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Integrated calcareous nannofossil and ammonite data from the upper Barremian–lower Albian of the northeastern Transdanubian Range (central Hungary): Stratigraphical implications and consequences for dating tectonic events

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ABSTRACT

The transition of post-obduction Neotethyan contraction to Eo-Alpine ("Austroalpine") nappe stacking that took place during the Early Cretaceous is an important event in the Cretaceous history of the Alpine-Carpathian-Dinaridic orogenic system. The Transdanubian Range (TR) in Hungary has been shown to have been impacted by both events. Dating of this transition has proved to be difficult; several interpretations were published during the last decades. Uniquely exposed in and around the Gerecse Mountains, the Lábatlan Sandstone Formation (LSF) and the Vértessomló Aleurolite Formation (VAF) bracket this time interval. The last phase of Neotethyan contraction occurred after the deposition of the LSF, and the Eo-Alpine nappe stacking started during the deposition of the VAF. Earlier stratigraphical studies provided valuable data for our understanding of geodynamics, but precise bio- and chronostratigraphy – to constrain the interval of deformations – became possible only with systematic correlation of macrofossil-poor outcrops to ammonite-rich series with the help of calcareous nannofossil data. Here new nannofossil data, and whenever still available, a re-examination of the original smear slides yields new constraints on the age of the younger part of the sequence. The nannofossil and ammonite record is now combined to create a local chronostratigraphical correlation, with records tied in to the integrated Tethyan nannofossil and ammonite biozonation, which, in turn, is numerically calibrated by international zonal standards and radiometric ages. Our study demonstrates that the youngest part of the sandstone-dominated LSF is in nannozone NC7B of late Aptian age. The overlying Köszörűkőbánya Conglomerate Member has a closely similar age in NC7A/B, noticeably older than previously suggested. On the other hand, the VAF clearly is of early Albian age (NC8). This latter unit is not represented in the inner Gerecse Mountains, in contrast to what has been suggested in previous studies. The observed earlier two sub-phases of Neotethyan compression with N–S to ENE–WSW shortening possibly are latest Aptian in age and are within nannofossil subzone NC7C, while the following Eo-Alpine deformation has an early Albian age (NC8) and is marked by W–E to NW–SE compression. The Aptian/Albian boundary (around 113 Ma) may indicate the switch of the TR from lower to upper position with respect to Neotethyan subduction to "Austroalpine" nappe stacking. Our data on deformational ages may support the idea that the onset of "Austroalpine" transpressional deformation at *c.* 114–112 myr ago could be related to the start of Penninic subduction, or, alternatively, to the onset of intra-oceanic subduction within the Austroalpine realm.

1. Introduction

Calcareous nannoplankton and ammonites are common and well-preserved fossils in Lower Cretaceous sedimentary units of the Transdanubian Range (TR). Since Hantken (1868), deposits of the

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Gerecse and the northernmost Vértes Mountains of the TR have been interpreted to have fundamentally different origins (Haas and Császár, 1987; Kázmér, 1988). In view of their unique nature, the exposed siliciclastic Cretaceous sediments of the Gerecse Mountains, and their subsurface continuations in the northwestern Vértes foreland, have always been in the focus of Hungarian stratigraphy and palaeontology (Somogyi, 1914; Fülöp, 1958, 1997; Báldi-Beke, 1963; Császár, 1986, 1995; Kázmér, 1987; Árgyelán, 1989, 1996; Sztanó, 1990; Bodrogi, 1992; Fogarasi, 1995, 2001; Bodrogi and Fogarasi, 2002; Sasvári, 2009; Főzy et al., 2013). Following earlier geodynamic models and advances in stratigraphy, intensive field work in the Gerecse Mountains during the last 25 years has provided new information on structural evolution (Bada et al., 1996; Csontos et al., 2005; Sasvári, 2008, 2009; Fodor and Főzy, 2013; Fodor et al., 2017, 2018). However, in order to draw geodynamic conclusions from these data sets more precise biostratigraphical knowledge of the Gerecse clastics sequence would be needed, particularly for its late stage.

From a structural point of view, the TR represents a particular unit within the Alpine-Carpathian-Dinaridic orogen, while its tectono-sedimentary evolution includes processes related to both Dinaric and Austroalpine domains (Tari, 1994; Schmid et al., 2008) (Fig. 1A). Mesozoic palaeotectonic reconstructions suggest that the TR was situated between two major oceanic domains, the Middle Triassic—Late Jurassic Neotethyan Meliata-Vardar and the Jurassic—Paleogene Piemont-Ligurian (South Penninic or Alpine Tethys) oceans (Fig. 1B, C) (Csontos and Vörös, 2004; Schmid et al., 2008; Handy et al., 2010). At present, the TR is surrounded by tectonic units derived from these oceans and their passive margins (Fig. 1A). However, its tectonic boundaries formed during consecutive deformation phases from the Late Jurassic to Early Miocene.

In consequence of its transitional Mesozoic palaeogeographical position, the tectonic evolution and related basin formation were controlled by both oceanic domains. This is particularly clear in Cretaceous basin evolution and connected deformation phases. During the Early Cretaceous, a clastic sedimentary basin evolved in the northern part of the TR, which represents a flexural basin (Császár and Árgyelán, 1994; Tari, 1994, 1995; Mindszenty et al., 1994, 2001). The loading nappe stack was derived from the obducted Neotethyan oceanic lithosphere and its imbricated passive margin (Fig. 1C). In this way, the TR shares a common geodynamic link with Dinaridic units located along its southeastern boundary (Fig. 1A).

On the other hand, the Late Cretaceous tectonic evolution of the TR is linked to the Austroalpine nappe system. This stack of nappes was essentially formed during the Late Cretaceous, and at present is situated to the north and west of the TR (Plašienka, 2003; Schmid et al., 2004) (Fig. 1C). Nappe stacking is part of the Eo-Alpine orogeny, which has an indirect geodynamical link with the subduction of the Piemont-Ligurian (Penninic) ocean (Fig. 1C) (Handy et al., 2010). Thus, the TR changed its position with respect to the subducting oceanic lithospheres. This fairly important switch in tectonic connections occurred during the mid-Cretaceous, during the final phase, or right after the Early Cretaceous foreland basin evolution of the northeastern TR. One important goal of the present paper is to provide precise biostratigraphy-based age constraints for this change, dating formations in relation with deformation phases.

On the basis of nannofossils - combined with ammonite data - the main purpose of the present work is threefold. Firstly, to identify the age of certain sedimentary units represented by surface outcrops or wells with no available macrofossil record, which have not been precisely dated so far. Secondly, to update previously unpublished nannofossil biostratigraphical work for the area (Fogarasi, 2001), and lastly, to provide a more precise time frame for structural deformation phases of the clastic basin. Analysis on foraminifer and ostracod assemblages are also on the way, and a detailed ammonite stratigraphy for the area and its sedimentary units were provided previously by Főzy et al. (2002) and Szives (1999, 2002) and Szives et al. (2007).

The present paper holds the novelty of a revised subdivision of structural phases with respect to the combined nanno- and ammonite zones. These zones are calibrated to absolute time scales (Ogg et al., 2016), thus the suggested extent of deformation phases can be expressed in millions of years, which makes it comparable to other types of sources for deformation phases derived from neighbouring Alpine-Carpathian areas.

2. Nannofossil research in the area

The history of nannoplankton research of the Lower Cretaceous of Hungary is rather brief. The most influential Hungarian nannofossil micropalaeontologist has been Mária Báldi-Beke (1963, 1965; Báldi-Beke *in* Fülöp, 1964, 1976; Báldi-Beke *in* Császár, 1986; Sztanó and Báldi-Beke, 1992). Later, Félegyházy (Félegyházy and Nagymarosy, 1991, 1992) and Fogarasi (Fogarasi, 2001; Főzy et al., 2002) started to work on the topic. Since then no nannofossil research was done on Lower Cretaceous sedimentary rocks in the TR.

3. Geological setting

3.1. General background

The Mesozoic sedimentary sequences of the TR reflect complex sedimentary and tectonic processes that occurred in the neighbouring Vardar-Meliata branch of the Neotethys Ocean and also in the Piemont-Ligurian Ocean (Császár and Árgyelán, 1994; Tari, 1994; Csontos and Vörös, 2004; Fodor and Főzy, 2013). Extensional tectonic movements connected to the Neotethyan breakup started in the Middle Triassic. Convergent tectonics became dominant from the late Middle Jurassic, related to intra-oceanic subduction and subsequent obduction of the Vardar ophiolites onto the passive Adriatic margin, possibly from the Middle Jurassic onwards (Schmid et al., 2008; Handy et al., 2010) (Fig. 1B, C).

Reflecting these processes, two different subbasins developed in the TR during the Early Cretaceous; the northeastern Gerecse siliciclastic basin and the southwestern maiolica carbonate basin (Fig. 1A) (Haas and Császár, 1987; Kázmér, 1988; Császár, 2002). These two subbasins were separated by an elevated high. The siliciclastic sedimentary units of the Gerecse Mountains represent the depocentre of the northeasterly subbasin, while the high to the southwest corresponds to the forebulge of a typical flexural foreland basin (Császár and Árgyelán, 1994; Tari, 1994; Mindszenty et al., 1994, 2001). The load for flexural deformation was the overriding Neotethyan Vardar ophiolites, although the distance between the obducted ophiolites and the TR was considerable. Petrographic work has demonstrated that such ophiolites represented a part of the source for the clastic input (Árgyelán, 1989, 1996; Vaskó-Dávid, 1991; Császár et al., 2008). Sedimentological research has determined sediment transport directions mainly from the northeast, subordinately from the east (Sztanó, 1990; Fogarasi, 1995). These directions are in agreement with the foreland basin model that postulated the source east or northeast of the TR, where ophiolites could have been present (see position of TR in Fig. 1A and C).

3.2. The Early Cretaceous sedimentary cycle in the area

The evolution of the Gerecse and Vértes foreland basins started during the earliest Cretaceous (Berriasian), when deposition of widespread maiolica limestones ceased. The earliest sign of a clastic source came with the deposition of the Felsővadács Conglomerate