# Miocene extensional unroofing of the Medvednica Mountains in Croatia: tectonic implications for the Alpine-Dinaridic junction.

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**Introduction** In the Mediterranean realm interfering tectonics between different orogens is very common. For instance, the interference between the Alps and Dinarides related to changing subduction polarities (i.e. Adria in upper plate position versus Adria in lower plate position). Additionally, the orogenic structures at the Alpine-Dinaridic junction are modified by Pannonian basin extension driven by the Miocene roll-back of the Carpathian retreating slab whilst Miocene-recent indentation by Adria takes place. A key location to study the effects of these interfering tectonics are the Medvednica Mountains. The Medvednica Mountains forms an 'inselberg' situated near the Alpine-Dinaric transition at the southwestern margin of the Pannonian basin. The inselberg exposes a direct contact between a metamorphosed and non-metamorphosed Cretaceous Dinaridic nappe stack (Tomljenovic et al., 2008), which is surrounded and overlain by Miocene sediments. From similar inselbergs within the region it is known that exhumation of the metamorphosed units took place along Miocene low-angle detachments, e.g. Kosera-Prosera, Fruska Gora (Ustaszewski et al., 2010; 2012; Tolijc et al.,2013). In this study we have investigated the possible presence of similar Miocene tectonics leading to the exhumation of the Medvednica Mountains.

A field kinematic and microstructural study combined with new thermochronological data (apatite and zircon fission track, and Rb-Sr thermochronology) provides further insights into the exhumation of the metamorphosed units of Medvednica Mountains. Our data allow for refining tthe spatial position of the Paleozoic-Mesozoic units relative to Europe and Adria, and provide important quantitative constraints on vertical motions in context of Alpine-Dinaridic interactions during Adriatic indentation.

## Geological setting

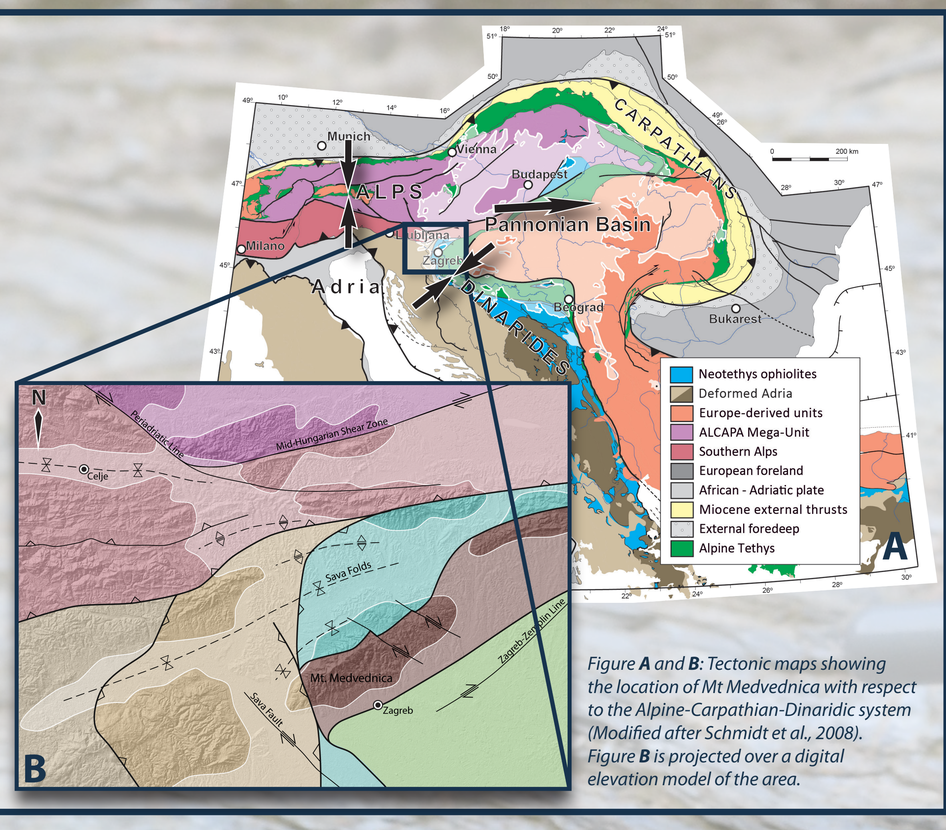
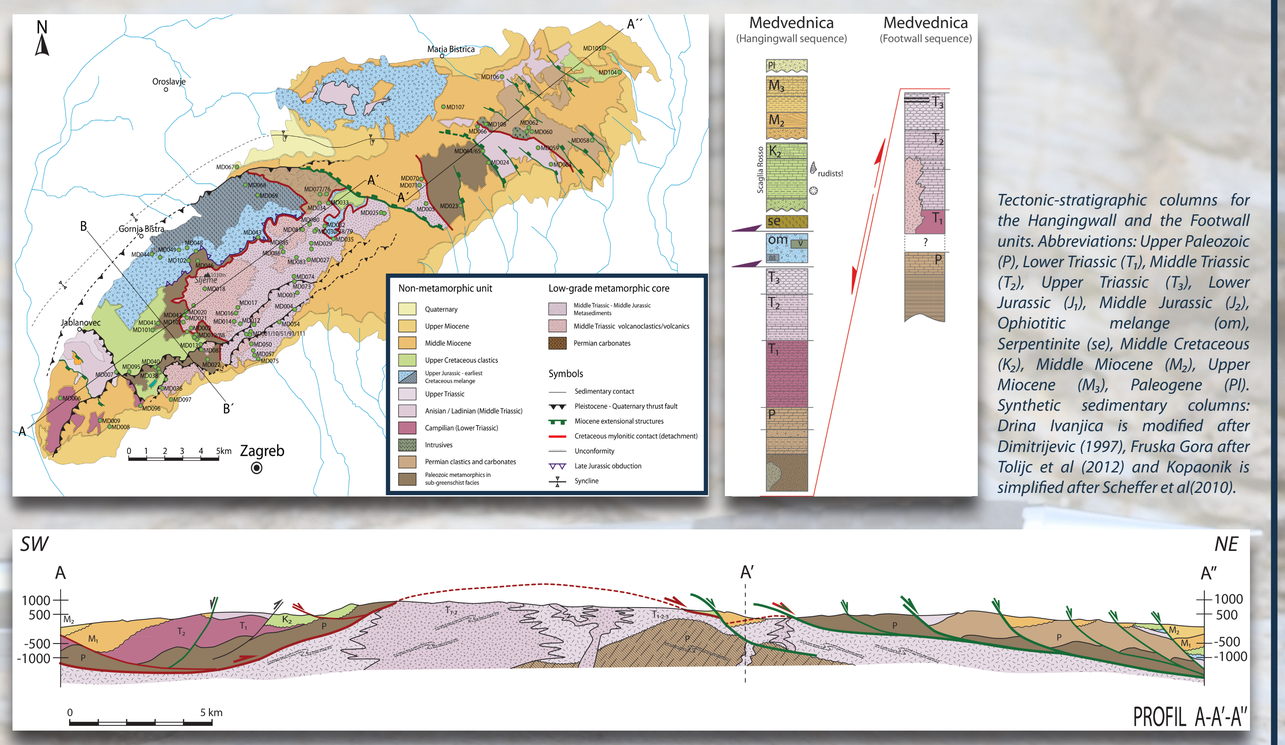
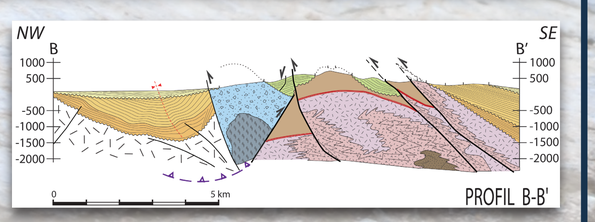



*Figure **A** and **B**: Tectonic maps showing the location of Mt Medvednica with respect to the Alpine-Carpathian-Dinaridic system (Modified after Schmidt et al., 2008). Figure **B** is projected over a digital elevation model of the area.*

## Geological interpretation



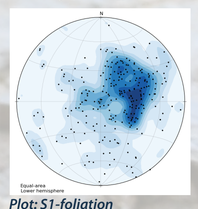

*Tectonic-stratigraphic columns for the Hangingwall and the Footwall units. Abbreviations: Upper Paleozoic (P), Lower Triassic ($T_1$), Middle Triassic ($T_2$), Upper Triassic ($T_3$), Lower Jurassic ($J_1$), Middle Jurassic ($J_2$), Ophiotitic melange (om), Serpentinite (se), Middle Cretaceous ($K_2$), Middle Miocene ($M_2$), Upper Miocene ($M_3$), Paleogene (Pl). Synthetic sedimentary columns: Drina Ivanjica is modified after Dimitrijevic (1997), Fruska Gora after Tolijc et al (2012) and Kopaonik is simplified after Scheffer et al(2010).*




*Cross-section AA'A'' demonstrates the relationship between the Cretaceous low-angle detachment and Miocene reactivation. Section BB' highlights the trunctation of thrusting during Pliocene inversion.*

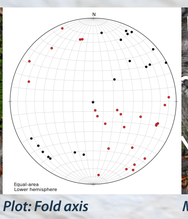
## Field kinematics and microscopic analysis

### Early stage of contractional kinematics




*Plot: S1-foliation*


*MD001*

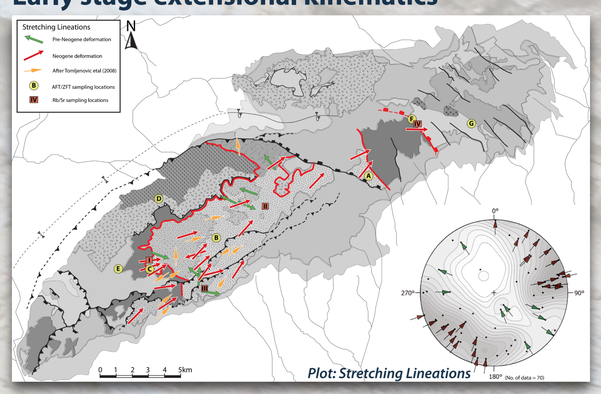


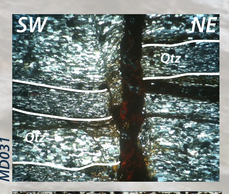

*Plot: Fold axis*

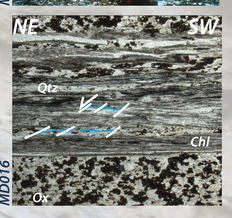

*MD016*

***Field observations:** penetrative foliation, isoclynal and assymetric folding.*
***Microscopic analysis:** Peak metamorphic conditions (greenschist facies) with top-to-the-NW shearing.*

### Early stage extensional kinematics




***Field observations:** Mylonitisation, penetrative stretching lineations with top-to-the-ENE shearing.*
***Microscopic analysis:** (ultra) mylonitic foliation associated with top-to-the-ENE shearing.*

### Late stage extensional kinematics - Reactivation D2


*Plots: observed normal faults*

*MD005*

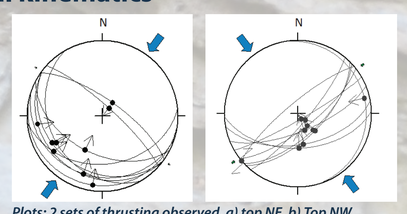



*MD021*

***Field observation:** Brittle reactivation of the early stage kinematics overprinted by brittle normal faulting.*
***Microscopic analysis:** (semi-)brittle shearing of the metamorphozed and non-metamorphozed units with a dominant top-to-the-ENE sense of shear*

### Late stage of contractional kinematics


*MD091*



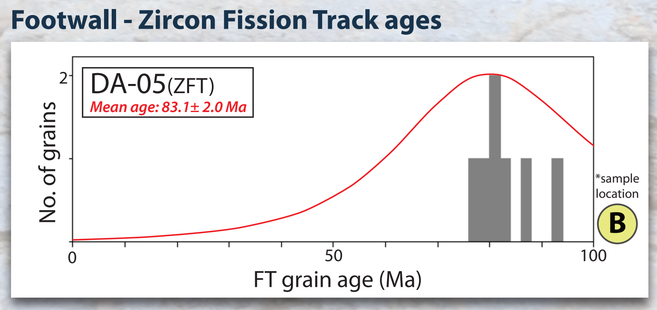

*Plots: 2 sets of thrusting observed, a) top NE, b) Top NW*

***Field observations:** Brittle shearing and thrusting with a top-to-the NE and NW transport direction*

*Abbreviations: Quartz (Qtz), Chlorite (Chl), Epidote (Ep), Oxides (Ox)*

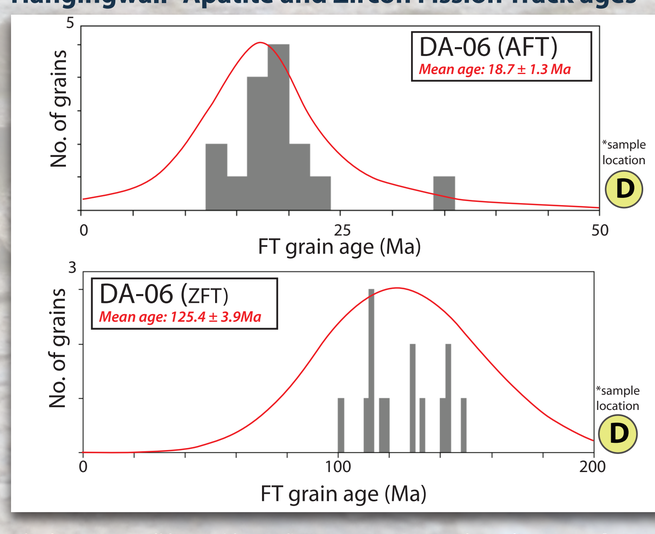
## Thermochronology

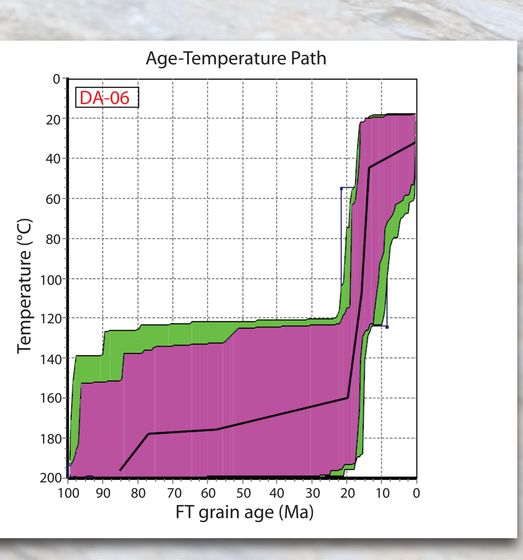
### Footwall - Zircon Fission Track ages




*The Zircons Fission Track age for the metamorphic units of the footwall indicates a Upper Cretaceous cooling phase.*

### Hangingwall- Apatite and Zircon Fission Track ages




*The hangingwall has a (detrital) Zircon Fission Track cooling age of 125,4 Ma, which is relates to the age of the obduction of the Neotethys. The Apatite Fission Track age suggest no significant cooling until the Lower Miocene. But at 18.7 Ma rapid cooling/exhumation took place.*

**Note: Sample locations are marked on the grey-scale map*

## Conclusions

New thermochronological data, linked to field and microstructural observations portray a two-stage exhumation history of the Medvednica mountains.

1. Upper Cretaceous (Santonian) exhumation occurred along a low-angle detachment, which separates a metamorphosed, deep water sequence in the footwall from a shallow water facies from the Adriatic passive margin in the hangingwall.
2. During the Middle Miocene a second events of exhumation took place accommodating an estimated 5-7 km of uplift. This phase of extension and exhumation is related to Pannonian basin back-arc extension. Finally, the present-day geometry of the inselberg is attributed to Pliocene-Quaternary inversion of the Pannonian basin.

Our study derives critical inferences for the location and geometry of the nappe stack pre-dating the extension at or near the Adria-Europe contact.

**References:** *Tomljenovic, B., Csontos, L., Márton, M., Márton, P. (2008) Tectonic evolution of the northwestern Internal Dinarides as constrained by the structures and rotation of Medvednica Mountains, North Croatia. Geological Society, London, v.298, p.145-167. | Tolijc, M., Matenco, L., Ducea, M. et al (2012). The evolution of a key segment in the Europe-Adria collision: The Fruska Gora of northern Serbia. Global and Planetary Change, v.103, p.39-62. | Schmid, S.M., Bernoulli, D., Fügenschuh, B., et al (2008). The Alpine–Carpathian–Dinaridic orogenic system: correlation and evolution of tectonic units. Swiss Journal of Geosciences 101 (1), 139–183. | Ustaszewski, K., Kounov, A., Schmid, S.M., Schaltegger, U., Krenn, E., Frank, W. and Fügenschuh B. (2010). Evolution of the Adria-Europe plate boundary in the northern Dinarides: From continent-continent collision to back-arc extension, Tectonics, 29, TC6017 .*