GEOLOGY | THE GEOLOGICAL SOCIETY OF AMERICA®

https://doi.org/10.1130/G52556.1

Manuscript received 9 July 2024
Revised manuscript received 11 December 2024
Manuscript accepted 23 December 2024

Published online 7 January 2025

The two-sided continental subduction of the Adria microplate (Mediterranean)

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ABSTRACT

The recycling of the continental lithosphere back into the mantle significantly impacts the structure and dynamics of orogens, particularly in the central Mediterranean region. We demonstrate that variations in the rheological properties of the continental lithosphere, as revealed by high-resolution regional tomography, influence the style of continental subduction. We explain the geometry and evolution of the oppositely verging Apennines and Dinarides orogens, as given by contrasting subduction processes, such as underplating and continental delamination, affecting the same plate (the Adriatic microplate, or Adria). In the case of the Apennines, slab peel-back predominates during subduction, resulting in a steeply dipping slab. In contrast, the Dinarides experience flat subduction due to the underplating of continental material. These different mechanisms, influencing kinematics and surface processes, are governed by rheological heterogeneities and different buoyancies of the continental lithosphere.

INTRODUCTION

Many open questions feed the intense debate on the evolution of continental subduction; particularly, on how deeply the lithosphere penetrates (Ranalli et al., 2000) and its impact on surface field deformation (e.g., Regard et al., 2003). In this context, variations in the buoyancy of the subducting lithosphere are thought to control both subduction rate and slab dip (Royden and Husson, 2009). These conditions are potentially widespread across continental margins, especially those of past oceans. The central Mediterranean area constitutes a key case study for understanding the long-term development of continental subduction (e.g., Dewey et al., 1989). The Apennines and the Dinarides orogenic belts are two distinct examples of how this process evolved differently (Fig. 1A) from the subduction of the same microplate (i.e., Adria; e.g., Doglioni et al., 2007; Royden and Faccenna, 2018). In addition to the general large-scale framework of African and Eurasian plates convergence, the evolution of this system is dominated by small oceanic basins and continental microplates, like Adria (Kissling, 2024).

In the Apennines and the Dinarides orogens, positive velocity anomalies at mantle depth indicate the presence of subducting lithosphere, extending to varying depths. However, the slab continuity is debated due to lateral and vertical velocity variations in tomographic models. These velocity anomalies are interpreted as resulting from differences in subduction velocities or the timing of subduction onset (Šumanovac et al., 2017; Chiarabba et al., 2023), slab detachment or windows (Piromallo and Morelli, 2003; Koulakov et al., 2009; Belinić et al., 2021), and propagating slab tear (Rosenbaum et al., 2008; Handy et al., 2015). The coexistence of these differing models also stems from the knowledge gap that persists regarding the subduction of continental lithosphere and the role played by lateral heterogeneities in the composition of the uppermost mantle (Giacomuzzi et al., 2022).

GEODYNAMIC OUTLINE

Continental collision and subduction have a long history in the central Mediterranean, resulting from the ongoing convergence between Eurasia and Africa since the late Cenozoic (ca. 40 Ma; Dewey et al., 1989). Squeezed between the two major plates, the Adria microplate (McKenzie, 1972; Kissling, 2024) has been progressively consumed by subduction beneath the Apennines and Dinarides-Hellenides (Fig. 1A). Adria currently represents the last largest strip of continental lithosphere in the Mediterranean. It remains attached to the remnants of the ancient Tethys oceanic basin to the south, while the majority of the oceanic lithosphere has been consumed in the subduction zones (Kissling, 2024).

Throughout the long evolution of the Apennines and the Dinarides, the varying convergence rates of slow (1–2 mm/yr) and fast (5–10 mm/yr) episodes (Faccenna et al., 2004) have led to the complex and different structures of these two orogenic systems (Royden and Faccenna, 2018). This evolution has resulted in the bending of the Apennine orogen and the Adriatic slab at depth (Handy et al., 2015). Such complexity is testified by the debated lateral and vertical continuity of high-velocity anomalies in the mantle observed in teleseismic models (Piromallo and Morelli, 2003; Koulakov et al. 2009; Giacomuzzi et al., 2012; Šumanovac et al., 2017; Paffrath et al., 2021).

GPS data (Eurasia fixed frame; Serpelloni et al., 2022) have confirmed the different kinematics of the two orogens (Fig. 1). In the Apennines, seismicity and strain indicators have revealed active compression spreading along the northern Adriatic coast, coupled with an across-belt extension (Serpelloni et al., 2022). Seismicity concentrates mainly within a shallow brittle crustal layer along the axis of the belt, while deep seismicity occurs under the northern part of the belt and in the Ionian subduction (Fig. 1C). In contrast, the Dinarides are characterized by compression in the inner portion of the belt (43°–46°N and 15°–20°E), which shifts into transpression in the northern area (Balling et al., 2021; Serpelloni et al., 2022; Fig. 1A).

THE Vp AND Vp/Vs SIGNATURE OF ADRIA

The seismic velocity structure (P- and S-wave velocities) of the Adria lithospheric

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CITATION: Menichelli, I., et al., 2025, The two-sided continental subduction of the Adria microplate (Mediterranean): Geology, v. XX, p. ,
https://doi.org/10.1130/G52556.1

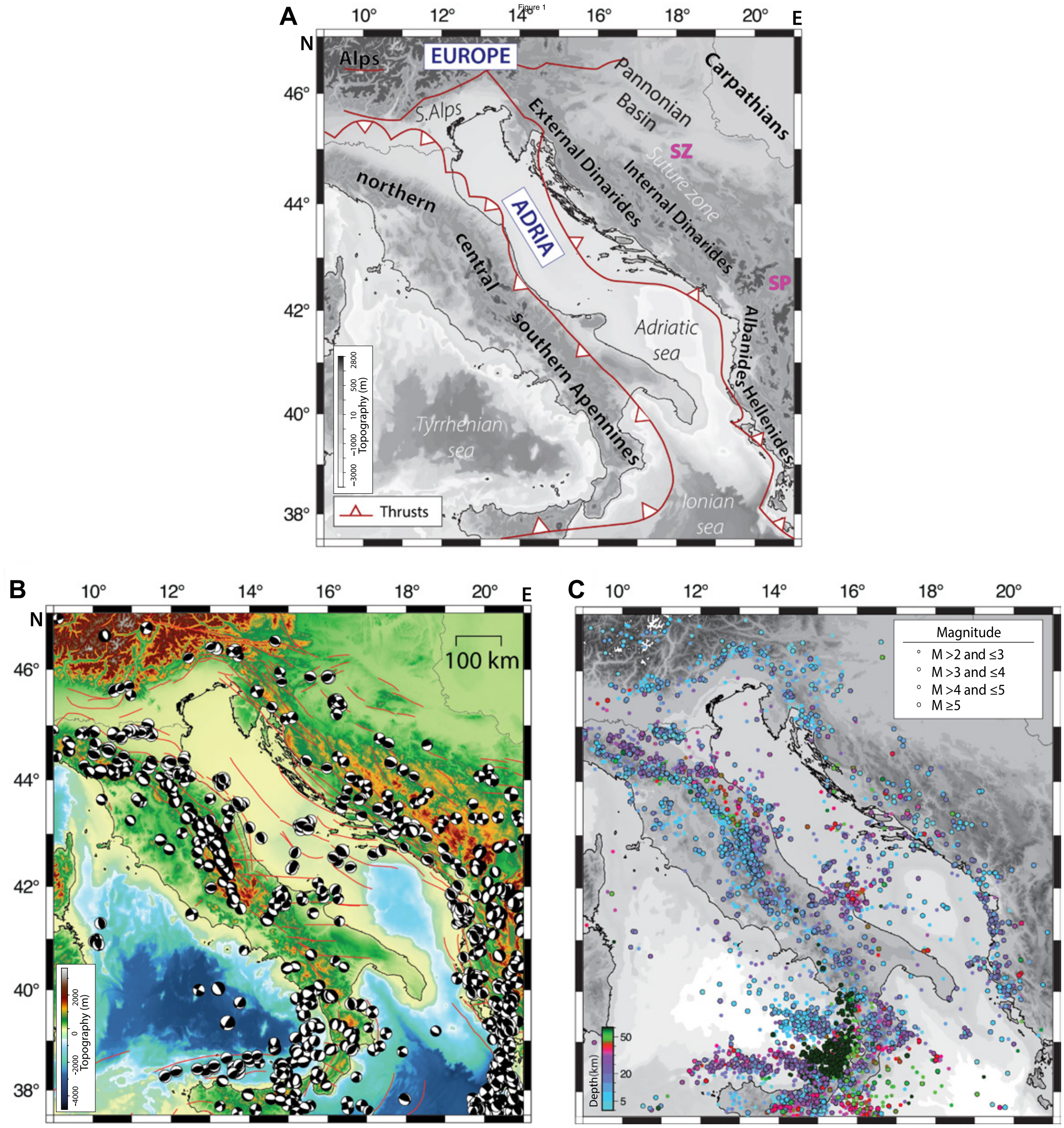

Figure 1. (A) Tectonic map of the Apennines-Dinarides-Hellenides system in the central Mediterranean region. Red triangles are the frontal thrusts. SZ—suture zone; SP—Scutari Pec Zone. (B) Map with main structural lineaments (red lines) and focal mechanisms (extracted from the regional centroid-moment tensors; Pondrelli et al., 2002). (C) Map with 2005–2020 CE seismicity relocated in the one-dimensional model of Menichelli et al. (2022), colored according to depth values.

mantle shows significant variations, especially at depths of 40–60 km (see Fig. S1 in the Supplemental Material[1]). In the northern part of the Adria plate, the mantle exhibits a predominant pattern characterized by high Vp and low Vp/Vs values, marking a distinct continental signature. Conversely, the southern portion displays localized areas with low Vp and high Vp/Vs values. At a depth of 60 km (Fig. 2), a prominent high-Vp anomaly is observed extending from the northern sector (from 43°N to 14–17.2°E) eastward into the inner portion of the Dinarides. Within this high-Vp lithosphere, high Vp/Vs anomalies (hydrated mantle [HM] in Fig. 2B) are present between 50 km and 80 km depth. Two strong and marked low-Vp interruptions are identified in the velocity structure: the first is located at ~43.2°N, 18.8–19.2°E, and the second covers the Albanides region (41–42°N, 19.5–21°E), aligning with a change in the strike of the belt. At 80 km depth, the velocity structure becomes more continuous. A high-Vp anomaly (+3%) aligns with the strike of the Dinarides, spreading into the Adriatic Sea. South of 41°N, a low-Vp anomaly stretches from the Calabrian arc to the Ionian Sea, marked by a sharp transition from west to east. Additionally, a negative Vp/Vs anomaly extends below the Ionian Sea and the central part of the Adriatic, while a smaller positive Vp/Vs anomaly can be found in its northernmost part, extending up to 44° N.

[1]Supplemental Material. Additional figures (S1–S5) and a text analyzing Vp and Vp/Vs perturbations at lithospheric mantle depths, synthetic slab test beneath the Dinarides, checkerboard and recovery tests for the Adria plate, comparisons with previous tomographic studies, and a detailed discussion of the observed velocity anomalies and model comparisons. Please visit https://doi.org/10.1130/GEOL.S.28095581 to access the supplemental material; contact editing@geosociety.org with any questions.

DEEP STRUCTURE OF THE APENNINES AND DINARIDES

The seismic velocity structure shows significant lateral and vertical variations in the Adria lithosphere, indicating a different geometry and, in turn, nature. The main feature that we recovered is a laterally continuous and well-resolved (see Fig. S2) high-velocity lithosphere subducting beneath the two belts, extending down to 100 km in depth and showing an intriguing connection with deeper mantle anomalies (Bijwaard and Spakman, 2000; Piromallo and Morelli, 2003; Ustaszewski et al., 2010; Handy et al., 2015). The plunge of the Adriatic lithospheric mantle is steep beneath the Apennines (from 30° to subvertical) but is almost flat beneath the Dinarides (Fig. 3B). To track how this feature extends into the upper mantle, we integrated our regional model with the teleseismic model of Paffrath et al. (2021). We observe that the high-Vp Adria lithosphere is consistent with

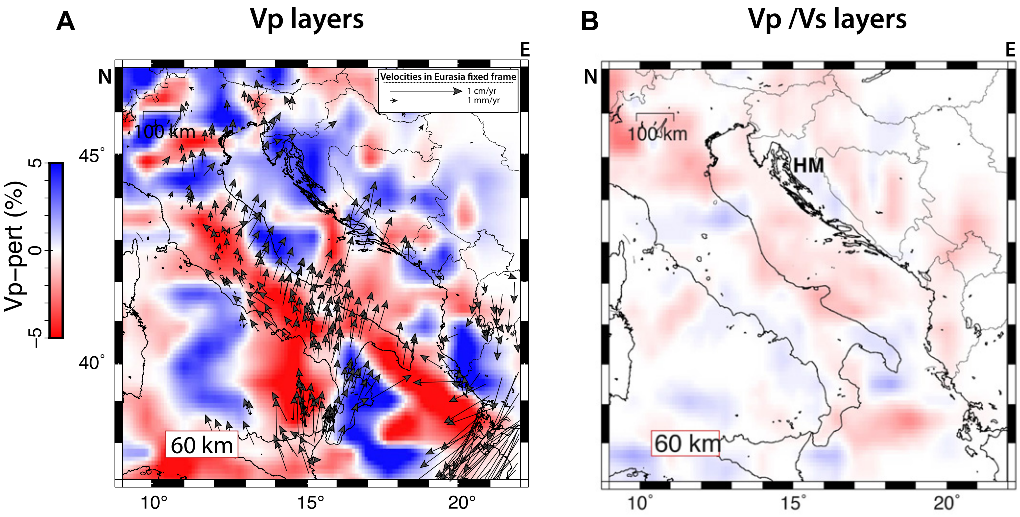

Figure 2. P-wave velocity (Vp) percent perturbation (pert %) (A), and Vp/Vs (Vs—S-wave velocity) percent perturbation layers (B) of the tomographic model of Menichelli et al. (2023) at 60 km depth. Black arrows indicate GPS velocities (mm/yr) extracted from Serpelloni et al. (2022). HM marks the location of the high Vp/Vs upper lithospheric mantle below the northern Dinarides linked to a hydrated mantle.

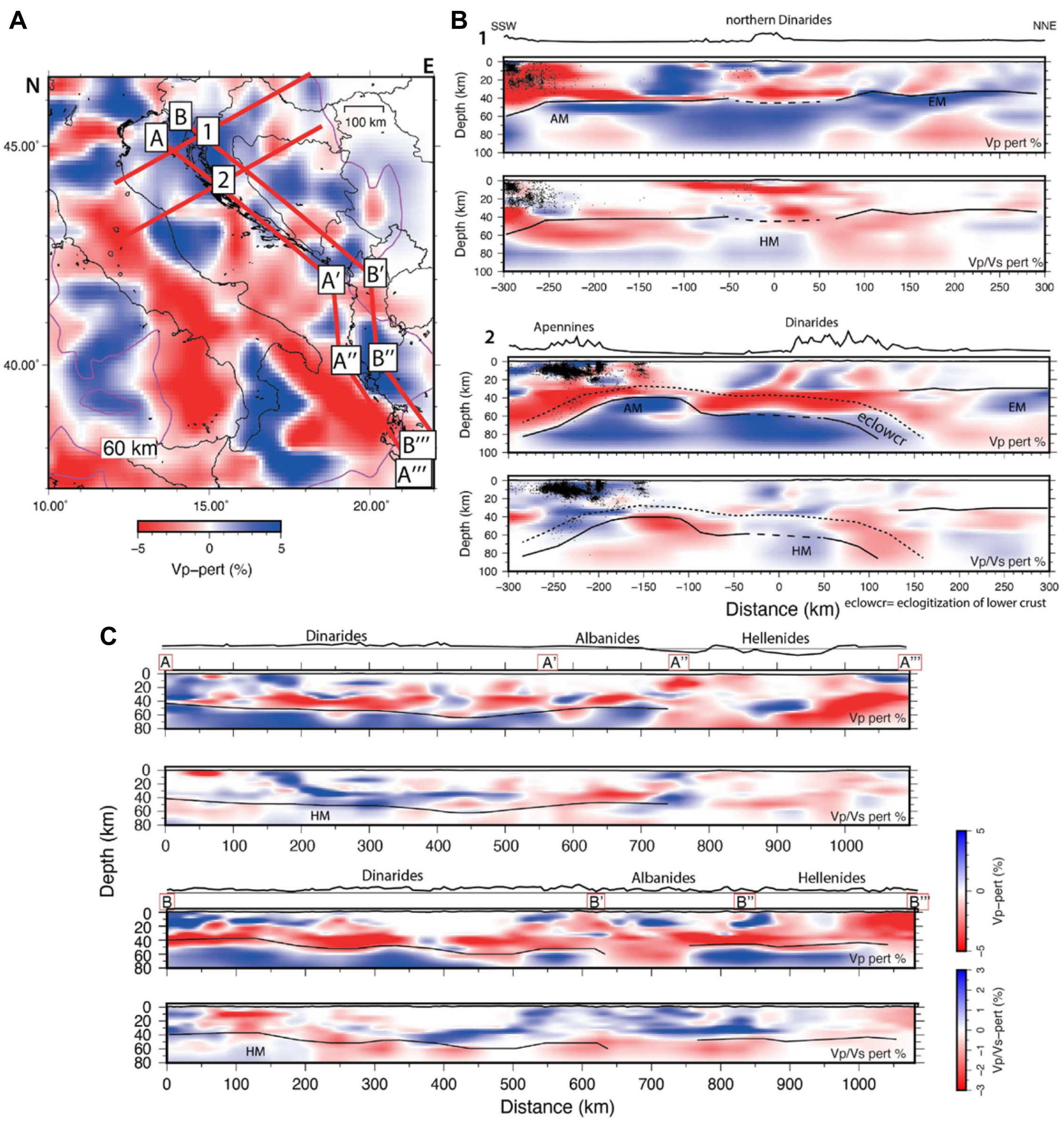

Figure 3. P-wave velocity (Vp) and Vp/Vs (Vs—S-wave velocity) percent perturbation (pert %) at 60 km depth (A) and in cross sections along the Apennines and Dinarides (B) and along the strike of the Dinarides-Albanides system (C). Cross sections are shown in A. HM—hydrated mantle below the northern Dinarides. Black lines indicate the Adria (AM) and European (EM) lithospheric mantle boundary.

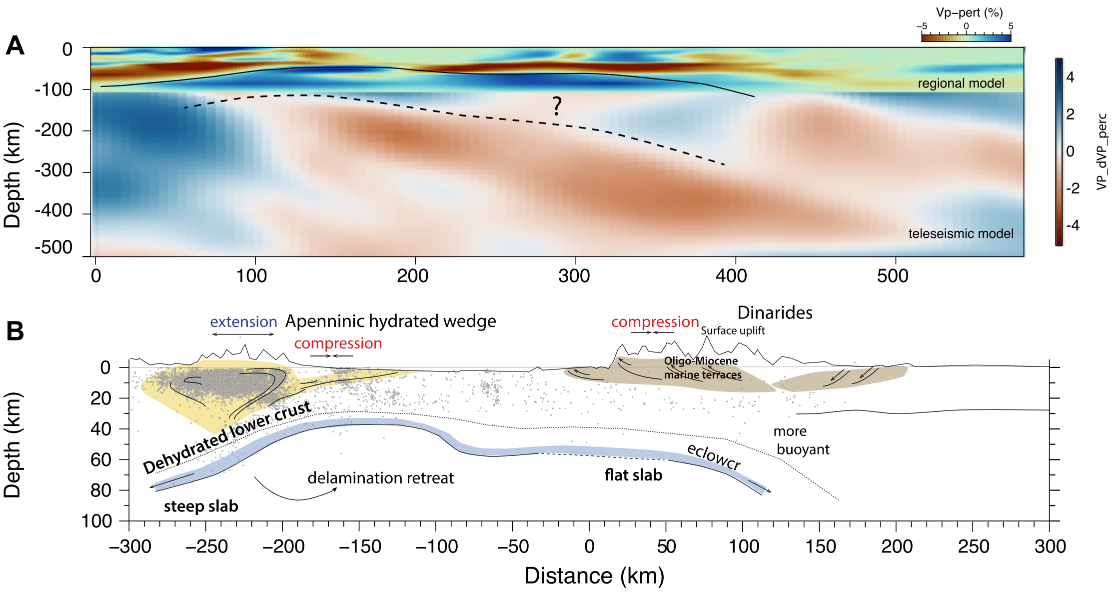

Figure 4. (A) Cross section along the Apennines-Dinarides orogens obtained by merging the regional model of Menichelli et al. (2023) (0–100 km) and the teleseismic model of Paffrath et al. (2021) (100–500 km) using the JuliaGeodynamics Geophysical Model Generator (https://github.com/JuliaGeodynamics/GeophysicalModelGenerator.jl). Vp-pert (%) is P-wave velocity percent perturbation. (B) Geological sketch of the cross section in A. The gray dots represent the seismic events (2005–2022 CE) relocated in the three-dimensional velocity model. The light-brown area defines the Oligocene–Miocene marine terraces, and the yellow area defines the Apenninic wedge. eclowcr—eclogitization of the lower crust.

both steep and flat dips between the opposite orogens. The high-Vp anomaly extends down to 300 km beneath the Dinarides (Fig. 4) and aligns with the results of Sun et al. (2019) and Belinić et al. (2021), resolving the doubts on a slab gap in this region. This high velocity, i.e., east-plunging Adria lithosphere, extends southward until the connection with the Albanides (Fig. 3C), where a strong low-Vp anomaly is consistent with the slab edge of the Hellenides system.

A negative anomaly interrupts the high-Vp Adria lithosphere between the outer and inner Dinarides beneath the HM volume identified by our study, consistent with the low Vs indicated by S-wave receiver function (Stipčević et al., 2020).

DISCUSSION AND CONCLUSIONS

Our new results enhance our understanding of the continental lithosphere structure at depths that are crucial for current tomographic models, offering deeper insights into the mechanisms that drive kinematics and surface processes in orogens. The Adria double subduction beneath the Apennines and Dinarides features different deformative styles: slab peel-back (i.e., lithospheric delamination; see Göğüş et al., 2016) and crustal accumulation, respectively.

The different subduction mechanisms significantly influence active surface deformation (Figs. 1B and 2). In the northern Apennines, the steeper dip of the plunging lithosphere, indicated by positive anomalies and intermediate-depth seismicity, results from the delamination of the Adria lower crust and mantle lithosphere. The high-velocity Adria mantle aligns perfectly with the region where a few millimeters per year of shortening are observed at the front (Fig. 2). The internal mountain range exhibits across-belt extension, on top of a wedge volume that shows low-Vp and high Vp/Vs anomalies (Fig. 3). This wedge serves as a barrier between the stretching crust and the subducting lithosphere. In the Dinarides, flat subduction aligns with underplating of crustal material beneath the belt and indicates a coupling of the two plates. Compression and large earthquakes mainly occur in the inner part of the chain, which corresponds to the deflection of the lithosphere (Fig. 3).

The diffuse pattern of low-Vp and high Vp/Vs anomalies in the Apennines wedge (Fig. 3) suggests that intense hydration, due to fluids released from the underthrusting material, accompanies the delamination process. Below the Dinarides, the transition from low to high Vp anomalies, along with the corresponding decrease of Vp/Vs (Fig. 3B, cross section 2, 40–150 km horizontal distance), marks the eclogitization process of the Adriatic lower crust, from granulitic to eclogitic rocks.

We hypothesize that the different styles of continental subduction, whether steep or flat, and the associated deformation, are influenced by the rheology of the continental lithosphere and the varying degrees of fluids released during the underthrusting of the lower crust (Piana Agostinetti et al., 2011). This process enhances slab peel-back (Fig. 4), promoting delamination retreat (Chiarabba et al., 2014), extension across the mountain belt, uplift, and slab verticalization. In contrast, the dehydration of the Adria lower crust and delamination are less prominent in the Dinarides. In this region, the bending of the lithosphere is less pronounced and occurs at a slower rate, possibly due to either higher lithospheric buoyancy or interactions with the retreat of the Apennines and the associated mantle circulation (Király et al., 2018; van Unen et al., 2019). The former hypothesis is supported by the HM anomaly (Figs. 2 and 3) that may indicate a change in the composition of the continental mantle due to the presence of hydrated material.

The geometry of the shallow subduction system and the maturity of delamination can be explained by varying subduction velocities, which tend to be faster in areas where the peeled lithosphere is denser. According to Lallemand et al. (2008), variations in the continental plate's resistance to bending can promote trench advance, seismic activity, and compressional spreading, which is likely applicable also to the inner Dinaric belt. Conversely, systems experiencing trench retreat, such as the Apennines, are characterized by paired frontal compression and inner extension. Additionally, the subduction of a more buoyant lithosphere, as in the Dinarides, may slow this process, contributing to the advance of the compressional front and altering surface uplift between the external and internal belts (Balling et al., 2021). This is consistent with results from numerical modeling (Göğüş et al. 2016). Therefore, the asymmetrical evolution beneath mountain chains can be attributed to the varying buoyancy of the continental lithosphere, which reduces the slab pull force (Király et al., 2018).

In summary, our work highlights how the rheological and compositional heterogeneities within the lithosphere can significantly affect the behavior of continental subduction. Different conditions can lead to varying degrees of delamination which, in turn, can tune the buoyancy of the slab and influence the overall buoyancy of the continental lithosphere. Specifically, when applying these observations to the central Mediterranean region, our findings suggest that in flat continental subduction, underplating is the dominant process and compression is transmitted to the inner portion of the mountain chain. In contrast, when the lithosphere plunges subvertically, slab peeling becomes more pronounced, resulting in the separation of the less dense part of the crust. This process creates a decoupled lower section, leading to a paired system where compression is observed at the front of the belt and extension beneath it. We hypothesize that the variations in subduction styles are primarily due to differences in the continental mantle, which is influenced by whether delamination or underplating is more significant in the given contrast.

ACKNOWLEDGMENTS

For further information, visit http://www.alparray.ethz.ch. Section 2 shown in Figure 4 (top panel) was plotted using the JuliaGeodynamic Geophysical Model Generator (https://github.com/JuliaGeodynamics/GeophysicalModelGenerator.jl). We gratefully acknowledge a grant to the Department of Science, Roma Tre University (Ministero dell'Istruzione e del Merito–Italy Dipartimenti di Eccellenza), European Plate Observing System Italia, Fondo Italiano per la Scienza SCALEMOD, and Piano Nazionale di Ripresa e Resilienza–MEET. We thank reviewers O.H. Göğüş and E. Willingshofer for very constructive comments and science editor Marc Norman for his support.

REFERENCES CITED

Agostinetti, N.P., Bianchi, I., Amato, A., and Chiarabba, C., 2011, Fluid migration in continental subduction: The Northern Apennines case study: Earth and Planetary Science Letters, v. 302, p. 267–278, https://doi.org/10.1016/j.epsl.2010.10.039.

Balling, P., Grützner, C., Tomljenović, B., Spakman, W., and Ustaszewski, K., 2021, Post-collisional mantle delamination in the Dinarides implied from staircases of Oligo-Miocene uplifted marine terraces: Scientific Reports, v. 11, 2685, https://doi.org/10.1038/s41598-021-81561-5.

Belinić, T., Kolínský, P., Stipčević, J., and the AlpArray Working Group, 2021, Shear-wave velocity structure beneath the Dinarides from the inversion of Rayleigh-wave dispersion: Earth and Planetary Science Letters, v. 555, https://doi.org/10.1016/j.epsl.2020.116686.

Bijwaard, H., and Spakman, W., 2000, Non-linear global p-wave tomography by iterated linearized inversion: Geophysical Journal International, v. 141, p. 71–82, https://doi.org/10.1046/j.1365-246X.2000.00053.x.

Chiarabba, C., Giacomuzzi, G., Bianchi, I., Agostinetti, N.P., and Park, J., 2014, From underplating to delamination-retreat in the northern Apennines: Earth and Planetary Science Letters, v. 403, p. 108–116, https://doi.org/10.1016/j.epsl.2014.06.041.

Chiarabba, C., Menichelli, I., Bianchi, I., Giacomuzzi, G., and De Gori, P., 2023, Continental subduction of Adria in the Apennines and relation with seismicity and hazard: Frontiers of Earth Science, v. 11, https://doi.org/10.3389/feart.2023.1253443.

Dewey, J.F., Helman, M.,L. Knott, S.D., Turco, E., and Hutton, D.H.W., 1989, Kinematics of the western Mediterranean, *in* Coward, M.P., et al., eds., Alpine Tectonics: Geological Society, London, Special Publications, v. 45, p. 265–283, https://doi.org/10.1144/GSL.SP.1989.045.01.15.

Doglioni, C., Carminati, E., Cuffaro, M., and Scrocca, D., 2007, Subduction kinematics and dynamic constraints: Earth-Science Reviews, v. 83, p. 125–175, https://doi.org/10.1016/j.earscirev.2007.04.001.

Faccenna, C., Piromallo, C., Crespo-Blanc, A., Jolivet, L., and Rossetti, F., 2004, Lateral slab deformation and the origin of the western Mediterranean arcs: Tectonics, v. 23, TC1012, https://doi.org/10.1029/2002TC001488.

Giacomuzzi, G., Civalleri, M., De Gori, P., and Chiarabba, C., 2012, A 3D Vs model of the upper mantle beneath Italy: Insight on the geodynamics of central Mediterranean: Earth and Planetary Science Letters, v. 335–336, p. 105–120, https://doi.org/10.1016/j.epsl.2012.05.004.

Giacomuzzi, G., De Gori, P., and Chiarabba, C., 2022, How mantle heterogeneities drive continental subduction and magmatism in the Apennines: Scientific Reports, v. 12, 13631, https://doi.org/10.1038/s41598-022-17715-w.

Göğüş, O.H., Pysklywec, R.N., and Faccenna, C., 2016, Postcollisional lithospheric evolution of the southeast Carpathians: Comparison of geodynamical models and observations: Tectonics, v. 35, p. 1205–1224, https://doi.org/10.1002/2015TC004096.

Handy, M.R., Ustaszewski, K., and Kissling, E., 2015, Reconstructing the Alps–Carpathians–Dinarides as a key to understanding switches in subduction polarity, slab gaps and surface motion: International Journal of Earth Sciences, v. 104, p. 1–26, https://doi.org/10.1007/s00531-014-1060-3.

Király, Á., Faccenna, C., and Funiciello, F., 2018, Subduction zones interaction around the Adria microplate and the origin of the Apenninic arc: Tectonics, v. 37, p. 3941–3953, https://doi.org/10.1029/2018TC005211.

Kissling, E., 2024, Adria microplate: A puzzling key stone in west-central Mediterranean geodynamics: Annals of Geophysics, v. 67, p. S431, https://doi.org/10.4401/ag-9160.

Koulakov, I., Kaban, M.K., Tesauro, M., and Cloetingh, S., 2009, P- and S-velocity anomalies in the upper mantle beneath Europe from tomographic inversion of ISC data: Geophysical Journal International, v. 179, p. 345–366, https://doi.org/10.1111/j.1365-246X.2009.04279.x.

Lallemand, S., Heuret, A., Faccenna, C., and Funiciello, F., 2008, Subduction dynamics as revealed by trench migration: Tectonics, v. 27, https://doi.org/10.1029/2007TC002212.

McKenzie, D., 1972, Active tectonics of the Mediterranean region: Geophysical Journal International, v. 30, p. 109–185, https://doi.org/10.1111/j.1365-246X.1972.tb02351.x.

Menichelli, I., et al., 2022, Minimum 1D V_P and V_P/V_S models and hypocentral determinations in the central Mediterranean area: Seismological Society of America, v. 93, p. 2670–2685, https://doi.org/10.1785/0220220079.

Menichelli, I., De Gori, P., Lucente, F.P., Improta, L., and Chiarabba, C., 2023, Lithosphere structure, processes and physical state of the Alpine-Apennine system: Journal of Geophysical Research: Solid Earth, v. 128, https://doi.org/10.1029/2023JB026411.

Paffrath, M., et al., 2021, Imaging structure and geometry of slabs in the greater Alpine area—A P-wave travel-time tomography using AlpArray seismic network data: Solid Earth, v. 12, p. 2671–2702, https://doi.org/10.5194/se-12-2671-2021.

Piromallo, C., and Morelli, A., 2003, P wave tomography of the mantle under the Alpine-Mediterranean area: Journal of Geophysical Research: Solid Earth, v. 108, B2, p. 1–23, https://doi.org/10.1029/2002JB001757.

Pondrelli, S., Morelli, A., Ekström, G., Mazza, S., Boschi, E., and Dziewonski, A.M., 2002, European–Mediterranean regional centroid-moment tensors: 1997–2000: Physics of the Earth and Planetary Interiors, v. 130, p. 71–101, https://doi.org/10.1016/S0031-9201(01)00312-0.

Regard, V., Faccenna, C., Martinod, J., Bellier, O., and Thomas, J.-C., 2003, From subduction to collision: Control of deep processes on the evolution of convergent plate boundary: Journal of Geophysical Research: Solid Earth, v. 108, B4, https://doi.org/10.1029/2002JB001943.

Ranalli, G., Pellegrini, R., and D'Offizi, S., 2000, Time dependence of negative buoyancy and the subduction of continental lithosphere: Journal of Geodynamics, v. 30, p. 539–555, https://doi.org/10.1016/S0264-3707(00)00011-9.

Rosenbaum, G., Gasparon, M., Lucente, F.P., Peccerillo, A., and Miller, M.S., 2008, Kinematics of slab tear faults during subduction segmentation and implications for Italian magmatism: Tectonics, v. 27, https://doi.org/10.1029/2007TC002143.

Royden, L.H., and Husson, L., 2009, Subduction with variations in slab buoyancy: Models and application to the Banda and Apennine systems, *in* Lallemand, S., and Funiciello, F., eds., Subduction Zone Geodynamics: Berlin, Springer p. 35–45, https://doi.org/10.1007/978-3-540-87974-9_2.

Royden, L., and Faccenna, C., 2018, Subduction orogeny and the Late Cenozoic evolution of the Mediterranean arcs: Annual Review of Earth and Planetary Sciences, v. 46, p. 261–289, https://doi.org/10.1146/annurev-earth-060115-012419.

Serpelloni, E., Cavaliere, A., Martelli, L., Pintori, F., Anderlini, L., Borghi, A., and Cacciaguerra, S., 2022, Surface velocities and strain-rates in the Euro-Mediterranean region from massive GPS data processing: Frontiers of Earth Science, v. 10, https://doi.org/10.3389/feart.2022.907897.

Stipčević, J., Herak, M., Molinari, I., Dasović, I., Tkalčić, H., and Gosar, A., 2020, Crustal thickness beneath the Dinarides and surrounding areas from receiver functions: Tectonics, v. 39, https://doi.org/10.1029/2019TC005872.

Šumanovac, F., Markušić, S., Engelsfeld, T., Jurković, K., and Orešković, J., 2017, Shallow and deep lithosphere slabs beneath the Dinarides from teleseismic tomography as the result of the Adriatic lithosphere downwelling: Tectonophysics, v. 712, p. 523–541, https://doi.org/10.1016/j.tecto.2017.06.018.

Sun, W., Malusà, M., Zhao, L., Guillot, S., and Fu, L.-Y., 2019, Continental subduction without a precursor oceanic slab: geological and geophysical evidence from the Adria-Europe plate boundary zone: Geophysical Research Abstracts, v. 21, https://meetingorganizer.copernicus.org/EGU2019/EGU2019-5581-2.pdf.

Ustaszewski, K., Kounov, A., Schmid, S.M., Schaltegger, U., Krenn, E., Frank, W., and Fügenschuh, B., 2010, Evolution of the Adria-Europe plate boundary in the northern Dinarides: From continent-continent collision to back-arc extension: Tectonics, v. 29, https://doi.org/10.1029/2010TC002668.

van Unen, M., Matenco, L., Demir, V., Nader, F.H., Darnault, R., and Mandic, O., 2019, Transfer of deformation during indentation: Inferences from the post-middle Miocene evolution of the Dinarides: Global and Planetary Change, v. 182, https://doi.org/10.1016/j.gloplacha.2019.103027.

Printed in the USA