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Tournaisian $^{40}Ar/^{39}Ar$ age for alkaline basalts from the Lublin Basin (SE Poland)

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The main aim of this study is to precisely determine the age of the alkaline basalts occurring within the lowermost part of Carboniferous succession in the northeastern part of the Lublin Basin (Parczew IG 7 and Parczew IG 9 boreholes; SE Poland). The new whole-rock $^{40}Ar/^{39}Ar$ data constrain the age of volcanic activity and emplacement of alkaline basalts to the Late Tournaisian (348.0 ± 0.8 Ma) with possible prolongation to the Middle Visean (338.5 ± 0.7 Ma). However, the younger age is of evidently poorer quality than the older one. The new data caused to correlate the volcanic processes occurring within the Lublin Basin with alkaline intrusions drilled in NE Poland within the Paleozoic cover of the East European Platform. They also correspond to the stratigraphic position of volcanoclastic horizons found in different parts of the Trans-European Suture Zone in Poland.

Key words: alkaline basaltic rocks, Ar-Ar geochronology, Carboniferous, Lublin Basin.

INTRODUCTION

The Lublin Basin, located in southeastern Poland (Fig. 1), is filled with siliciclastic and carbonate sediments as well as coal deposits of the Early Carboniferous through the Early Bashkirian age (e.g., Dembowski and Porzycki, 1988; Zdanowski and Żakowa, 1995; Skompski, 1998; Waksmundzka, 2013). The elongated sedimentary basin, which extends from the Lviv-Volhynian Coal Basin in West Ukraine, had developed on the southwestern margin of the East European Platform. The volcanic rocks occur within the lowermost part of Carboniferous succession in the northeastern part of the Lublin Basin and cover fluvial siliciclastic rocks (e.g., Porzycki, 1988; Waksmundzka, 2010, 2011). These terrigenous sediments are deprived of fossils. Their age is unknown (Skompski, 1998), and only relicts of Early Carboniferous plants (Porzycki, 1988) were identified in few boreholes (e.g., Parczew IG 9 and Parczew IG 10). Porzycki (1988) strongly suggested a Middle Visean age of these deposits. However, a similar complex of coarse sedimentary rocks in the Ukrainian part of the Carboniferous basin was assigned to the Tournaisian (Porzycki, 1988).

The first radiometric investigation of volcanic rocks from this area was conducted by Depciuch (1974). The whole-rock K-Ar age (319 and 333 Ma) pointed to a Late Visean and Serpukhovian age, whereas the overlying marine succession is very well biostratigraphically constrained to the Late Visean (Skompski, 1996, 2011). Moreover, Skompski (2011) suggested that post-volcanic palaeotopography caused that volcanic units had not been flooded during the initial phases of marine transgression.

The volcanic rocks, which were described as diabases or tuffo-lavas, were discovered only by drilling in many places in the northeastern part of the Lublin Basin (e.g., Parczew IG 7, Parczew IG 9, Parczew IG 10, Lublin 1, Niedrzwica IG 1 and Kolechowice 24 boreholes; Fig. 1). Presumably, the lava flows and pyroclastic rocks formed a plateau that covered an area of up to 5000 km^2 (Grocholski and Ryka, 1995). The thickness of this volcanic sequence, which comprises massive lava flows within the lower part, and tuffs in the upper part of this profile, is poorly identified. It typically exceeds 60 m with the maximum thickness of 160 m drilled in the Kolechowice 24 borehole (Porzycki, 1988). According to the geochemical classification (TAS diagram), Grocholski and Ryka (1995) classified the volcanic rocks from the Lublin Basin as foidites, tephrites and basanites, and trachybasalts.

Knowledge of the age of magmatic events is crucially important for reconstruction of the tectonic evolution of sedimentary basins. Good quality isotope ages of magmatic bodies can be served as a tool for time calibration of basin fills containing them, especially in case of poor biostratigraphic evidence. The main aim of this study was to precisely define the age of volcanic activity in the Lublin Basin. For this purpose, whole-rock $^{40}Ar/^{39}Ar$ dating of selected basalts was performed. We compared our data with the stratigraphic position of well-known Carboniferous volcanogenic horizons determined in the neighbouring areas in order to understand the nature of the Early Carboniferous magmatism in this part of the Trans-European Suture Zone and the East European Platform.

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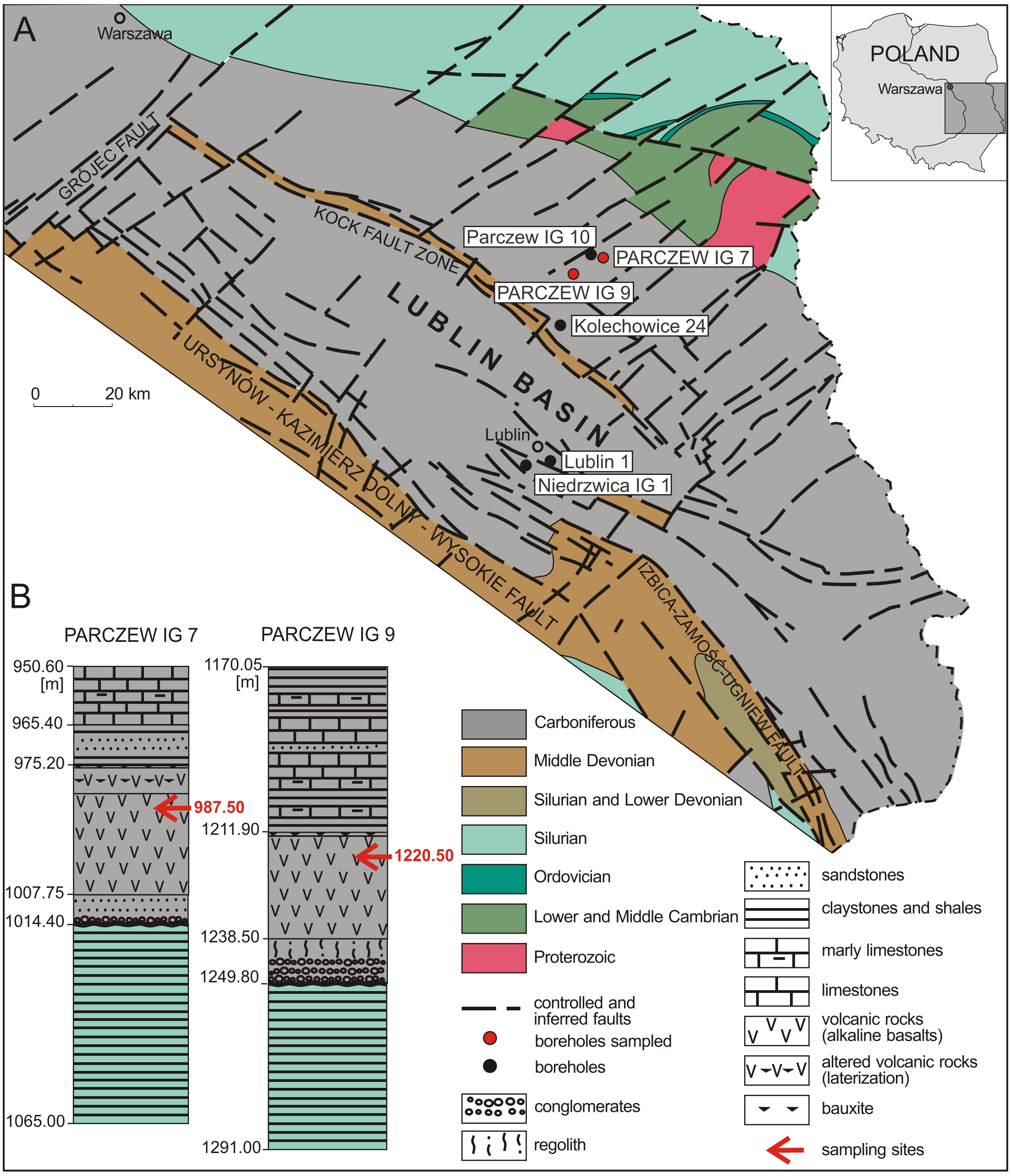

Fig. 1A – geological sketch map of the Lublin Basin, without strata younger than Carboniferous (modified after Żelichowski and Porzycki, 1983; Waksmundzka, 2011) with marked boreholes where the $^{40}Ar/^{39}Ar$ age estimations were performed; B – sampling sites with ^{40}Ar-^{39}Ar age determinations and simplified lithological logs of the analysed boreholes

MATERIALS AND METHODS

SAMPLING

The present study of the volcanic succession was conducted in the northeastern part of the Lublin Basin. The selected boreholes of Parczew IG 7 and Parczew IG 9 comprise the sequence of massive basaltic lava flows within the lower and middle part, and amygdaloidal, locally brecciated and strongly altered lavas in the uppermost part of the volcanic succession. In the Parczew IG 9 borehole, the volcanic sequence is covered by bauxite rocks. Fresh, massive, less altered pieces of lava flow were collected for whole-rock $^{40}Ar/^{39}Ar$ analysis from depths of 987.5 and 1220.5 m in the Parczew IG 7 and Parczew IG 9 boreholes, respectively (Fig. 1).

SAMPLE PREPARATION AND ANALYSIS

Following microscope examination, samples were chosen for further microprobe analyses at the Micro-area Analysis Laboratory of Polish Geological Institute – NRI in Warszawa in order to determine chemical composition of phenocrysts and crystals in the groundmass, using a *CAMECA SX 100* apparatus. The analyses were performed under the following condition: 30 s counting time, 5 μm beam diameter, and 15 kV excitation voltage.

All whole-rock samples for $^{40}Ar/^{39}Ar$ geochronology were crushed with a jaw-crusher and subsequently milled. The geochronological analysis was carried out at the Lund University $^{40}Ar/^{39}Ar$ Geochronology Lab (Sweden). Selected samples were irradiated together with the TCR sanidine standard (28.34 Ma following Renne et al., 1994) for 24 hours at the Oregon State research reactor (USA). J-values were calculated with a precision of <0.25% and are reported for each sample in the data tables. The decay constants utilized were those given in Steiger and Jäger (1977). The $^{40}Ar/^{39}Ar$ geochronology laboratory at the University of Lund uses a *Micromass 5400* mass spectrometer with a Faraday and electron multiplier system. A metal extraction line, which contains two *SAES C50-ST101* Zr-Al getters and a cold finger cooled to ca. –155°C by a *Polycold P100* cryogenic refrigeration unit, is also present. Whole-rock separates were loaded into a copper planchette that comprises several 3 mm holes. Samples were step-heated using a defocused 50W CO_2 laser. Sample clean-up time that made use of the two hot Zr-Al *SAES* getters and a cold finger with a *Polycold* refrigeration unit was five minutes. The laser was rastered over the samples to provide even-heating of all grains. The entire analytical process is automated and runs on a *Macintosh-steered OS 10.2* with software modified specifically for the Lund University laboratory and developed originally at the Berkeley Geochronology Center by Al Deino. Time zero regressions were fitted to data collected from 10 scans over the mass range of 40 to 36. Peak heights and backgrounds were corrected for mass discrimination, isotopic decay and interfering nucleogenic Ca-, K- and Cl-derived isotopes. Isotopic production values for the cadmium-lined position in the OSU reactor are $^{36}Ar/^{37}Ar(Ca) = 0.000264$, $^{39}Ar/^{37}Ar(Ca) = 0.000695$, and $^{40}Ar/^{39}Ar(K) = 0.00073$. ^{40}Ar blanks were calculated before every new sample and after every three sample steps. Blank values were subtracted for all incremental steps from the sample signal. The laboratory was able to produce very good incremental gas splits, using a combination of increasing time at the same laser output, followed by increasing laser output. Age plateaus were determined using the criteria of Dalrymple and Lamphere (1971), which specify the presence of at least three contiguous incremental heating steps with statistically indistinguishable ages and constituting more than 50% of the total ^{39}Ar released during the experiment. In some places, where a statistical overlap of steps is not obtained, a forced-fit age is given over a certain percentage of gas. $^{40}Ar/^{39}Ar$ geochronology data were produced, plotted and fitted using the argon programme provided by Al Deino from the Berkeley Geochronology Center, USA.

PETROGRAPHIC CHARACTERIZATION

The lava from Parczew IG 7 is characterized by fine-grained, massive texture. The groundmass consists of plagioclase laths of labradorite-andesine composition, fine-grained clinopyroxene and olivine crystals (Fig. 2A, B). Additionally, analcime occurred between the plagioclase, pyroxene and olivine crystals. Olivine phenocrysts, up to 400–500 μm in length, were found rarely. Accessory minerals include magnetite (euhedral and skeletal), titanomagnetite, ilmenite and apatite (Fig. 2C). An insignificant amount of secondary minerals such as chlorite was identified.

The sample from Parczew IG 9 is characterized by fine-grained, slightly porphyritic and amygdaloidal texture. The rock is evidently altered. The plagioclase crystals of labradorite-andesine composition occur as euhedral and subhedral phenocrysts, some exceeding 5 mm in length, but often occur in the groundmass as irregularly and randomly oriented laths, less than 0.5 mm in length (Fig. 2D). The altered groundmass contains plagioclase laths, clinopyroxene and olivine crystals as well as analcime (Fig. 2E). The main accessory mineral components are apatite, ilmenite, titanomagnetite and pyrite. Amygdales are filled by calcite, chlorite, analcime and pumpellyite (Fig. 2F). The rock is cut by microveins filled by a very similar paragenesis of secondary minerals, excluding pumpellyite. The identified paragenesis of secondary minerals occurring within the veins and amygdules is a product of intense metasomatism.

All analysed sample fall within the tephrite/basanite and trachybasalt field in the total alkalis *versus* silica (TAS; Fig. 3A) classification diagram (Le Maitre et al., 1989). According to the diagram of Winchester and Floyd (1977), which is based on the trace elements such as Ti, Zr, Nb, Y that are commonly regarded as immobile in hydrothermal or metamorphic conditions, the rocks from the Lublin Basin are classified as alkaline basalts (Fig. 3B).

RESULTS

Alkaline basalts from drill cores of the Parczew IG 9 and Parczew IG 7 boreholes have yielded well-defined Ar-Ar plateau ages of 338.5 ± 0.7 Ma and 348.2 ± 0.8 Ma, respectively (Appendix 1*; Fig. 4), with medium MSWDs (1.99 and 1.11) and medium to low probabilities of x^2 distribution (0.35 and 0.08). The six steps defining the plateaus for lava flows from the Parczew IG 7 borehole correspond to about 52.5% of the ^{39}Ar released (Fig. 4A), whereas the five steps for volcanic rocks from the Parczew IG 9 borehole correspond to about 55% of the ^{39}Ar released (Fig. 4B). The low probability of x^2 distribution received for the younger age means that it should be interpreted with caution, i.e. not necessarily regarded as coeval with the magma emplacement.

DISCUSSION

The new isotopic ages presented here constrain the age of volcanic activity and emplacement of the alkaline basalts to the Late Tournaisian with possible prolongation to the Middle Visean. On the other hand, at this stage of investigation we cannot exclude that the obtained results might indicate the presence of two separate events of volcanic activity in the Lublin Basin or existence of older magmatic and younger hydrothermal events. The extensive hydrothermal alteration of rocks from the Parczew IG 9 borehole supports the latter solution. Anyway, best defined Ar-Ar age in the basalts from the Parczew IG 7 drill core undoubtedly indicates that volcanic activity took place there in the Late Tournaisian. The volcanic rocks cover coarse-grained sediments classified as Lower Visean by Porzycki (1988). According to new isotopic data, the age of these sediments cannot be younger than Late Tournaisian.

The new data allowed correlating the volcanic processes occurring in the Lublin Basin with alkaline and carbonatite volcanism discovered in NE Poland (southern Fennoscandia; Fig. 5). Demaiffe at al. (2013) documented an Early Carboniferous emplacement age of the Tajno alkaline-carbonatite complex, the Ełk syenite massif and the Pisz gabbro-syenite complex by U-Pb *SHRIMP* dating of zircons. The Late Tournaisian

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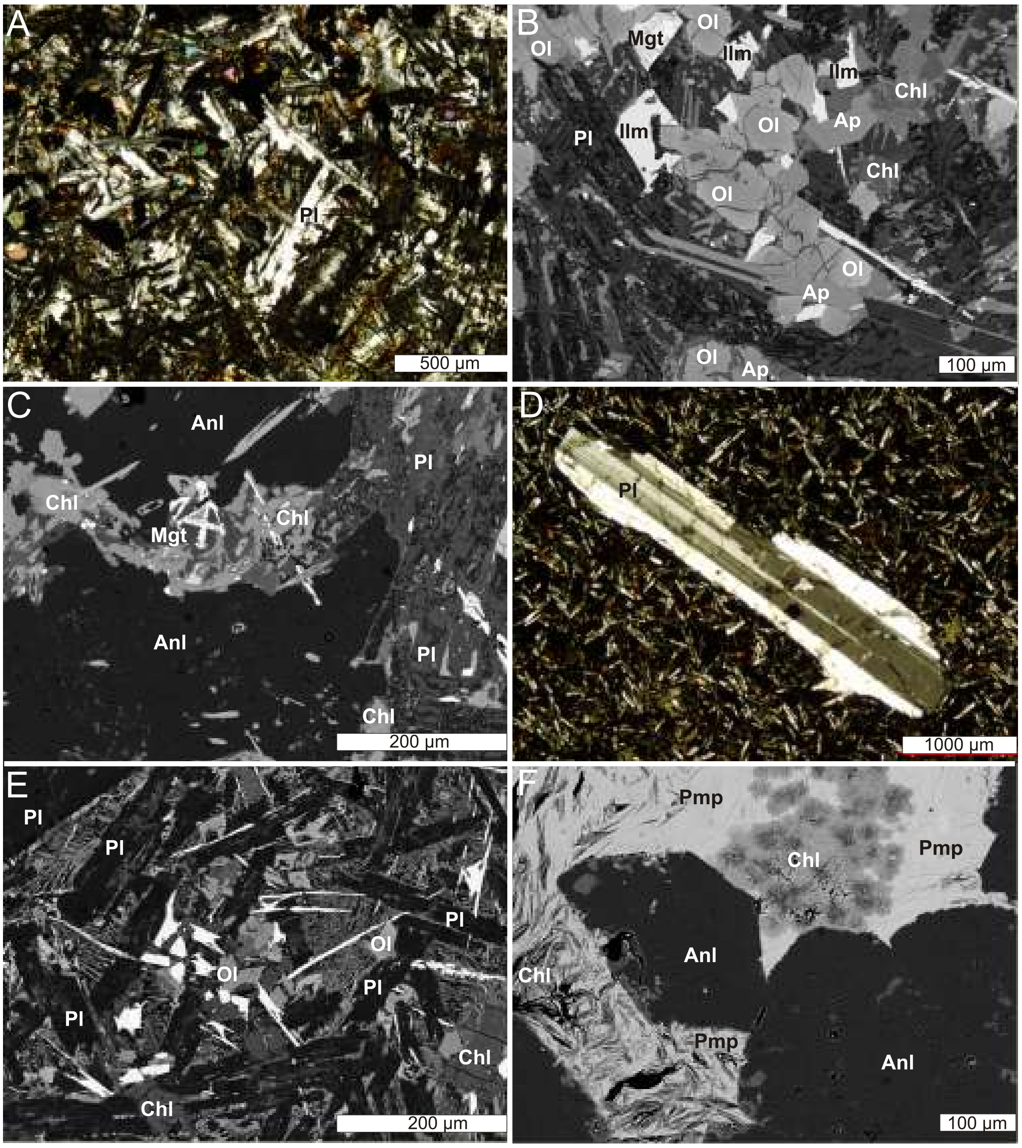

Fig. 2. Photomicrographs of samples analysed from the Lublin Basin – Parczew IG 7 borehole, depth 987.5 m (A–C), and Parczew IG 9 borehole, depth 1220.5 m (D–F)

A – fine-grained groundmass with plagioclase laths, clinopyroxene and olivine grains (crossed polars); **B** – predominant olivine crystals accompanied by plagioclase, apatite, magnetite and ilmenite (back-scatter electron image, BSE); **C** – plagioclase laths, chloritized clinopyroxene, analcime and skeletal magnetite crystals, (back-scatter electron image BSE); **D** – plagioclase phenocryst (crossed polars); **E** – fine-grained groundmass with plagioclase laths, clinopyroxene, olivine grains and analcime (back-scatter electron image, BSE); **F** – amygdules infilled with analcime, chlorite and pumpellyite (back-scatter electron image, BSE); mineral symbols: Anl – analcime, Ap – apatite, Chl – chlorite, Ilm – ilmenite, Mgt – magnetite, Ol – olivine, Pl – plagioclase, Pmp – pumpellyite; all BSE images and mineral phases' identification were performed at the Microprobe Analysis Laboratory (PGI-NRI) in Warszawa using a *Cameca SX 100* instrument

pyroclastic or volcanic rocks were also reported from several places of the Trans-European Suture Zone in Poland (see e.g., Narkiewicz, 2007). They occur within the Middle and Late Tournaisian sediments of Pomerania, the Łysogóry-Radom Block, the Małopolska Block and the Upper Silesian Coal Basin (Szulczewski et al., 1996; Muszyński et al., 1996; Narkiewicz, 2007; Matyja, 2008). At that time, regional continental extension in the shelf basin area triggered widespread magmatism, particularly intense during the Late Tournaisian (see e.g., Krzemiński, 1999; Narkiewicz, 2007). This extensional regime prevailed most probably at least until the end of Visean in the area of the Holy Cross Mountains and Upper Silesian Coal Basin where mafic intrusions of that age were documented (Nawrocki et al., 2010, 2013).

According to the previous isotope data (Depciuch, 1974; Grocholski and Ryka, 1995), Narkiewicz (2007) has constrained the Carboniferous magmatism of the Lublin area to mid-Visean time and regarded it as consistent with the general pattern of diachronous occurrence of rift-related magmatic activity in the southern part of the East European Platform, peaking during the Givetian in the Peri-Caspian Depression, during the Early Frasnian in the Donbas area, during the late Famennian-Early Tournaisian in the Pripyat Graben, and finally, during mid-Visean in the Lublin Basin. Results of our study indi-

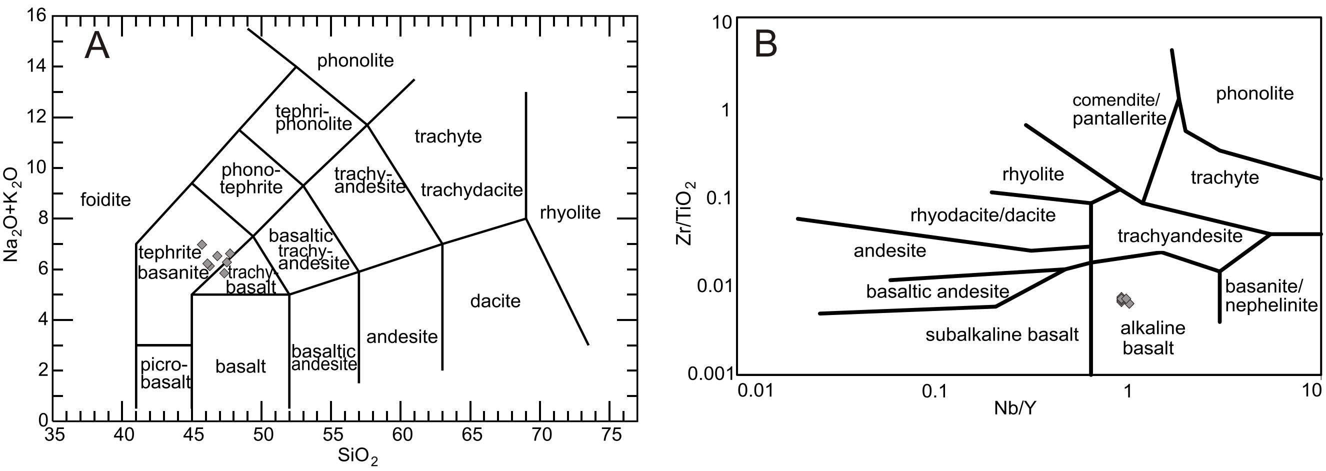

Fig. 3A – chemical classification of the rocks on the total alkalis vs. silica (TAS) diagram of Le Maitre et al. (1989); B – chemical classification of the rocks using the Zr/TiO$_2$ vs. Nb/Y diagram (Winchester and Floyd, 1977)

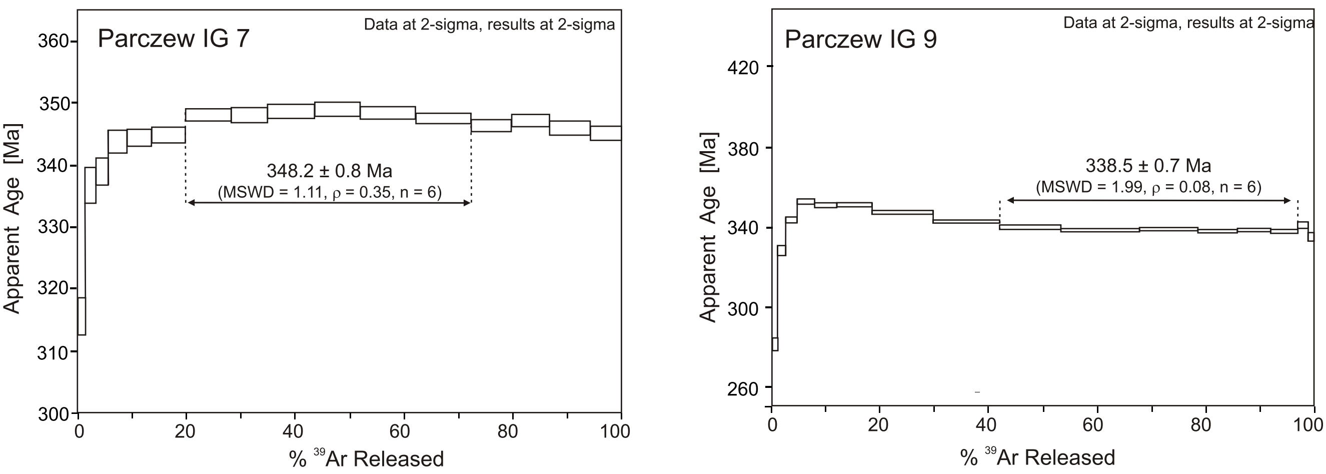

Fig. 4. Whole-rock $^{40}Ar/^{39}Ar$ age spectra of alkaline basaltic rock samples from the Lublin Basin

Error bars of step apparent ages are drawn at 1σ analytical uncertainties; plateau and pseudoplateau ages (±2 σ error) are also listed; MSWD – mean square deviation, ρ – probability of occurrence based on Chi Square Tables, n – number of steps defining the plateau age

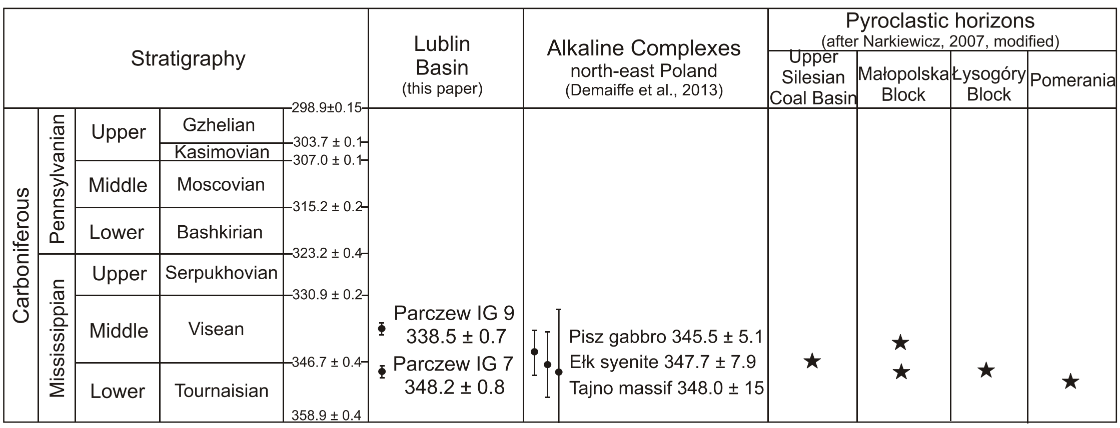

Fig. 5. $^{40}Ar/^{39}Ar$ ages (in Ma) of alkaline basalts from the Lublin Basin, and U-Pb ages of alkaline complexes from north-east Poland (after Demaiffe et al., 2013) *versus* a stratigraphic chart (after Gradstein et al., 2012)

cate that without reliable and precise isotopic ages such regional interpretations should be treated with caution.

CONCLUSIONS

1. The new isotopic ages presented in this paper indicate that magma extrusion in the Lublin Basin took place in the Late Tournaisian with possible prolongation to the Middle Visean. It cannot be excluded, however, that the younger age may be related to the hydrothermal alteration of these rocks.

2. The alkaline basalts from the Lublin Basin are coeval with the alkaline intrusions known from northeastern Poland and with pyroclastic/volcanic rocks occurring in the Carboniferous sediments of the Polish Variscan foreland. Therefore, the Late Tournaisian phase of magmatism seems to be there the most intense and widespread over the entire area located outside the Variscan orogen in Poland.

3. The Late Tournaisian age of the alkaline basalts points to a Tournasinan age of fluvial, coarse sedimentary rocks occurring within the lowermost part of the Carboniferous succession in the Lublin Basin.

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