CONNECTION OF NEOGENE BASIN FORMATION, MAGMATISM AND COOLING OF METAMORPHICS IN NE SLOVENIA

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Abstract: The Mura-Zala basin was born due to crustal extension between ~18 and~13 Ma. Extension resulted in half grabens and fastly subsiding basin floor. However, metamorphic rocks and Neogene magmatites were exhumed synchronously at the western basin margin, probably along low-angle ductile shear zones. After a late Miocene thermal phase and a Pliocene folding of the southernmost half grabens, all the area suffered a uniform, ~30º counterclockwise rotation.

Key words: Pannonian basin, Neogene, Pohorje, granodiorite, exhumation, paleomagnetism

Introduction

The Mura-Zala basin is situated in the SW part of the Pannonian Basin in NE Slovenia and SW Hungary. The morphological depression is bounded in the south and west by the high hills of the Haloze and the Pohorje-Kozjak, respectively. At the rifting stager, these hills were integrated parts of the Mura-Zala basin. Our paper describes the different processes which led to the present day morphology. In addition, we give a conceptual model which connects exhumation and uplift of the basement and subsidence of the basin fill.

Geological settings

The Neogene basin was superimposed on Createaceous Alpine nappes composed of low to medium-grade metamorphic rocks and slightly or non-metamorphosed Paleozoic and Permo-

Mesozoic rocks. These basement rocks were encountered by boreholes and occur in the Pohorje-Kozjak and Haloze.

The metamorphic sequence is built up by three series (Hinterlechner, 1973; Mioč, 1977): (i) The ***Pohorje-series*** (PS) is dominated by medium-grade metamorphic rocks (micaschist, gneiss, amphibolite with marble and quartzite lenses) containing also small bodies of relic eclogites and ultramafic rocks. (ii) The ***Kobansko-series*** (KS) consists of amphibolites, epidote-chlorite-amphibole-schists and associated quartz-feldspar-mica-chlorite schists showing mostly transitional greenschist to lower amphibolite metamorphic conditions. (iii) The ***Magdalensberg-series*** (MS) is built up predominantly by (very) low-grade slates, phyllites and basic metavolcanites and forms the uppermost tectonic unit on the top of the previous two series. A quartz-sericite ***phyllite unit*** is often found at the top of the PS or KS series, below the MS or Mesozoic rocks.

Neogene sequences of the Mura-Zala basin starts with Ottnangian(?)-Karpatian coarse clastics which go upward to fine sandstone, siltstone and silty marl (Pleničar 1973; Kőrössy, 1988). Paleobathymetric studies (e.g. plankton/bentos ratio and benthic foraminifera taxa distribution) indicate upper-middle bathyal depth, with a maximum of ~900-1000m in the late Karpatian and early Badenian. Deep water sedimentation is represented by deposits of gravity mass movements (sliding, slumping, debris and mud flows, and turbiditic currents).

The deep water conditions were maintained in depocenters during the middle Miocene but the fine-grained turbidites had mixed siliciclastic/carbonatic sources. Facies differentiation is marked by shallow water organodetritic carbonates (Kőrössy, 1988). During the late Miocene delta progradation is detected in basin (Szentgyörgyi and Juhász, 1988), although turbiditic sedimentation prevailed in deep parts.

Magmatism

The large magmatic body of the Pohorje was oftern refered to as "tonalite" (Dolar–Mantuani, 1935; Faninger E., 1970). However, new petrologic and geochemical data clearly show that it is a ***granodiorite*** (Zupančič, 1994a). It includes a small gabbro (cizlakite) body. Both contain mafic xenolites and are crosscut by aplite and pegmatite veins. Lamprophyre dykes represent the last magmatic event.

A shallow intrusive dacite stock occurs in the western Pohorje. Petrologic and geochemical evidences suggest that the western dacites and the main granodioritic body could be cogenetic (Zupančič, 1994b). In addition, new researches indicate that the granodiorite body is somewhat older and later was affected by dacite intrusions (Márton et al., this volume).

Deformation

Normal or oblique-normal ***faulting*** occured during the rifting phase, from Ottangian(?) to middle Miocene (~18 to ~13 Ma). The direction of tension varied from E-W–NE-SW (Pohorje-Kozjak) to NNE-SSW (Haloze). The resulting faults are trending NNW to NE while trending ENE in the Budafa-Haloze sub-basin. All major faults bounded half-grabens and intervenning highs (Márton et al., in press).

The Haloze-Budafa sub-basin was strongly to moderately ***folded*** after the Miocene. The resulting anticlines and synclines are well-known in the literature (Horváth and Rumpler, 1984; Pávai Vajna, 1919; Mioč and Marković, 1998) Microtectonic data show that folding was coaxial and not associated with rotation. Compressional deformation is also reflected in the magnetic fabric (low field susceptibility anisotropy).

Although part of the ***ductile structures*** in metamorphic rocks can be Eoalpine in age, some of them may have connection to Miocene basin formation. All studied lithologies are characterised by a well-developed penetrative foliation dipping mostly to S(SW) or N(NW). An associated stretching lineation plunges E(SE) or NE, already observed by Mioč (1977). The rocks frequently display a prominent mylonitic microfabrics in sections parallel to lineation. Well-developed kinematic indicators (extensional crenulation cleavage, asymmetric boudinage, etc.) show a very uniform top-to-the-E(SE) extensional shearing. The intesity of ductile extensional strain is varying, and was particularly strong in the phyllite unit which could be regarded as a low-angle ductile shear zone.

In the Pohorje-Kozjak Hills and the main Mura basin counterclockwise ***rotation*** was demonstrated both from the magmatites and Miocene sediments (Márton et al., in press, and this volume). Sites in different stratigraphical levels show similar amount of CCW rotation having occurred after the Pontian. In the Haloze, part of the magnetisation process and the total rotation post-date the folding (Márton et al., in press), demonstrating a Pliocene timing for the rotation.

Thermochronology of metamorphic and magmatic rocks

We have new geochronological data from the metamorfic rocks of the Pohorje and Kozjak Hills (Fig. 1). These latters are marked by older ages, both by conventional K/Ar (96

Ma), and by zircon fission track method (26 Ma). Two samples from the Pohorje and one from the basement of the Mura depression show Miocene ages (18,4-13,2 Ma). All these data can be interpreted as cooling ages through the closure temperature of K/Ar system of the dated minerals. Zircon and apatite fission track ages fit this cooling trend (18 and 10 Ma, respectively)(Sachsenhofer et al., 1998).

K/Ar ages from metamorphics and magmatites (~19,5-15,7 Ma) are not significantly different from each other. This means that Pohorje rocks suffered important cooling during and after magmatic intrusions, from temperature over ~350°C to ~110°C. However, the presence of Permo-Mesozoic and Paleozoic sequences in the western and eclogite in the east Pohorje would suggest an asymmetric uplift, the eastern part being more displaced. Both K/Ar and apatite fission track ages seems to be older in the west, supporting this model. Tilting is also evidenced by combined magmatic-paleomagnetic study (Márton et al., this volume).

Model for Neogene basement exhumation, basin formation and later deformation

We put forward a structural model to connect Miocene cooling of metamorphics, the presence of extensive plutonism and the opening of the Mura-Zala basin (Fig. 1).Ductile extension in the Kozjak Hills might have occurred in the Cretaceous, because pre-Miocene K/Ar and fission track data is obtained from the underlying rocks. In the Pohorje, all rocks were still over 350º C at the beginning of basin formation (~18 Ma). This tempreature was large enough to activate mylonitic shear zones. Thus, low-angle detachments could play important role in Neogene exhumation (unroofing). If our assumption is valid, the Pohorje can be considered as a Miocene metamorphic core complex, similar to other neighbouring examples (Tari, 1996). Exhumation was asymmetric, resulted in a westward tilt of the eastern Pohorje. Similar low- and high-angle brittle and ductile faulting and tilted blocks continue below the Neogene cover of the Mura-Zala basin (Gosar, 1995), up to the Transdanubian Range (Fodor and Koroknai, 2000). Normal faulting resulted in formation of half-grabens and their subsidence to bathyal depth.

Low-angle detachment faulting and exhumation of footwall metamorphics were associated with magmatism (Lister and Baldwin, 1993). This phenomenon contributed to the perturbation of the isotherms and shifted the depth of ductility to a shallow level which helped the tectonic exhumation. Very high vitrinite reflection data from Karpatian-Badenian sediments could also reflect the combined effect of heat transfer from intrusion(s) and uplifting hot metamorphic rocks (Sachsenhofer et al., 1998).

Following varying exhumation of basement metamorphics and magmatites, and coeval subsidence, the Pohorje-Kozjak Hills, the Mura-Zala basin and the Haloze underwent the same rotation. This post-Pontian, ~30 CCW rotation affected a larger area, including NW Croatia and possibly SW Hungary (Márton et al., in press).

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Fig. 1. Conceptual cross section throught the Pohorje/Kozjak Hills, Mura-Zala basin. K/Ar and fission track ages are projected (partly after Fodor and Koroknai, 2000).

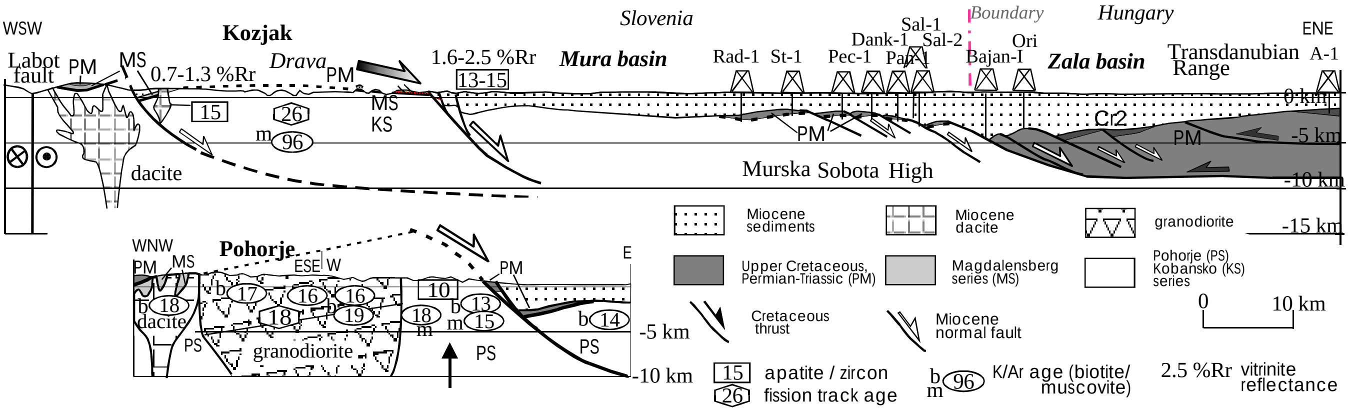

Fig. 1. Simplified cross section through NE Slovenia, partly after Fodor and Koroknai (2000). Vitrinite reflectance and apatite fission track data from Sachsenhofer et al. (1998).

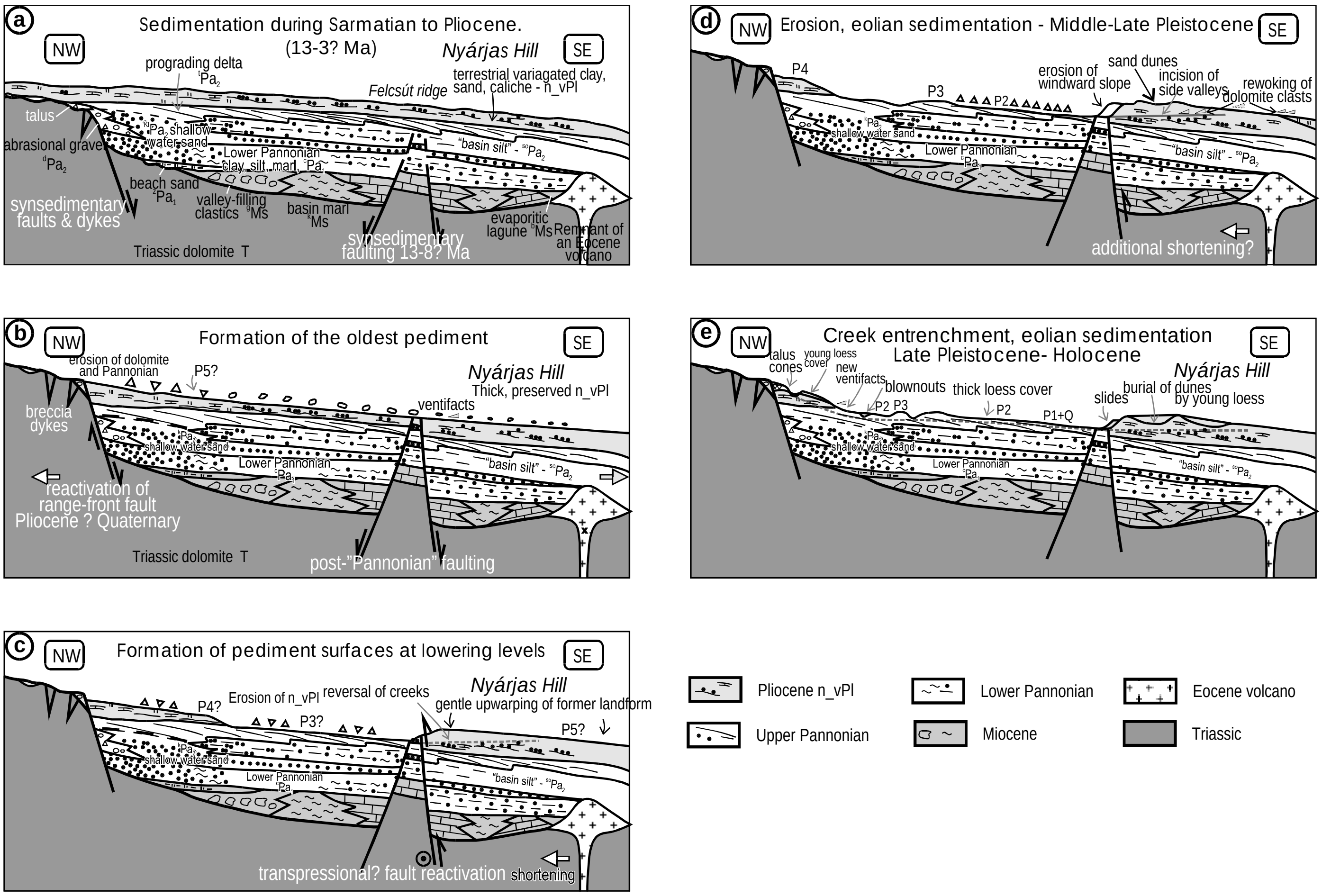

Fig. 2. Conceptual evolution model for the area. For legend see Fig. 1.
After Csillag et al., (2001).