

Review article

Sedimentology and stratigraphy of the Neogene rift-type North Croatian Basin (Pannonian Basin System, Croatia): A review

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ABSTRACT

Development of the rift-type North Croatian Basin located in the south-western Neogene Pannonian Basin System and belonging to the Central Paratethys realm, was controlled by tectonics, climate, volcanic activity and eustatic fluctuations. The extrabasinal controls produced a succession of depositional environments from terrestrial to marine, and back to terrestrial, and the deposits form a large-scale transgressive-regressive cycle. Basin evolution is subdivided into the syn-rift phase which lasted from the Early Miocene (Ottmangian) until the Middle Miocene (middle Badenian), and in the post-rift phase from the Middle Miocene (late Badenian) to the Quaternary. These complex controls on deposition generated the opening and closing of connections to the open sea that occasionally resulted in the formation of unfossiliferous continental deposits, or generated the radiation of endemic species, such that it has been necessary to use regional Neogene stages for stratigraphic analysis of the Central Paratethys history. Earlier stratigraphic studies of the North Croatian Basin, that had been primarily based on biostratigraphy and superposition, were improved by recent results yielded from radiometric dating, and integrated biostratigraphy. They have been focused mainly on the Early/Middle Miocene and the Miocene/Pliocene boundaries that separate intervals of the specific depositional evolution of the basin. Most important depositional and palaeogeographic differences concern a relatively long period of development of the early continental phase that lasted from the Ottmangian to the early Badenian. In contrast to parts of the Pannonian Basin System characterized by marine deposition in the early Badenian, the NCB was characterized by long-lived fresh-water lacustrine deposition. The fresh-water Lake Slavonia that developed from the middle Pliocene to the early Pleistocene, indicates an independent phase of evolution of the south Pannonian Basin System, so the Cernikian regional stage was introduced for the lacustrine succession. Those stratigraphic and palaeogeographic differences additionally support the complexity of the Pannonian Basin System within the Central Paratethys realm supporting heterogeneous depositional development of continental rift-type basins.

1. Introduction

The North Croatian Basin (NCB) represents a south-western part of the back-arc Pannonian Basin System (PBS), the formation of which commenced in the Early Miocene generated by continental collision and subduction of the Euroasian Plate beneath the Pannonian crustal fragment. Its development is subdivided into two successive phases: syn-rift and post-rift. The syn-rift phase of basin evolution was marked by the asthenosphere rising, extensional tectonic thinning of the crust and isostatic subsidence, while the post-rift phase was characterized by basin subsidence due to cooling of the lithosphere (Royden, 1988; Tari et al., 1992). The development was complex and heterogeneous as reflected in the individual evolution of several sub-basins, and the different and debatable stratigraphic positions of the boundary between

syn-rift and post-rift deposits (Fig. 1) (e.g. Ebner and Sachsenhofer, 1995; Horváth, 1995; Fodor et al., 1999; Tari et al., 1999; Cloetingh et al., 2005; Corver et al., 2009; Horváth et al., 2015; Radivojević and Rundić, 2016). In the SE part of the PBS, the extensional tectonics were diachronous across the basin and migrated in time and space from ~28 Ma near the Dinarides to 8–5.5 Ma to the NE and E (Matenco and Radivojević, 2012; Balázs, 2017).

After the separation of the Western Tethys Ocean into the Paratethys Sea and the Mediterranean Sea around the Eocene-Oligocene boundary (Rögl, 1999), a large area of north Croatia became land. Sedimentation continued in the Oligocene only in north-western Croatia (Fig. 1). During the Miocene, a marine connection between the Central Paratethys that includes the Eastern Alpine - Carpathian Foreland basins from Eastern Bavaria to Moldavia, and the Pannonian Basin

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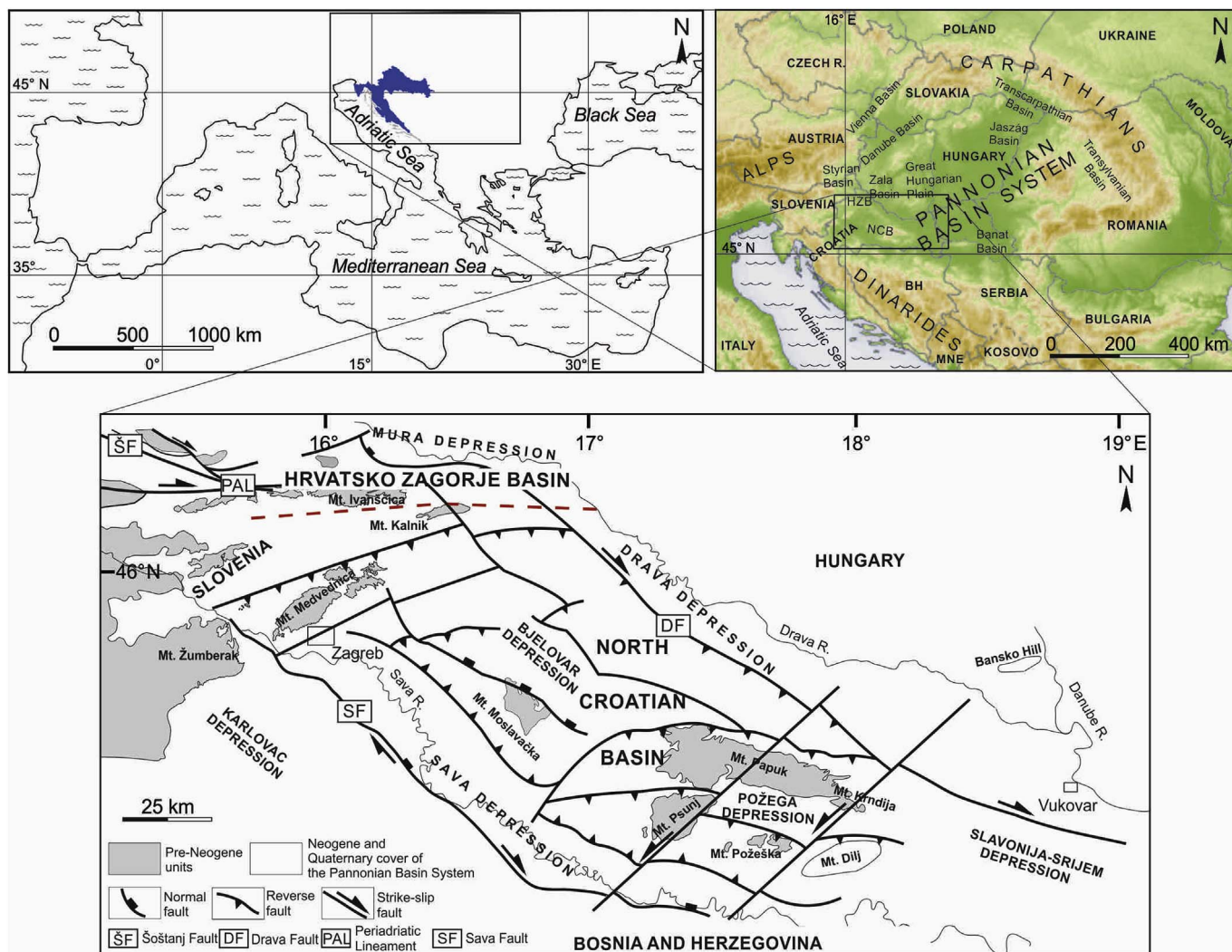


Fig. 1. Location map. The North Croatian Basin belongs to the south-western part of the Pannonian Basin System occupying most of northern Croatia. The Hrvatsko Zagorje Basin is in the north-western part of the country. The red dotted line shows a tentative boundary between the Hrvatsko Zagorje Basin and the North Croatian Basin. Main faults are modified after Márton et al. (2002) and Ustaszewski et al. (2014). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

System, and the North Sea, Mediterranean and Indo–Pacific Ocean was repeatedly established and then closed, strongly controlling deposition in the NCB (Rögl and Steininger, 1983; Pavelić, 2001; Popov et al., 2004; Harzhauser and Piller, 2007; Kováč et al., 2007, 2017; Piller et al., 2007). Marine transgressions, particularly during the Early Miocene, did not affect the entire basin. Therefore, the basement was unconformably overlain by deposits of different ages, ranging from the Early to Late Miocene. The deposits accumulated in marine, brackish and fresh-water environments, while some uplifted parts of the basin were characterized by temporary emersions. The final isolation of the Central Paratethys Sea commenced some 11.6 Ma ago when Lake Pannon formed (Magyar et al., 1999; Harzhauser and Piller, 2007; Piller et al., 2007). The specific style of Central Paratethyan development and the evolution of endemic faunas have necessitated the establishment of regional Neogene stages (Fig. 2).

The NCB has had a complicated evolutionary history strongly controlled by external factors, such as tectonics, climate changes, volcanic activity and eustatic sea-level changes. The stratigraphy of the NCB strongly depends on the specific development of depositional environments during the Neogene that also controlled organic evolution. Biostratigraphy has been the main tool for correlation of the marine deposits. However, endemic species whose evolution was triggered by fresh-water and brackish environments complicated the use of this

method. Additionally, some Neogene continental beds are non-fossiliferous. This method of correlation resulted in the formation of a partly erroneous stratigraphic time scale for the NCB that was in use for more than 40 years. However, recent studies recalibrated bioevents that produced serious consequences for NCB stratigraphy requiring stratigraphic reinterpretation. They are based on radiometric dating and integrated biostratigraphy, particularly concerning the correlation of Lower/Middle Miocene and Miocene/Pliocene boundaries (Čorić et al., 2009; Mandić et al., 2012; Marković, 2017).

In order to achieve better understanding of the modern stratigraphy of the NCB, this review presents a summary of the evolution of ideas within recent decades on the basis of surface data, indicating the main stratigraphic and palaeogeographic differences from the rest of the Central Paratethys, that emphasizes the complex evolution of the Pannonian Basin System.

2. Geological setting

The PBS is surrounded by mountain chains comprising the Alps, Carpathians and Dinarides, and palaeogeographically occupies most of the Central Paratethys realm that had the south-western margin in north-western Croatia and northern Bosnia (Rögl and Steininger, 1983; Popov et al., 2004; Harzhauser and Piller, 2007; Piller et al., 2007;

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