Data Repository for Subduction initiation without magmatism: The case of the missing Alpine magmatic arc, Anders McCarthy, Cyril Chelle-Michou, Othmar Müntener, Richard Arculus, Jon Blundy

Contents:

Supplementary Methods for Detrital Zircon Treatment

Zircon U-Pb data from 129 Triassic to Quaternary detrital samples were compiled from available sources (See supplementary references below). When data table were not attached to the publications authors were contacted and kindly provided them. The $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$, $^{207}Pb/^{206}Pb$ and concordia dates for each analysis were computed with IsoplotR (Vermeesch, 2018).
The percentage of concordance was estimated based on the two U-Pb dates as $100\times(^{206}Pb/^{238}U\times^{207}Pb/^{235}U)$. This approach is more relevant for Cenozoic to Mesozoic dates (which are the focus of this study) than the commonly used percentage of concordance defined as $100\times(^{206}Pb/^{238}U\times^{207}Pb/^{206}Pb)$. This is because for such young dates, very small variations of the $^{207}Pb/^{206}Pb$ ratio causes very large variation of the $^{207}Pb/^{206}Pb$ date such that perfectly concordant zircon (i.e., overlap with the concordia) would be identified as excessively discordant using a common discordance criteria of 10%. We considered a strict concordance threshold of 95–105%. Out of 12524 analyses, 9268 passed the concordance test. The $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ dates were considered for analysis younger and older than 1200 Ma, respectively. Kernel density estimates of the "concordant" population was plotted with DensityPlotter (Vermeesch, 2012).

Zircon U-Pb Metholodogy References

Vermeesch P., (2012), On the visualisation of detrital age distributions: Chemical Geology, 312-313, 190–194, doi: 10.1016/j.chemgeo.2012.04.021.

Vermeesch P., (2018), IsoplotR: a free and open toolbox for geochronology: Geoscience Frontiers, doi: 10.1016/j.gsf.2018.04.001.

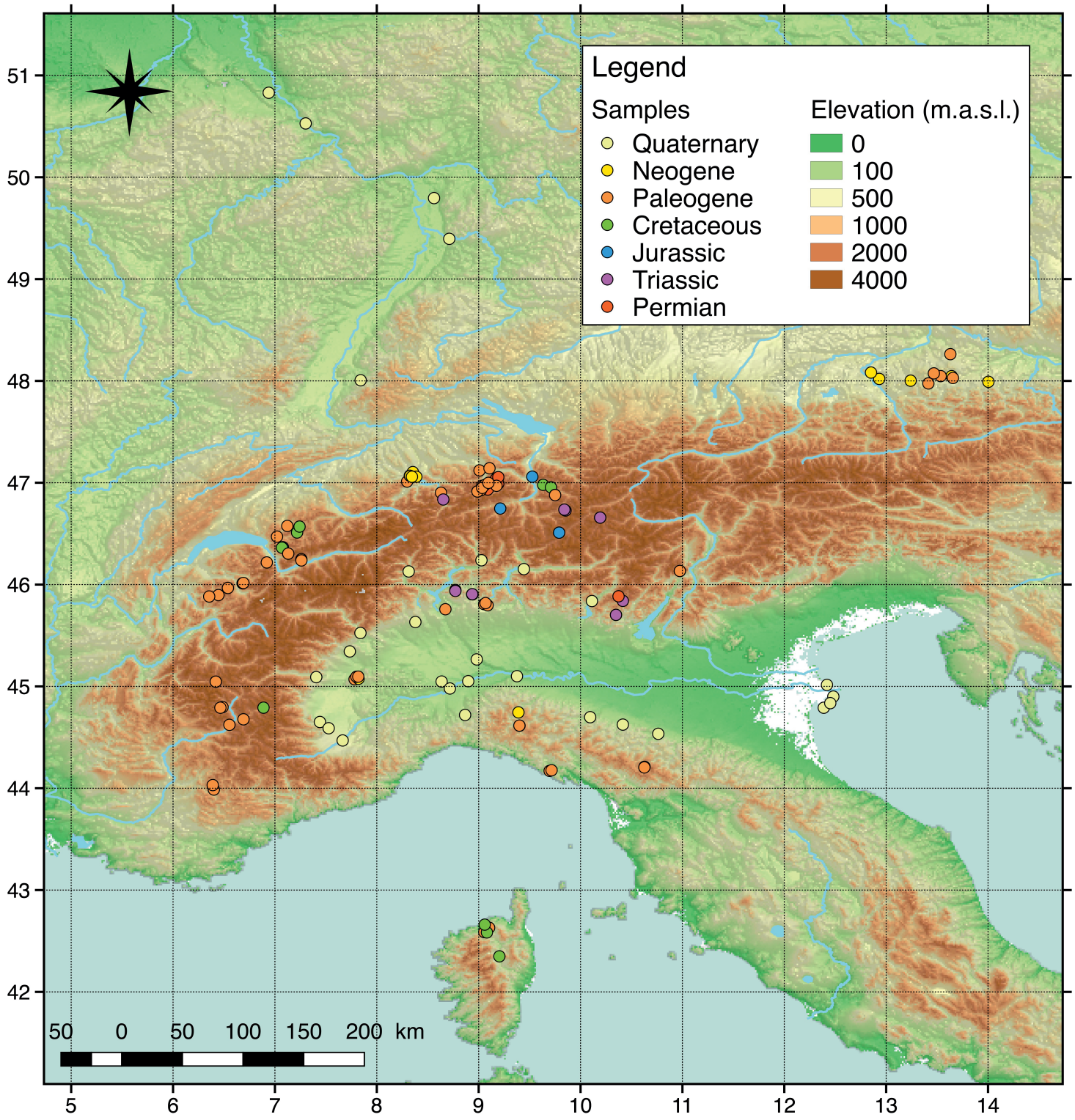

Fig. DR1: Map of the European Alps and Apennines showing the locations of samples used for detritial zircon analysis (see References sections in appendix). Note that Quaternary to Paleogene samples are sampled from all major watersheds: Rhône, Rhine, Po and Danub watersheds.

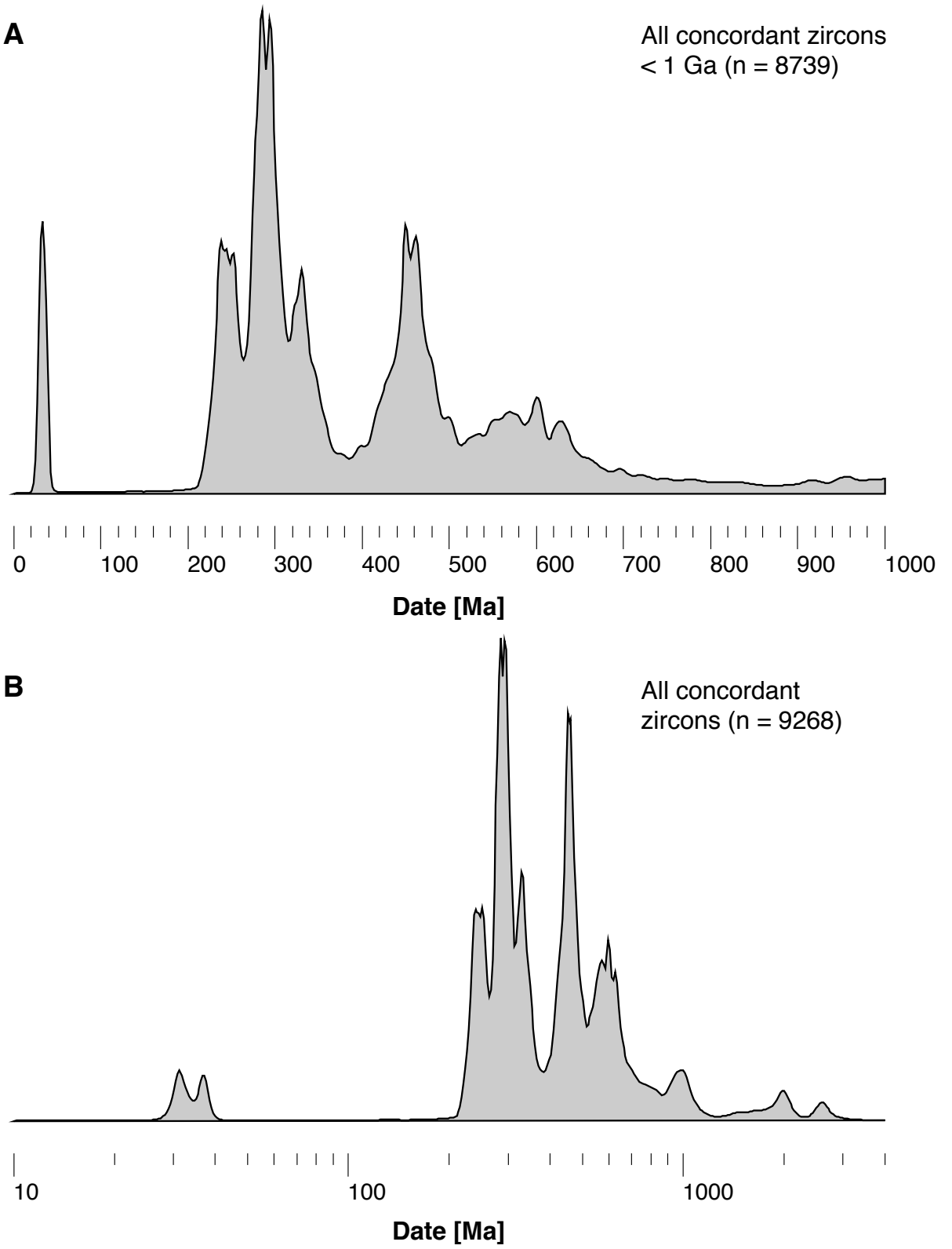

Fig. DR2: Detrital zircon U–Pb date distribution for (A) grains younger than 1 Ga and (B) all grains (note the log scale).

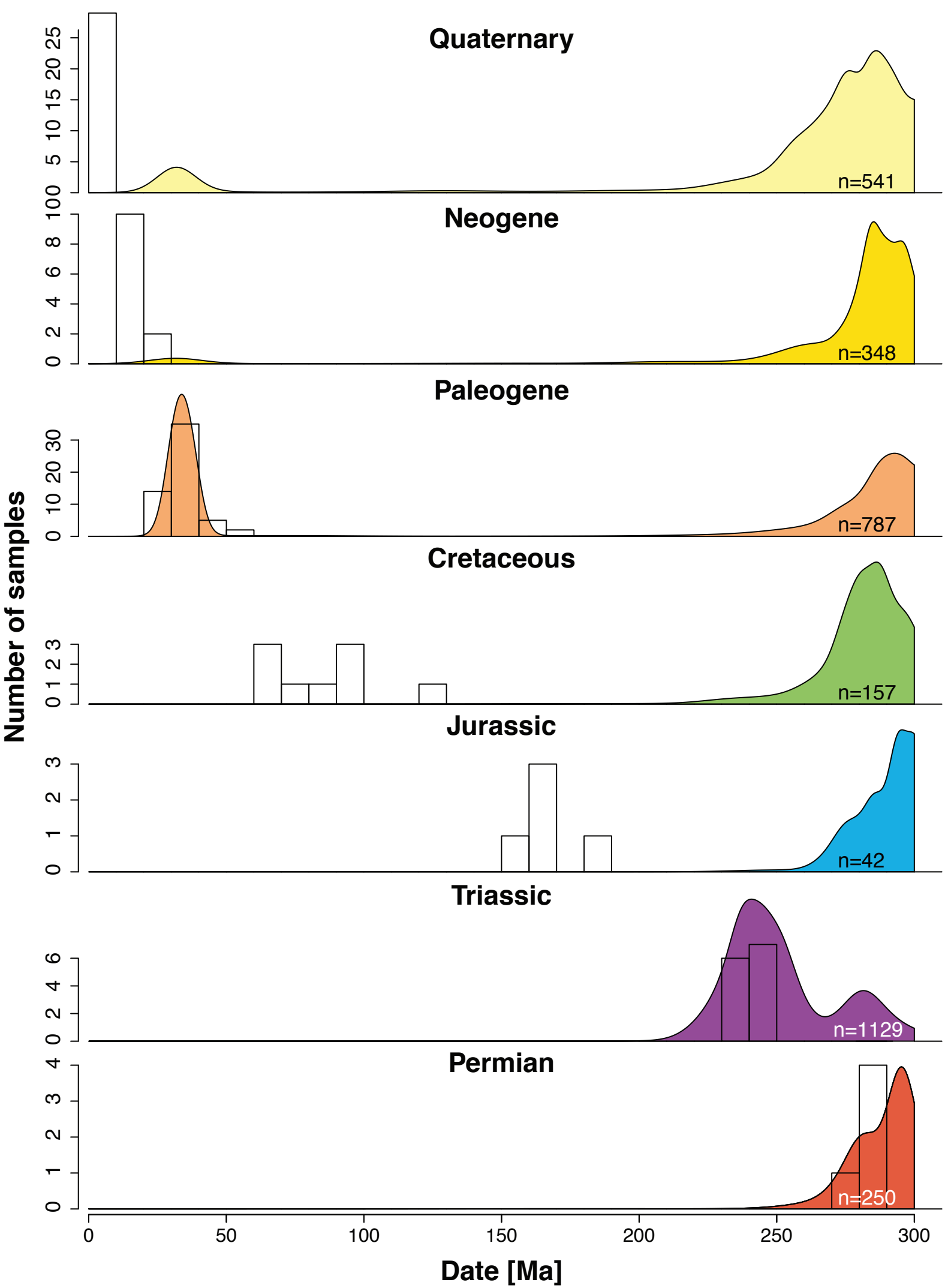

Fig.DR3: Detrital zircon U–Pb date distribution (colored curves) compared to depositional age (white histograms) from Permian (bottom) to Present (Top).

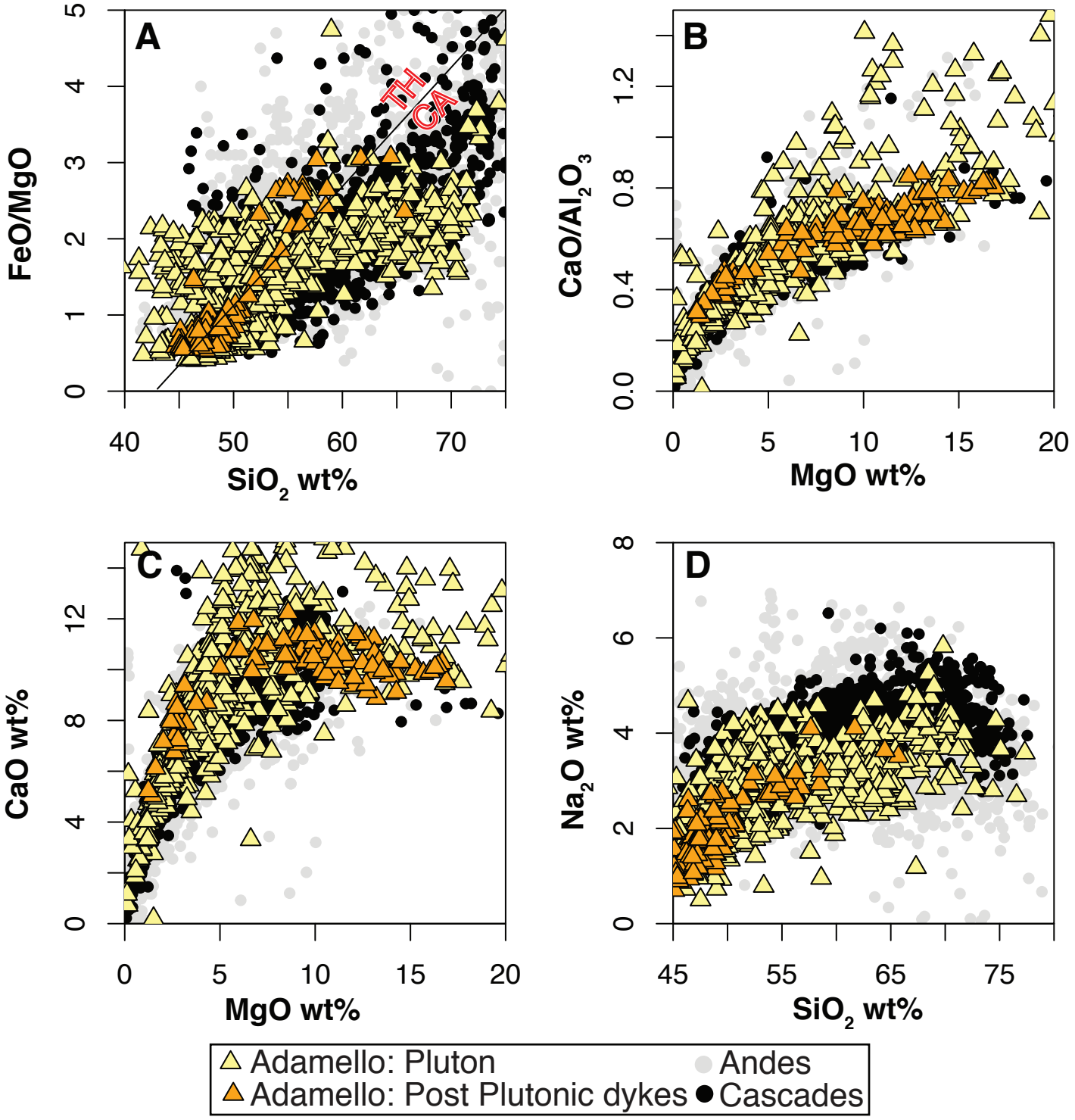

Fig. DR4: Geochemical plots showing the compositional evolution of the Adamello Pluton and post-plutonic dykes compared to the Andes (GEOROC - Geochemical database: n = 13912 volcanic rocks) and Cascades (n = 1679 published volcanic rocks). A: FeO*/MgO vs SiO_2 wt% of Myashiro (1974) showing the arc tholeiitic (TH) to low-Fe «calc-alkaline» (CA) compositional trends of the Adamello Pluton; B-D: CaO/Al_2O_3 and CaO wt% vs MgO wt% and Na_2O wt% vs SiO_2 wt%. Adamello post-plutonic dykes from Hürlimann *et al.,* (2016). Adamello pluton compilation (n = 675) includes the composition of granitoids-tonalites-diorites-gabbros (authors' unpublished data) and data from Macera *et al.,* (1985) and Blundy and Sparks (1992)

Supplementary References for Figures 2 to 4

Figure 2 Subduction initiation:

Data for the Alps include papers cited in the manuscript and :

Zanchetta, S., Garzanti, E., Doglioni, C., Zanchi, A., (2012) The Alps in the Cretaceous: a doubly vergent pre‐collisional orogen. *Terra Nova*, 24(5), 351-356.

Regis, D., Rubatto, D., Darling, J., Cenki-Tok, B., Zucali, M., Engi, M., (2014) Multiple metamorphic stages within an eclogite-facies terrane (Sesia Zone, Western Alps) revealed by Th–U–Pb petrochronology. *Journal of Petrology*, 55(7), 1429-1456.

Rubatto, D., Regis, D., Hermann, J., Boston, K., Engi, M., Beltrando, M., McAlpine, S.R., (2011) Yo-yo subduction recorded by accessory minerals in the Italian Western Alps. *Nature Geoscience*, 4(5), 338-342.

Skora, S., Lapen, T.J., Baumgartner, L.P., Johnson, C.M., Hellebrand, E. and Mahlen, N.J., (2009) The duration of prograde garnet crystallization in the UHP eclogites at Lago di Cignana, Italy. *Earth and Planetary Science Letters*, 287(3-4), 402-411.

Data from the western Pacific and Neotethys papers cited in the manuscript and:

Arculus, R.J., et al., (2015)**,** A record of spontaneous subduction initiation in the Izu-Bonin-Mariana arc: *Nature Geoscience*, v. 8, p. 728–733,

Ishizuka, O., Tani, K., Reagan, M.K., Kanayama, K., Umino, S., Harigane, Y., Sakamoto, I., Miyajima, Y., Yuasa, M., Dunkley, D.J., (2011) The timescales of subduction initiation and subsequent evolution of an oceanic island arc. *Earth and Planetary Science Letters*, 306(3), 229-240.

Ishizuka, O., Hickey-Vargas, R., Arculus, R.J., Yogodzinski, G.M., Savov, I.P., Kusano, Y., McCarthy, A., Brandl, P.A., Sudo, M., (2018) Age of Izu–Bonin–Mariana arc basement. *Earth and Planetary Science Letters*, 481, 80-90.

Reagan, M.K., Ishizuka, O., Stern, R.J., Kelley, K.A., Ohara, Y., Blichert‐Toft, J., Bloomer, S.H., Cash, J., Fryer, P., Hanan, B.B. and Hickey-Vargas, R., (2010) Fore-arc basalts and subduction initiation in the Izu‐Bonin‐Mariana system. *Geochemistry, Geophysics, Geosystems*, 11(3).

Searle, M.P., Cherry, A.G., Ali, M.Y., Cooper, D.J., (2014) Tectonics of the Musandam Peninsula and northern Oman Mountains: From ophiolite obduction to continental collision. *GeoArabia*, 19(2), 135-174.

Rollinson, H., (2015) Slab and sediment melting during subduction initiation: granitoid dykes from the mantle section of the Oman ophiolite. *Contributions to Mineralogy and Petrology*, 170(3):32.

MacLeod, C.J., Johan Lissenberg, C., Bibby, L.E., (2013) "Moist MORB" axial magmatism in the Oman ophiolite: the evidence against a mid-ocean ridge origin. *Geology*, 41(4), 459-462.

Maffione, M., Thieulot, C., van Hinsbergen, D. J. J., Morris,A., Plumper, O., Spakman, W., (2015)a Dynamics of intra-oceanic subduction initiation. 1: Oceanic detachment fault inversion and the formation of forearc ophiolites. *Geochemistry, Geophysics, Geosystems*, doi:10.1002/2015GC005746.

Maffione, M., Van Hinsbergen, D.J., Koornneef, L.M., Guilmette, C., Hodges, K., Borneman, N., Huang, W., Ding, L., Kapp, P., (2015)b Forearc hyperextension dismembered the south Tibetan ophiolites. *Geology*, 43(6), 475-478.

Maffione, M., Hinsbergen, D.J., Gelder, G.I., Goes, F.C. and Morris, A., (2017) Kinematics of Late Cretaceous subduction initiation in the Neo‐Tethys Ocean reconstructed from ophiolites of Turkey, Cyprus, and Syria. *Journal of Geophysical Research: Solid Earth,* 122(5), 3953-3976.

Guilmette, C., Smit, M., Van Hinsbergen D., Gurer, D., Corfu F., Maffione, M., Savard, (2018) Forced subduction initiation in Oman revealed by ophiolite-sole couple geochronology, *EGU Abstract EGU2018-10723, EGU General Assembly 2018, Vienna*

.

Figure 3: Alpine Compilation:

(Post-)Variscan Magmatism

Beltrando M., Rubatto D., Compagnoni R., Lister G., (2007) Was the Valaisan basin floored by oceanic crust? Evidence of Permian magmatism in the Versoyen Unit (Valaisan domain, NW Alps). Ofioliti, 32, 85-99.

Berra F., Tiepolo M., Caironi V., Siletto G.B., (2015) U–Pb zircon geochronology of volcanic deposits from the Permian basin of the Orobic Alps (Southern Alps, Lombardy): chronostratigraphic and geological implications. *Geological Magazine,* 152, 429-443.

Bussy F., Cadoppi P., (1996) U-Pb zircon dating of granitoids from the Dora-Maira massif (western Italian Alps). *Schweizerische Mineralogische und Petrographische Mitteilungen*, 76, 217-233.

Brack P., Muttoni G., (2000) High-resolution magnetostratigraphic and lithostratigraphic correlations in Middle Triassic pelagic carbonates from the Dolomites (northern Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 161, 361-380.

Cocherie A., Rossi Ph., Fanning C.M., Guerrot C., (2005) Comparative use of TIMS and SHRIMP for U–Pb zircon dating of A-type granites and mafic tholeiitic layered complexes and dykes from the Corsican Batholith (France). *Lithos*, 82, 185-219.

Dallagiovanna G., Gaggero L., Maino M., Seno S., Tiepolo M., (2009) U-Pb zircon ages for post-Variscan volcanism in the Ligurian Alps (Northern Italy). *Journal of the Geological Society,* 166, 101-114.

Dal Piaz G.V., De Vecchi Gp., Hunziker J.C., (1977) The austroalpine layered gabbros of the Matterhorn and Mt. Collon - Dents de Bertol. *Schweizerische Mineralogische und Petrographische Mitteilungen*, 57, 59-88.

Galli A., Le Bayou B., Schmidt M.W., Burg J-P., Reusser E., Sergeev S.A., Larionov A., (2012) U–Pb zircon dating of the Gruf Complex: disclosing the late Variscan granulitic lower crust of Europe stranded in the Central Alps. *Contributions to Mineralogy and Petrology*, 163, 353-378.

Henk A., Franz L.T.S., Oncken O., (1997) Magmatic underplating, extension and crustal reequilibration: insight from a cross section through the Ivrea Verbano Zone and Serie del Laghi. N.W. Italy. *The Journal of Geology*, 105, 367-377.

Maino M., Dallagiovanna G., Gaggero L., Seno S., Tiepolo M., (2012) U–Pb zircon geochronological and petrographic constraints on late to postcollisional Variscan magmatism and metamorphism in the Ligurian Alps, Italy. *Geological Journal*, 47, 632-652.

Marocchi M., Morelli C., Mair V., Klötzli U., Bargossi G.M., (2008) Evolution of large silicic magma systems: new U-Pb zircon data on the NW Permian Athesian Volcanic group (Southern Alps, Italy). *The Journal of Geology,* 116, 480-498.

Marroni M., Tribuzio R., (1996) Gabbro-derived granulites from external Liguride units (northern Apennine, Italy): implications for the rifting processes in the western Tethys. *International Journal of Earth Sciences (Geologische Rundschau),* 85(2), 239-249.

Mayer A., Mezger K., Sinigoi S., (2000) New Sm-Nd ages for the Ivrea-Verbano Zone, Sesia and Sessera valleys (Northern-Italy). *Journal of Geodynamics*, 30, 147-166.

Monjoie P., Bussy F., Schaltegger U., Mulch A., Lapierre H., Pfeifer H-R., (2007) Contrasting magma types and timing of intrusion in the Permian layered mafic complex of Mont Collon (Western Alps,Valais, Switzerland): evidence from U/Pb zircon and 40Ar/39Ar amphibole dating*. Swiss Journal of Geoscience*, 100, 125-135.

Mulch A., Rosenau M., Dörr W., Handy M.R., (2002) The age and structure of dikes along the tectonic contact of the Ivrea-Verbano and Strona-Ceneri Zones (Southern Alps, Northern Italy, Switzerland). *Schweizerische Mineralogische und Petrographische Mitteilungen,* 82(1), 55-76.

Mundil R., Brack P., Meier M., Rieber H., Oberli F., (1996) High resolution UPb dating of Middle Triassic volcaniclastics: Time-scale calibration and verification of tuning parameters for carbonate sedimentation. *Earth and Planetary Science Letters,* 141, 137-151.

Paquette J-L., Ménot R-P., Pin C., Orsini J-B., (2003) Episodic and short-lived granitic pulses in a post-collisional setting: evidence from precise U–Pb zircon dating through a crustal cross-section in Corsica. *Chemical Geology,* 198, 1-20.

Peressini G., Quick J.E., Sinigoi S., Hoffmann A.W., Fanning M., (2007) Duration of a large mafic intrusion and heat transfer in the lower crust: a SHRIMP U-Pb zircon study in the Ivrea-Verbano Zone (Western Alps, Italy). *Journal of Petrology*, 50, 1-34.

Petra V., Frank S., Friedrich F., (2011) Magmato-sedimentary Carboniferous to Jurassic evolution of the western Tauern window, Eastern Alps (constraints from U-Pb zircon dating and geochemistry). *International Journal of Earth Sciences (Geologische Rundschau)*, 100, 993-1027.

Petri B., Mohn G., Skrzypek E., Mateeva T., Galster F., Manatschal G., (2017) U–Pb geochronology of the Sondalo gabbroic complex (Central Alps) and its position within the Permian post-Variscan extension. *International Journal of Earth Sciences (Geologische Rundschau)*, 106(8), 2873-2893.

Poitrasson F., Pin C., Duthou J-L., (1994) The size-isotopic evolution connection among layered mafic intrusions: Clues from a Sr-Nd isotopic study of a small complex. *Journal of Geophysical Research*, 99, B5, 9441-9451.

Quick J.E., Sinigoi S., Peressini G., Demarch G., Wooden J.L., Sbisà A., (2009) Magmatic plumbing of a large Permian caldera exposed to a depth of 25 km. Geology, 7; 603-606.

Renna M.R., Tribuzio R., Tiepolo M., (2007) Origin and timing of the post-Variscan gabbro–granite complex of Porto (Western Corsica). *Contribution to Mineralogy and Petrology,* 151, 493-517.

Romer R.L., Schärer U., Steck A., (1996) Alpine and pre-Alpine magmatism in the root-zone of the western Central Alps. *Contributions to Mineralogy and Petrology*, 123, 138-158.

Schaltegger U., Gebauer D., (1999) Pre-Alpine geochronology of the Central, Western and Southern Alps. *Schweizerische Mineralogische und Petrographische Mitteilungen.* 79, 79-87.

Schaltegger, U., Ulianov, A., Müntener, O., Ovtcharova, M., Peytcheva, I., Vonlanthen, P., Vennemann, T., Antognini, M. and Girlanda, F., (2015) Megacrystic zircon with planar fractures in miaskite-type nepheline pegmatites formed at high pressures in the lower crust (Ivrea Zone, southern Alps, Switzerland). *American Mineralogist*, 100(1), 83-94.

Tribuzio R., Thirlwall M.F., Messiga B., (1999) Petrology, mineral and isotope geochemistry of the Sondalo gabbroic complex (Central Alps, Northern Italy): implications for the origin of post-Variscan magmatism. *Contribution to Mineralogy and Petrology,* 136, 48-62.

Vavra G., Gebauer D., Schmid R., Compston W., (1996) Multiple zircon growth and recrystallization during polyphase Late Carboniferous to Triassic metamorphism in granulites of the Ivrea Zone (Southern Alps): an ion microprobe (SHRIMP) study. *Contributions to Mineralogy and Petrology*, 122, 337-358.

Villa I.M., Hermann J., Müntener O., Trommsdorf V., (2000) ^{39}Ar-^{40}Ar dating of multiply zoned amphibole generations (Malenco, Italy Alps). *Contributions to Mineralogy and Petrology*, 140, 363-381.

<u>Oceanic Magmatism</u>

Bill M., Bussy F., Cosca M., (1997) High-precision U-Pb and ^{40}Ar/^{39}Ar dating of an Alpine ophiolite (Gets nappe, French Alps). *Eclogae Geologicae Helvetiae*, 90, 43-54.

Borsi L., Schärer U., Gaggero L., Crispini L., (1996) Age, origin and geodynamic significance of plagiogranites in lherzolites and gabbros of the Piedmont-Ligurian ocean basin. *Earth and Planetary Science Letters*, 140, 227-241.

Costa S., Caby R., (2001) Evolution of the Ligurian Tethys in the Western Alps: Sm/Nd and U/Pb geochronology and rare-earth element geochemistry of the Montgenèvre ophiolite (France). *Chemical Geology*, 175, 449-466.

Kaczmarek M.-A., Müntener O., Rubatto D., (2008) Trace element chemistry and U–Pb dating of zircons oceanic gabbros and their relationship with whole rock composition (Lanzo, Italian Alps). *Contributions to Mineralogy and Petrology,* 155, 295-312.

Lombardo B., Rubatto D., Castelli D., (2002) Ion microprobe U–Pb dating of zircon from a Monviso metaplagiogranite: implications for the evolution of the Piedmont–Liguria Tethys in the Western Alps. *Ofioliti,* 27(2), 109-117.

Li X.H., Faure M., Rossi P., Lin W., Lahondère D., (2015) Age of Alpine Corsica ophiolites revisited: Insights from in situ zircon U–Pb age and O–Hf isotopes. *Lithos*, 220, 179-190.

Liati A., Froitzheim N., (2006) Assessing the Valais ocean, Western Alps: U–Pb SHRIMP zircon geochronology of eclogite in the Balma unit, on top of the Monte Rosa nappe. *European Journal of Mineralogy,* 18(3), 299–308

Liati A., Gebauer D., Fanning C.M., (2003) The youngest basic oceanic magmatism in the Alps (Late Cretaceous; Chiavenna unit, Central Alps): geochronological constraints and geodynamic significance. *Contributions to Mineralogy and Petrology*, 146, 144-158.

Manatschal G., Engstrom A., Desmurs L., Schaltegger U., Cosca M., Müntener O., Bernoulli D., (2006) What is the tectono-metamorphic evolution of continental break-up: the example of the Tasna Ocean–Continent Transition. *Journal of Structural Geology,* 28(10), 1849-1869.

McCarthy A., Müntener O., (2015) Ancient depletion and mantle heterogeneity: Revisiting the Permian- Jurassic paradox of Alpine peridotites. *Geology*, 43(3), 255-258.

Ohnenstetter M., Ohnenstetter D., Vidal Ph., Cornichet J., Hermitte D., Mace J., (1981) Crystallization and age of zircon from Corsican ophiolitic albitites: consequences for oceanic expansion in Jurassic times. *Earth and Planetary Science Letters*, 54, 397-408.

Peters Tj., Stettler A., (1987) Radiometric age, thermobarometry and mode of emplacement of the Totalp periodite in the Eastern Swiss Alps. *Schweizerische Mineralogische und Petrographische Mitteilungen,* 67, 285-294.

Rubatto D., Gebauer D., Fanning M., (1998) Jurassic formation and Eocene subduction of the Zermatt-Saas-Fee ophiolites: implications for the geodynamic evolution of the Central and Western Alps. *Contributions to Mineralogy and Petrology*, 132, 269-287.

Rubatto D., Hermann J., (2003) Zircon formation during fluid circulation in eclogites (Monviso, Western Alps): implications for Zr and Hf budget in subduction zones. *Geochimica et Cosmochimica Acta*, 67, 2173-2187.

Rampone E., Hofmann A.W., Raczek I., (1998) Isotopic contrasts within the Internal Liguride ophiolite (N. Italy): the lack of a genetic mantle–crust link. *Earth and Planetary Science Letters,* 163, 175-189.

Renna, M.R., Tribuzio, R., Sanfilippo, A. and Tiepolo, M., (2017) Zircon U–Pb geochronology of lower crust and quartzo-feldspathic clastic sediments from the Balagne ophiolite (Corsica). *Swiss Journal of Geosciences*, 110(2),479-501.

Rubatto D., Müntener O., Barnhoorn A., Gregory C.J., (2008) Dissolution–precipitation of zircon at low-temperature, high-pressure conditions (Lanzo Massif, Italy). *American Mineralogist*, 93(10), 1519-1529.

Rubatto D., Scambelluri M., (2003) U–Pb dating of magmatic zircon and metamorphic baddeleyite in the Ligurian eclogites (Voltri Massif, Western Alps). *Contributions to Mineralogy and Petrology,* 146, 341-355.

Schaltegger U., Desmurs L., Manatschal G., Müntener O., Meier M., Frank M., Bernoulli D., (2002) The transition from rifting to sea-floor spreading within a magma-poor rifted margin: field and isotopic constraints. *Terra Nova*, 14, 156-167.

Tribuzio R., Thirlwall M.F., Vannucci R., (2004) Origin of the gabbro-peridotite association from the Northern Apennine ophiolites (Italy). *Journal of Petrology*, 45, 1109-1124.

Tribuzio, R., Garzetti, F., Corfu, F., Tiepolo, M., Renna, M.R., (2016) U–Pb zircon geochronology of the Ligurian ophiolites (Northern Apennine, Italy): Implications for continental breakup to slow seafloor spreading. *Tectonophysics*, 666, 220-243.

<u>(Post-)Collisional Magmatism</u>

Berger A., Thomsen T.B., Ovtcharova M., Kapferer N., Mercolli I., (2012) Dating emplacement and evolution of the orogenic magmatism in the internal Western Alps: 1. The Miagliano Pluton. *Swiss Journal of Geosciences*, 105(1), 49-65.

Bergomi M.A., Zanchetta S., Tunesi A., (2015) The Tertiary dike magmatism in the Southern Alps: geochronological data and geodynamic significance. *International Journal of Earth Sciences (Geologische Rundschau)*, 104, 449-473.

Blundy, J.D., Sparks, R.S.J. (1992) Petrogenesis of mafic inclusions in granitoids of the Adamello Massif, Italy. *Journal of Petrology*, 33, 1039–1104.

Boyet M., Lapierre H., Tardy M., Bosch D. & Maury R., (2001) Nature des composants andésitiques des Grès du Champsaur et des Grès de Taveyannaz. Implications dans l'évolution des Alpes occidentales au Paléogène. *Bulletin de la Société géologique de France*, 172(4), 487-501.

Broderick C., Wotzlaw J.F., Frick D.A., Gerdes A., Ulianov A., Günther D., Schaltegger U., (2015) Linking the thermal evolution and emplacement history of an upper-crustal pluton to its lower-crustal roots using zircon geochronology and geochemistry (southern Adamello batholith, N. Italy). *Contributions to Mineralogy and Petrology*, 170, 28.

D'Adda P., Zanchi A., Bergomi M., Berra F., Malusà M.G., Tunesi A., Zanchetta S., (2011) Polyphase thrusting and dyke emplacement in the central Southern Alps (Northern Italy). *International Journal of Earth Sciences (Geologische Rundschau)*, 100, 1095-1113.

Féraud G., Ruffet G., Stephan J.F., Lapierre H., Delgado E., Popoff M., (1995) Nouvelles données géochronologiques paléogène des Alps Occidentals: existence d'un événement magmatique bref generalize. In *"Magmatismes dans le sud-est de la France*", *Séanc. Spé. Soc Géol. Fr. et de l'Assoc. des géologues du SE* p.38.

Fischer H., Villa I.M., (1990) Erste K/Ar und $^{40}Ar/^{39}Ar$- Hornblende-Mineralalter des Taveyannaz-Sandsteins. *Schweizerische mineralogische und petrographische Mitteilungen*, 70, 73-75.

Hürlimann N., Müntener O., Ulmer P., Nandedkar R., Chiaradia M., Ovtcharova M., (2016) Primary Magmas in Continental Arcs and their Differentiated Products: Petrology of Post-plutonic Dyke Suite in the Tertiary Adamello Batholith (Alps). *Journal of Petrology,* 57, 495-534.

Kapferer N., Mercolli I., Berger A., Ovtcharova M., Fügenschuh B., (2012) Dating emplacement and evolution of the orogenic magmatism in the internal Western Alps: 2. The Biella Volcanic Suite. *Swiss Journal of Geosciences*, 105(1), 67-84.

Macera, P., Ferrara, G., Pescia, A. and Callegari, E., (1983) A geochemical study on the acid and basic rocks of the Adamello batholith. *Memorie di Scienze Geologiche*, 26, 223-259.

Oberli F., Meier M., Berger A., Rosenberg C.L., Gieré R., (2004) U-Th-Pb and $^{230}Th/^{238}U$ disequilibrium isotope systematics: Precise accessory mineral chronology and melt evolution tracing in the Alpine Bergell intrusion. *Geochemica et Cosmochimica Acta*, 68(11), 2543-2560.

Samperton K.M., Schoene B., Cottle J.M., Keller C.B., Crowley J.L., Schmitz M.D., (2015) Magma emplacement, differentiation and cooling in the middle crust: Integrated zircon geochronological–geochemical constraints from the Bergell Intrusion, Central Alps. *Chemical Geology,* 417, 322-340.

Skopelitis A., (2014) Formation of a tonalitic batholith through sequential accretion of magma batches. Ph.D. thesis, University of Geneva, no. Sc. 4660, 328 pages.

Schoene B., Schaltegger U., Brack P., Latkoczy C., Stracke A., Günther D., (2012) Rates of magma differentiation and emplacement in a ballooning pluton recorded by U–Pb TIMS-TEA, Adamello batholith, Italy. *Earth and Planetary Science Letters*, 355, 162-173.

<u>Hf-Nd Radiogenic Isotopes</u>

Borsi L., Schärer U., Gaggero L., Crispini L., (1996) Age, origin and geodynamic significance of plagiogranites in lherzolites and gabbros of the Piedmont-Ligurian ocean basin. *Earth and Planetary Science Letters,* 140, 227-241.

Costa S., Caby R., (2001) Evolution of the Ligurian Tethys in the Western Alps: Sm/Nd and U/Pb geochronology and rare-earth element geochemistry of the Montgenèvre ophiolite (France). *Chemical Geology*, 175, 449-466.

Hürlimann N., Müntener O., Ulmer P., Nandedkar R., Chiaradia M., Ovtcharova M., (2016) Primary Magmas in Continental Arcs and their Differentiated Products: Petrology of Post-plutonic Dyke Suite in the Tertiary Adamello Batholith (Alps). *Journal of Petrology,* 57, 495-534.

Letsch D., Winkler W., von Quadt A., Gallhofer D., (2015) The volcano-sedimentary evolution of a post-Variscan intramontane basin in the Swiss Alps (Glarus Verrucano) as revealed by zircon U-Pb age dating and Hf isotope geochemistry. *International Journal of Earth Sciences (Geologische Rundschau),* 104, 123-145.

Lu G., Winkler W., Rahn M., von Quadt A., Willett S.D., (2018) Evaluating igneous sources of the Taveyannaz formation in the Central Alps by detrital zircon U–Pb age dating and geochemistry. *Swiss Journal of Geosciences,* 3(5), 1–18.

Mayer A., Mezger K., Sinigoi S., (2000) New Sm-Nd ages for the Ivrea-Verbano Zone, Sesia and Sessera valleys (Northern-Italy). *Journal of Geodynamics*, 30, 147-166

McCarthy A., Müntener O, unpublished data.

Montanini A., Tribuzio R., Vernia L., (2008) Petrogenesis of basalts and gabbros from an ancient continent–ocean transition (External Liguride ophiolites, Northern Italy). *Lithos*, 101, 453-479.

Monjoie P., (2004) The Mont Collon mafic complex (Austroalpine Dent Blanche nappe): permian evolution of the western European mantle. *Ph.D. thesis*, University Lausanne and Grenoble, 156 pages.

Müntener O., Desmurs L., Pettke T., Meier M., Schaltegger U., (2004) Formation of fertile mantle in embryonic ocean basins controlled by melt/rock reaction. *Earth and Planetary Science Letters*, 221, 239-308.

Paquette J-L., Ménot R-P., Pin C., Orsini J-B., (2003) Episodic and short-lived granitic pulses in a post-collisional setting: evidence from precise U–Pb zircon dating through a crustal cross-section in Corsica. *Chemical Geology,* 198, 1-20.

Pinarelli L., Del Moro A., Boriani A (1988) Rb–Sr geochronology of Lower Permian plutonism in Massiccio dei Laghi, Southern Alps (NW Italy). *Rend. Soc. Ital. Miner. Petr.,* 43, 411-428.

Pinarelli L., Del Moro A., Boriani A., Caironi V., (2002) Sr, Nd isotope evidence for an enriched mantle component in the origins of the Hercynian gabbro-granite series of the "Serie dei Laghi" (Southern Alps, NW Italy). *European Journal of Mineralogy*, 14, 403-415.

Poitrasson F., Pin C., Duthou J-L., (1994) The size-isotopic evolution connection among layered mafic intrusions: Clues from a Sr-Nd isotopic study of a small complex. *Journal of Geophysical Research, 99 (B5),* 9441-9451.

Renna M.R., Tribuzio R., Tiepolo M., (2007) Origin and timing of the post-Variscan gabbro–granite complex of Porto (Western Corsica). *Contribution to Mineralogy and Petrology,* 151, 493-517.

Rampone E., Hofmann A.W., Raczek I., (1998) Isotopic contrasts within the Internal Liguride ophiolite (N. Italy): the lack of a genetic mantle–crust link. *Earth and Planetary Science Letters,* 163, 175-189.

Schaltegger U., Brack P., (2007) Crustal-scale magmatic systems during intracontinental strike-slip tectonics: U, Pb and Hf isotopic constraints from Permian magmatic rocks of the Southern Alps. *International Journal of Earth Sciences (Geologische Rundschau)*, 96, 1131-1151.

Schaltegger U., Desmurs L., Manatschal G., Müntener O., Meier M., Frank M., Bernoulli D., (2002) The transition from rifting to sea-floor spreading within a magma-poor rifted margin: field and isotopic constraints. *Terra Nova*, 14, 156-167.

Schaltegger U., Brack P., Ovcharova M., Peytcheva I., Schoene B., Stracke A., Marocchi M., Bargossi G.M., (2009) Zircon and titanite recording 1.5 million years of magma accretion, crystallization and initial cooling in a composite pluton (southern Adamello batholith, northern Italy). *Earth and Planetary Science Letters,* 286, 208-218.

Schoene B., Schaltegger U., Brack P., Latkoczy C., Stracke A., Günther D., (2012) Rates of magma differentiation and emplacement in a ballooning pluton recorded by U–Pb TIMS-TEA, Adamello batholith, Italy. *Earth and Planetary Science*, 355-356, 162-173.

Skopelitis A., (2014) Formation of a tonalitic batholith through sequential accretion of magma batches. *Ph.D. thesis*, University of Geneva, no. Sc. 4660, 328 pages.

Tribuzio R., Thirlwall M.F., Messiga B., (1999) Petrology, mineral and isotope geochemistry of the Sondalo gabbroic complex (Central Alps, Northern Italy): implications for the origin of post-Variscan magmatism. *Contribution to Mineralogy and Petrology,* 136, 48-62.

Tribuzio R., Thirlwall M.F., Vannucci R., (2004) Origin of the Gabbro---Peridotite Association from the Northern Apennine Ophiolites (Italy). *Journal of Petrology*, 45, 1109-1124.

Voshage H., Hofmann AW., Mazzucchelli M., Rivalenti G., Sinigoi S., Demarchi G., (1990) Isotopic evidence from the Ivrea zone for a hybrid lower crust formed by magmatic underplating. *Nature*, 347, 731-736.

<u>Detrital Zircons</u>

Beltran-Triviño A., Winkler W., von Quadt A., (2013) Tracing Alpine sediment sources through laser ablation U–Pb dating and Hf-isotopes of detrital zircons. *Sedimentology,* 60, 197-224.

Beltran-Triviño A., Winkler W., von Quadt A., Gallhofer D., (2016) Triassic magmatism on the transition from Variscan to Alpine cycles: evidence from U–Pb, Hf, and geochemistry of detrital minerals. *Swiss Journal of Geosciences*, 109, 309-328.

Chu Y., Lin W., Faure M., Wang Q., (2016) Detrital zircon U-Pb ages and Hf isotopic constraints on the terrigenous sediments of the Western Alps and their paleogeographic implications. *Tectonics*, 35, 2734-2753.

Jourdan S., Bernet M., Tricart P., Hardwick E., Paquette J.L., Guillot S., Dumont T., Schwartz S., (2013) Short-lived, fast erosional exhumation of the internal western Alps during the late early Oligocene: Constraints from geothermochronology of pro- and retro-side foreland basin sediments. *Lithosphere*, 5(2), 211-225.

Krippner A., Bahlburg H., (2013) Provenance of Pleistocene Rhine River Middle Terrace sands between the Swiss–German border and Cologne based on U–Pb detrital zircon ages. *International Journal of Earth Sciences (Geologische Rundschau),* 102, 917-932.

Letsch D., Winkler W., von Quadt A., Gallhofer D., (2015) The volcano-sedimentary

evolution of a post-Variscan intramontane basin in the Swiss Alps (Glarus Verrucano) as revealed by zircon U-Pb age dating and Hf isotope geochemistry. *International Journal of Earth Sciences (Geologische Rundschau),* 104, 123-145.

Lu G., Winkler W., Rahn M., von Quadt A., Willett S.D., (2018) Evaluating igneous sources of the Taveyannaz formation in the Central Alps by detrital zircon U–Pb age dating and geochemistry. *Swiss Journal of Geosciences,* 3(5), 1–18.

Malusà M.G., Carter A., Limoncelli M., Villa I.M., Garzanti E., (2013) Bias in detrital zircon geochronology and thermochronometry. *Chemical Geology*, 359, 90-107.

Malusà M., Anfinson O.A., Davof L.N., Stockli D.F., (2016) Tracking Adria indentation beneath the Alps by detrital zircon U-Pb geochronology: Implications for the Oligocene–Miocene dynamics of the Adriatic microplate. *Geology*, 44, 155-158.

Miller J.C., (2009) Detrital thermochronology of the Alpine foreland basin in Central Switzerland: Insights into tectonic and erosion history of the North Central Alps. *Master of Science,* University of Kansas, 169 pages.

Sharman G.R., Hubbard S.M., Covault J.A., Hinsch R., Linzer H-G., Graham S.A., (2017) Sediment routing evolution in the North Alpine Foreland Basin, Austria: interplay of transverse and longitudinal sediment dispersal. *Basin Research*, 1-22.

<u>Metamorphism</u>

Agard P., Monie P., Jolivet L., Goffe B., (2002) Exhumation of the Schistes Lustre´s complex: in situ laser probe 40Ar/39Ar constraints and implications for the Western Alps. *Journal of Metamorphic Geology*, 20, 599-618.

Agard P., Yamato P., Jolivet L., Burov E., (2009) Exhumation of oceanic blueschists and eclogites in subduction zones: timing and mechanisms. *Earth-Science Reviews*, 92(1), 53-79. ***And references therein.***

Amato J.F., Johnson C.M., Baumgartner L.P., Beard B.L., (1999) Rapid exhumation of the Zermatt-Saas ophiolite deduced from high-precision Sm–Nd and Rb–Sr geochronology. *Earth and Planetary Science Letters*, 171, 425-438.

Berger A., Bousquet R., (2008) Subduction-related metamorphism in the Alps: review of isotopic ages based on petrology and their geodynamic *From: Siegesmund S., Fügenschuh B., Froitzheim N., (eds) Tectonic Aspects of the Alpine-Dinaride-Carpathian System. Geological Society, London, Special Publications*, 298, 117-144. ***And references therein.***

Brouwer F.M., Burri T., Engi M., Berger A., (2005) Eclogite relics in the Central Alps: Regional distribution, metamorphic PT-evolution, Lu-Hf ages, and genetic implications on the formation of tectonic mélange zones. *Schweizerische Mineralogische Petrographische Mitteilungen*, 85, 147-174

Dal Piaz G-V., Cortiana G., Del Moro A., Martin S., Pennachioni G., Tartarotti P., (2001) Tertiary age and paleostructural inferences of the eclogitic imprint in the Austroalpine outliers and Zermatt-Saas ophiolite, western Alps. *International Journal of Earth Sciences (Geologische Rundschau)*, 90, 668-684.

Duch S., Blichert-Toft J., Luais B., Télouk P., Lardeaux J.M., Albarède F., (1997) The Lu–Hf dating of garnets and the ages of the Alpine high-pressure metamorphism. *Nature*, 387, 586-588.

Federico L., Capponi G., Crispini L., Scambelluri M., Villa I.M., (2005) $^{39}Ar/^{40}Ar$ dating of high-pressure rocks from the Ligurian Alps: Evidence for a continuous subduction–exhumation cycle. *Earth and Planetary Science Letters*, 240(3), 668-680.

Hermann J., Rubatto D., Trommsdorff V., (2006) Sub-solidus Oligocene zircon formation in garnet peridotite during fast decompression and fluid infiltration (Duria, Central Alps). *Mineralogy and Petrology*, 88, 181-206.

Rubatto D., Gebauer D., (1999) Eo/Oligocene (35 Ma) high-pressure metamorphism in the Gornergrat Zone (Monte Rosa, Western Alps): implications for paleogeography. *Schweizerische Mineralogische und Petrographische Mitteilungen*, 79, 353-362.

Rubatto D., Gebauer D., Compagnoni R., (1999) Dating of eclogite facies zircons: the age of Alpine metamorphism in the Sesia-lanzo Zone (Western Alps). *Earth and Planterary Science Letters,* 167,141-158.

Rubatto D., Gebauer D., Fanning M., (1998) Jurassic formation and Eocene subduction of the Zermatt-Saas-Fee ophiolites: implications for the geodynamic evolution of the Central and Western Alps. *Contributions to Mineralogy and Petrology*, 132: 269-287.

Skora S., Lapen T.J., Baumgartner L.P., Johnson C.M., Hellebrand E., Mahlen N.J., (2009) The duration of prograde garnet crystallization in the UHP eclogites at Lago di Cignana, Italy. *Earth and Planetary Science Letters*, 287(3), 402-411.

Zimmermann R., Hammerschmidt K., Franz G., (1994) Eocene High Pressure Metamorphism in the Penninic Units of the Tauern Window (Eastern Alps)—Evidence from Ar-40-Ar-39 Dating and Petrological Investigations. *Contributions to Mineralogy and Petrology*, 117, 175-186.

<u>Jurassic-Tertiary Sediments and volcanic tuffs</u>

Brügel A., Dunkl I., Frisch W., Kuhlemann J., Balogh K., (2000) The record of Periadriatic volcanism in the Eastern Alpine Molasse zone and its palaegeographic implications. *Terra Nova,* 12, 42-47.

Burkhard M., Sommaruga A., (1998) Evolution of the western Swiss Molasse basin: structural relations with the Alps and the Jura belt. *In: Mascle A., Puigdefabregas C., Luterbacher H. P. and Fernandez, M. (eds) Cenozoic Foreland Basins of Western Europe. Geological Society Special Publications,* 134, 279-298.

Caron C., Homewood P., Wildi W., (1989) The Original Swiss Flysch: A Reappraisal of the Type Deposits in the Swiss Prealps. *Earth-Science Reviews,* 26, 1-45.

O'Dogherty L., Bill M., Gorican Š., Dumitrica P., Masson H., (2006) Bathonian radiolarians from an ophiolitic mélange of the Alpine Tethys (Gets Nappe, Swiss-French Alps). *Micropaleontology,* 51, 425-485.

Rocholl A., Schaltegger U., Gilg H.A., Wijbrans J., (2017) The age of volcanic tuffs from the Upper Freshwater Molasse (North Alpine Foreland Basin) and their possible use for tephrostratigraphic correlations across Europe for the Middle Miocene. *International Journal of Earth Sciences (Geologische Rundschau),* https://doi.org/10.1007/s00531-017-1499-0.

Ruffini R., Polino R., Callegari E., Hunziker J.C., Pfeifer H.R., (1997) Volcanic clast-rich turbidites of the Taveyanne sandstones from the Thônes syncline (Savoie, France): records for a Tertiary postcollisional Volcanism. *Schweizerische Mineralogische und Petrographische Mitteilungen*, 77(2), 161-174.

Tricart P., Schwartz S., (2006) A north-south section across the Queyras Schistes lustrés (Piedmont zone,Western Alps): Syn-collision refolding of a subduction wedge. *Eclogae Geologicae Helvetiae,* 99, 429-442.

<u>Rift Basins</u>

Mohn G., Manatschal G., Müntener O., Beltrando M., Masini E., (2010) Unravelling the interaction between tectonic and sedimentary processes during lithospheric thinning in the Alpine Tethys margins. *International Journal of Earth Sciences (Geologische Rundschau),* 99, 75-101.

Villa I.M., Hermann J., Müntener O., Trommsdorff V., (2000) ^{39}Ar-^{40}Ar dating of multiply zoned amphibole generations (Malenco, Italian Alps). *Contributions to Mineralogy and Petrology,* 140, 363-381.

Figure 4

Present-day Alpine-cross-section after:

Escher, A., Masson, H., Steck, A., Epard, J.-L., Marchant, R., Marthaler, M., Sartori, M., Venturini, G., (1994) Coupe Géologique des Alpes Occidentales: University of Lausanne, Section Sciences de la Terre.

Jurassic Alpine cross-section after:

Schenker, F.L., Schmalholz, S.M., Moulas, E., Pleuger, J., Baumgartner, L.P., Podladchikov, Y., Vrijmoed, J., Buchs, N., Müntener, O., (2015). Current challenges for explaining (ultra) high‐pressure tectonism in the Pennine domain of the Central and Western Alps. *Journal of Metamorphic Geology*, 33(8), 869-886.