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Early Palaeozoic initial-rift volcanism in the Central European Variscides (the Kaczawa Mountains, Sudetes, SW Poland): evidence from SIMS dating of zircons

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Abstract: Early Palaeozoic volcanic suites are widespread throughout the Variscan Belt, and have commonly been ascribed to incipient rifting along the northern periphery of Gondwana in Cambrian to Ordovician times. Their distribution across Europe defines the present-day extent of Gondwana-derived terranes and constrains the timing of their separation from the Gondwanan margin. The Kaczawa Mountains in the West Sudetes, at the eastern termination of the Variscan Belt, include bimodal rift-related rocks, but their protolith age and, hence, their significance have been highly uncertain. We have applied secondary ionization mass spectrometry zircon geochronology to a metarhyodacite and a metatrachyte from this suite, yielding ages of 502.4 ± 2.6 Ma and 485.7 ± 1.6 Ma, respectively. This constrains the initial rift magmatism to *c.* 500–485 Ma in this part of the European Variscides. The rift-related Early Palaeozoic volcanism thus seems to have been broadly synchronous throughout the peri-Gondwanan terranes of Europe.

‘Bimodal’ magmatic complexes of Early Palaeozoic age are common within the Variscan Belt of Europe. They mostly show geochemical features of within-plate lavas and are commonly interpreted as emplaced during Cambrian–Ordovician rifting along the northern periphery of Gondwana (e.g. Van Calsteren & den Tex 1978; Perekalina 1981; Pin & Lancelot 1982; Narębski *et al*. 1986; Pin 1990; Pin & Marini 1993; Bankwitz *et al*. 1994; Furnes *et al*. 1994; Briand *et al*. 1995; Abati *et al*. 1999; Floyd *et al*. 2000; Crowley *et al*. 2001; Dostal *et al*. 2001; Von Raumer *et al*. 2003; Pin *et al*. 2007; for contrasting views, see Oliver *et al*. 1993; Kröner & Hegner 1998). Consequently, the beginning of Early Palaeozoic volcanism constrains the break-up of the northern Gondwana margin and the change in tectonic regime following the Cadomian (Pan-African) orogeny. The Kaczawa Complex of the West Sudetes in the NE part of the Bohemian Massif (Fig. 1a and b) potentially includes an important record of this event, although the lack of reliable protolith ages has thus far prevented its firm identification. The mafic and felsic metavolcanic rocks of this epimetamorphic complex have been interpreted as emplaced in a continental initial rift setting at the inception of the Early Palaeozoic pre-orogenic basin (e.g. Furnes *et al*. 1994). However, the lack of reliable time constraints has allowed alternative interpretations. Kozdrój & Skowronek (1999), for instance, suggested a Silurian age for the felsic volcanic rocks, and hence for this rifting event, based on ambiguous stratigraphic relationships (e.g. Skowronek & Steffahn 2000). Thus, an isotope geochronological study of the metavolcanic rocks of this basin is critical to constraining the initiation of the Early Palaeozoic rifting that led to the dispersion of peri-Gondwanan terranes.

In this study, we present new sensitive high-resolution ion microprobe (SHRIMP) results from two representative samples of a metarhyodacite and a metatrachyte from the lower part of the Kaczawa sequence. The new dates documented here reliably constrain the onset of the Early Palaeozoic extensional basin that is now incorporated into the Variscan accretionary prism.

Geological setting

The Kaczawa Complex in the West Sudetes (Fig. 1a and b) occurs within one of several diverse tectonostratigraphic terranes at the NE margin of the Bohemian Massif, juxtaposed along thrust- and normal-fault contacts and, in particular, along strike-slip faults and shear zones (e.g. Aleksandrowski & Mazur 2002; Kryza *et al*. 2004; Mazur *et al*. 2006). The Kaczawa Complex is formed of metavolcanic and metasedimentary rocks (Cambrian?–Ordovician to Late Devonian–Early Carboniferous) and sedimentary–tectonic mélange (Late Devonian–Early Carboniferous). The Variscan metamorphic overprint ranges from low grade in some mélange bodies, to blueschist- and subsequent greenschist-facies conditions in other units (Kryza *et al*. 1990; Kryza & Muszyński 2003).

The Kaczawa Complex is subdivided into a number of tectonic units of various sizes up to *c*. 20 km along strike and 10 km across (their names and extents are shown in Fig. 1a). These are interpreted as thrust sheets and slices, alternating with olistostromes and mélange bodies (Baranowski *et al*. 1990; Collins *et al*. 2000; Seston *et al*. 2000; Cymerman 2002; Kryza & Muszyński 2003).

The lower part of the stratigraphic succession (Fig. 2) comprises felsic and mafic metavolcanic rocks associated with metavolcaniclastic and other metasedimentary rocks: the Gack-

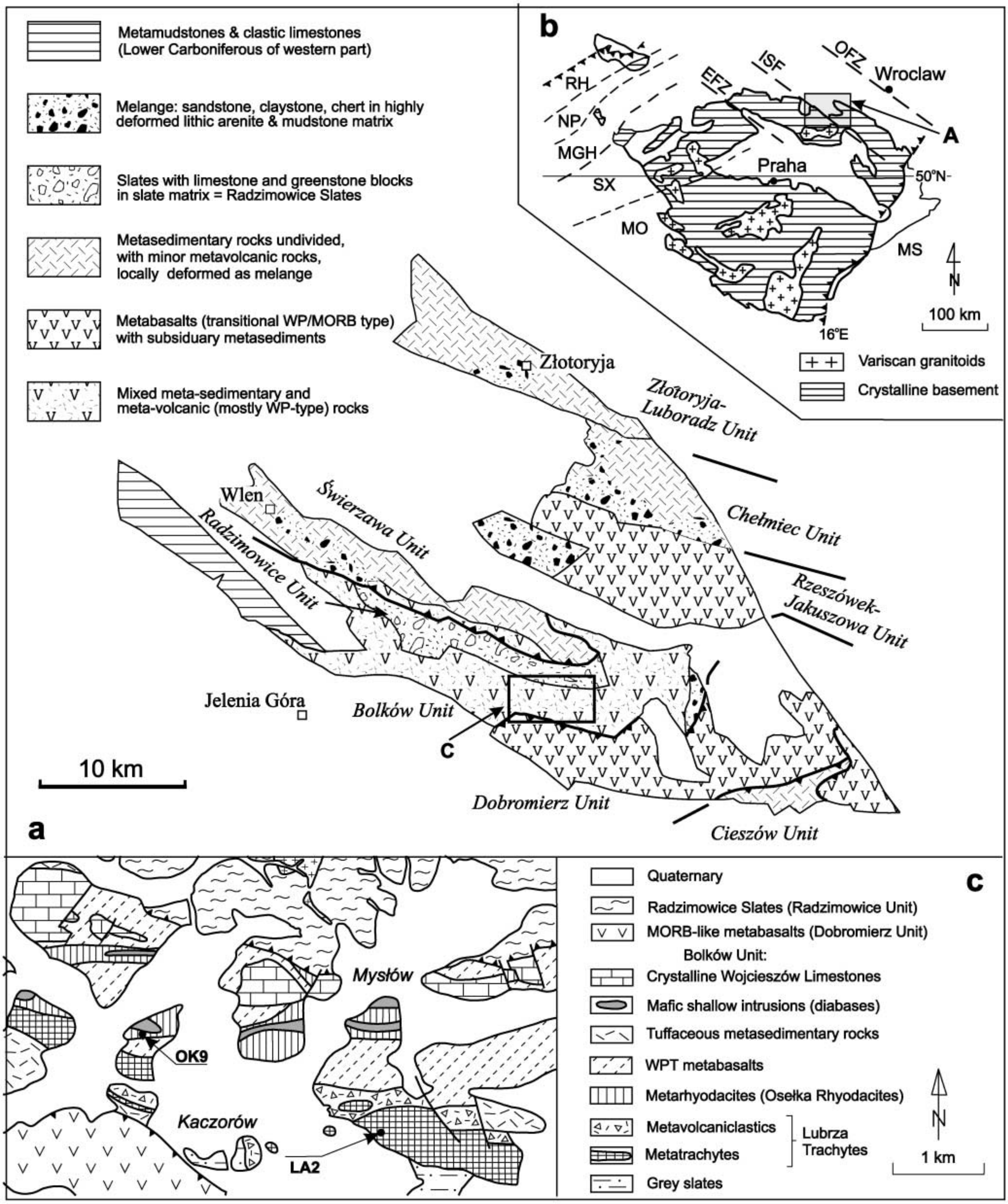

Fig. 1. Geological sketch map of the Kaczawa Mountains (**a**) showing major lithological subdivisions, tectonic units and location of the study area and sampling sites (**c**). Inset map (**b**) shows the location of the area in the Bohemian Massif. EFZ, Elbe Fault Zone; ISF, Intra-Sudetic Fault; MGH, Mid-German Crystalline High; MO, Moldanubian Zone; MS, Moravo-Silesian Zone; NP, Northern Phyllite Zone; OFZ, Odra Fault Zone; RH, Rheno-Hercynian Zone; SX, Saxo-Thuringian Zone. WPT, within-plate tholeiite; MORB, mid-ocean ridge basalt.

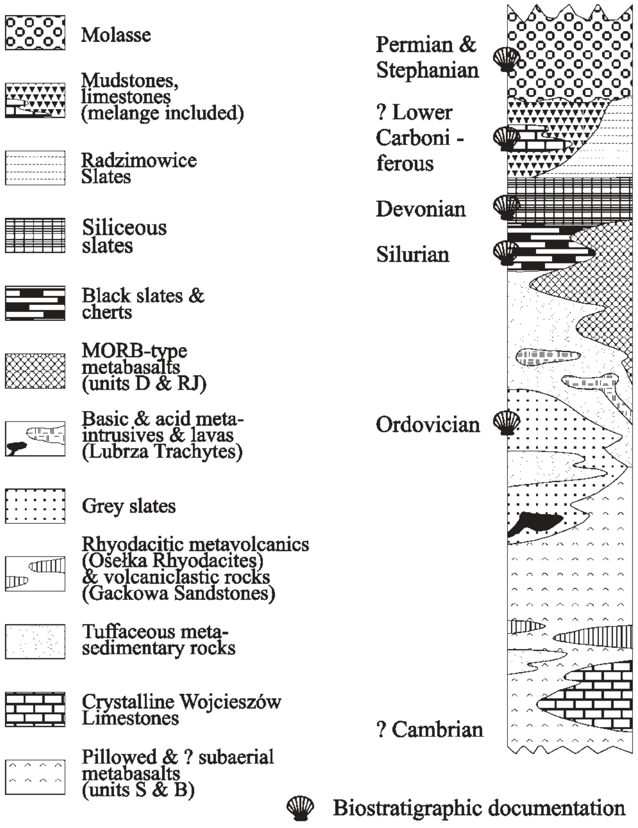

Fig. 2. Lithostratigraphic column for the Kaczawa Complex (modified from Furnes *et al.* 1994).

owa Formation sandstones, the crystalline Wojcieszów Limestone, and locally abundant metamudstones (Teisseyre 1963; Baranowski *et al.* 1990; Kryza & Muszyński 1992; Kryza 1993; Muszyński 1994). Based on geochemical and isotopic characteristics of the metavolcanic rocks, this part of the Kaczawa succession was interpreted as emplaced in an initial rift setting within continental crust (Furnes *et al.* 1994).

Higher in the Kaczawa succession (Fig. 2), thick bodies of pillowed and massive metabasalts occur, in association with Silurian black cherts and graptolitic slates (Rzeszówek–Jakuszowa and Dobromierz units in Fig. 1a). The mid-ocean ridge-type basalts, together with the pelagic deposits, suggest that this higher part of the succession developed in a mature basin underlain by an oceanic-type crust (Furnes *et al.* 1994).

The youngest part of the Kaczawa Complex is represented by polygenetic mélange bodies that formed within the Variscan accretionary prism (Baranowski *et al.* 1990; Collins *et al.* 2000; Kryza & Muszyński 2003).

Petrography of the metavolcanic rocks

The lower part of the Kaczawa succession comprises composite metavolcanic suites and intercalated metasedimentary rocks. The metavolcanic rocks include (Kryza & Muszyński 1992): (1) transitional tholeiitic–alkaline metabasalts; (2) metarhyodacites (the Osełka Rhyodacites); (3) a bimodal alkaline metabasalt–trachyte suite (the Lubrza Trachytes).

The transitional metabasalts are represented by pillowed and massive lavas and pillow breccias, all of within-plate geochemical character (Furnes *et al.* 1994). The metarhyodacites are found as discontinuous, strongly elongated, relatively thin (up to 100–200 m) and often strongly sheared rock bodies (interpreted as ash-flow sheets). Their geochemical and isotopic features are typical of magmas derived from continental crust. In contrast, the bimodal suite (the Lubrza Trachytes) forms small shallow intrusions and extrusions associated with minor volcaniclastic rocks. The composition of these rocks ranges from alkali basalts to trachytes, and is typical of continental initial rift settings (Furnes *et al.* 1994).

Sample OK9, metarhyodacite

The sampled rock from Osełka Hill, west of the village of Mysłów (Fig. 1c) is a moderately sheared, pale cream coloured, aphanitic rock, locally with a mylonitic texture. The rock is fine grained (grain size *c.* 0.01 mm) and composed of quartz, K-feldspar, plagioclase, sericite, minor chlorite, and abundant accessory zircon and apatite.

Sample LA2, metatrachyte

The rock collected from Lubrza Hill, east of Mysłów, is dark grey, purple-tinted, massive and generally aphanitic with scarce alkali-feldspar phenocrysts a few millimetres in size. The microcrystalline felsic matrix is composed of feldspars, quartz, sericite, iron oxides and, commonly, finely crystalline aegirine. Rare jadeite was ascertained as small relict inclusions in feldspars and it was interpreted to have been formed during an early high P–T metamorphic event (Kryza *et al.* 1990; Muszyński & Kryza 1993).

Sensitive high-resolution ion microprobe (SHRIMP) results

Methods

The samples, each *c.* 5 kg in weight, were crushed in a jaw crusher to a grain size of < 0.25 mm, and heavy mineral concentrates were extracted by sieving, heavy liquid and paramagnetic techniques. Zircon grains were hand-selected and mounted in epoxy resin together with chips of the TEMORA (Middledale Gabbroic Diorite, New South Wales, Australia) and 91500 (Geostandart zircon) reference zircons. The grains were sectioned approximately in half and polished. Reflected and transmitted light photomicrographs and cathodoluminescence (CL) SEM images were prepared for all zircons. The CL images were used to decipher the internal structures of the sectioned grains and to target specific areas within these zircons.

In situ SIMS U–Pb analyses were performed on a SHRIMP II at the Centre of Isotopic Research (CIR) at VSEGEI following the procedure described by Williams (1998) and Larionov *et al.* (2004). The results were processed with the SQUID v1.12 (Ludwig 2005*a*) and ISOPLOT/Ex 3.22 (Ludwig 2005*b*) software, using the decay constants of Steiger & Jäger (1977). The Pb/U ratios have been normalized relative to a value of 0.0668 for ^{206}Pb/^{238}U of the TEMORA reference zircons, equivalent to an age of 416.75 Ma (Black *et al.* 2003). The common lead correction was made using measured ^{204}Pb according to the model of Stacey & Kramers (1975). Uncertainties given for individual analyses (ratios and ages) are at the 1σ level; however, the uncertainties in calculated concordia ages are reported at 2σ level. The results are presented in Table 1 and Figures 3–6.

Metarhyodacite OK9

Typically, the zircons of the Osełka Rhyodacites are euhedral, short- to medium-prismatic, with dominant (100) prism and (101) pyramid. Most crystals have a clear central domain, and

Table 1. *Results of U–Pb SHRIMP II dating of zircons from the metarhyodacite sample OK9 and the metatrachyte sample LA2*

Spot no.	$^{206}Pb_c$ %	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{206}Pb_R$ (ppm)	$^{238}U/^{206}Pb_R$	Error %	Age $^{206}Pb/^{238}U$	1σ error	$^{207}Pb_R/^{206}Pb_R$	Error %	Age $^{207}Pb/^{206}Pb$	1σ error	D %	$^{207}Pb_R/^{235}U$	Error %	$^{206}Pb_R/^{238}U$	Error %	Error corr.
Sample OK9																			
6.1	21.84	1344	771	0.59	62.9	23.48	1.6	268.8	±4.1	0.061	20	656	±430	59	0.361	20	0.04259	1.6	0.077
3.2	23.96	1686	503	0.31	113	16.90	1.7	370.6	±6.0	0.046	32	−9	±770	4367	0.37	32	0.05918	1.7	0.052
1.2	14.60	1070	627	0.61	69.8	15.43	1.1	404.9	±4.3	0.0736	11	1,029	±230	61	0.657	11	0.06482	1.1	0.096
2.1	13.26	1091	396	0.38	79.4	13.60	1.3	457.5	±5.8	0.047	25	60	±590	−660	0.48	25	0.07355	1.3	0.053
1.1	7.93	986	992	1.04	68.6	13.42	0.77	463.3	±3.4	0.0549	9.4	406	±210	−14	0.564	9.4	0.07452	0.77	0.082
8.2	11.44	1102	254	0.24	81.4	13.12	1.1	473.5	±5.1	0.0579	15	524	±320	10	0.608	15	0.07621	1.1	0.075
9.1	1.49	701	251	0.37	48.4	12.63	2.5	491	±12	0.0575	4.0	511	±89	4	0.628	4.8	0.0792	2.5	0.533
7.1	0.44	246	58	0.24	17.1	12.42	0.94	499.2	±4.5	0.0566	3.6	475	±81	−5	0.628	3.8	0.08051	0.94	0.250
11.1	0.00	599	329	0.57	41.4	12.423	0.59	499.1	±2.8	0.05897	1.3	566	±28	12	0.6545	1.4	0.08050	0.59	0.413
5.1	1.95	570	889	1.61	40.4	12.359	0.71	501.6	±3.4	0.0515	5.4	262	±120	−92	0.574	5.5	0.08091	0.71	0.130
3.1	1.25	598	573	0.99	42.1	12.360	0.60	501.5	±2.9	0.0562	4.2	461	±94	−9	0.627	4.3	0.08091	0.60	0.139
10.1	1.19	377	383	1.05	26.5	12.36	1.4	501.7	±6.7	0.0501	8.2	200	±190	−151	0.559	8.3	0.0809	1.4	0.168
4.1	0.09	802	403	0.52	56.2	12.272	0.54	505.0	±2.6	0.0569	1.9	488	±43	−4	0.639	2.0	0.08149	0.54	0.269
8.1	0.14	1025	236	0.24	73.9	11.934	0.46	518.7	±2.3	0.05702	1.5	492	±33	−5	0.659	1.6	0.08379	0.46	0.298
14.1	0.00	92	32	0.36	7.95	9.91	1.4	620.0	±8.4	0.0603	2.8	613	±61	−1	0.839	3.2	0.1009	1.4	0.451
13.1	0.08	265	112	0.44	89.6	2.541	0.63	2139	±11	0.13312	0.68	2139	±12	0	7.223	0.93	0.3935	0.63	0.677
12.1	0.16	219	74	0.35	74.3	2.535	0.75	2144	±14	0.1327	0.77	2134	±13	0	7.218	1.1	0.3945	0.75	0.700
15.1	0.07	169	61	0.38	60.3	2.405	1.0	2241	±20	0.1407	1.1	2236	±18	0	8.07	1.5	0.4158	1.0	0.704
Sample LA2																			
6.1	0.06	3151	2579	0.85	195	13.869	0.30	448.8	±1.3	0.05450	0.73	392	±16	−15	0.5418	0.79	0.07211	0.30	0.375
1.1	0.17	556	387	0.72	36.5	13.097	0.56	474.3	±2.5	0.0553	2.2	422	±49	−12	0.582	2.3	0.07635	0.56	0.245
4.2	0.62	1418	1654	1.21	95.0	12.899	0.38	481.3	±1.7	0.0557	2.0	442	±45	−9	0.596	2.1	0.07753	0.38	0.182
7.1	0.79	445	385	0.89	29.9	12.884	0.66	481.9	±3.1	0.0542	4.0	381	±91	−26	0.581	4.1	0.07761	0.66	0.161
8.1	0.45	631	461	0.75	42.4	12.858	0.60	482.8	±2.8	0.0552	2.6	419	±59	−15	0.592	2.7	0.07777	0.60	0.222
3.1	0.49	351	268	0.79	23.6	12.82	0.81	484.4	±3.8	0.0532	2.6	336	±60	−44	0.572	2.8	0.07803	0.81	0.291
2.1	0.00	364	307	0.87	24.5	12.767	0.69	486.1	±3.2	0.05860	1.7	552	±37	12	0.633	1.8	0.07833	0.69	0.378
2.2	0.31	787	1032	1.35	53.3	12.738	0.48	487.2	±2.2	0.0574	2.1	508	±46	4	0.622	2.1	0.07851	0.48	0.224
4.1	0.21	811	771	0.98	54.8	12.738	0.45	487.2	±2.1	0.05588	1.7	447	±39	−9	0.605	1.8	0.07851	0.45	0.253
3.2	0.33	625	789	1.30	42.4	12.726	0.54	487.6	±2.5	0.0562	2.2	459	±50	−6	0.609	2.3	0.07858	0.54	0.234
1.2	0.15	1049	1116	1.10	71.2	12.686	0.49	489.1	±2.3	0.05616	1.5	459	±34	−7	0.6104	1.6	0.07883	0.49	0.304
9.1	1.50	533	236	0.46	39.7	11.713	0.60	528.1	±3.0	0.0624	3.8	687	±80	23	0.734	3.8	0.08538	0.60	0.157
5.1	0.00	150	56	0.39	11.8	10.86	0.97	567.6	±5.3	0.0624	2.2	688	±48	18	0.792	2.4	0.09204	0.97	0.398

Pb_C and Pb_R are common and radiogenic lead, respectively. Errors are 1σ unless otherwise specified. The 1σ error in standard calibration is 0.38%. Given ages are corrected for measured ^{204}Pb. D%, discordancey, D = 100 [(age $^{207}Pb/^{206}Pb$)/(age $^{206}Pb/^{238}U$)−1]

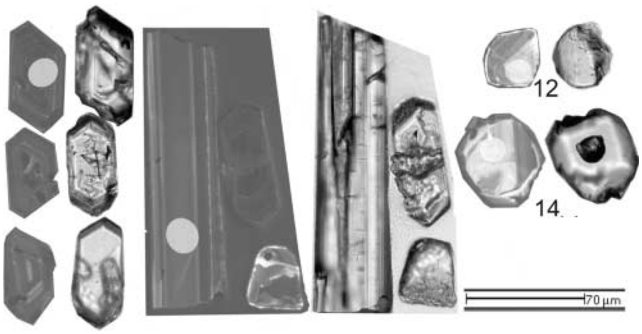

Fig. 3. Metarhyodacite sample OK9: CL and transmitted light (dextral counterparts) microphotographs of the zircons studied. The euhedral magmatic zircons have concentric oscillatory zoning seen even with an optical microscope and various types of inclusions. Anhedral zircons (such as 12 and 14) were found to be inherited.

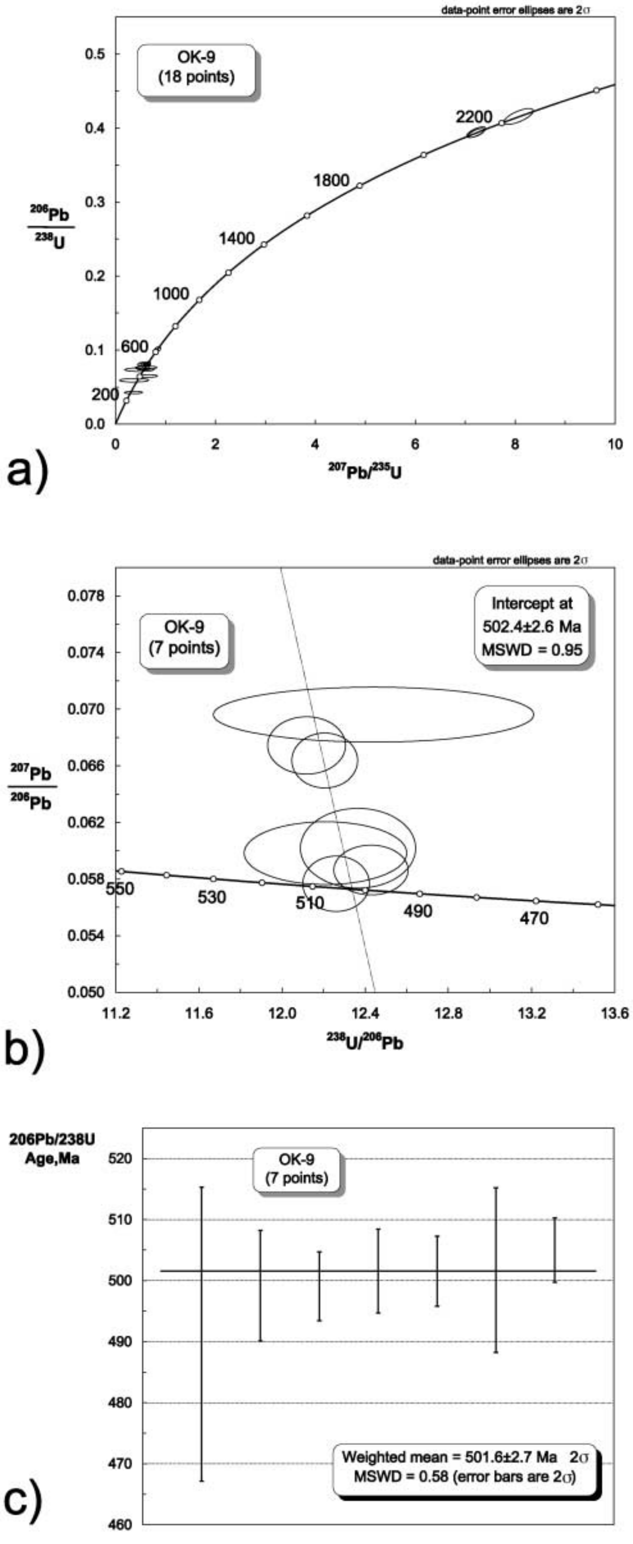

Fig. 4. (**a**) Concordia diagram showing results of SHRIMP II zircon analyses from metarhyodacite sample OK9 (all analytical points); (**b**) Tera–Wasserburg plot, with a regression analysis to common Pb of $7/6 = 0.84$ (Stacey & Kramers 1975, common Pb composition for 500 Ma) for seven selected analyses of *c*. 500 Ma; (**c**) ^{206}Pb/^{238}U weighted mean diagram for the seven selected analyses. MSWD, mean square weighted deviation.

moderately pronounced growth zoning in their outer parts (Fig. 3). A few crystals have less regular habits: isometric, subrounded or ellipsoidal, occasionally broken; the zircons of that group are usually very bright in CL images and appear to represent inherited grains (see below).

Group A, inherited zircons

Three zircon grains yielded concordant ages >2.1 Ga (Table 1, Fig. 4): OK9_15.1, 2241 ± 20 Ma, 12.1, 2144 ± 14 Ma, and 13.1, 2139 ± 11 Ma. One point shows a concordant age of 620 ± 8 Ma. All these old zircons have common distinct characteristics: (1) an irregular but generally isometric habit, with some broken edges; (2) internal zoning often cut by grain boundaries; (3) bright CL images, reflecting low Th (32–112 ppm) and low U (92–265 ppm) contents. The Th/U values in these old zircons of 0.34–0.42 are typical of zircons often considered as magmatic in origin (e.g. Rubatto & Gebauer 2000; but see also critical discussions by Möller *et al*. 2002; Whitehouse & Kamber 2005).

Group B, zircons of 502.4 ± 2.6 Ma (2σ) mean age

This is the main population represented by seven selected points (inner and outer crystal parts) from seven grains (Table 1: OK9_9.1, 7.1, 11.1, 5.1, 3.1, 10.1 and 4.1). The zircons of this group have uniform features: short- to long-prismatic euhedral crystals, with clear interiors displaying very weak to distinct recurrent regular zoning. Most of these have moderate contents of Th (typically, i.e. excluding extreme values, 236–573 ppm) and U (typically 373–802 ppm), with Th/U scattered but fairly high, between 0.24 and 1.56, corresponding to those of likely igneous origin.

Group C, young and problematic zircons

Six analytical points in five grains give strongly discordant younger ages spread between 269 ± 4 and 474 ± 5 Ma. All these 'young' zircon grains display elevated values of Th (typically 396–992 ppm) and U (986–1686 ppm) along with high common lead (^{206}Pb$_c$ 7.93–23.96%). However, their Th/U ratios fall within the same range as those of the main group B. An important feature of these 'young' zircons is that they are usually strongly cracked. The core of one of such crystal

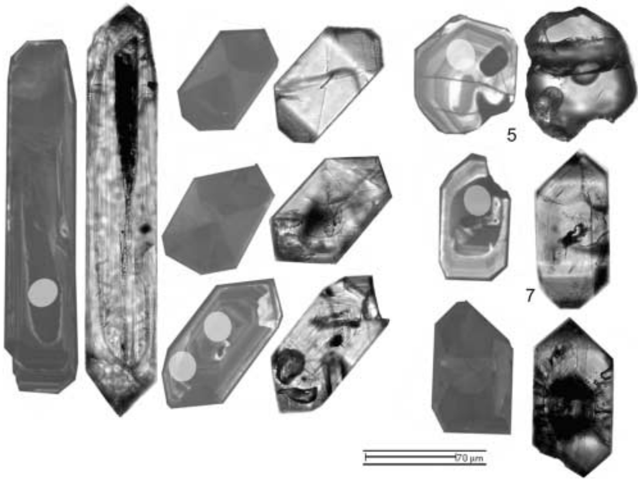

Fig. 5. Metatrachyte sample LA2: CL and transmitted light (dextral counterparts) microphotographs of the studied zircons. The igneous euhedral zircons have zoning of concentric oscillatory as well as ‘hourglass’ sectorial type (the latter dominates). Some are core-bearing (see grain 7), and contain irregularly shaped inclusions (melt?). Inherited scarce xenocrysts (grain 5) display anhedral morphology, whereas their internal structure suggests magmatic origin.

(OK9_8.1) yielded a slightly discordant older age of 519 ± 2 Ma.

Metatrachyte LA2

The zircons are not very abundant despite the high Zr contents determined in bulk chemical analyses, up to 1186 ppm (see Furnes *et al.* 1994). Typically, they are euhedral, short-prismatic, with strongly dominant (100) prism and (110) pyramid. Most are clean and homogeneous, with only a few displaying indistinct cores and zoning (e.g. LA2_5.1, 6.1, 7.1, 9.1); the latter grains are usually brighter in CL images (Fig. 5).

Group A, inherited zircons

Two of the 13 analytical points yielded relatively old and somewhat discordant ages: LA2_5.1: 568 ± 5 Ma; 9.1: 528 ± 3 Ma (Fig. 6). They represent the central areas of subhedral crystals, distinctly zoned and relatively CL-bright. The crystals contain 150–533 ppm U and 53–236 ppm Th, and have Th/U ratios of 0.39–0.46.

Group B, zircons of 485.7 ± 1.6 Ma (2σ) mean age

This is the main population of zircons, represented by nine analytical points in six grains, both in their inner and outer parts. All these zircons are similar in their habit and physical features: euhedral, usually short-prismatic, mostly with no internal zoning. They have moderate to high Th and U concentrations (268–1654 and 351–1418 ppm, respectively) and thus are CL-dark. The Th/U ratios are high, at 0.73–1.31.

Group C, young or problematic zircons

Two analytical points depart from the main population in having moderately discordant and significantly younger ages: LA2_1.1: 474 ± 25 Ma; 6.1: 448 ± 1 Ma. Both points are located in the centres of crystals, 6.1 being slightly zoned, and

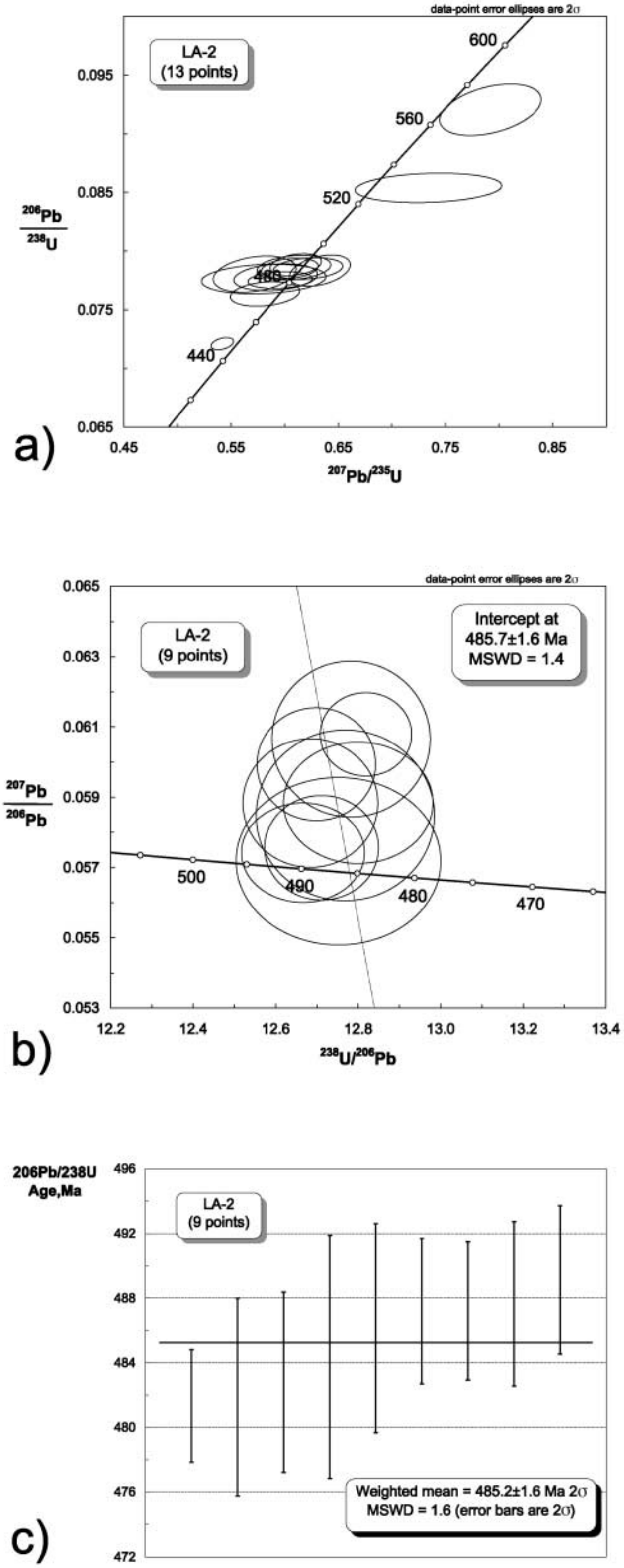

Fig. 6. (**a**) Concordia diagram showing results of SHRIMP II zircon analyses from metatrachyte sample LA2 (all analytical points); (**b**) Tera–Wasserburg plot, with a regression analysis to common Pb of $7/6 = 0.84$, for nine selected analyses of *c.* 485 Ma; (**c**) $^{206}Pb/^{238}U$ weighted mean diagram for the nine selected analyses.

1.1 having typical features of those from Group B. Also, the Th/U ratios are similar to those in Group B. However, the reverse discordance of these points makes their interpretation problematic.

Discussion and conclusion

The new SHRIMP zircon data indicate two different volcanic episodes that produced rhyodacites at *c*. 502 ± 3 Ma and trachytes at *c*. 486 ± 2 Ma (see Fig. 7). The somewhat older rhyodacitic rocks were shown to have been derived from continental crustal substrates as indicated by their geochemical characteristics, and negative ϵ_{Nd} signatures (Furnes *et al*. 1994). Characteristically, these rocks contain inherited zircons of Precambrian age (2.13–2.24 Ga), consistent with the magmatic reworking of old crustal materials. Such Palaeoproterozoic ages are typical inherited components of Central European crust incorporated into the Variscan belt, indicating intense continental crust-forming processes at that time (Gebauer *et al*. 1989; Friedl *et al*. 2000, 2004; Zeh *et al*. 2001).

The metarhyodacite sample included several points with strongly discordant younger ages dispersed between 474 ± 5 Ma and 269 ± 4 Ma. These zircon grains were traversed by numerous cracks, suggesting a disturbed U–Th–Pb system, as further indicated by higher Th and U concentrations at these analytical points. The enclosing metarhyodacites are usually strongly sheared, in contrast to the weakly deformed metatrachytes (the latter thus being more resistant to Pb loss).

The younger trachytic lavas represent acidic fractionates of a bimodal, mantle-derived magmatic suite as shown by their geochemical comagmatic character and ϵ_{Nd} values of +1.9 to +3.7 within the suite (Furnes *et al*. 1994). They belong to the Lubrza Trachytes, which on the basis of field evidence (e.g. way-up indicators in the associated pillow lavas, consistently pointing here to the south) are stratigraphically above the metarhyodacites (Kryza & Muszyński 1992), which is consistent with our SHRIMP data.

In contrast to the metarhyodacites, inherited zircons were sparse in the metatrachytes, and nearly all the analytical points indicate a considerable homogeneity of the zircon population. This feature indicates alkaline magma undersaturation with Zr, which could have led to complete dissolution of inherited zircons; this is also in line with the earlier interpretation of these lavas as differentiates of mantle-derived magmas, based, for example, on positive ϵ_{Nd} values (Furnes *et al*. 1994).

The rare inherited component of zircons in the metatrachyte (age group A) represents a vestige of magmatic events dispersed in time throughout the Proterozoic to Cambrian transition. The inherited component dated at 568 ± 5 Ma corresponds to the younger period of Cadomian magmatic activity in the Armorican Massif (Inglis *et al*. 2005; Samson *et al*. 2005) and the age of granitic pebbles and detrital zircons extracted from Lusatian greywackes (Linnemann *et al*. 2000, 2004) and Kaczawa metasandstones (Kryza *et al*. 2007). Zircons of similar ages are common in Cadomian basement blocks of peri-Gondwanan affinity (Friedl *et al*. 2000, 2004; Zeh *et al*. 2001). The younger inherited age of 528 ± 3 Ma is similar to the ages of some felsic metavolcanic rocks from the Central Sudetes (Kröner *et al*. 1997; Turniak *et al*. 2005) and can be interpreted in terms of Cadomian post-orogenic magmatism otherwise recognized in the Czech Tepla–Barrandian zone (Chlupáč *et al*. 1998; Drost *et al*. 2004; Pin *et al*. 2007).

The new results are in accord with a model that suggests a uniform timing for the initial break-up of the Gondwana margin throughout the Variscan Belt (Pin & Marini 1993; Abati *et al*. 1999). This is the case despite the complexity of modern terrane interpretations (e.g. Matte 1991; Franke & Żelaźniewicz 2000; Von Raumer *et al*. 2003). The ensuing birth of the Rheic Ocean is clearly readable from the magmatic record in the Kaczawa Complex and, thus, appears to be a widespread and

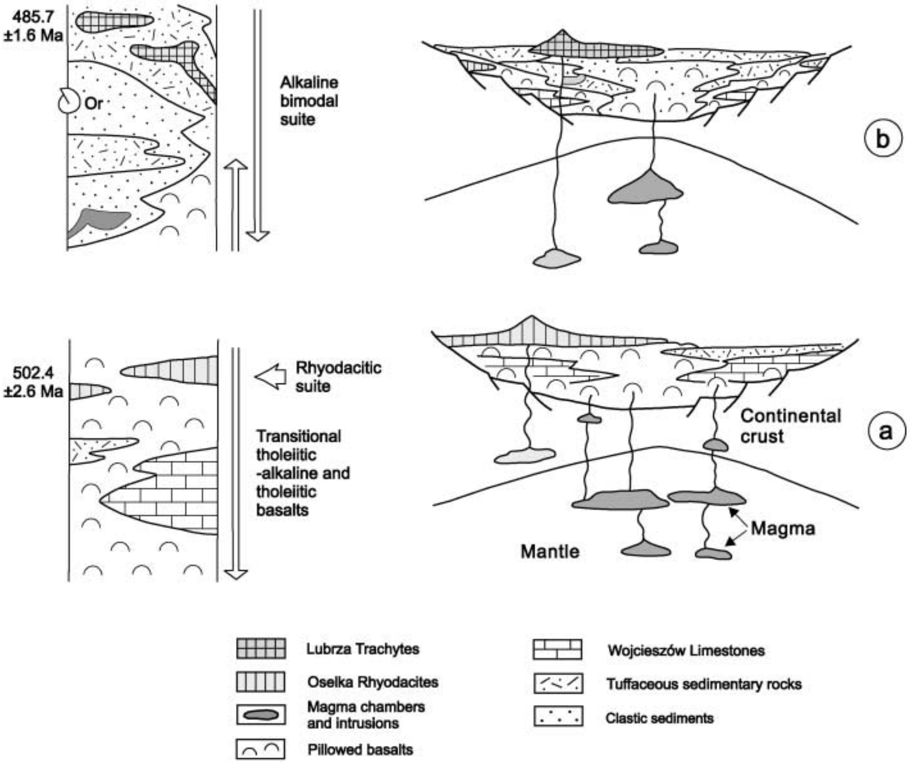

Fig. 7. Schematic illustration of a model of an evolving continental rift, from (**a**) to (**b**), and associated magmatism producing the lower part of the Kaczawa succession (modified after Furnes *et al*. 1994). The new SHRIMP zircon data from the Osełka Rhyodacites (502.4 ± 2.6 Ma) and the Lubrza Trachytes (485.7 ± 1.6 Ma) provide rigorous time constraints for the Early Palaeozoic rifting processes recorded in rock complexes in that part of the Variscides. The shell symbol in (b) denotes Ordovician fossils.

broadly synchronous event in the peri-Gondwanan realm. The significantly older rhyodacitic magmas probably came from partial melting of continental crust material, caused by a distal heat source. They were followed *c.* 16 Ma later by mantle-derived alkaline magmas (the bimodal volcanic suite). The general change in tectonic regime, following the termination of the Cadomian orogeny, may reflect mantle plume activity (Floyd *et al*. 2000; Crowley *et al*. 2001) or the collision of an oceanic ridge with the Gondwana margin (Nance & Murphy 1996; Nance *et al*. 2002). A modern analogue for such ridge–continent collision is the Baja California region on the Pacific coast of North America. We regard this type of process as the most likely trigger for the inception of the widespread continental rifting that led to the dispersion of Early Palaeozoic terranes from Gondwana.

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