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Nd AND Sr ISOTOPIC EVIDENCE FOR PROVENANCE OF CLASTIC MATERIAL OF THE UPPER TRIASSIC ROCKS OF SILESIA, POLAND

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Abstract: Nd and Sr isotope data were used to characterize the sources of the Upper Triassic (Keuper) siliciclastic rocks of Silesia in southern Poland. This continental succession, consisting predominantly of fine-grained mudstones and siltstones, yields a remarkably uniform Nd isotopic composition. Nd model ages T_{2DM} vary from 1.56 to 1.69 Ga and ε_{Nd} values are in the range from –8.9 to –11.2, documenting old crust contribution in the provenance. In contrast, the Sr isotopic composition ($^{87}Sr/^{86}Sr$) of the clastics exhibits a relatively large variation from 0.710 to 0.723. The isotopic compositions indicate that the southern part of the Germanic Basin in Silesia was supplied with clastic material from the Bohemian Massif. The axis of the drainage area must have crossed from SW to NE the Saxothuringian units of the East Sudetes and most probably also the area of the Tepla–Barrandian Unit. There is no indication of any sediment transport from the Moravo-Silesian Belt and the Fore-Sudetic Block. It seems, that the Palaeozoic rocks of the latter domain must have been buried completely during Late Triassic times.

Key words: Nd isotopes, Sr isotopes, clastics, provenance, Upper Triassic, Poland.

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INTRODUCTION

Although the Upper Triassic (Keuper) clastic rocks of Silesia have been the subject of a very long history of scientific research, starting in the mid-nineteenth century (Roemer, 1867, 1870), they gained notoriety in the last decade after discoveries of very rich accumulations of vertebrate fossils (e.g., Dzik *et al.*, 2000, 2008b; Sulej, 2005; Dzik and Sulej, 2007). The faunal assemblages contain both aquatic and land animals (amphibians, reptiles, various invertebrates, insects), associated with algal flora and vascular plant debris. The fossils were discovered at several sites across Silesia (Fig.1), which yielded fauna and flora of different compositions (for summary see Sulej *et al.*, 2012). There is general agreement that the varicolored, predominantly fine-grained clastics were deposited in terrestrial environments, the detailed interpretation of which still is very much debated (Szulc, 2005; Dzik and Sulej, 2007; Gruszka and Zieliński, 2008). Sedimentological studies provided the first insight into the sediment dynamics and transport, but nothing is known about the provenance of the clastic material.

In this contribution, Nd and Sr isotopic data are presented on fine-grained, clastic sediments from the Upper Triassic of Silesia with the aim of constraining their provenance regions. The combined use of Sr and Nd isotopes can be particularly useful for the recognition of major terrestrial reservoirs (Dickin, 2005) and is a common research method which has been utilized successfully in various provenance determinations, tectonic reconstructions and modeling of crustal growth and evolution (e.g., Goldstein *et al.*, 1984; Goldstein and Jacobsen, 1988; Stille *et al.*, 1994; Weldeab *et al.*, 2002; Smith *et al.*, 2003; Mahoney, 2005). Neodymium isotopic data are powerful tools for tracing sediment provenance (e.g., DePaolo and Wasserburg, 1976; McCulloch and Wasserburg, 1978; Miller *et al.*, 1986; McLennan *et al.*, 1990; McDaniel *et al.*, 1997; Dera *et al.*, 2014). This is because the Sm-Nd system usually appears to remain undisturbed during sedimentary and diagenetic processes. In general, the Sm/Nd and $^{143}Nd/^{144}Nd$ ratios of a clastic sedimentary rock, commonly expressed as ε_{Nd} values, reflect the average for the source rocks in the provenance region (e.g., Allegre and Rousseau, 1984; Goldstein *et al.*, 1984; DePaolo, 1988; Goldstein and Jacobsen, 1988). In addition, the radiogenic Sm and Nd isotopes provide also estimates of

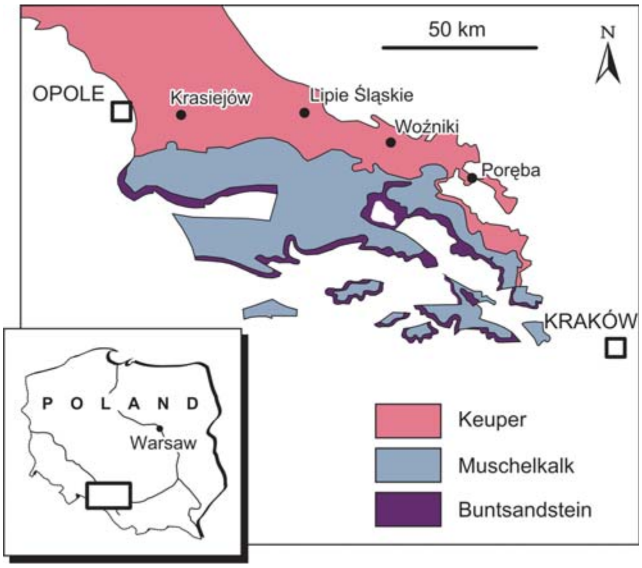

Fig. 1. A schematic geological map to show the location of the studied sections. The distribution of Triassic rocks after Dadlez *et al.* (2000). For coordinates of investigated localities see Table 1.

the mean age of mantle extraction for material that built sedimentary rocks. This age usually termed as the Nd model age (DePaolo, 1981) or the Nd crustal residence time is based on the assumption that the fractionation of Sm and Nd in the source material took place before its incorporation into the crust, when the source material was extracted from a depleted mantle (DM). Hence, the method provides the opportunity to determine the primary crust-formation ages which remain preserved in rocks despite of erosion, sedimentation, metamorphism and even crustal melting events (e.g., Taylor and McLennan, 1985; Liew and Hofmann, 1988; Whitehouse, 1988; Barovich and Patchett, 1992; McLennan and Hemming, 1992). However, some studies showed that sometimes the Sm-Nd system can be modified during erosion and sedimentation (Bock *et al.*, 1994; Ohlander *et al.*, 2000). In such cases better constraints on the model age of the source can be obtained by applying a "two-stage" model age calculation (e.g., Keto and Jacobsen, 1987). In addition, sedimentary rocks may be composed of material from several sources and thus, a "single-stage" evolution model only give a minimum Nd model age of their crustal sources (Dickin, 2005). During this study in order to eliminate possible disturbances during sedimentary processes depositional ages of the samples were taken as times beyond which an average crustal Sm/Nd ratios were used to estimate the crustal-formation ages of samples.

GEOLOGICAL BACKGROUND

The Upper Triassic of Silesia comprises deposits that accumulated in the marginal part of the Germanic Basin. Lithostratigraphically, the succession belongs to the Keuper Group (Fig. 2). It consists predominantly of varicolored, fine-grained clastics, evaporites and carbonates, which were deposited mainly in ephemeral-lake and fluvial systems under semi-arid and arid climate conditions (Bilan, 1975; Pieńkowski, 1988; Szulc *et al.*, 2006). This continental area was very flat (e.g., Gruszka and Zieliński, 2008), and depositional conditions may have been controlled by fluctuations in relative sea level and runoff from the neighboring highlands. The Keuper Group is about 200 m thick and thickens gradually toward the north (Deczkowski *et al.*, 1997; Bachmann *et al.*, 2010), where it attains locally up to 2000 m in Central Poland. In Silesia, the succession is accessible in a small number of quarries because in the past the Upper Triassic claystones were economically important for the local brick production. It differs, however, in its lithological development from the classical sequence of the South German Keuper Basin. For example, one of the regional features unknown elsewhere in the Germanic Basin is the presence of up to 30 m thick palustrine carbonates (Woźniki Limestone) that deposited within shallow swampy depressions, fed by springs of deep-circulating groundwater, partly of hydrothermal nature (Szulc *et al.*, 2006). The age of the most frequently studied sequence at Krasiejów was subject of debate since several years (see for review Bodzioch and Kowal-Linka, 2012), and although the stratigraphic correlation of the Keuper rocks within Silesia is still somewhat uncertain, an integrated regional event-stratigraphic approach enables a revision of the climate-driven facies-temporal relationships of two bone-breccia horizons (Szulc and Racki, 2015; Fig. 2). According to Szulc and Racki (2015), the Krasiejów succession is placed now in the lower part of the Grabowa Variegated Mudstone-Carbonate Formation including in its basal part a transition from the Ozimek Mudstone-Evaporite Member to the Patoka Mudstone-Sandstone Member (recorded in disappearance of barite-bearing celestines; see Szulc, 2005; Bzowska and Racka, 2006). The Krasiejów bone-bearing level represents probably the lower to middle Norian interval, whilst the more widely distributed Lisowice level (also Woźniki and Poręba sites) corresponds certainly to the middle Norian (Fig. 2). The exclusively terrestrial origin of the Grabowa Fm succession is now confirmed (Szulc and Racki, 2015), and possible influence of marine ingressions, which were inferred from the presence of shark remains, the distribution of charophytes or clay minerals (e.g., Zatoń *et al.*, 2005; Bzowska and Racka, 2006), is overall excluded.

MATERIAL AND METHODS

A total of 31samples were taken to analyze the Sm-Nd and Sr isotopic composition of the Upper Triassic clastics of Silesia. The samples were collected from four successions: Krasiejów, Lipie Śląskie, Woźniki and Poręba (Fig. 1). Rock samples, each about 200 g, were predominantly mudstones; only a few samples were taken from siltstones and fine-grained sandstones (Table 1). The study focused, first of all, on the sequence of Krasiejów (Fig. 3), which is the best exposed and has the largest sedimentological and palaeontological database. From other localities only few pilot samples were investigated (Fig. 4). At Krasiejów, samples were collected from across the entire section, which is today exposed. In addition, as there are strongly diverging

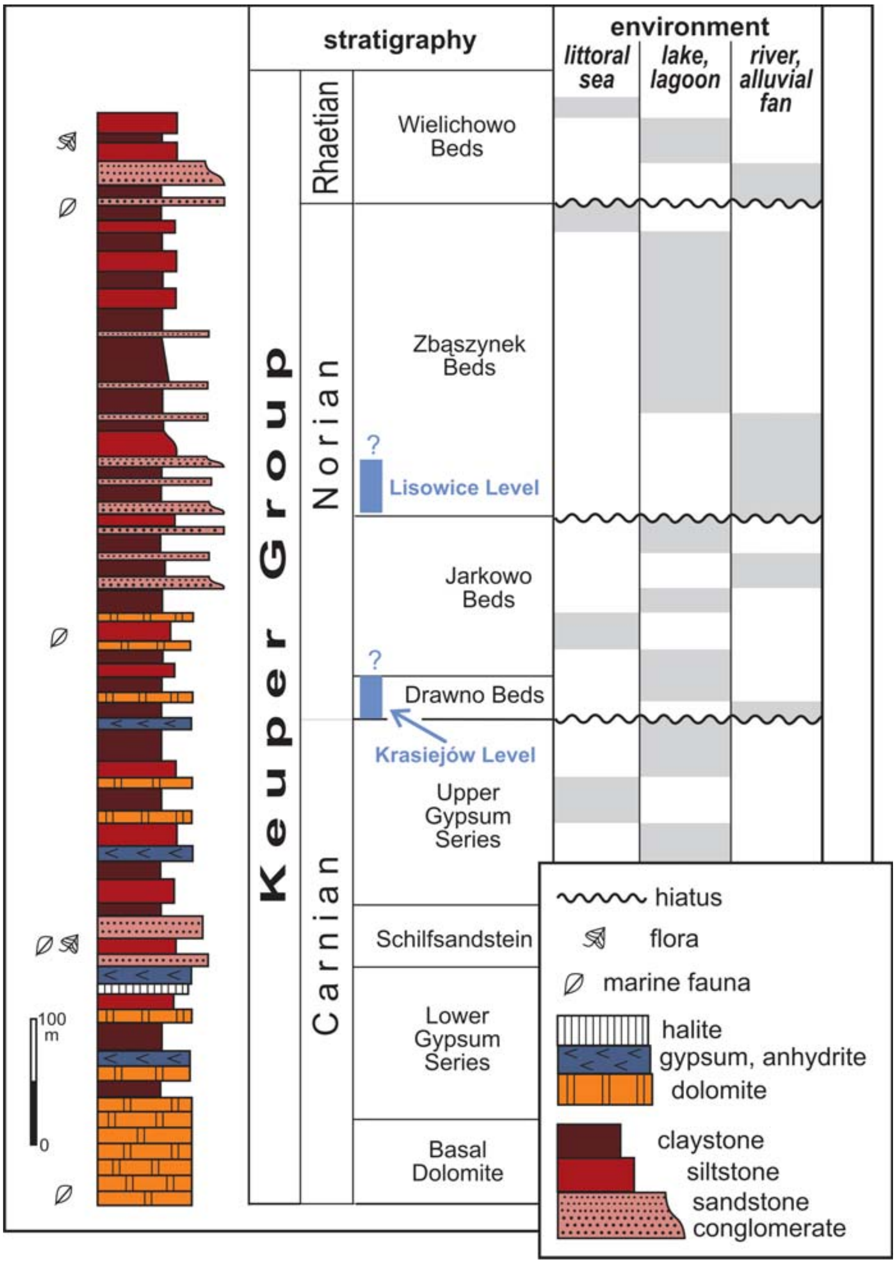

Fig. 2. Lithostratigraphical scheme of the Upper Triassic of Poland (modified after Gruszka and Zieliński, 2008) to show the revised stratigraphic position of the investigated bone-bearing successions in Silesia (after Szulc and Racki, 2015). Note that the upper age boundary of the Krasiejów and Lipie Śląskie successions is still somewhat uncertain, and the Lisowice level includes also Woźniki and Poręba localities (see Fig. 1).

opinions on the origin of bone accumulations in the Krasiejów sequence, the upper bone-bed horizon has been densely sampled to check the homogeneity of its clastic material. At Lipie Śląskie, only the upper grey-coloured part of the section was sampled, the underlying red beds are recently drowned and not accessible.

Nd and Sr isotopic data were collected in the Isotope Laboratory of the Adam Mickiewicz University at Poznań (Poland) on spiked samples using a Finnigan MAT 261 multi-collector thermal ionization mass spectrometer. Approximately 50 to 80 mg of sample powder were carefully weighted, spiked with a mixed ^{149}Sm–^{150}Nd spike, and dissolved with concentrated HF-HNO_3. Sr and LREE were separated from matrix elements on 50 µl teflon columns filled with Eichrom Sr Spec and TRU resins, respectively (see Pin *et al.*, 1994). Separation of Nd and Sm was achieved on 2 ml columns packed with Eichrom Ln resin. Details of the analytical procedures are described in Dopieralska (2003). Nd and Sm (loaded as phosphate) were measured in a Re double filament configuration, whereas strontium was loaded with a TaCl5 activator on a single W filament. Isotopic ratios were collected in static (Sm) and dynamic (Nd, Sr) mode. During the course of this study, the AMES standard yielded $^{143}Nd/^{144}Nd = 0.512127 \pm 7$ (2σ

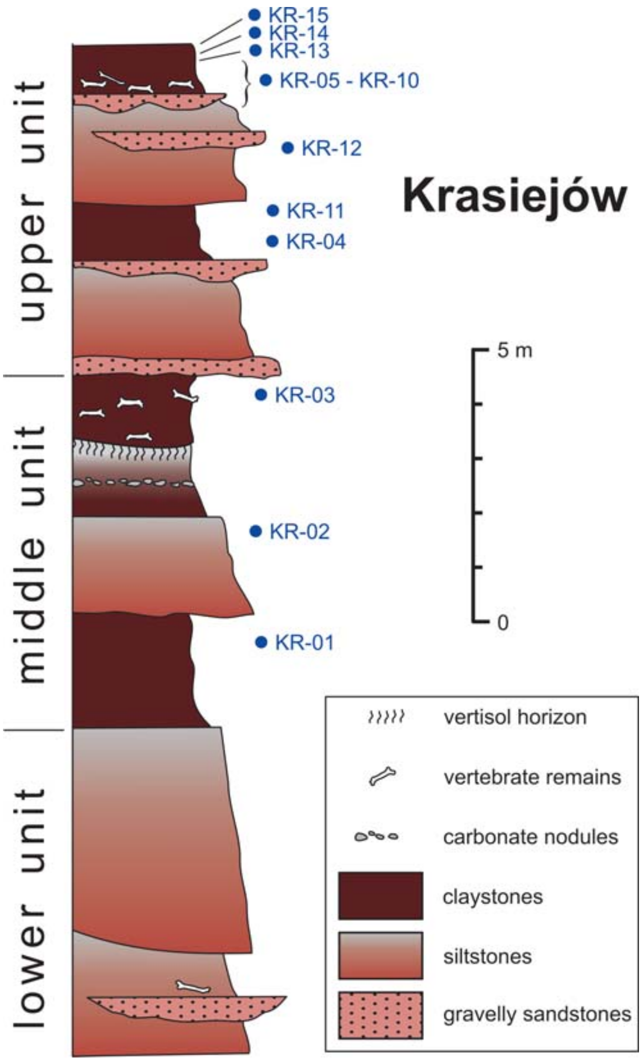

Fig. 3. Simplified lithological column of the Krasiejów succession (after Bodzioch and Kowal-Linka, 2012, modified) with location of the investigated samples. Bracket shows the position of the upper bone-bearing horizon which has been densely sampled.

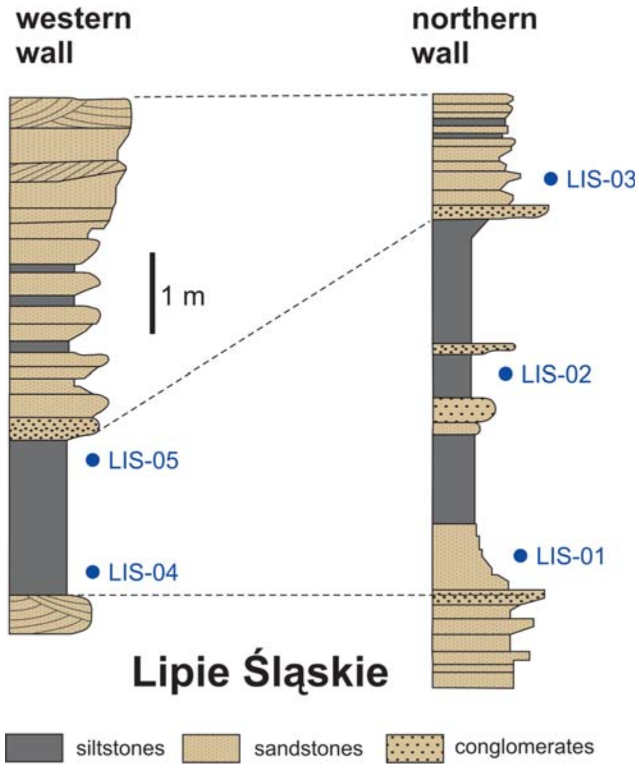

Fig. 4. Simplified sedimentological logs of the Lipie Śląskie succession (from Dzik *et al.*, 2008a, modified) with location of the collected samples.

mean on twenty four analyses). The $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd = 0.7219$, and Sm isotopic ratios to $^{147}Sm/^{152}Sm = 0.56081$. Total procedure blanks were less than 35 pg for Nd and Sm, and less than 80 pg for Sr. The NBS987 Sr standard yielded $^{87}Sr/^{86}Sr = 0.710228 \pm 10$ (2σ mean on thirteen analyses). Nd isotope data are reported in the standard epsilon notation (l) calculated using $^{143}Nd/^{144}Nd = 0.512638$ and $^{147}Sm/^{144}Nd = 0.1967$ for present-day CHUR (Jacobsen and Wasserburg, 1980). The single-stage model ages (T_{DM}) were calculated after DePaolo (1981) by using present day depleted mantel values $^{143}Nd/^{144}Nd = 0.513151$ and $^{147}Sm/^{144}Nd = 0.2137$ and the two-stage model ages (T_{2DM}) were calculated using the same assumption as Keto and Jacobsen (1987).

RESULTS

Results of Nd and Sr isotopic analyses of the investigated samples are reported in Table 1 and Figures 5 and 6, where it can be seen that the composition of the Upper Triassic clastics of Silesia is remarkably uniform. At Krasiejów, the $^{147}Sm/^{144}Nd$ ratios vary from 0.1158 to 0.1260 and the $\varepsilon_{Nd(0)}$ values range from –8.9 to –10.7. Consequently, the depleted mantle model ages (T_{DM}) are within a narrow range 1.59–1.71 Ga. It is important to note that model ages calculated by the "two stage" method (T_{2DM}) are practically in the same range (1.56–1.69 Ga). The Sm-Nd isotopic characteristics of clastics at Lipie Śląskie are almost identical to those of Krasiejów. The $^{147}Sm/^{144}Nd$ ratios range from 0.1127 to 0.1196, the $\varepsilon_{Nd(0)}$ values vary from –9.0 to –11.2 and all model ages are around 1.6 Ga. There is also no difference between Nd model ages calculated by a single- and by a two-stage method (see Table 1). The Nd isotopic data of two pilot samples from the Woźniki sequence are within the variation observed at Lipie Śląskie. In overall, the collected data do not show any evidence that the Sm-Nd isotopic system has been disturbed by post depositional processes. This is because there is no positive correlation between Sm/Nd ratios and model ages, which is a characteristic feature of Sm-Nd isotopic disturbance (Bock *et al.*, 1994). A secondary oxide signal in the isotopic signatures can also be excluded because Fe oxides, if present, occur in the Upper Triassic clastics in very small quantities. Środoń *et al.* (2014), who analyzed the mineralogical composition of these rocks, reported the occurrence of hematite among detrital components. Authigenic hematite has been observed only in the soil horizons, which were not sampled during the current study. In light of preliminary mineralogical-geochemical study of Bzowska and Racka (2006), sediment variet-

Table 1

Sm-Nd and Sr isotopic data of the Upper Triassic clastics of Silesia

Sample*	Sample weight (mg)	$^{87}Sr/^{86}Sr$ (t = 0)	Nd (ppm)	Sm (ppm)	Sm/Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd^{\#}$ (t = 0)	ε_{Nd} (t = 0)	T_{DM} (Ga)	T_{2DM} (Ga)	Lithology
KR-01	83.15	0.719578 ± 13	32.76	6.35	0.19	0.1171	0.512091 ± 30	–10.7	1.67	1.69	mudstone
KR-02	85.68	0.712721 ± 9	36.26	7.21	0.20	0.1202	0.512128 ± 9	–9.9	1.67	1.63	siltstone
KR-03	82.82	0.712385 ± 9	40.22	7.87	0.20	0.1188	0.512134 ± 12	–9.8	1.63	1.62	
KR-04	84.52	0.713121 ± 10	35.20	6.78	0.19	0.1164	0.512104 ± 11	–10.4	1.64	1.66	
KR-05a	42.82	0.713663 ± 12	-	-	-	-	-	-	-	-	mudstone
KR-05b	42.01	0.714070 ±10	23.36	4.70	0.20	0.1217	0.512146 ± 24	–9.6	1.66	1.61	
KR-06a	42.01	0.714070 ±10	31.21	6.18	0.20	0.1197	0.512151 ± 21	–9.5	1.62	1.60	
KR-06b	43.48	0.713669 ± 12	25.07	5.02	0.20	0.1211	0.512142 ± 38	–9.7	1.66	1.61	
KR-07a	44.37	0.713573 ± 14	-	-	-	-	-	-	-	-	
KR-07b	47.30	0.717660 ± 13	22.94	4.59	0.20	0.1210	0.512124 ± 46	–10.0	1.69	1.64	
KR-08a	43.73	0.713179 ± 17	22.76	4.58	0.20	0.1216	0.512117 ± 27	–10.2	1.71	1.65	
KR-08b	45.32	0.712500 ± 15	-	-	-	-	-	-	-	-	
KR-09a	47.31	0.715395 ± 13	21.60	4.43	0.21	0.1241	0.512169 ± 27	–9.1	1.67	1.58	
KR-09b	43.45	0.714380 ± 14	39.52	8.24	0.21	0.1260	0.512180 ± 14	–8.9	1.69	1.59	
KR-10a	44.02	0.712210 ± 19	-	-	-	-	-	-	-	-	
KR-10b	44.59	0.716099 ± 12	21.29	4.24	0.20	0.1203	0.512102 ± 27	–10.5	1.71	1.67	
KR-11	45.25	-	21.90	4.33	0.20	0.1195	0.512130 ± 37	–9.9	1.65	1.63	
KR-12	45.87	-	26.51	5.34	0.20	0.1217	0.512150 ± 29	–9.5	1.66	1.60	
KR-13	81.07	0.714031 ± 10	31.64	6.06	0.19	0.1158	0.512125 ± 17	–10.0	1.60	1.63	
KR-14	77.35	0.717720 ± 9	28.56	5.58	0.20	0.1182	0.512155 ± 10	–9.4	1.59	1.59	
KR-15	63.98	0.720441 ± 10	-	-	-	-	-	-	-	-	siltstone
LIS-01	65.08	0.710649 ± 8	-	-	-	-	-	-	-	-	sandstone
LIS-02	64.55	0.711155 ± 11	23.72	4.57	0.19	0.1164	0.512122 ± 12	–10.1	1.61	1.63	siltstone
LIS-03	65.64	0.710791 ± 10	32.89	6.51	0.20	0.1196	0.512179 ± 11	–9.0	1.57	1.55	sandstone
LIS-04	65.61	0.712736 ± 10	24.78	4.62	0.19	0.1127	0.512065 ± 10-11.2	–11.2	1.64	1.72	siltstone
LIS-05	66.40	0.713277 ± 11	26.16	4.96	0.19	0.1147	0.512087 ± 14	–10.7	1.64	1.69	
WO-01	67.85	0.719064 ± 9	25.70	4.90	0.19	0.1152	0.512110 ± 10	–10.3	1.61	1.65	mudstone
WO-02	65.00	0.718913 ± 9	29.55	5.70	0.19	0.1165	0.512093 ± 10	–10.6	1.66	1.68	
WO-03	65.12	0.723213 ± 9	-	-	-	-	-	-	-	-	
PO-01	64.33	0.717773 ± 9	-	-	-	-	-	-	-	-	siltstone
PO-02	65.58	0.718121 ± 8	-	-	-	-	-	-	-	-	mudstone

* KR: Krasiejów (50°39′54.63″N; 18°16′31.76″E); LIS: Lipie Śląskie (50°40′41.07″N; 18°38′42.39″E); WO: Woźniki (50°35′14.36″N; 19°02′48.66″E); PO: Poręba (50°29′39.88″N; 19°22′50.96″E).
\# errors are 2σ means.

ies at Krasiejów (clayey marls, marly claystones, sandy marls and marly sandstones) show chondrite-normalized distributions of REE almost the same throughout the section, what strongly suggest an overall unchanged provenance pattern and uniform climate conditions.

The Sr isotopic composition ($^{87}Sr/^{86}Sr$) of the investigated clastics at Krasiejów yields a relatively large variation from 0.712 to 0.720, whereas the most radiogenic values occur only at the base and the top of the exposed succession. But even within the upper bonebed horizon, where from the majority of samples was taken, the range is relatively wide from 0.712 to 0.717. The clastics at Lipie Śląskie are characterized by a more restricted range of $^{87}Sr/^{86}Sr$, from 0.710 to 0.713. To the east, at Woźniki and Poręba, the clastics exhibit more radiogenic $^{87}Sr/^{86}Sr$ values ranging from 0.718 to 0.723. However, due to the small number of samples it is difficult to determine whether the data reflect a regional trend of more radiogenic Sr isotopic composition in the easterly direction, or not.

DISCUSSION AND CONCLUSIONS

Late Triassic palaeogeography and facies development of the Germanic Basin are well recognized (for summary see Feist-Burkhardt *et al.*, 2008; Bachmann *et al.*, 2010). In the Polish sub-basin, however, information on directions of sediment supply is sparse. In the south, this part of the basin

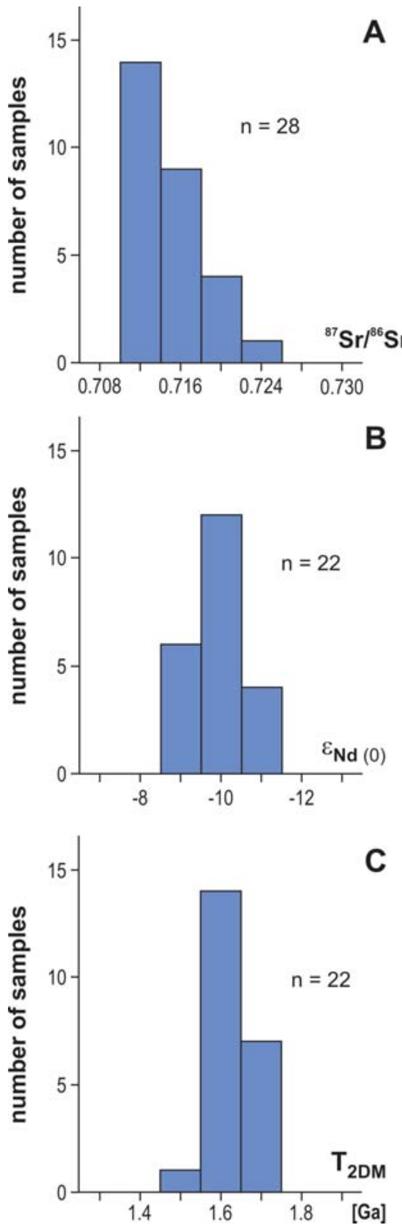

Fig. 5. Histograms showing the summary of the Sr and Nd isotopic composition of the Upper Triassic clastics of Silesia: $^{87}Sr/^{86}Sr$ ratio (A); ($\varepsilon_{Nd(0)}$ (B); model ages T_{2DM} (C).

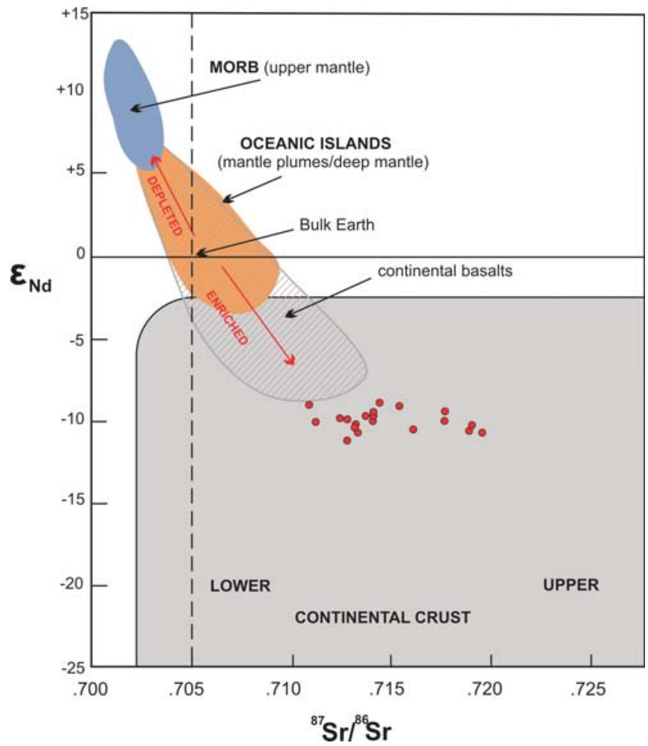

Fig. 6. Diagram to show Sr and Nd isotopic ratios in Upper Triassic clastics of Silesia (red circles) in relation to major geochemical reservoirs. The variations of the isotopic composition in major Earth's reservoirs taken from White (2013).

is bounded by the Bohemian Massif which permanently constituted an elevated land area during Triassic times. Consequently, the sediment influx from the south is in Silesia most likely. According to Szulc (2005), sediment supply at Krasiejów and Lipie Śląskie was dominated by generally N- and NW-directed transport. In contrast, Gruszka and Zieliński (2008) recognized in the Krasiejów sequence sedimentological evidence for rivers that flowed in the NE direction and must have drained an extremely flat lowland. Recently, Bodzioch and Kowal-Linka (2012) suggested that vertebrate remains from a lower bonebed of Krasiejów were transported from an area which was situated dozen kilometres southwest of Krasiejów.

The Sm-Nd and Sr isotopic characteristics of the investigated Upper Triassic clastics ($\varepsilon_{Nd(0)}$ values = –9.0 to –11.2; Nd model ages = 1.59–1.71 Ga; $^{87}Sr/^{86}Sr$ = 0.710–0.723; Figs 5, 6) suggests a derivation of clastic material from metamorphic rocks of the Bohemian Massif (see Liew and Hofmann, 1988). On the one hand, the search for sources of clastic material within the Bohemian Massif is facilitated by the availability of Sm-Nd and Sr isotopic characteristics of rocks in the majority of tectonic units. On the other hand, the tectonic structure of the Bohemian Massif is extremely complex (for summary see Franke and Żelaźniewicz, 2000; Aleksandrowski and Mazur, 2002) and many small terranes with contrasted isotopic characteristics are amalgamated together. Therefore, it is to be expected that during extensive erosion mixing of material derived from different sources occurred rather than a transport of the material from a single source over long distances.

Taking into consideration sedimentological observations carried out in the Krasiejów sequence (Gruszka and Zieliński, 2008) the closest potential source for the clastic material of the Upper Triassic of Silesia should be the Moravo-Silesian Belt in the East Sudetes. This domain consists of a Cadomian crystalline basement (Brunovistulian) and a Neoproterozoic to Carboniferous sedimentary cover. The crystalline rocks and the Neoproterozoic metasediments, however, were certainly not a source for the Triassic clastics in Silesia. In contrast to the Triassic clastics, they are characterized by less radiogenic Sr isotopic composition (from 0.704 to 0.710) reported by Finger *et al.* (2000) and younger Nd model ages from 1.1 to 1.3 Ga (Hegner and Kröner, 2000). There are only two, small Cadomian orthogneiss bodies in the Kerpnik Nappe, located very close to the boundary with the Saxothuringian Belt, which are isotopi-

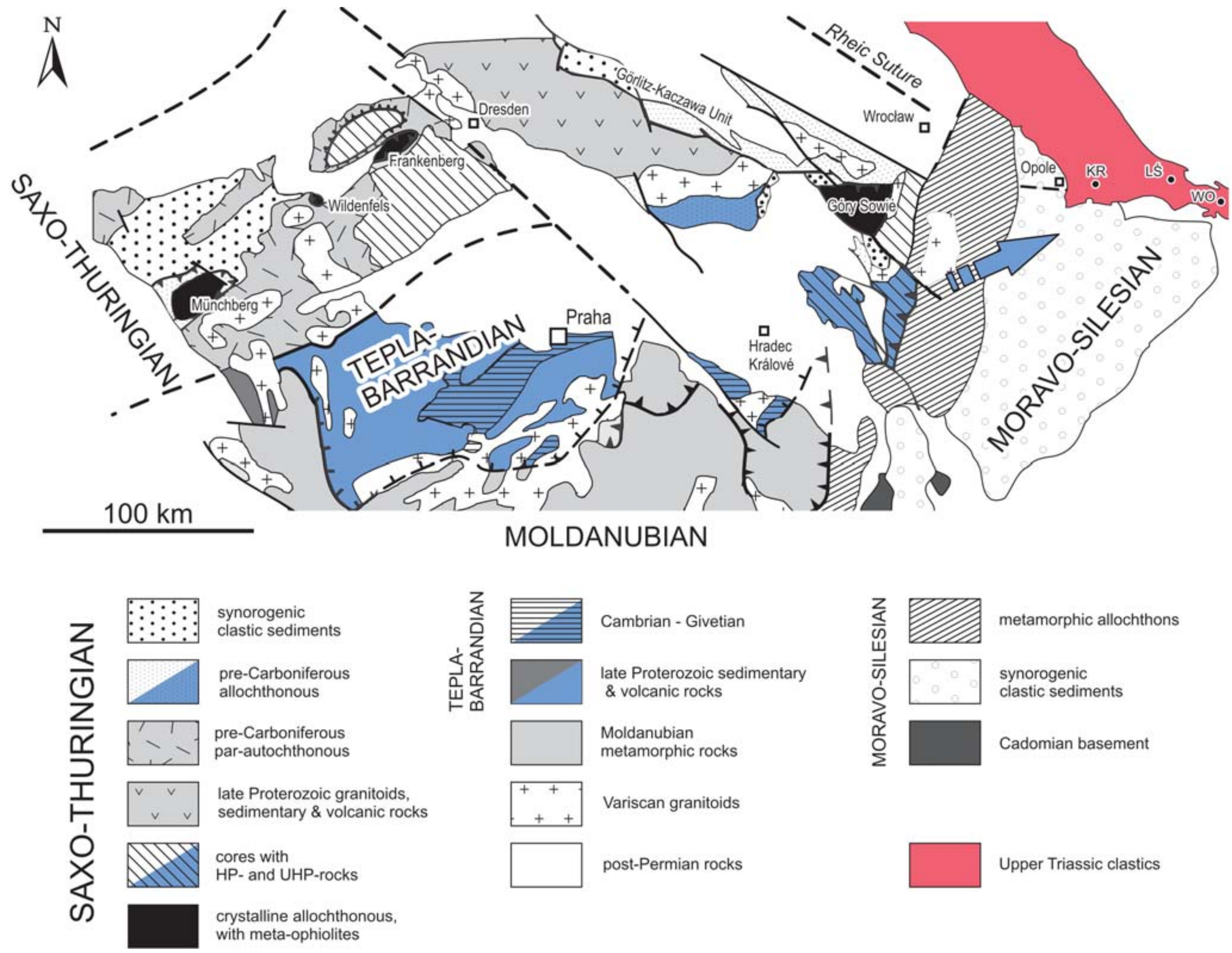

Fig. 7. Simplified geological map of the northern part of the Bohemian Massif (adapted from Franke and Żelaźniewicz, 2000). The suggested source area for the Upper Triassic clastics of Silesia is indicated in blue. The location of the investigated sites Krasiejów (KR), Lipie Śląskie (LŚ) and Woźniki (WO) is marked on the map.

cally consistent with the Upper Triassic clastics in Silesia. The Upper Carboniferous coal measures, the most prominent lithological formations in the Moravo-Silesian Belt, do not seem to be a source for clastic material present in the Upper Triassic rocks. The first preliminary isotopic data (unpublished) show that these rocks have much more radiogenic Nd composition.

Sediment supply from the Fore-Sudetic Block, a tectonic domain located directly west of the Triassic exposures in Silesia, is also excluded. This unit, which today is mostly hidden under Tertiary sediments, comprises variably deformed and predominantly weakly metamorphosed Cambro-Ordovician to Early Carboniferous lithologies and ophiolitic rocks, and is intruded by the Carboniferous post-orogenic granites. The pre-Variscan felsic rocks and Variscan granitoids have Nd model ages lower than 1.6 Ga and more radiogenic Nd isotopic composition than the Upper Triassic clastics (see Kröner and Hegner, 1998; Crowley *et al.*, 2002; Pietranik and Waight, 2008). Any mixing of these lithologies with ophiolitic rocks (Kryza and Pin, 2010) would create a clastic material with even more distinct Nd isotope characteristics. Further to the west, the Görlitz–Kaczawa Unit contains almost exclusively rocks (volcanic suites and deep-water metasediments) characterized by a strongly radiogenic (= positive ε_{Nd} values) Nd composition (Furnes *et al.*, 1994) and therefore cannot also be regarded as a potential source.

In contrary, the Saxothuringian tectonic units located more southerly, south of the Intra Sudetic Fault in the West Sudetes and south of the Marginal Sudetic Fault in the East Sudetes (Fig. 7), contain rocks yielding Sm-Nd isotopic characteristics consistent with the Nd isotopic composition of the Upper Triassic clastics in Silesia. Hegner and Kröner (2000) reported rocks of the Orlica–Śnieżnik dome, a continental domain consisting of pre-Cadomian crust and large volumes of Cambrian–Ordovician granitoids, which have $\varepsilon_{Nd(t)}$ values between –3.5 and –6.5 (calculated for 500 Ma) and Nd model ages from 1.4 to 1.7 Ga. Pin *et al.* (2007) identified in this domain orthogneisses with similar Nd isotopic composition but exhibiting a wider range of Nd model ages (from 1.4 to 2.2 Ga). Felsic metavolcanics in the eastern envelope of the Karkonosze pluton display ε_{Nd} values, which are within the range of Nd isotopic characteristics of the Upper Triassic clastics, and model ages from 1.5 to 1.8 Ga.

(Hegner and Kröner, 2000; Dostal *et al.*, 2001). It does not seem, however, that the largest rock unit in this segment of the Saxothuringian, the Carboniferous Karkonosze pluton, could supply a clastic material. Its granitic lithologies yield Nd isotopic composition, with $\varepsilon_{Nd(0)}$ values between –4.5 and –8.9 (Słaby and Martin, 2008), which is more radiogenic than this of the Upper Triassic clastics. Moreover, like other Variscan granitoids (Liew and Hofmann, 1988), the rocks of the Karkonosze pluton have younger model ages, from 1.3 to 1.5 Ga (calculated here from data of Słaby and Martin (2008)).

The area which could have potentially represented a more proximal part of the drainage system is the Tepla–Barrandian Unit. It borders directly the Saxothuringian units of the East Sudetes (Fig. 7) and contains rock formations which have the Sm-Nd and Sr isotopic characteristics consistent with the Upper Triassic of Silesia. The Tepla–Barrandian Unit is one of the best preserved fragments of the Avalonian–Cadomian belt (Hajná *et al.*, 2011). Its Cadomian basement and Early Paleozoic cover consists of several kilometres thick, volcanic and clastic rocks which have contrasting model ages and Nd isotopic signatures (Drost *et al.*, 2007; Pin and Waldhausrová, 2007). The former yield model ages from 0.6 to 1.0 Ga and the latter from 1.6 to 2.1 Ga. Mixing of detritus from both lithologies could have produced a material with Nd isotopic composition similar to that of the Upper Triassic clastics. Such a mixing has already been partly implemented in the Tepla–Barrandian during the deposition of the Devonian greywackes (Drost *et al.*, 2011). Model ages and the Nd isotopic composition of these rocks (Strnad and Mihaljevic, 2005) are very close to those of the Upper Triassic clastics in Silesia.

In summary, the Sm-Nd and Sr isotopic data used for the provenance analysis (Figs 5, 6) allow to formulate well-founded conclusion that the southern part of the Germanic Basin in Silesia was supplied with a clastic material from the Bohemian Massif. The axis of the drainage area must have crossed, from SW to NE, the Saxothuringian units of the East Sudetes and most probably also the area of the Tepla–Barrandian Unit. The lack of any noticeable impact of Palaeozoic rocks from the Fore-Sudetic Block on the composition of the river load suggests that at least the eastern part of this Variscan domain must have been totally buried during the entire Late Triassic.

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