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ADVANTAGES AND LIMITATIONS OF INTERPRETATIONS OF EXTERNAL MORPHOLOGY OF DETRITAL ZIRCON: A CASE STUDY OF THE ROPIANKA AND MENILITE FORMATIONS (SKOLE NAPPE, POLISH FLYSCH CARPATHIANS)

Dorota SALATA

Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland,
e-mail: dorota.salata@uj.edu.pl

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Abstract: The zircon populations from the Campanian–Maastrichtian part of the Ropianka (Upper Cretaceous–Palaeocene) and Menilite (Oligocene–lower Miocene) formations in the northern part of the Skole Nappe in Poland were examined to evaluate interpretations of the external morphology of detrital zircon in provenance research. The advantage of the zircon typology method, supplemented with elongation measurements, is that it may be applied successfully to comparisons of euhedral zircon populations from sedimentary deposits of different ages and unknown provenance. The zircon typology method, along with elongation measurements of zircons, contributes valuable data that supplement conventional heavy-mineral analyses. It also permits the recognition of potential source areas and rock types for further comparative research.

Key words: detrital zircon, morphology, flysch, Skole Nappe, Outer Carpathians.

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INTRODUCTION

The identification of the source rocks supplying sediments to depositional basins is a challenging task in the study of ancient deposits, especially when the source massifs no longer exist or are unavailable for direct investigation. The task is more complicated, if only depleted monotonous heavy-mineral assemblages, lacking or poor in diagnostic minerals, are available for analyses. In such a case, single-grain examinations of garnet, tourmaline and also zircon are valuable for the identification of provenance and source rocks (e.g., Eynatten and Dunkl, 2012). Zircon is regarded as one of the most resistant of the heavy minerals in sedimentary rocks, with regard to weathering and burial diagenesis (e.g., Morton and Hallsworth, 1999, 2007; Mange and Wright, 2007a). Moreover, zircon is sensitive to the host environment, which may control its morphology (e.g., Pupin, 1980, 1988) and growth rate (Vavra, 1990, 1993; Benisek and Finger, 1993; Sturm, 1999) during crystallisation. Zircon typology, the evaluation of external zircon faces (introduced by Pupin, 1980), assumes that the growth of zircon pyramids is controlled by the aluminium and alkali content in the parent melt (index A), while the development of prisms depends on the crystallisation temperature (index T). Although zircon typology is a simplified method of protolith identification, *in situ* zircon studies (e.g., Caironi *et al.*, 2000; Szczepanik, 2001 or Köksal *et al.*, 2008) displayed a correlation of zircon types with host-rock geochemistry. The typology method is used as a petrogenetic indicator of zircon host environment. It also is applied to protolith evaluation for detrital zircons, palaeogeographic and geotectonic reconstructions of source areas, and comparative studies of sediments (e.g., Caironi *et al.*, 1996; Loi and Dabard, 1997; Schöfer and Dörr, 1997; Fekkak *et al.*, 2000; Lisa and Uher, 2006). Zircon tends to form rather short-prismatic and “stubby” crystals in deep-seated igneous bodies, whereas zircon from volcanic rocks is frequently more elongated or “long-shaped” (e.g., Corfu *et al.*, 2003). To obtain additional data, zircon typology may be supplemented with measurements of crystal elongation, i.e. length:width ratio (e.g., Shahbazi *et al.*, 2014). However, the external morphology of detrital zircon commonly is omitted in modern provenance studies and replaced with LA-ICP-MS or SHRIMP dating. The positive aspect of external morphology studies is that they can be done by means of a petrographic microscope. Evaluation of zircon types and measurements of crystal elongation also may be conducted using scanning electron microscopy (SEM), which

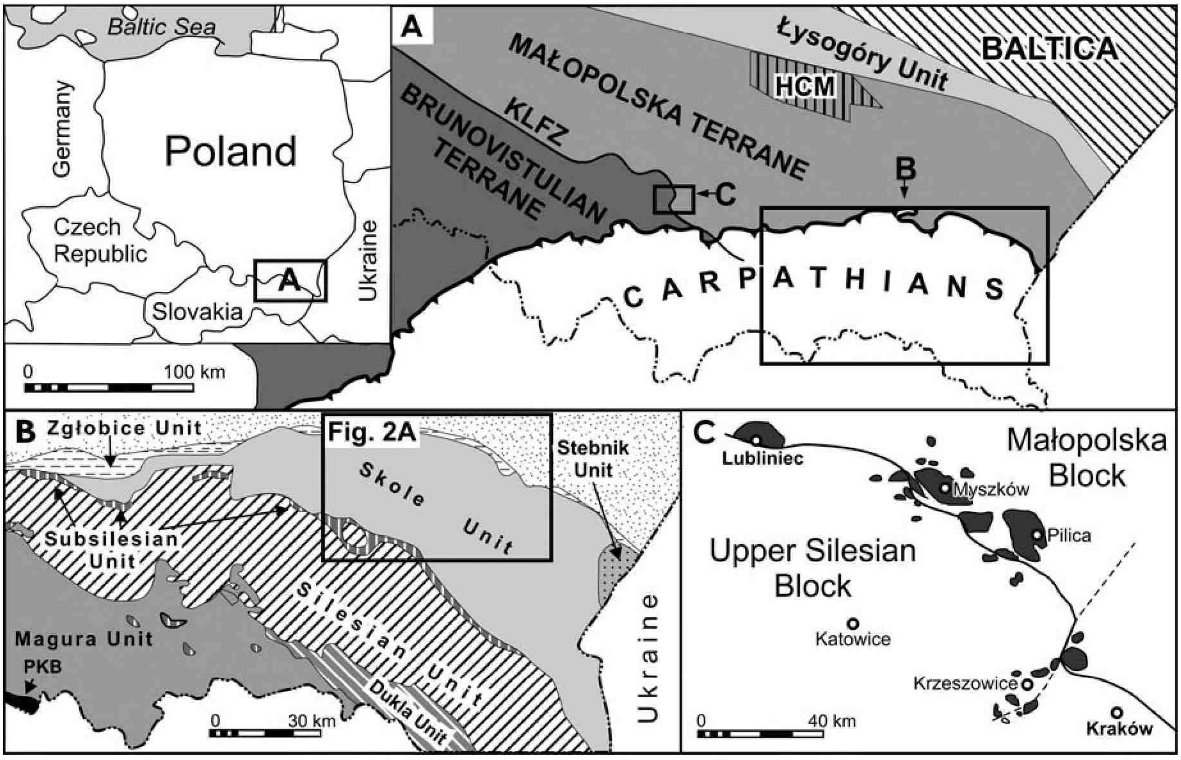


Fig. 1. Sketch-maps of geotectonics of southern Poland. **A**. Location of Brunovistulian and Małopolska terranes on tectonic sketch-map of Poland (according to Winchester and the PACE TMR Network Team, 2002). **B**. Structural units in eastern part of Polish Flysch Carpathians (according to Oszczypko *et al.*, 2008). **C**. structural position of igneous bodies in contact zone of Upper Silesian and Małopolska blocks (according to Żaba, 1999). Abbreviations: HCM – Holy Cross Mountains; KLFZ – Kraków–Lubliniec Fault Zone; PKB – Pieniny Klippen Belt.

provides high-resolution imaging. However, the question arises as to whether there are still fields, in which studies of the external morphology of detrital zircon alone may provide valuable data for the comparison of heavy-mineral assemblages and the evaluation of the provenance of clastic material.

The current study of zircon types is based on the zircon typology method (Pupin, 1980), measurements of crystal elongation and observations of other textural features. It is accompanied by consideration of the pros and cons of studies of zircon external morphology, applied to detrital zircon populations in the context of their provenance. The study is based on euhedral zircons from the flysch sandstones of the Campanian–Maastrichtian interval of the Ropianka (Upper Cretaceous–Palaeocene) and Menilite (Oligocene–lower Miocene) formations in the northern part of the Skole Nappe, in Polish Flysch Carpathians. The sediments have well defined palaeocurrent directions and described heavy-mineral assemblages, including high-resolution heavy-mineral analyses (Salata and Uchman, 2012, 2013), which help to verify interpretations of zircon morphology in sedimentary provenance research.

GEOLOGY

Palaeogeography

The northward movement of the Alpine-Carpathian-Pannonian terrane (ALCAPA) during the Eocene–early Miocene, led to its collision with the North European plate (e.g., Winchester and the PACE TMR Network Team, 2002). The final effect of this event was the formation of the Carpathian nappes and overthrusting of them on to the European Platform and Miocene deposits of the Carpathian Foredeep (e.g., Oszczypko *et al.*, 2008). The Skole Nappe forms the north-eastern part of Polish Flysch Carpathians (Fig. 1). The area, where heavy-mineral research currently is being conducted (Fig. 2), is located south-east of Rzeszów and Łańcut in the northern part of the nappe (Salata and Uchman, 2012, 2013). Palaeotransport directions indicate that in the study area the deposits of the Ropianka and Menilite formations were supplied from the north-west (e.g., Książkiewicz, 1962; Kotlarczyk, 1966, 1976; Ślączka and Unrug, 1966; Bromowicz, 1974; Kotlarczyk and Leśniak, 1990). The distribution of the palaeotransport directions suggests the existence of a source massif in the northern margin of the Skole Basin, made up of medium-grade metamorphic rocks and igneous rocks. This is indicated by the lithology of pebbles found in the Ropianka Formation (e.g., Bukowy, 1957; Kotlarczyk and Śliwowa, 1963; Rajchel, 1990; Rajchel and Myszkowska, 1998 and references therein), heavy-mineral assemblages of the Ropianka and Menilite formations, and the chemical composition of garnet and tourmaline from these formations (e.g., Salata and Uchman, 2012, 2013; Salata, 2013a, b, 2014). Additionally, the clastic material was delivered to the Skole Basin from the sedimentary cover of the easternmost part of the Upper Silesian Block and the Małopolska Block (Fig. 1A), which

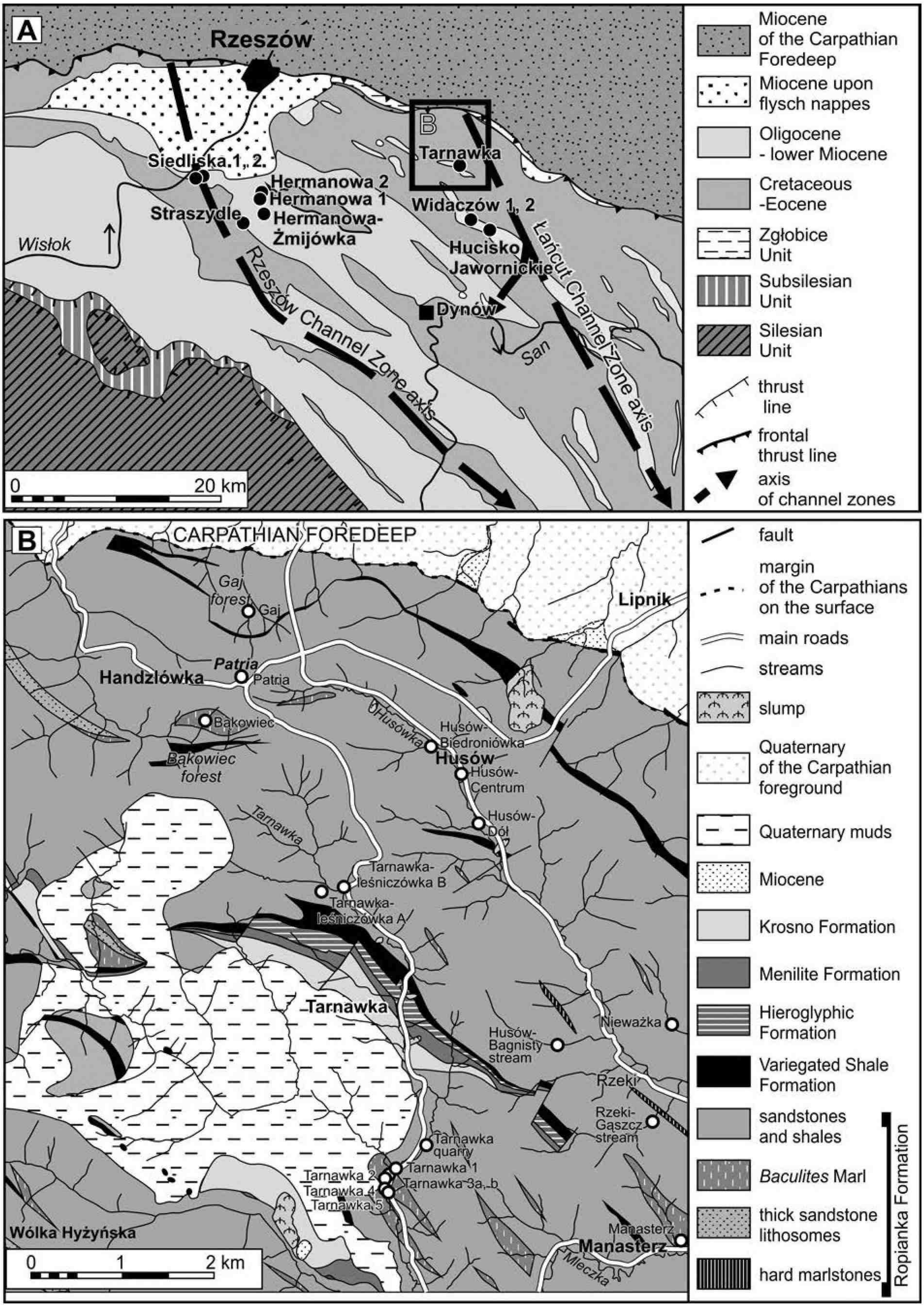


Fig. 2. Geological maps with location of profiles sampled for heavy-mineral analyses. **A.** Sampled localities of Boryslav and Kliva Sandstone members of the Menilite Formation **B.** Sampled localities of sandstones of Ropianka Fm (Salata and Uchman, 2013 and Salata, 2013b modified; part A based on Kotlarczyk and Leśniak (1990); part B based on Wdowiarz (1949) with modified description of lithostratigraphic units).

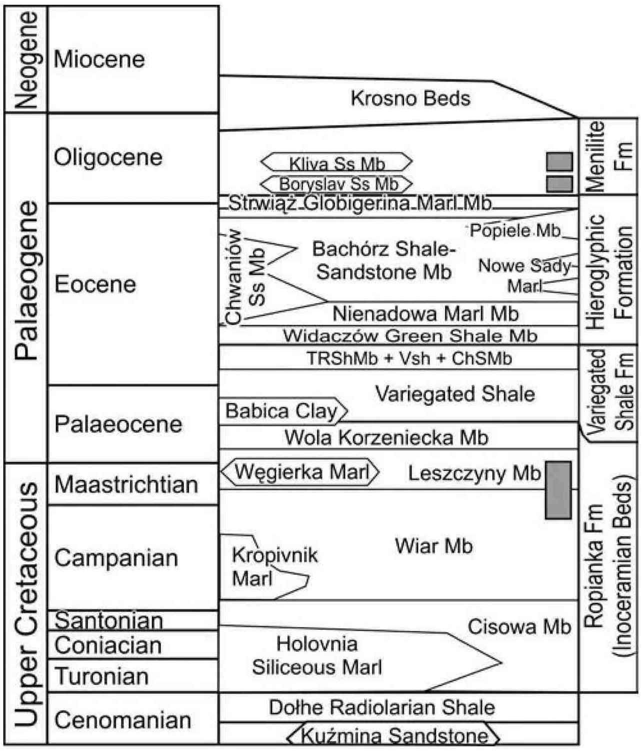


Fig. 3. Stratigraphic scheme of Upper Cretaceous–Miocene time interval of the Skole Nappe (based on Gasiński and Uchman, 2009 and references therein – modified) with indication of studied time-span intervals of Ropianka and Menilite formations (grey rectangles). Abbreviations: Mb – member; Fm – formation; Ss – sandstone; TRShMb – Trójca Red Shale Member, VSh – Variegated Shale, ChSMb – Chmielnik Striped Sandstone Member.

at that time were parts of the Brunovistulian terrane and the Laurussia–Baltica palaeocontinent, respectively (e.g., Winchester and the PACE TMR Network Team, 2002). The Upper Silesian and Małopolska blocks are separated by the Kraków–Lubliniec Fault Zone (e.g., Buła *et al.*, 1997; Żaba, 1999), which is part of the Hamburg–Kraków–Dobrogea tectonic zone, parallel to the Trans-European Suture Zone (TESZ). The Upper Silesian and Małopolska blocks are considered to be parts of micro-plates, translocated during the Palaeozoic (e.g., Żaba, 1999; Słaby *et al.*, 2010 and references therein). The Kraków–Lubliniec Fault Zone (Fig. 1A, C) was formed during the collision of the blocks and was accompanied by Carboniferous–Permian volcanism of calc-alkaline affinity (e.g., Żelaźniewicz *et al.*, 2008; Lewandowska *et al.*, 2010; Słaby *et al.*, 2010; Wolska, 2012). According to Pietsch *et al.* (2010), the Kraków–Lubliniec Fault Zone continues under the Carpathian overthrust to the south-east of Kraków, in the general direction of Smilno in Slovakia.

Outline of lithostratigraphy of zircon host rocks

The deposits of the Ropianka Formation in the Skole Nappe (Fig. 3) are an Upper Cretaceous–Palaeocene flysch succession (Kotlarczyk, 1978 and references therein). They are followed by the Upper Palaeocene–Eocene mudstone-dominated Variegated Shale Formation and the Eocene Hieroglyphic Formation (Rajchel, 1990). The deposits sampled within the Campanian–Maastrichtian sedimentary interval of the Ropianka Formation belong to the Wiar and Leszczyny members (Kotlarczyk, 1978). The sandstone-dominated sections represent the proximal part of the depositional system and also more distal parts of the system. The outcrops sampled for heavy-mineral analyses belong to the Marginal Thrust Sheet, the Husów Thrust Sheet and the Hadle Kańczudzkie–Chmielnik Thrust Sheet (Fig. 2B). For details of the sections sampled of the Ropianka Formation, see Salata and Uchman (2013). The zircons studied were extracted from samples, representing each of the thrust sheets.

The Oligocene and Lower Miocene fill of the Skole Basin is represented by the Menilite (Kotlarczyk and Leśniak, 1990) and Krosno formations (Malata, 1996; the latter is an equivalent of the Krosno Beds) (Fig. 3). Rocks of the Menilite Formation are distinguishable, owing to the presence of dark, black or brown shales, but thick sandstone units are also present. The latter predominate in the Kliva and the Boryslav Sandstone members, which were deposited as gravitational flows, mainly in the Rzeszów and Łańcut channel zones. The Kliva sandstone types also may be found outside the main channel zones (Kotlarczyk and Leśniak, 1990). The zircons examined are from samples, representing the Kliva and Boryslav Sandstone members (Fig. 3) from both channel zones (Fig. 2A). For details of the sections of the Menilite Formation sampled for heavy-mineral assemblages, see Salata and Uchman (2012).

Sandstones of the members of the Ropianka and Menilite Formations sampled are compositionally similar. They are dominated by quartz, which is accompanied by feldspar, mica, glauconite and coalified plant debris (e.g., Żgiet, 1963; Kotlarczyk, 1966, 1976; Ślączka and Unrug, 1966; Bromowicz, 1974, 1986). However, the deposits differ in the types of metamorphic and igneous rocks as pebbles, which are more abundant in the Ropianka Formation, while the Menilite Formation contains mainly small clasts and pebbles of sedimentary rocks (Wdowiarz, 1949; Bukowy, 1957; Kotlarczyk and Śliwowa, 1963; Bromowicz, 1974, 1986; Rajchel, 1990; Rajchel and Myszkowska, 1998 and references therein).

Heavy-mineral assemblages of the Campanian–Maastrichtian part of the Ropianka and Menilite (Oligocene) formations display great similarities. Zircon, tourmaline, rutile, garnet, kyanite and staurolite are dominant in both formations. However, the Ropianka Formation has proportionally larger amounts of zircon, garnet and apatite, whereas the Menilite Formation contains more kyanite + staurolite, and almost lacks apatite (Fig. 4). Individual grains of hornblende occur in the Ropianka Formation, while the Menilite Formation contains andalusite, which was not found in the Ropianka Formation (Salata and Uchman, 2012, 2013).

METHODS

The sandstones sampled were very weakly consolidated and so they were gently disintegrated and washed to remove the clay fraction. The samples were sieved by means of a

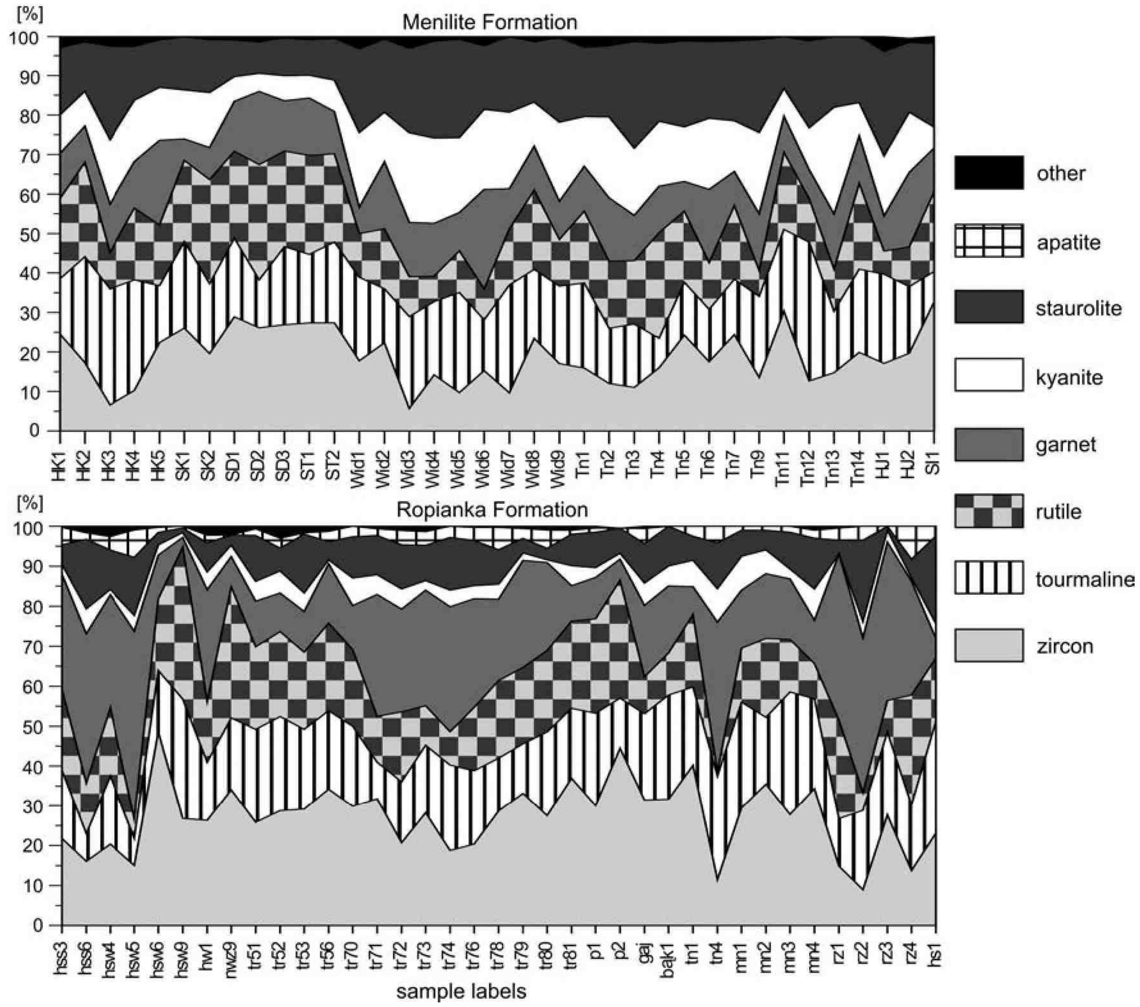


Fig. 4. Abundances of heavy mineral species in Ropianka and Menilite formations (data according to Salata & Uchman, 2012, 2013). Other minerals' group include single grains of monazite, chromian spinel, hornblende, titanite, epidote, brookite.

mechanical shaker and the heavy minerals were separated from the fraction of 0.063–0.25 mm, using sodium polytungstate of density 2.9 g/cm^3. Optical analyses of the heavy minerals were done on grain mounts in Canada balsam in transmitted light. Zircons for morphological examination were hand-picked from the heavy-mineral fractions, using a stereomicroscope. The zircons were arranged in rows on a carbon adhesive tape. Zircon morphology and elongation measurements were studied by means of a HITACHI S-4700 Field Emission Scanning Electron Microscope in the Laboratory of Field Emission Scanning Electron Microscopy and Microanalysis, at the Institute of Geological Sciences, Jagiellonian University of Kraków. To obtain representative data of zircon types according to the Pupin (1980) method, between 100 and 140 euhedral, unbroken zircons were studied for each locality. If an euhedral, but broken zircon was found, it was examined only if the pyramid and prism faces and their proportions could be evaluated. For measurements of zircon elongation, at least 75 unbroken zircons per locality were selected. In total, 358 grains were examined from the Ropianka Formation and 270 grains from the Menilite Formation. Zircon subtypes were evaluated, according to the method provided by Pupin (1980). A detailed description of the high-resolution heavy-mineral analyses (HRHMA) was published in Salata and Uchman (2013).

RESULTS

Zircon belongs to the main constituents of heavy-mineral assemblages of the Ropianka and Menilite formations. It comprises 9–49% (average 27%) and 6–33% (average 18%) in the Ropianka and Menilite formations, respectively (Fig. 4). Previous investigations, applying high-resolution heavy-mineral analysis (HRHMA method; Salata and Uchman, 2013), revealed great similarity of the zircon populations studied. The zircon populations studied in all samples from both formations are dominated by rounded grains (up to 90%), while subrounded zircon grains mostly constitute several percent (Fig. 5). Euhedral grains are less abundant, occurring in amounts of usually about 10% of the zircon populations in both formations. Both highly elongated and "stubby" prismatic crystals are present in the euhedral zircon groups and the elongated crystals are the more abundant. The euhedral zircons are mostly colourless and fre-

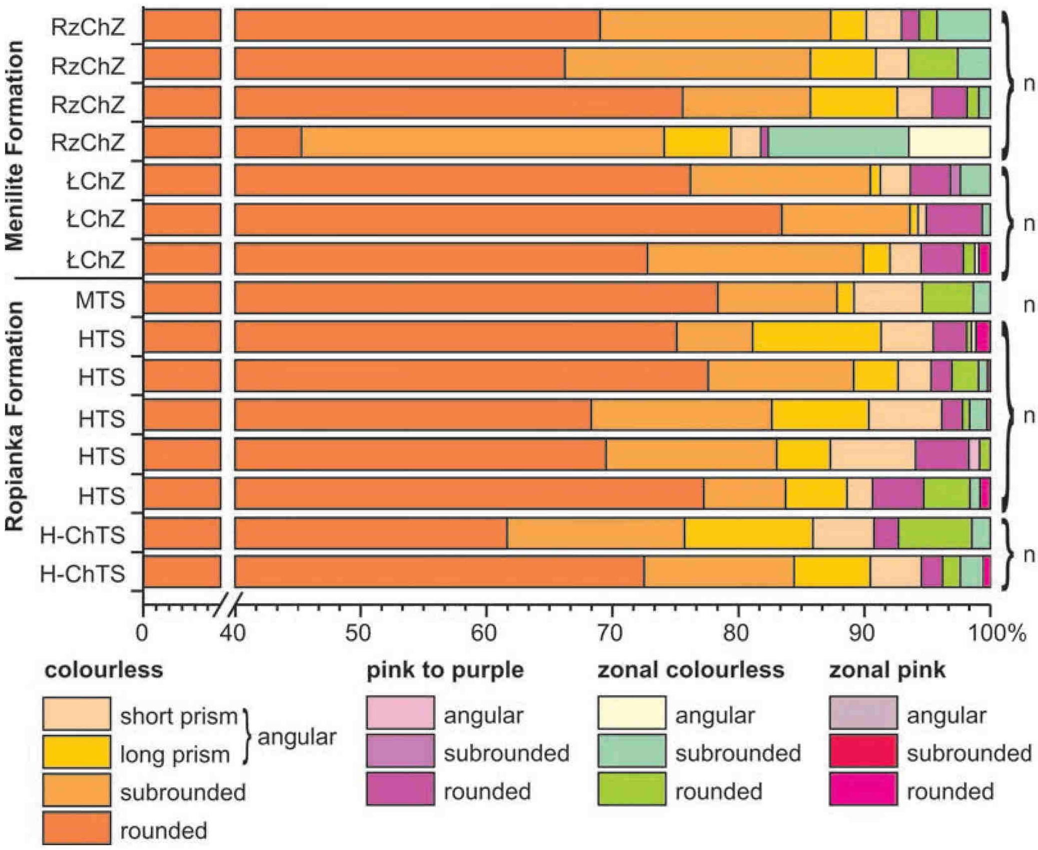
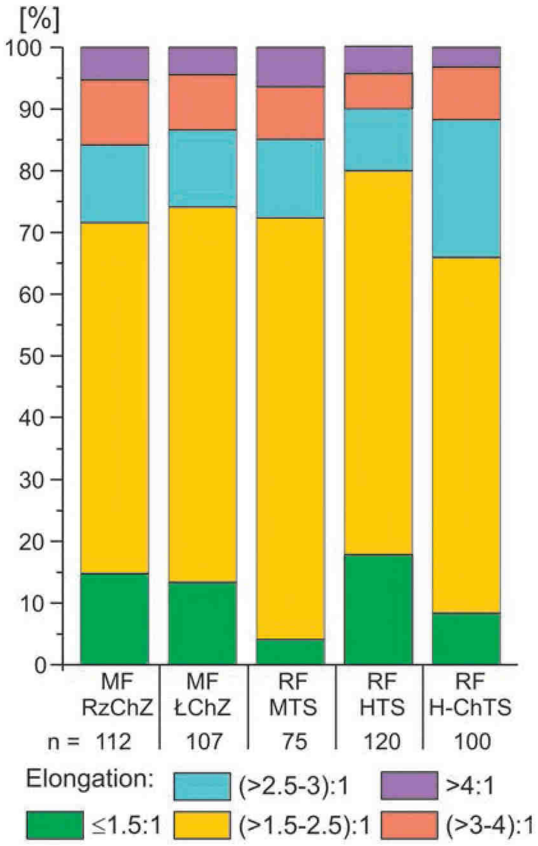


Fig. 5. Mean values of zircon types in terms of roundness, colour and zonality (data according to Salata & Uchman, 2013). Abbreviations: H-ChTS – Hadle-Kańczudzkie-Chmielnik Thrust Sheet; HTS – Husów Thrust Sheet; ŁChZ – Łańcut Channel Zone; MTS – Marginal Thrust Sheet; RzChZ –Rzeszów Channel Zone; n – number of samples studied.



quently contain ovoid melt inclusions. Pink colour varieties are found occasionally (for details see Salata and Uchman, 2013).

The measurement of crystal elongation (length:width ratio = E) of the euhedral zircons showed that very short (almost isometric; E ≤ 1.5:1), “stubby” (E < 2.5:1) and needle-shaped (E from > 4:1 to 9.5:1) grains are present in both formations (Fig. 6). The total amount of elongated and needle-shaped zircons (E > 2.5:1) is lower than the sum of short-prismatic and “stubby” ones, which comprise 13–34% and 66–87%, respectively (Fig. 6). However, the true content of elongated zircons, especially the needle-shaped ones, could have been initially higher than current measurements indicate. Observations in transmitted light revealed that elongated zircons (especially with E > 3:1) occur often as grains that are broken across the prisms, while the short prismatic and almost isometric zircons are usually intact. Therefore, elongated zircons appear to have been less resis-

Fig. 6. The content of euhedral zircons of definite elongation in studied localities. Abbreviations: H-ChTS – Hadle-Kańczudzkie-Chmielnik Thrust Sheet; HTS – Husów Thrust Sheet; ŁChZ – Łańcut Channel Zone; MF – Menilite Formation; MTS – Marginal Thrust Sheet; RzChZ – Rzeszów Channel Zone; RF – Ropianka Formation; n – number of crystals measured.

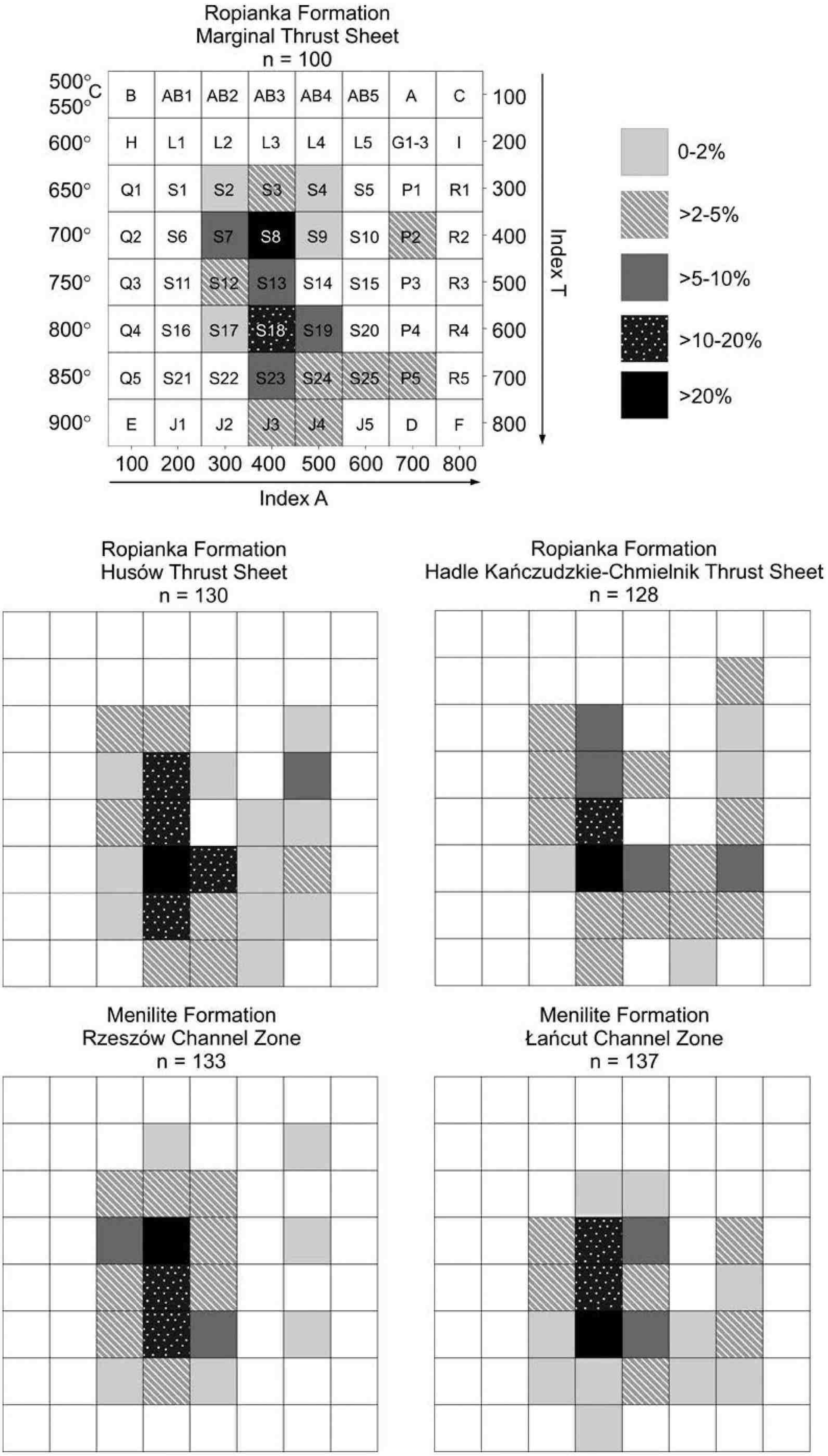
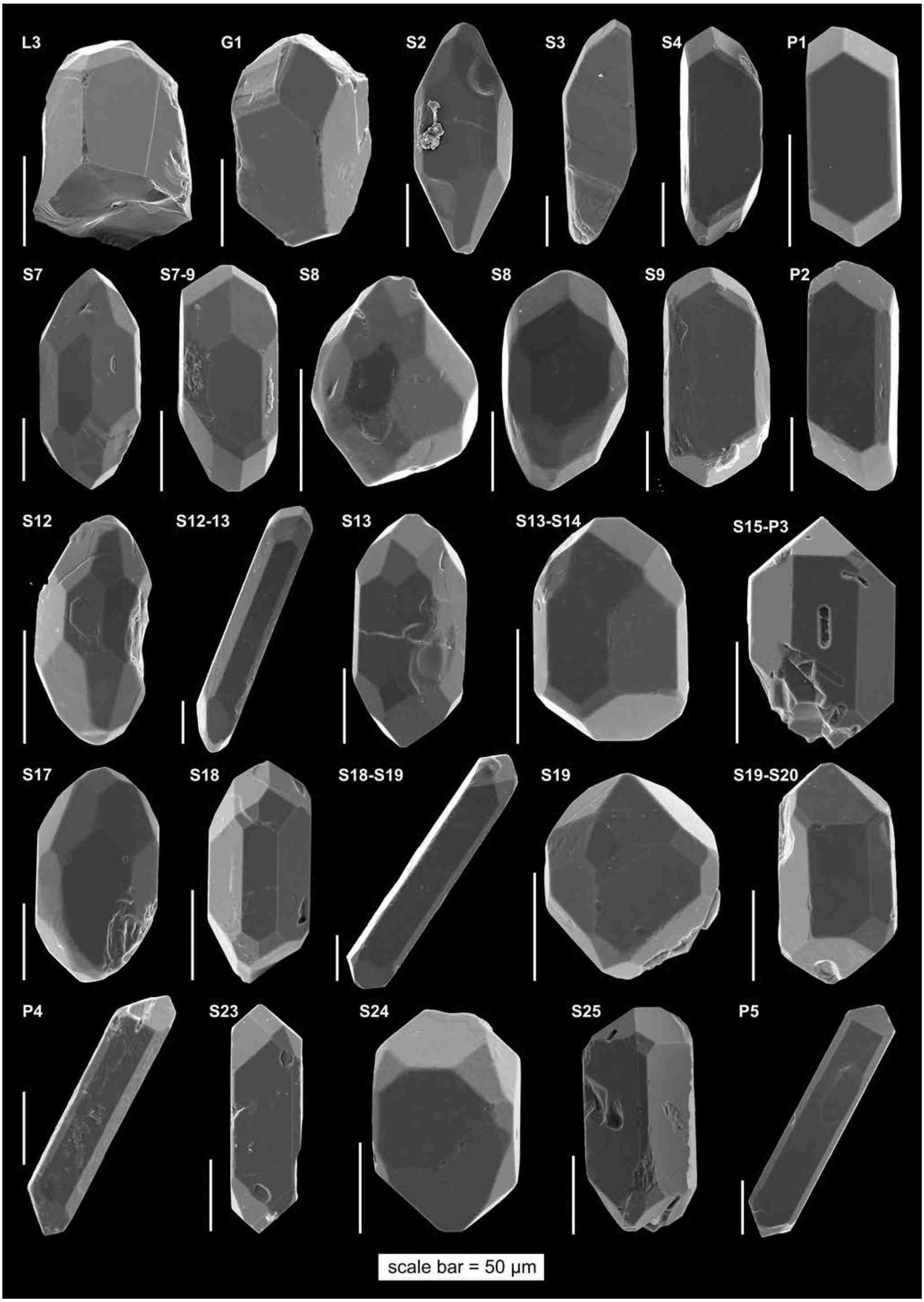


Fig. 7. Distribution and abundances of zircon subtypes, studied in typological diagram by Pupin (1980); n – number of zircon crystals studied.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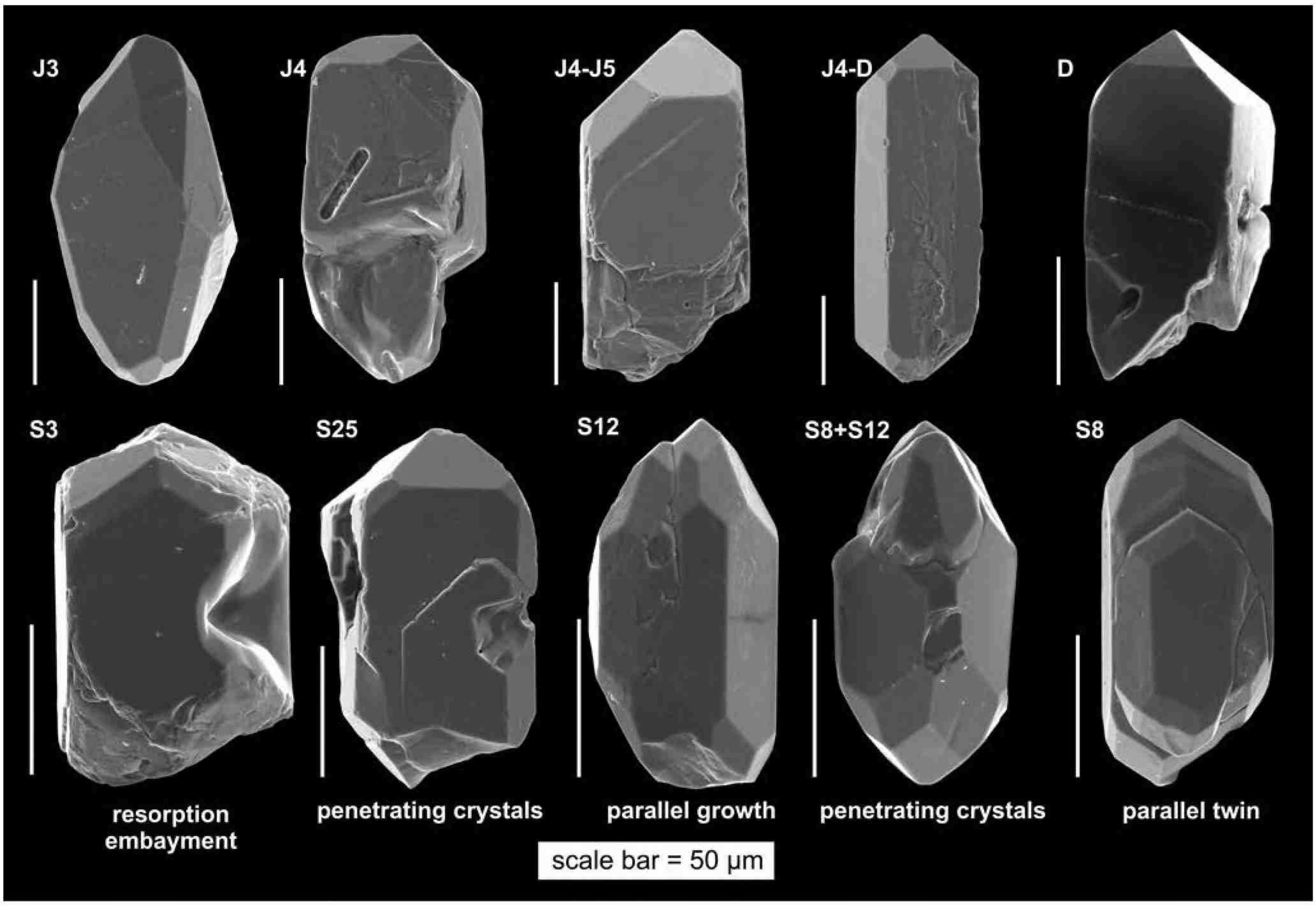

Fig. 8. Zircon subtypes occurring in Ropianka and Menilite formations in relation to zircon typology by Pupin (1980), zircon twins and embayed crystals.

tant to breakage than the short-prismatic and "stubby" zircons. As the elongation of the broken long-prismatic zircons cannot be estimated, the population appears to be relatively less abundant than it actually should be.

Morphological zircon types (Pupin, 1980) from the Ropianka and Menilite formations are similar. S-type zircons are most typical for the populations studied, and subtypes S8, S12, S13, which show equal proportions of pyramidal faces {101} and {211}, are the most abundant. The zircon subtypes concentrate in the ranges of 300–500°C and 700–850°C for index A and index T values, respectively. The S-subtypes comprise predominantly 10–20% or >20% of the zircon populations studied, while the remaining S-subtypes occur in amounts fewer than 10% or 5% (Fig. 7). Additionally, the not abundant (mostly <5%) P-types (subtypes P1–P5) and J-types (up to 5%) are present in all samples, while L- and G-types occur sporadically, <2% (Figs 7, 8). The distribution of concentration fields for the zircon subtypes in typological diagrams is also similar for both formations. The concentration fields of zircons are located mainly near the centre of the diagrams (Fig. 7). Asymmetry, combinations of zircon subtypes and twinning are typical for the zircons. Penetrating twins and parallel crystals are also present. Many zircon grains display embayments (Fig. 8) or inherited cores. These morphological features are equally common in both the Ropianka and Menilite formations.

DISCUSSION

Zircon typology applied to detrital euhedral zircon populations may result in subtype abundances, scattered over the typological diagram without any specific concentration fields visible. The dominance of mostly S8, S13 and S18 subtypes of the zircon populations, in clearly defined concentration fields (Fig. 7) indicates that the euhedral zircons in both formations originated from the same source area and protolith types. This interpretation is reinforced by comparable elongation of euhedral zircon crystals and similarity in the external features of the zircons studied (e.g., embayments, inherited cores, twinning). The data are consistent in all the samples studied, implying a first-cycle provenance for the euhedral zircon populations. The similar contribution of the zircon types in older (the Ropianka Formation) and younger (the Menilite Formation) units indicates that the lithology of the zircon source rocks most likely did not change with time. This confirms the data provided by Salata and Uchman (2013) obtained from the HRHMA, which revealed great similarities, most probably reflecting the same provenance of the zircon in both of the formations studied. The HRHMA method is particularly useful for ultrastable, highly resistant minerals, such as the zircons remaining in recycled deposits. It categorises the main mineral species in terms of their colour varieties, internal zoning, inclusions

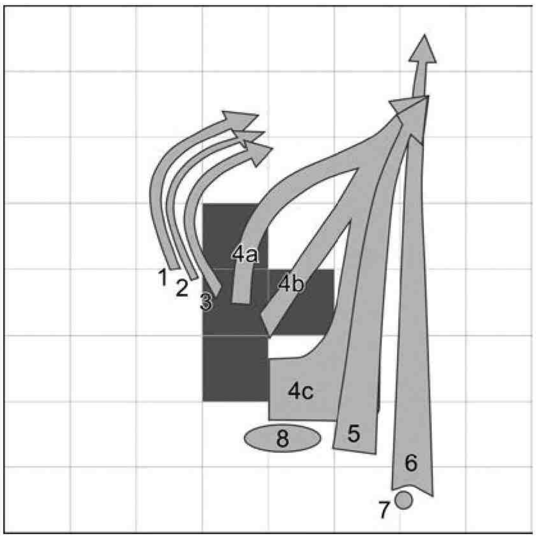

Fig. 9. Diagrams denoting fields of mean point concentrations and mean Typological Evolutionary Trends (Pupin, 1980) of zircons from: Granites of crustal or mainly crustal origin: 1 – aluminous leucogranites; sub-autochtonous monzogranites and granodiorites; 3 – intrusive aluminous monzogranites and granodiorites. Granites of crustal+mantle origin or hybrid granites: stock 4 (a, b, c) – calc-alkaline series granites, monzogranites and granodiorites; stock 5 – sub-alkaline series granites. Granites of mantle or mainly mantle origin: stock 6 – alkaline series granites; 7 – tholeiitic series granites; 8 – magmatic charnockites. Grey squares indicate fields of highest concentration of zircon subtypes in the samples studied.

and degree of roundness (Mange-Rajetzky, 1995; Lihou and Mange-Rajetzky, 1996; Mange and Wright, 2007b; Nie *et al.*, 2012; Salata and Uchman, 2013). The analogous conclusions drawn on the basis of the HRHMA method and zircon typology, supplemented with data on zircon elongation, show that the methods mentioned may be applied successfully to the comparative study of zircon populations in sedimentary rocks. However, euhedral zircon typology is limited to populations, in which zircon subtype concentration fields are defined distinctly (see also e.g., Caironi *et al.*, 1996; Loi and Dabard, 1997; Fekkak *et al.*, 2000; Lisá and Uher, 2006; Zajzon *et al.*, 2011). In other cases, the typology method applied to detrital zircons may yield results that are impossible to interpret.

The question arises as to whether detrital zircon typology may be an unequivocal tool for identification of the primary location of igneous and/or volcanic bodies and their tectonic history. The palaeotransport directions, established in the deposits of the Ropianka and Menilite formations (e.g., Książkiewicz, 1962; Kotlarczyk, 1966, 1976; Ślączka and Unrug, 1966; Bromowicz, 1974; Kotlarczyk and Leśniak, 1990), permit a search for the igneous bodies in a north-westerly direction, while the euhedral habit of zircons indicate a location of these bodies in a relatively proximal position, in relation to the Skole Basin. The presence of volcanic bodies under the Skole Nappe overthrust has not been confirmed directly and so their exact location remains unknown. Nevertheless, the numerous discoveries of igneous rocks (see references above) indicate that lithologically diverse igneous rocks were exposed during sedimentation of the Ropianka and Menilite formations.

Distribution of the main zircon crystal subtypes, clearly concentrated in lower levels of the stock-4 branches in the typological diagrams (Fig. 9), are typical for zircons originating from magma of calc-alkaline affinity (e.g., Pupin, 1980; El Baghdadi *et al.*, 2003), which is characteristic for active tectonic margins (e.g., Wilson, 1989 and references therein). The presence of subtypes at the right margin of the diagram (Fig. 9) indicates that alkaline rocks of mantle origin also might be taken into account as additional protoliths for the euhedral zircon population studied here (Pupin, 1980).

The calc-alkaline character of the protolith indicated by zircon morphology may be a basis for postulating the existence of volcanic processes along convergent margins, which may be related to a former active tectonic zone. Igneous bodies with a collision-related calc-alkaline character are located along the Kraków–Lubliniec Fault Zone, between Kraków and Lubliniec (Fig. 1C). The Carboniferous–Permian volcanism there was due to the collision between the Brunovistulian and Małopolska terranes (e.g., Buła *et al.*, 1997; Żaba, 1999; Malinowski *et al.*, 2005; Żelaźniewicz *et al.*, 2008; Nawrocki *et al.*, 2010; Słaby *et al.*, 2010). The volcanism is evidenced by a suite of mafic-intermediate and felsic rocks (e.g., Harańczyk, 1989; Czerny and Muszyński, 1997; Lewandowska *et al.*, 2010; Słaby *et al.*, 2010; Wolska, 2012 and references therein). The *in situ* study of zircon types in rhyodacite-dacite rocks from Zawiercie by Szczepanik (2001) showed concordance of the zircons with a calc-alkaline character of their host rocks (Czerny and Muszyński, 1997). The calculated initial, main and closing crystallization temperatures for the zircons denoted on average 850°C, 680°C and 600°C, respectively, with concentration fields of the predominant zircon types ranging from 300 to 500 in index T values (Szczepanik, 2001). In view of these data and the fact that the Kraków–Lubliniec Fault Zone continues under the Carpathian overthrust (Pietsch *et al.*, 2010), the provenance of the zircons examined here may be connected with the same tectonic event that gave rise to the igneous bodies in the Kraków–Lubliniec area.

The dominance of short and stubby zircons with elongation E<2.5:1 in the Ropianka and Menilite formations indicates a need to search for plutonic bodies (e.g., Corfu *et al.*, 2003 and references therein) as host rocks for the zircon populations studied. This idea is supported by the late Cambrian to early Permian K/Ar ages, obtained for a granite pebble derived from a northern source and found in the Skole Unit (Poprawa *et al.*, 2006 and references therein). Poprawa *et al.* (2006) related this age to that, obtained for granites associated with the Kraków–Lubliniec Fault Zone. Additionally, Jasionowicz and Wieser (1963) described andesite (see also Gucwa and Pelczar, 1992) pebbles and blocks from the Lower Cretaceous Spas Shale in Niedźwiada, indicating a pre-Tithonian age for the volcanic activity in the area.

The zircons examined and the plutonic (mainly finely crystalline granitic rocks) and volcanic pebbles from the Ropianka Formation, the Babica Clay and the Menilite Formation may have originated from the same tectono-magmatic event, perhaps related to the south-eastern prolongation of the Kraków–Lubliniec Fault Zone. Preliminary interpretations of the geochemical composition of the pebbles of igneous rock found in the Menilite Formation revealed great similarities to igneous rock bodies in the Małopolska Block (Salata, Uchman, Dudek, 2014, unpublished data). However, it cannot be excluded that the zircon populations studied may have been derived from plutonic bodies, other than those of Carboniferous–Permian age. To confirm the assumption on protolith location and obtain high-resolution data, the detrital zircon typology method should be followed by single-grain chemical analyses and age determination (e.g., Willner *et al.*, 2003; Zajzon *et al.*, 2011; Nehyba *et al.*, 2012).

Considering host-rock lithology, detrital zircon typology is not a definitive tool, at least in the case of zircons with a calc-alkaline affinity. Calc-alkaline rocks may be represented by a large spectrum of rocks, ranging from intermediate to felsic. They may be granitoids, monzonites and diorites or quartz-gabbros, whereas volcanic rocks may be represented by rhyolitic bodies (e.g., see Figs 3, 10 in Pupin, 1980). Caironi *et al.* (2000) noticed a difference in the development of zircon crystal faces from monzonite and granite. Additionally, the recent study by Shahbazi *et al.* (2014) revealed that finely crystalline granitic bodies contain a particular abundance of the S12 subtype of zircon crystals. However, it is impossible to establish source rock lithology with certainty, using detrital zircon typology alone without additional evidence. Measurements of zircon elongation may assist the general establishment of depth for an igneous body that is a possible source rock. The dominance of "stubby" and short-prismatic crystals in the zircon populations indicates deeply situated, slowly cooled plutonic bodies, while highly elongated, needle-shaped zircons indicate, in turn, rapidly crystallized, porphyritic, sub-volcanic intrusions, high-level granites and gabbros as host rocks (Corfu *et al.*, 2003). The dominance of short-prismatic and "stubby" shapes in the population studied indicates that the zircons were eroded mostly from plutonic bodies. However, in other cases, if neither "stubby" nor needle-shaped zircons were to predominate, such a conclusion could be inadmissible, because plutonic bodies also might contain elongated zircons (e.g., Corfu *et al.*, 2003; Sturm, 2010; Shahbazi *et al.*, 2014).

Detrital zircon typology in the context of source-rock lithology provides only limited petrogenetic and geotectonic knowledge. The advantage of the method is that it contributes valuable data enabling the preliminary establishment of the geotectonic setting of the source area. In combination with elongation measurements, zircon typology allows an investigator to delimit potential source areas and rocks that can be the focus of further comparative research.

CONCLUSIONS

The study showed that detrital zircon typology, supplemented with elongation measurements, yields useful information on source and, under favourable conditions, is a valuable tool for comparison of the zircon populations in sedimentary deposits of different ages in terms of their provenance. The zircon populations examined from the Ropianka and Menilite formations display great similarities with respect to external crystal morphology, which indicate provenance from the same type of protolith. Moreover, the similar contributions of the dominant euhedral zircon subtypes and crystals of definite elongation in older (the Ropianka Formation) and younger (the Menilite Formation) deposits indicate that the lithology of the source rocks did not change through time for the euhedral zircons studied. Zircon typology, supplemented with data on zircon elongation, gives comparable results for the HRHMA method, showing that the methods may be successfully applied as a supplement for the comparison of heavy-mineral populations and their provenance in sedimentary rocks.

Studies of the morphology of detrital zircon yield only limited knowledge, regarding geotectonics and igneous source rocks. However, they contribute useful premises for the establishment of the geotectonic setting of a source area on a provisional basis. The elongation of the euhedral zircon crystals of the present study indicates a provenance mostly from slowly cooled deep-seated igneous bodies. Nevertheless, if neither stubby nor needle-shaped zircons were to predominate in other situations, it would be impossible to determine source-rock lithology on the basis of only zircon typology and elongation measurements. In the case of the zircon populations studied, a combination of zircon-elongation measurements and zircon typology permits the recognition of potential source areas and rocks that will be the focus of further analytical research.

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