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On the palaeomagnetic age of the Zalas laccolith (southern Poland)

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ABSTRACT:

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An age estimation for the Zalas laccolith (Kraków area, South Poland) using the palaeomagnetic method is presented. 29 hand samples were taken from the rhyodacites and neighbouring Visean sediments cropping out in three localities. Two components of magnetization were isolated in the volcanic rocks and Visean sediments. The "A" component, common to the greenish rhyodacites and Visean sediments from Orlej, is carried by magnetite and is regarded as primary. Comparison of the mean inclination of this component with the expected (reference) stable European inclinations leads to the conclusion that the Zalas laccolith was emplaced about 280 Ma ago. The second component, "B", characteristic of the reddish rhyodacites, is carried by hematite and was recorded during the Late Permian (c. 260 Ma) metasomatic alterations of these rocks. The palaeomagnetic poles calculated for the "A" component show a distinct departure from the Permian segment of the Baltic apparent polar wander path (APWP) due to anticlockwise block rotations of the rocks studied that were most probably connected with the Early Permian sinistral transtensional tectonic regime in Central Europe.

Key words: Paleomagnetism, Rhyodacites, Permian, Zalas, Southern Poland.

INTRODUCTION

The igneous rocks of the Kraków region were attributed to the Late Carboniferous – Early Permian magmatic cycle (HARAŃCZYK 1989). However, the ages of particular magmatic bodies are a matter of controversy (HARAŃCZYK 1989, DŻUŁYŃSKI 1955, KOZŁOWSKI 1955). The Early Permian age of some lava flows can be inferred from their setting with respect to the lowermost Permian Myślachowice conglomerate (HARAŃCZYK & HOCYK 1989). Up to now no reliable isotope age estimations of the Krakow igneous rocks have been performed.

The outcrops of rhyodacites from the localities Orlej and Zalas belong to a single laccolith that intruded into uppermost Visean – Namurian sediments (Text-fig. 1, DŻUŁYŃSKI 1955). It remains unclear whether the rhyodacites were intruded during the Late Carboniferous or Early Permian. The age estimation basing on traces of split of uranium nucleus (SKOWROŃSKI 1974) gave an Asselian (295 Ma) age.

The rhyodacites from Orlej and Zalas quaries were studied palaeomagnetically by BIRKENMAJER & NAIRN (1964). Their results, however, were based on four hand samples only and the obtained statistical

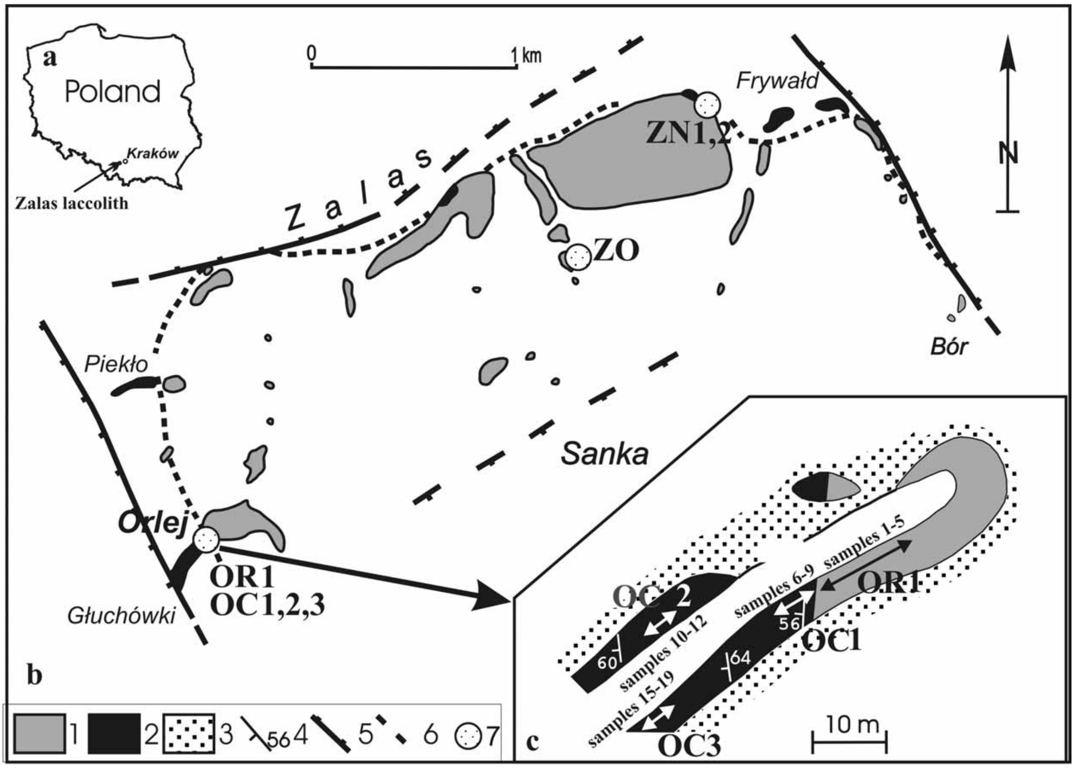


Fig. 1. The location of the studied outcrops within a countur map of Poland (a) and the Zalas laccolith (b) (after DŻUŁYŃSKI 1955). (c) Sites of palaeomagnetic sampling within a geological sketch map of the Orlej quarry (after PIŁAT 1957). 1– rhyodacites, 2 – Visean-Namurian sediments, 3 – debris, 4 – directions and values of dip, 5 – faults, 6 – limits of laccolith, 7 – sampling localities

parameters are very poor and consequently this study is not very helpful for palaeomagnetic dating of these rocks. Moreover, these authors did not perform the palaeomagnetic contact test that could be done in this part of the Zalas laccolith. The aim of the present paper is to give new palaeomagnetic data from the igneous and sedimentary rocks that could be useful for the determination of the emplacement time of the Zalas laccolith.

MATERIAL AND METHODS

The rhyodacites and the host Visean sediments from the Orlej abandoned quarry (e.g. PIŁAT 1957, LEWANDOWSKA & ROSPONDEK 2003) and the Zalas working quarry were sampled for the palaeomagnetic study. In the Orlej quarry three sites consisting of 12 hand samples (i.e. fragments of beds) were collected from the Visean dark sediments and five hand samples were taken from the greenish and reddish rhyodacites (Text-fig. 1c). Seven hand samples were taken from the reddish rhyodacites and adjacent Visean sedimentary rocks cropping out in the Zalas working quarry. The greenish rhyodacites were also sampled in the Zalas abandoned quarry, with five hand samples taken. The proximity of the volcanic and sedimentary rocks was promising for performing the palaeomagnetic contact test (IRVING 1964). Several core specimens 2.5 cm in diameter and 2.2 cm in length were drilled from each hand sample.

Specimens were subjected to both alternating field (AF) and thermal demagnetization experiments. Demagnetization results were analysed using orthogonal vector plots (ZIJDERVELD 1967), and the directions of the linear segments were calculated using principal component analysis (KIRSCHVINK 1980). In the Orlej quarry the Visean sediments dip to the west (Text-fig. 1). The value and azimuth of the dips are not homogeneous in the sites OC1 and OC2 and therefore the palaeomagnetic inclination and synfolding tests of ENKIN & WATSON (1996) were used to assess the origin of the component characteristic of these rocks. There are no differences in the dip orientation of particular Visean beds sampled in the Zalas new quarry, where these rocks dip to the north. Magnetic mineralogy was determined using isothermal remanent magnetization (IRM) techniques and thermomagnetic analyses (LOWRIE 1990).

RESULTS

The intensities of the natural remanent magnetization (NRM) of the Visean sediments are significantly higher than those noted in the rhyodacites (Text-fig. 2a). The samples of the greenish rhyodacites from the Zalas old quarry and the Orlej quarry contain one well clustered component “A” defined by lines of best fit (Text-figs 2a and 3b, Table 1). This magnetization is isolated as a straight-line segment directed towards the origin in orthogonal projection. Component “A” was usually removed in a field of about 60 mT and temperatures not exceeding 600°C. Reddish specimens of the rhyodacite from the Orlej and Zalas new quarry dis-

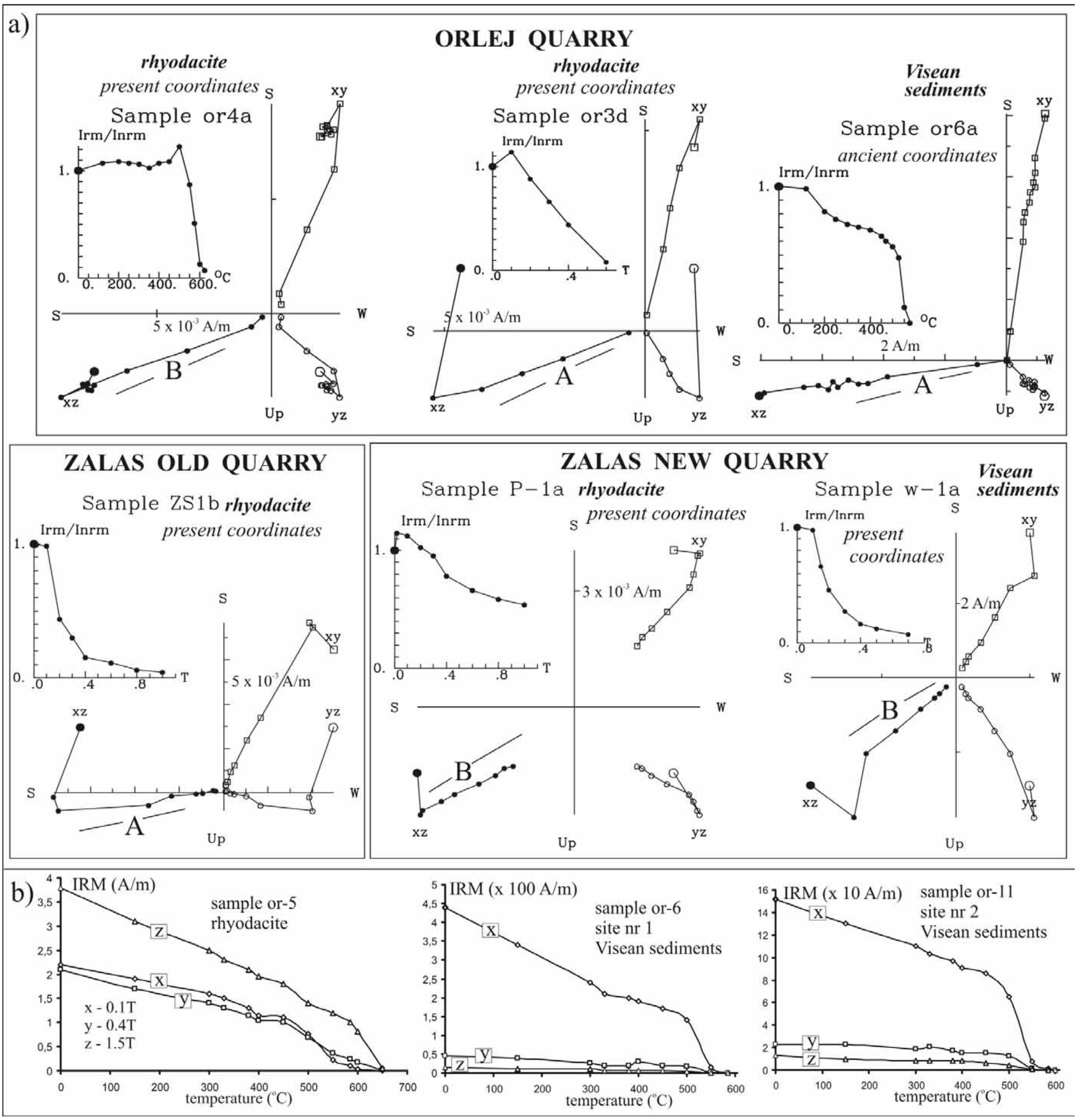


Fig. 2. (a) Typical demagnetization characteristics (intensity decay curves and orthogonal plots) of rhyodacites and Visean sediments from the Orlej and Zalas quarries. Circles in the orthogonal plots represent vertical projections, squares represent horizontal projections. The characteristic components “A” and “B” are marked on the orthogonal plots. Irm- intensity of remanent magnetization, Inrm - initial intensity of natural remanent magnetization. Figures were generated by the computer package of LEWANDOWSKI & *al*. (1997) (b) Thermal demagnetization of orthogonal-axis IRM curves obtained for rhyodacites and Visean sediments from the Orlej quarry

played different palaeomagnetic behaviour. The demagnetizing fields and unblocking temperatures were here higher than 100 mT and 600 °C respectively. The high coercivity component of magnetization was labelled "B" (Text-figs 2a and 3b, Table 1). Subsequent thermal demagnetization of the isothermal remanent magnetizations confirms the presence of two magnetic phases differing in coercivity and unblocking temperatures (Text-fig. 2b). The observed demagnetization behaviour is typical of grains of magnetite (low coercivities, medium unblocking temperatures) and hematite (high coercivities and unblocking temperatures).

The Visean sediments from the Orlej quarry contain a single well defined component of the NRM. This component was removed in a field of about 80 mT and a temperature of 570 °C (Text-fig. 2a). The NRM intensity decay curves and the results of the IRM experiment (Text-fig. 2b) point to the presence of magnetite as the main carrier of the NRM in these rocks. The results of the inclination and synfolding tests (Enkin and Watson 1996) performed at the sample level in the sites OC1 and OC2 (Text-fig. 3a) clearly indicate that the characteristic component was recorded before tectonic deformation of the Visean sediments from the site OC2. In the beds from the site OC1 this component was recorded in the early stages of tectonic deformation because the parameter K reaches the maximum value after 70% of unfolding (Text-fig. 3a). The corrected inclinations obtained from the Visean sediments correspond strictly to the inclinations of component "A" isolated from the neighbouring rhyodacites and the rhyodacites sampled in the Zalas old quarry. Because of this, the characteristic component of magnetization of these sediments was also labelled "A".

The Visean sediments from the Zalas new quarry also contain a well defined component of the NRM. The mean direction of this component, calculated in the present coordinates, fits well to the direction "B" defined in the neighbouring volcanic rocks (Table 1).

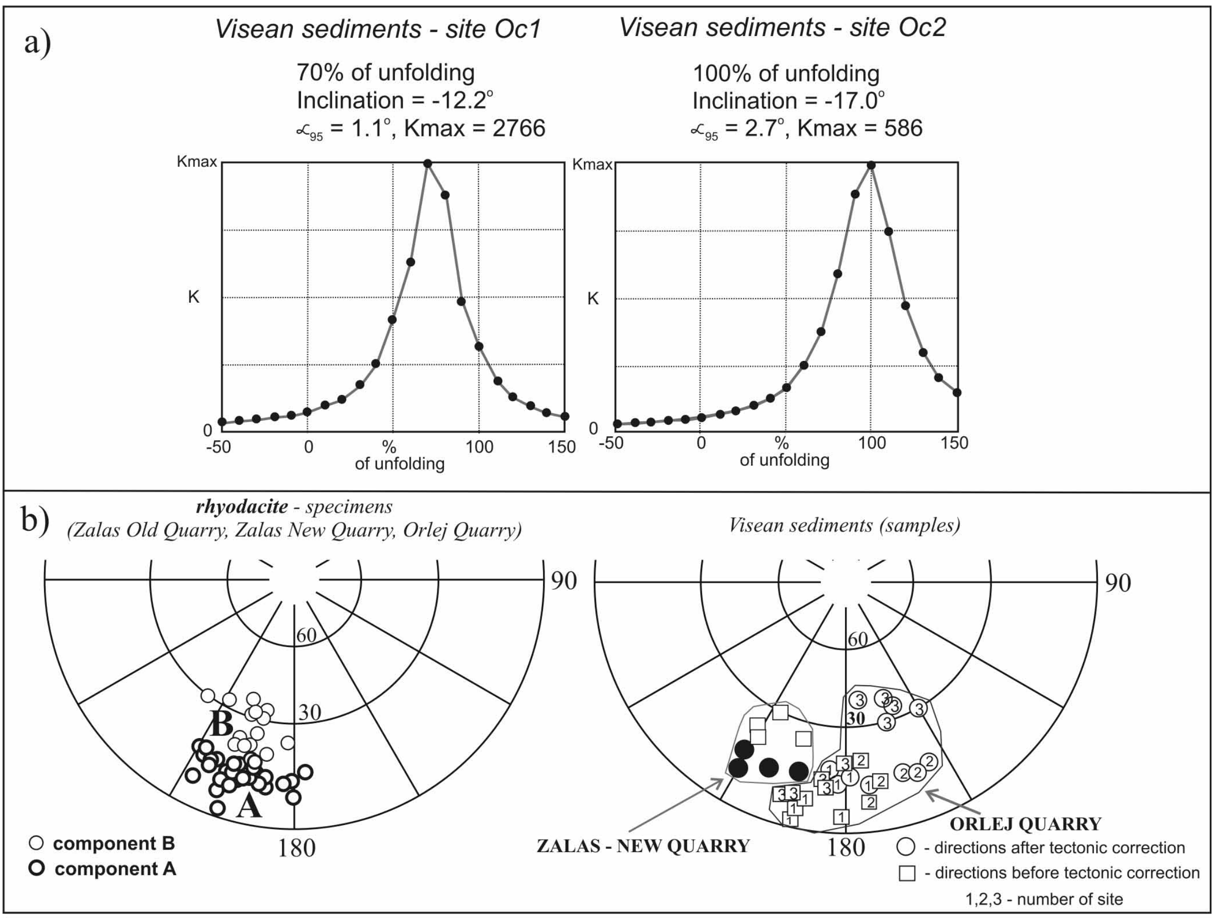


Fig. 3. (a) Results of inclination test (Enkin & Watson 1996) performed on the Visean sediments from the Orlej quarry (K - precision parameter (after Fisher 1953); α_{95}, semi-angle of the cone of 95% confidence). (b) Stereographic projections of line-fit paleomagnetic directions isolated from the studied volcanic and sedimentary rocks. Open symbols denote upward pointing inclinations

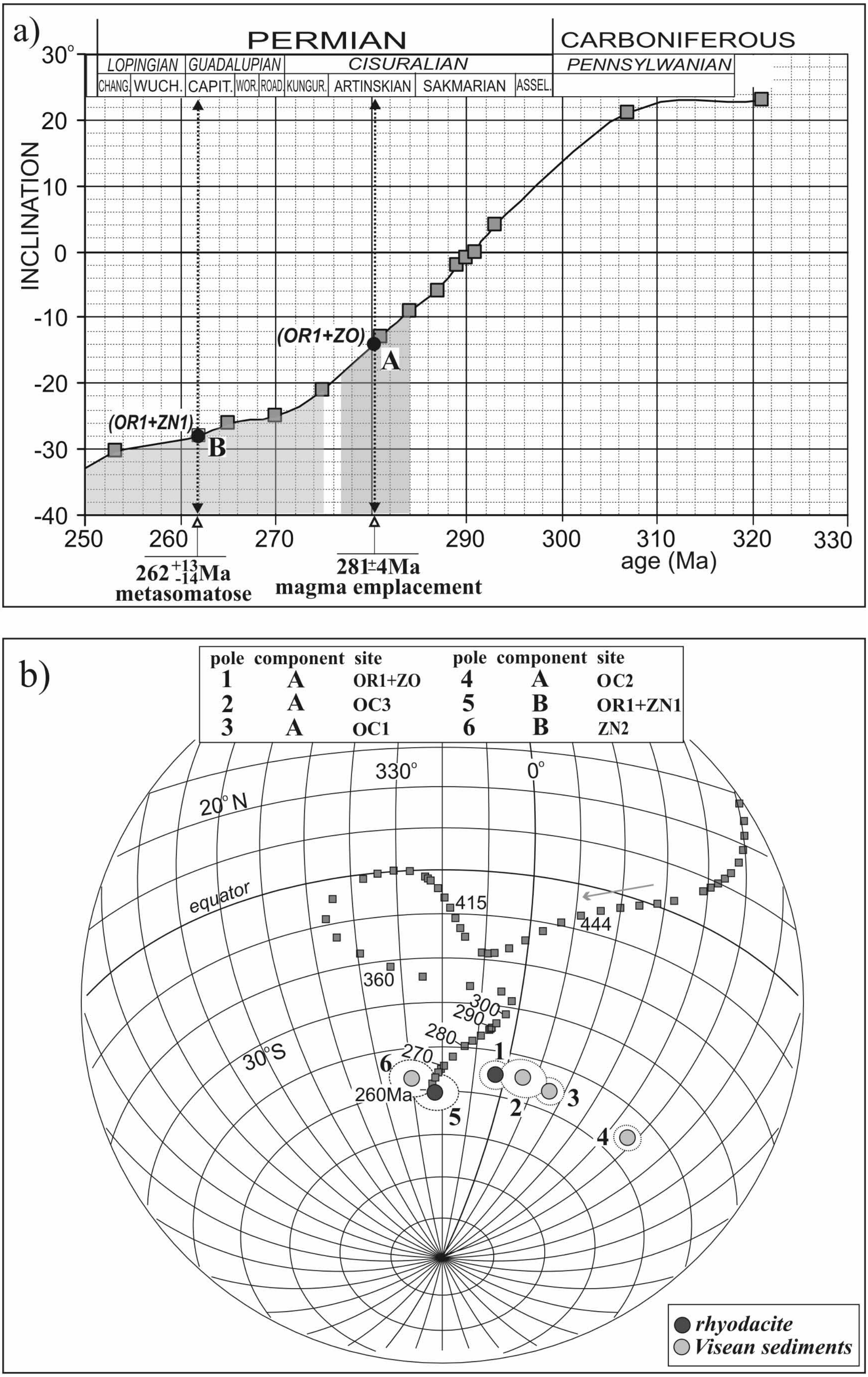
Rocks, site, **component**	N	D	I	α_{95}	K	Dc	Ic	α_{95}	K	Plong.	Plat.	dp	dm	Unf
Visean sediments														
Orlej –site OC1, **A**	4	189	-4	7.5	150	179	-14	7.2	162					
	12						-12*	1.1*	2766*					70%
						184	-12	7.1	170	14°E	46°S	4	7	63%
Orlej – site OC2, **A**	3	173	-15	11.9	109	159	-17	5.7	462					
	10						-17*	2.7*	586*					99%
						160	-17	5.7	471	48°E	45°S	4	6	93%
Orlej – site OC3, **A**	5 *11*	190	-10	7.5	104	163	-33	7.7	99	5°E	44°S	4	8	0%
Zalas New Quarry -site ZN2, **B**	4 *9*	206	-25	8.8	111	205	15	8.9	108	340°E	47°S	5	9	0%
Rhyodacites														
Zalas Old Quarry (ZO), **A**	5 *14*	201	-14	4.3	319					350°E	43°S	2	4	
Zalas New Quarry site ZN1, **B**	3 *7*	206	-31	14.6	59					338°E	51°S	8	15	
Orlej –site OR1, **A**	5 *16*	190	-14	6.8	128					5°E	46°S	4	7	
B	4 *8*	197	-26	7.2	162					353°E	51°S	4	8	
ZO+OR1, **A**	10 *30*	196	-14	4.8	102					357°E	45°S	3	5	
ZN1+OR1, **B**	7 *15*	201	-28	6.9	77					347°E	51°S	4	8	

N – number of hand samples used in final statistics and number of specimen (written in italic), D- declination before bedding correction, I – inclination before bedding correction, α_{95}, K – Fisher's statistics parameters, Dc- declination after bedding correction, Ic – inclination after bedding correction, Plat. – geographic paleolatitude of south paleopole, Plong. – geographic paleolongitude of south paleopole, dp – paleodeclination error, dm – error of the distance between the site and paleopole. Data created by the inclianation test are marked by asterisks. Data obtained from synfolding test are underlined. Unf – percentage of unfolding.

Table 1. The Zalas laccolith (lat.= 50.1°N, long. = 19.7°E) - summary of paleomagnetic directions and poles isolated in rhyodacites and Visean sediments.

DISCUSSION AND CONCLUSIONS

Extremely high values of the NRM intensities indicate a secondary, thermal or thermochemical origin of the palaeomagnetic directions recorded in the Visean sediments. The results of the inclination and synfolding tests performed in the sites OC1 and OC2 show the characteristic magnetization of these rocks acquired before the tectonic deformation, or during its early stages. This deformation is evidently connected with the magma emplacement. Because of this, the palaeomagnetic directions from the Visean sediments of the OC1 and OC2 sites can be regarded as coeval with the emplacement of the laccolith. The inclinations characteristic of the Visean


a)
PERMIAN
CARBONIFEROUS
LOPINGIAN
GUADALUPIAN
CISURALIAN
PENNSYLWANIAN
CHANG.
WUCH.
CAPIT.
WOR.
ROAD
KUNGUR.
ARTINSKIAN
SAKMARIAN
ASSEL.
INCLINATION
30°
20
10
0
-10
-20
-30
-40
(OR1+ZO)
A
(OR1+ZN1)
B
250
260
270
290
300
310
320
330
age (Ma)
262 +13 -14 Ma
metasomatose
281±4Ma
magma emplacement
b)
pole component site
1 A OR1+ZO
2 A OC3
3 A OC1
4 A OC2
5 B OR1+ZN1
6 B ZN2
330°
0°
20° N
equator
30°S
415
444
360
300
290
280
270
260Ma
1
2
3
4
5
6
rhyodacite
Visean sediments

sediments correspond strictly to the inclinations of direction "A" isolated in the greenish rhyodacites. Comparison of the mean inclination of this direction (-14°) with the expected Baltic inclinations leads to the conclusion that the Zalas laccolith was emplaced 281 (+/-4) Ma ago (Text-fig. 4a). The margin of error in this estimation could be slightly greater due to possible age inaccuracy of the palaeomagnetic poles used for the calculation of the reference APWP (apparent polar wander path).

The palaeomagnetic poles calculated for the volcanic and sedimentary rocks of Orlej clearly show the eastern departures form the Permian segment of the reference Baltic path (Text-fig. 4b). These departures are most probably due to anticlockwise local horizontal rotation of the studied rocks. A similar direction of deviation of the Early Permian palaeomagnetic poles was observed in the Sudetes (NAWROCKI 1998, JELEŃSKA & *al*. 2003). According to NAWROCKI (1998), the emplacement of the Early Permian volcanic rocks of Central Europe took place in a sinistral transtensional tectonic regime and the observed rotations of the palaeomagnetic poles are connected with sinistral fault activity. An Early Permian sinistral transtensional tectonic regime was assumed in Central Europe by MATTERN (2001), and particularly in the area of the Kraków-Lubliniec fault zone by ŻABA (1999).

The palaeoinclinations from the Orlej quarry are the same as defined in the Sudetian porphyre from Wielisław (NAWROCKI 1998). They are also comparable with the palaeoinclinations of secondary components of magnetizations isolated from the remagnetized Devonian carbonates of the Upper Silesia and Lublin region (NAWROCKI 1993; GRABOWSKI & *al*. 2002). Hence, it is possible that, about 280 Ma ago, the same event of tectonic transtension opened the way for the volcanic activity and put in motion brines remagnetizing the Devonian carbonates.

The studied volcanics from the Zalas new quarry were strongly influenced by potassium metasomatose. This process can also be observed in several places of the Orlej quarry. The direction "B" carried by hematite was most probably recorded during the hydrothermal activity that created the observed potassium metasomatose. The metosomatic changes were especially extensive in the Zalas new quarry, where the direction "B" was recorded not only in the rhyodacites but in the neighboring Visean sediments as well. The "B" component corresponds well to the Late Permian segment of the Baltic APWP (Text-fig. 4b). Its inclination indicates a palaeomagnetic age of about 260 Ma (Text-fig. 4a). This age most probably coincides with the age of metasomatic alterations of the Zalas laccolith. It should be stressed, however, that the margin of error in this estimation is quite large, due mainly to the slow rate of the Late Permian drift of stable Europe.

Fig. 4. (a) Expected Baltic paleoinclinations calculated for the geographic coordinates of the Zalas (data after TORSVIK & *al*. 1996), and inclianations of the NRM components "A" and "B" isolated from volcanic rocks of Zalas laccolith (see text). The shaded area indicate error of age estimation of components "A" and "B" related to the values of α_{95}. (b) Paleomagnetic poles obtained from the studied volcanic and sedimentary rocks (with 95% confidence oval), against the apparent polar wander path of Baltica in the Paleozoic (after TORSVIK & *al*. 1996)

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REFERENCES

BIRKENMAJER, K. & NAIRN, A.E.M. 1964. Paleomagnetic studies of Polish rocks. I. The Permian igneous rocks of the Kraków District and some results from the Holy Cross Mountains. *Annales de la Societe Geologique de Pologne*, **34**, 225-244.

DŻUŁYŃSKI, S. 1955. O formie geologicznej występowania porfirów zalaskich. *Biuletyn Instytutu Geologicznego*, **97**, 9-38.

ENKIN, R.J. & WATSON, G.S. 1996. Statistical analysis of paleomagnetic inclination data. *Geophysical Journal International*, **126**, 495-504.

GRABOWSKI, J., NARKIEWICZ, M., NAWROCKI, J. & WAKSMUNDZKA, M.I. 2002. Permian remagnetization of the Devonian carbonates in southern Poland – probable link with diagenetic processes. *Przegląd Geologiczny*, **50**, 78-86. [*In Polish with English summary*]

HARAŃCZYK, C. 1989. Rozwój wulkanizmu krakowskiego. *In*: Przewodnik 60 Zjazdu Polskiego Towarzystwa Geologicznego w Krakowie, pp. 51-58. *Wydawnictwo Geologiczne AGH*; Kraków.

HARAŃCZYK, C. & CHOCYK, M. 1989. Melafirowe potoki Regulic. *In*: Przewodnik 60 Zjazdu Polskiego Towarzystwa Geologicznego w Krakowie, pp. 58-60. *Wydawnictwo Geologiczne AGH*; Kraków.

IRVING, E. 1964. Paleomagnetism and its application to geological and geophysical problems, 485 pp. *Wiley & Sons*; New York – London – Sydney.

JELEŃSKA, M., KÀDZIAŁKO-HOFMOKL & M., ŻELAŹNIEWICZ, A. 2003. The Devonian-Permian APWP for the West Sudetes, Poland. *Studia Geophysica et Geodetica*, **47**, 419-433.

KOZŁOWSKI, S. 1955. Intruzje porfirowe w grzbiecie dębnickim. *Biuletyn Instytutu Geologicznego*, **97**, 38-102.

KIRSCHVINK, J.L. 1980. The least square line and plane and the analysis of paleomagnetic data. *Geophysical Journal of Royal Astronomical Society*, **62**, 699-718.

LEWANDOWSKA, A. & ROSPONDEK, M. 2003. Geochemistry of Volcanics of the Zalas Area near Kraków, South Poland. *Polskie Towarzystwo Mineralogiczne – Prace specjalne*, **23**, 119-121.

LEWANDOWSKI, M., WERNER, T. & NOWOŻYŃSKI, K. 1997. PCA – a package of Fortran programs for paleomagnetic data analysis. Institute of Geophysics, Polish Academy of Sciences, *manuscript*, p. 18.

LOWRIE, W. 1990. Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. *Geophysical Research Letters,* **17**, 159-162.

MATTERN, F. 2001. Permo-Silesian movements between Baltica and Western Europe: tectonics and 'basin families'. *Terra Nova*, **13**, 368-375.

NAWROCKI, J. 1993. The Devonian-Carboniferous platform paleomagnetic directions from the Silesian-Cracow area and their importance for Variscan paleotectonic reconstructions. *Geological Quarterly*, **37**, 397-430.

— 1998. Paleomagnetic data and tectonic regime during Permian sedimentation in Sudety Mountains. *Przegląd Geologiczny*, **46**, 1023-1027. [*In Polish with English summary*]

PIŁAT, T. 1957. Otoczaki porfirowe z łupków górnego wizenu z okolic Zalasu (okolice Krakowa). *Biuletyn Instytutu Geologicznego*, **115**, 167-185.

SKOWROŃSKI, A. 1974. Oznaczanie wieku bezwzględnego tzw. porfirów z Zalasu metodą śladów rozszczepienia jąder atomów uranu. *Sprawozdania z Posiedzeń Komisji Polskiej Akademii Nauk, Oddział w Krakowie*, **17**, 236-237.

TORSVIK, T.H., SMETHURST, M.A., MEERT, J.G., VAN DER VOO, R., MC KERROW, W.S., BRASIER, M.D., STURT, B.A. & WALDERHAUG, H.J. 1996. Continental break-up and collision in the Neoproterozoic and Paleozoic – a tale of Baltica and Laurentia. *Earth Science Review,* **40**, 229-258.

ZIJDERVELD, J.D.A. 1967. AC demagnetization of rocks: Analysis of results. *In*: D.W. COLLINSON & *al*. (*Eds*), Methods in paleomagnetism, pp. 254-287. *Elsevier*; New York.

ŻABA, J. 1999. The structural evolution of Lower Palaeozoic succession in the Upper Silesia Block and Małopolska Block border zone (Southern Poland). *Prace Państwowego Instytutu Geologicznego,* **166**, 1-162. [*In Polish with English summary*]

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