# Early Palaeozoic Intracontinental Rifting and Early Sea-Floor Spreading in the Central West Sudetes (Bohemian Massif): Geochemical and Nd–Sr Isotopic Study on Metavolcanic Rocks of the East Krkonoše Complex

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The West Sudetes (NE Bohemian Massif) are a collage of terranes amalgamated during the Variscan Orogeny (e.g., Narebski 1994). The East Krkonoše Complex (EKC) is situated in the central part of the West Sudetes. Most of the EKC is formed by a volcano-sedimentary group comprising a varied sequence of phyllites, marbles and quartzites, interlayered with porphyroids and greenschists. Porphyroids (high-silica metarhyolites) are more abundant than greenschists. The mafic–felsic volcanism is dated close to the Cambrian/Ordovician boundary by a Rb–Sr whole-rock age of 501 ± 8 Ma (Bendl and Patočka 1995).

Based on the trace element composition the greenschists resemble modern basalts of OIB- to MORB-types. The $^{143}Nd/^{144}Nd$ isotope ratios of the EKC greenschists (expressed as $\varepsilon_{Nd500}$ corrected for in situ decay of $^{147}Sm$ assuming a 500 Ma age) vary from +3.1 to +6.6. According to the trace element and isotope features, the greenschist protolith origin can be related to progressive melting in the upper mantle upwelling associated with intracontinental rifting. At the early stage, limited melting of an upwelling asthenosphere in the garnet stability field produced alkali basalts and enriched tholeiites, compositionally equivalent to OIBs. A later stage of extensional tectonics caused increasing degrees of melting at shallower depths (in the spinel stability field), resulting in the generation of tholeiitic basalts with E- to N-MORB-like characteristics.

The Nd isotope compositions of the porphyroids and greenschists disprove a direct evolution of the rhyolites from the associated mafic magmas through closed-system fractionation. The values of $(^{87}Sr/^{86}Sr)_{500}$ = 0.706 (Bendl and Patočka 1995) and $\varepsilon_{Nd500}$ = -5 ± 1 of the porphyroids suggest that their protolith contained a major continental crust component, reflecting either pure crustal melting of reservoirs with low Sm/Nd and moderate Rb/Sr ratios, or substantial incorporation of crustal melts during differentiation from mantle magmas (via AFC). In either case the mantle melts provided thermal energy for partial melting at the continental crust.

A cluster of bodies of partly retrogressed mafic blueschists is exposed along the eastern margin of the EKC. It represents the southern promontory of the Leszczynie Volcanic Fm. (LFV), fully exposed further north in Poland. The U–Pb data on zircons from the mafic blueschists yielded a protolith age of 485 ± 4 Ma (Timmermann et al. 1999), compatible with U–Pb zircon ages of 505 ± 5 Ma and 494 ± 2 Ma for the felsic and mafic rocks of the LVF main body (Oliver et al. 1993), i.e. the age corresponding to the Cambrian/Ordovician boundary, too.

The mafic blueschists of the EKC correspond in chemical terms mostly to N- to E-MORB, while the OIB-like types are minor. The blueschists are poor in REE and usually display flat to LREE-depleted chondrite-normalized distribution patterns; the types showing moderate light-to-heavy REE fractionation are rather subordinate. The relative fractionation of HFSE and REE groups is illustrated by the La/Ta values usually near N-MORB ones, and the Th/La, La/Hf, Sc/La and $(La/Sm)_N$ ratios transitional between those of N- and E-MORBs; only the Zr/Y values are analogous also to the OIB-type ratios.

The age-corrected Nd isotopic signatures of the EKC mafic blueschists, $\varepsilon_{Nd500}$ (i.e. corrected for the ca. 500 Ma magmatic age), are strongly radiogenic, with usually high and tightly grouped values (+6.0 to +7.7); only one sample has a lower value (+3.1) which might reflect a contamination by terrigenous sedimentary material. These Sm–Nd isotope characteristics point to rather homogeneous mantle source materials that were largely depleted in LREE on a time-integrated basis ($\varepsilon_{Nd}$ = +7), a typical feature of the convecting upper mantle. An upper mantle-related origin of the EKC mafic blueschist protolith is also indicated by the low $(^{87}Sr/^{86}Sr)_{500}$ values (<0.704) which were obtained from the least altered samples (Bendl et al. 1997).

The LVF mafic rocks (dominated by amphibolites) also show generally MORB-like major and trace element compositions as well as high $\varepsilon_{Nd500}$ values (+7 to +8) (Kryza et al. 1995; Winchester et al. 1995; Patočka and Smulikowski 1998). Kryza et al. (1995) considered that the LVF metabasite protolith had affinity with basic melt extracted from a strongly depleted mantle source such as N-MORB; the subordinate felsic rocks of the LVF are interpreted as fractionation products of parent melts in common with the metabasite protolith.

The geochemistry of the EKC bimodal metavolcanics and their association with abundant terrigenous metasediments suggest a primary origin as a felsic-mafic volcanic suite generated in an evolved intracontinental rift setting. An incipient continental break-up and oceanic crust formation may be indicated by the geochemistry of the EKC mafic blueschists, and also of the LVF metabasites. These processes, ubiquitous in Western and Central Europe during the Early Palaeozoic (e.g., Pin and Marini 1993), evidence large-scale fragmentation of the Gondwana supercontinent northern margin. The EKC mafic blueschist trace element compositions follow the theoretical mixing curves between N- and E-MORB-type end-members. Recent basalts showing a similar spectrum occur in volcanoes (seamounts) located near the axes of mid-ocean ridges. The seamounts form pronounced irregularities of the ocean-floor and are therefore more likely to be scraped off the sinking lithosphere and incorporated into accretionary wedges during subduction. Such a process may be responsible for the preservation of the mafic blueschist bodies in the Variscan mélange of the EKC.

## References


BENDL J. and PATOČKA F. (1995): The $^{87}Rb-^{86}Sr$ isotope geochemistry of the metamorphosed bimodal volcanic association of the Rýchory Mts. crystalline complex, West Sudetes, Bohemian Massif. *Geol. Sudetica*, 29: 3-18.

BENDL J., PATOČKA F. and PIVEC E., 1997. The $^{87}Rb-^{86}Sr$ isotope geochemistry of the blueschist and greenschist metavolcanics of the Rýchory Mts. crystalline complex, West Sudetes, Bohemian Massif. *Geol. Sudetica*, 30: 3-20.

KRYZA R., MAZUR S. and PIN CH., 1995. The Leszczyniec meta-igneous complex in the eastern part of the Karkonosze-Izera Block, Western Sudetes: trace element and Nd isotope study. *N. Jb. Min., Abh.*, 170: 59-74.

NAREBSKI W., 1994. Lower to Upper Paleozoic tectonomagmatic evolution of NE part of the Bohemian Massif. Zblt. *Geol. Paläont.*, 9/10: 961-972.

OLIVER G.J.H., CORFU F. and KROGH T.E., 1993. U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. *J. Geol. Soc., London*, 150: 355-369.

PATOČKA F. and SMULIKOWSKI W., 1998. The geochemical correlation of the East Krkonoše Complex metabasites (West Sudetes, Czech Republic and Poland) – relation to the Cambrian–Ordovician northern Gondwana breakup: A review. *Acta Univ. Carol., Geol.*, 42: 105-108.

PIN CH. and MARINI F., 1993. Early Ordovician continental break-up in Variscan Europe: Nd–Sr isotope and trace element evidence from bimodal igneous associations of the southern Massif Central, France. *Lithos*, 29: 177-196.

TIMMERMANN H., PARRISH R.H., NOBLE S.R., KRYZA R. and PATOČKA F., 1999. Single cyle Variscan orogeny inferred from new U–(Th–)Pb data from the Sudetes mountains in Poland and the Czech Republic. Abstracts of the PACE mid-term review and 4th PACE network meeting, Geological Institute, University of Copenhagen, October 9-10, 1999, Copenhagen, Denmark, p. 24.

WINCHESTER J.A., FLOYD P.A., CHOCYK M., HORBOWY K. and KOZDROJ W., 1995. Geochemistry and tectonic environment of Ordovician meta-igneous rocks in the Rudawy Janowickie Complex, SW Poland. *J. Geol. Soc., London*, 152: 105-115.


# p-T-t Conditions of the Calc-Silicate Skarn Formation from Garby Izerskie, Karkonosze–Izera Block, Poland


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Exocontact skarns of the Garby Izerskie mountain group in the Izera Mts. (Sudetes, Southern Poland) occur as intercalations (ca. 20 cm up to 1 m thick) in hornfels schists at the Stanisław Mine at Garby Izerskie, which is about 5 km north of the contact. The skarns developed from calcium-rich rocks. The following parageneses were identified: pyroxene – plagioclase (andesine); pyroxene – wollastonite – garnet – plagioclase (albite); pyroxene – wollastonite – garnet with vesuvianite; amphibole – calcite; epidote – calcite – quartz; calcite – quartz (calcite forms pseudomorphs after wollastonite); calcite – fluorite – quartz. The minerals in skarns formed during four stages characterized by different physico-chemical conditions.

Stage I was connected with prograde metamorphism. During this process hedenbergite (T = 330–324 °C, salinities of ca. 12 wt.% eq.NaCl) and wollastonite (liquid $CO_2$ – ca. 17–15 vol. %) probably crystallized at ca. 545–556 °C and grossular at ca. 500–525 °C (core – T = 330–310 °C, salinities of 14–10 wt.% eq.NaCl) and ca. 460–470 °C (rim – inclusions with $CO_2$, solution of 10 % NaCl) at $p_{static} = p_{total} = p_{fluids}$ = 1.5–1.8 kbar in a quasi-isochemical system. This crystallization represented peak metamorphic temperatures. Progressive metamorphism of protolith of these skarns resulted in a variety of stage-I mineral assemblages occurring within small domains probably defined by the initial bulk composition of individual sedimentary layers. Comparison of many samples shows that the following reactions were important for stage I:

$Tr + 3Cc + 2Qtz \Leftrightarrow 5Di + 3CO_2 + H_2O$

$Cc + Qtz \Leftrightarrow Wo + CO_2$

$Cc + An + Wo \Leftrightarrow Gr + CO_2$

Stage II is characterized by retrograde metamorphism which resulted in the formation of vesuvianite, actinolite, prehnite, epidote and pseudomorphs of calcite after wollastonite, also in a quasi-isochemical system. The first retrograde mineral was vesuvianite (T = 290–270 °C, salinities of 7–3 wt.% eq.NaCl) which formed at ca. 440–400 °C at p = 1.5–1.6 kbar. Stage II is linked with the following reactions:

$5Gr + 3Di + Wo + H_2O \Leftrightarrow Ves + 4Qtz$

$5Di + 3CO_2 + H_2O \Leftrightarrow Tr + 3Cc + 2Qtz$

$3Gr + 5CO_2 + H_2O \Leftrightarrow 2Zo + 5Cc + 3Qtz$

$Wo + CO_2 \Leftrightarrow Cc + Qtz$

$2Zo + 2Gr + 3Qtz + 4H_2O \Leftrightarrow 5Prh.$

Stage III was associated with extensive silicification (T = 430–310 °C after Kozłowski 1978, salinities of 8–5 wt.% eq.NaCl) of all existing rocks, especially along dislocations, at temperatures of 410–300 °C under allochemical conditions. It may have partly overlapped with stages I and II in time.

Stage IV was characterized by fluorite metasomatosis, yielding fluorite and apophyllite, associated with quartz, calcite and zeolites at 360 to 110 °C (after Kozłowski 1978) also in an allochemical system. The presented p-T conditions were estimated on the basis of fluid inclusion investigations.

Thus, the skarns from Garby Izerskie were high-temperature calc-silicate varieties, with late silica and fluorine metasomatosis. High-grade metamorphism was characterized by the appearance of wollastonite, grossular and a change in plagioclase to more albitic compositions. According to fluid inclusion data and mineral compositions, the metasomatic fluid was mainly $CO_2$ at peak metamorphic conditions, while during retrograde metamorphism the liquid phase contained very low $CO_2$ concentrations, which meant high water activity with $X_{CO_2}$ less than ≅ 0.02 (prehnite formation). The presence of prehnite replacing grossular in some of the samples particulary indicates