Geophysical Research Abstracts
Vol. 15, EGU2013-12994, 2013
EGU General Assembly 2013

Tectonic and erosional exhumation processes in the western Northern Apennines of Italy: coeval compressional and extensional tectonics affecting an eroding orogenic wedge

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In the Northern Apennines of Italy the Ligurian and Subligurian Units (LSU) represent far-travelled/allochthonous units which, since early Miocene to Recent, migrated towards NE, above the Tuscan-Umbrian foredeep deposits, reaching the present-day frontal ranges of the chain.
In the NE-facing side of the western Northern Apennines the present-day geometry of the LSU does not reflect the shape they acquired during the late Oligocene, when the early orogenic collisional phases produced a wedge whose geometry tapered out towards the foreland area, i.e. to the E-NE. In fact, at present, geological evidences indicate that the LSU are characterized by a doubly-tapering geometry, whose thickness ranges from less than 1 km at the main ridge zone (SW) up to more than 4 km along the NE slope of the chain and then tips out again few km N of the Northern Apennines topographic front, underneath the late Messinian to Recent marine and continental deposits of the Po Plain foredeep. These data imply that since late Oligocene the LSU geometry has been deeply reshaped inside a context of overall growth of the orogenic wedge. Therefore the reshaping of the LSU is related to their post-early Miocene progressive emplacement over the foredeep units and to the late orogenic evolution of the Northern Apennines, characterized by the coeval activity of extensional and compressional tectonics.
In order to put new constraints on the relationships existing between timing and modes of reshaping of the LSU and the Miocene to Recent evolution of the western Northern Apennines, we adopted a multidisciplinary approach which took into account field evidences, low temperature thermal and thermochronological data (vitrinite reflectance, clay mineral analyses, apatite fission track dating), numerical modelling of the AFT cooling ages through the use of Pecube finite element code, recently published works on the evolution of the external slope of the chain, and a new interpretation of seismic lines and boreholes data.
This multidisciplinary approach allowed us to: 1) build a 3D representation of the LSU present-day geometry; 2) highlight two main stages of reshaping of the LSU, first during late Miocene ($\sim$10 to 6 Ma), and subsequently during Pliocene to Recent (?) time ($\sim$6 to 0 (?) Ma); 3) relate, during the first stage, the LSU thinning processes, achieved by means of low-angle extensional faults, to the tectonic denudation of the foredeep units; 4) envisage the importance of coupled tectonic (high-angle extensional tectonics) and progressively increased surface erosion processes as responsible for the denudation of the foredeep units during the second stage; 5) define estimates of the exhumation/erosion rates characterizing the investigated area during the last $\sim$10 My.
These results allowed us to give new insights, temporal and spatial constraints on the morphostructural evolution of the western Northern Apennines, which has been mainly affected initially ($\sim$10-6 Ma) by the interplay between deep compressional and coeval shallow extensional tectonics (< 20 and < 4 km, respectively), and subsequently by the progressively more relevant onset of surface erosion processes.