

PREFACE

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Dynamics of collisional mountain ranges: a progress report on the Alps Special Issue on the results from the 14th Emile Argand Alpine Workshop, Sion 2019, Switzerland

Paola Manzotti^{1*}, Othmar Müntener², Stefan Schmid³ and Daniel Marty⁴

1 Introduction

This Special Issue of the Swiss Journal of Geosciences presents papers presented during the 14th Workshop on Alpine Geological Studies (Emile Argand Conference sponsored by EGU and supported by the University of Lausanne), a biannual meeting focused on Alpine geology held in Sion (Switzerland) in 2019 (Fig. 1). The conference was organised by Paola Manzotti (University of Lausanne, now Stockholm University) and Othmar Müntener (University of Lausanne) and benefited from the precious collaborations of many junior and senior researchers from the University of Lausanne, Switzerland. 110 scientists from 11 countries attended the meeting. The plenary session took place from September 4–6th and covered the following main topics: (a) lithospheric structures, plate motions, neotectonics, (b) geodynamic modelling of Alpine processes, (c) pre-Alpine lithospheric structures, (d) timing and rates of mountain building, and (e) eroding a mountain chain: from sedimentary archives to past glaciers. Several field excursions in the core of the Alps preceded and followed the plenary session (Fig. 2), receiving the enthusiastic participation of many researchers and stimulating fruitful discussions.

This Special Issue comprises 15 articles, with several contributions from junior researchers, and hereafter, we present a summary of the various research papers.

2 Ediacaran-Cambrian arc-magmatism

The basement units of the Alps are one of the best examples to illustrate the recycling of polyphase continental crust. The reconstruction of the early evolution of continental basement is challenging because the isotopic data of accessory minerals (i.e. zircon) is the only accurate memory of these episodes. New geochronological data from the Eastern Austroalpine Alps reveal two stages of continental arc-like magmatism during Ediacaran (500–520 Ma) and Cambrian (550–570 Ma) times in the continental crust of the Adriatic plate (Neubauer et al. 2020). These data are tentatively linked to the Cambrian (550–570 Ma) continental arc-type magmatism and potential oceanic lithosphere of Proto-Tethyan affinity, which is also preserved in the Austroalpine domain. A nearly-uniform 2.1–2.5 Ga signature of detrital zircons in metasediments from the same domain suggests Lower Proterozoic continental crust as a source and shows relationships to northern Gondwana especially West Africa and Amazonia. The zircon Hf isotopic compositions of metagranites in the Eastern Alps also indicates recycling of older continental crust (Yuan et al. 2020).

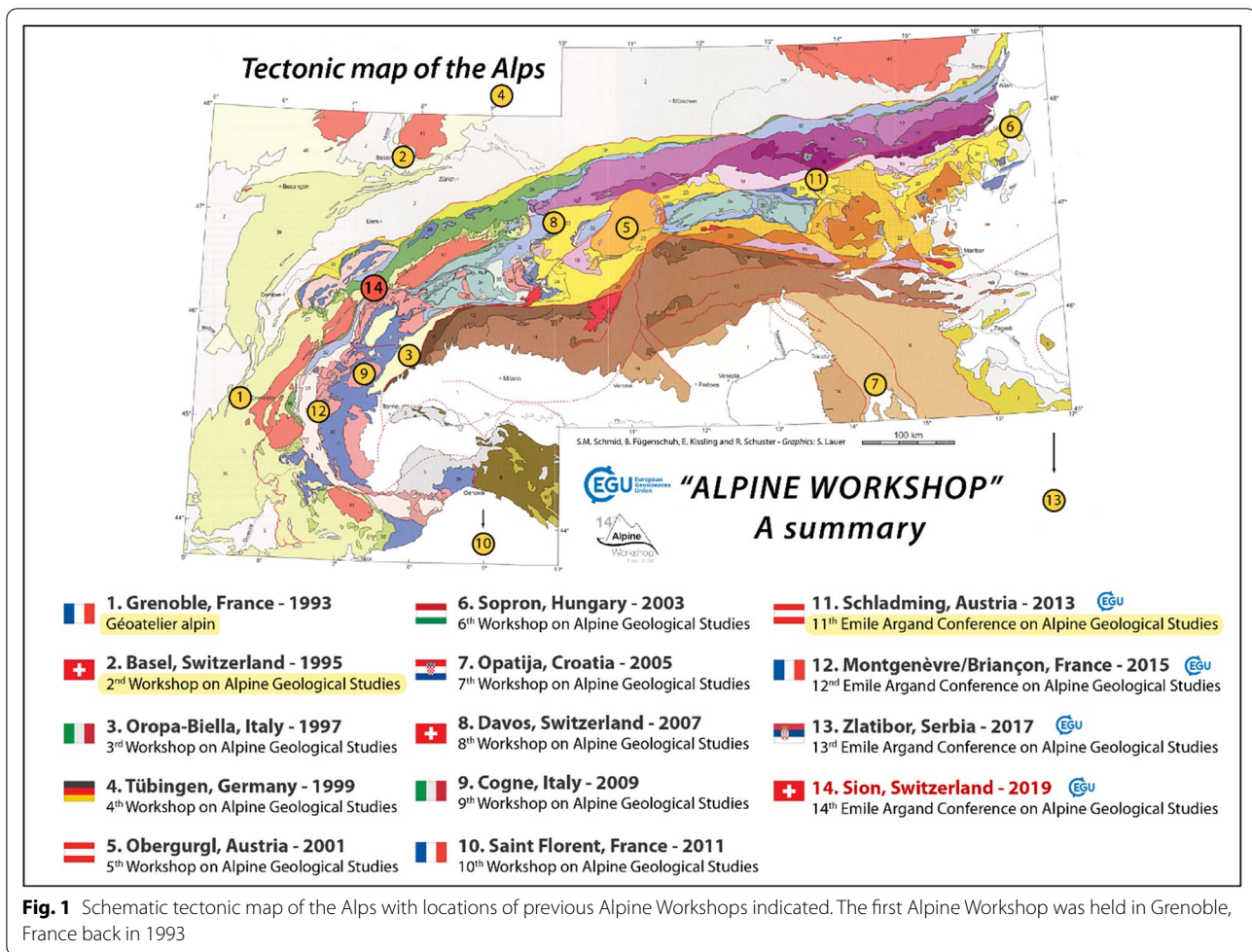
3 Permian crustal differentiation

Partial melting in the asthenosphere and in the lower crust and the ascent of mafic and silicic magmas emplaced at different crustal levels are among the main processes leading to crustal differentiation in Southern Europe during the Permian. Widespread magmatic activity accompanied by high-temperature metamorphism affected the Alpine realm during Permian time and is

*Correspondence: paola.manzotti@geo.su.se

¹ Department of Geological Sciences, Stockholm University, 106 91 Stockholm, Sweden

Full list of author information is available at the end of the article



preserved in both the Adriatic and European domains. The Permian age of these crust-forming processes and their geochemical signatures have been constrained in the Austroalpine domain (Pohorje Mountains: Chang et al. 2020; Grobgneis complex: Yuan et al. 2020), in the Sesia-Dent Blanche nappes (Who et al. 2020), in the Briançonnais domain (Ballèvre et al. 2020) as well as in Corsica, Sardinia and Calabria (Di Rosa et al. 2020; Molli et al. 2020). In a few cases, Triassic ages on allanite (Sesia: Who et al. 2020; Corsica: Di Rosa et al. 2020) have been interpreted as potential records of further metasomatic/magmatic episodes during late Triassic extension.

4 Inherited pre-Alpine structures

The Permian crustal differentiation was associated with an extensional/transcurrent regime responsible for the development of large-scale (i.e. hundreds of km long) faults (e.g. Santa Lucia Fault in Corsica and East Tuscan Fault in Central Italy: Molli et al. 2020). During the Jurassic period, normal faulting is recorded in the brittle upper crust, especially along the internal margin of the Briançonnais domain. Faulting is associated to erosion of uplifted blocks, leading to syn-tectonic erosion providing abundant material deposited in the nearby sedimentary basins (Pantet et al. 2020).

(See figure on next page.)

Fig. 2 Field excursions are an essential part of the Alpine Workshops, allowing direct scientific exchanges between participants in front of the studied rocks and structures, and building a common heritage to young researchers. Examples shown here are **a** evidence for syndimentary record of extensional faulting in the Jurassic palaeomargin (led by A. Pantet, J.-L. Epard and L. Cardello), **b** nappe stacking and exhumation history in the core of the Alpine belt (led by P. Manzotti and M. Ballèvre), and **c** Jurassic magmatism, mantle exhumation and sedimentation in an ultra-slow spreading system (led by T. Decrausaz and O. Müntener)



5 Age and architecture of the Alpine ophiolites

Alpine ophiolites of the Piemonte-Liguria Ocean result from the mid-Jurassic breakup of the thinned continental crust and represent ancient analogues to present day (ultra)-slow spreading environments such as the Southwest Indian ridge. In the Western Alps, Piemonte-Liguria ophiolites are made of dismembered slivers dominated by variably serpentinised mantle rocks with minor basaltic dykes and small gabbro intrusions (Decrausaz et al. 2021). New field, geochemical and isotopic data constrains the evolution of the Aiguilles Rouges Ophiolite in the Swiss Alps (Decrausaz et al. 2021). This area exceptionally exposes inherited seafloor sequences and the remnants of a large Jurassic (~155 Ma) gabbro body potentially exhumed by a Jurassic detachment fault. As observed in present-day (ultra-) slow-spreading seafloor, the Aiguilles Rouges Ophiolite preserves a segmented lithosphere with punctuated magmatism and carbonated ultramafic seafloor covered by basalts and Jurassic tectono-sedimentary deposits. Oceanic hydrothermal alteration affecting the exhumed mantle produced pervasive serpentinization and rodingitisation of mafic dykes as observed in several oceanic units in the Alps (e.g. Zermatt Zone, Kempf et al. 2020).

6 From oceanic subduction to crustal thickening

During the convergence of Eurasia and Adria, the fate of the Jurassic extensional faults was twofold: some were reactivated as thrusts by Alpine tectonics (Aiguilles Rouges d'Arolla Ophiolite, Decrausaz et al. 2021) whereas others were passively deformed without inversion and reactivation (Mont Fort nappe, Briançonnais domain, Pantet et al. 2020; eastern Aar Massif, Nibourel et al. 2021). The identification of faults that preserve their Jurassic rifting history is an important step in our understanding of the geometry of the Briançonnais palaeomargin.

Subduction and high-pressure metamorphism of some ophiolitic units was associated with dehydration reactions and fluid release. Indeed, in the Zermatt-Saas ophiolite, serpentine + brucite formed during Jurassic oceanic serpentinization reacted to produce metamorphic olivine at eclogite facies conditions (Kempf et al. 2020). Fluids released by this reaction (estimated between 3.4 and 7.2 wt% H₂O) escaped in a network of veins and shear zone.

More external continental domains of the Western Alps were buried at shallower depth (External Briançonnais, Ballèvre et al. 2020; Aar Massif, Nibourel et al. 2021). Lawsonite-bearing veins in the Guil andesites in the Queyras testify to a lower grade metamorphism (0.4 GPa, 350 °C) associated with a brittle deformation in the External Briançonnais (Ballèvre et al. 2020).

In the external domain of the Alps in the eastern Aar Massif, collisional deformation started with the activation of NNW-directed thrusts at ~26 Ma (Nibourel et al. 2021). Subsequent peak to post-metamorphic deformation was dominated by steep, NNW-vergent reverse faults (~22–14 Ma) and was associated with large vertical displacements. 13 km shortening and 9 km exhumation occurred between 14 Ma and present.

7 Exhumation of the nappe stack

Exhumation of Alpine nappes is accommodated by erosion, material transport and sediment deposition in the flysch sequences, analyzed in detail in one of the Pré-alpes nappes (Ragusa et al. 2021) and by displacement along km-scale Alpine faults (e.g. the Susa Shear Zone, Ghignone et al. 2020; the Rocca Canavese Thrust Sheets, Roda et al. 2021).

Cenozoic tectonic activity during unroofing of the Western Alps was active for more than 20 million years and was linked to top-NNW, top-WNW and top-SW thrusting in association with strike-slip faulting. Its timing is constrained by new geochronological data (~36 Ma, ~32–30 Ma, and ~25–23 Ma) on hydrothermal monazite in fissures formed during greenschist to amphibolite facies retrograde metamorphism in the high-pressure units of the internal Western Alps (Ricchi et al. 2020).

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Authors' contributions

The paper has been written by all authors. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Author details

¹ Department of Geological Sciences, Stockholm University, 106 91 Stockholm, Sweden. ² Institute of Earth Sciences, University of Lausanne, 1015 Géopolis-Lausanne, Quartier Mouline, Switzerland. ³ Institute of Geophysics, ETH Zurich, 8092 Zurich, Switzerland. ⁴ Naturhistorisches Museum Basel, Augustinerstrasse 2, 4001 Basel, Switzerland.

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