A new 4D model of Alpine orogenesis based on AlpArray

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Wholesale slab breakoff or detachment in the Alps in late Paleogene time has been invoked to explain Periadriatic calc-alkaline magmatism (43-29 Ma), rapid exhumation of HP metamorphics, as well as clastic infill of proximal parts of the Alpine Molasse basin (30-28 Ma). However, the 14 My timespan of these events exceeds the duration of slab detachment estimated from thermomechanical modelling (2-8 My) and from foreland depocenter migration (~5 My) along equivalent lengths of neighboring Alpine orogens with torn slabs (Carpathians, Apennines). Moreover, wholesale slab detachment does not explain major E-W differences in Neogene crustal structure, basin evolution, erosion and indentation in the Alps.

Teleseismic Vp tomography from AlpArray suggests that the slab segment beneath the Central Alps comprises European lithosphere, is attached to its orogenic lithosphere and extends down to ~250 km depth, in parts possibly even to the Mantle Transition Zone (Fig. 1). This marks a first phase of partial slab detachment, probably in late Paleogene time based on comparing slab length with shortening in the C. Alps and of Adria-Europe convergence since 35 Ma. In contrast, the slab segment beneath the Eastern Alps is detached between 80-150 km depth. The age of this second phase of slab detachment is bracketed at 23-19 Ma by criteria below and by comparing vertical detachment distance with global slab sink rates.

We propose a new model of Alpine mountain-building that features the northward motion of subduction singularities above delaminating and detaching Alpine slab segments, respectively in the C. and E. Alps (Fig. 2), to explain the aforementioned E-W differences in Oligo-Miocene structure, magmatism, and foreland sedimentation. Mountain-building began at ~35 Ma with a decrease in Adria-Europe convergence to <1cm/yr collision, causing the European slab to steepen and detach beneath both the Central and Eastern Alps. Periadriatic magmatism may have initiated prior to slab detachment due to fluxing of the cold mantle wedge by fluids from devolatilizing crust along the steepened Alpine slab. Thereafter, the Central and Eastern Alps evolved separately (Fig. 2). Northward motion of the singularity during slab delamination in the Central Alps increased both horizontal shortening and the taper angle of the orogenic wedge, with rapid exhumation and denudation in the retro-wedge. Slab steepening and delamination are inferred to have been more pronounced in the Eastern Alps, possibly due to the greater negative buoyancy of the slab in the absence of Brianconnais continental lithosphere in the eastern part of Alpine Tethys. The delaminating slab in the east drove subsidence and continued marine sedimentation in the E. Molasse basin from 29-19 Ma, while the western part of the basin in the C. Alps filled with terrigeneous sediments. Slab detachment beneath the E. Alps at ~20 Ma coincided broadly with several dramatic events within only 5 Ma (23-17 Ma): (1) a switch from advance of the northern thrust front to indentation of the E. Alps by the eastern S. Alps along the sinistral Giudicarie Fault; (2) rapid exhumation of Penninic nappes in the core of the orogen (Tauern Window) and orogen-parallel escape of orogenic crust toward the Pannonian Basin; (3) rapid filling of the E. Molasse basin. These events are attributed to a northward and upward shift of the singularity to within the orogenic crust during Adriatic indentation (Fig. 2). The eastward propagation of the uplifting depocenter in the E. Molasse basin is interpreted to reflect propagation of a subhorizontal slab tear beneath the E. Alps which is imaged by Vp teleseismic tomography. This slab tearing ultimately accompanied Miocene rollback subduction in the Carpathians, as inferred from the migrating depocenter around the orogenic foredeep.

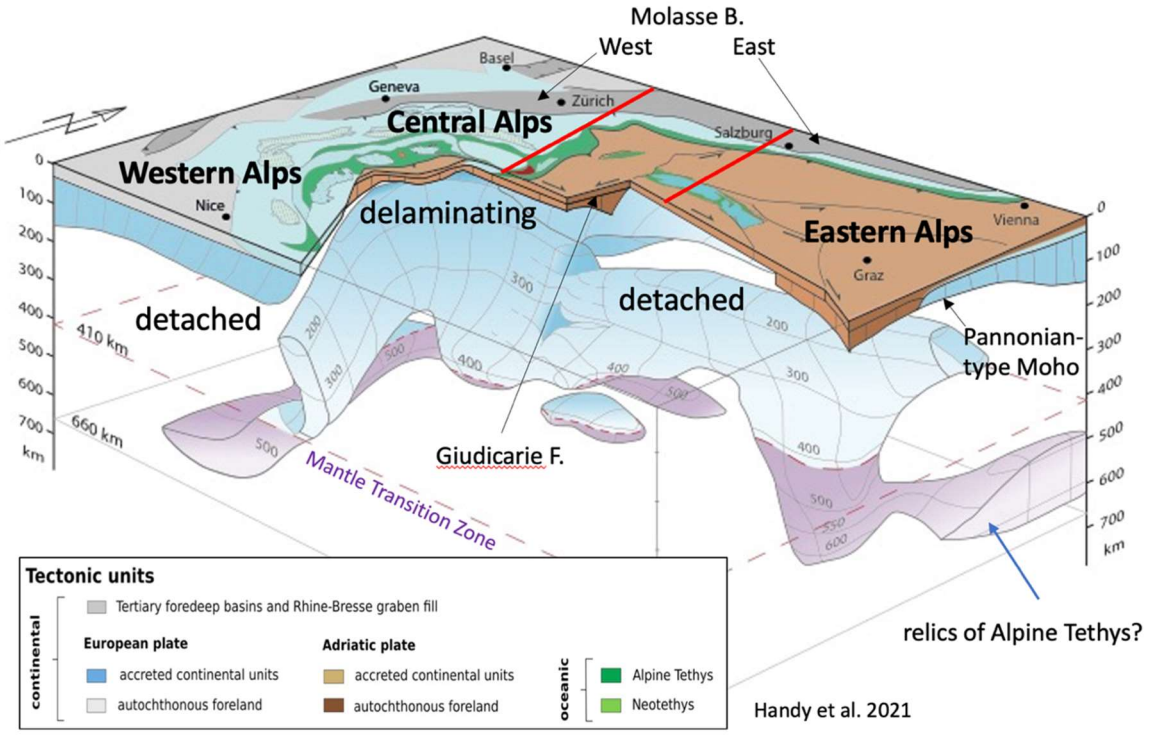

Figure 1: European slab beneath Alps as interpreted from teleseismic V_P tomography (Handy et al. 2021). Red lines show traces of section in Fig. 2

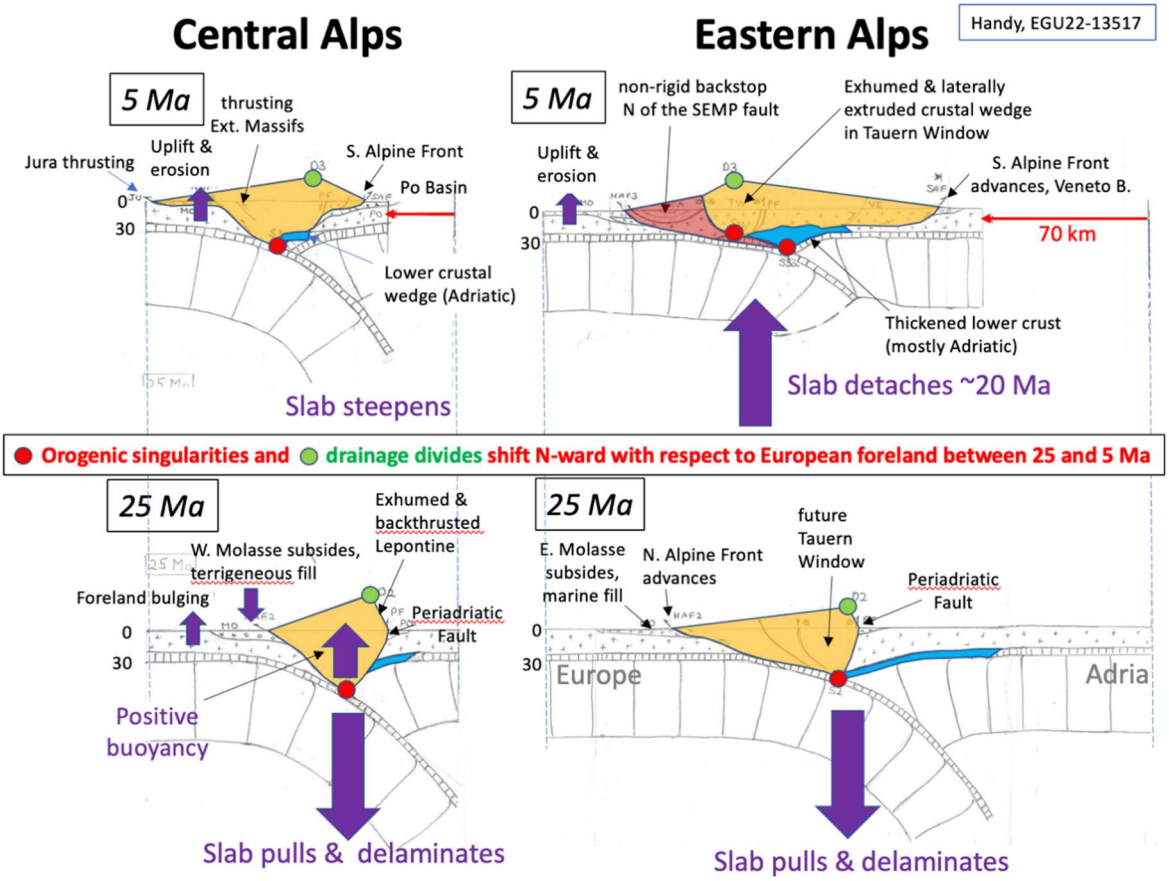

Figure 2: Schematic N-S cross sections for Miocene time showing migrating singularities in relation to the shapes of orogenic wedges, exhumation and deposition in the Central and Eastern Alps. Note that previous slab detachment in Paleogene time is not shown.