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Mesozoic faults and folds in the South-Alpine and Austroalpine upper crust and its sedimentary cover

Sudalpino e Austroalpino: faglie e pieghe mesozoiche nella crosta superiore e loro coperture sedimentarie

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The Alps locally preserve structures that are related to its pre-Alpine history. These structures include not only Variscan and older elements visible in the continental-basement nappes but also extensional and compressional structures related to continental rifting preceding the opening of the Alpine-Mediterranean Tethys during the Jurassic. In part, these structures have been reactivated during the Alpine orogeny whereby the mechanical heterogeneities inherited from (early Permian extension and) Jurassic rifting led to pronounced strain partitioning; in other cases such structures survived the Alpine orogeny and can be observed particularly well in the upper plate of the Alpine subduction zone, i.e. in the Austroalpine orogenic lid or in the South-Alpine retrowedge. These Mesozoic, mainly extensional structures occur at different levels in the crust and in the cover sediments; deformation typically occurred under retrograde conditions (e.g. MANATSCHAL 1999; DESMURS *et alii* 2001), in near-surface environments or in non-consolidated sediments.

In the South-Alpine–Austroalpine–South-Pennine (Err- and Platta nappes) domain, two major phases of rifting can be distinguished. During a first phase, active from late Norian to about middle Liassic time, the South-Alpine–Austroalpine continental crust was moderately thinned (b < 2, MANATSCHAL *et alii* 2007). Extension, decoupled from the lower crust and mantle lithosphere, was accommodated more or less symmetrically by listric faults soling at about 10 km depth at the brittle-ductile transition whereas the middle crust was ductilely extended. With cooling and embrittlement of the entire crust, upper and lower crust were no longer decoupled and extension became localized in the future distal margin where low-angle detachments, cutting into the sub-continental mantle, exposed ultramafic rocks at the sea floor during the second phase of rifting in late Liassic to middle Jurassic times.

The first phase of rifting is particularly well documented in the Lombardian sector of the Southern Alps and the Upper Austroalpine nappes (Silvretta s.l., Ortles), where early on abrupt changes in sediment thickness and facies suggested the presence of active faults and fault scarps in Liassic times (BERNOULLI 1964; CASTELLARIN 1972; EBERLI 1988). Locally, such faults are sealed by post-rift sediments (EBERLI 1988), and tilted blocks of pre-rift sediments are unconformably overlain by post-rift deposits (BALLY *et alii* 1981). The listric geometry of master faults, bounding syn-rift basins about 25 to 30 km across can, in cases, be reconstructed from depositional geometries and the distribution of fault rocks (BERTOTTI 1991, BERTOTTI *et alii* 1993). In the early-cemented shallow-water carbonates of the late Triassic, deformation was brittle as testified to by the numerous neptunic dykes and related tectono-sedimentary breccias (*Macchia vecchia*, WIEDENMAYER 1963), in un-cemented basinal deposits, slump-folding was plastic as documented by flow folds which contrast strongly with brittle Alpine folds. In partially lithified spongolithic limestones, near-surface growth faults developed (BERNOULLI, 1964).

By latest Liassic-middle Jurassic times, the crust had been thinned from about 30 to about 15 km or less, and rifting activity concentrated in the

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evolving distal margin: Deposition of syn-rift sediments in the Lower Austroalpine nappes (and the Canavese zone) was contemporaneous with the deposition of hemipelagic post-rift sediments in the proximal margin where differences in facies and formation thickness may reflect inherited submarine relief and differential compaction of basinal sediments. The most prominent structures related to final rifting observable in the distal margin (Err nappe) and the ocean–continent–transition zone (Platta nappe) are low-angle detachment faults that exhumed sub-continental mantle rocks and along which extensional allochthons of continental basement and pre-rift sedimentary rocks were transported onto the exhumed serpentinized mantle (FROITZHEIM & EBERLI, 1990: MANATSCHAL & NIEVERGELT, 1997). These low-angle, at depth presumably concave-downward faults led to a different basin architecture during syn-rift sedimentation, and syn-rift sediments onlap directly onto the exhumed low-angle detachments yielding clasts of the exhumed fault rocks. Tectono-sedimentary breccias, the ophicalcites, mark the trace of no-longer active, exhumed segments of the low-angle detachments atop the mantle rocks exposed at the sea-floor (BERNOULLI *et alii* 2003).

Oceanwards, extension affected a magmatically active system: MORB-type gabbros, intruded into partly serpentinized mantle rocks, were deformed under decreasing temperature conditions (amphibolite- to greenschist-grade) and exhumed to the sea-floor; they are overlain by pillow basalts and form clasts in volcanoclastic sediments (DESMURS *et alii* 2001). Overall, the tectonic evolution of the South-Alpine–Austroalpine–South-Pennine margin finds an uniformitarian analog in the magma-poor Cretaceous margin offshore Portugal (MANATSCHAL & BERNOULLI 1999; MANATSCHAL *et alii* 2007).

With time, during rifting, extension exhumed deeper and deeper levels of the crust and the sub-continental mantle lithosphere. Exhumation of these deeper levels along the distal margin is reflected by the clast content of the syn-rift sediments: Triassic carbonate fragments in the proximal margin; upper to lower crustal rocks in the distal margin, and sub-continental mantle and mafic igneous rock fragments in the distal ocean–continent–transition zone. In latest middle to late Jurassic times, deep-water radiolarites were to overlie both proximal and distal margin and the ocean–continent–transition.

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