Palaeogeography, Palaeoclimatology, Palaeoecology 302 (2011) 338–348

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Low-latitude Oxfordian position of the Oravic crustal segment (Pieniny Klippen Belt, Western Carpathians): Palaeogeographic implications

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ARTICLE INFO

Article history:
Received 3 December 2009
Received in revised form 22 December 2010
Accepted 21 January 2011
Available online 26 January 2011

Keywords:
Western Carpathians
Jurassic palaeogeography
Pieniny Klippen Belt
Palaeomagnetic analysis

ABSTRACT

The Bajocian and the Oxfordian–Kimmeridgian crinoidal limestones of the Pieniny Klippen Belt (PKB), Western Carpathians and the Bathonian–Callovian neptunian dykes which cut them were sampled for rock magnetic and palaeomagnetic study. The sampled sections were: Babiná, Mestečko, Vršatec, Bolešovská dolina and Szaflary. SIRM(T) curves show that the limestone and the dykes from Mestečko contain hematite with blocking temperature T_b about 650–670 °C. Babiná limestone and dykes contain magnetite with T_b between 470 and 570 °C, usually accompanied by small hematite tail. Sometimes goethite with T_b about 80–100 °C is seen. Dykes and limestone from Vršatec contain magnetite with T_b of 570 °C or hematite with unblocking temperature of 670 °C. After cleaning of recent soft component by a temperature of 200 °C and a field of 10–20 mT, the hard component was revealed. After tilt correction the locality-mean directions found in limestones have scattered declination but similar reversed inclination between −35° and –40° for the Bajocian and between −35° and −49° for the Oxfordian–Kimmeridgian. An exception was the mean direction for the Bajocian limestone from Bolešovská dolina which has normal polarity. Fold test for inclination only showed pre-folding inclinations for the Bajocian and Oxfordian–Kimmeridgian limestones and scattered inclinations for the in situ and tilt corrected directions for the dykes. The mean palaeoinclination calculated for Bajocian and Oxfordian–Kimmeridgian by means of "inclination-only" test are −38.5° +/−3° and −42.5° +/−11.2°, respectively, which corresponds to 21.7 +/−1.5°N and 24.6 +/−5.6°N of palaeolatitude. This is about 10°–15° lower than the value of inclination expected for that age for the Pieniny Klippen Belt from the Jurassic poles for Stable Europe. As positive inclination only fold test proves pre-folding age of isolating directions other possibility — flattening of inclination should be considered. Anisotropy of magnetic susceptibility (AMS) and magnetic unhysteretic remanent magnetisation (AARM) can be used for the evaluation of origin and for the deviation of natural remanent magnetisation NRM. The axes of AMS are scattered for all localities. The degree of anisotropy is low. The shape parameter T shows equal distribution of oblate and prolate fabric. On the contrary, the ARM maximum axes are well clustered, especially for Mestečko and Vršatec. The maximum axes are distributed in a vertical plane for Mestečko and in horizontal plane for Babiná and Vršatec. This evidences that the AARM fabric is not related to sedimentation and compaction. The anisotropy axes are not close to the NRM directions. For Mestečko they are steeper. This excludes an effect of shallowing of NRM. On this basis we can assume that more southern palaeolatitude of the Pieniny Klippen Belt than expected is a demonstration of palaeogeography and tectonics and points to a close vicinity of the PKB to the African plate in the Jurassic. The results from the Polish part of PKB which emerged in the latest years showed the same palaeolatitude for the Callovian–Kimmeridgian limestones. The low palaeomagnetic inclinations measured in the Bajocian crinoidal limestones show that the southward drift may have started earlier than previously expected.

1. Introduction

The Jurassic period was characterised by a continuous break-up of Pangea by opening of the Central Atlantic. The process continued to the margin of the North European Platform where it caused breakage of the shelf area (Mandl, 2000). After the shelf was separated from the main land, a system of oceans, called the Penninic Ocean (Ligurian–Piemontaise–Penninic–Vahic) formed between them. This break-up was characterised by passive rifting with asymmetric extension (Kováč et al., 1993), causing dissection of the previously flat shelf and leaving numerous segments of continental crust within the ocean.

One of these segments was the Oravic segment which recently forms the substantial part of the Pieniny Klippen Belt in the

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doi:10.1016/j.palaeo.2011.01.021

Carpathian arc. This belt represents the boundary between the Carpathian internides and externides in the Western and Eastern Carpathians. The zone itself is a narrow strip of non-volcanic mélange consisting mostly of Jurassic to Cretaceous sedimentary rocks.

Despite strong deformation, thermal overprint on the Pieniny Klippen Belt rocks was relatively low and palaeomagnetic methods were successfully used in palaeogeographic reconstructions (e.g. Pagáč and Marschalko, 1979; Aubrecht and Túnyi, 2001; Grabowski et al., 2008; Grabowski, 1997; Grabowski and Michalik, 2005; Krs et al., 1996; Kruczyk et al., 1992; Pruner et al., 1998) and magnetostratigraphy (Houša et al., 1999; Lewandowski et al., 2004). The palaeomagnetic analyses showed surprisingly low palaeomagnetic inclinations for the time interval near the Middle/Late Jurassic boundary. These low inclinations correspond with low geographic latitudes in the time when the measured sediments originated. Lewandowski et al. (2004) not only showed that the Penninic ocean might be considerably wider than supposed by the earlier workers who attempted to reconstruct this domain (e.g. Stampfli and Borel, 2002) but their results from the Velyky Kamenets locality of the Czorsztyn Unit (a shallow-water unit originally belonging to the Oravic crustal segment) indicated that Penninic spreading should be unusually rapid (about 1000 km per 6 Ma). The basis of their assumption was a big difference between the palaeomagnetic inclinations in the Bajocian–Bathonian limestones and the overlying Oxfordian limestones. This change in inclination happened mostly during the Callovian which, however, represents just a stratigraphic gap at the studied locality (omission surface). The lower palaeogeographic latitudes of the Oravic units in the Late Jurassic were also confirmed by other data (e.g. Houša et al., 1999; Aubrecht and Túnyi, 2001; Lewandowski et al., 2006; Grabowski et al., 2008). Very few data exist from the Bajocian–Bathonian time interval. Therefore, there was little evidence for the estimation of a spreading speed. This paper brings further data, including also measurements from the Bajocian limestones.

2. Geological setting and the sections studied

For this study, the localities of Aubrecht and Túnyi (2001) and one additional locality were sampled and analysed (Fig. 1). The studied sections belong to the Czorsztyn Succession which was palaeogeographically situated in the most shallow part of the Oravic sedimentary area, close to the so-called Czorsztyn Swell (Birkenmajer, 1977). Sedimentary evolution of this unit to a large extent reflects the Middle Jurassic extension. After the Aalenian time of relatively uniform sedimentation of dysoxic to suboxic facies of black shales and spotted marls, shallowing started in the Bajocian, evidenced by the deposition of crinoidal limestones, which in the western segment of the Pieniny Klippen Belt were preceded by the coral reef limestones (Vršatec Limestone — Schlögl et al., 2006). The crinoidal limestones are traditionally divided to the lower, white Smolegowa Limestone Formation and the upper, red Krupianka Limestone Formation (Birkenmajer, 1977). This division has, however, limited validity as at most occurrences in the western part of the Pieniny Klippen Belt, colour-based stratigraphic division is not possible (Aubrecht, 1992; Aubrecht et al., 1997). The originally estimated age of the crinoidal limestones was also changed by later research; from Bajocian–Bathonian, as inferred by Birkenmajer (1977) it was restricted solely to Bajocian (Krobicki and Wierzbowski, 2004). The global sea-level rise after Bajocian caused submersion of the Czorsztyn Swell and deepening of the neighbouring sedimentary areas. This is reflected in the Czorsztyn Succession by the onset of typical Rosso Ammonitico limestones in the uppermost Bajocian (Parkinsoni Zone — Rakús, 1990; Wierzbowski et al., 1999; Schlögl et al., 2005). Originally this onset was estimated to start in Callovian (Birkenmajer, 1977). At some localities, the limestones lack nodularity and are named as the Bohunice Limestone Formation (Mišík et al., 1994). This pelagic sedimentation lasted to Early Cretaceous. Pelagic sedimentary material also fills neptunian dykes which were the subject of previous palaeomagnetic study of Aubrecht and Túnyi (2001). In the present study, the same sections were studied in the western Slovakia (for a detailed description — see Aubrecht and Túnyi, 2001): Babiná (N 49°1′55.1″, E 18°10′46.5″), Mestečko (N 49°10′ 47.6″, E 18°15′32.7″), Vršatec (N 49°03′56.2″, E 18°09′04.7″), Bolešovská dolina (N 49°01′11.8″, E 18°07′24.8″), together with the newly sampled locality Szaflary (N 49°26′16.2″, E 20°0′52.4″) in the Polish sector of the Pieniny Klippen Belt (Fig. 1). At all localities, the Bajocian crinoidal limestones and the red, micritic Bohunice Limestones were sampled, the latter also from neptunian dykes. A total of 62 hand samples were taken.

3. Methods

Three or more cylindrical specimens of 2×2.2 cm size were cut from each hand sample. Samples were measured in the Paleomagnetic Laboratory in the Institute of Geophysics, Slovak Academy of Sciences in Bratislava and in the Paleomagnetic Laboratory of the Institute of Geophysics, Polish Academy of Sciences in Warsaw. In the Warsaw laboratory remanent magnetisation was measured by a 2G SQUID cryogenic magnetometer accompanied by an AF demagnetiser. Thermal demagnetisation (TD) was performed in a screened furnace made by the Magnetic Measurements, UK. Palaeomagnetic measurements were carried out in the magnetically shielded room. Samples were demagnetised by thermal (TD) and alternating field (AF) treatment. In Bratislava mainly TD was performed using a demagnetising system MAVACS made in Czech Republic. Remanent magnetisation was measured by a spinner magnetometer JR-5 made by the AGICO, Czech Republic. Demagnetisation curves were analysed using the principal component analysis of Kirschvink (1980) by means of the PDA programme package (Lewandowski et al., 1997). Magnetic mineralogy was determined by continuous TD of saturation isothermal remanence (SIRM). Continuous thermal demagnetisation of SIRM was carried out with the use of a device made by the TUS, Poland. SIRM was imparted on a sample in the field of 9 T and measured during heating to 700 °C in a magnetic screen. The SIRM decay curves provide blocking temperature (T_b) spectra of magnetic minerals.

A KLY-2 Kappa-bridge was used for measurements of anisotropy of magnetic susceptibility (AMS) and mean susceptibility. Anisotropy parameters were calculated using the programme ANISO of Jelínek (1977).

4. Results

Fig. 2 shows the examples of SIRM(T) curves for limestone and dykes from Mestečko, Babiná and Vršatec. The limestone and neptunian dykes from Mestečko contain haematite with blocking temperature of about 650–670 °C (Fig. 2a,b). The Babiná limestone and dykes contain magnetite with T_b between 470 and 570 °C, usually accompanied by small hematite tail (Fig. 2 c,d). Sometimes goethite with T_b of about 80–100 °C is seen (Fig. 2 b,c). The dykes and limestone from Vršatec contain magnetite with T_b of 570 °C (Fig. 2e) or hematite with unblocking temperature of 670 °C (Fig. 2f). Both magnetic minerals magnetite and hematite can be carriers of primary or secondary magnetisation.

Majority of the samples were demagnetised smoothly and were suitable for isolating of palaeomagnetic components. Fig. 3 shows the examples of thermal and AF demagnetisation treatments. A soft component was usually removed by a temperature of 200 °C and a field of 10–20 mT. A hard component was removed at a different temperature range and a different field intensity depending on