Feedback relations between deformation and melt, the evolution from weakening to hardening in transpressive orogens

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Since orogens control the mechanics of interactions between converging plates, it is important to understand both weakening and hardening mechanisms. Although orogens are grouped into weak and strong, we argue that the rheology of transpressive orogens evolves from weak to strong. Orogeny commonly is diachronous, so that this evolution occurs in space and time. Below the brittle-viscous transition, the beginning of melting (the anatectic front), marked by the migmatite front in the field, represents a second strain-dependent crustal discontinuity, below which melt present viscous flow occurs. Syntectonic pervasive melt flow, evolution of melt pressure, particularly transient overpressuring, episodic melt expulsion, ascent and emplacement, and crystallization of melt all affect the rheology and control the mechanical response to the imposed stresses. We exemplify these effects with reference to part of the Acadian orogen of the Appalachians. The Appalachians is divided into three segments, within which the metamorphic grade and the implied depth exhumed to the surface increases from N to S, whereas the age of peak metamorphism/granite magmatism decreases. These segments are the Newfoundland, New Brunswick-New England (NBNE) and central-southern Appalachians. The NBNE segment is divided into several tectonostratigraphic units. The Central Maine belt (CMB) is a principal unit occupying most of the E part; it is composed of a Lower Paleozoic sedimentary succession, deformed and metamorphosed at greenschist to upper amphibolite facies conditions, which exceeded the anatectic front as recorded by migmatites, and intruded by plutons of Devonian age. The CMB is located between Ordovician rocks of the Bronson Hill belt (BHB) to the W and Neoproterozoic to Silurian rocks of the Avalon Composite terrane (ACT) to the E, from which it is separated by the dextral-transcurrent Norumbega shear zone system (NSZS). The tectonic regime in the CMB involved non-coaxial non-plane strain flow, in which the inclined vorticity vector was stretched along its length and the deformation was partitioned into alternating steeply inclined S > L and L >> S tectonite zones within the CMB shear zone system. Regionally distributed asymmetric structures indicate dextral-SE-side-up kinematics. The orogeny was transpressive, driven by oblique convergence. Metamorphic P-T paths are clockwise, with peak T late in the deformation history, and cooling that progressed S. In ME, the metamorphic field gradient reflects (late) syntectonic polymetamorphism related to a regionally elevated thermal gradient overprinted by local pluton-driven thermal pulses. Geochemical data show that migmatites are residual, and isotope data indicate granite commonly was derived predominantly from a CMB source. Age data suggest contemporaneous deformation, metamorphism and granite emplacement. At higher structural levels, above the anatectic front, in the Presidential Range of eastern NH, E-verging inclined folds are superimposed on km-scale recumbent E-verging folds, consistent with structures to the S. We interpret the contrast between the comparatively simple deformation history in ME and the more complex sequence in NH to reflect proximity to the free surface. At this level, gravitational collapse occurred and superimposed structures, including multiple foliations, developed during ongoing deformation. The age of syntectonic metamorphism and plutonism is the same as that in ME. To the W of the BHB is the Connecticut Valley Belt (CVB), which most likely is a correlative of the CMB transported W. In the CVB of western NH, structural relations and counter clockwise metamorphic P-T paths suggest a sequence of thrust sheets, each associated with syntectonic melt at the base, emplaced from W to E, contemporaneously with deformation, metamorphism and magmatism in ME, with cooling progressing from W to E, reflecting increasing isostatic rebound toward the orogenic core. We conclude that factors controlling the rheology include melting and the weakening effect of melt, volume strain hardening by melt loss along steep fabrics in middle crust, and crystallization of melt, which hardens the crust. In the NBNE segment, feedback relations between deformation, melting and melt flow facilitated concentration of deformation in the weak orogen. The transition from melt ascent to emplacement in the upper crust led to crystallization and decay of melt flow by back freezing, which hardened the crust. Whether this leads to coupling depends on the plate kinematics. In the NBNE segment, hardening in the CMB led to localization of deformation into the NSZS during the Carboniferous.

Coupling between surface processes and various modes of continental compressional deformation

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Models of tectonic deformation commonly neglect the surface processes and subsurface heterogeneities such as lateral variations in the crustal composition, minor or healed faults, assuming that they are negligible with respect to the effects of the topography and tectonic forces. Recent problems with estimation of lithospheric strength in cratons and common problems with simultaneous reproduction of realistic vertical tectonic velocities and surface geometries in the mechanical tectonic models suggest that the above factors may play a leading role in many cases. Using a forward numerical approach allows to account for brittle-elasto-ductile rheologies, erosion and non-predefined faults, we demonstrate the crucial importance of the account for the surface processes and distributed faulting in modelling of compressional deformation and orogeny. Erosion allows to obtain 10times higher vertical tectonic rates than for the conventional models, and significantly influence the evolution and distribution (spacing) of faults, finite amplitudes of tectonic movements and even the subsurface structure of the lithosphere. In contrast to the traditional opinion, our model show that volumetric shortening, folding instabilities associated with long-distance transmission of far-field tectonic stress and faulting can actually co-exist for a very long time, partly thanking to the stabilizing feedback with the surface processes. The importance of coupling between the surface and deep processes was also demonstrated in our HT-HP rock exhumation models in which we test three basic mechanisms presumably responsible for ultra-rapid exhumation, compressional instability, RT-type instability in the subducted crust, and crustal squeezing.

Mechanisms involved in the formation of the Tertiary Piemonte Basin in a collisional setting and relations between source area and basin infill from $^{40}Ar/^{39}Ar$ dating

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The Tertiary Piemonte Basin (TPB) is a syn-orogenic basin located in an area of convergence straddling the junction of the Alpine and Apennine chains. The TPB contains >4000 m of clastic transitional/marine deposits with subsidence and deposition starting in the Oligocene and continuing until the Late Miocene. During this time span important events were taking place in the surrounding areas like the continental collision between the Adrian and European plates and the opening of the Liguro-Provencal basin. Despite this, the TPB has not suffered major deformation and it is not separated by major faults from the surrounding orogen. Subsidence analyses have been carried out in order to establish the tectonic evolution of the basin and to investigate the mechanisms involved. Two main periods of subsidence are detected: the first in early Oligocene time and the second, stronger event, in middle Miocene time. The beginning of the subsidence coincides in time with the backthrust of the Brianconaise zone on the Gran Paradiso nappe, which occurred in the Western Alps 30-35 Ma ago.

To derive further information on the exhumation/erosion history of the orogen surrounding the basin and on the basin depositional pattern, $^{40}Ar/^{39}Ar$ dating has been applied to white micas from clastic sediments. The entire basin stratigraphy (early Oligocene-upper Miocene) was sampled and up to 10 grains from each sample dated. A first order age distribution shows that the con-