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THE ALKALINE MAGMATISM FROM THE POLISH WESTERN CARPATHIANS

Evidence of Mesozoic volcanic activity can be found in all the main geotectonic zones of the Western Carpathians. A classic area of rocks belonging to the teschenite-picrite association is restricted to the western part of the Outer Carpathians. This province (~ 1500 km²) is 15-25 km wide and extends in the NE direction for over 100 km from Hranice in Moravia, Czech Republic, to Cieszyn and Bielsko-Biała in Poland (Fig. 1). Teschenites and related rocks outcrop in the Silesian nappe.

The Outer Carpathians are formed by the Subsilesian, Silesian, Fore-Magura and Magura Units (Nappes) which are structural remnants of several basins developed on the margin of the European Platform incorporated later into the Tertiary Carpathian accretionary wedge.

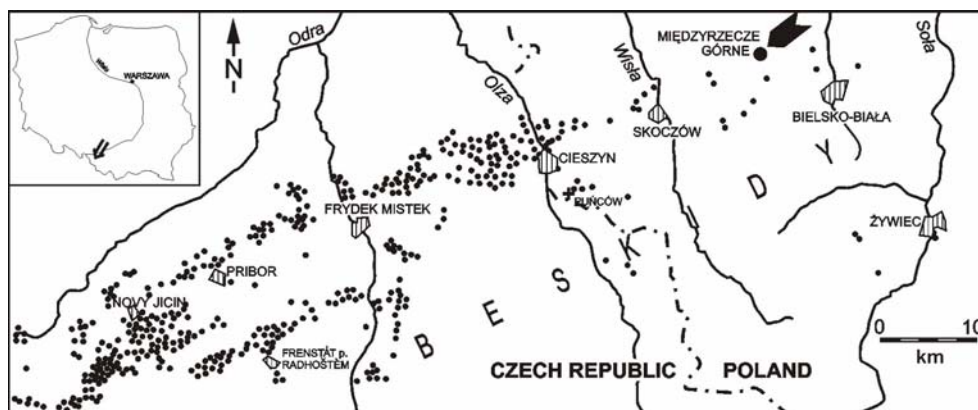


Fig. 1. Location map of the picrite-teschenite association in southern Poland and Czech Republic (from Smulikowski 1930 and Šmid 1978).

According to Golonka (2004) during the Late Jurassic and Early Cretaceous the southern part of the North European Platform, north from the Pieniny/Magura realm began to be rifted. The Outer Carpathian rift (Silesian Basin) had developed with the onset of calcareous flysch sedimentation. The western Carpathian Silesian Basin probably extended into the eastern Carpathian Sinaia or

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“black flysch” Basin and to the southern Carpathian Severin zone. The Outer Carpathian Basin reached its greatest width during the Hauterivian – Aptian. With the widening of the basin, several subbasins (the Silesian, Sub-Silesian, Skole, Dukla and Tarca~u began to show their distinctive features.

The evolution of the Silesian basin was the scope of several sedimentary and kinematic analyses. The data presented by Nem~ok et al. (2001) show that this basin started to develop during the rifting events from the Jurassic/Cretaceous boundary through to the Cenomanian. The original width of the Silesian Basin was about 130-138 km. The rifting formed the horst and graben system defined by NW-SE striking normal faults. Average widths of the horsts and grabens were about 18 and 50 km, respectively, while the altitude differences between them were smaller than 2 km. The rift fill comprises Valanginian (rarely Tithonian)-Cenomanian sedimentary sequences. The subsidence analysis of Poprwa et al. (2002) attributed the same rift fill to post-rift thermal sag stage of the Silesian basin evolution. The syn-rift fill was not recognised due to preferential emplacement of detachment surfaces at a level of the post-rift sediments. The above authors suggest that the rifting in the Outer Carpathians basins could have taken place during Oxfordian-Kimmeridgian. They regard the Early Cretaceous extension as a supplementary mechanism of subsidence to thermal sag. This hypothesis may be supported by tectonic evolution of the surrounding basins, i. e. the Southern peri-Tethyan realm (Polish Basin), where the increased tectonic subsidence rates during Oxfordian – Kimmeridgian times is correlated with intensified rifting and wrench activity within the Arctic–North Atlantic rift system and along the northern Tethyan margin. According to Olszewska and Wieczorek (2001) the Silesian basin belongs to a pull-apart type of sedimentary basins.

Teschenites and related rocks have a consistent stratigraphic position; they are chiefly encountered in Upper Cieszyn Shales (Valanginian-Hauterivian) while in Lower Cieszyn Shales (Kimmeridgian-Tithonian) and Cieszyn Limestones (Tithonian-Beriasian) they occur sporadically. Redeposited fragments of these rocks were recognised in the Albian sediments (Geroch et al. 1972). The unit of the Cieszyn Beds (up to 700 m thick) is the oldest one of the Silesian Basin; the Lower Cieszyn Shales constitute the detachment horizon of the Cieszyn Nappe. Radiometric data presented by Lucińska-Anczkiewicz et al. (2002) and Grabowski et al. (2003) imply the period of magmatism activity in the Silesian Basin from Valanginian up to Barremian-Aptian. These data correspond to geochronological data (approx. 100 Ma) published by Spišiak and Balogh (2002) for alkaline basalts/basanites in the Krížna Nappe of the Western Carpathians. Probably, at that time the Upper Cieszyn Shales formed so-called soft sediment, with wet-bulk density below 1.5 g/cm³ (Einsle 1980). From a mechanical point of view, the basaltic magma upwelling along tensional fissure must form sills as soon as it reaches soft sediments. At that time magma pressure is greater than lithostatic pressure of neighbouring rock or sediment plus their tensile strength. This phenomenon can explain the occurrence of teschenite sills mainly in the Upper Cieszyn Shales. The main products of the volcanic activity are shallow, subsurface sills, which predominate over effusive or volcanoclastic rocks (Gucwa et al. 1971).

The thickness of these sills varies from a few centimetres to 40 meters (Lamberger 1971). Teschenites and related rocks were also traced in 31 boreholes down to depth of 820 m (Konior 1966). Thus, the volcanism described here was localized in the longitudinal area, which was parallel to the axis of the Silesian basin. The teschenite dykes and sills intruded in an extensional regime of a horst-graben system in the soft sediments of Silesian basin. This rifting was aborted and not followed by spreading and oceanization, probably because the tectonic inversion occurred during the Late Cretaceous (Nemčok et al. 2001).

The term “teschenite” was used for the first time by Hohenegger (1861) to describe all granular rocks from the Moravskosliezské Beskydy Mts. Tschermak (1866) distinguished melanocratic olivine-rich rocks (picrite), confining the term teschenite to olivine-free granular rocks. The studies of Smulikowski (Cieszyn Silesia, 1929, and the region as a whole, 1930) and Pacák (Moravia, 1926) provided basic information on the chemistry and petrography of these rocks.

Table 1. Averages for picrite (1), lamprophyre (2), diabase (3), teschenite (4), syenoteschenite (5) and syenite (6). Numbers of the samples averaged and the standard deviations are given in brackets.

	1. (n=31)	2. (n=38)	3. (n=15)	4. (n=28)	5. (n=12)	6. (n=10)
SiO ₂	39.13(1.61)	39.76(3.11)	47.72(2.26)	41.42(2.79)	43.13(3.27)	49.23(1.70)
TiO ₂	1.76(0.63)	3.17(0.74)	2.11(0.34)	2.66(0.72)	2.47(0.56)	0.67(0.36)
Al ₂ O ₃	9.08(2.01)	12.55(1.44)	14.13(0.92)	14.11(1.77)	15.87(2.94)	21.03(1.30)
Fe ₂ O ₃	4.53(1.57)	5.51(2.35)	2.78(1.21)	5.32(2.26)	6.32(2.86)	2.65(2.16)
FeO	6.77(1.27)	6.35(1.19)	7.64(1.15)	6.26(1.21)	5.99(2.26)	2.67(1.80)
MnO	0.17(0.06)	0.18(0.07)	0.12(0.03)	0.17(0.03)	0.18(0.03)	0.11(0.05)
MgO	20.01(5.52)	8.22(1.54)	6.25(1.03)	6.21(1.01)	4.06(0.92)	0.93(0.85)
CaO	10.37(3.88)	13.65(1.80)	9.41(2.27)	13.25(1.71)	9.75(1.26)	6.14(1.33)
Na ₂ O	1.23(0.72)	2.00(0.82)	3.44(0.79)	2.75(1.16)	3.63(1.06)	5.25(1.41)
K ₂ O	0.90(0.32)	1.71(0.63)	0.85(0.49)	2.08(0.61)	2.75(0.73)	5.10(1.18)
P ₂ O ₅	0.55(0.57)	1.12(1.14)	0.34(0.07)	0.71(0.45)	1.09(0.88)	0.17(0.05)
CO ₂	1.01(1.24)	1.91(2.15)	1.75(1.80)	1.30(1.91)	0.10(0.16)	0.55(0.63)
H ₂ O ⁺	4.45(1.24)	3.54(1.59)	3.30(0.92)	3.73(1.99)	3.39(2.03)	4.97(0.98)
Total	99.96	99.61	99.85	99.89	99.56	99.48

The teschenite-picrite association contains a wide range of rocks with variable textures, structures and quantitative mineral abundances. Following Smulikowski (1980), the rocks of hypabyssal intrusions can be classified as picrites, alkaline lamprophyres, teschenites and diabases. These granular rocks, distinctly silica-undersaturated, belong to essexite or theralite groups with analcite as the main feldspathoid. Among them, melanocratic (colour index > 60) varieties include picrite and lamprophyre. The picrites (Table 1, an. 1) consist of abundant crystals of olivine (up to 50 vol. %), amphibole (kaersutite), clinopyroxene (diopside), phlogopite and Cr-spinel. Felsic cryptocrystalline matrix, forms up to several per

cent of volume. The picrite sills are up to 30- 40 m thick (Konior 1966). Monchiquite, sannaite and camptonite represent the alkaline lamprophyre group. They are very common in the whole region forming thinner sills up to 4 - 6 meters thick. These rocks are fine-grained, even aphanitic to medium-grained ones containing phenocrysts of olivine (up to 9-12 vol. %), clinopyroxene, amphibole and phlogopite. The matrix comprises a younger generation of pyroxene and amphibole together with feldspars, apatite, Fe-Ti oxides, sphene and zeolites (or glass). The camptonite groundmass contains plagioclase while alkali feldspars predominate in the sannaite matrix. In the monchiquites, the matrix is mainly composed of glass, which in most cases has been replaced by secondary analcime. The lamprophyre sills locally contain leucocratic pegmatitic clusters enriched in titanite and apatite (Tab. 1, an. 2). Their average chemical composition (Tab. 1, an. 2) is very similar to teschenite (Tab. 1, an. 4) which forms the following chilled-margin part of the teschenite sill.

The teschenites and the diabases are mesocratic (colour index 30 and 70, respectively), granular rocks. In a continuous vertical section between the upper and lower chilled margins of any teschenite sill, the following varieties can be distinguished: teschenite (Tab. 1, an. 4), syenoteschenite (Tab. 1, an. 5) and syenite (Tab. 1, an. 6). The gradation upward from teschenite to syenite is characterised by a progressive increase in the proportion of felsic mesostasis (plagioclase, alkali feldspars and nepheline) and by a decrease in clinopyroxene and amphibole contents. In the syenoteschenite, felsic phases predominate over mafic phases. The syenite occurs only as small irregular bodies with sharp boundaries in the upper part of the sill or as veins cross-cutting the upper or lower chilled margins. In syenite, the alkali feldspars and nepheline constitute about 80 vol.% (leucocratic rocks). The teschenite form the thickest sills reaching up to 40- 50 m in thickness, (Konior 1966, Lamberger 1971). Diabase is not very common in the area (Tab. 1, an. 3). This rock is medium-grained with ophitic texture. It contains the largest amounts of SiO₂; some of the diabase samples are quartz- and hyperstene-normative while the other show nepheline in their CIPW norms. The largest diabase sill (20 m thick) was described by Smulikowski (1929) from Boguszowice near Cieszyn.

The mineral composition of the alkali rocks described here is relatively simple; the main phases are olivine (Fo₉₀₋₇₅), clinopyroxene, amphibole, dark mica (phlogopite, Ti-rich biotite, lepidomelane) and spinel. Among the light minerals, feldspar and nepheline are dominant.

Clinopyroxene is the most abundant minerals (up to 70 vol.%) in the rock series. It exhibits typical for alkali rocks sector zoning with pyramidal sectors enriched in Mg and Si, and depleted in Fe, Al and Ti, as opposed to prismatic sectors. Most of the clinopyroxene analyses plot above the Di-Hd join on the pyroxene quadrilateral as a consequence of Ti-Tschermak's molecule being the dominant substitution. The silica concentration is the most important factor controlling the solubility of Al and Ti (CaTiAl₂O₆ amount) in diopsidic pyroxenes; the presence of sector-zoned, subsiliceous Al-Ti diopsides and subsiliceous amphiboles (kaersutite) is characteristic of melts low in SiO₂. Only diabase

pyroxenes do not exhibit pronounced sector zoning, what was connected with the high silica concentration in these rocks. The Ti-Tschermak's substitution reached a minimal level at these pyroxenes.

Generally, according to the IMA pyroxene classification, the pyroxenes are diopsides; only clinopyroxene from syenite plots in the field of hedenbergite. In the most altered parts of the teschenite sill, secondary pyroxenes of aegirine composition occur, containing up to 6 wt % TiO₂. The sector-zoned pyroxenes originated during rapid, disequilibrium crystallization, at high temperature and relatively low pressure, near the Earth's surface when the upwelling magma injected wet flysch sediments. Only in the picrite sill from the Międzyrzecze complex the megacrysts of chrome-diopside have been found. These were interpreted as xenocrysts derived from disaggregation of mantle xenoliths, which became unstable during magma ascent and were resorbed for the greater part.

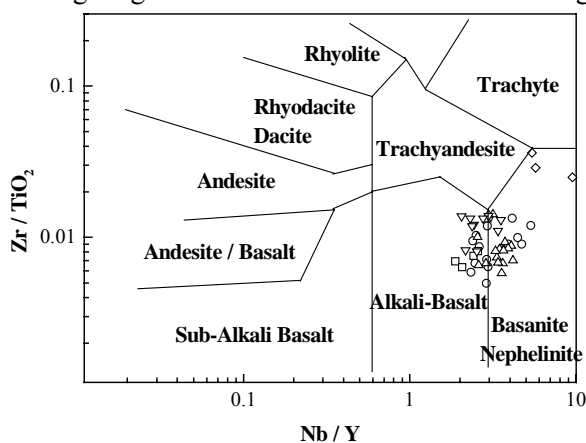


Fig. 2. Position of teschenite and related rocks in the classification diagram of Winchester and Floyd (1977).

In the rocks examined, there are numerous intergrowths and epitaxial relations of pyroxene and amphibole that indicate their simultaneous crystallisation or amphibole nucleation after pyroxene. The amphibole ranges in composition from kaersutite through ferro-kaersutite and ferro-pargasite to hastingsite. In the picrites, the chemical composition of spinel varies from Al-rich chromite to Al/Cr-rich magnetite while the remaining rocks (diabase, teschenite and lamprophyre) contain titanomagnetite as the dominant spinel. An extensive subsolidus, low-temperature oxidation of titanomagnetite to titanomaghemite is a characteristic feature of these rocks (Harańczyk et al. 1971, Hubicka-Ptasińska et al. 1971). The occurrence of perovskite in the picrite-teschenite association was recorded for the first time by Włodyka et al. (2000).

Plagioclase is one of the dominant minerals in most of the rocks with the exception of the picrite. In general, plagioclase composition varies between An₇₀ and An₂₀ and Or content increases (up to Or₁₀) with increasing Ab. The compositions of K-feldspar grains range from Or₇₀Ab₂₈An₂ to Or₄₈Ab₄₈An₄; some individual grains of alkali feldspar are Ba-rich (up to 6 wt.% BaO). Nephelines

show evolutionary trends from $\sim Qz_4Ne_{80}Ks_{16}$ to $\sim Qz_{32}Ne_{62}Ks_6$ (mol %). The first stage of primary feldspar metasomatism led to formation of an adularia-albite paragenesis. The zeolitization process, post-dating the deuteric formation of feldspar, resulted in the development of the following zeolites: analcime, natrolite mesolite, thomsonite, heulandite, harmotome and ferrierite.

In the most interesting picrite sill in Międzyrzecze, the following minerals, newly found in this area, have been identified: datolite and fluorapophyllite (Włodyka et al. 1998), pectolite (Włodyka et al. 1999) and Ti-bearing garnets belonging to the andradite-titanian andradite (melanite)-schorlomite series (Włodyka et al. 2000).

In terms of major element compositions, teschenite and related rocks are characterized by low SiO_2 contents (39-50%) and variable Mg# values. They show a broad range of compositions, from primitive (Mg# = 0.70, Cr = 1400 ppm) to strong fractionated (Mg# = 0.10, Cr = 6 ppm). The rocks are alkaline as shown by high contents of alkalis, associated with elevated amounts of P_2O_5 , TiO_2 , and incompatible trace elements such as LREE, Zr, Nb, Y, Ba and Sr. In the diagram of Winchester and Floyd (1977) they show quite coherent group which plots in the field of alkaline basalts (the first sub-group) and basanites/nephelinites (the second sub-group). On the tectonic discrimination diagrams (Fig. 3a, b) these rocks plots in within-plate (WPB), continental basalts, which could be generated by hot spot activity (Golonka 2004).

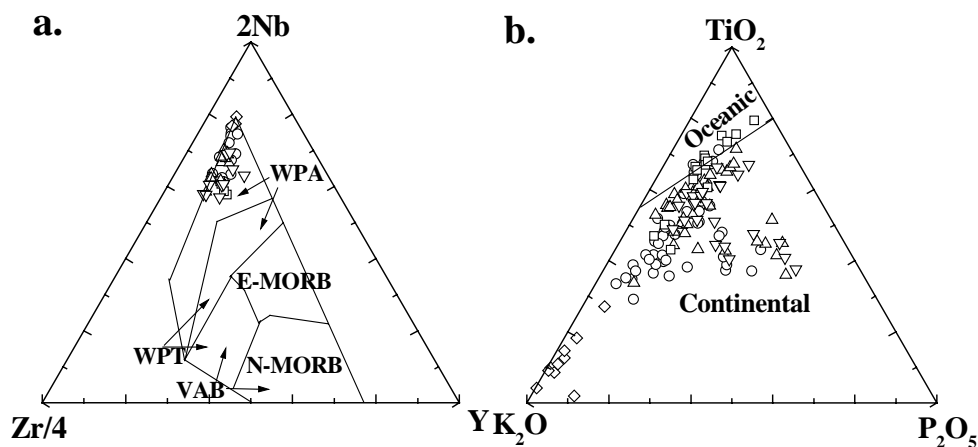


Fig. 3. Position of teschenite and related rocks in the discrimination diagrams of: a. Meschede (1986); b. Pearce et al. (1975).

The lack of the Nb-Ta depletion in the REE patterns (Lucińska-Anczkiewicz 2000) indicates rather limited crustal contamination (Lucińska-Anczkiewicz 2000). The major- and trace-element patterns, and also the Nd-Sr isotopic values, indicate that the parent magma of such a differentiated rocks series was likely to have been the product of partial melting in the upper mantle (Narebski 1990; Dostal et al. 1998). The geochemical modelling shows that rocks described could be generated by the melting of a garnet-bearing upper mantle source followed by fractional crystallization. The basaltic rocks of the first sub-group were formed due to more

advanced melting than the second one at a depth larger than 60-80 km (Dostal et al. 1998).

The geochemical patterns of the Central Western Carpathians (Spišiak 2002) volcanics rocks are very similar to those of the External Western Carpathians (Kudělásková 1987) and the Eastern Carpathians (Varitchev 1997). Based on geochemical and petrological comparisons, it is reasoned that volcanism in these geotectonic zones was closely connected with initial rifting in continental crust of reduced thickness (Gucwa et al. 1985, Narebski 1990, Spišiak 2002, Varitchev 1997). Cretaceous alkali volcanic rocks in the External Western Carpathians can be compared to the Late Cenozoic alkali volcanic rocks of Central and Western Europe. They are also similar to Mesozoic alkali volcanic rocks from various parts of Europe, e.g. the North-Pyrenean rift zone and Northern Calcareous Alps. For all these rock series it was evidenced that their parent magmas were derived from a HIMU-type deep-seated mantle source (Spišiak, Balogh 2002).

In general, volcanic activity was located in a zone parallel to the axis of the Silesian Basin. Volcanic activity was confined to isolated tensional fissures; the upwelling magma was emplaced mainly as sills in soft sediment. Sometimes, on reaching the seafloor, it flowed laterally to form lava beds. Smulikowski (1929, 1930) and Mahmood (1973) postulated a two-stage differentiation model, one in a deep-seated magma chamber and the second in the individual sill through the mechanism of fractional crystallization. The sill was formed by multiple injections of various magmas, which were produced in a lower-level magma chamber by differentiation of alkali-rich picritic magma. The magma injections caused metamorphism of the country rock at their contacts. According to Wieser (1971), paragenetic contact metamorphic assemblages indicate that temperatures of 400-500°C were reached in the neighbourhood of the contacts.

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