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Crustal thinning and exhumation along a fossil magma-poor distal margin preserved in Corsica: A hot rift to drift transition?

Marco Beltrando [a,b,*], Ivan Zibra [c], Alessandra Montanini [d], Riccardo Tribuzio [e,f]

[a] Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso 35, 10125 Torino, Italy
[b] CNRS-EOST, Université de Strasbourg, 1 rue Blessig, 67084 Strasbourg Cedex, France
[c] Geological Survey of Western Australia, Dept. of Mines and Petroleum, 100 Plain Street, East Perth, East Perth, WA 6004, Australia
[d] Dipartimento di Fisica e Scienze della Terra, Università di Parma, Parco Area delle Scienze 157A, 43100 Parma, Italy
[e] Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy
[f] C.N.R.—Istituto di Geoscienze e Georisorse, Unità Operativa di Pavia, Via Ferrata 1, 27100 Pavia, Italy

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ABSTRACT

Rift-related thinning of continental basement along distal margins is likely achieved through the combined activity of ductile shear zones and brittle faults. While extensional detachments responsible for the latest stages of exhumation are being increasingly recognized, rift-related shear zones have never been sampled in ODP sites and have only rarely been identified in fossil distal margins preserved in orogenic belts. Here we report evidence of the Jurassic multi-stage crustal thinning preserved in the Santa Lucia nappe (Alpine Corsica), where amphibolite facies shearing persisted into the rift to drift transition. In this nappe, Lower Permian meta-gabbros to meta-gabbro-norites of the Mafic Complex are separated from Lower Permian granitoids of the Diorite–Granite Complex by a 100–250 m wide shear zone. Fine-grained syn-kinematic andesine + Mg-hornblende assemblages in meta-tonalites of the Diorite–Granite Complex indicate shearing at $T = 710 \pm 40$ °C at $P < 0.5$ GPa, followed by deformation at greenschist facies conditions. $^{40}Ar/^{39}Ar$ step-heating analyses on amphiboles reveal that shearing at amphibolite facies conditions possibly began at the Triassic–Jurassic boundary and persisted until $t < 188$ Ma, with the Mafic Complex cooling rapidly at the footwall of the Diorite–Granite Complex at ca. 165.4 ± 1.7 Ma.

Final exhumation to the basin floor was accommodated by low-angle detachment faulting, responsible for the 1–10 m thick damage zone locally capping the Mafic Complex. The top basement surface is onlapped at a low angle by undeformed Mesozoic sandstone, locally containing clasts of footwall rocks. Existing constraints from the neighboring Corsica ophiolites suggest an age of ca. 165–160 Ma for these final stages of exhumation of the Santa Lucia basement.

These results imply that middle to lower crustal rocks can be cooled and exhumed rapidly in the last stages of rifting, when significant crustal thinning is accommodated in less than 5 Myr through the consecutive activity of extensional shear zones and detachment faults. High thermal gradients may delay the switch from ductile shear zone- to detachment-dominated crustal thinning, thus preventing the exhumation of middle and lower crustal rocks until the final stages of rifting.

1. Introduction

The geometry of magma-poor rifted margins has been increasingly constrained in the last 20 years thanks to studies conducted along present day rifted margins (e.g. Afilhado et al., 2008; Espurt et al., 2012; Péron-Pinvidic and Manatschal, 2009; Whitmarsh and Wallace, 2001; Whitmarsh et al., 2001; Zhu et al., 2012) and fossil analogues (e.g. Froitzheim et al., 1994; Jammes et al., 2009; Manatschal, 2004). The resulting picture indicates that crustal thickness decreases from the proximal domain, affected by block faulting and limited crustal stretching, to the Zone of Exhumed Subcontinental Mantle, where continental crust is completely excised. Crustal thinning is accomplished within the distal continental margin, which generally consists of a 'necking zone', where crustal thickness decreases rapidly from ca. 25–30 km to ca. 10 km, followed oceanward by a wide area with <10 km thick crust (e.g. Mohn et al., 2012; Osmundsen and Ebbing, 2008).

Despite these significant advances, the dynamics of lithospheric thinning leading to the architecture described above are still poorly understood, since the large scale extensional structures commonly observed in distal margins are related to the final stages of deformation, characterized by low-angle detachment faulting (e.g. Froitzheim and

* Corresponding author at: Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso 35, 10125 Torino, Italy. Tel.: +39 6705110.
E-mail address: marco.beltrando@unito.it (M. Beltrando).

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Eberli, 1990; Jammes et al., 2009; Manatschal, 2004; Whitmarsh and Wallace, 2001). However, several lines of evidence suggest that extensional shear zones should play a key role in accommodating crustal thinning along distal continental margins, decoupling deformation at different crustal levels. Middle to lower crustal decoupling horizons have been advocated based on the bathymetric evolution of Atlantic-type distal margins (e.g. Dupré et al., 2007; Huismans and Beaumont, 2008; Kusznir and Karner, 2007), where wide regions of extremely attenuated crust are overlain by a thin shallow marine syn-rift sedimentary cover (e.g. Wilson et al., 2001). In these settings, transient isostatic support may be provided by greater thinning of the lower crust and upper mantle with respect to the upper crustal layers, leading to the anomalous shallow bathymetry (Brun and Beslier, 1996; Kusznir and Karner, 2007; Huismans and Beaumont, 2008, 2011). Middle crustal shear zones have also been proposed to account for the apparent lack of upper crustal deformation in the early rift stages despite significant bulk crustal thinning, possibly accommodated in the lower crust (Lavier and Manatschal, 2006). However, rift-related shear zones have only rarely been detected in fossil distal continental margins (Bissig and Hermann, 1999; Mohn et al., 2012). Therefore, the presence of crustal scale shear zones and their timing of activity with respect to the rifting and drifting evolution awaits to be tested with field studies on fossil margins preserved in orogenic belts and with future IODP's.

In this study we report evidence of multi-stage thinning and cooling of a crustal section from amphibolite facies conditions to the floor of the Western Tethys in the Mesozoic. Our results indicate that amphibolite-facies shear zones can still be active at the rift-to-drift transition and that significant crustal/lithospheric thinning and cooling can be achieved very rapidly at the edge of continental plates in the last stages of rifting.

2. Geological setting

The Santa Lucia nappe is located in the northern part of Corsica (France), in the Western Mediterranean area (Fig. 1). The island originally represented the south-western continuation of the Western Alps and of its European foreland (e.g. Molli, 2008), prior to counter-clockwise rotation that initiated at ca. 30 Ma (e.g. Speranza et al., 2002). The domain that largely escaped the Alpine tectonic reactivation is commonly referred to as 'Hercynian Corsica', since it consists of Carboniferous to Permian intrusives and volcanics (e.g. Paquette et al., 2003; Tribuzio et al., 2009). A North–South trending deformation zone, labeled Central Corsica Fault Zone (Maluski et al., 1973; Waters, 1990), with predominantly strike-slip kinematics separates Hercynian Corsica from 'Alpine Corsica', characterized by variable extents of Alpine deformation and metamorphism (Vitale Brovarone et al., 2013). Basement–cover

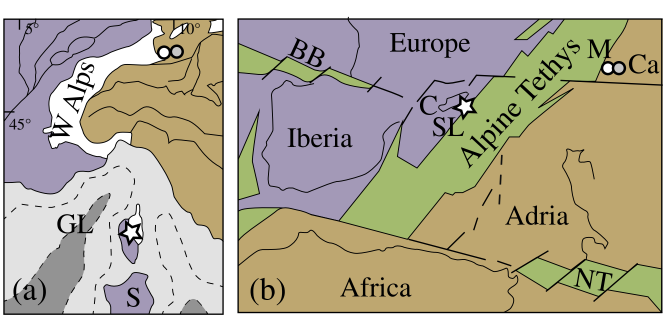

Fig. 1. (a) Tectonic sketch map of the NW Mediterranean area. Star marks the location of the Santa Lucia nappe (SL). White and gray circles indicate the location of the Malenco Unit (M) and Campo-Grosina units (Ca), respectively. (b) Paleogeographic reconstruction of the Western Tethys in the Early Cretaceous. GL = Gulf of Lion; S = Sardinia; C = Corsica; NT = Neo-Tethys; BB = Bay of Biscay.
Modified from Mohn et al. (2012).

relationships and comparisons with the Western Alps result in Jurassic paleogeographic reconstructions where the proximal European margin, represented by Hercynian Corsica, graded outboard into a transitional domain, now sampled in the Corte slices, Caporalino unit and Santa Lucia nappe, followed by an 'oceanic domain' (e.g. Rossi et al., 1994, 2006 and references therein). The latter mostly consisted of serpentinized lithospheric mantle overlain by pillow lavas, Middle-Upper Jurassic cherts and, locally, slivers of allochthonous continental basement (Vitale Brovarone et al., 2011, 2013).

2.1. The Santa Lucia nappe

The Santa Lucia nappe (Fig. 2) is bounded to the west by the Corte slices, to the north by the Caporalino unit (Puccinelli et al., 2012) and to the east and south by the Inzecca unit, which originated from the lithosphere flooring the Jurassic Tethys (Amaudric Du Chaffaut et al., 1972). The Santa Lucia nappe consists of Paleozoic continental basement and Mesozoic sediments. Several sub-units, bounded by steep NS-trending tectonic contacts, may be recognized. In this study, the different sub-units will be referred to as:

(1) the Granitic Complex, mainly consisting of Hbl- to Bt-bearing tonalites and of two-mica microgranitoids (Zibra, 2006);
(2) the Belli Piani unit, which consists of Permian meta-gabbros to meta-gabbro-norites belonging to the Mafic Complex and of Permian diorites, tonalites and granites of the Diorite–Granite Complex (Paquette et al., 2003; Rossi et al., 2006; Zibra et al., 2010, 2012). This unit is separated from the Granitic Complex to the west by the Bocca di Civenti Shear Zone, while the eastern margin is marked by the high-angle Mandriola and Tomboni faults (Fig. 2);
(3) the Murato unit, consisting of meta-gabbro-norites from the Mafic Complex and Mesozoic sediments;
(4) the Tralonca unit, consisting of Mesozoic to Tertiary sediments (Tomboni conglomerate and Tralonca Flysch).

The Granitic Complex and the Belli Piani unit, which are exposed in the western part of the Santa Lucia nappe, experienced minor Alpine deformation and metamorphism, restricted to low-grade metamorphic veins and localized faulting. The Murato and Tralonca units, located in the eastern part, underwent a greater amount of Alpine overprint, resulting in large scale folding and thrusting at T ~ 300 °C (Vitale Brovarone et al., 2013; Zibra, 2006).

This study is mainly focused on the Mafic Complex and the Diorite–Granite Complex of the Belli Piani unit, where the low extent of Alpine overprint allows detailed investigation of the pre-Alpine tectonometamorphic evolution. The Mafic Complex, which corresponds to the 'Mafic Layered Intrusion' of Libourel (1985), consists of a 2–4 km thick sequence mostly made up of meta-gabbro-norites and minor meta-hornblendites, containing meta-pelitic septa (Fig. 2; Libourel, 1985, 1988). The base of the mafic sequence hosts slices of mantle rocks, reaching up to 50 m in thickness. Magmatic and sub-magmatic fabrics in the Mafic Complex were extensively overprinted by post-intrusion solid state deformation. Pervasive shear fabrics developed during multi-stage deformation under granulite facies conditions, with an early phase at $T = 850 \pm 50$ °C and $P = 0.7 \pm 0.1$ GPa followed by a second step at P ~ 0.5 GPa and T ~ 800 °C (Zibra et al., 2010). High-resolution U–Pb geochronology on zircons separated from meta-pelitic septa yielded three age clusters at ~280 Ma, 240 Ma and 190–160 Ma (Rossi et al., 2006). The oldest peak was interpreted to date the granulite facies metamorphism induced by the mafic intrusion (Rossi et al., 2006). Sm–Nd analyses on a metapelite yielded a plagioclase–garnet–whole rock isochron age of 195 ± 9 Ma, interpreted as indicating the onset of cooling of the Mafic Complex at T < 750–800 °C (Rossi et al., 2006).

The Diorite–Granite Complex consists of a magmatic suite of gabbro-dioritic to granitic composition. In the northernmost part of