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PRELIMINARY RESULTS OF PROVENANCE ANALYSES OF EXOTIC MAGMATIC AND METAMORPHIC ROCK PEBBLES FROM THE EOCENE FLYSCH DEPOSITS OF THE MAGURA NAPPE (KRYNICA FACIES ZONE, POLISH OUTER CARPATHIANS)

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Abstract: During the Late Cretaceous to Palaeogene, the Magura Basin was supplied by clastic material from source areas situated at the northern and southern margins of the basin, which are presently not outcropped at the surface. The northern source area is traditionally connected with the Silesian Ridge, whereas position of the southern one is still under discussion. The south-Magura source area supplied the Eocene pebbly paraconglomerates containing partly exotic material. The studied clastic material contains fragments of igneous and metamorphic rocks, derived from a continental type of crust, and frequent clasts of Mesozoic to Palaeogene deep and shallow-water limestones. Volcanites, rarely granitoids as well as schists, gneisses, quartzites and cataclasites were found in the group of crystalline exotic pebbles. Monazite ages of "exotic" pebbles from the Tylicz and Piwniczna-Mniszek sections document the Variscan age of metamorphic rocks. The provenance of these exotic rocks could be connected with the Eocene exhumation of the SE sector the Magura Basin basement or by supply of crystalline material from remote SE source area (Dacia and Tisza mega units).

Key words: exotic rocks, source areas, Magura Basin, stratigraphy and palaeogeography

1. Introduction

The Outer Carpathian flysch basins were supplied with clastics that were derived from external as well as internal source areas, sometimes referred to as "cordilleras" (Książkiewicz, 1962). Our palaeogeographic reconstructions of source areas are based on the investigations of sedimentary blocks and "exotic" pebbles that were transported into basinal areas by submarine gravity flows (see Książkiewicz, 1962). The Eocene deposits of the Krynica facies zone of the Magura Basin contain fragments of magmatic and metamorphic rocks, derived from a continental type of crust, and infrequent clasts of Mesozoic limestones. This clastic material is referred to as "exotic", since the original source areas are not cropping out in the neighbourhood of the Magura Basin at present surface. Mišík et al. (1991) suggested that carbonate material was derived from "the basement of the Magura Basin", that was exhumed during the Early/ Middle Eocene, but differs in composition from that of the adjacent Czorsztyn-Oravicum Ridge. Alternatively, the clastic material may have been derived from an Inner Carpathian type source area, located on the SE margin of the basin (e.g. tip of the ALCAPA Block, see Plašienka, 2000). The aim of this paper is to present preliminary results of the composition study of the Eocene igneous and metamorphic pebbles from conglomerates of the Krynica facies zones.

In the Krynica zone of the Magura Nappe (Fig. 1), the "exotic" conglomerates have been studied for many years (Jaksa-Bykowski, 1925; Mochnacka and Węcławik, 1967; Wieser, 1970; Oszczypko, 1975; Oszczypko et al., 2006, Olszewska and Oszczypko, 2010). The first detailed description of exotic pebbles from the Eocene deposits of the Beskid Sądecki Range (Krynica zone) were given by Oszczypko (1975). This author described granitoids, gneisses, phyllites and quartzites, with a relatively small amount of basic volcanic rocks and Mesozoic carbonates. The exotic carbonate material of the Strihovce Sandstone, an equivalent of the Piwniczna Sandstone Member of the Magura Formation in Poland, have been studied by Mišík et al. (1991). These carbonates are repre-sentted by deep-water Jurassic-Lower Cretaceous sediments as well as fragments of shallow-water limestones of the Triassic, Upper Jurassic, Lower and Upper Cretaceous, Palaeocene and Lutetian age (Mišík et al., 1991).

2. Geological setting

The studied area is located in the south-eastern part of the Magura Nappe south of the boundary between the Bystrica and Krynica subunits (Fig.1). The Krynica facies-tectonic zone is composed of the Upper Cretaceous to Oligocene deposits (Birkenmajer and Oszczypko, 1989; Oszczypko and Oszczypko-Clowes, submitted). The oldest deposits are known from the Muszyna-Złockie area, 5 km west of Krynica. They consist of the Turonian-Maastrichtian, deep-water variegated shales (Malinowa Fm.) with sporadic intercalations of thin-bedded sandstones (Oszczypko et al., 1990). That formation passes upwards into strongly tectonized, medium to thin-bedded turbidites of the Maastrichtian/Paleocene to Lower Eocene (Szczawnica Fm.), which are rich in calcite veins. Higher up in the succession, thin-bedded turbidites occur (Zarzecze Fm.), with intercalations of thick-bedded Krynica sandstones and conglomerates of the Lower-Middle Eocene. In the Krynica area the youngest deposits of the Krynica facies zone belong to the thick-bedded sandstones of the Magura Fm. (Middle Eocene to Oligocene). The stratigraphic thickness of the Magura Nappe reaches at least 2.6 km. During overthrust movements and tectonic repetitions, the total thickness of the flysch deposits in the Krynica subunit increased up to 5.5-7.5 km, as shown by magnetotelluric investigations (Oszczypko and Zuber, 2002). The Bystrica and Krynica subunits contact along the sub-vertical thrust fault, which dips to the NE. Three NE-SW trending transversal faults cut both the Bystrica and Krynica subunit into several blocks.

The Late Cretaceous to Oligocene flysch formations of the Krynica succession were deposited in a deep-water basin (Oszczypko, 1992). Starting from the Early Eocene, the sedimentary processes in the southern part of the Magura basin were accompanied by growth of the accretionary wedge (Oszczypko and Oszczypko-Clowes, 2009). Gradual shallowing of the basin started during the Late Eocene. This was followed by folding and uplifting of the basin after the Late Oligocene/Early Miocene, and prior to the Late Miocene.

The current study shows that bodies of exotic conglomerates in the Krynica zone are rare. These

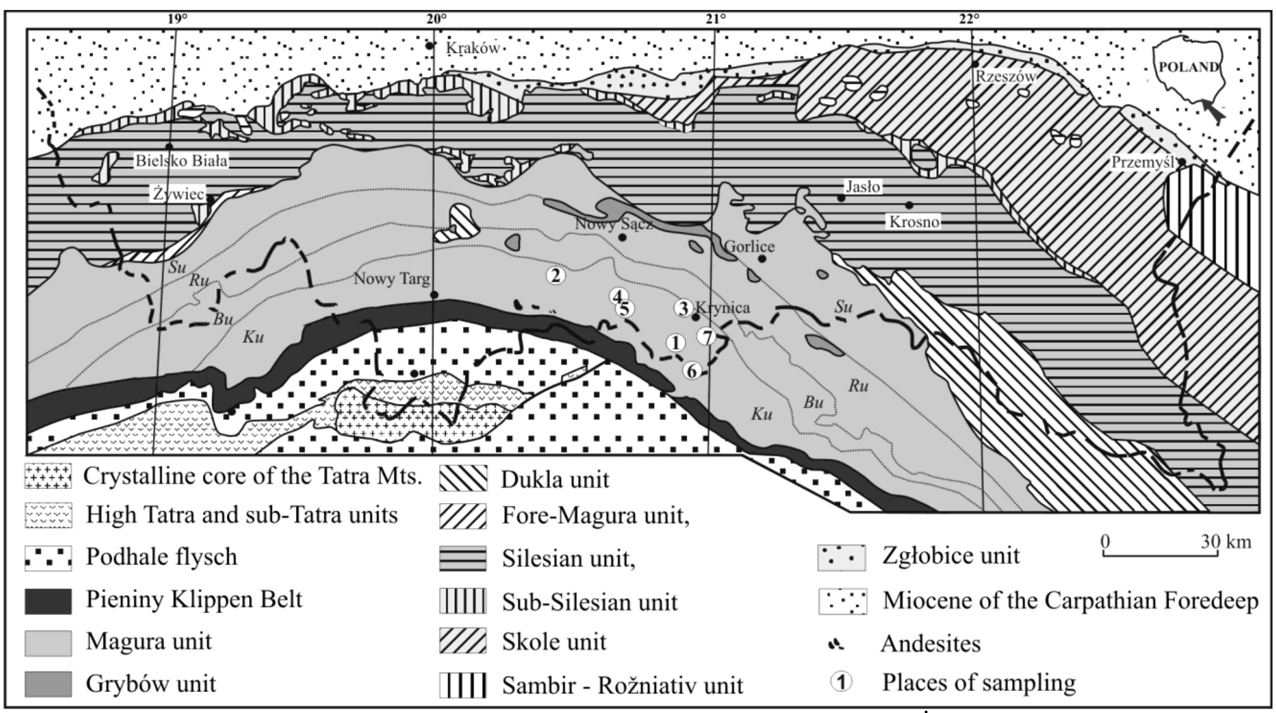

Fig. 1. Geological map of the Carpathians and location of the studied sections (after Żytko et al., 1989; supplemented and modified): Su - Siary, Ru - Rača, Bu - Bystrica, and Ku - Krynica subunits; sample locations: 1-Muszyna, 2-Zarzecze, 3-Łosie, 4-Rytro, 5-Mniszek-Piwniczna, 6-Leluchów, 7-Tylicz.

conglomerates are related to thick-bedded turbidites of the Szczawnica, Zarzecze and Magura formations. The exotic conglomerates of the Jarmuta-Proč Formation of the Grajcarek thrust-sheets, occurring along the contact zone between the Magura Nappe and Pieniny Klippen Belt, occupy a separate position (Birkenmajer, 1977; Birkenmajer and Wieser, 1990).

3. Materials and methods

In this paper, we have concentrated on investigation of the Krynica Sandstone Mb. of the Zarzecze Fm., Piwniczna Sandstone Mb. and Mniszek Shale Mb. of the Magura Formation. It must be mentioned that many of exposures described in literature in 70-ties and 80-ties do not exist today. Several dozens of pebbles were taken from each exposure. The Krynica Sandstone Mb. has been sampled in the Łosie, Muszyna and Zarzecze sections, while the Piwniczna Sandstone Mb. and Mniszek Shale Fm. have been studied in the Rytro, Piwniczna-Mniszek, Leluchów and Tylicz respectively (Fig. 1). Sandstones and conglomerates of the Krynica Mb occur within the thin-bedded flysch of the Zarzecze Fm. as one or more packages of 10 to 300 meters thick sediments.

Exotic rocks of the lower part of the Piwniczna Mb. are known from the Rytro area, whereas exotic conglomerates from the upper part of this member have been found in Piwniczna-Mniszek and Leluchów sections. They occur in a submarine slump body represented by pebbly mudstones. The Krynica and Piwniczna members display paleotransport direction from the south and south-east. The Tylicz conglomerates are underlain and overlain by the thin-bedded shally turbidites of the Mniszek Shale Mb. of the Magura Fm. (Oszczypko and Oszczypko-Clowes, submitted). The conglomerates and thick-bedded sandstones form two bodies 150 m and 50 m thick, which are separated by 50 m packet of thin-bedded flysch. These conglomerates represent a channel infill incised in thin-bedded turbidites (Olszewska and Oszczypko, 2010).

Among the whole spectrum of pebbles only those representing magmatic and metamorphic rocks were taken for analyses. EDS analyses were made using electron microscope (SEM) JEOL 5410 equipped with spectrometer Voyager 3100 (Noran) with accelerating voltage of 20 keV, spot size 7-9 μm and time of counting 100s were used during analyses and Cameca SX-100 with accelerating voltage of 15 keV, spot size 2-7μm. Measurements were performed at the State Geological Institute of D. Štúr in Bratislava, Slovakia. Quality analyses of micas, chlorite, apatite, epidote group and quantity analyses of feldspars, garnets, Fe-sulfides and oxides were made. Calculations of monazite ages were done according to Montel et al. (1996) using author's software DAMON. Geochemical analyses of main elements were made using ICP-ES and trace elements using ICP/MS methods. Immobile elements such as Y, Th, Zr, Ti, Nb were mostly used for classification of rocks and discrimination diagrams, especially for those rocks displaying alterations of minerals. It is to be mentioned that in many cases, the analysed pebbles were too small for geochemical analyses and very often they were altered which prohibited their proper microscopic identification and classification.

4. Results

4.1. Zarzecze Formation

Pebbles of magmatic and metamorphic rocks occurring in Zarzecze are small and usually do not exceed 3cm in diameter, while sedimentary rocks such as sandstones and limestones can reach 11cm. Pebbles from the Muszyna area are much smaller and do not exceed 6cm concerning sandstones and 2cm in case of magmatic and metamorphic rocks. Magmatic and metamorphic rocks comprise 18% and 21% of all pebbles in Muszyna and Zarzecze, respectively (Fig. 2). Among the plutonic rock pebbles from the Krynica Sandstone Mb from the Wilcze stream exposures near Muszyna and Zarzecze section, granitic rocks and aplites were identified. Between volcanic exotics, the following rocks were distinguished: 1) rhyolitic to dacitic rocks formed by feldspar phenocrysts settled in

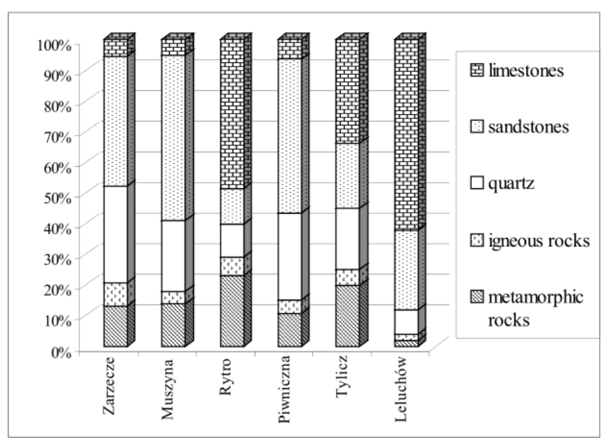

Fig. 2. Petrographic composition of the investigated exotic pebbles (in vol. %).

microcrystalline matrix composed of quartz, feldspars and single flakes of micas (Fig. 3A). Rutile, zircon, monazite, xenotime, apatite and pyrite occur in form of scattered crystals; pyrite also in small veinlets. Products of albitization, calcification and sericitisation are visible in the feldspar phenocrysts as well as in the matrix; 2) trachytic to andesitic rocks with phenocrysts of totally albitised feldspars and primary prismatic minerals (probably amphiboles) replaced by chlorite, epidote and quartz (Fig. 3B). The matrix is built of feldspars, quartz and anhedral minerals (primary biotite?) totally replaced by chlorite and scattered Fe-sulfides. A pebble composed of quartz and tourmaline with schörl-dravite composition, which could be a piece of granitic rock, was found as well.

Among metamorphic rock pebbles the following types were distinguished: 1) fine-blastic quartz-mica (muscovite) schists with sporadically occurring feldspars; 2) quartz-mica schists with biotite, albite, oligoclase ($Ab_{72-99}An_{0-20}Or_{0-9}$) and garnets ($Alm_{56-62}Grs_{19-28}$ $Adr_{9-13}Sps_{3-9}Prp_{0-3}$ in Muszyna and $Alm_{60-83}Adr_{2-18}$ $Sps_{1-15}Grs_{1-16}$ Prp_{1-9} in Zarzecze). In addition, minerals of epidote group, apatite, rutile, zircon and monazite were found there. Composition of garnets suggests that they formed under kyanite, sillimanite (for Zarzecze garnets) and garnet zone (Zarzecze and Muszyna) conditions; 3) gneisses built of quartz, K-feldspars, albite, oligoclase, biotite and garnet porphyroblasts ($Alm_{42-49}Grs_{24-36}Adr_{10-17}Sps_{8-12}Prp_1$), in some pebbles totally replaced by chlorite, micas and Fe-

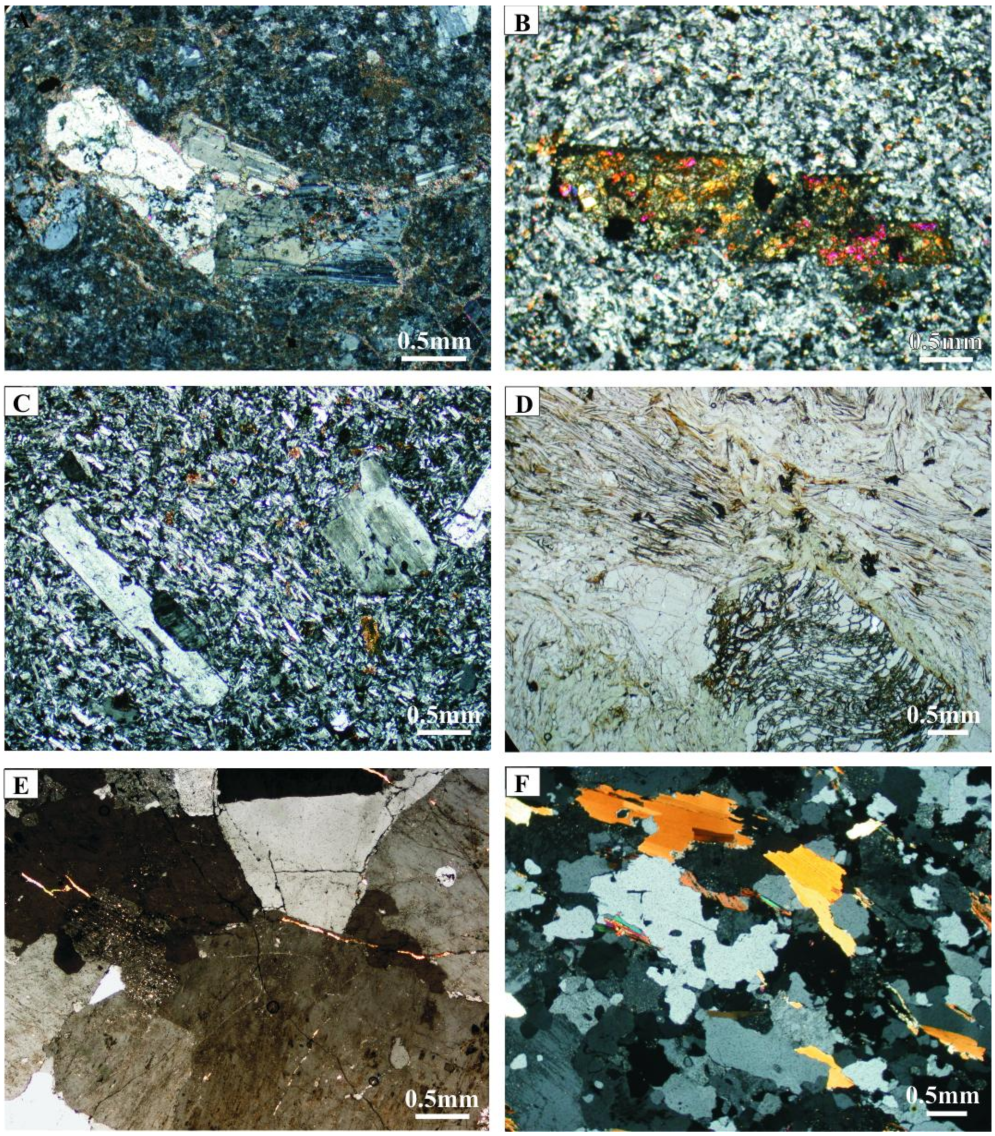

Fig. 3. Microphotographs of the main types of studied magmatic and metamorphic pebbles: A - rhyolitic to dacitic rock, Muszyna (*XPL*); B - trachytic to andesitic rock, Zarzecze (*XPL)*; C - trachytic rock, Piwniczna (*XPL*); D - quartz-mica schist with garnets, Leluchów (*PPL*); E – granitic rock, Tylicz (*XPL*); F - fine-blastic gneiss, Tylicz (*XPL*).

oxides. Zircon, rutile and epidote were also found. Composition of garnets represent garnet zone.

The investigated conglomerate sampled in Łosie locality consists mainly of quartz pieces, metasediments and small fragments of schists. Their size does not exceed 0.5cm, sporadically reaching about 1cm.

4.2. Magura Formation - Piwniczna Member

Pebbles in the Piwniczna-Mniszek conglomerates usually reach 7 cm in size and in Leluchów 14 cm in size, from among which sedimentary pebbles (sandstones and limestones) are bigger than those of igneous and metamorphic origin. Among exotic rocks occurring in the Piwniczna-Mniszek and Leluchów localities, only few pebbles of volcanites and metamorphic rocks were found. They comprised 15 % in Mniszek and only 4% in Leluchów (Fig. 2). Among these volcanites we distinguished: 1) rhyolitic rocks with partly altered phenocrysts of $Or_{93-98}Ab_{2-5}An_{1-2}$ feldspars or rarely quartz. Microcrystalline matrix is composed of feldspars and quartz and sporadically micas, zircon, epidote, pyrite and secondary Fe-oxides; 2) trachytic rocks with phenocrysts of feldspars (Fig. 3C). The trachyte-like background is built of feldspars and rarely quartz. Secondary calcite is present as well.

Pebbles of metamorphic rocks are represented by: 1) fine-blastic quartz-mica schist composed of feldspars and biotite. Tourmaline, rutile, minerals

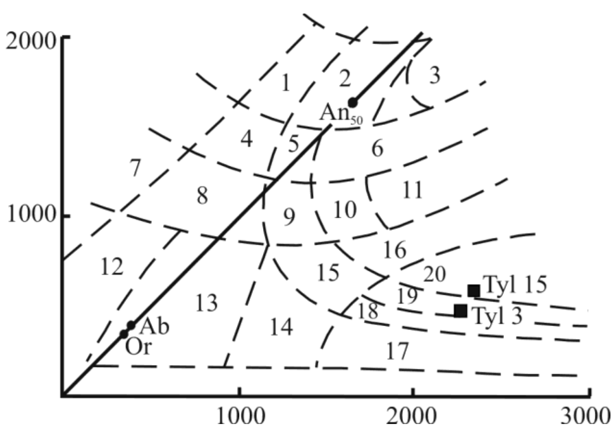

Fig. 4. Points reflecting composition of granitic rocks from Tylicz in the R1 *vs*. R2 diagram. R1=4Si-11(Na+K)-2(Fe+Ti), R2=6Ca+2Mg+Al (in milications) (de la Roche et al. 1980); numeration of fields: 1-Alkali gabro, 2-Olivine gabbro, 3-Gabbronorite, 4-Syenogabbro, 5-Monzogabbro, 6-Gabbro, 7-Essexite, 8-Syenodiorite, 9-Monzonite, 10-Monzodiorite, 11-Diorite, 12-Nepheline syenite, 13-Syenite, 14-Quartz syenite, 15-Quartz monzonite, 16-Tonalite,17- Alkali granite, 18-Syenogranite, 19-Monzogranite, 20-Grano-diorite.

of the epidote group, zircon, apatite and monazite are present as well. Monazites in schists from Piwniczna-Mniszek reach sizes in the range of 20-100 μm. They occur in spaces between main minerals as isolated subhedral grains. They are homogenous in terms of internal features, as well as chemical composition. The average calculated age is about 314±18 Ma (MSWD=1.11) (Fig. 6A). Further pebbles include 2) quartz-mica schists with garnets (Alm_{52-71} $Grs_{12-22}Sps_{0-16}Adr_{4-15}Prp_{3-8}$ in Leluchów and $Alm_{64-69}Sps_{12-17}Prp_{8-12}Adr_{5-10}$ in Mniszek), albite, oligoclase ($Ab_{87-98}An_{2-13}$) and K-feldspars ($Or_{96-97}Ab_{1-2}An_{2}$)(Fig. 3D). Composition of garnets suggest they crystallisation in conditions of kyanite and garnet zones. Garnets found in Leluchów display features of syntectonic rotation; 3) gneisses composed of quartz, $Ab_{93-98}An_{1-2}Or_{0-6}$ and $Or_{96-97}Ab_{1-3}An_{0-2}$ feldspars, micas, chlorite and accessory zircon and minerals of epidote group; 4) cataclasites; 5) metasandstones.

4.3. Magura Formation - Mniszek Shale Member

Pebbles of sedimentary rocks in the Tylicz conglomerates reach 16cm in size, while crystalline pebbles do not exceed 5cm. In this respect, the pebble population in Tylicz is similar to that found in the Leluchów section. magmatic and metamorphic rocks in Tylicz section compri-sed up to 25% of taken pebbles (Fig. 2). The most frequent pebbles are represented by metamorphic rocks such as schists and gneisses. Plutonic rocks of granite type are rare, while volcanic rocks were not found in this exposure. Two pebbles of plutonic rocks are composed of quartz, perthitic or microcline K-feldspar with $Or_{1-90}Ab_{10-95}An_{1-13}$ composition, subordinate muscovite-like mica and accessory zircon. Values of main elements (Tab. 1) indicate that they represent granitic rocks (Fig. 3E). The values of main cations allow to classify the rocks as monzogranites and granodiorites (Fig. 4). The calculated molar [Al/(Na+K+Ca/2)] para-meter exceeding 1.05 value for the studied grani-tes indicates an S-type of them (Pitcher 1982). The Y versus Nb proportions indicate that these granites represent volcanic-arc and syn-collisional granites, while relation (Y+Nb)/Rb fall allow to precise them as volcanic-arc granites (Fig. 5).

Among the metamorphic rocks in Tylicz, we have recognised: 1) fine-blastic gneisses (Fig. 3F) composed of feldspar, muscovite and biotite, quartz, garnet ($Alm_{68-70}Sps_{17-18}Adr_{8-10}Prp_{3-5}$, $Alm_{64-68}Sps_{16-19}$ $Prp_{8-10}Adr_{3-9}$ and $Alm_{43-71}Sps_{3-31}Grs_{3-20}$ Adr_{4-17}

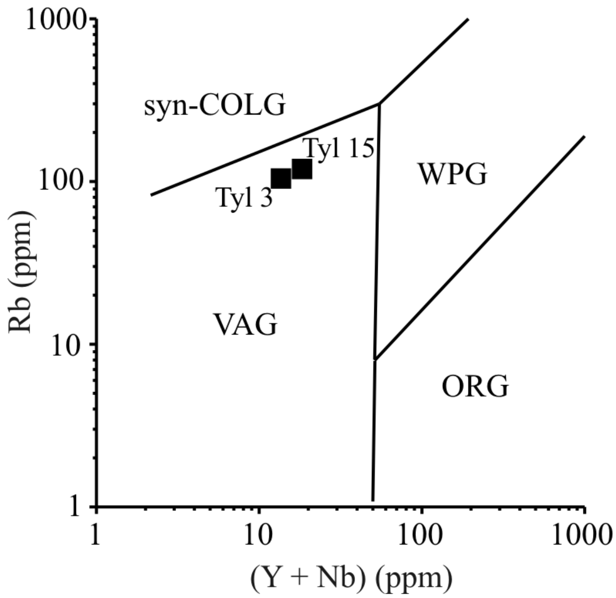

Fig. 5. Points reflecting composition of granites from Tylicz in the Rb *vs*. (Y+Nb) diagram (Pearce et al. 1984). VAG-volcanic-arc granites; syn-COLG-syn-collisional granites; WPG - within-plate granites; ORG-ocean-ridge granites.

Prp_{1-8}), zircon, monazite and apatite. Besides these, sillimanite fibrolites were found in one gneiss pebble. Composition of garnets indicates that they represent medium grade metamorphic conditions of kyanite and sillimanite zone. Monazite crystals are of 20-80 μm size and are present as subhedral isolated grains in spaces between the main minerals. Darker and lighter zones were visible in some grains, but they were homogenous considering U, Th and Pb values. Calculated ages for the monazites oscillate around 300 Ma isochrone. The average age of monazite grains is 303±2 Ma (MSWD 0.96); 2) fine-blastic quartz-mica schists consisting of quartz, $Or_{1-92}Ab_{8-94}An_{1-20}$ feldspars, micas of phlogopite and phengite composition and chlorites. Additionally apatite, zircon (sometimes as inclusions in biotite), rutile, monazite and garnets of $Alm_{42-65}Sps_{16-25}Adr_{6-8}Prp_{5-6}$ and $Alm_{65-67}Sps_{20-22}Adr_{6-9}Prp_{5-6}$ composition suggesting similar conditions as mentioned above. Monazite grains are smaller than those found in gneisses and are 15-30μm in size, but other features are similar. Monazites are compositionally homogenous and the calculated ages generally oscillate around 300 Ma, with average value of 314±2 Ma (MSWD 1.11)(Fig. 6B).

5. Discussion and conclusions

1. In the Palaeogene deposits of the southern part of the Magura Nappe (Krynica Zone), the exotic pebbles have been recognized in two stratigraphical positions:

   a) in the thick-bedded sandstones of the Krynica Sandstone Mb (Zarzecze Fm., Lower/Middle Eocene) and the Piwniczna Sandstone Mb. (Lower/Middle Eocene) of the Magura Fm. and its equivalent - the lower part of Strihovce Sandstone (see Nemčok 1990 a, b; Mišík et al. 1991). These conglomerates are rich in granitoids, medium grade metamorphic gneisses and schists, phyllites and quartzites, with a relatively small amount of felsic and intermediate volcanic rocks and Mesozoic carbonates (Oszczypko, 1975; Mišík et al., 1991; Oszczypko et al., 2006; this paper).

   b) in the thick-bedded sandstones and conglomerates of the Mniszek Shale Mb. (Upper Eocene - ?Oligocene) of the Magura Fm. (see the Tylicz Conglomerate in Olszewska and Oszczypko, 2010) and the upper part of the Strihovce Sandstone (Mišík et al. 1991). Population of pebbles in Tylicz is rich in medium grade metamorphic rocks such as

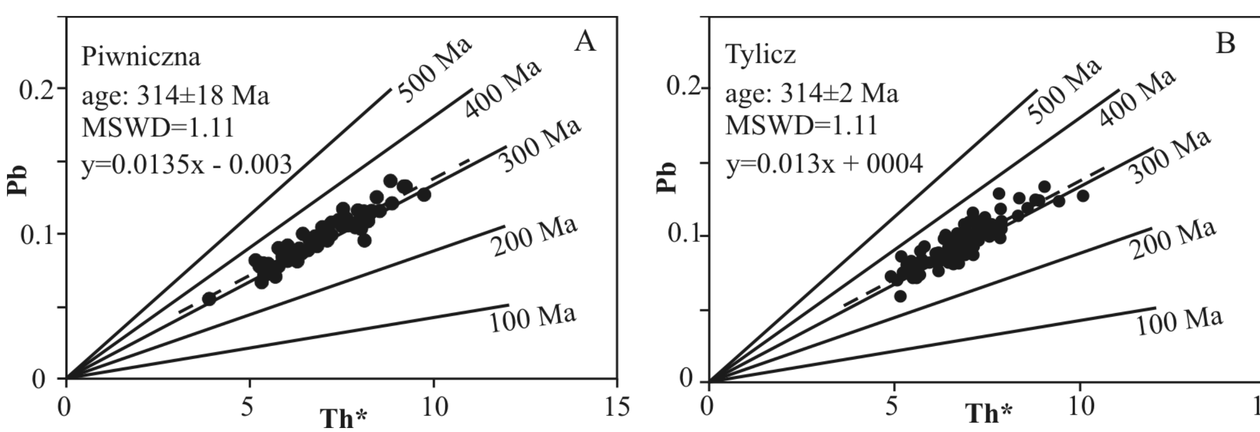

Fig. 6. Isochrones of the analysed monazite ages: A – Piwniczna (Piwniczna Member); B –Tylicz (Mniszek Shale Member).

gneisses and schists and poor in igneous rocks. Contrary to older conglomerates (see point a), no volcanic pebbles are present in the collected population of pebbles in Tylicz. The composition of carbonate material and microfossils assemblages of the Tylicz Conglomerate (Late Eocene – Oligocene) indicates similarity to both to the Jarmuta/Proč and Strihovce exotic pebbles (Olszewska and Oszczypko, 2010).

2. Metamorphic rocks found in all sampled conglomerates are similar and correspond to medium grade metamorphic conditions of epidote-amphibolite or amphibolite facies. Similar results were obtained on the basis of numerous analyses of detrital garnets found in the Jarmuta (Maastrichtian-Palaeocene) and Szczawnica (Palaeocene-Lower Eocene) Formations (Salata, 2004; Oszczypko and Salata, 2005). Monazite dates document the Variscan age of metamorphic rocks, what corresponds to earlier radiometric ages (Poprawa et al., 2004).

3. Plutonic rocks in Tylicz represent volcanic-arc granites and syn-collisional granites of S-type, which are well known from the Western Carpathians (e.g. Petrík et al., 1994; Broska and Uher, 2001). Such granites were also described as protoliths for Carpathian orthogneisses found as pebbles in Palaeocene flysch in the Dukla Nappe (Bąk and Wolska, 2005). According to Pitcher (1982) and Broska and Uher (2001) S-type granites are orogenic granites connected with continental collision. Low-pressure regional metamorphic rocks can accompany them (Pitcher, 1982).

4. The position of the source area for the investigated exotic pebbles is speculative. The obtained data suggest erosion and recycling, during the Late Eocene to Oligocene, material of an older accretionary wedge and deposition of detritus in the southern part of the Magura Basin. The supply of siliciclastic material from SE source area (Dacia and Tisza mega units) and carbonate material from S source area (ALCAPA Mega Unit: Central Carpathian Block and Pieniny Klippen Belt) is also possible. The latter solution can be deduced from the Oligocene?/Early Miocene pre-orogenic palaeogeographic restoration of the Alpine-Carpathian-Panonian realms (Ustaszewski et al. 2008).

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