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THE PROVENANCE OF THE UPPER SILURIAN GREYWACKES  
FROM THE HOLY CROSS MOUNTAINS (CENTRAL POLAND)

**Abstract:** The uniform trace element characteristics, clast spectrum and age of detritus of the Ludlovian greywackes, known from Kielce and Łysogóry regions in the Holy Cross Mountains (HCM), indicate that the greywackes of both areas are of the same provenance. However, the petrofacial contrast between greywackes of both HCM regions, along with convergent transport directions, may point to a different than the present-day relation between both paleogeographical regions. The geochemical study indicates a continental island arc provenance of the detritus. The cooling ages of micas indicate an eo-Cadomian basement of the arc and a presence of material from the Silurian volcanism, probably subduction related. The domination of the recycled orogen source terrane type, points to the arc - Peribaltica collision zone as a source area of the discussed sediments. The transport directions indicate location of this area a westwardly of the HCM.

**Keywords:** greywackes, Silurian, Holy Cross Mountains, provenance

INTRODUCTION

In the Holy Cross Mountains (HCM) of central Poland, the thick greywacke complexes are present in the Ludlovian of both tectonic-facies HCM units (i.e. Kielce and Łysogóry regions). The rapid deposition of the sediments, composed of the low matured detritus, was connected with turbidite sedimentation. The thickness pattern indicates that the source area of these sediments was located outside the Baltica (Jaworowski 1971). This work aims to investigate the provenance of Upper Silurian greywackes of both HCM regions (i.e. Kielce region greywackes – KRG, and Łysogóry region greywackes – ŁRG) and their comparison.

PROVENANCE ANALYSIS

For purposes of the provenance study 13 ŁRG and 17 KRG representative samples were chosen for a petrographic modal analysis, with over 300 points counting, using Gazzi-Dickinson method (Ingersoll et al. 1984). Whole rock

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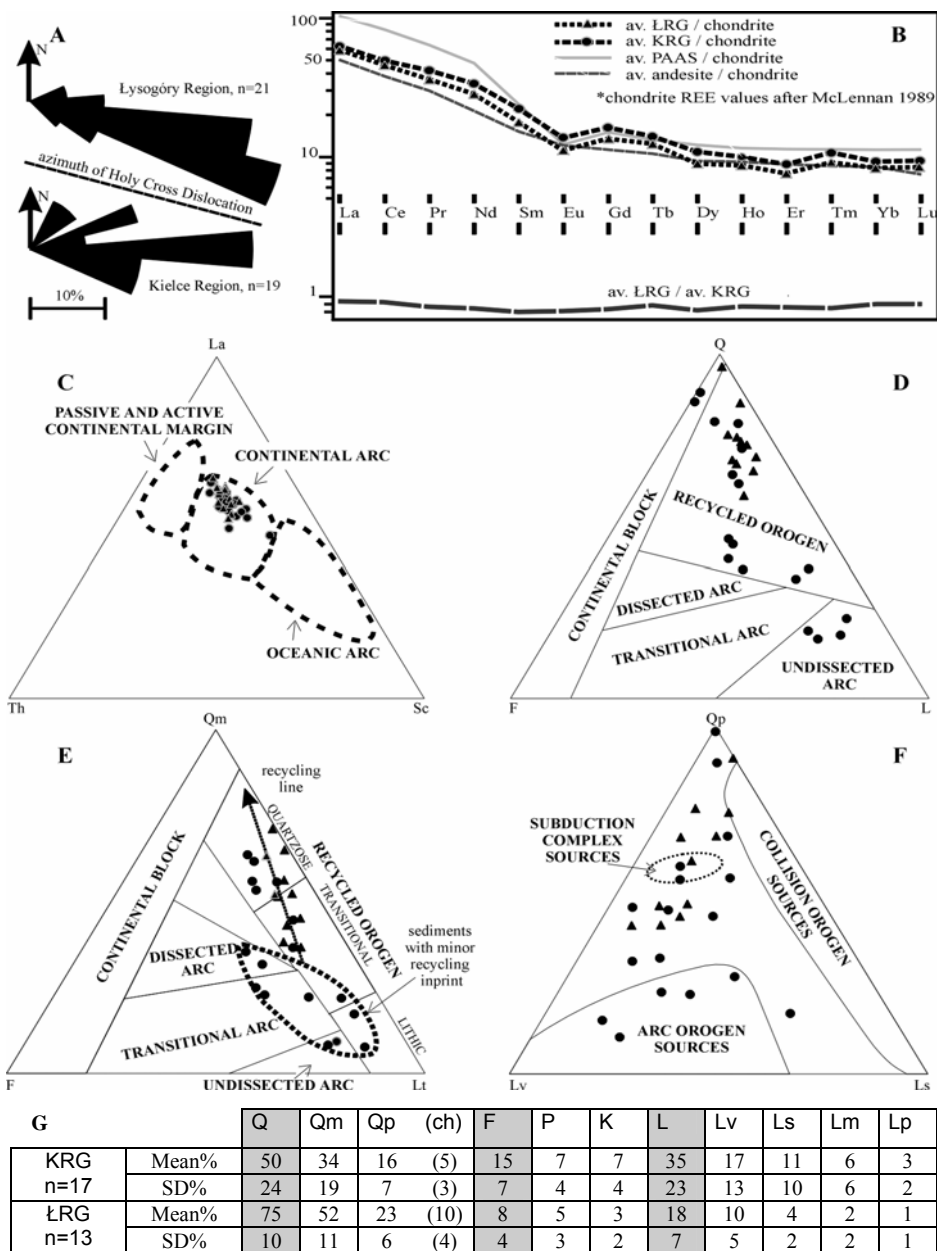


Fig. 1. A. Transport directions of the ŁRG and the KRG, B. Average REE patterns of the studied rocks in comparison to average andesite and PAAS REE patterns (after McLennan 1989), C-F Provenance (C) and source terrane type (D-F) discrimination diagrams for studied sediments (KRG – circles, ŁRG – triangles; discriminate fields after Bhatia & Crook 1986 /C/ and Dickinson et. al. 1983 /D-F/), G. average modal composition of the KRG and the ŁRG /abbreviations: Q – quartz (Qm – monocrystalline, Qp – polycrystalline including cherts – ch), F – feldspars (P – plagioclase, K – K-feldspars) L – lithoclasts (Lv – volcanic, Ls – sedimentary, Lm – metamorphic, Lp – plutonic in origin)/.

chemical analyses (ICP-MS method) of the samples were performed by ACME LAB, Vancouver, Canada. The transport directions (current hieroglyphs, parallel orientation of fauna) were measured in the same outcrops. The cooling ages of mica (both muscovite and biotite) were determined from the 6 mica-rich samples.

The dominating transport directions (Fig. 1a) in Łysogóry show derivation of material mostly from WNW, while in Kielce region mostly from W. This confirms earlier hypothesis of location of the source areas of studied sediments (Jaworowski 1971; Malec 2001).

The immobile elements characteristics of the KRG and the ŁRG are very similar. The average REE patterns of greywackes from both HCM regions are almost identical (Fig. 1B). The intermediate REE patterns of studied rocks, between the average andesite and the PAAS, with moderate  $La_N/Yb_N$  ratios (mean about 7), low to moderate  $Eu/Eu^*$  anomalies and flat HREE patterns, suggest active tectonic setting of the provenance of the detritus (McLennan 1989). This is confirmed by stable trace elements characteristics of studied sediments. On Th-La-Sc discrimination diagram (Bhatia, Crook 1986), all studied samples are located in Continental Island Arc discrimination field (Fig. 1C).

The cooling ages of mica recorded two main diastrophic episodes in this provenance component. The cooling ages of muscovite (KRG  $724 \pm 27$  Ma, ŁRG  $738 \pm 28$  Ma) may indicate a presence of an eo-Cadomian crust – probably forming a basement, upon which the arc was built. The biotite (often present inside volcanic rock fragments) cooling ages ( $442 \pm 17$  Ma,  $403 \pm 15$  Ma) may be connected with volcanic activity of the arc in the Silurian.

The compositions of the KRG and the ŁRG are also very similar in their grain spectrum. The Silurian greywackes are composed of quartz, cherts, feldspars and the rock fragments (wackes, sandstones, andesites, dacites, rhyolites and rare plutonic grains) identical in both HCM regions. Despite a very similar petrographic qualitative composition, the KRG and the ŁRG strongly differ in their modal composition (Fig. 1G). This fact is clearly seen on the provenance type discrimination diagrams (Fig. 1D-F) of Dickinson et. al. (1983). In these plots the KRG samples (circles), with more abundant feldspars and lithics, indicate both: magmatic arc and recycled orogen source types. The ŁRG samples (triangles), richer in quartz and cherts, indicate a recycled orogen derivation.

The linear sample patterns on diagrams may suggest a recycling of the primary arc related detritus. The position of samples, on the Qp-Lv-Ls discrimination diagram (Fig. 1F), suggests a compound character of the source area – including the arc orogen and the subduction complex (confirmed by abundant chert fragments).

## DISCUSSION

The geochemical analysis of the Upper Silurian rocks of both HCM regions indicates a continental island arc provenance of the greywacke detritus. The age of detritus may indicate a presence of eo-Cadomian crust, and the Silurian subduction related volcanic rocks as the arc components.

The modal composition of the studied rocks suggests reworking of older - arc related - sediments. The continental shelf position of greywackes (confirmed by the Cambrian – Lower Silurian history of the HCM basins) together with absence of any signs of the Silurian subduction under peri-Baltica exclude arc related type of the HCM Silurian basins.

In our opinion the Silurian greywackes of the HCM are reworked arc related sediments derived from the arc–continent collision orogen generally located on west of the HCM. The reworked detritus inherited its geochemical and (in part) petrographical characteristics after their arc related source deposits. The Silurian greywackes of the HCM are syn- to post-collision formation, deposited in a foreland basin of the arc–Peribaltica Late Silurian (Caledonian) collision orogen, located westward of the HCM. The elevated - forearc basin deposits, accretionary wedge, and arc volcanic rocks, were main components of the source.

The second key issue is palaeogeographical relation between both HCM regions. The convergence of transport directions, along with not homogenous sediments between regions (different particularly in their modal composition), can not confirmed the present-day position of both HCM parts in the Late Silurian. The higher maturity of the ŁRG along with an absence of any Caledonian deformation could suggests more distal (in relation to arc-continent collision zone) position of the Łysogóry region and more proximal (to this zone) position of the Kielce region (with less matured greywackes and a presence of the Silurian/Devonian unconformity).

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