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ABSTRACT

The tectonic and magmatic characteristics of the Alps and Pyrenees during convergence are quite distinct from characteristics associated with classic Benioff-type oceanic subduction. From the initiation of subduction at passive margins until the onset of continental collision, the closure of the Western Tethys never produced a long-lived magmatic arc. This is a consequence of the 3-D architecture of the Western Tethys (a series of hyper-thinned basins and continental blocks) and its narrow width (<500–700 km) prior to convergence. Subduction primarily involved the slow and amagmatic subduction of a narrow domain of dry lithospheric mantle. This type of congested Ampferer subduction led to the sequential and coherent accretion of inherited rifted domains which today form the Alpine and Pyrenean orogens.

KEYWORDS: amagmatic subduction; Ampferer-type, Benioff-type, hyperthinned basins, continental subduction

INTRODUCTION

Benioff-type oceanic subductions are typically characterized by compositionally variable and extensive magmatism from the onset of subduction initiation to mature arc magmatism (Grove et al. 2012; Stern et al. 2012; Jicha and Jagoutz 2015; Li et al. 2019 and references therein). Although variations in magmatism might occur over tens of millions of years (Paterson and Ducea 2015) and flat-slabs, or accretion of plateaus, might locally inhibit magmatism, the development of extensive magmatism during subduction is a consequence of two main factors: 1) upper-plate extension and adiabatic decompression mantle melting, particularly during subduction initiation or back-arc spreading; 2) dehydration (± melting) of subducted oceanic lithosphere at depths of ∼100 km, which triggers flux-melting of the mantle wedge (Grove et al. 2012 and references therein).

However, evidence of magmatism in the Alps and Pyrenees remains sparse to nonexistent during convergence (e.g., Trümpy 1975; McCarthy et al. 2020 and references therein). We address this conundrum by targeting the Jurassic– Cenozoic magmatic and tectonic history of the Western Tethys from rifting to subduction and collision. We also include the Pyrenean orogen because it shares similarities with the Western and Central Alps in term of its pre-orogenic setting (a series of former hyper-thinned rift basins) and lack of magmatism during convergence. We show that in order to constrain the mechanisms of lithospheric foundering and recycling, it is crucial to clearly characterize the lithosphere prior to convergence in terms of its architecture, size, and the lithologies of the "subductable" domain.

MAGMATISM IN THE ALPS AND PYRENEES

Paleogene magmatism in the Western and Central Alps (Fig. 1A), typically found as small plutons and dykes within the Alpine Orogen, occurs immediately prior to, and during, continental collision (43–29 Ma) (Müntener et al. 2021 this issue). The volume of this short-lived Paleogene magmatism, normalized to the length of the arc, is several orders of magnitude smaller than the volume of magmatism at mid-ocean ridges and typical arc systems (e.g., Jicha and Jagoutz 2015) (Fig. 1B). However, evidence of magmatism in the Alps occurring prior to 43 Ma—from the initiation of subduction (100–90 Ma) to subduction of the Western Tethys — remains unheard of in the Alps (e.g., Trümpy 1975; McCarthy et al. 2018, 2020). In addition, no evidence of subduction-related Paleogene magmatism is found in the Pyrenees. This implies that either no magmatism occurred during a 40–50 My period of subduction or that volcanic edifices and plutons were formed during subduction but were subsequently very efficiently eroded and redeposited in adjacent sedimentary basins.

Arc magmas generally contain zircons crystallized during magma differentiation in the crust. Once volcanic and plutonic edifices are eroded, these zircons are deposited in nearby sedimentary basins. Therefore, dating populations of detrital zircons can provide accurate snapshots of magmatism through time. Detrital zircon populations from continental arcs reveal the near-continuous output of volcanism over hundreds of millions of years, with detrital zircon populations overall mirroring the population of magmatic zircons (Paterson and Ducea 2015). Similar patterns are identified along intra-oceanic arcs, albeit over shorter timescales. For example, in the western Pacific, detrital zircon populations from 25–40 Ma volcaniclastic sediments shed from the juvenile Izu–Bonin Arc show a similar evolution in zircon crystallization ages with time of deposition, as evidenced by biostratigraphy and magnetostratigraphy (e.g., Barth et al. 2017). These overlapping ages imply that volcaniclastic rocks were rapidly erupted and deposited in proximal basins.

Detrital zircons in sediments deposited during convergence in the Western Tethys should, therefore, record a “lost” Alpine magmatic arc, if, in fact, it existed. A compilation of U–Pb detrital zircon ages from sediments deposited in the last 300 My for both the Alps and the Pyrenees (data compiled in McCarthy et al. 2018, 2020) shows a clear gap in zircon ages, which persists from rifting until the onset of continental collision (Fig. 1C). This dearth of magmatic zircons in the Western and Central Alps covers the timeline from the onset of subduction initiation between 90 Ma and 100 Ma until shortly prior to the onset of continental collision (e.g., Handy et al. 2010; Zanchetta et al. 2012; McCarthy et al. 2018), during which only minor volumes of arc-like magmatism were produced (Fig. 1A).

This magmatic zircon gap notably coincides with subduction- related eclogite-facies high-pressure metamorphism of continental fragments from the Adria margin, which reached the peak metamorphic conditions of 1.5–2.0 GPa at 65–75 Ma, implying a subducted depth of ~50–70 km (e.g., Berger and Bousquet 2008; Agard and Handy 2021 this issue). This zircon gap also coincides with the initial slow subduction of hydrated oceanic domains, for which metamorphic garnet documents a prograde metamorphism at 1.1–1.4 kbar, likely starting as early as 70–80 Ma, before reaching peak eclogite-facies metamorphism at 2–3 GPa, ~38–40 Ma (Skora et al. 2009 and references therein). The lack of magmatic zircons derived from arc magmas during these events implies that there is a 40–50 million year window when typical conditions relevant to hydrous arc magmatism—namely, a hydrated oceanic slab subducted to 50–150 km depth, which should lead to flux-melting of the mantle wedge (Grove et al. 2012)—did not produce any magmatism. Instead, detrital zircons reveal a "magmatic arc gap" consistent with the observed lack of plutonic and volcanic rocks (Fig. 1A) (Trümpy 1975; McCarthy et al. 2018). Notably, the detrital zircon record in the Pyrenees also shows no detrital zircon population from rifting to continental collision (Fig. 1C).

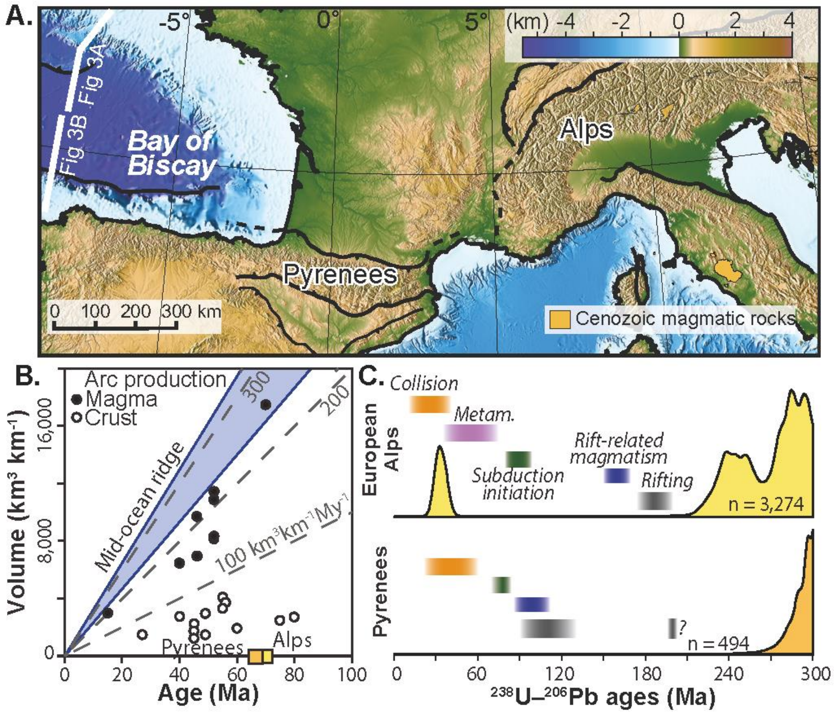

Figure 1: Fingerprinting magmatism during convergence along the Western Tethys. (A) The distribution of Cenozoic magmatism (orange) in the Alps, Pyrenees and Apennines. Note the locations of two seismic profile lines (white lines) in the Bay of Biscay: these are given as cross-sections in Figures 3A and 3B. (B) Estimated volume of magma production and crust production in arc systems and mid-ocean ridges (From Jicha and Jagoutz 2015) as compared to such production in the Alps and Pyrenees (From McCarthy et al. 2020). Volume of magmatism is normalized per kilometre of arc length (km3/km). (C) Distribution of detrital zircon ages from 300 Ma to present, showing important geodynamic markers (bars represent different geological processes) related to the opening and closing of the Western Tethys. Abbreviation: Metam = high-pressure metamorphism during subduction.

THE ARCHITECTURE OF THE WESTERN TETHYS

The history of the Western Tethys is related to the geodynamic evolution of Western Europe upon the opening of the Central and North Atlantic systems (Fig. 2A). The Western Tethys was hemmed in between two wide oceanic domains, namely the

Atlantic Ocean to the west and the Neotethys Ocean to the east, and consisted of a series of rift basins floored by hyperthinned crust, exhumed subcontinental mantle, and embryonic oceans formed in Jurassic–Cretaceous times between Europe and Adria (Alps) and Europe and Iberia (Pyrenees). Remnants of the Western Tethys are found in the Western and Central Alps, Apennines, and Pyrenees and form atypical ophiolitic sequences dominated by mantle rocks, sparsely distributed pillow lavas, lava flows, and gabbroic bodies (see Rampone and Sanfilippo 2021 this issue) partly overlain by their syn- to post-rift sedimentary cover. Sparse basaltic and gabbroic bodies of mid-ocean ridge basalt (MORB) affinity found preserved in the Alps and Apennines reveal a short-lived phase of magmatism, with magmatic zircon ages typically between 155 Ma and 165 Ma (Manatschal and Müntener 2009). These ophiolites are characterized by almost amagmatic spreading accommodated by kilometre-scale concave-downwards detachment faults that exhumed mantle rocks and gabbros to the sea floor, comparable to magma-poor and (ultra)slow-spreading systems such as the Mid-Atlantic Ridge and the Southwest Indian Ridge (e.g., Lagabrielle et al. 2015 and references therein). Published chemical analyses of MORB-like basalts that originally formed in the Western Tethys have Ti and V abundances similar to MORB from (ultra)slow mid-ocean ridges, implying that these basalts shared similar sources and partial melting processes and are unlike magmatism associated with subduction initiation (Fig. 2B).

Certain remnants of the Western Tethys that are found in Alpine ophiolites also preserve pre- and syn-rift contacts between thinned continental crust and subcontinental mantle; syn-rift sedimentary deposits also directly overly exhumed mantle, and there are large continental blocks (allochthons, or microcontinents) separated by heterogeneous mantle domains. The characteristics of these remnants are analogous to present-day ocean–continent transitions as seen in Iberian and Newfoundland (Canada) margins (e.g., Manatschal and Müntener 2009 and references therein) (Fig. 2C).

Along the narrowest sections of the Pyrenean basins, the Western Tethys did not exceed a width of ~150 km, with exhumed subcontinental mantle typically less than 50 km wide (e.g., Tugend et al. 2015). Palaeogeographic reconstructions suggest that the Western Tethys reached a maximum width of 500–700 km along the Western and Central Alps prior to convergence (Rosenbaum and Lister 2005). Overall, the Western Tethys represents a large-scale pinch-and-swell architecture where continental blocks of variable size (from kilometre-scale allochthons to microcontinents tens of kilometres wide) were separated by hyper-thinned rift basins and exhumed mantle domains (Figs. 2A, 2C) (Manatschal and Müntener 2009; Mohn et al. 2010; Manzotti et al. 2014; Tugend et al. 2015 and references therein). A large part of the Jurassic and Cretaceous extension of the Western Tethys was, therefore, accommodated by the extreme thinning of the continental lithosphere. Measurements compiled from present-day rifted margins suggest that the width of hyper-thinned crustal domains may range from ~20 km to ~80 km (Chenin et al. 2017) prior to the exhumation of variably wide domains of exhumed subcontinental mantle. The extent to which the 500–700 km wide Western Tethys was underlain by an oceanic lithosphere that had formed at an active spreading centre is, therefore, unclear. However, based on the Jurassic timing of short-lived

MORB magmatism in the Western Tethys and ultraslow spreading rates (<2cm/y), Manzotti et al. (2014) estimated a width of the Piemonte–Liguria Ocean (or Basin) of 200–300 km (Fig. 2A). In spite of the large uncertainties, these estimations, combined with the estimated width of rifted domains, are consistent with a maximum extension of 500–700 km for the Western Tethys in what would become the Western Alps, as suggested by Rosenbaum and Lister (2005).

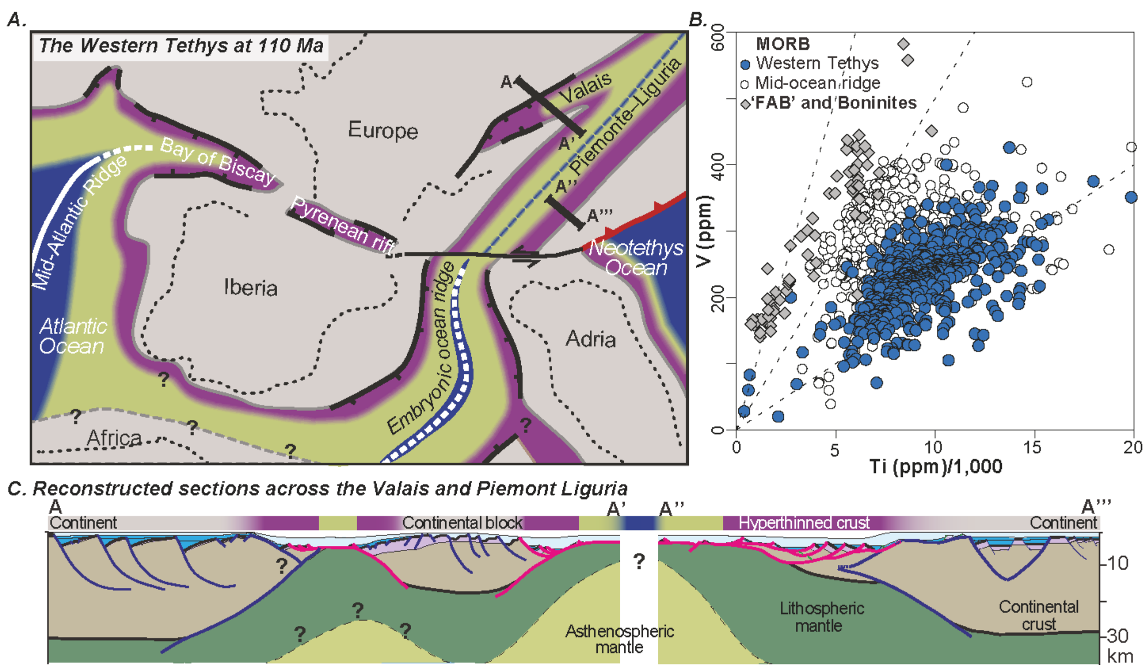

Figure 2: (A) Palaeogeographic reconstruction of the Western Tethys at ~110 Ma. Note locations of the two sections A–A' and A''–A'''. After Mohn et al. (2010) and Tugend et al. (2015). (B) Compilation of Ti and V compositions from published mid-ocean ridge basalt (MORB)-like ophiolitic rocks originally formed in the Western Tethys (filled circles); from published data for MORBs from (ultra-) slow-spreading mid-ocean ridges (the Atlantic Ridge and the Gakkel Ridge) (open circles); and depleted tholeiitic basalt and forearc basalt ('FAB') and boninites from the Izu–Bonin Mariana Arc (data from Li et al. 2019 and references therein). (C) Transect through the wider domains of the Western Tethys (Piemonte–Liguria Basin and

Valais Basin) illustrating how rift-related extension was accommodated by (hyper)extension of continental lithosphere. For location of sections see Figure 2A. From Mohn et al. (2010).

ACCOMMODATING CONVERGENCE AT HYPERTHINNED BASINS

The initial stages of convergence along a rift basin and passive margin are well documented along the Bay of Biscay–Pyrenean system (Tugend et al. 2014). Seismic imaging along the Northern Bay of Biscay reveals that deformation has been accommodated along a series of thrust slices located at the edge of the continental crust where mantle is exhumed (Tugend et al. 2014) (Fig. 3A). Increasing amounts of convergence accommodated along the Northern Iberia margin (southern Bay of Biscay) led to the almost complete overprint of the former hyper-thinned margin and its incorporation as part of the accretionary prism (Gallastegui et al. 2002; Tugend et al. 2014, 2015) (Fig. 3B). These seismic observations and interpretations highlight how compressional deformation was initiated upon convergence and highlights how the Bay of Biscay represents a unique place where the initial stages of subduction at passive margins are preserved. The transitions between rifted margin domains and, notably, between hyper-thinned continental crust and exhumed mantle represent key weaknesses which can accommodate deformation at the onset of convergence (Tugend et al. 2014). This convergence may evolve to become a forced subduction initiation along a passive margin, as suggested by numerical modeling (McCarthy et al. 2020).

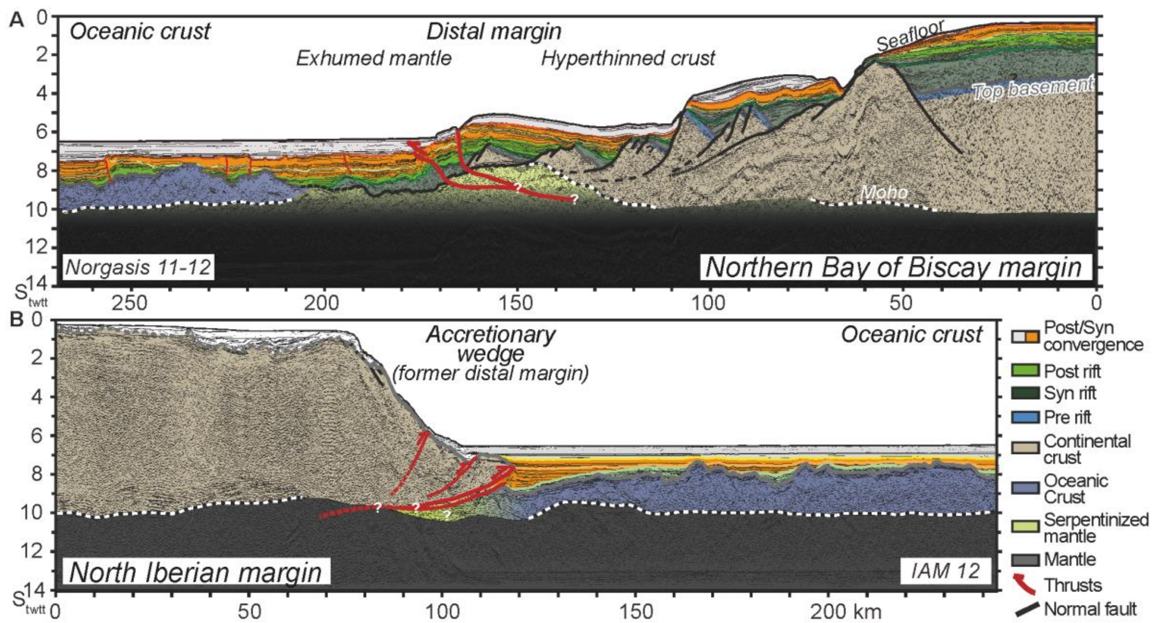

Figure 3: (A) Interpretation of seismic imaging of hyperthinned passive margin along the northern margin of the Bay of Biscay, illustrating how deformation is accommodated along the ocean–continent transition during convergence. From Tugend et al. (2014). (B) Interpretation of seismic imaging of accretionary wedge along the opposite north Iberian margin, on the southern side of the Bay of Biscay. Location of the seismic transects can be found in Figure 1. Abbreviation: Stwtt = two-way-travel-time in seconds.

Field mapping and petrological studies along the Central Alps have revealed complex lithostratigraphic associations, including continental crust, serpentinized mantle, and pre to post-rift sediments related to Jurassic rifting (Fig. 4). Such associations and related tectonic structures are the result of the coherent underthrusting (as large thrust sheets) of large fragments of the former ocean–

continent transition below the continental margin during convergence (Mohn et al. 2010, 2011). Tectonometamorphic studies reveal an abrupt change in metamorphic conditions and deformation style within the former ocean–continent transition zone of the Adriatic margin (Mohn et al. 2011; Picazo et al. 2019 and references therein). Segments that represent the Adriatic upper plate (Bernina–Err–Platta, a low greenschist facies unit) have not been extensively affected by Alpine metamorphic overprint during subduction and collision. In contrast, accreted lower plate sequences (Malenco–Margna Sella, an epidote-amphibolite facies unit that reached ~0.5–0.7 GPa and 450–500 °C) show higher P–T conditions and pervasive Alpine deformation consistent with being underthrust during convergence. This change in degree of metamorphism occurs within exhumed mantle domains between the hyper-thinned continental margin of Adria and the continental allochthons further oceanward (Figs. 4B, 4C) (Mohn et al. 2010 and references therein). In accordance with observations from the Bay of Biscay margins, field and petrological evidence in the Central Alps indicates that subduction initiation occurred at the edge of hyper-thinned continental crust. Following subduction initiation, rift-related features, such as extensional shear zones and continental allochthons, may typically control the localization of large-scale shear zones that accommodated compression during subduction (e.g., Mohn et al. 2011) (Figs. 4B, 4C). Therefore, the plate interface between the subducting plate and the upper plate is formed of a wide domain of sequentially underthrusted coherent lithospheric slices from the downgoing plate (Fig. 4). Similarly Beltrando et al. (2014) and Lagabrielle et al. (2015) showed that rift-related lithostratigraphic associations (e.g., syn- to post-rift sediments associated with continental basement or with serpentinitized mantle and large gabbroic bodies) can still be identified even in the high-pressure (blueschist–eclogite facies) domains of the Western Alps. Despite having a pervasive Alpine metamorphic overprint, rocks of the ocean–continent transitions and the slivers of ultra-slow-spreading oceanic lithosphere can still be coherently preserved and identified throughout the Alpine orogen (Beltrando et al. 2014; Lagabrielle et al. 2015).

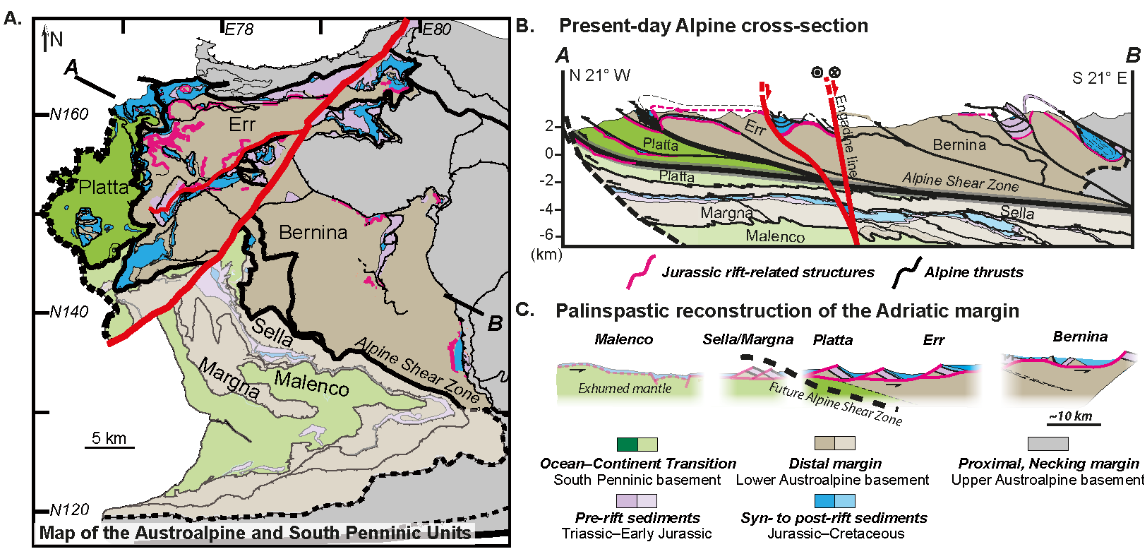

Figure 4 (A) Simplified tectonic map along the Central Alps (Eastern Switzerland) highlighting continental units from the Adria margin (Austroalpine: Err, Bernina, Margna–Sella) and exhumed mantle and oceanic units (Penninic: Platta and Malenco). Note location of section line A–B. From Mohn et al. (2011). (B) Present-day Alpine crosssection, taken along line A–B in Figure 4A. The thick black line is a major Alpine Shear Zone that delimits units from the distal Adriatic margin with distinct Alpine overprint. Above the shear-zone, the Upper Platta, Err and Bernina are poorly affected by Alpine deformation. Below the shear-zone, the underthrusted

Lower Platta, Malenco, Margna–Sella Units are affected by pressure-dominated (subduction-related) Alpine metamorphism. Thick, near-vertical, lines (Engadine line) are Cenozoic strike-slip faults crosscutting the Alpine nappe stack. (C) Palinspastic reconstruction of the Adria margin showing the location of subduction initiation within the Continent–Ocean Transition of the Adriatic margin (Future Alpine Shear Zone). The darker, more pronounced, colours represent the upper plate (with a weak Alpine metamorphic overprint); the lighter colours (strong Alpine overprint) represent the lower-plate accreted sequences.

Tectonic, metamorphic, and sedimentary fingerprints related to subduction initiation are preserved in the Western Tethys (Fig. 5). Plate kinematic reconstructions indicate that Africa and Adria followed a NE trajectory starting from ~85–100 Ma recorded by slow rates of convergence (~1–2 cm/y) in the Western Tethys (Rosenbaum and Lister 2005). Convergence is accommodated by highly oblique to strike-slip motions along the former Adriatic margin and upper-plate compression at ~85–100 Ma, leading to the forced subduction of the Western Tethys under Adria (e.g., Rosenbaum and Lister 2005; Zanchetta et al. 2012). Along the upper plate, compression is recorded by the dating of thrust faults, as well as by syn-sedimentary deformation of detrital turbidites (the Lombardian Basin of the Southern Alps) (Zanchetta et al. 2012 and references therein). In addition, the oldest deep-water conglomerates and sandstones (Alpine Flysch), which resulted from the erosion of a nascent wedge along the Western and Central Alps, are ~90–100 Ma (e.g., Handy et al. 2010; Agard and Handy 2021 this issue). In terms of subduction-related metamorphism, continental fragments from the Adriatic passive margin were affected by peak eclogite-facies metamorphism at 75–65 Ma along the Western Alps (e.g., Agard and Handy 2021 this issue). The peak metamorphism of continental fragments occurs prior to prograde and peak metamorphism of the oceanic domains (Fig. 5) (e.g., Berger and Bousquet 2008 and references therein). From all these observations, the closure of the Western Tethys along the Western and Central Alps, from ~90–100 Ma until continental collision in the Western Alps at ~34–32 Ma, most likely occurred as a consequence of highly oblique, slow, and forced subduction that had initiated at a hyper-thinned passive margin.

The record of subduction initiation at the Western Tethys passive margins is unlike the magmatic response to intraoceanic subduction initiation. Although subduction initiation mechanisms are likely diverse and complex, one general model has been developed on the basis of two examples. First, Neotethys supra-subduction-zone ophiolites formed upon subduction initiation (e.g., Stern et al. 2012 and references therein). Second, the development of the Izu–Bonin–Mariana Arc, where intra-oceanic subduction initiated at 50–52 Ma and formed a long-lived intraoceanic arc (Stern et al. 2012; Li et al. 2019 and references therein). (Fig. 5). These systems are characterized by extensive upper-plate extension and variably extensive hydrous shallow mantle ± slab melting (e.g., depleted tholeiitic basalts or "forearc basalts", boninites, and high-Mg andesites) upon subduction initiation. Subduction initiation is then followed shortly after either by obduction, as was the case for the Neotethys ophiolites (Stern et al. 2012 and references therein), or, in the case of the Izu–Bonin– Mariana Arc, the development into a mature arc volcanic system within ~7

My after subduction initiation (Fig. 5). Thus, a variety of compositionally distinct magmas can be produced and erupted within a distinctively short timeframe upon intra-oceanic subduction initiation.

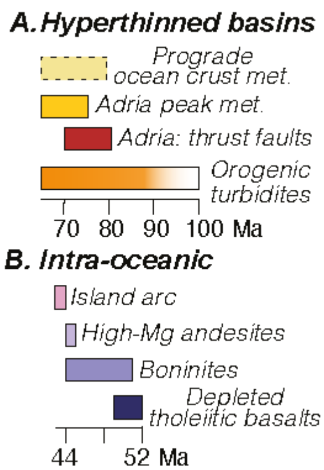

Figure 5: Two contrasting tectonic responses to subduction initiation. (A) An amagmatic response to subduction initiation at hyper-thinned basins and passive margins as recorded in the Western and Central Alps. The dotted line part of the "prograde metamorphism of ocean crust" bar signifies uncertainty as to when garnet started growing during prograde metamorphism (Skora et al. 2009). Timescales are from Skora et al. (2009), Zanchetta et al. (2012 and references therein) and Handy et al. (2010 and references therein). (B) The short-term magmatic response to intraoceanic subduction initiation of the Izu–Bonin–Mariana Arc. After Stern et al. (2012 and references therein). Abbreviation: met = metamorphism.

SHUTTING DOWN MAGMATISM

The (ultra-)slow-spreading Western Tethys was dominated by serpentinized mantle and hydrated oceanic sediments, representing the main reservoirs of volatiles that should typically drive arc magmatism. So, why was magmatism so sparse, played such a late role during convergence in the Alps, and was nonexistent in the Pyrenees following subduction initiation?

Initially, unlike intra-oceanic subduction initiation, upper plate compression during the onset of convergence (e.g., Zanchetta et al. 2012) likely inhibited decompression driven magmatism. Then, because even a small percentage (10%–15%) of serpentinization lowers the brittle strength of peridotites (Escartín et al. 2001), the hydrated upper layers of the Western Tethys, namely the serpentinites and oceanic sediments, are likely to have been efficiently sheared off from the underlying dry peridotites during forced convergence and then sequentially accreted as coherent slivers to the nascent orogenic wedge (Fig. 4B) (e.g., Mohn et al. 2010; Beltrando et al. 2014). Numerical modeling supports this scenario (McCarthy et al. 2020). The subducting slab will, therefore, primarily be dry lithospheric mantle (Fig. 6) (McCarthy et al. 2018, 2020). The combination of a highly oblique and slow subduction and decoupling of hydrated lithologies from a downgoing dry slab would then form a congested subduction zone characterized by the inefficient subduction of hydrated lithologies. This would have suppressed magmatism for up to 40–50 My even as subducted continental and oceanic fragments were affected by prograde and peak high-pressure metamorphism starting at 70–80 Ma (Fig. 5). Further west along the Pyrenean basins (Tugend et al. 2014), the combination of narrow (<150 km) hyper-thinned rift basins, including only limited exhumed mantle domains (<50 km), implies that the cumulative convergence was likely not sufficient to produce any high-pressure metamorphism nor arc magmatism even upon collision (Fig. 6).

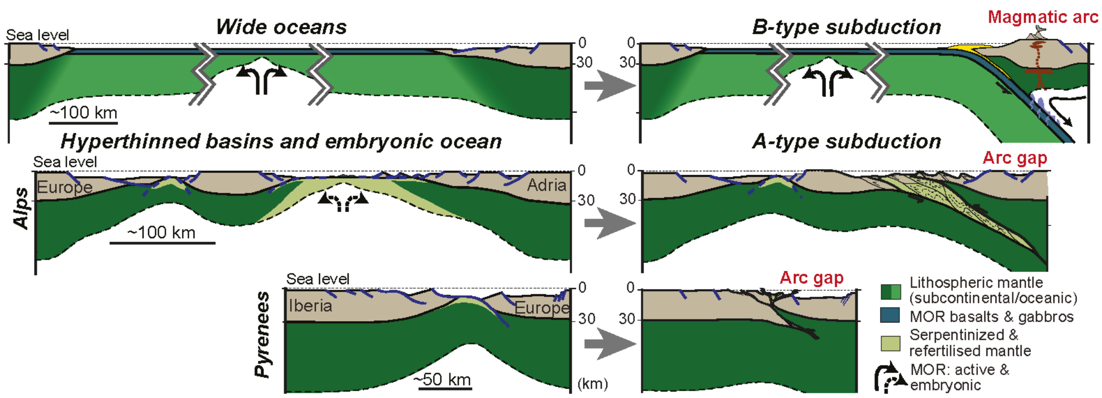

Figure 6: Illustration of Benioff-type ("B-type", with a magmatic arc) oceanic subduction versus amagmatic Ampferer-type ("A-type", without a magmatic arc) continental subduction. Modern subductions represent a continuum between both end-members and are controlled by the pre-existing lithosphere and width of the "subductable domain" prior to the initiation of subduction. MOR = mid-ocean ridge. Modified from McCarthy et al. (2020).

FROM AMPFERER TO BENIOFF… AND BACK AGAIN ?

In 1911, Otto Ampferer introduced the conceptual idea of downthrusting of continental crust to great depth, or Verschluckung (Ampferer and Hammer 1911), a term later defined as Ampferer-type continental subduction. Almost 65 years later, as plate tectonics became an accepted and established paradigm, Trümpy (1975) raised the problematic issue of the lack of magmatism in the Alps.

Still, the presence of (1) ophiolites interpreted as oceanic lithosphere; (2) (sparse) arc-like magmatism; (3) seismic tomography images of a subducted slab attached to the Alpine Orogen (e.g., Handy et al. 2010 and references therein), and (4) the presence of eclogite-facies continental and oceanic crust (Berger and Bousquet 2008) have all been used as strong evidence in favour of a classical Benioff-type oceanic subduction zone in the Alps. Such a plate tectonic model implies the long-lived efficient subduction of hydrated oceanic crust and sediments. The observed short timescale of Jurassic MORB magmatism recorded in the Alps is then interpreted as a consequence of the efficient subduction of oceanic lithosphere, explaining its poor preservation in the Alpine orogen (Fig. 6). If this were so, processes akin to present-day Benioff-type subduction zones would have driven convergence along the Western Tethys, from subduction initiation to the burial and exhumation of high-pressure rocks and continuing until collision. In this case, the formation of the Alps would have been essentially controlled by buoyancy-driven slab pull and slab roll-back forces, as well as by possible slab breakoff mechanisms.

However, we emphasize an alternative view. The Western Tethys was formed subsequent to extreme continental lithosphere extension and the ultraslow plate separation was controlled by regional plate kinematics. As a result, prior to convergence, the Western Tethys can be described as a series of rift basins, floored by hyper-thinned continental crust and exhumed subcontinental mantle as well as having sporadic embryonic oceanic crust formed by ultraslow spreading (Fig. 2) (e.g., Manatschal and Müntener 2009; Lagabrielle et al. 2015; Tugend et al. 2015). In this scenario, the observed short timescale of Western Tethys MORB magmatism was not a consequence of the efficient subduction of oceanic lithosphere. On the contrary, it would represent the preservation of the rather small (200–300 km wide) (Manzotti et al. 2014) and short-lived ultra-slow-spreading events of the Piemonte–Liguria Basin (Fig. 2) (Manatschal and Müntener 2009; McCarthy et al. 2020). This view is compatible with the limited width of the Western Tethys inferred from plate kinematic restorations (e.g., Rosenbaum and Lister 2005). Slow convergence forced by regional plate kinematics outside of the Western Tethyan realm was first accommodated at the exhumed mantle domain at the edge of hyper-thinned continental crust (Fig. 3). Increasing convergence resulted in partial underthrusting and subduction of the distal margin (Fig. 4) prior to that of the embryonic oceanic lithosphere, as supported by the ages of subduction-related metamorphism.

In the above scenario, an Ampferer-type continental subduction would imply that Western Tethyan oceanic lithosphere played a limited and rather passive role during convergence. This mechanism of continental—and congested—Ampferer-type subduction might lead to alternative interpretations regarding the origins of sporadic, late-stage Paleogene magmatism in the Alps, including the necessity of slab break-off mechanisms (e.g., Müntener et al. 2021 this issue) and the origin and significance of (ultra) high-pressure metamorphism in collisional orogens..

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