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New paleomagnetic results from the Upper Cretaceous red marls of the Pieniny Klippen Belt, Western Carpathians: Evidence for general CCW rotation and implications for the origin of the structural arc formation

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ABSTRACT

The Pieniny Klippen Belt (PKB) is a narrow arcuate structure separating the Central and Outer Western Carpathians formed during several Cenozoic deformational stages. The primary aim of this study was to obtain paleomagnetic constraints for the mechanism of formation of the arc. We investigate Albian–Santonian red pelagic marls from 14 localities, distributed along a strike length of ca. 400 km. AMS measurements reveal a pattern characteristic of weakly deformed sedimentary rocks and magnetic lineations do not correlate with the general strike of the PKB. Paleomagnetic analysis revealed well defined hematite-based ancient magnetization components at 13 localities, which are dated using fold- and inclination tests. A within-locality fold test is negative for two localities exhibiting large CCW rotations of similar magnitude situated at the two ends of the PKB. Remanences of pre-folding age were documented for 11 localities, with an overall mean paleomagnetic direction of D = 311°, I = 53°, and α_{95} = 11°. The indicated general CCW rotation most probably took place during the Miocene, together with Western Central and Outer Carpathians. Paleolatitudes for the PKB indicate a considerable separation from the southern margin of stable Europe leaving space for coordinated rotation. A paleomagnetic oroclinal test involving all localities with primary magnetizations was negative. When localities with monoclinal steep dips are omitted due to possible declination bias, the overall mean paleomagentic direction does not change significantly, but correlation is observed between the general trend of the PKB and the paleomagnetic declinations. Thus, we conclude that the present shape of the arc can be partly due to oroclinal bending. This must have happened before Oligocene since paleomagnetic declinations for neighboring Paleogene basins in the Central and Outer Western Carpathians reveal a uniform CCW rotation of ca. 50° magnitude, irrespective of the position of the localities in relation to the Carpathian arc.

1. Introduction

The Western Carpathians, like all other Alpine collisional mountain systems, are characterized by a zonal structure. The main divisions are provided by two narrow subparallel zones regarded as oceanic sutures and/or ancient plate boundaries (e.g. Froitzheim et al., 2008). One of them, the Meliata suture separates the Internal and the Central Western Carpathians, the other, the Pieniny Klippen Belt (PKB) is the dividing zone between the Central and the Outer Western Carpathians (Fig. 1). The origin of the Western Carpathian arc has not yet been clearly explained by application of the paleomagnetic method. The typical paleomagnetic approach applied to reveal the nature of orogenic arc is an "orocline test" which compares paleomagnetic declinations and structural trends in a well defined stratigraphic horizon, from sampling localities situated in several parts of the arc differing in structural orientation (e.g. Speranza et al., 1997; Weil and Sussman, 2004; Weil et al., 2001). This type of investigations was performed by Bazhenov et al. (1980) on Upper Cretaceous red marls in the Pieniny Klippen Belt (PKB) of Poland and western Slovakia. In the conclusions it was suggested that the curvature of the PKB had been acquired in post-Early Campanian times,

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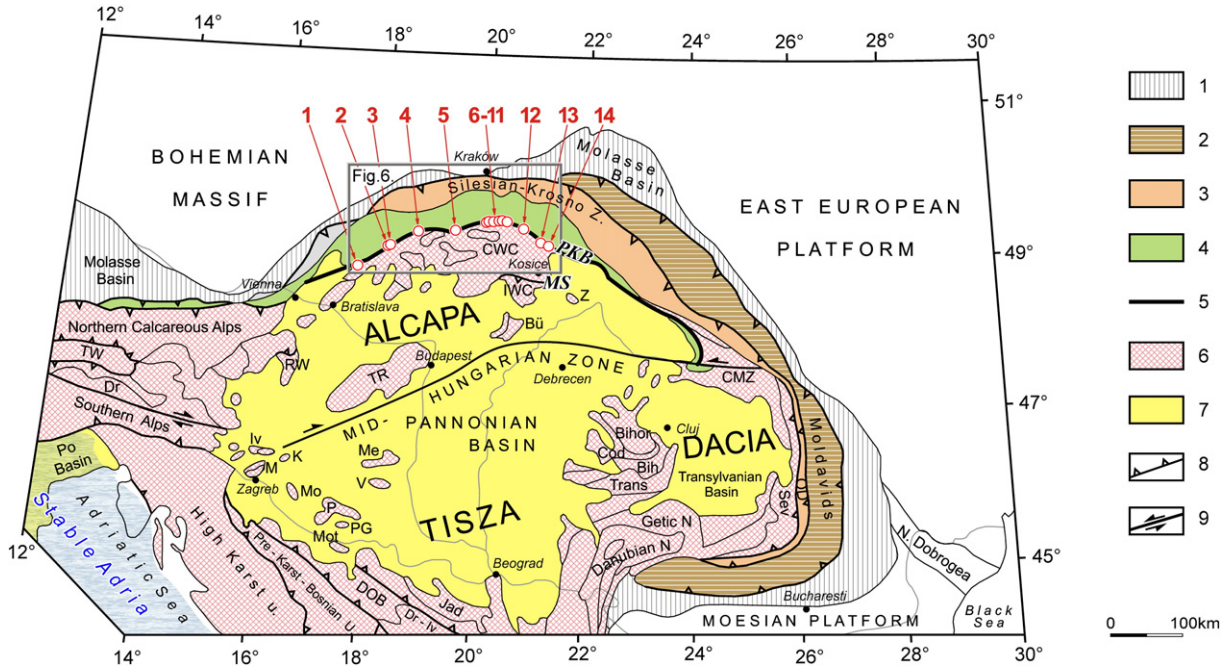

Fig. 1. Major structural units of the Carpathic–Balkan–Dinaric region (modified after Haas, 2012). The rectangle shows the extent of area presented in Figs. 6 and 8 and the paleomagnetic sampling localities are numbered within this area from 1 to 14. The boxed keys are: 1: Molasse Basin; 2: Moldavides; 3: Silesian–Krosno Zone; 4: Magura Zone; 5: Pieniny Klippen Belt; 6: Pre-Neogene of inner Carpathian, Alpine and Dinaric orogenic zones; 7: Cenozoic of the Pannonian Basin; 8: overthrust; and 9: strike-slip fault;. Abbreviations are: MS: Meliata suture; PKB: Pieniny Klippen Belt; IWC: Inner West Carpathians; CWC: Central West Carpathians; Bih: Biharia Unit; Bü: Bükk Unit; CMZ: Crystalline-Mesozoic Zone; Cod: Codru; DOB: Dinaridic Ophiolite Belt; Dr: Drau Range; Dr–Iv: Drina–Ivanjuca Unit; Iv: Ivanscica; Jad: Jadar Unit; K: Kalnik; Me: Mecsek; Mo: Moslavačka Gora; P: Papuk; PG Požekša Gora; RW: Rechnitz window; Sev: Severin Nappe; TR: Transdanubian Range Unit; TW: Tauern window; V: Villány; Z: Zemplén Mts.

probably during the Neogene. However recent results from the Cretaceous and Paleogene rocks of the Outer West Carpathians, just north of the PKB (Grabowski et al., 2006; Márton et al., 2009a) indicate that there is no evidence for formation of the structural arc during Neogene tectogenesis in the Outer Carpathians. The Magura nappe reveals a uniform 50° counter-clockwise (CCW) rotation along its strike. The Silesian nappe shows similar CCW rotation except in its western part, where the CCW rotation is even larger. The latter is more easily explained by additional CCW rotations in a left lateral wrench corridor (Márton et al., 2009a), than a uniform bending of the entire unit. Paleomagnetic results from Paleogene and Neogene basins situated in both the western and eastern parts of the Central Western Carpathians also suggest fairly uniform CCW rotation (e.g. Márton et al., 1992, 1996, 1999, 2009b) which also does not support the Neogene bending model. Although the secondary oroclinal bending model is tacitly agreed on by several geologists (e.g. Golonka et al., 2006), there is a large number of geological models (Burchfiel, 1980; Gealey, 1988; Nemčok et al., 1998) which argue that the arcuate shape of the Outer Western Carpathians resulted from embayment in the present day southern margin of the European Platform. According to Nemčok et al. (2007), the Western Carpathian arc could not originate from oroclinal bending, since the sigma1 stress trajectories in the orogen and its foreland do not reveal the same radial pattern. These authors claim that the arc originated due to uneven rollback of the subduction zone.

In contrast to the Cenozoic, Mesozoic paleomagnetic results from the Central Western Carpathians reveal significantly more CCW rotations towards the west (Križna unit of Male Karpaty, Mala Fatra, Strážovské Vrchy) and moderate clockwise rotation in the Tatra Mts. (Grabowski et al., 2009, 2010; Kruczyk et al., 1992). This pattern of rotations more or less follows the Carpathian arc indicating a possible oroclinal bending, which, in the context of the Paleogene–Neogene paleomagnetic results, must have taken place during Late Cretaceous orogeny. Csontos and Vörös (2004) and Schmid et al. (2008) suggested such timing for the formation of the arcuate shape mainly on geological grounds.

As the PKB is a suture between the Central and Outer West Carpathians, we decided to carry out a systematic paleomagnetic study along the strike of PKB, in order to test the origin of the present day curvature of the PKB. The target of our study was the horizon studied by Bazhenov et al. (1980) i.e. red pelagic marls of Late Cretaceous age. Our decision to re-study the same rocks after more than 30 years had the following reasons:

1. Although the identified magnetic remanence carrier was hematite, the maximum temperature applied to some specimens in demagnetization was 400 °C. The majority of the specimens were subjected to blanket demagnetization at 300 °C; thus full demagnetization, which requires at least 650 °C was not achieved.
2. A fold test and principal component analyses were not performed.
3. Statistically acceptable paleomagnetic directions were obtained only for three localities. The paleomagnetic direction for the Polish (northern) segment was obtained using the remagnetization circle method, which has developed considerably since 1980 (e.g. McFadden and McElhinny, 1988).

2. Geological setting

The PKB, belongs to the Western Carpathian orogenic system (Fig. 1), which is ultimately bounded in the south by the Mid-Hungarian Fault Zone, a kinematically complicated Cenozoic wrench corridor, against the intra-Carpathian Tisza terrane (e.g. Csontos and Vörös, 2004; Csontos et al., 1992; Fodor et al., 1999). This fault system is covered by Cenozoic deposits of the Pannonian Basin (Csontos and Nagymarosy, 1998). The outer limit of the Western Carpathians is the Carpathian mountain front overriding the sediments of the Carpathian foredeep (continuation of the North Alpine Molasse Zone), which covers the southern flanks of the downbended North European Platform (Oszczypko, 2006 and references therein).

The Western Carpathian orogen shows a distinct progradation of Mesozoic shortening and collision events from the south towards the