.0	3.3	9.8	2.6	2.9	0.7	0.0	0.0	72.7	0.0	0.0
Dukla II	3076	32.3	26.7	12.9	3.7	1.4	0.0	0.0	0.0	12.4	10.6	0.0
	3077	30.9	25.3	16.3	6.0	0.4	2.6	0.4	0.4	13.3	4.3	0.0
Magura Ia	2955	6.7	3.5	6.7	0.0	5.9	1.9	0.0	0.0	75.1	0.3	0.0
	3063	3.3	2.7	8.3	3.0	4.0	3.0	0.0	1.0	74.8	0.0	0.0
	3064	3.4	3.0	9.5	2.0	10.1	3.7	0.0	0.3	67.6	0.3	0.0
	3071	8.8	4.8	8.8	3.6	13.5	3.2	0.0	0.5	56.8	0.0	0.0
	3055	9.1	9.6	17.4	3.2	10.0	7.3	0.5	0.0	42.9	0.0	0.0
	3417	9.1	3.2	6.6	3.5	17.0	1.6	0.6	0.0	58.4	0.0	0.0
	3418	28.3	10.2	5.1	5.1	8.8	4.1	0.5	0.9	36.6	0.0	0.5
	3421	15.1	8.5	10.1	3.5	19.5	2.5	0.0	0.0	40.9	0.0	0.0
Magura Ib	3419	18.3	20.5	13.5	4.5	16.3	13.1	0.0	1.6	11.9	0.3	0.0
	3437	11.5	4.5	8.0	2.2	2.9	17.6	0.3	0.0	53.0	0.0	0.0
	3438	10.0	6.1	10.0	2.4	4.1	15.9	0.0	0.2	51.2	0.0	0.0
	3439	15.8	6.4	10.9	4.2	9.4	12.4	0.0	1.5	39.4	0.0	0.0
	3440	12.3	3.6	7.6	4.7	8.0	10.1	0.0	2.5	50.7	0.4	0.0
Magura II	3066	2.9	0.8	7.6	5.2	5.2	0.3	0.0	0.0	77.9	0.0	0.0
	3067	23.2	3.5	9.6	5.5	23.2	0.0	0.0	0.5	34.3	0.0	0.0
	3069	8.6	4.5	5.1	2.0	3.0	1.0	0.0	0.0	75.8	0.0	0.0
	3435(160)	18.8	3.8	6.3	12.5	18.8	0.6	0.0	1.2	37.5	0.6	0.0
	3436(175)	23.4	4.0	13.7	12.6	17.1	4.0	0.0	1.1	24.0	0.0	0.0
Magura III	3074	5.8	3.6	8.4	4.2	0.3	0.3	0.6	0.0	65.9	10.7	0.0
	3065	8.8	12.5	15.8	3.4	1.7	1.3	0.7	0.0	52.5	3.4	0.0
	3072	10.9	14.1	15.9	5.0	6.9	1.3	0.0	0.0	44.7	1.3	0.0
	3433	13.1	4.9	2.9	5.6	8.5	0.7	0.0	0.3	56.5	7.5	0.0
	3434	7.5	3.2	4.3	4.5	9.4	0.5	0.0	0.0	64.4	6.1	0.0
	3450	6.8	5.0	8.1	2.3	3.8	1.8	0.0	0.0	68.5	3.8	0.0
	3454	9.2	6.2	10.2	2.1	11.5	0.2	0.0	0.2	59.4	0.9	0.0
Magura IVa	3061	29.1	10.8	23.0	3.3	14.1	19.7	0.0	0.0	0.0	0.0	0.0
	3062	28.5	20.8	20.0	6.1	14.6	10.0	0.0	0.0	0.0	0.0	0.0
	3425	30.3	14.9	29.7	3.1	14.9	2.6	0.0	0.0	4.6	0.0	0.0
Magura IVb	3051(109)	26.6	15.6	22.0	14.7	14.7	4.6	0.0	0.0	1.8	0.0	0.0
	3054	29.2	12.5	21.4	20.3	15.1	1.0	0.0	0.5	0.0	0.0	0.0
	2963	43.8	4.9	27.1	9.9	9.4	0.5	0.0	0.5	3.9	0.0	0.0
Magura IVc	3056	26.2	17.3	20.3	7.9	15.3	2.0	0.0	0.0	10.9	0.0	0.0
	3073	15.3	24.5	9.1	6.9	4.7	0.0	3.6	0.0	35.8	0.0	0.0
	3052(27)	7.4	40.7	11.1	0.0	3.7	3.7	0.0	0.0	33.3	0.0	0.0
Magura V	3057	16.1	7.6	21.3	10.0	10.9	2.4	0.5	0.5	30.8	0.0	0.0
	3058	16.1	6.2	29.0	6.2	28.5	1.6	0.0	0.5	11.9	0.0	0.0
	3059	23.7	31.2	29.3	1.9	4.2	1.9	0.0	0.5	7.4	0.0	0.0

Grajcarek and Pieniny Klippen Belt formations/members

		tourm	zircon	rutile	br/an/ti	apatite	chromite	epidote	chloritoid	garnet	staurolite	kyan/sill
Malinowa	3410	8.9	6.7	7.8	0.4	8.9	0.0	0.4	1.1	64.4	1.5	0.0
	3411	9.2	7.3	5.0	2.3	17.2	2.6	0.3	0.3	55.4	0.3	0.0
Jarmuta	2961	50.5	7.7	20.1	1.0	13.9	4.6	0.5	0.0	1.5	0.0	0.0
	3423	26.9	11.5	12.0	1.9	21.2	17.8	0.0	1.4	7.2	0.0	0.0
	3424	26.5	9.6	12.5	5.6	9.4	4.5	0.0	5.9	26.5	0.0	0.0
	3428	25.3	8.4	6.8	5.6	16.9	2.8	0.0	1.2	32.9	0.0	0.0
	3431	35.0	8.7	8.4	1.9	10.7	4.5	0.0	2.6	27.8	0.3	0.0
	3432	37.9	17.1	11.7	2.5	7.9	9.2	0.0	2.5	11.3	0.0	0.0

Continuation of Tab. 3.

		tourm	zircon	rutile	br/an/ti	apatite	chromite	epidote	chloritoid	garnet	staurolite	kyan/sill
Szlachtowa	2962	15.5	16.0	16.5	11.0	22.5	0.0	0.0	0.0	18.5	0.0	0.0
	3415(160)	18.1	20.0	7.5	7.5	21.3	2.5	0.0	0.0	23.1	0.0	0.0
	3422	27.6	4.2	6.1	1.9	28.0	0.0	0.0	0.0	32.2	0.0	0.0
	3429	16.0	11.0	5.0	5.6	12.4	0.0	0.0	0.0	42.2	7.8	0.0
Sromowce	2960	29.4	9.2	23.2	6.2	0.0	27.3	0.0	0.0	4.6	0.0	0.0
	3412	37.5	6.5	13.9	5.1	25.9	6.5	0.0	0.0	4.6	0.0	0.0
	3457	41.7	7.2	9.7	2.1	14.8	22.1	0.0	0.0	2.4	0.0	0.0
Macelowa	3455	35.5	10.8	18.3	4.7	6.8	22.9	0.0	0.0	1.1	0.0	0.0
Sneznica	3276	42.9	10.1	15.5	6.4	8.7	15.5	0.0	0.0	0.9	0.0	0.0
	3456	26.5	22.2	15.8	4.3	5.4	23.3	0.0	0.0	2.5	0.0	0.0
Trawne	3451	31.0	18.1	13.9	6.5	12.5	6.9	3.7	6.0	1.4	0.0	0.0
	3452	47.1	11.9	9.9	3.6	15.9	2.6	1.3	4.3	3.0	0.3	0.0
Grobka	3458	18.1	11.3	9.4	4.9	40.1	2.9	0.0	0.0	13.3	0.0	0.0
Individual samples												
	3075	17.2	25.5	16.5	3.7	0.0	1.9	0.0	0.0	35.2	0.0	0.0
	3080	27.4	21.9	16.7	0.5	0.0	0.5	0.0	0.0	15.8	9.7	7.5
	3092	32.4	15.6	17.4	5.5	0.9	0.4	0.0	0.0	27.9	0.0	0.0
	3413	13.6	6.6	10.8	4.4	15.4	4.7	0.0	0.0	44.3	0.0	0.0
	3453	14.1	3.2	4.8	1.6	24.9	4.4	0.0	46.2	0.8	0.0	0.0
Literature data												
Silesian III	mean IIIa	37.5	46.1	14.0	0.0	0.0	0.0	0.0	0.0	1.5	0.7	0.2
	mean IIIb	26.6	50.2	9.7	0.0	0.0	0.0	0.0	0.0	12.5	0.9	0.0
	mean IIIc	8.6	17.7	8.4	0.0	0.0	0.0	0.0	0.0	65.3	0.0	0.0
	mean IIId	8.3	22.2	2.7	0.0	0.0	0.0	0.0	0.0	17.3	49.5	0.0
Magura VI	mean VIa	11.6	23.4	6.5	0.0	0.0	0.0	0.0	0.0	58.5	0.0	0.0
	mean VIb	11.8	46.4	5.1	0.0	0.0	0.0	0.0	0.0	36.7	0.0	0.0

been supplied from associated Apulian continental basement rocks. However, the reworked ophiolithic detritus (chromian spinel) was obviously eroded from tectonically included oceanic basement in the common source terrain. We cannot exclude, however, that part of the heavy minerals was also reworked from tectonically uplifted and re-eroded sediments deposited earlier in the Pieniny Basin s. l. and Czorsztyn Ridge realms.

Detrital blue amphibole and lawsonite were not detected in the presently reported heavy mineral fractions, although, they occur in the Klape unit sediments (unpublished heavy mineral data WW). There, they are necessarily expected, because of the known presence of blueschist pebbles in associated conglomeratic beds (Marschalko 1986). We have measured especially high chromian spinel supply in the Middle and Upper Eocene Magura Sandstone Formation and Hieroglyphic beds (Zawoja-Babia Gora area, see the present sample group Magura Ib) which are situated closely to the north of the Peri-Klippen Belt in Slovakia containing the Klape unit. This indicates that the particular source terrain contained larger occurrences of ophiolithic (serpentinite) rocks.

Geodynamic reconstruction

The petrographic results combined with stratigraphic and sedimentological data allow us to suggest a palinspastic model depicting the Late Cretaceous and Early Tertiary geodynamic evolution of the inner Magura, Grajcarek, Pieniny s. l. and Czorsztyn Ridge paleogeographic realms. However, this attempt is biased in the way that the actually observed spatial arrangement of these structural units was aquired by later Neogene lateral tectonic displacements. Important left lateral movements should have occured along the steeply south plunging Pieniny Klippen Belt (Csontos et al. 1992).

From the petrographical data in terrigeneous clastic sediments we can assume that during Cretaceous convergence south of the Pieniny realm continental crust and sedimentary cover of the Apulian margin (Tatra platform and basins) together with oceanic basement were imbricated and uplifted (Fig. 5) to form an elevated structural feature under erosion. This source terrain corresponds to the earlier recognized "Exotic" ridge which should have represented, in our view, a convergence (subduction) related marginal thrust belt. From simple stratigraphic and lithologic relations (the onset of terrigeneous clastic turbidite sedimentation) a start of corvengence earliest during Aptian/Albian is implied, because during the Early Cretaceous carbonate sedimentation still prevailed in the adjacent Pieniny s. l. and Tatra realms. However, the erosion and resedimentation of high-p/low-T metamorphic minerals (glaucophane) and blueschist pebbles in Upper Albian Klape sediment series would suggest, even in the presence of a very highly efficient working uplift mechanism, an earlier onset of convergence. Hence, we observe an astonishing mineralogical and stratigraphic similarity with flysch series comprised in the Walsertal melange zone and the Northern Calcareous Alps of the western part of the Eastern Alps. There, Winkler & Bernoulli (1986) and Winkler (1988) suggest that convergence should have started earlier during the Valanginian or Hauterivian to allow firstly a deep-seated metamorphism and subsequent (rapid) uplift of the blueschist rocks to the surface. This view is supported by Marschalko (1986) who mentions radiometric datings of blueschist pebbles comprised in the Klape unit with 138.4 and 140 My (without indication of methods applied). After the Harland et al. (1990) time scale these ages would correspond to

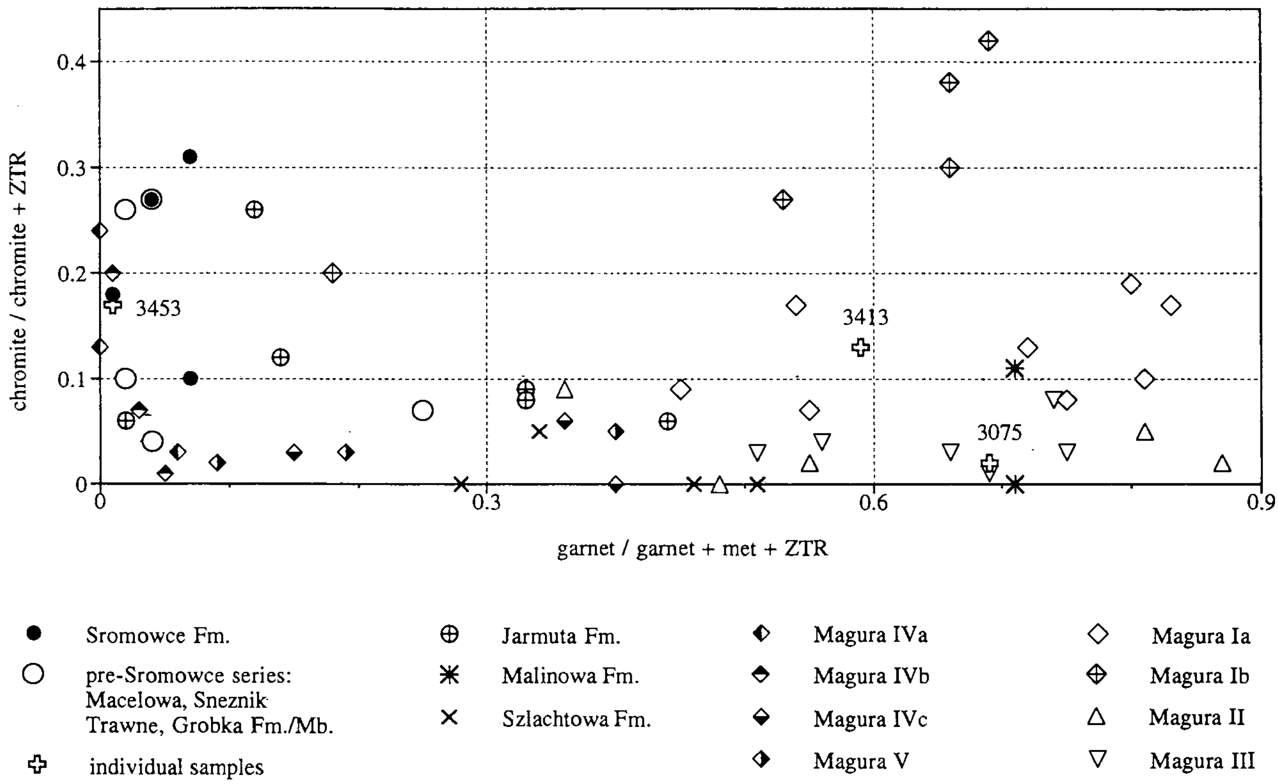

Fig. 3. Heavy mineral plot reflecting essentially the varying proportions of chromian spinel and garnet with respect to the other minerals in the present sandstone groups. Some individual (ungrouped) samples are labelled. Chromian spinel and garnet are significant discriminating mineral species for the sample grouping. **Abbreviations:** ZTR = zircon + tourmaline + rutile; met = other metamorphic minerals as staurolite, chloritoid, sillimanite, kyanite.

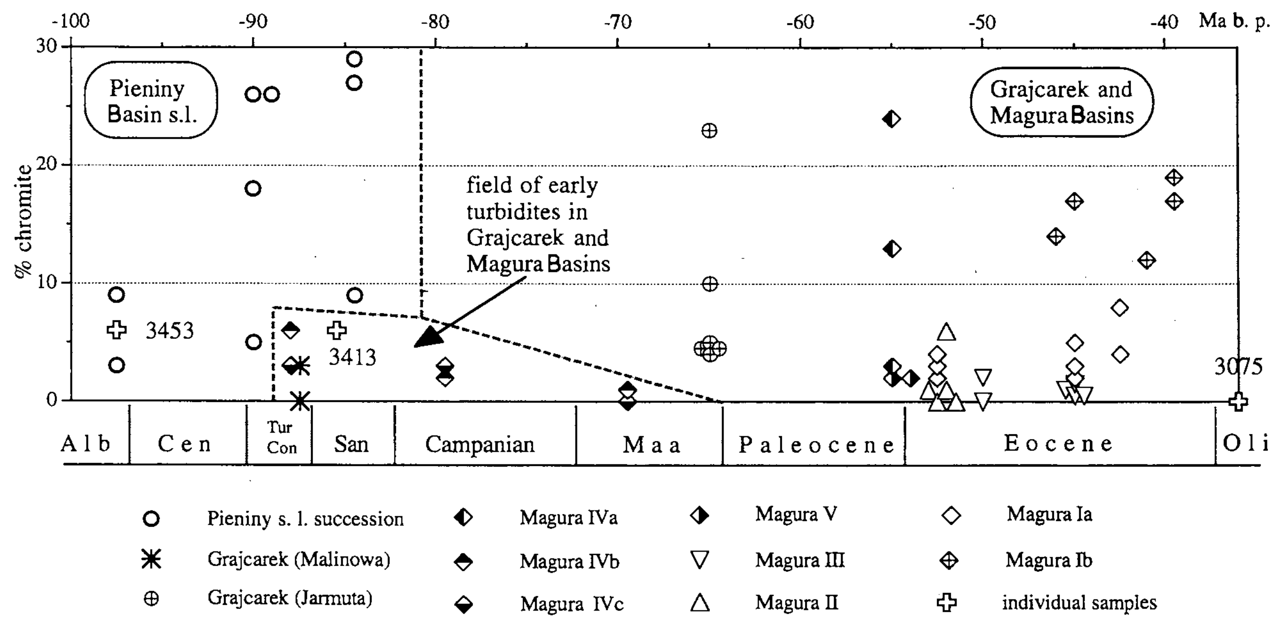

Fig. 4. Plot comparing chromian spinel contents quantified in the bulk transparent heavy mineral fractions (but ignoring the highly variable apatite contents) with the assumed mean age of the sandstone sample. This was obtained by simple averaging over the chronostratigraphic range of the sampled formations using age numbers in Harland et al. (1990). Some individual (ungrouped) samples are labelled separately.

the Valanginian period. Hence, it seems reasonable to suggest an onset of convergence along the Apulian (Tatra) margin at least as early as in Valanginian time and the denudation of the uplifted mixed continental/oceanic marginal thrust belt ("Exotic" ridge) from Mid-Cretaceous on.

However, for the moment in the presently studied transect we cannot provide a solution for the position of the Klape and Manín sedimentary realms with respect to this marginal thrust belt and the Pieniny realm. But from our petrographic data (complete lack of blue amphiboles in the samples investigated) the existence of a mineralogically similar formation as the Klape series on a line (as sketched in Fig. 5) between the Pieniny Basin s. l. to the north and the thrust belt to the south can be excluded.

Along the inner south slope of and on the Czorsztyn Ridge, respectively, from the Valanginian on a zone of non-deposition (of fragmentary stratigraphic record, Birkenmajer 1985) appears to have developed (Tab. 1). Consequently, at the inner slope the sedimentation regime was re-established generally from the end of the Valanginian to the Barremian and during the Albian to Cenomanian on the Czorsztyn Ridge (Pustelnia Marl Fm.). In the Pieniny Basin s. l. transect the preserved pre-Cenomanian sediments consist of Early Cretaceous Biancone-type limestones (Pieniny Limestone Fm.) overlain by Aptian-Albian shales (Kapusnica Fm.), siliceous limestones and sandstones (Jaworki Fm., see Tab. 1, Fig. 5). Coarse detrital sediment supply from the hypothetical marginal thrust belt to the south started in Cenomanian with the deposition of chromian spinel-bearing sandstones intercalated into the marly Trawne and further on in the Sneznica, Grobka, Macelowa (belonging to the Jaworki Fm.) and Sromowce series. Contemporaneously, on the Czorsztyn Ridge mainly marlstones (Pustelnia Marl series) were deposited forming a more or less continuous barrier to the Grajcarek/Magura Basin. In the Grajcarek/Magura Basin during Cenomanian to Santonian hemipelagic sedimentation (Malinowa Shale and Variegated Shale Fms.) prevailed. Only few chromite-bearing sandstones were intercalated (e. g. in the Bystrica unit).

The fragmentary stratigraphic record in the Czorsztyn slope and ridge domain and the northward prograding trend of coarse clastic sediments indicate that this domain formed a positive morphological element (bulge zone) separating the Pieniny Basin s. l. from the Grajcarek and Magura Basins. The prograding style of the Cenomanian to Maastrichtian clastic sediments suggests that the bulge zone (see Fig. 5) migrated northwards from Valanginian to Santonian. Such migration of a foreland bulge situated on continental crust combined with the coarsening of the prograding material (sensu Flemings & Jordan 1990) could reflect crustal flexure caused by pre-Valanginian crustal loading to the south and subsequent relaxation and northward

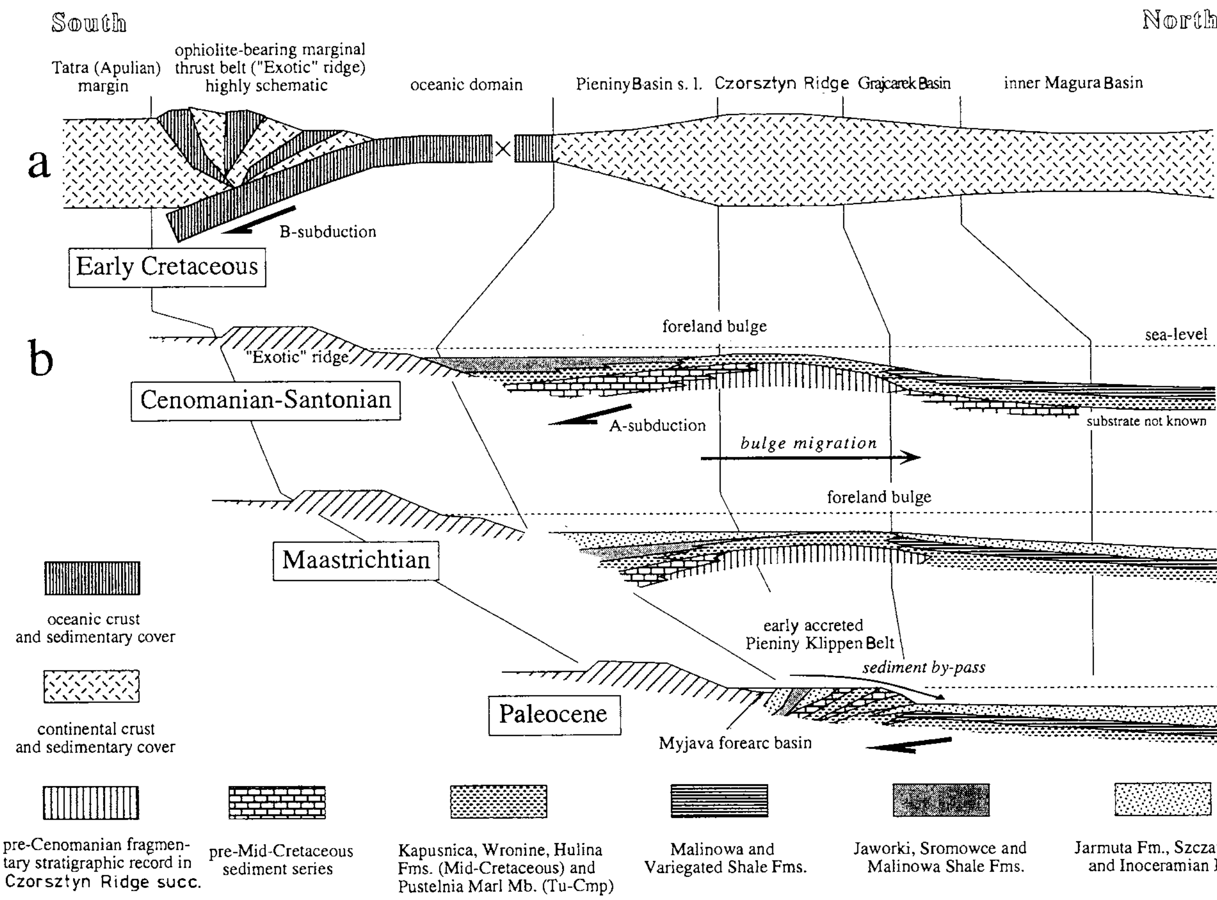

Fig. 5. Interpreted palinspastic sections in the inner part of the Polish Carpathians (not to scale). **A** - the supposed general Early Cretaceous arrangement of the paleogeographic domains. The heavy mineral results presented here imply the generation of a mixed ophiolitic/continental source terrain in a hypothetical thrust belt (the "Exotic" ridge) situated in front of the Apulian margin. The oceanic basin seems to have been subducted in the course of the Early Cretaceous. **B** - from Albian/Cenomanian to Santonian the marginal thrust belt supplied mainly the Pieniny Basin s. l. and then from Maastrichtian to Eocene also the Grajcarek and southern Magura Basin with chromian spinel-bearing detritus. In Paleocene times the Pieniny Klippen Belt was accreted and sediment by-pass prevailed. The fragmentary Early Cretaceous sediment record in the Czorsztyn Ridge and southern slope domains and the Late Cretaceous northward progradation of the coarse grained sediment cover is interpreted to be due to foreland bulge migration caused by overthrusting and loading on the continental plate from the south. See further discussion in the text.

migration of the bulge zone. Consequently, it seems necessary that the hypothetical oceanic domain south of the Pieniny Basin s. l. was eliminated during earliest Cretaceous and loading on distal parts of the northern margin was the result of the northward thrusting ophiolite-bearing ("Exotic") belt and Apulian margin.

The coarse grained Jarmuta sandstones were deposited after Campanian folding and thrusting (manifested by the general break of sedimentation in the Pieniny realm, Birkenmajer 1986) during the Maastrichtian in the Pieniny area s. l. and from Early Paleocene on in the Grajcarek/Magura Basin. From the Maastrichtian/Paleocene transition on the Czorsztyn Ridge domain was subdued and the marginal thrust belt directly supplied its detrital material to the Grajcarek/Magura Basins. This we can infer from the coarse grained facies of the flysch sediments and from the heavy mineral data presented here (increased chromite contents in the Paleogene Grajcarek and Magura flysch series from Paleocene on, Fig. 4). In fact, the Jarmuta, Szczawnica and internal parts of the Lacko Marls in the Grajcarek/Magura Basin reveal mineral associations quite similar to earlier Pieniny Basin fill sandstones (Figs. 3, 4). Except for some scarce Eocene Magura sandstone sediments which can be attributed to the Pieniny s. l. succession that domain did not receive any more significant coarse sediment supply, but by-pass prevailed. It can be assumed that from the Paleocene on the sediment series of the Pieniny Basin s. l. and Czorsztyn Ridge were tectonically accreted against the southern margin and shallowly buried (Fig. 5). Generally, from the Early Eocene on also garnet-rich sandstones are supplied from the south to the Grajcarek/Magura Basin (groups Magura Ia, Ib and II, see Fig. 3 and Tab. 2) indicating the advanced denudation of deeper crustal levels in the marginal thrust belt. From these observed mineralogical trends and dispersal patterns it appears also that we have no positive evidence for the presence of a Late Cretaceous-Tertiary oceanic basement-bearing belt at the transition between the Pieniny and Grajcarek/Magura Basins.

The precise position and age of the southern oceanic domain (Fig. 5) is not well known. The preserved bathymetric deepest sediment facies of the Pieniny Basin s. l. were situated in the Branisko, Pieniny s. str. and Haligowce realms as supposed by Birkenmajer (1977, 1985) from the occurrence of radiolarite beds of Bathonian - Callovian age. These and other Early to Middle Jurassic calcareous, marly and sandy deposits comprised do not provide conclusive evidence for the presence of an oceanic basement floor. In particular the reasoning based on radiolarite beds is ambiguous, because the Apulian (Tatric and Austroalpine) continental margin series also contains coeval radiolarite beds (e. g. Kotanski 1976; Lefeld 1976; Winkler 1988). Therefore, the sediments facies preserved from the Pieniny Basin s. l. do not give a conclusive answer to that question. However, from the spatial and mineralogical relations discussed here it appears that the former oceanic domain documented mineralogically should have been situated south of the Pieniny s. l. realm and in front of the Tatric (Apulian) distal continental margin. Comparable data from Cretaceous clastic deposits in the Tatra units would provide a better understanding of the situation.

Some evidence for the time of the ocean basin formation can probably be derived from the detrital basement pebbles (porphyritic diabase and basalts) resedimented in the Klape Basin unit. They were dated radiometrically (data in Marschalko 1986, without indication of methods applied) with 179, 160 and 156 Ma correlating with the Middle Jurassic (time scale Harland et al. 1990). These age data fit with the supposed opening of the Southern Penninic ocean basin in the Central and Eastern Alps as derived from sediment-basement relations (Weissert & Bernoulli 1985; Winkler 1988).

Conclusions

We have presented heavy mineral data derived from Cenomanian to Upper Eocene flysch sandstones in the transect of the Polish Outer Carpathians and Pieniny Klippen Belt. The goal was to identify the nature of the basement rocks in the source areas of the turbidite basins and to reveal the probable paleogeographic position of convergence related ophiolite-bearing belts.

As discussed in Winkler & Slaczka (1992) the outer basins (Silesian, Dukla) and northern part of the Magura Basin were supplied essentially by continental basement rock series and occupied the position of a deep continental basement floored foreland basin. But the Magura/Grajcarek and Pieniny s. l. Basins received detrital material from mixed continental and oceanic basement sources. We observe a time dependent quantitative trend in chromian spinel supply from the S (Late Cretaceous Pieniny Basin s. l.) to the N (Tertiary Grajcarek, southern Magura Basin). The basement source can be located tentatively at the transition between the Pieniny s. l. and Tatra domains. We suggest that the mixed ophiolitic/continental basement source formed during the Early Cretaceous subduction of a hypothetical oceanic basin situated between the Eurasian and Apulian margin. In the present model the Pieniny realm was hosted on the southern distal part of Eurasian plate. The lost oceanic basin appears to have occupied a similar position as the Southern Penninic-Ligurian ocean in the Eastern and Central Alps. We found no clear evidence for oceanic basement obduction along the border between the Grajcarek/Magura and Czorsztyn Ridge paleogeographic domains.

Acknowledgements: This work was supported by the Polish Research Committee grant No. 726/6/91 and the Swiss National Science Foundation grant No. 70PP-031568 for the initiation of scientific collaboration with scientists from former Eastern European countries. We thank K. Birkenmajer for stimulating discussion and R. Marschalko for introducing us to the geology of the Slovakian Klippen Belt. M. Casey kindly improved the English text.

References

Andrusov D., 1938: Etude géologique de la zone des klippes internes des Carpathes occidentales III. *Rozpr. St. geol. úst.*, V/9, 1 - 135.

Birkenmajer K., 1977: Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians, Poland. *Studia Geol. Pol.*, 65, 1 - 158.

Birkenmajer K., 1985: Main geotraverse of the Polish Carpathians (Cracow-Zakopane). *Wydawnictwa Geologiczne*, 1 - 188.

Birkenmajer K., 1986: Stages of structural evolution of the Pieniny Klippen Belt, Carpathians. *Studia Geol. Pol.*, 88, 7 - 32.

Birkenmajer K., 1988: Exotic Andrusov ridge: its role in plate tectonic evolution of the West-Carpathian fold belt. *Studia Geol. Pol.*, 91, 7 - 37.

Birkenmajer K. & Oszczypko N., 1989: Cretaceous and Paleogene lithostratigraphic units of the Magura Nappe. Krynica unit. Carpathians. *Ann. Soc. Geol. Polon.*, 59, 145 - 181.

Cieszkowski M., 1992: Marine Miocene deposits near Nowy Targ, Magura Nappe, Flysch Carpathians (Southern Poland). *Geol. Carpathica*, 43, 339 - 347.

Csontos L., Nagymarosy A., Horváth F. & Kováč M., 1992: Tertiary evolution of the Intra-Carpathian area: a model. *Tectonophysics*, 208, 221 - 241.

Debelmans J. & Sandulescu M., 1987: Transformante nordpennique et problemes de corrélation entre les Alpes et Carpathes. *Bull. Soc. Geol. France*, 8, 403 - 408.

Harland W. B., Armstrong R. L., Cox A. V., Smith A. G. & Smith D. G., 1990: A geologic time scale in 1989. *Cambridge University Press*, 1 - 263.
Flemings P. B. & Jordan T. E., 1990: Stratigraphic modeling of foreland basins: Interpreting thrust deformation and lithosphere rheology. *Geology*, 18, 430 - 434.
Kotanski Z., 1976: Trias. The Inner Carpathians (The Tatras). *Geology of Poland*, Geol. Inst., 1/2, 105 - 124.
Krysowska-Iwaszkiewicz M., 1967: Heavy minerals in the flysch of the Polish Western Carpathians. *Bull. Acad. Pol. Sc., Ser. Sc. geol. geogr.*, 15, 57 - 62.
Ksiazkiewicz M., 1962: Geological atlas of Poland, stratigraphic and facial problems, 1 : 600 000. *Wydawnictwa Geologiczne*, Warszawa.
Ksiazkiewicz M., 1977: The tectonics of the Carpathians. *Geology of Poland*, Geol. Inst., 4, 476 - 620.
Łefeld J., 1976: The Jurassic. The Inner Carpathians (The Tatras). *Geology of Poland*, Geol. Inst., 1/2, 443 - 450.
Marschalko R., 1986: Evolution and geotectonic significance of the Klippen Belt Cretaceous flysch in the Carpathian megastructure. *VEDA*, Bratislava, 1 - 137.
Mišík M., 1978: Some paleogeographical problems concerning Klippen Belt. In: Vozár J. (Ed.): Paleogeographical Evolution of the West Carpathians, *GÚDŠ* Bratislava, 147 - 160.
Mišík M. & Sýkora M., 1981: Der pieninische Rücken, rekonstruiert aus Geröllen karbonatischer Gesteine kretazischer Konglomerate der Klippenzone und der Manin-Einheit. *Západné Karpaty, ser. geológia*, 7, 1 - 111 (in Slovak, German summary).
Mišík M. & Marschalko R., 1988: Exotic conglomerates in flysch sequences: Examples from the West Carpathians. *Mém. Soc. Géol. France*, Nouv. sér., 154, 95 - 114.
Oszczypko N., 1975: Exotic rocks in the Paleogene of the Magura Nappe between the Dunajec and Poprad rivers (Carpathians, Poland). *Ann. Soc. Geol. Polon.*, 45, 403 - 431.
Oszczypko N., 1992a: Late Cretaceous through Paleogene evolution of Magura Basin. *Geol. Carpathica*, 43, 334 - 338.
Oszczypko N., 1992b: Stratigraphy of the Magura Nappe, Polish Carpathians. *Przew. LXIII Zjazdu Pol. Tow. Geol. Koninki*, 11 - 29 (in Polish, English summary).
Oszczypko N., Weclawik S., Uchman A. & Hoffman M., 1992: Stratygraphia i sedymentologia formacji zarzeckiej. *Przew. LXIII Zjazdu Pol. Tow. Geol. Koninki*, 115 - 120 (in Polish, English summary).
Pober E. & Faupl P., 1988: The chemistry of detrital spinels and its implications for the geodynamic evolution of the Eastern Alps. *Geol. Rdsch.*, 77, 641 - 670.
Sokolowski S., 1973: Geology of the Paleogene and Mesozoic basement of the Podhale trough southern limb in the column of the Zakopane deep borehole. *Inst. Geol. Bull.*, 265, 5 - 103.
Szczurowska J., 1980: Research on heavy minerals. *Inst. Geol. Profile Gleb. Otw. Wiert.*, 49, Trzebunia IG 1, 105 - 117 (in Polish).
Szczurowska J., 1985: Heavy minerals from the Godula Beds, Grodziszcze Beds, Lower Cambrian. *Inst. Geol. Profile Gleb. Otw. Wiert.*, 59, Potrojna IG 1, 127 - 131 (in Polish).
Trümpy R., 1988: A possible Jurassic-Cretaceous transform system in the Alps and Carpathians. *Geol. Soc. America, Spec. Paper*, 218, 93 - 109.
Wieser T., 1985: Fundamental researchers in the western part of the Polish Carpathians - *Guide to Exc. 1. Carp.-Balk. Geol. Ass. XIII. Congress*, Poland, 1 - 102.
Weissert H. J. & Bernoulli D., 1985: A transform margin in the Mesozoic Tethys: evidence from the Swiss Alps. *Geol. Rdsch.*, 74, 665 - 679.
Winkler W. & Bernoulli D., 1986: Detrital high-pressure/low-temperature minerals in a Late Turonian flysch sequence of the Eastern Alps (western Austria): Implications for early Alpine tectonics. *Geology*, 14, 598 - 601.
Winkler W., 1988: Mid- to early Late Cretaceous flysch and mélange formations in the western part of the Eastern Alps - Palaeotectonic implications. *Jb. Geol.* B.-A., 131, 341 - 389.
Winkler W. & Slaczka A., 1992: Sediment dispersal and provenance in the Silesian, Dukla and Magura flysch nappes (Outer Carpathians, Poland). *Geol. Rdsch.*, 81, 371 - 382.