geosciences

MDPI

Article

Basic Role of Extrusion Processes in the Late Cenozoic Evolution of the Western and Central Mediterranean Belts

Marcello Viti [1,*], Enzo Mantovani [1], Daniele Babbucci [1], Caterina Tamburelli [1], Marcello Caggiati [2] and Alberto Riva [2]

[1] Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università di Siena, 53100 Siena, Italy; enzo.mantovani@unisi.it (E.M.); babbucci@unisi.it (D.B.); tamburelli@unisi.it (C.T.)
[2] Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, 44121 Ferrara, Italy; marcello.caggiati@unife.it (M.C.); alberto.riva@unife.it (A.R.)
* Correspondence: marcello.viti@unisi.it

Abstract: Tectonic activity in the Mediterranean area (involving migrations of old orogenic belts, formation of basins and building of orogenic systems) has been determined by the convergence of the confining plates (Nubia, Arabia and Eurasia). Such convergence has been mainly accommodated by the consumption of oceanic and thinned continental domains, triggered by the lateral escapes of orogenic wedges. Here, we argue that the implications of the above basic concepts can allow plausible explanations for the very complex time-space distribution of tectonic processes in the study area, with particular regard to the development of Trench-Arc-Back Arc systems. In the late Oligocene and lower–middle Miocene, the consumption of the eastern Alpine Tethys oceanic domain was caused by the eastward to SE ward migration/bending of the Alpine–Iberian belt, driven by the Nubia–Eurasia convergence. The crustal stretching that developed in the wake of that migrating Arc led to formation of the Balearic basin, whereas accretionary activity along the trench zone formed the Apennine belt. Since the collision of the Anatolian–Aegean–Pelagonian system (extruding westward in response to the indentation of the Arabian promontory) with the Nubia-Adriatic continental domain, around the late Miocene–early Pliocene, the tectonic setting in the central Mediterranean area underwent a major reorganization, aimed at activating a less resisted shortening pattern, which led to the consumption of the remnant oceanic and thinned continental domains in the central Mediterranean area.

Keywords: Mediterranean tectonics; extrusion; trench-arc-back arc systems

Citation: Viti, M.; Mantovani, E.; Babbucci, D.; Tamburelli, C.; Caggiati, M.; Riva, A. Basic Role of Extrusion Processes in the Late Cenozoic Evolution of the Western and Central Mediterranean Belts. *Geosciences* **2021**, *11*, 499. https://doi.org/10.3390/geosciences11120499

Academic Editors: Rodolfo Carosi, Mario da Costa Campos Neto, Haakon Fossen, Chiara Montomoli, Matteo Simonetti, Olivier Lacombe and Jesus Martinez-Frias

Received: 15 October 2021
Accepted: 2 December 2021
Published: 7 December 2021

1. Introduction

Since the Oligocene, the tectonic and morphological configuration of the Mediterranean region (Figure 1A) has considerably changed (e.g., [1–18]), involving long migrations (even greater than 1000 km) and strong distortions of old and new orogenic belts (hereafter Arcs) and the formation of extensional zones backwards of the migrating belts (Back-Arc basins, Figure 1B).

In the Central-Western Mediterranean area this kind of tectonic processes, which are interlinked to form Trench-Arc-Back Arc (TABA) systems (as sketched in Figure 2), developed in the Balearic and Tyrrhenian regions (e.g., [18–22]).

The Balearic basin (including the Liguro–Provencal and Algerian basins) developed from the Late Oligocene to the middle–late Miocene, in the wake of the migrating Alpine-Iberian–Apennine (Northern Arc) and Alpine–Iberian–Maghrebian (Southern Arc) belts. The internal parts of these Arcs included the Corsica-Sardinia and the AlKaPeCa (Alboran, Kabilides, Peloritani and Calabria) European continental fragments [23–25].

During this phase, the subduction of the Alpine Tethys oceanic domain produced accretionary activity along the outer fronts of the Northern Arc (forming the Apennine belt) and then of the Southern Arc (forming the Maghrebian belt). The migration of the Northern Arc ended in the Middle Miocene when it collided with the continental Adriatic domain. The Southern Arc stopped migrating in the Late Miocene, when it collided with the continental Nubian domain. These events determined the slowdown and then cessation of crustal stretching in the Balearic basin. In the subsequent evolution, the Maghrebian belt did not experience major tectonic events, whereas the Alpine–Apennine belt underwent a rather complex deformation pattern, involving a further east and southeastward migration, longitudinal shortening and important changes of strain regime. Around the late Miocene–early Pliocene, the tectonic setting in the central Mediterranean region underwent a drastic reorganization, with the activation of several major tectonic processes.

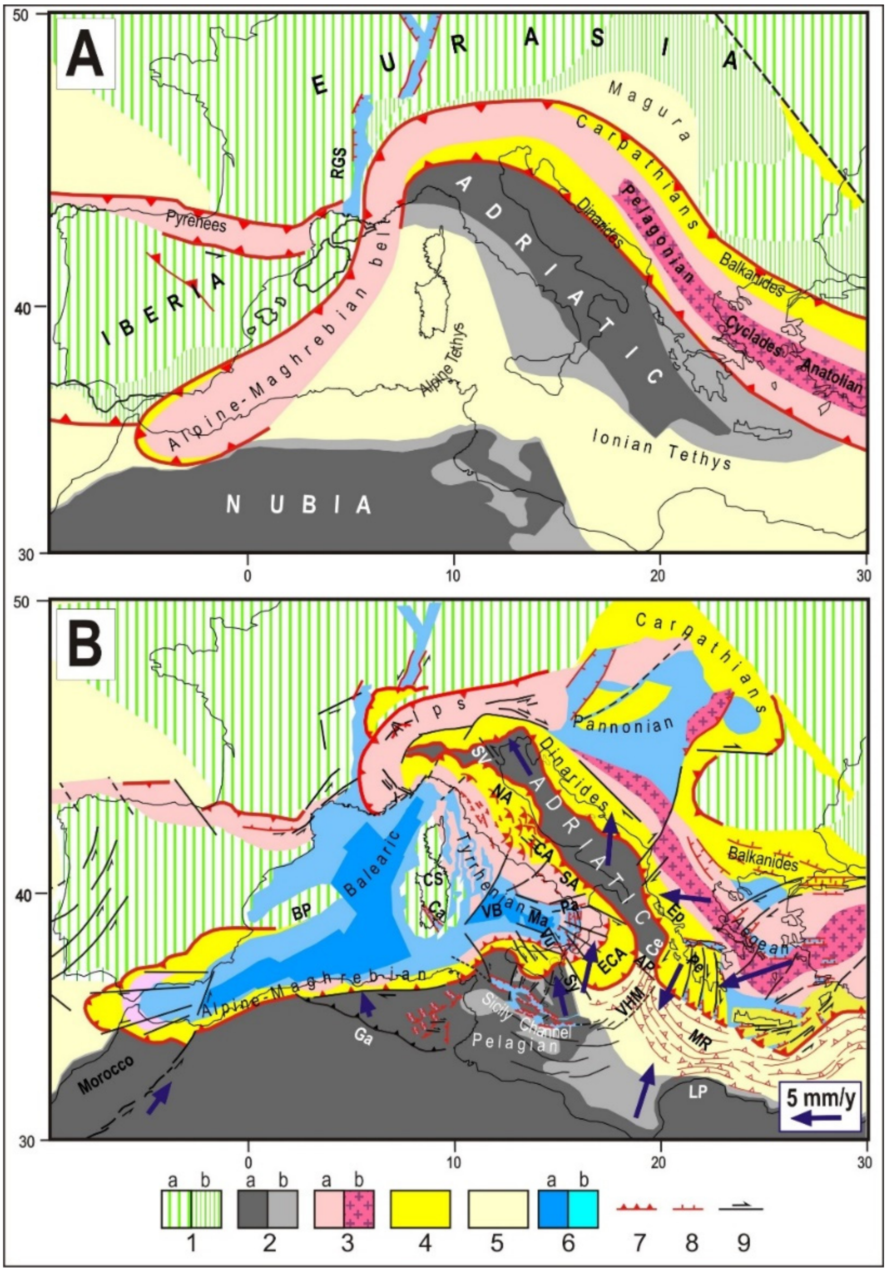

Figure 1. (**A**) Oligocene paleogeographic configuration. (**B**) Present tectonic setting. (**1a,b**) Continental and thinned continental Eurasian domains. (**2a,b**) Continental and thinned continental African/Adriatic domains (**3a,b**) Tethyan belt, constituted by ophiolitic and metamorphic units and crystalline massifs (**4**) Other orogenic belts (**5**) Oceanic domains (eastern Alpine and Ionian Tethys) (**6a,b**) Zones affected by intense or moderate crustal thinning (**7,8,9**) Compressional, tensional and strike-slip features. Ap = Apulian escarpment, BP = Balearic Promontory, CA = Central Apennines, Ca = Campidano graben, Ce = Cephalonia fault system; CS = Corsica-Sardinia block, ECA = External

Calabrian accretionary belt, Ep = Epirus; Ga = Gafsa Fault; LP = Libyan promontory; Ma = Marsili basin; MR = Mediterranean Ridge; NA = Northern Apennines; Pa = Palinuro fault; Pe = Peloponnesus; RGS = Rhine Graben System, Sy = Syracuse fault system SA = Southern Apennines; SV = Schio–Vicenza fault; VB = Vavilov basin, VHM = Victor–Hensen–Medina fault system, Vu = Vulcano fault. Blue arrows indicate the average long-term kinematic pattern [13,26,27]. Present geographical contours (thin black lines) are reported for reference.

Various hypotheses have been advanced about the geodynamic context responsible for such a complex time-space distribution of tectonic processes. In the recent literature, the most cited interpretations are the ones that are generally identified as “slab-pull” and “extrusion” models. The first suppose that the migration of the Arc is caused by the retreat of the trench, driven by the gravitational sinking of subducted lithosphere (e.g., [18,19,28,29]). The second model does not assume any additional driving force with respect to that postulated by Plate Tectonics, i.e., the relative motions of the confining plates (Nubia, Arabia and Eurasia); the migration of the Arc is explained as an effect of belt-parallel compression, that induces the decoupling of the Arc from the related foreland and then forces its lateral displacement, at the expense of thinned domains (Figure 2, e.g., [10–13,30–32]. In both models, the formation of the Back Arc basin is interpreted as an effect of the divergence between the migrating Arc and the stable foreland.

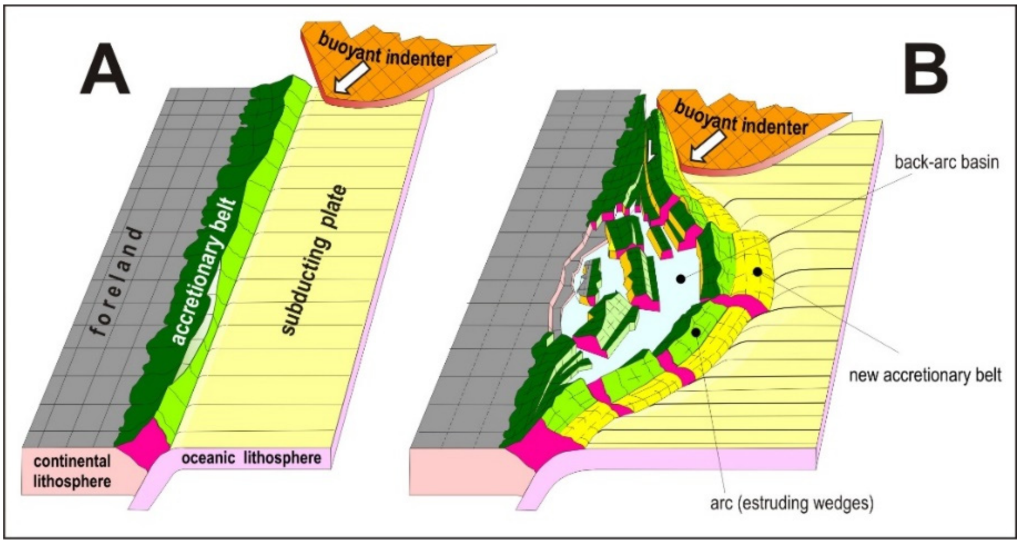

Figure 2. Sketch of the tectonic process that is supposed to generate TABA systems. (**A**) An orogenic belt, flanked by an oceanic domain, is longitudinally stressed by a continental indenter. (**B**) The stressed structure detaches from the foreland and undergoes uplift and oroclinal bending, through the lateral escape of crustal wedges. The extruded orogenic material overthrusts the oceanic domain inducing its downward flexure and consequent sinking. The separation of the migrating and bowing Arc from the overriding plate induces crustal extension in the interposed zone (Back Arc basin), whereas accretionary activity occurs at the front of the extruding Arc. See [33,34] for laboratory modeling of that process.

This work suggests that plausible and coherent explanations of the observed deformation pattern in the study area can be identified by assuming that in the constrictional contexts created by plate convergence the least resisted shortening process was the consumption of oceanic or thinned continental domains where such process was favoured by the lateral escape of orogenic wedges (Figure 2).

On the other hand, we point out that the implications of the slab-pull model cannot be reconciled with several major features of the observed deformation pattern.

Some considerations are also made about the uncertainty that still surrounds the trend of the Nubia-Eurasia convergence [26,27].

2. Oligocene Configuration, Driving Forces and Tectonic Processes

The initial configuration of the Western and Central Mediterranean regions shown in Figure 1A derives from previously proposed paleogeographic maps (e.g., [1,5,6,16,18,24,35–46]). In the Oligocene the Nubia and Eurasia plates were separated by a heterogeneous structure, constituted by a continental domain (Adriatic core, e.g., [38,47]) surrounded by oceanic and thinned continental domains (e.g., [5,6,41,48–52]) and by a long orogenic system (Tethyan belt) constituted by an inner metamorphic belt generated by the consumption of the Tethys domain since the Cretaceous and by accretion of continental fragments interposed between small oceanic basins (e.g., [14,24,25,53–58]). The Tethyan belt was flanked by two external accretionary chains (yellow in Figure 1), one with European affinity, Carpathians and Balkanides, and one with African affinity, Dinarides and Taurides (e.g., [35,45,55,59–61]).

Plate tectonics provide that deformation in the upper crust, is driven by the relative motions of plates. In the Mediterranean region, this implies that tectonic processes are determined by the convergence of the confining plates (Nubia, Arabia and Eurasia). The shortening processes that have accommodated such convergence involved subduction, crustal thickening and lateral escape of buoyant crustal wedges at the expense of low buoyancy lithosphere (Figure 2, [10–12]). In a given evolutionary phase, the time-space distribution of shortening processes is controlled by the well-known minimum-action principle (e.g., [62–64]). This principle also controls the dimension and nature of the extruded wedges. The activation of an extrusion process is due to the fact that in the related geodynamic context the lateral escape of the migrating Arc (mainly constituted by orogenic material), at the expense of a low buoyancy domain) opposes a lower resistance with respect to the buoyancy reaction which would be induced by the sinking (or uplift) of that light material. Thus, the portion of the upper crust that is forced to decouple from its substratum (to shorten the compressed structure in the direction of maximum stress) depends on several factors, such as the strength of the driving force, the composition and thickness of the stressed crust, the presence of weak zones inside the crust, the activation of major decoupling fault system between the Arc and the related foreland. Further considerations about this problem and some examples of the structural features of migrating Arcs in the study area are given in the next sections.

The consumption of old and cold oceanic lithosphere, devoid of intracrustal asthenospheric layers [65,66] is the less resisted kind of subduction, since such lithosphere is considerably denser than the surrounding mantle [67] and thus subducts as a whole, only leaving very limited amounts of accreted material (mostly light oceanic sediments) at the trench zone. When the subducting lithosphere has a continental character, its sinking is accompanied by the decoupling between the non-buoyant mantle part of the lithosphere and the buoyant upper crust. In this case, the amount of material accumulated at the trench zone increases considerably, as well as the work needed for fracturing and imbricating brittle upper crustal slivers and for intruding ductile lower crustal material inside or under the crust of the overriding plate (e.g., [68,69]). Thus, the underthrust of the thick continental crust may cause the end of subduction, depending on the alternative shortening processes (as lateral escape of buoyant wedges at the expense of oceanic domains) that can be activated in the surrounding zones.

The computation of rheological profiles in various structural provinces of the Mediterranean area (e.g., [70]) indicates that lithosphere devoid of ductile decoupling layers only exists in the Ionian and Levantine old oceanic domains, whereas a ductile lower crust is present in most of the Mediterranean zones.

To recognize the most convenient shortening processes it is necessary to integrate the above concepts with basic evidence, i.e., the fact that in the previous Eocene-Oligocene evolution the remnants of the Mesozoic Tethyan oceanic domains did not undergo any subduction, despite the very strong compression they were subjected to during the long collisional phase between the Nubia–Adriatic and Eurasia plates (e.g., [58,71–73]). This means that the consumption of an oceanic lithosphere may not simply occurs as an effect of plate convergence. Such a behavior is consistent with long-term rheological profiles (e.g., [70]), which indicate that in geological time intervals the oceanic lithosphere is characterized by a horizontal compressional strength larger than the one of a continental domain. This concept is supported by the behaviour of oceanic domains in various zones of the world (e.g., [74–76]).

Thus, to explain why since the Oligocene the subduction of oceanic lithosphere has occurred in various Mediterranean zones, it is necessary to recognize which were the different conditions (with respect to the Eocene context) that allowed such process to occur. The above problem could be solved by taking into account what happens in an extrusion process, in particular the fact that the margin of an oceanic domain being overthrust by the extruding orogenic material, undergoes downward flexure, due to isostasy (Figure 2). This perturbs the previous equilibrium in the collision zone, triggering the sinking of the denser oceanic lithosphere, which then goes on, being driven by plate convergence ([33,77]). The results of numerical (e.g., [78–80]) and laboratory (e.g., [33,34,81–83]) experiments testify that in zones of plate convergence the lateral escape of buoyant orogenic wedges is the most convenient shortening process and that crustal extension may develop in the wake of a migrating arc.

Once a stationary least-action complex of shortening processes is reached, that tectonic context lasts until when a significant increase in resistance occurs in one or more of the consuming boundaries. This may occur, for instance, when continental crust enters a trench zone, causing a considerable increase in buoyancy forces against any further subduction (e.g., [84,85] and references therein). The tectonic reorganization that may follow such an event, aimed at developing a new least-action tectonic configuration, depends on the nature of the lithosphere involved in the collision zone and the surrounding area. If low buoyancy oceanic lithosphere is not present in that area the underthrust process goes on, despite the increased resistance. In such a context the amount of buoyant crustal material scraped off the descending lithosphere and accumulated in the trench zone and below the upper crust of the overriding plate increases significantly, causing crustal thickening and uplift in that collision zone (e.g., [69,86,87]**).** This kind of process led to the formation of large and elevated accretionary belts in the India-Eurasia collisional boundary,

If, instead, low buoyancy lithosphere is present somewhere in the surrounding regions, the above process may be interrupted by the formation of major fault systems, which behave as lateral guides for the extrusion of buoyant upper crustal wedges from the constricted zones towards weak lateral boundaries (e.g., [10–13,32,88–90]). A well-known example of this process is the widely recognized lateral escape of Anatolia from the indentation of the Arabian promontory [91–94]. Extrusion of wedges allows releasing stress in front of the indenter (e.g., [95]), thus the starting of extrusion generally coincides with the end of accretionary activity (suture) at the old consuming boundary. Gravitational spreading of crustal material away from the most thickened and uplifted zones may contribute to drive the lateral escape of crustal wedges towards thinner, possibly oceanic, adjacent structures (e.g., [69,92]). In line with the above considerations, we will use the term "collision" to identify the beginning of interaction between two converging continental domains and the term "suture" to identify the end of accretionary activity and welding of the colliding blocks. The plausibility of extrusion processes and their possible importance in the generation of back arc basins have been quantitatively demonstrated by a number of authors (e.g., [78,81,83,89,95–99]).

The most debated problem in the Mediterranean region concerns the driving force of the migrating Arcs in the TABA Balearic and Tyrrhenian systems.

In this regard, one must take into account the crucial role played by the westward displacement of the Anatolian-Aegean-Pelagonian system (e.g., [90] and references therein, [100,101]) and its interaction with the Nubia-Adriatic plate. Until the late Miocene, the convergence between the above system and the Nubia–Adriatic plate was accommodated by the consumption of the interposed thinned continental domain (Pindos zone, [102–104]). After the consumption of such zone the westward push of the Anatolian-Aegean–Pelagonian system caused a drastic reorganization of the tectonic setting in the central Mediterranean region, aimed at activating extrusion processes at the expense of the oceanic and thinned continental domains that lay west of the Adriatic continental core.

3. From the Late Oligocene to the Middle-Late Miocene (Migration of the Alpine-Iberian Belt, Building of the Apennine Belt and Formation of the Balearic Basin)

It is widely agreed that, around the late Oligocene, the Alpine–Iberian belt (Arc), along with a fragment of the European foreland (the Sardinia–Corsica–Balearic Promontory block) detached from Western Europe (Figure 3) and then underwent considerable East to Southeast ward migration and bending until the Middle Miocene, at the expense of the eastern Alpine Tethys oceanic domain (e.g., [13] and references therein). In the wake of the migrating Arc extensional tectonics occurred leading to the formation of the Balearic Back Arc basin (Figure 4), whereas accretionary activity developed along the trench zones, forming the Apennine and Maghrebian belts.

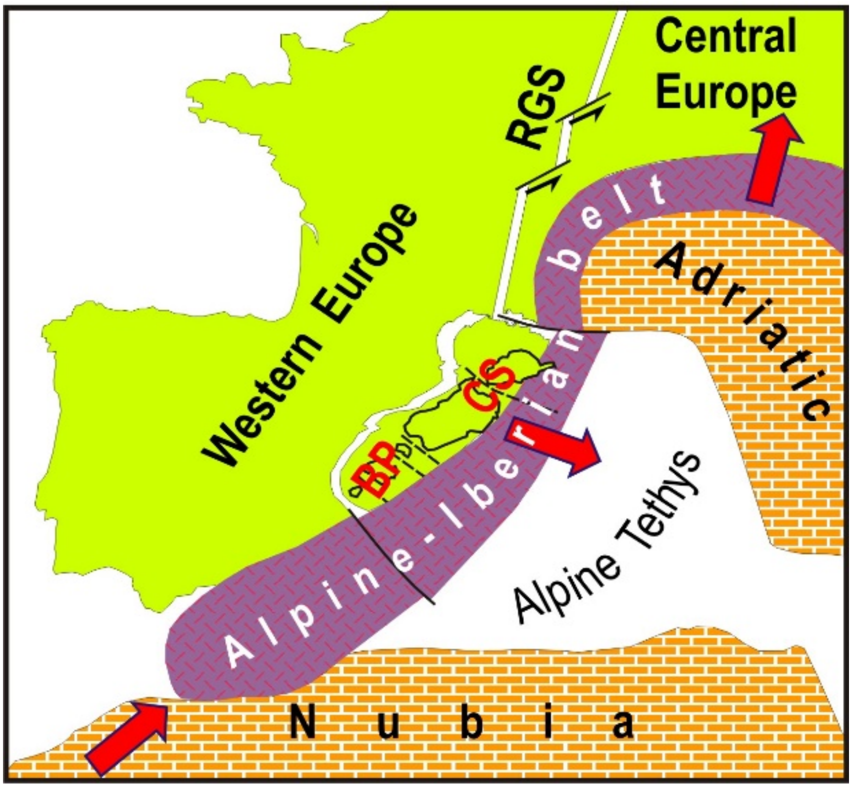

Figure 3. After the collision of the Alpine–Iberian belt with the continental African domain, the Northeastward push of Nubia was transmitted to Central Europe, causing the formation of a sinistral transtensional fault system, running from Western Europe to the Rhine Graben System (RGS). BP = Balearic promontory, CS = Corsica Sardinia.

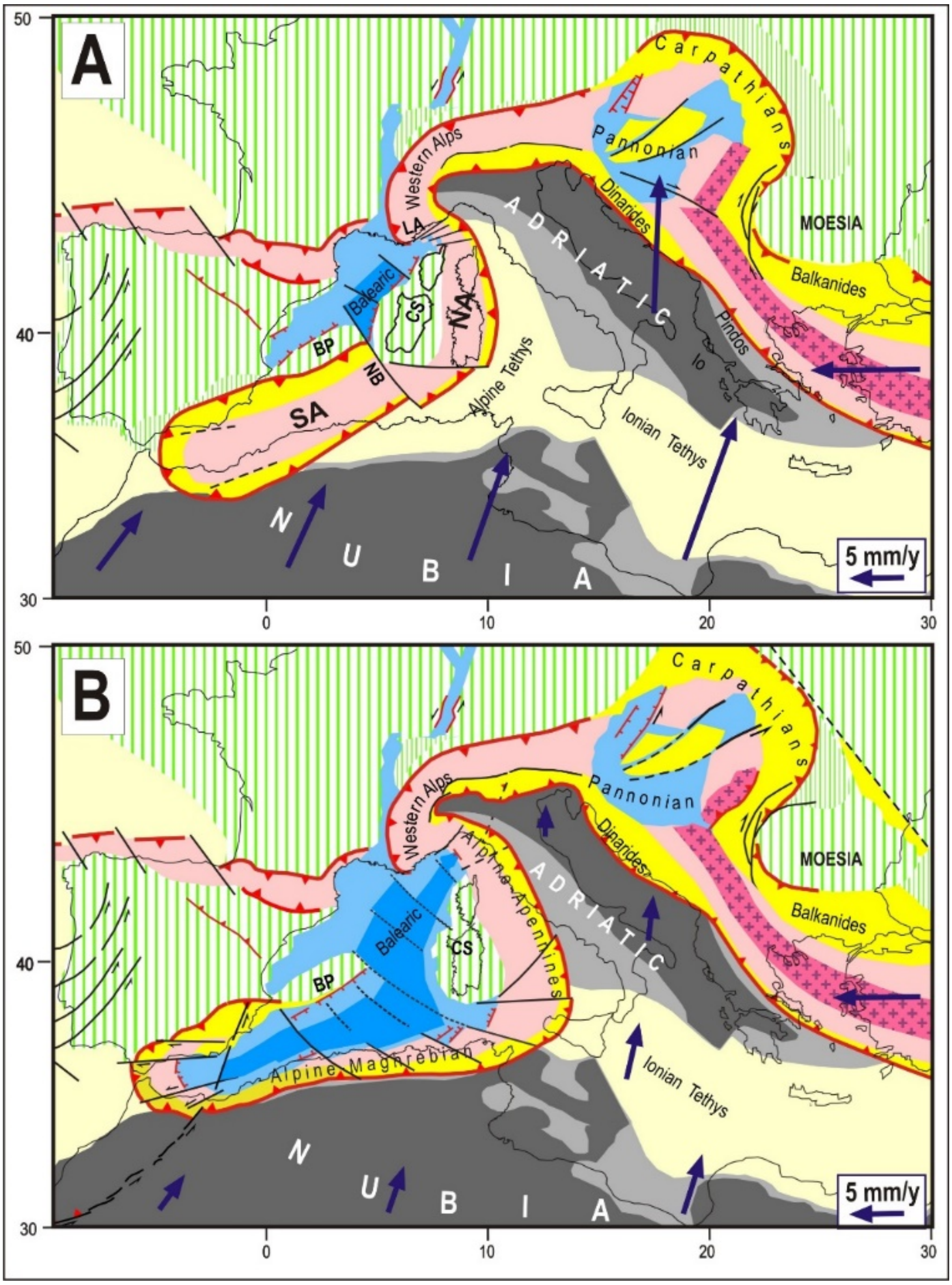

Figure 4. (**A**) Early Miocene. The Northern Arc (NA, Alpine–Iberian–Apennine belt) underwent a greater rotation with respect to the Southern Arc (SA, Alpine–Iberian–Maghrebian belt), allowed by the North Balearic dextral shear zone (NB). BP = Balearic Promontory, CS = Corsica-Sardinia, Io = Ionian thinned continental zone, LA = Ligurian Alps. (**B**) Middle–Late Miocene. After long migration and considerable bending (induced by the Nubia–Eurasia convergence) the Arc reached a configuration with two almost perpendicular segments. The Corsica-Sardinia block reached its final location, after the collision of the Northern Arc with the Adriatic continental domain (Middle Miocene). The Southern Arc stopped its migration against the continental Nubian domain (Upper Miocene). Colours and symbols as in Figure 1.

This TABA process was driven by the Nubia-Eurasia convergence (e.g., [12,13]), after the collision of the Nubia continental domain with the southernmost edge of the Alpine-Iberian belt (e.g., [105–107]). Initially, this belt efficiently transmitted the roughly northeastward push of Nubia to central Europe, causing the formation of a major sinistral transtensional fault system (Figure 3; e.g., [43,105,108–111]). Then, stressed by belt-parallel compression and favoured by the previous detachment, the migrating Arc underwent eastward displacement/bending at the expense of the eastern Alpine Tethys oceanic domain (Figure 4). The crustal extension that developed in the wake of the migrating Arc led to the formation of the Balearic basin. Evidently, in the above geodynamic context this process has opposed less resistance than any other shortening pattern involving subduction or strong uplift of the squeezed buoyant material.

Then, the progressive convergence between Nubia and Eurasia caused further migration and bending of the Alpine-Iberian belt. In the first phase (Figure 4A), the migration mainly involved the Northern Arc, which decoupled from the Southern Arc by the North Balearic transpressional fault. The migration of the Arc was accommodated by the consumption of the Alpine Tethys oceanic domain. Accretionary activity developed along the outer front of the migrating Northern Arc, forming the Miocene Apennine belt. In the wake of the Arc, crustal extension formed the Northern Balearic (Liguro–Provencal) basin (Figure 5, [8,10,13,112]). This process lasted until the middle Miocene, when the Northern Arc collided with the continental Adriatic domain. In the second phase (Figure 5) the migration mainly involved the Southern Arc, forming the Maghrebian belt and the Southern Balearic (Algerian) basin. This process slowed down, finally to cease in the Late Miocene, when the Southern Arc reached the Nubian continental margin.

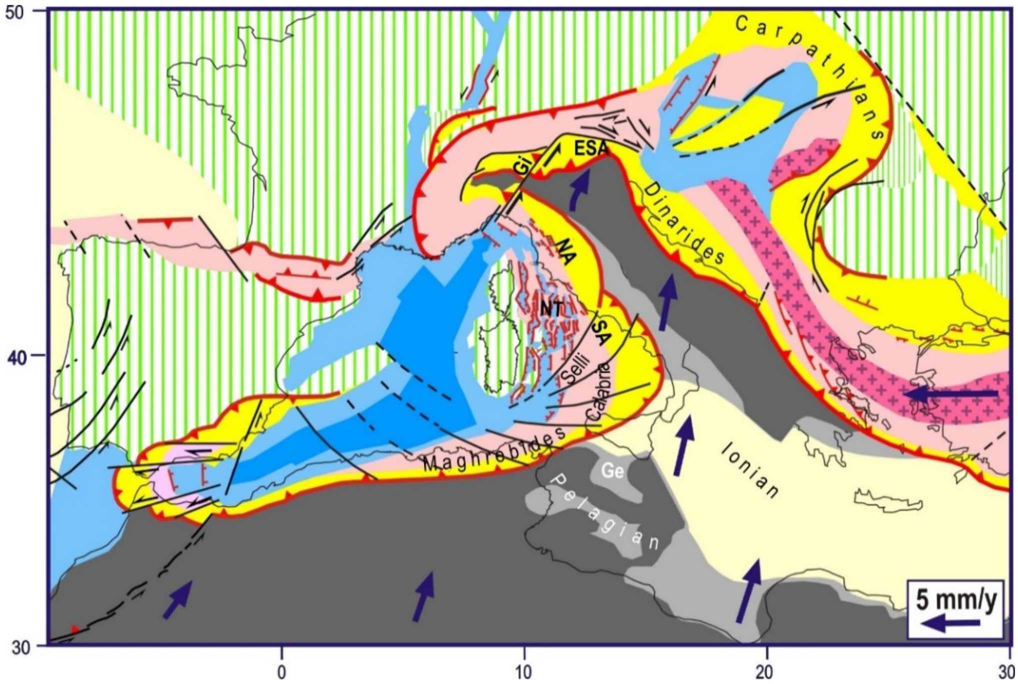

Figure 5. Late Miocene. The reactivation of the Giudicarie fault system (Gi), around the Tortonian, allowed the main Adriatic domain to move roughly NE ward with respect to its northwestern edge. The consequent divergence between the main Adriatic domain and the fixed Corsica-Sardinia block induced crustal extension in the interposed sector of the Alpine–Apennine belt, forming the Northern Tyrrhenian basin (NT). ESA = Eastern Southern Alps; NA = Northern Apennines; SA = Southern Apennines.

A tentative reconstruction of the crustal structures which were involved in the development of the Balearic TABA system is shown in Figure 6. This image suggests that the above process started with the detachment of a crustal fragment from Europe, including a foreland block (Corsica–Sardinia–Balearic Promontory) and the orogenic belt (Alpine–Iberian) that lay over its eastern margin. This hypothesis is supported by the numerous seismic cross sections reported in the results of the CROP project [113] for the central Mediterranean region.

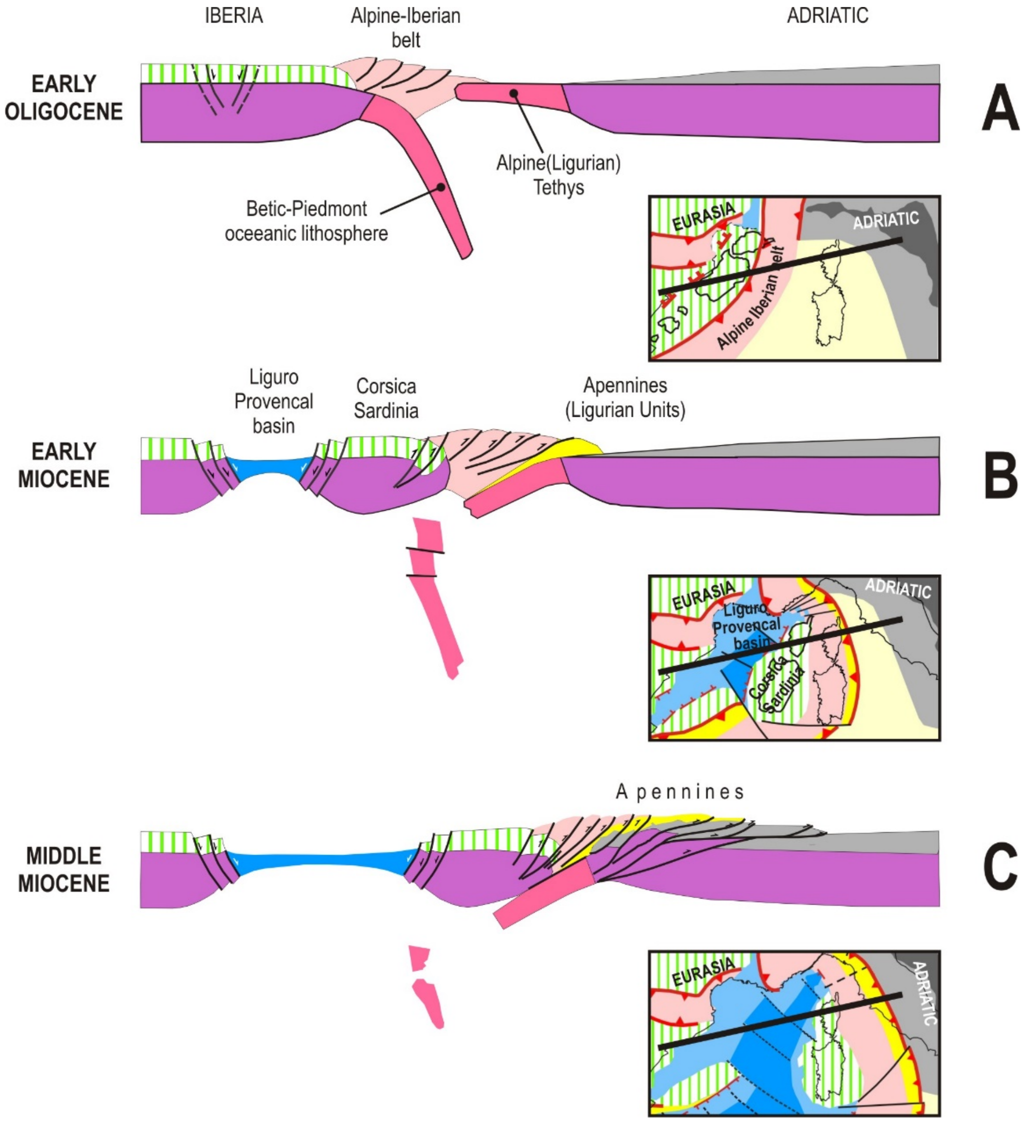

Figure 6. Tentative reconstruction, of the main tectonic processes that developed since the Oligocene along an East–West section crossing the Western Mediterranean region: (**A**) The old oceanic lithosphere which lay along the eastern side of Iberia is completely consumed and the Alpine–Iberian accretionary belt is formed. Crustal sinistral transtension, induced by the push of Nubia on the Alpine-Iberian belt affects the eastern margin of Iberia (see Figure 3). (**B**) Due to belt-parallel compression the Arc (Corsica-Sardinia-Balearic Promontory fragment and the Alpine–Iberian belt) undergoes an eastward displacemet/bending, at the expense of the eastern Alpine Tethys. In the wake of the migrating Arc, crustal extension forms the Northern Balearic (Liguro–Provencal) basin, whereas the old eastward dipping slab is undergoing progressive disruption. Accretionary activity along the outer front of the migrating Arc led to the formation of the Apennine belt. (**C**) The stop of the Arc against the continental Adriatic domain causes the end of crustal extension in the Liguro–Provencal basin.

The fact that since the upper Oligocene transtensional tectonics in the Rhine graben system underwent a progressive attenuation (e.g., [105,110]) can be explained as an effect of the increasing bending of the Alpine–Iberian belt, which made the transmission of Nubian's push less and less efficient.

The hypothesis that the Western Mediterranean TABA system was generated by an extrusion process induced by the Nubia–Eurasia convergence is also supported by the following evidence and arguments:

- The structural/tectonic setting of the Balearic basin indicated by geophysical investigations (e.g., [5,6,36]), is characterized by several wedges decoupled from each other by strike-slip faults, with an overall geometry very similar to that expected in extrusion contexts (Figure 2)
- The strong bending that the Arc underwent during its migration, changing from a more or less straight configuration (Figure 1A) to its final shape, characterized by two almost perpendicular sectors (Figure 5), is consistent with a SSW-NNE driving force induced by the convergence between Nubia and Europe (e.g., [1,13,89,114]). Conversely, the modelling of the slab-pull mechanism cannot reproduce such strong arc's curvature ([13,29] and references therein, [115]).
- A sinistral transpressional deformation is recognized in the Alpine–Iberian belt during the phase which preceded its detachment from western Europe (e.g., [41,116]), i.e., a regime which is compatible with the one which was induced in the Oligocene by the left lateral displacement of the Alpine-Iberian belt with respect to Western Europe (Figure 3).
- The major distortion that the northernmost sector of the Northern Arc underwent (Figures 4 and 6) seems to be a plausible effect of a belt parallel push.

4. From the Late Miocene to the Latest Miocene–Early Pliocene (Formation of the Northern Tyrrhenian Basin and Extension–Subsidence of the Northern Apennines)

The available evidence clearly indicates that from the Tortonian to the late Messinian (9–6 My) the sector of the Alpine–Apennine belt which lay aside the Corsica–Sardinia block underwent E-W crustal extension and subsidence (Figure 5), which turned an orogenic zone into a basin (e.g., [112,117–120]). During this phase the Selli fault divided the extending North Tyrrhenian zone from the southern sector of the Alpine–Apennine belt [121,122].

It is worth noting that the development of this basin was characterized by rather different features with respect to the back arc basins generated in TABA systems. First of all, the Arc (Northern Apennines) underwent dominant subsidence and extension instead of the expected accretionary activity and uplift. Moreover, at that time the trench was facing a continental domain whose retreat would have encountered strong resistance from buoyancy forces. The hypothesis that a well-developed slab is present under the Northern Apennines is only supported by some tomographic analyses (e.g., [123–125]), but cannot be reconciled with the results of seismic soundings (e.g., [41,112]), with the absence of seismicity deeper than 70 km and with the fact that the magnitudes of subcrustal earthquakes are mostly lower than 5. More recent tomographic cross sections do not show any slab beneath the Northern Apennines ([126,127]).

The opening of the Northern Tyrrhenian basin and other major features may be interpreted as an effect of the divergence between the northern Adriatic domain, moving roughly NE ward, and the stable Corsica–Sardinia block ([8,10–13,32,128]). The long oblique indentation of the Adriatic continental domain against Eurasia induced very high resistance, presumably accompanied by internal torsion and uplift of that promontory (e.g., [6,10,11,129]). The development, in the early middle Miocene, of a weak lateral boundary, constituted by the Carpatho–Pannonian tectonic zone (e.g., [130,131]) favoured the eastward extrusion of buoyant crustal wedges from the Eastern Alps, with the formation of the Tauern window extensional zone in the wake of the extruding wedges (Figure 5, e.g., [132,133]). This weak lateral boundary along the northeastern Adriatic front triggered the release of the internal deformation previously accumulated by that promontory. This incipient release may have induced a high shear stress between the main Adriatic domain and its northwestern edge, which at that time was deeply stacked beneath the Western Alps. This context led to the reactivation (as a sinistral transpressional fault system, Figure 5) of an old discontinuity, the Giudicarie fault ([71,134–138]), which allowed the main Adriatic domain to move Northeast ward with respect to its fixed northwestern protuberance. The fact that since then thrusting activity in the Alps mostly occurred in the sector lying east of the Giudicarie fault (e.g., [139–141] and references therein) testifies the sinistral motion of the decoupled Adriatic domain with respect to its northwestern Padanian protuberance.

The resulting relative motion between the main Adriatic domain and the fixed Corsica–Sardinia block (e.g., [142] and references therein) caused crustal extension and subsidence in the interposed Alpine–Apennine belt, leading to the formation of the Northern Tyrrhenian basin (Figure 5). This interpretation can explain the starting time of crustal extension (following the Tortonian activation of the Giudicarie fault system), the location of extension (between two diverging domains) and the reason why during the formation of that basin the adjacent Northern Apennines underwent dominant subsidence and extension (being located on the subsiding margin of Adria [10–12]).

5. From the Late Miocene-Early Pliocene to the Late Pliocene-Early Pleistocene (Reorganization of the Tectonic Setting in the Central Mediterranean Area)

During the late Miocene–early Pliocene interval, several major coeval tectonic events took place in the central Mediterranean area:

- The consuming boundary between the southern Adriatic domain and the Anatolian-Aegean–Pelagonian system sutured, as suggested by the cessation of accretionary activity in the Pindos zone (e.g., [102,143–145])
- Crustal stretching stopped in the Northern Tyrrhenian basin and occurred in the zone lying south of the Selli fault, forming the Vavilov basin (Figures 7 and 8, e.g., [7,15,122,146]).
- In the Pliocene accretionary activity accelerated in the Apennine chain, after the previous quiescent phase (e.g., [42,147,148]).
- Some longitudinal oroclinal arcs developed in the Apennine belt ([149]).
- The Adriatic crust and the Apennine belt were affected by strong shortening, with the development of major thrust faults (e.g., [41,150]).
- A major fracture (Sicily Channel and Victor Hensen–Medina fault systems, Figure 7) developed in the Pelagian foreland and the Ionian oceanic zone (e.g., [146,151–157] and references therein [158]). In the Sicily Channel the main transcurrent fault system was associated with some troughs (Pantelleria, Malta and Linosa (e.g., [159–163]). Dextral shear occurred along the Sciacca fault [162,163].
- The formation of the present orocline in the Sicilian Apennines (Gela nappe) is mostly attributed to the southward bowing of that belt, driven by E-W compression (e.g., [164]).
- The Alpine–Maghrebian chain sector which lay north of the Adventure block underwent compressional deformations and northward displacement (e.g., [165]), as testified by the present location and configuration of that belt (Figure 9).
- Since the Early Middle Pliocene, transtensional tectonics affected the southern part of the Corsica-Sardinia block, forming the Campidano graben (Figures 7 and 8, e.g., [166–168]).
- In the northern Adriatic foreland an old weak zone was reactivated as a sinistral NNW-SSE fault system (Schio–Vicenza), (Figure 7, e.g., [71,139,169,170]). Since then, NW-SE to North–South shortening has affected the Alpine sector lying east of the Schio-Vicenza fault, whereas such activity almost ceased west of that fault (e.g., [171,172]).
- A system of thrust faults reactivated as dextral strike-slip faults along the northeastern border of the Adria plate (Northern Dinarides, e.g., [173]).

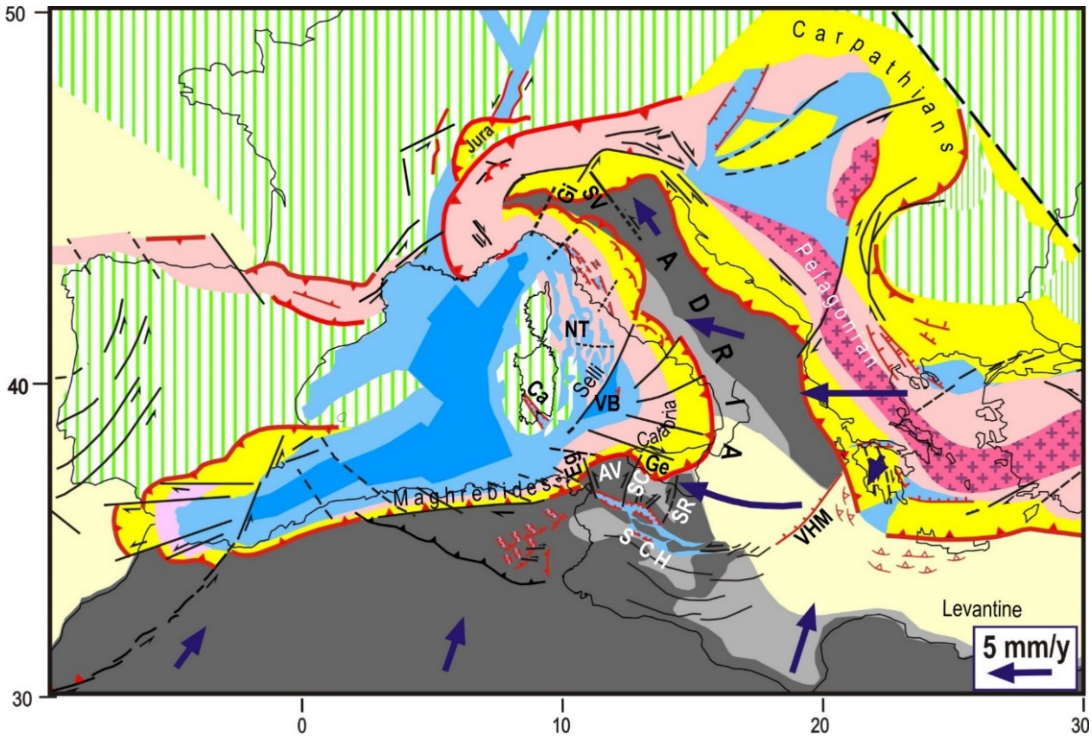

Figure 7. Middle Pliocene tectonic setting. The westward push of the Anatolian–Aegean–Pelagonian system causes the decoupling of the Adria plate from Nubia by the activation of the Victor Hensen–Medina-Sicily Channel fault system. Once decoupled, Adria underwent a clockwise rotation and a minor NW ward motion. The rotation determined major E-W shortening in the Pelagian zone as well as in the Alpine–Maghrebian and Alpine–Apennine zones, whereas the NW displacement of Adria caused the activation of the Schio–Vicenza fault system in the northern Adriatic domain. AV = Adventure wedge, Ca = Campidano graben, CT = Central Tyrrhenian, Eg = Egadi fault, Ge = Gela nappe, Gi = Giudicarie fault system, NT = Northern Tyrrhenian, SCH = Sicily Channel, SC = Sciacca fault, SR = Scicli–Ragusa fault, SV = Schio–Vicenza fault, VB = Vavilov basin, VHM = Victor Hensen–Medina fault. Colours and symbols as in previous evolutionary maps.

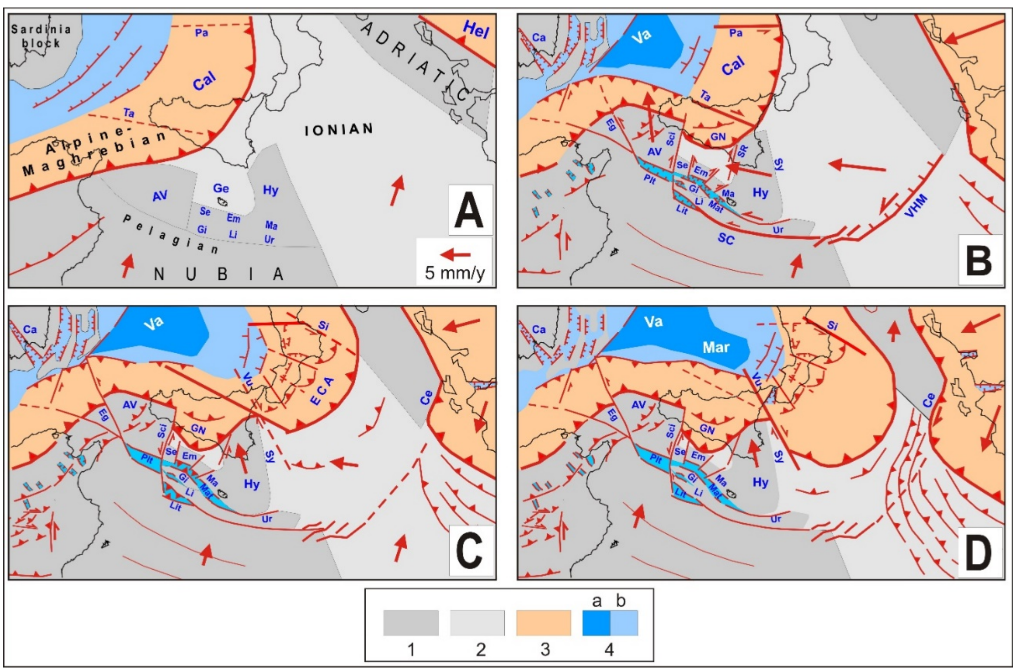

Figure 8. Tentative reconstruction of the tectonic processes that developed in the Hyblean–Adventure domain, in the

Alpine–Maghrebian belt and even in Sardinia, as effects of the convergence between the Adria plate and northern Nubia. (1) Continental domains; (2) thinned continental and oceanic domains; (3) Orogenic belts; (4) zones of intense (a) or moderate (b) crustal thinning. (**A**) Late Miocene. Initial configuration of the study area. AV = Adventure wedge; Cal = Calabrian wedge; Em, Gi, Li, Ma, Se, Ur = Empedocle–Girgenti–Linosa–Malta–Selinunte–Urialo plateau; Ge = Gela thinned domain; Hel = Hellenides; Hy = Hyblean plateau; Pa = Palinuro fault, Ta = Taormina fault. (**B**) Middle Pliocene. In response to the westward push of the Anatolian–Aegean–Pelagonian system the Adria plate (Figure 5) decouples from Nubia by the activation of the Victor Hensen–Medina (VHM) and Sicily Channel (SC) fault systems. The Adventure wedge underwent a roughly northward escape, guided by the Sciacca and Egadi fault systems, causing extension at its inner boundary (Pantelleria trough) and compressional deformations along its northern front. In the Hyblean domain the E-W shortening occurred at the expense of the thinned sector (Gela basin). The interaction between the migrating Maghrebian belt and Sardinia caused tectonic activity in the Campidano graben (Ca). Eg = Egadi fault, GN = Gela Nappe; Lit, Mat, Plt = Linosa, Malta and Pantelleria troughs; Sci = Sciacca fault system; SR= Scicli-Ragusa fault; Ta = Taormina fault; Va = Vavilov basin; Sy = Syracuse escarpment. (**C**,**D**) **Pleistocene to Present.** Two new lateral guides (Vulcano and Sibari, Vu and Si) for the escape of the Calabrian wedge activate. This has allowed the Hyblean plateau to accelerate its NNW ward motion. See text for explanations. The geometry and locations of the plateau fragments (Em, Gi, Li, Ma, Se, Ur) in the present Sicily Channel have been taken from the tectonic scheme of [134]. Ce = Cefalonia fault system; ECA = External Calabrian Arc; Mar = Marsili basin; Si = Sibari fault; Vu = Vulcano fault. Other symbols as in Figure 1.

The occurrence of so many coexisting tectonic processes in the central Mediterranean region can plausibly and coherently be explained as an effect of the tectonic reorganization that followed the collision between the Anatolian–Aegean–Pelagonian belt and the continental Adriatic domain (Figure 5), once the interposed thinned continental domain (Pindos thinned domains, e.g., [102]) had been completely consumed. After an initial phase of strong collisional deformations, such as crustal thickening and uplift, the strong increase in resistance against any further plate convergence required the activation of another (less resisted) shortening pattern in the central Mediterranean area. The first step was the decoupling from Nubia of a large portion of the Adriatic promontory (Adria here after), which included the continental Adriatic domain and the northern Ionian Tethys. Such decoupling was allowed by the generation of a long fracture (Figures 7 and 8B) through the Ionian oceanic zone (Victor Hensen–Medina fault system, [156–158] and the Pelagian zone (Sicily Channel fault system, e.g., [146,153]). The very high strength of the driving force which determined this process is testified by the fact that such break occurred in zones formerly belonging to the undeformed Nubian foreland (e.g., [146,153,163]). Once decoupled, the new plate underwent a clockwise rotation and a minor NNW ward displacement (Figure 7). To understand the reason why this decoupling and the subsequent kinematics of Adria occurred (in the view of the minimum-action principle) one can consider that such context finally produced the consumption of the last remnants of the Alpine oceanic and thinned continental domains in the central Mediterranean area, as described in the following.

The convergence between the southernmost Adria plate, moving roughly westward, and Nubia, moving roughly NNE ward ([13,26]), caused compressional deformations in a relatively large sector of the northern Nubian domain, from the Pelagian to the Tunisian–Algerian zones (Figure 7). The roughly East–West shortening was accommodated by the northward escape of the Adventure block, guided by the Sciacca and Egadi fault systems [146] and by the consumption of the thinned internal domain of the Hyblean plateau (Gela basin, Figure 8B,C).) The escape of the Adventure block caused thrusting activity and northward displacement of the Alpine-Maghrebian belt that lay north of it ([165,174–177]), whereas tensional deformation developed in the wake of that block, forming the Pantelleria trough [178]. In the Hyblean plateau the consumption of the thinned Gela domain was achieved by two converging extrusions. One was the southward oroclinal bending of the Sicilian Maghrebides (forming the curved Gela nappe) and the other was the fragmentation and subsequent northward bending of the elongated plateau which lay just north of the Sicily Channel fault system (Figure 8A,B). The small zones where the plateau fragments diverged from each other underwent crustal extension, forming the Malta and Linosa grabens and other minor troughs (Figure 8C,D). This context lasted until the complete consumption of the Gela thinned domain, around the Early Pleistocene [179], which determined a considerable slowdown of extensional deformation in the Linosa and Malta troughs [179].

The northward extrusion of the Adventure wedge may explain the present shape of the Kabylo–Calabrides–Maghrebian belt (Figures 7, 8C,D and 9) and consequently the occurrence of tectonic activity in the southwestern edge of the Corsica–Sardinia block (stressed by the migrating belt). In this regard, one should consider that finding another plausible explanation for the occurrence of major tectonic activity in a block (Sardinia) that had been stable since the middle Miocene [112,142,180–182] and was far from any other mobile plate or microplate is not a simple task. Further support to the above interpretation is given by the fact that tectonic activity in Sardinia mainly developed from the lower-middle Pliocene to the Pleistocene, (e.g., [166–168]), i.e., the period during which the northward displacement of the Adventure wedge and the consequent displacement of the Alpine–Maghrebian belt were taking place.

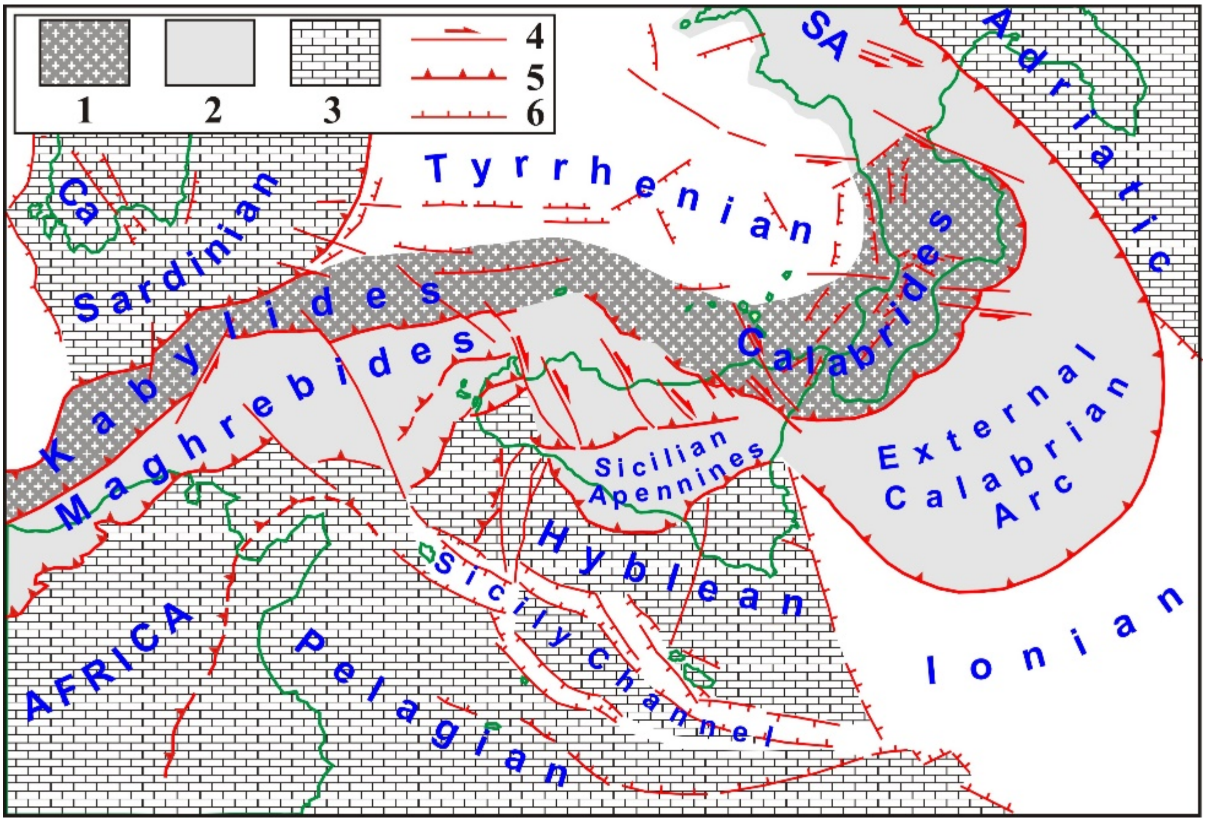

Figure 9. Shape of the Kabylides–Calabrides (1) and Maghrebides (2) belts (modified after [174,175,182]), (3) foreland domains, (4,5,6) strike-slip, compressional and tensional features. In white the basins. Ca = Campidano graben, SA = Southern Apennines.

The sinistral shear here proposed in the Sicily Channel transtensional fault system **is** suggested by other authors (e.g., [183,184]), whereas a dextral shear is proposed in other papers (e.g., [146,153,179,185–187]). However, this last hypothesis is not compatible with major pieces of evidence in the surrounding zones. In particular, one should consider that a dextral shear in the Sicily Channel fault system would imply a southeastward motion of the Hyblean domain with respect to Nubia. Such presumed kinematics would have caused compressional deformations somewhere in the Ionian zone, where instead no evidence of this effect is recognized, especially at the Syracuse escarpment, (e.g., [188]). Furthermore, the SE ward motion of the Hyblean domain would have induced extension between the

Hyblean–Adventure plateau and Sardinia, where instead a strong shortening is evidenced by the CROP section crossing the Sardinia and Sicily Channels [182].

The minor NNW ward motion of Adria, after its decoupling from Nubia, required the generation of another major decoupling zone (at least partial) in the northern Adriatic domain, which was achieved by the reactivation of an old weak zone, the Schio–Vicenza fault, with a sinistral shear (Figure 5). This can explain why in the Pliocene the orientation of the compressional axis in the eastern Southern Alps changed from SW-NE to SSE-NNW (e.g., [71]) and why many thrust zones in the Northern Dinarides were reactivated as right lateral strike-slip faults [173].

6. From the Early Pleistocene to the Middle–Upper Pleistocene (Suture of the Southern Apennines Consuming Boundary and Formation of the Marsili Basin)

During this time interval, some coeval tectonic processes developed in the central Mediterranean region (Figure 10A,B):

- Crustal extension ended up in the Vavilov basin and started in the Marsili basin (Figure 10B, e.g., [146,189,190]).
- Accretionary activity slowed down up to stop in the Southern Apennines consuming boundary (e.g., [51,191–193]).
- The lateral escape, uplift and fragmentation of the Calabria–Peloritani (CP) wedge, underwent a considerable acceleration (e.g., [5,194–202]).
- Along the outer front of the CP wedge, thrusting activity formed the external Calabrian accretionary complex (e.g., [5,203,204]).
- Tectonic activity along the outer front of the Adventure block and in the Pantelleria graben slowed down with respect to the Pliocene ([162,165,178]).
- The upward flexure of southern Adria was accelerated, forming the present Apulian swell (e.g., [146,205,206]), whereas the northern Adriatic foreland and the surrounding foredeeps underwent intense subsidence [147,207].

The tectonic processes listed above may plausibly and coherently be interpreted as effects of the arrival of the Southern Apennines wedge against the Adriatic continental domain. This event is inferred by the coeval cessations of thrusting in the southern Apennines and crustal stretching in the Vavilov basin, i.e., the zones, located at the front and the inner side of the escaping wedge, respectively. Since the strong increase in resistance at that consuming boundary the main objective of plate convergence in the central Mediterranean region became the consumption of the remnant Ionian oceanic domain, which was achieved by the acceleration of the CP wedge (Figure 10A). This is suggested by the fact that accretionary activity developed along the outer front of that wedge, building up the External Calabrian belt, and crustal stretching occurred backwards of the same wedge, generating the Marsili basin. The lateral guides of the above extrusion were the Taormina and Palinuro transpressional fault systems, as suggested by the acceleration of the Pleistocene tectonic and volcanic activity in those faults (e.g., [146,199,208]).

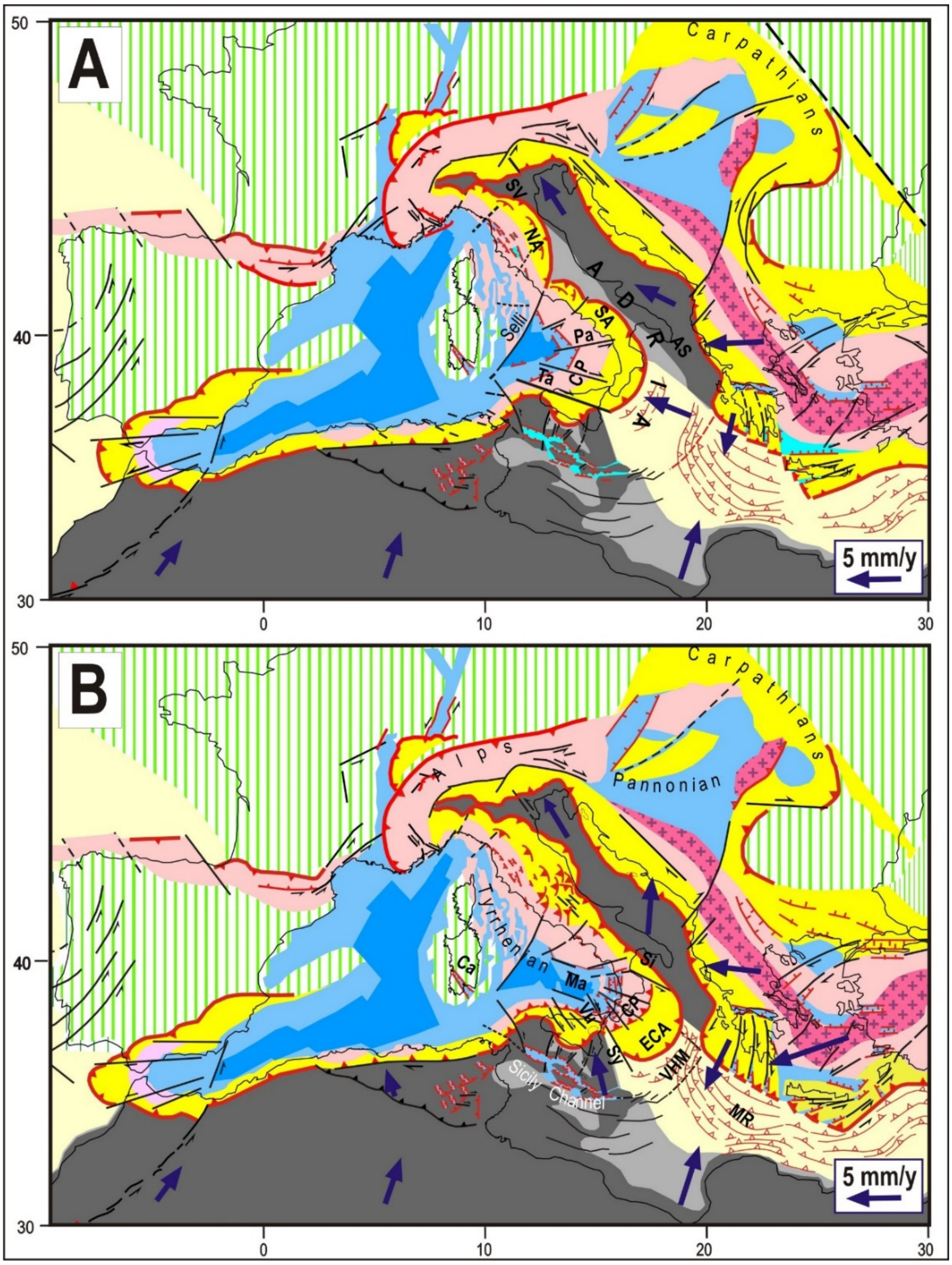

Figure 10. (**A**) Early Pleistocene tectonic setting. Since the suture of the Southern Apennine consuming boundary the lateral escape of the Alpine–Apennine material has only involved the Calabria-Peloritani (CP) wedge, which has extruded roughly southeastward at the expense of the Ionian oceanic domain. Stressed by E-W compression, the southern Adriatic platform has undergone upward flexure, accelerating the formation of the Apulian Swell (AS). Accretionary activity along the outer Calabrian front has formed the External Calabrian accretionary belt (ECA), whereas crustal extension has developed in the wake of the migrating Arc, forming the Marsili basin (Ma). In this strong compressional context, the CP wedge has undergone fast uplift, bowing and fragmentation. Pa = Palinuro fault, Ta = Taormina fault. (**B**) Late Pleistocene tectonic setting. The potential gravitational energy accumulated by the southern Adriatic in the previous phase has triggered the northward displacement of Adria. Since the collision of the extruding CP wedge with the Adriatic continental domain, the escape trend of such wedge changed by activating new lateral guides, the Sibari (Si) and Vulcano–Syracuse (Vu-Sy) faults. MR = Mediterranean ridge. Colours and symbols as in Figures 1 and 5.

The available evidence indicates that crustal stretching in the Marsili basin mainly developed from 2.1 to 1.6 My (with a very high rate, up to 19 cm/y) and that since 0.78 My spreading in the Marsili basin underwent a considerable slow down [209]. The phase of very fast arc migration, uplift and basin extension may be due to the fact that, since the suture of the Southern Apennines consuming boundary, the Calabrian wedge was forced to extrude through a very narrow corridor confined by lateral continental domains (Nubia and Adriatic). The very strong outward push that was induced by such context is testified by the present structural settings of Calabria (Figure 11A), which shows a European upper crust overthrust onto the Adriatic units [49] and by the vertical bending that the European crust underwent during that process (Figure 11A). The section crossing the Southern Apennines (Figure 11B) does not show an analogous vertical deformation of the crust, confirming that the stress values that drove the extrusion of the Calabrian wedge were particularly high. The above evidence and the strong and fast Quaternary uplift of Calabria (about 2000 m) can particularly be useful for recognizing the real driving force responsible for the development of that TABA system. Indeed, it is evident that such effects cannot be imputed to the SE ward pull induced by the presumed retreat of the Ionian slab.

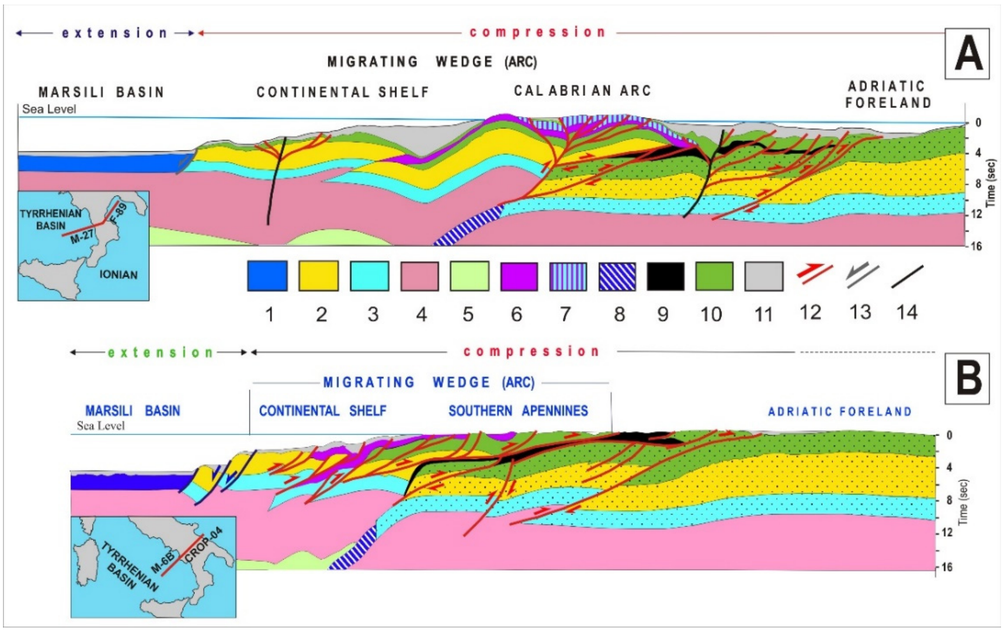

Figure 11. (**A**) CROP section from the Marsili basin to Adriatic foreland through Northern Calabria (modified after [49]). (1) Oceanic crust; (2) upper continental crust; (3) lower continental crust; (4) Lithospheric mantle; (5) Asthenospheric mantle; (6) remnants of the Alpine Tethys; (7) Kabylo–Calabrides units; (8) Ionian Tethys oceanic slab; (9) Ionides; (10) pre-Pliocene sedimentary cover; (11) Pliocene–Quaternary sediments; (12,13,14) major thrust, normal and strike-slip faults developed during the formation of the Tyrrhenian basin. Dots mark the Adriatic crustal units (from Mantovani et al., 2007, modified). (**B**) CROP cross section from the Southernmost Tyrrhenian (Marsili basin) to the Adriatic foreland, through the Southern Apennines (modified after [150]).

The Late Pleistocene slowdown of extension in the Marsili basin could be due to the collision of the northern part of the CP wedge against the continental Adria domain (e.g., [11] and references therein, [197–199,210]).

Since the complete consumption of the thinned Periadriatic domains in the late Pliocene–early Pleistocene, the roughly E-W compressional regime induced by plate convergence (Figure 10A) was mainly accommodated by upward flexure and crustal thickening of the southern Adria domain, accelerating the formation of the Apulian swell. The Early Pleistocene subsidence recognized in the northern Adria zone [147,207,211] might relate to the uplift that affected the southern Adriatic region during the same period.

7. From the Middle Pleistocene to the Present (Northward Acceleration of Adria, Belt Parallel Shortening and Uplift in the Apennines)

During this time interval, the tectonic setting in the study area underwent major changes, with particular regard to Apennine belt, the Adriatic area, the Calabrian wedge and the Hyblean zone, as suggested by the following pieces of evidence:

- The axial part and the eastern sector of the Apennine belt underwent generalized uplift (e.g., [212–215]).
- A system of NW-SE sinistral strike-slip faults developed in the southernmost Apennines (Lucanian), with the generation of compressional and tensional features at restraining and releasing stepovers (e.g., [192,216,217]).
- Belt parallel transtensional and normal faults are recognized in the axial part of the Southern Apennines, in the Irpinia, Benevento and Matese zones (e.g., [218,219])
- - In the Fucino and L'Aquila zones of the Central Apennines, major sinistral transtensional faults are recognized (e.g., [220–222]).
- Sinistral transtensional faults are recognized in the axial part of the Northern Apennines (e.g., [223–226]), whereas thrusting dominates in the outer border of that zone (e.g., [227–229]). The observed deformation pattern mainly indicates uplift and widening of the Northern Apennine range [147].
- The internal part of the Adriatic plate has been affected by a longitudinal compression, as suggested by the main features of the Middle Adriatic Ridge (e.g., [8,228,230]);
- Quaternary magmatic activity in the Apennine belt involved two major volcanic episodes (Roman and Campanian provinces, [208,231]), associated with transtensional faulting ([232,233]).
- The previous lateral guides of the Calabrian extrusion (Palinuro and Taormina fault systems) were deactivated, whereas two new lateral guides (Vulcano and Sibari fault systems) were activated (e.g., [198,199,234,235]).
- The Sciacca fault system in the Hyblean plateau has become a sinistral shear zone, affected by magmatic activity (e.g., [162,163,236]).

The coexisting tectonic events listed above may coherently be explained by the following interpretation. The gravitational energy accumulated by the southern Adriatic domain during the Early Pleistocene uplift has been released by the northward displacement of that plate (Figure 10B). This hypothesis can explain the late Pleistocene reactivation of thrusting and strike-slip tectonics in the northern (Eastern Alps) and eastern (Dinarides) boundaries of Adria ([128] and references therein).

A more complex deformation pattern is recognized in the Apennine belt (Figure 12), whose eastern part has undergone a greater deformation, involving belt-parallel shortening and uplift, with respect to the western side which was moderately deformed ([11] and references therein [128,237],). Such differentiated deformation patterns can be explained by the fact that the eastern Apennine sector, being closely connected with the underlying Adriatic margin, was more efficiently dragged by that plate. The same drag had limited effects on the western Apennine sector, due to the greater depth of the underlying slab and to the possible presence of decoupling asthenospheric layers. The belt-parallel shortening of the eastern Apennines side has been accommodated by marked uplift, formation of oroclinal arcs and underthrustings along transversal discontinuities (e.g., [147,215,238,239]). The formation of oroclinal arcs has mainly involved the sedimentary cover of the belt, which decoupled from the underlying crust by exploiting the presence of weak layers (Upper Triassic evaporites and non-competent Neogene clastics). In particular, such units were present in the Molise–Sannio (MS) and Romagna–Marche–Umbria (RMU) wedges. The cross section given in Figure 13 shows an example of such process in the Northern Apennines (e.g., [41]). The faults that cut the entire crust (Figure 13) evidence the effects of the strong compression that the Adria underwent since its latest Miocene collision with the Anatolian–Aegean–Pelagonian system (Figure 7).

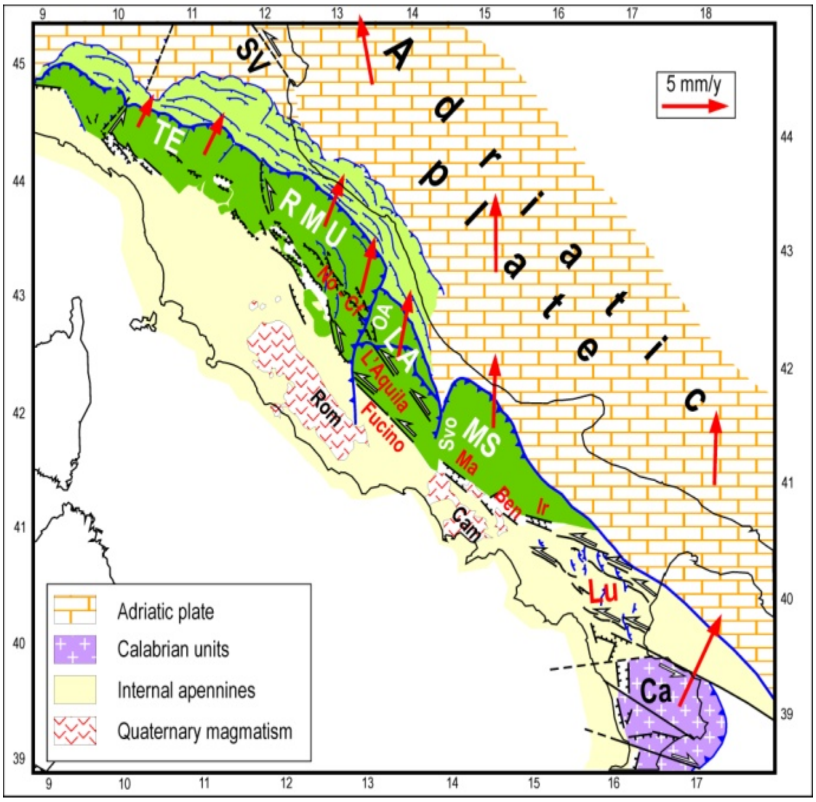

Figure 12. Dragged by the Adriatic plate, the eastern part of the Apennine belt (green) has undergone belt parallel shortening, which has caused the formation of oroclinal arcs and significant uplift. Ben = Benevento, Ca = Calabria, Cam, Rom = Campanian and Roman magmatic provinces, Ir = Irpinia, LA = Lazio-Abruzzi wedge, Lu = Lucania Apennines, Ma = Matese, MS = Molise–Sannio wedge, No-Cf = Norcia–Colfiorito fault system, OA = Olevano–Antrodoco thrust front, RMU = Romagna–Marche–Umbria wedge, SV = Schio–Vicenza fault, SVo= Sangro–Volturno thrust front, TE = Toscana–Emilia wedge. The buried external folds in the Northern Apennines are light green. Red arrows indicate the kinematic pattern, compatible with the Pleistocene deformation pattern and geodetic data (Figure 10). Other symbols as in Figure 1.

The belt-parallel shortening of the eastern Apennine side resulted in a faster northwest ward motion of this structure with respect to the western side. The different kinematic behaviors of the western and eastern Apennine sectors caused their progressive separation of the two sides, with the development of longitudinal troughs in the axial part of the belt, such as the Irpinia–Benevento–Matese in the MS wedge, the L'Aquila and Fucino faults in the Lazio-Abruzzi platform and the Norcia–Colfiorito–Val Tiberina faults in the RMU wedge (Figure 12, e.g., [128] and references therein, [219,222,237,239–242]), also involving the northernmost belt sector (Romagna–Emilia Apennines) and its buried folds beneath the Po Valley ([147,229,243–246]).

A system of strike-slip faults in the Lucanian Apennines (Figure 12, [128] and references therein) allowed the relative motion between the southernmost part of the MS wedge and the Calabrian wedge.

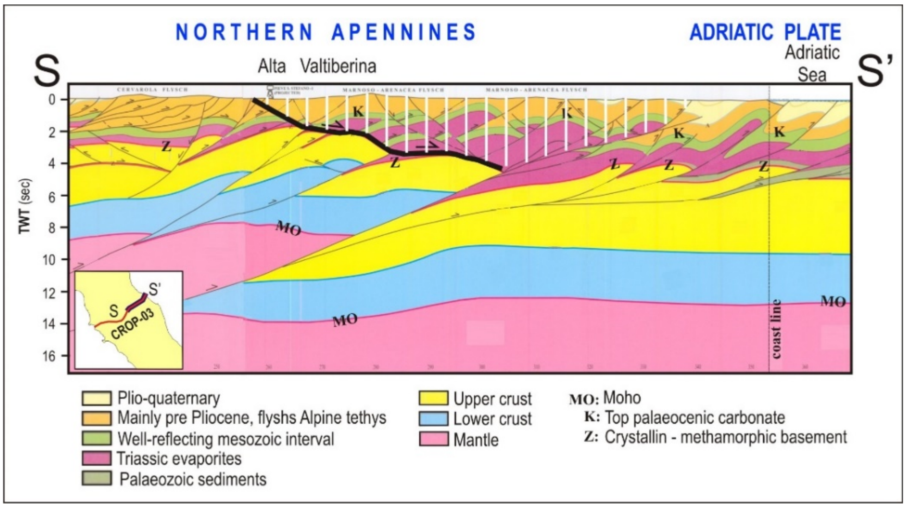

Figure 13. Eastern sector (see inset) of the CROP-03 cross-section ([41,112] modified). The white vertical strips evidence the RMU sedimentary wedge, which is decoupled from its basement by the Valtiberina fault (thick black line). This decoupling has been favored by the presence of Triassic evaporites. The eastward migration of the RMU wedge (driven by belt parallel compression) induces extension in the inner zone and thrusting at the outer front, where the wedge overthrusts the Adriatic domain (see text for explanations).

The faster motion of the eastern Apennine belt with respect to the western belt, inferred from the Pleistocene deformation pattern (Figure 12), is compatible with the geodetic velocity field inferred from geodetic measurements (Figure 14).

More in general, the fact that the recent-present kinematics of the Adria plate (Figures 12 and 14) is compatible with the NNE-ward Africa–Eurasia convergence trend suggested by [25] can explain why no clear tectonic or seismic evidence can be recognized about a possible decoupling zone between the Adria plate and Nubia. The various attempts at identifying such decoupling (e.g., [247–249] and references therein) suggest very different solutions located in several Adriatic zones and related to various strain regimes, which clearly testifies the scarce significance of the tectonic evidence about possible decouplings.

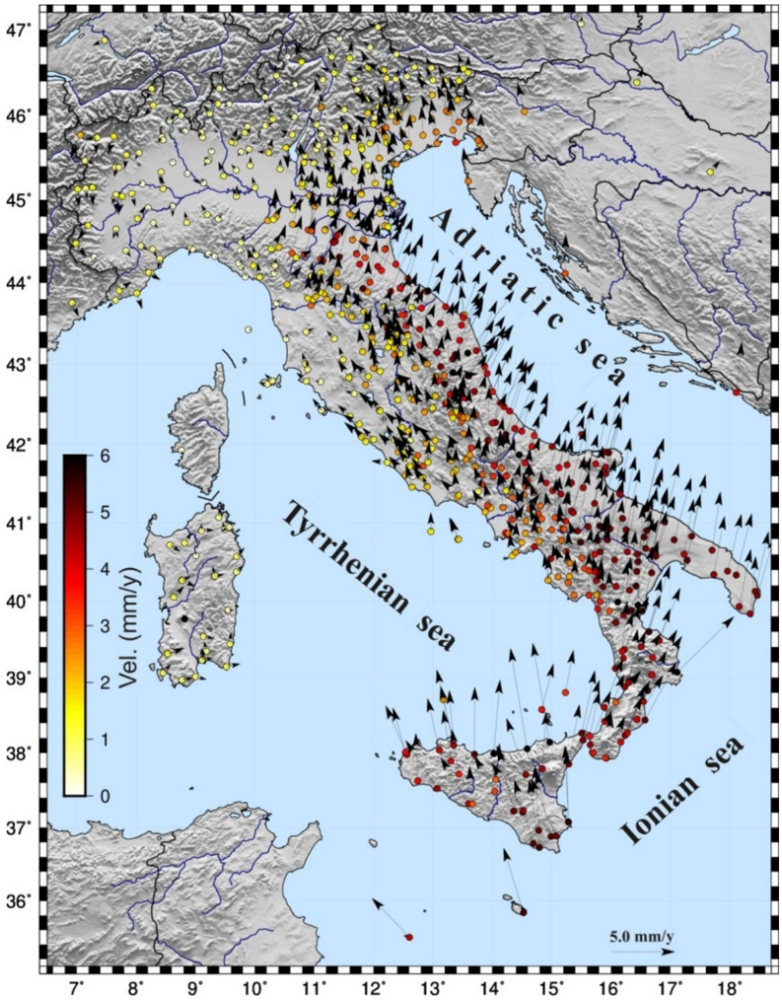

Figure 14. Horizontal velocity field in the Italian peninsula, derived by GPS data, with respect to a fixed Eurasian plate in the ITRF2014 reference frame [237]. The colours of station sites indicate velocity following the chromatic scale on the left. The description of the GPS network and data analysis is given by [250–252].

The possible connection of the short-term kinematic behavior of the Adriatic and Periadriatic zones with the time-space distribution of major earthquakes is discussed by [253,254].

The location and timing of the most evident magmatic episodes in the Apennines belt, the Roman and Campanian volcanic provinces, correspond very well to the development of transtensional regimes in the wake of the most extruded wedges (RMU and MS, Figure 12). This evidence could suggest that such volcanic activity was closely connected with the formation of pull-apart troughs, which have allowed the uprising of magmatic material previously generated by the underlying slab (e.g., [208,255–257]).

Around the middle Pleistocene, the collision of the northern Calabrian edge with the continental Adriatic domain (Figure 15A,B) may have caused a significant change in the tectonic setting in the southernmost part of Italy. This change involved the activation of new lateral guides, the Sibari and Vulcano–Syracuse fault systems (e.g., [198,199,234,235,258,259]) which have allowed a more southward-oriented extrusion of the CP wedge, at the expense of the Ionian oceanic domain (Figure 15B). In the new context, the Vulcano–Syracuse fault became the main decoupling between the CP wedge and the Hyblean–Adventure block, which were moving in almost opposite directions. The trend of the Vulcano fault allowed the Hyblean block to accelerate its northward motion. This hypothesis can explain why the Sciacca fault system (Figures 9 and 10) became a sinistral shear zone [162].

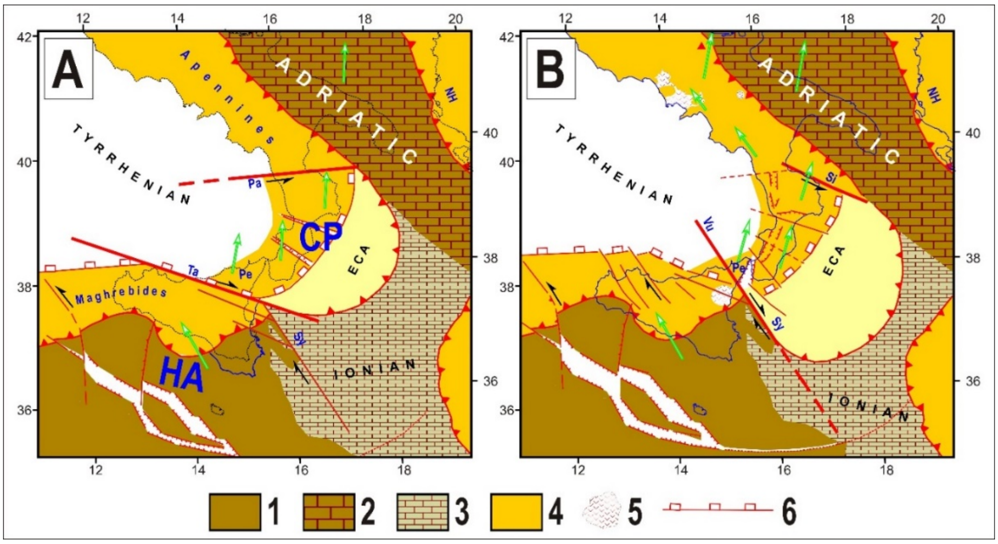

Figure 15. Tectonic sketch of the Calabria–Peloritani (CP) and Hyblean–Adventure (HA) wedges before and after the collision of Northern Calabria with the Adriatic continental domain. (1) Nubian continental domain; (2) Adriatic continental domain; (3) Ionian oceanic domain; (4) Orogenic belts; (5) Volcanism; (6) Outer fronts of the Alpine belt. (**A**) Early Pleistocene configuration. The lateral escape of the CP wedge (evidenced by yellow) is guided by the Taormina (Ta) and Palinuro (Pa) faults. NH = Northern Hellenides; Sy = Siracuse; Pe = Peloritani. (**B**) Post-middle Pleistocene tectonic setting: after the collision of Northern Calabria with the continental Adriatic domain, the extrusion trend of the CP wedge changed significantly due to the activation of two new lateral guides (Sibari (Si) and Vulcano–Syracusa (Vu-Sy) faults, e.g., [146,182,199]). The lateral guides of the CP and HA wedges are evidenced by red boldface lines. Green arrows indicate the kinematic pattern (with respect to Eurasia) which is compatible with the observed Quaternary deformations (e.g., [10,27,32] and with the present velocity field (Figure 14). Other symbols as in Figure 1.

At present, the shortening required by the compressional regime in the central Mediterranean area is accommodated by various kinds of deformation in the Periadriatic belts (Hellenides, Dinarides, Alps and Apennines) and by the opposite lateral escapes of the Calabria–Peloritani and Hyblean–Adventure wedges (Figure 15B). The first wedge, a sector of the Alpine/Apennine belt, is undergoing outward extrusion at the expense of the Ionian oceanic domain, whereas the Hyblean wedge, a fragment of the Nubian foreland carrying a segment of the Maghrebian–Alpine belt, tends to move roughly NNW-ward [10–12,27]. The relative motion between the above two wedges is allowed by dextral transpressional shear at the Vulcano–Syracuse fault (Figure 15B).

The supposed role of the above fault as an active decoupling zone might explain why the eastern side of Sicily has been the site of strong historical earthquakes (e.g., the 1169 M = 6.5 and 1693 M = 7.3 shocks, [260]).

8. Conclusions

In the Oligocene, the Adriatic continental core was surrounded by the remnants of a formerly vast oceanic (Alpine, Ionian and Levantine Tethys) and thinned continental domains (Figure 1A). During the long collision of the Africa–Adriatic plate with the Eurasian plate, the low buoyancy sectors that surrounded the Adriatic core transmitted compressional stress very efficiently without undergoing any consumption. This evidence, along with other analogous situations in the world, indicates that horizontal compression may not be sufficient to induce the subduction of a low buoyancy oceanic domain. However, subduction can be made feasible in the collision zones where extruded orogenic material overthrusts the low buoyancy domain. The weight of this material can cause the downward flexure of the overthrust domain triggering its sinking into the mantle. This kind of tectonic mechanism may have determined the consumption of the remnants of the Alpine Tethys oceanic domain and the consequent formation of the Balearic basin. The development of this TABA system started when the Alpine–Iberian belt collided with the Nubian continental domain. Then, the Nubia–Eurasia convergence induced a strong sinistral transtensional regime in the European foreland leading to a major break in the Iberian domain and Central Europe (Rhine–Rhone graben system). In response to that belt-parallel compression, the decoupled structure (Arc), constituted by the Alpine–Iberian belt and the Corsica–Sardinia–Balearic Promontoy European fragment, underwent a long migration and oroclinal bending until to the Late Miocene, when it reached a shape characterized by two almost perpendicular branches.

The accretionary activity which developed along the outer front of the migrating Arc built up the Miocene Apennine chain (accreted to the Alpine–Iberian belt), whereas crustal extension occurred in the wake of the Arc, forming the Balearic basin. The eastward migration of the Northern Arc went on until the Middle Miocene, when it collided with the Adriatic continental domain, whereas the Southern Arc stopped migrating in the Late Miocene, when it collided with the Nubia continental domain (Figure 4B).

The main alternative interpretation of the Balearic TABA systems in the study area suggests that the driving force of the Arc's migration was the gravitational sinking of the underlying slabs (e.g., [18]). However, the implications of this hypothesis are not compatible with major features of the observed deformation pattern:

- The comparison between the Oligocene (Figure 1A) and the middle Miocene configurations (Figure 4B) shows that the northernmost sector of the northern Iberian Arc (running from the Western Alps to Corsica) underwent a counterclockwise rotation and left lateral shift. This is confirmed by the analysis of paleomagnetic data ([261]) which quantify the rotation in about 50°. Such deformation is compatible with the SW-NE Nubia-Eurasia convergence here proposed (Figures 1A, 3 and 4), whereas it cannot be reconciled with the effects of the roughly southeastward traction that would have been exerted by the presumed slab-pull driving force.
- Geological evidence suggests that the consuming process which built up the Eocene Alpine–Iberian belt involved the southward subduction of the Tethys oceanic lithosphere under the oceanic domain facing the western Adriatic margin (e.g., [41,180,262,263]). This implies that the beginning of extension in the Balearic basin, coinciding with an inversion of the subduction direction at that plate boundary, can hardly be attributed to slab-pull forces, since the new embryonal northward subducting lithosphere was not long enough to induce an appreciable gravitational sinking.
- The occurrence of a major break in the European foreland, with the formation of the Rhine-Rhone graben system, cannot easily be reconciled with the effects of a slab-pull force in the Western Mediterranean region. Conversely, the interpretation here proposed provides plausible explanations for this event (Figure 3), concerning the observed sinistral transtensional stress regime in Western Europe, the timing of its occurrence and its progressive attenuation over time (corresponding well to the increasing curvature of the migrating Arc).
- Numerical modelling of slab-pull mechanisms ([13] and references therein [29]) indicate that such driving force cannot reproduce the strong bending that the migrating Arc underwent, forming two almost perpendicular segments (Figure 4). This deformation would have required a very peculiar distribution of trench retreat rates along the Arc, with much higher values in the central sector with respect to lateral sectors. However, one should explain why the presumed subducted lithosphere beneath the almost linear initial Arc (Figure 1A) may have induced such pattern of retreat rates in its various sectors.

From about 9 to 6–5 My, crustal extension developed in the Alpine–Iberian–Apennine belt located along the eastern side of the Corsica–Sardinia block, forming the northern Tyrrhenian basin. We suggest that such event was driven by the divergence between the northern Adriatic domain (moving NE ward) and the fixed Corsica-Sardinia Block. This interpretation provides plausible and coherent explanations for the major features of this tectonic event, i.e., the timing of beginning and cessation of crustal extension, the location and geometry of the extended zone, the orogenic quiescence of the Northern Apennines during this phase and the coeval tectonic pattern in the northern Adriatic zones.

Conversely, the hypothesis that the formation of this basin was driven by slab-pull forces cannot account for the following major features:

- The retreat of the northern Tyrrhenian slab would have started around the uppermost Miocene (9 My), i.e., about 5–7 My after the Middle Miocene cessation of crustal extension in the Balearic basin. This stop and go of slab retreat cannot easily be justified.
- At about 9 My, the subducted lithosphere beneath the Southern Apennines and Calabria was certainly more developed than the one lying under the Northern Apennines. Thus, one should explain why the slab-pull mechanism would have occurred only under the second zone for about 3 My.
- The slab-pull mechanism provides accretionary activity at the outer front of the migrating Arc, whereas during this phase the Northern Apennines were characterized by tectonic quiescence (e.g., [189,264,265]).
- Some major tectonic events occurred in the northern Adriatic area during the formation of the northern Tyrrhenian basin, such as the reactivation of the Giudicarie fault system, the stop of tectonic activity in the Western Alps and the strengthening of thrustings in the Eastern Alps. Our interpretation suggests a close connection between the above events and the formation of the Northern Tyrrhenian basin. Since such events cannot easily be explained as effects of slab pull forces, the supporters of such models must identify another independent cause to account for the observed tectonic activity in the northern Adriatic zones.

In the Miocene, tectonic activity in the central-western Mediterranean area was mainly driven by the Nubia–Eurasia convergence. This situation underwent a remarkable change around the latest Miocene, when the thinned continental domain lying along the eastern side of the Adriatic continental core was completely consumed. Since then, the westward push of the Anatolian–Aegean–Pelagonian system was directly applied to the Adriatic continental domain. After an initial phase, characterized by crustal thickening and uplift in the collision zone, the necessity of activating less resisted shortening processes (able to accommodate the fast westward motion of the Anatolian–Aegean–Pelagonian system) required a drastic reorganization of the tectonic setting in the central Mediterranean area. This change developed by means of a series of processes in the whole central Mediterranean region, with the final purpose of activating lateral escapes of orogenic wedges at the expense of the remnant parts of the oceanic and thinned continental sectors surrounding the Adriatic continental core.

The first step was the decoupling from Nubia of the Adria plate by the activation of a relatively long fracture crossing the Ionian oceanic domain (Victor–Hensen–Medina fault system) and the Pelagian zone (Sicily Channel fault system). Once decoupled, the Adria plate underwent a clockwise rotation and a minor NNW ward motion. The consequent convergence between the southern Adria plate (moving roughly westward) and Nubia (moving roughly NNE ward) was accommodated by a series of shortening processes in the Hyblean–Adventure plateaus and in the Tunisian–Algerian zones. The Adventure wedge underwent a roughly northward escape, causing the displacement of the adjacent Alpine–Maghrebian belt. The interaction of this belt with the southwestern edge of the Corsica–Sardinia block may have caused the formation of the Campidano graben in Sardinia. Furthermore, the same mechanism induced a strong compressional regime in the Alpine–Iberian–Apennine belt which lay south of the Selli fault zone, causing the eastward escape of wedges at the expense of the Periadriatic thinned domain. This process produced accretionary activity in the Southern Apennines and crustal extension in the wake of the migrating wedges, forming the Vavilov basin.

This tectonic phase lasted until the late Pliocene–early Pleistocene, when the Southern Apennines wedge reached the Adriatic continental domain. Since then the compressional regime in that zone was accommodated by lateral escape of the Calabrian wedge, i.e., the only belt sector which was facing an oceanic domain. The considerable reduction in the corridor width through which this wedge could escape towards the Ionian oceanic domain caused a considerable increase in the escaping rate and uplift of the Calabrian wedge and consequently of the extensional rate in the Marsili basin.

Regarding the slab underlying Calabria, one should consider the main difficulties that the slab-pull hypothesis would involve. In the middle Miocene (12–16 My), that slab was already well developed (hundreds of Kms), after to the consumption of a large part of the Alpine Tethys oceanic domain. In spite of this, such slab did not undergo any gravitational sinking until the late Miocene (5–6 My), as testified by the lack of back-arc extension. Then, the slab is supposed to have undergone gravitational sinking from about 5–6 to 2 My (to explain the generation of the Vavilov basin). In the Pleistocene, slab sinking would have occurred in a relatively short phase (2.1 to 1.6 My), with very high extensional rates (up to 19 cm/y), forming the Marsili basin. Since 0.78, the slab would have considerably decreased its retreat [209]. Thus, to support the reliability of the slab-pull hypothesis, one should provide physically plausible explanations for such a complex alternance of active and non-active sinking phases, for strong variations of slab retreat rates and for other major features.

The deformation pattern in the southern Italian region changed around the Early Pleistocene, when the northern edge of Calabria collided with the continental Adria domain. This obstacle forced the above wedge to change its escaping trend by activating new lateral guides (Vulcano and Sibari). This also changed the escape trend of the Hyblean block, causing tectonic effects in the surrounding zones.

A problem that is often matter of debate in geodynamic interpretations concerns the structural setting of the migrating Arc in TABA systems. A common question regards the ambiguity between thick- and thin-skinned crustal delamination and the conditions that may have led to one or the other style. The information provided by seismic soundings in various zones of the Mediterranean area (e.g., [113]) and the evidence on major tectonic processes provides important insights about the above problem, which led us to believe that the crustal structure of migrating wedges may be quite variable, being controlled by the minimum-action principle that holds in the related geodynamic contexts. This hypothesis is consistent with the deformation pattern observed in the study area.

In the development of the Western Mediterranean TABA system, the Arc was constituted by a whole crustal block encompassing a continental fragment (Corsica–Sardinia) with the overlying orogenic belt (Alpine–Apennine, Figure 6).

The genetic mechanism of the Vavilov and Marsili basins was very similar to the one in the Balearic TABA system. After the formation of the Northern Tyrrhenian basin, the previous connection between the Corsica–Sardinia block and the Alpine–Apennine belt was considerably reduced. Thus, the northward indentation of the Adventure block and the consequent displacement of the Maghrebian belt induced a strong compression in the Alpine–Apennine orogenic material which lay south of the Selli line. This caused the eastward extrusion of the Southern Apennines and Calabrian crustal wedges at the expense of the remnant thinned margin of Adria (Figure 11A,B). The crustal extension that developed in the wake of such wedges led to the formation of the Vavilov and Marsili basins.

In the Quaternary, the lateral escape of orogenic material in some sectors of the Apennine belt (Molise–Sannio and Romagna–Marche–Umbria) mainly involved the sedimentary cover (Figure 14). This decoupling (favoured by Triassic evaporites) was also determined by the dynamic context, which mainly involved belt-parallel compression in the uppermost crust (Figure 14).

The hypothesis that the Mediterranean Back Arc basins were generated by extrusion processes has been questioned by some authors (e.g., [18]), who suggest that the high extension rates estimated in such basins (mostly lower than 5–6 cm/y) cannot be reconciled with the low Nubia-Eurasia convergence rate (about 1 cm/y). This opinion does not take into account the contexts that determined the extrusion processes in the above zones. In the case of the Balearic TABA system, the rate of the Arc's migration and of crustal extension in the Balearic basin was mainly determined by the outward bending of a long belt. In this context, it can easily be demonstrated that the migration rate of the central part of the bending Arc can be significantly higher than the rate of plate convergence. Regarding the Vavilov and Marsili basins, the context was more complex. First of all, one must consider that the driving force was given by the Nubia–Eurasia convergence and by the westward push of the Anatolian–Aegean–Pelagonian belt. In addition, it must be considered that the extrusion rate of orogenic wedges from a squeezed belt may be considerably influenced by the dimensions of the corridor through which the extruding material can flow out. For instance, the lateral escape of the Calabrian wedge, cited by [18], developed through a very narrow corridor flanked by buoyant continental domains.

This can explain why the rate of crustal stretching in the Marsili basin was considerably higher (19 cm/y) than the one estimated for the Balearic and Vavilov basins. Furthermore, in this last case the strong deformation of the extruding wedge that is evidenced by the cross section shown in Figure 11A cannot be reconciled with the effects of a slab-pull driving force.

Author Contributions: Conceptualization and methodology, M.V. and E.M.; Investigation and data curation, M.V., E.M., D.B., C.T., M.C., A.R.; Writing, E.M.; Funding Acquisition, E.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Regione Toscana (Italy), Department of Seismic Prevention, Grant number: B65F19003190002.

Data Availability Statement: This information is reported by the cited references.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dercourt, J.; Zonenshain, L.P.; Ricou, L.E.; Kazmin, V.G.; Le Pichon, X.; Knipper, A.L.; Grandjacquet, C.; Sbortshikov, I.M.; Geyssant, J.; Lepvrirer, C.; et al. Geological Evolution of the Tethys Belt from the Atlantic to the Pamirs since the LIAS. *Tectonophysics* **1986**, *123*, 241–315. [CrossRef]
2. Dewey, J.F.; Helman, M.L.; Turco, E.; Hutton, D.H.W.; Knott, S.D. Kinematics of the western Mediterranean. *Geol. Soc. Lond. Spec. Publ.* **1989**, *45*, 265–283. [CrossRef]
3. Patacca, E.; Scandone, P. Post-Tortonian Mountain Building in the Apennines. The Role of the Passive Sinking of a Relict Lithospheric Slab. In *The Lithosphere in Italy. Advances in Earth Science Research*; Boriani, A., Bonafede, M., Piccardo, G.B., Vai, G.B., Eds.; Accademia Nazionale dei Lincei: Roma, Italy, 1989; Volume 80, pp. 157–176.
4. Sartori, R.; Capozzi, R. Patterns of Neogene to Recent Rift-Related Subsidence in the Tyrrhenian Domain. In *Sedimentary Basins: Models and Constraints*; Cloetingh, S., Ranalli, G., Ricci, C.A., Eds.; Tipografia Senese: Siena, Italy, 1998; pp. 147–158.
5. Finetti, I.R. Geodynamic Evolution of the Mediterranean Region from the Permo-Triassic Ionian Opening to the Present, Constrained by New Lithospheric CROP Seismic Data. In *CROP PROJECT, Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 34; pp. 767–776.
6. Finetti, I.R. Ionian and Alpine Neotethyan Oceans Opening. In *CROP PROJECT, Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 6; pp. 103–107.
7. Finetti, I.R.; Del Ben, A. Ionian Tethys Lithosphere Roll-Back Sinking and Back-Arc Tyrrhenian Opening from New CROP Seismic Data. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 21; pp. 483–504.
8. Mantovani, E. Evolutionary Reconstruction of the Mediterranean Region: Extrusion Tectonics Driven by Plate Convergence. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 32; pp. 705–746.
9. Schmid, S.M.; Bernoulli, D.; Fugenschuh, B.; Matenco, L.; Schefer, S.; Schuster, R.; Tischler, M.; Ustaszewski, K. The Alpine-Carpathian-Dinaridic Orogenic System: Correlation and Evolution of Tectonic Units. *Swiss J. Geosci.* **2008**, *101*, 139–183. [CrossRef]
10. Mantovani, E.; Babbucci, D.; Tamburelli, C.; Viti, M. A Review on the Driving Mechanism of the Tyrrhenian-Apennines System: Implications for the Present Seismotectonic Setting in the Central-Northern Apennines. *Tectonophysics* **2009**, *476*, 22–40. [CrossRef]
11. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C.; Cenni, N. How and Why the Present Tectonic Setting in the Apennine Belt Has Developed. *J. Geol. Soc. Lond.* **2019**, *176*, 1291. [CrossRef]
12. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C.; Cenni, N. Geodynamics of the Central Western Mediterranean Region: Plausible and Non-Plausible Driving Forces. *Mar. Pet. Geol.* **2020**, *113*, 104121. [CrossRef]

13. Viti, M.; Mantovani, E.; Tamburelli, C.; Babbucci, D. Generation of Trench-Arc-Backarc Systems in the Western Mediterranean Region Driven by Plate Convergence. *Boll. Della Soc. Geol. Ital.* **2009**, *128*, 89–106.
14. Handy, M.R.; Schmid, S.M.; Bousquet, R.; Kissling, E.; Bernoulli, D. Reconciling Plate-Tectonic Reconstructions with the Geologicalgeophysical Record of Spreading and Subduction in the Alps. *Earth Sci. Rev.* **2010**, *102*, 121–158. [CrossRef]
15. Guillaume, B.; Funiciello, F.; Faccenna, C.; Martinod, J.; Olivetti, V. Spreading Pulses of the Tyrrhenian Sea during the Narrowing of the Calabrian Slab. *Geology* **2010**, *38*, 819–822. [CrossRef]
16. Schettino, A.; Turco, E. Tectonic History of the Western Tethys since the Late Triassic. *Geol. Soc. Am. Bull.* **2011**, *123*, 89–105. [CrossRef]
17. Milia, A.; Torrente, M.M.; Iannace, P. Pliocene-Quaternary Orogenic Systems in Central Mediterranean: The Apulia-Southern Apennines-Tyrrhenian Sea Example. *Tectonics* **2017**, *36*, 1614–1632. [CrossRef]
18. Romagny, A.; Jolivet, L.; Menant, A.; Bessière, E.; Maillard, A.; Canva, A.; Gorini, C.; Augier, R. Detailed Tectonic Reconstructions of the Western Mediterranean Region for the Last 35 Ma, Insights on Driving Mechanisms. *Bull. Société Géologique Fr.* **2020**, *191*, 37. [CrossRef]
19. Malinverno, A.; Ryan, W.B.F. Extension in the Tyrrhenian Sea and Shortening in the Apennines as Result of Arc Migration Driven by Sinking of the Lithosphere. *Tectonics* **1986**, *5*, 227–245. [CrossRef]
20. Royden, L.H. Evolution of Retreating Subduction Boundaries Formed during Continental Collision. *Tectonics* **1993**, *12*, 629–638. [CrossRef]
21. Faccenna, C.; Piromallo, C.; Crespo-Blanc, A.; Jolivet, L. Lateral Slab Deformation and the Origin of the Western Mediterranean arcs. *Tectonics* **2004**, *23*, TC1012. [CrossRef]
22. Rosenbaum, G. Geodynamics of Oroclinal Bending: Insights from the Mediterranean. *J. Geodyn.* **2014**, *82*, 5–15. [CrossRef]
23. Bouillin, J.-P. Le « Bassin Maghrebin »; Une Ancienne Limite Entre L'europe Et L'afrique à L'ouest Des Alpes. *Bull. Société Géologique Fr.* **1986**, *2*, 547–558. [CrossRef]
24. Michard, A.; Chalouan, A.; Feinberg, H.; Goffé, B.; Montigny, R. How Does the Alpine Belt End between Spain and Morocco? *Bull. Société Géologique Fr.* **2002**, *173*, 3–15. [CrossRef]
25. Michard, A.; Negro, F.; Saddiqi, O.; Bouybaouene, M.L.; Chalouan, A.; Montigny, R.; Goffé, B. Pressure-Temperature-Time Constraints on the Maghrebide Mountain Building: Evidence from the Rif-Betic Transect (Morocco, Spain), Algerian Correlations, and Geodynamic Implications. *Comptes Rendus Geosci.* **2006**, *338*, 92–114. [CrossRef]
26. Mantovani, E.; Viti, M.; Babbucci, D.; Albarello, D. Nubia-Eurasia Kinematics: An Alternative Interpretation from Mediterranean and North Atlantic Evidence. *Ann. Geophys.* **2007**, *50*, 311–336. [CrossRef]
27. Viti, M.; Mantovani, E.; Babbucci, D.; Tamburelli, C. Plate Kinematics and Geodynamics in the Central Mediterranean. *J. Geodyn.* **2011**, *51*, 190–204. [CrossRef]
28. Faccenna, C.; Funiciello, F.; Giardini, D.; Lucente, P. Episodic back-Arc Extension during Restricted Mantle Convection in the Central Mediterranean. *Earth Planet. Sci. Lett.* **2001**, *187*, 105–116. [CrossRef]
29. Schellart, W.P.; Freeman, J.; Stegman, D.R.; Moresi, L.; May, D. Evolution and Diversity of Subduction Zones Controlled by Slab Width. *Nature* **2007**, *446*, 308–311. [CrossRef]
30. Tapponnier, P. Evolution Tectonique Du Système Alpin En Méditerranée: Poinçonnement Et Ecrasement Rigide-Plastique. *Bull. Société Géologique Fr.* **1977**, *19*, 437–460. [CrossRef]
31. Boccaletti, M.; Conedera, C.; Dainelli, P.; Gocev, P. The Recent (Miocene-Quaternary) Regmatic System of the Western Mediterranean Region. *J. Petrol. Geol.* **1982**, *5*, 31–49. [CrossRef]
32. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C.; Cenni, N.; Baglione, M.; D'Intinosante, V. Generation of back-Arc Basins as Side Effect of Shortening Processes: Examples from the Central Mediterranean. *Int. J. Geosci.* **2014**, *5*, 1062–1079. [CrossRef]
33. Driehaus, L.; Nalpas, T.; Cobbold, P.R.; Gelabert, B.; Sàbat, F. Effects of Margin-Parallel Shortening and Density Contrasts on back-Arc Extension during Subduction: Experimental Insights and Possible Application to Anatolia. *Tectonophysics* **2013**, *608*, 288–302. [CrossRef]
34. Boutelier, D.; Gagnon, L.; Johnston, S.; Cruden, A. Buckling of Orogens: Insights from Analogue Modelling. *J. Struct. Geol.* **2019**, *125*, 213–217. [CrossRef]
35. Boccaletti, M.; Dainelli, P. Il Sistema Regmatico Neogenico-Quaternario Nell'area Mediterranea: Esempio Di Deformazione Plastico-Rigida Post-Collisionale. *Mem. Soc. Geol. Ital.* **1982**, *24*, 465–482.
36. Rehault, J.P.; Boillot, G.; Mauffret, A. The Western Mediterranean Basin: Geological Evolution. *Mar. Geol.* **1984**, *55*, 447–477. [CrossRef]
37. Rehault, J.P.; Moussat, E.; Fabbri, A. Structural Evolution of the Tyrrhenian back-Arc Basin. *Mar. Geol.* **1987**, *74*, 123–150. [CrossRef]
38. Dercourt, J.F.; Gaetani, M.; Vrielynck, B.; Barrier, E.; Biju-Duval, B.; Brunet, M.-F.; Cadet, J.P.; Crasquin, S.; Sandulescu, M. *Atlas Peri-Tethys Paleogeographical Maps Vol.I-XX*; CCGM/CGMW: Paris, France, 2000; pp. 1–269.
39. Royden, L.H.; Baldi, T. Early Cenozoic Tectonics and Paleogeography of the Pannonian and Surrounding Regions. In *The Pannonian Basin: A Study in Basin Evolution*; Royden, L.H., Horvath, F., Eds.; American Association of Petroleum Geologists, AAPG Memoir: Tulsa, OK, USA, 1988; Volume 45, pp. 1–16.
40. Vigliotti, L.; Laugenheim, V.E. When Did Sardinia Stop Rotating? New Paleomagnetic Results. *Terra Nova* **1995**, *7*, 424–435. [CrossRef]

41. Finetti, I.; Boccaletti, M.; Bonini, M.; Del Ben, A.; Geletti, R.; Pipan, M.; Sani, F. Crustal Section Based on CROP Seismic Data across the North Tyrrhenian-Northern Apennines-Adriatic Sea. *Tectonophysics* **2001**, *343*, 135–163. [CrossRef]
42. Casado, C.L.; De Galdeano, C.S.; Palacios, C.M.; Romero, J.H. The Structure of the Alboran Sea: An Interpretation from Seismological and Geological Data. *Tectonophysics* **2001**, *338*, 79–95. [CrossRef]
43. Dèzes, P.; Schmid, S.M.; Ziegler, P.A. Evolution of the European Cenozoic Rift System: Interaction of the Alpine and Pyrenean Orogens with Their Foreland Lithosphere. *Tectonophysics* **2004**, *389*, 1–33. [CrossRef]
44. Van Hinsbergen, D.J.J.; Schmid, S.M. Map-View Restoration of the Aegean back-Arc. *Tectonics* **2012**, *31*, TC5005. [CrossRef]
45. Van Hinsbergen, D.J.J.; Torsvik, T.H.; Schmid, S.M.; Maţenco, L.C.; Maffione, M.; Vissers, R.L.M.; Gürer, D.; Spakman, W. Orogenic Architecture of the Mediterranean Region and Kinematic Reconstruction of Its Tectonic Evolution since the Triassic. *Gondwana Res.* **2020**, *81*, 79–229. [CrossRef]
46. Jolivet, L.; Baudin, T.; Calassou, S.; Chevrot, S.; Ford, M.; Issautier, B.; Lasseur, E.; Masini, E.; Manatschal, G.; Mouthereau, F.; et al. Geodynamic Evolution of a Wide Plate Boundary in the Western Mediterranean, near-Field versus Far-Field Interactions. *BSGF—Earth Sci. Bull.* **2021**, *192*, 48. [CrossRef]
47. Improta, L.; Moretti, M.; Govoni, A.; Pastori, M.; Chiarabba, C.; De Gori, P.; Dannowski, A.; Kopp, H. The Contribution of the Istituto Nazionale Di Geofisica E Vulcanologia (INGV) to "Adria LithosPHere investigAtion (ALPHA)" Active Seismic Experiment. *Ann. Geophys.* **2018**, *61*, SE667. [CrossRef]
48. Robertson, A.H.F. Mesozoic-Tertiary Tectonic-Sedimentary Evolution of a South Tethyan Oceanic Basin and Its Margins in Southern Turkey. In *Tectonics and Magmatism in Turkey and the Surrounding Area*; Bozkurt, E., Winchester, J.A., Piper, J.D.A., Eds.; The Geological Society: London, UK, 2000; Volume 173, pp. 97–138.
49. Finetti, I.R. The Calabrian Arc and Subducting Ionian Slab from new CROP Seismic Data. In *CROP PROJECT, Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 17; pp. 393–412.
50. Finetti, I.R. Understanding the Ionides and Their Geodynamics. In *CROP PROJECT, Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Volume 10, pp. 197–208.
51. Patacca, E.; Scandone, P. Geology of the Southern Apennines. *Boll. Della Soc. Geol. Ital.* **2007**, *7*, 75–119.
52. Guerrera, F.; Martin-Martin, M.; Perrone, V.; Tramontana, M. Tectono-Sedimentary Evolution of the Southern Branch of the Western Tethys (Maghrebian Flysch Basin and Lucanian Ocean): Consequences for Western Mediterranean Geodynamics. *Terra Nova* **2005**, *17*, 358–367. [CrossRef]
53. Robertson, A.H.F.; Dixon, J.E.; Brown, S.; Collins, A.; Morris, A.; Pickett, E.A.; Sharp, I.; Ustaömer, T. Alternative Tectonic Models for the Late Palaeozoic-Early Tertiary Development of Tethys in the Eastern Mediterranean Region. In *Paleomagnetism and Tectonics of the Mediterranean Region*; Morris, A., Tarlino, D.H., Eds.; The Geological Society: London, UK, 1996; Volume 105, pp. 239–263.
54. Gessner, K.; Ring, U.; Passchier, C.W.; Güngör, T. How to Resist Subduction: Evidence for Large-Scale out-of-Sequence Thrusting during Eocene Collision in Western Turkey. *J. Geol. Soc.* **2001**, *158*, 769–784. [CrossRef]
55. Ring, U.; Layer, P.W. High-Pressure Metamorphism in the Aegean, Eastern Mediterranean: Underplating and Exhumation from the Late Cretaceous until the Miocene to Recent above the Retreating Hellenic Subduction Zone. *Tectonics* **2003**, *22*, 1–23. [CrossRef]
56. Golonka, J. Plate Tectonic Evolution of the Southern Margin of Eurasia in the Mesozoic and Cenozoic. *Tectonophysics* **2004**, *381*, 235–273. [CrossRef]
57. Dilek, Y.; Furnes, H. Tethyan Ophiolites and Tethyan Seaways. *J. Geol. Soc.* **2019**, *176*, 899–912. [CrossRef]
58. Handy, M.R.; Ustaszewski, K.; Kissling, E. Reconstructing the Alps-Carpathians-Dinarides as a Key to Understanding Switches in Subduction Polarity, Slab Gaps and Surface Motion. *Int. J. Earth Sci.* **2015**, *104*, 1–26. [CrossRef]
59. Royden, L.H.; Burchfiel, B.C. Are Systematic Variations in Thrust Belt Style Related to Plate Boundary Processes? (The Western Alps versus the Carpathians). *Tectonics* **1989**, *8*, 51–61. [CrossRef]
60. Okay, A.I.; Tüysüz, O. Tethyan Sutures of Northern Turkey. In *The Mediterranean Basins: Tertiary Extension within the Alpine Orogen*; Durand, B., Jolivet, L., Horváth, F., Seranne, M., Eds.; The Geological Society: London, UK, 1999; Volume 156, pp. 475–515.
61. Schmid, S.M.; Fügenschuh, B.; Kounov, A.; Matenco, L.; Nievergelt, P.; Oberhansli, R.; Pleuger, J.; Schefer, S.; Schuster, R.; Tomljenovic, B.; et al. Tectonic Units of the Alpine Collision Zone between Eastern Alps and Western Turkey. *Gondwana Res.* **2020**, *78*, 308–374. [CrossRef]
62. Sleep, N.H.; Stein, S.; Geller, R.J.; Gordon, R.G. Comment on "The Use of the Minimum-Dissipation Principle in Tectonophysics", by P. Bird and D.A. Yuen. *Earth Planet. Sci. Lett.* **1979**, *45*, 218–220. [CrossRef]
63. Molnar, P.; Lyon-Caen, H. Some Simple Physical Aspects of the Support, Structure and Evolution of Mountain Belts. In *Processes in Continental and Lithospheric Deformation*; Clark, S.P., Ed.; The Geological Society: Boulder, CO, USA, 1988; Volume 218, pp. 179–207.
64. Masek, J.G.; Duncan, C.C. Minimum-Work Mountain Building. *J. Geophys. Res.* **1998**, *103*, 907–917. [CrossRef]
65. Ranalli, G.; Murphy, D.G. Rheological Stratification of the Lithosphere. *Tectonophysics* **1987**, *132*, 281–295. [CrossRef]
66. Lobkovski, L.I.; Kerchmann, V.I. A Two-Level Concept of Plate Tectonics: Application to Geodynamics. *Tectonophysics* **1991**, *199*, 343–374. [CrossRef]
67. Cloos, M. Lithospheric Buoyancy and Collisional Orogenesis: Subduction of Oceanic Plateaus, Continental Margins, Island Arcs, Spreading Ridges, and Seamounts. *GSA Bull.* **1993**, *105*, 715–737. [CrossRef]

68. Van den Beukel, J. Some Thermomechanical Aspects of the Subduction of Continental Lithosphere. *Tectonics* **1992**, *11*, 316–329. [CrossRef]
69. Meissner, R.; Mooney, W. Weakness of Lower Continental Crust: A Condition for Delamination, Uplift and Escape. *Tectonophysics* **1998**, *296*, 47–60. [CrossRef]
70. Viti, M.; Albarello, D.; Mantovani, E. Rheological Profiles in the Central-Eastern Mediterranean. *Ann. Geofis.* **1997**, *40*, 849–864.
71. Castellarin, A.; Cantelli, L. Neo-Alpine Evolution of the Southern Eastern Alps. *J. Geodyn.* **2000**, *30*, 251–274. [CrossRef]
72. Ceriani, S.; Schmid, S.M. From N-S Collision to WNW-Directed Post-Collisional Thrusting and Folding: Structural Study of the Frontal Penninic Units in Savoie (Western Alps, France). *Eclogae Geol. Helv.* **2004**, *97*, 347–369. [CrossRef]
73. Rosenberg, C.L.; Kissling, E. 3D Insight into Central Alpine Collision: Lower Plate or Upper Plate Indentation? *Geology* **2013**, *41*, 1219–1222. [CrossRef]
74. Stern, R.J. Subduction Initiation: Spontaneous and Induced. *Earth Planet. Sci. Lett.* **2004**, *226*, 275–292. [CrossRef]
75. Copley, A.; Avouac, J.-P.; Royer, J.-Y. India-Asia Collision and the Cenozoic Slowdown of the Indian Plate: Implications for the Forces Driving Plate Motions. *J. Geophys. Res.* **2010**, *115*, B03410. [CrossRef]
76. Hippolyte, J.C.; Murovskaya, A.; Volfman, Y.; Yegorova, T.; Gintov, O.; Kaymakci, N.; Sangu, E. Age and Geodynamic Evolution of the Black Sea Basin: Tectonic Evidences of Rifting in Crimea. *Mar. Pet. Geol.* **2018**, *93*, 298–314. [CrossRef]
77. Hall, R. The Subduction Initiation Stage of the Wilson Cycle. In *Fifty Years of the Wilson Cycle Concept in Plate Tectonics*; Wilson, R.W., Houseman, G.A., Mccaffrey, K.J.W., Doré, A.G., Buiter, S.J.H., Eds.; The Geological Society: London, UK, 2018; Volume 470. [CrossRef]
78. Mantovani, E.; Viti, M.; Albarello, D.; Tamburelli, C.; Babbucci, D.; Cenni, N. Role of Kinematically Induced Horizontal Forces in Mediterranean Tectonics: Insights from Numerical Modelling. *J. Geodyn.* **2000**, *30*, 287–320. [CrossRef]
79. Mantovani, E.; Cenni, N.; Albarello, D.; Viti, M.; Babbucci, D.; Tamburelli, C.; D'Onza, F. Numerical Simulation of the Observed Strain Field in the Central-Eastern Mediterranean Region. *J. Geodyn.* **2001**, *3*, 519–556. [CrossRef]
80. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C. Major Evidence on the Driving Mechanism of the Tyrrhenian-Apennines Arc-Trench-back-Arc System from CROP Seismic Data. *Boll. Soc. Geol. Ital.* **2007**, *126*, 459–471.
81. Ratschbacher, L.; Merle, O.; Davy, P.; Cobbold, P. Lateral Extrusion in the Eastern Alps, Part I: Boundary Conditions and Experiments Scaled for Gravity. *Tectonics* **1991**, *10*, 245–256. [CrossRef]
82. Davy, P.; Hansen, A.; Bonnet, E.; Zhang, S.Z. Localisation and Fault Growth in Layered Brittle-Ductile Systems: Implications for Deformations of the Continental Lithosphere. *J. Geophys. Res.* **1995**, *100*, 6281–6294. [CrossRef]
83. Faccenna, C.; Davy, P.; Brun, J.P.; Funiciello, R.; Giardini, D.; Mattei, M.; Nalpas, T. The Dynamics of back-Arc Extension: An Experimental Approach to the Opening of the Tyrrhenian Sea. *Geophys. J. Int.* **1996**, *126*, 781–795. [CrossRef]
84. Shemenda, A.I. Subduction of the Lithosphere and back Arc Dynamics: Insights from Physical Modelling. *J. Geophys. Res.* **1993**, *98*, 167–185. [CrossRef]
85. Boutelier, D.; Chemenda, A.; Jorand, C. Continental Subduction and Exhumation of High-Pressure Rocks: Insights from Thermo-mechanical Laboratory Modelling. *Earth Planet. Sci. Lett.* **2004**, *222*, 209–216. [CrossRef]
86. Zhao, W.L.; Morgan, J. Uplift of Tibetan plateau. *Tectonics* **1985**, *4*, 359–369. [CrossRef]
87. Westaway, R. Crustal Volume Balance during the India-Eurasia Collision and Altitude of the Tibetan Plateau: A Working Hypothesis. *J. Geophys. Res.* **1995**, *100*, 173–192. [CrossRef]
88. Tapponnier, P.; Molnar, P. Slip-Line Field Theory and Large-Scale Continental Tectonics. *Nature* **1976**, *264*, 319–324. [CrossRef]
89. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C.; Albarello, D. Back Arc Extension: Which Driving Mechanism? *J. Virtual Explor.* **2001**, *3*, 17–44. [CrossRef]
90. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C.; Albarello, D. Geodynamic Connection between the Indentation of Arabia and the Neogene Tectonics of the Central-Eastern Mediterranean Region. In *Post-Collisional Tectonics and Magmatism in the Mediterranean region and Asia*; Dilek, Y., Pavlides, S., Eds.; The Geological Society: Boulder, CO, USA, 2006; Volume 490, pp. 15–49. [CrossRef]
91. Şengör, A.M.C.; Kidd, W.S.F. Post-Collisional Tectonics of the Turkish-Iranian Plateau and a Comparison with Tibet. *Tectonophysic* **1979**, *55*, 361–376. [CrossRef]
92. Dewey, J.F.; Hempton, M.R.; Kidd, W.S.F.; Saroglu, F.; Şengör, A.M.C. Shortening of Continental Lithosphere: The Neotectonics of Eastern Anatolia a Young Collision Zone. *Geol. Soc. Lond. Spec. Publ.* **1986**, *19*, 3–36. [CrossRef]
93. Yilmaz, Y.; Şaroğlu, F.; Güner, Y. Initiation of the Neomagmatism in East Anatolia. *Tectonophysics* **1987**, *134*, 177–199. [CrossRef]
94. Barka, A.A. The North Anatolian Fault Zone. *Ann. Tecton.* **1992**, *6*, 164–195.
95. Hubert-Ferrari, A.; King, G.; Manighetti, I.; Armijo, R.; Meyer, B.; Tapponnier, P. Long-Term Elasticity in the Continental Lithosphere; Modelling the Aden Ridge Propagation and the Anatolian Extrusion Process. *Geophys. J. Int.* **2003**, *153*, 111–132. [CrossRef]
96. Tapponnier, P.; Peltzer, G.; Le Dayn, A.Y.; Armijo, R.; Cobbold, P. Propagating Extension Tectonics in Asia: New Insights from Simple Experiments with Plasticine. *Geology* **1982**, *110*, 611–616. [CrossRef]
97. Lavé, J.; Avouac, J.P.; Lacassin, R.; Tapponnier, P.; Montagner, J.P. Seismic Anisotropy beneath Tibet-Evidence for Eastward Extrusion of the Tibetan Lithosphere. *Earth Planet. Sci. Lett.* **1996**, *140*, 83–96.
98. Seyferth, M.; Henk, A. Syn-Convergent Exhumation and Lateral Extrusion in Continental Collision Zones-Insights from Three-Dimensional Numerical Models. *Tectonophysics* **2004**, *382*, 1–29. [CrossRef]

99. Viti, M.; De Luca, J.; Babbucci, D.; Mantovani, E.; Albarello, D.; D'Onza, F. Driving Mechanism of Tectonic Activity in the Northern Apennines: Quantitative Insights from Numerical Modeling. *Tectonics* **2004**, *23*, TC4003. [CrossRef]
100. Sengor, A.M.C.; Tuysuz, O.; Imren, C.; Sakinc, M.; Eyidogan, H.; Gorur, N.; Le Pichon, X.; Rangin, C. The North Anatolian Fault: A new look. *Annu. Rev. Earth Planet. Sci.* **2005**, *33*, 37–112. [CrossRef]
101. Hubert-Ferrari, A.; King, G.; Van Der Woerd, J.; Villa, I.; Altunel, E.; Armijo, R. Long-Term Evolution of the North Anatolian Fault: New Constraints from its Eastern Termination. In *Collision and Collapse at the Africa–Arabia–Eurasia Subduction Zone*; Van Hinsbergen, D.J.J., Edwards, M.A., Govers, R., Eds.; The Geological Society: London, UK, 2009; Volume 311, pp. 133–154. [CrossRef]
102. Robertson, A.; Shallo, M. Mesozoic-Tertiary Tectonic Evolution of Albania in Its Regional Eastern Mediterranean Context. *Tectonophysics* **2000**, *316*, 197–254. [CrossRef]
103. Royden, L.H.; Papanikolaou, D.J. Slab Segmentation and Late Cenozoic Disruption of the Hellenic Arc. *Geochem. Geophys. Geosyst.* **2011**, *12*, Q03010. [CrossRef]
104. Burchfiel, B.C.; Royden, L.H.; Papanikolaou, D.; Pearce, F.D. Crustal Development within a Retreating Subduction System: The Hellenides. *Geosphere* **2018**, *14*, 1119–1130. [CrossRef]
105. Le Pichon, X.; Bergerat, F.; Roulet, M.J. Kinematics and Tectonics Leading to Alpine Belt Formation: A New Analysis. In *Processes in Continental Lithospheric Deformation*; Clark, S.P., Ed.; The Geological Society: Boulder, CO, USA, 1988; Volume 218, pp. 111–131.
106. Şengör, A.M.C. Some Current Problems on the Tectonic Evolution of the Mediterranean during the Cainozoic. In *Recent Evolution and Seismicity of the Mediterranean Region*; Boschi, E., Mantovani, E., Morelli, A., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1993; pp. 1–51.
107. Gelabert, B.; Sàbat, F.; Rodriguez-Perea, A. A New Proposal for the Late Cenozoic Geodynamic Evolution of the Western Mediterranean. *Terra Nova* **2002**, *14*, 93–100. [CrossRef]
108. Sissingh, W. Comparative Tertiary Stratigraphy of the Rhine Graben, Bresse Graben and Molasse Basin: Correlation of Alpine Foreland Events. *Tectonophysics* **1998**, *300*, 249–284. [CrossRef]
109. Schreiber, U.; Rotsch, S. Cenozoic Block Rotation According to a Conjugate Shear System in Central Europe—Indications Form Palaeomagnetic Measurements. *Tectonophysics* **1998**, *299*, 111–142. [CrossRef]
110. Laubscher, H. Plate Interactions at the Southern End of the Rhine Graben. *Tectonophysics* **2001**, *343*, 119. [CrossRef]
111. Michon, L.; Balen, R.T.; van Merle, O.; Pagnier, H. The Cenozoic Evolution of the Roer Valley Rift System Integrated at a European Scale. *Tectonophysics* **2003**, *367*, 101–126. [CrossRef]
112. Finetti, I.R.; Boccaletti, M.; Bonini, M.; Del Ben, A.; Pipan, M.; Prizzon, A.; Sani, F. Lithospheric Tectono-Stratigraphic Setting of the Ligurian Sea-Northern Apennines-Adriatic Foreland from Integrated CROP Seismic Data. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 8; pp. 119–158.
113. Finetti, I.R. *Deep Seismic Exploration of the Central Mediterranean and Italy, CROP PROJECT*; Elsevier: Amsterdam, The Netherlands, 2005; p. 794.
114. Mantovani, E.; Albarello, D.; Babbucci, D.; Tamburelli, C.; Viti, M. Trench-Arc-BackArc Systems in the Mediterranean Area: Examples of Extrusion Tectonics. *J. Virtual Explor.* **2002**, *8*, 125–141. [CrossRef]
115. Becker, T.W.; Faccenna, C.; O'Connel, R.J. The Development of Slabs in the Upper Mantle: Insights from Numerical and Laboratory Experiments. *J. Geophys. Res.* **1999**, *104*, 207–226. [CrossRef]
116. Marroni, M.; Treves, B. Hidden Terranes in the Northern Apennines, Italy: A Record of Late Cretaceous-Oligocene Transpressional Tectonics. *J. Geol.* **1998**, *106*, 149–162. [CrossRef]
117. Carmignani, L.; Conti, P.; Cornamusini, G.; Meccheri, M. The Internal Northern Apennines, the Northern Tyrrhenian Sea and the Sardinia-Corsica Block. In *Geology of Italy*; Crescenti, V., D'Offizi, S., Merlino, S., Sacchi, L., Eds.; Società Geologica Italiana: Roma, Italy, 2004; pp. 59–77.
118. Sartori, R. Bedrock Geology of the Tyrrhenian Sea Insights on Alpine Paleogeography and Magmatic Evolution of the Basin. In *CROP PROJECT, Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Volume 4, pp. 69–80.
119. Moeller, S.; Grevemeyer, I.; Ranero, C.R.; Berndt, C.; Klaeschen, D.; Sallares, V.; Zitellini, N.; de Franco, R. Early-Stage Rifting of the Northern Tyrrhenian Sea Basin: Results from a Combined Wide-Angle and Multichannel Seismic Study. *Geochem. Geophy. Geosy.* **2013**, *14*, 3032–3052. [CrossRef]
120. Cornamusini, G.; Foresi, L.M.; Dall'Antonia, B.; Bossio, A.; Mazzei, R.; Salvatorini, G. The Miocene of Pianosa Island: Key to Understanding the Opening of the Northern Tyrrhenian back-Arc Basin (Central Mediterranean). *J. Geol. Soc. Lond.* **2014**, *171*, 801–819. [CrossRef]
121. Sartori, R.; Carrara, G.; Torelli, L.; Zitellini, N. Neogene Evolution of the Southwestern Tyrrhenian Sea (Sardinia Basin and Western Bathyal Plain). *Mar. Geol.* **2001**, *175*, 47–66. [CrossRef]
122. Sartori, R.; Torelli, L.; Zitellini, N.; Carrara, G.; Magaldi, M.; Mussoni, P. Crustal Features along a W-E Tyrrhenian Transect from Sardinia to Campania Margins (Central Mediterranean). *Tectonophysics* **2004**, *383*, 171–192. [CrossRef]
123. Di Stefano, R.; Chiarabba, C.; Lucente, F.; Amato, A. Crustal and Uppermost Mantle Structure in Italy from Inversion of P Wave Arrival Times: Geodynamic Implications. *Geophys. J. Int.* **1999**, *139*, 483–498. [CrossRef]

124. Wortel, M.J.R.; Spakman, W. Subduction and Slab Detachment in the Mediterranean–Carpathian Region. *Science* **2000**, *290*, 1910–1917. [CrossRef] [PubMed]
125. Piromallo, C.; Morelli, A. P Wave Tomography of the Mantle under the Alpine-Mediterranean Area. *J. Geophys. Res.* **2003**, *108*, 2065. [CrossRef]
126. Scafidi, D.; Solarino, S.; Eva, C. P Wave Seismic Velocity and Vp/Vs Ratio beneath the Italian Peninsula from Local Earthquake Tomography. *Tectonophysics* **2009**, *465*, 1–23. [CrossRef]
127. Scafidi, D.; Solarino, S. Can Local Earthquake Tomography Settle the Matter about Subduction in the Northern and Central Apennines? Response from a New High Resolution P Velocity and Vp/Vs Ratio 3-D Model. *Tectonophysics* **2012**, *554–557*, 63–73. [CrossRef]
128. Viti, M.; Mantovani, E.; Babbucci, D.; Tamburelli, C. Quaternary Geodynamics and Deformation Pattern in the Southern Apennines: Implications for Seismic Activity. *Boll. Della Soc. Geol. Ital.* **2006**, *125*, 273–291.
129. Schmid, S.M.; Fugenschuh, B.; Schuster, R. Tectonic Map and Overall Architecture of the Alpine Orogen. *Eclogae Geol. Helv.* **2004**, *97*, 93–118. [CrossRef]
130. Horváth, F.; Musitza, B.; Balázsb, A.; Véghd, A.; Uhrine, A.; Nádorc, A.; Koroknaia, B.; Papd, N.; Tótha, T.; Wóruma, G. Evolution of the Pannonian Basin and Its Geothermal Resources. *Geothermics* **2015**, *53*, 328–352. [CrossRef]
131. Réka, L.; Harangi, S.; Guillong, M.; Bachmann, O.; Fodor, L.; Buret, Y.; Dunkl, I.; Sliwinski, J.; von Quadt, A.; Peytcheva, I.; et al. Early to Mid-Miocene Syn Extensional Massive Silicic Volcanism in the Pannonian Basin (East-Central Europe): Eruption Chronology, Correlation Potential and Geodynamic Implications. *Earth Sci. Rev.* **2018**, *179*, 1–19.
132. Robl, J.; Stuwe, K. Continental Collision with Finite Indenter Strength: 2. European Eastern Alps. *Tectonics* **2005**, *24*, TC4014. [CrossRef]
133. Wölfler, A.; Kurz, W.; Fritz, H.; Stüwe, K. Lateral Extrusion in the Eastern Alps Revisited: Refining the Model by Thermochronological, Sedimentary, and Seismic Data. *Tectonics* **2011**, *30*, TC4006. [CrossRef]
134. Peresson, H.; Decker, K. The Tertiary Dynamics of the Northem Eastem Alps (Austria): Changing Palaeostresses in a Collisional Plate Boundary. *Tectonophysics* **1997**, *272*, 125–157. [CrossRef]
135. Frisch, W.; Dunkl, I.; Kuhlemann, J. Post-Collisional Orogen-Parallel Large-Scale Extension in the Eastern Alps. *Tectonophysics* **2000**, *327*, 239–265. [CrossRef]
136. Viola, G.; Mancktelow, N.S.; Seward, D. Late Oligocene–Neogene Evolution of Europe Adria Collision: New Structural and Geochronological Evidence from the Giudicarie Fault System (Italian Eastern Alps). *Tectonics* **2001**, *20*, 999–1020. [CrossRef]
137. Fellin, M.G.; Martin, S.; Massironi, M. Polyphase Tertiary Fault Kinematics and Quaternary Reactivation in the Central-Eastern Alps (Western Trentino). *J. Geodyn.* **2002**, *34*, 31–46. [CrossRef]
138. Favaro, S.; Handy, M.R.; Scharf, A.; Schuster, R. Changing Patterns of Exhumation and Denudation in Front of an Advancing Crustal Indenter, Tauern Window (Eastern Alps). *Tectonics* **2017**, *36*, 1053–1071. [CrossRef]
139. Zampieri, D.; Massironi, M.; Sedea, R.; Saracino, V. Strike-Slip Contractional Stepovers in the Southern Alps (Northeastern Italy). *Eclogae Geol. Helv.* **2003**, *96*, 115–123.
140. Castellarin, A.; TRANSALP Working Group. Structural Synthesis of the Eastern Alps: A Collisional Orogenic Chain. In *Geology of Italy: Special Volume of the Italian Geological Society for the IGC 32 Florence*; Crescenti, V., D'Offizi, S., Merlino, S., Sacchi, L., Eds.; Società Geologica Italiana: Roma, Italy, 2004; pp. 3–13.
141. Verwater, V.F.; Le Breton, E.; Handy, M.R.; Picotti, V.; Jozi Najafabadi, A.; Haberland, C. Neogene Kinematics of the Giudicarie Belt and Eastern Southern Alpine Orogenic Front (Northern Italy). *Solid Earth* **2021**, *12*, 1309–1334. [CrossRef]
142. Gattacceca, J.; Deino, A.; Rizzo, R.; Jones, D.S.; Henry, B.; Beaudoin, B.; Vadeboin, F. Miocene Rotation of Sardinia: New Paleomagnetic and Geochronological Constraints and Geodynamic Implications. *Earth Planet. Sci. Lett.* **2007**, *258*, 359–377. [CrossRef]
143. Mercier, J.; Sorel, D.; Simeakis, K. Changes in the State of Stress in the Overriding Plate of a Subduction Zone: The Aegean Arc from the Pliocene to the Present. *Ann. Tecton.* **1987**, *1*, 20–39.
144. Mercier, J.L.; Simeakis, K.; Sorel, D.; Vergely, P. Extensional Tectonic Regimes in the Aegean Basins during the Cenozoic. *Basin Res.* **1989**, *2*, 49–71. [CrossRef]
145. Sorel, D.; Bizon, G.; Aliaj, S.; Hasani, L. Calage Stratigraphique De L'age Et De La Durée Des Phases Compressives Des Hellénides Externes (Grèce Nord-Occidentale Et Albanie) Du Miocène à L'actuel. *Bull. Société Géologique Fr.* **1992**, *163*, 447–454.
146. Finetti, I.R.; Del Ben, A. Geophysical Study of the Tyrrhenian Opening. *Boll. Geof. Teor. Appl.* **1986**, *110*, 75–156.
147. Ghielmi, M.; Minervini, M.; Nini, C.; Rogledi, S.; Rossi, M. Late Miocene–Middle Pleistocene Sequences in the Po Plain–Northern Adriatic Sea (Italy): The Stratigraphic Record of Modification Phases Affecting a Complex Foreland Basin. *Mar. Pet. Geol.* **2013**, *42*, 50–81. [CrossRef]
148. Vitale, S.; Prinzi, E.P.; Tramparulo, F.D.A.; De Paola, C.; Di Maio, R.; Piegari, E.; Sabbatino, M.; Natale, J.; Notaro, P.; Ciarcia, S. Late Miocene-Early Pliocene out-of-Sequence Thrusting in the Southern Apennines (Italy). *Geosciences* **2020**, *10*, 301. [CrossRef]
149. Amadori, C.; Toscani, G.; Di Giulio, A.; Maesano, F.E.; D'Ambrogio, C.; Ghielmi, M.; Fantoni, R. From Cylindrical to Non-Cylindrical Foreland Basin:Pliocene–Pleistocene Evolution of the Po Plain–Northern Adriatic Basin (Italy). *Basin Res.* **2019**, *31*, 991–1015. [CrossRef]

150. Finetti, I.R.; Lentini, F.; Carbone, S.; Del Ben, A.; Di Stefano, A.; Guarnieri, P.; Pipan, M.; Prizzon, A. Crusta1 Tectono-Stratigraphy and Geodynamics of the Southern Apennines from CROP and Other Integrated Geophysical-Geological Data. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 12; pp. 225–262.
151. Reuther, C.-D. Extensional Tectonic within Central Mediterranean Segment of the Afro-European Zone of Convergence. *Mem. Soc. Geol. Ital.* **1987**, *38*, 69–80.
152. Reuther, C.-D.; Ben Avraham, Z.; Grasso, M. Origin and Role of Major Strike-Slip Transfers during Plate Collision in the Central Mediterranean. *Terra Nova* **1993**, *5*, 249–257. [CrossRef]
153. Finetti, I.R.; Del Ben, A. Crustal Tectono-Stratigraphic Setting of the Pelagian Foreland from New CROP Seismic Data. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 26; pp. 581–596.
154. Argnani, A. Neogene Basins in the Strait of Sicily (Central Mediterranean): Tectonic Settings and Geodynamic Implications. In *Recent Evolution and Seismicity of the Mediterranean Region*; Boschi, E., Mantovani, E., Morelli, A., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1993; pp. 173–187.
155. Hieke, W.; Dehghani, G.A. The Victor Hensen Structure in the Central Ionian Sea and its Relation to the Medina Ridge (Eastern Mediterranean). *Z. Dtsch. Geol. Ges.* **1999**, *149*, 487–505. [CrossRef]
156. Hieke, W.; Hirschleber, H.B.; Deghani, G.A. The Ionian Abyssal Plain (Central Mediterranean Sea): Morphology, Sub-Bottom Structures and Geodynamic History—An Inventory. *Mar. Geophys. Res.* **2003**, *24*, 279–310. [CrossRef]
157. Hieke, W.; Cita, M.B.; Forcella, F.; Müller, C. Geology of the Victor Hensen Seahill (Ionian Sea, Eastern Mediterranean): Insights from the Study of Cored Sediment Sequences. *Boll. Soc. Geol. Ital.* **2006**, *125*, 245–257.
158. Gallais, F.; Gutscher, M.A.; Graindorge, D.; Chamot-Rooke, N.; Klaeschen, D. A Miocene Tectonic Inversion in the Ionian Sea (Central Mediterranean): Evidence from Multichannel Seismic Data. *J. Geophys. Res.* **2011**, *116*, B12108. [CrossRef]
159. Catalano, R.; Infuso, S.; Sulli, A. The Submerged Alpidic Chain from Southern Sardinia Shelf to the Pelagian Rifting: Tectonic History. *Boll. Geof. Teor. Appl.* **1994**, *36*, 139–158.
160. Furlani, S.; Antonioli, F.; Biolchi, S.; Gambin, T.; Gauci, R.; Lo Presti, V.; Anzidei, A.; Devoto, S.; Palombo, M.; Sulli, A. Holocene Sea Level Change in Malta. *Quat. Int.* **2013**, *288*, 146–157. [CrossRef]
161. Civile, D.; Lodolo, E.; Alp, H.; Ben-Avraham, Z.; Cova, A.; Baradello, L.; Accettella, D.; Burca, M.; Centonze, J. Seismic Stratigraphy and Structural Setting of the Adventure Plateau (Sicily Channel). *Mar. Geophys. Res.* **2014**, *35*, 37–53. [CrossRef]
162. Civile, D.; Lodolo, E.; Accaino, F.; Geletti, R.; Schiattarella, M.; Giustiniani, M.; Fedorik, J.; Zecchin, M.; Zampa, L. Capo Granitola-Sciacca Fault Zone (Sicilian Channel, Central Mediterranean): Structure vs. Magmatism. *Mar. Pet. Geol.* **2018**, *96*, 627–644. [CrossRef]
163. Fedorik, J.; Toscani, G.; Lodolo, E.; Civile, D.; Bonini, L.; Seno, S. Structural Analysis and Miocene-to-Present Tectonic Evolution of Alithospheric-Scale, Transcurrent Lineament: The Sciacca Fault (SicilianChannel, Central Mediterranean Sea). *Tectonophysics* **2018**, *722*, 342–355. [CrossRef]
164. Ghisetti, F.C.; Gorman, A.R.; Grasso, M.; Vezzani, L. Imprint of Foreland Structure on the Deformation of a Thrust Sheet: The Plio-Pleistocene Gela Nappe (Southern Sicily, Italy). *Tectonics* **2009**, *28*, TC4015. [CrossRef]
165. Pepe, F.; Sulli, A.; Bertotti, G.; Catalano, R. Structural Highs Formation and Their Relationship to Sedimentary Basins in the North Sicily Continental Margin (Southern Tyrrhenian Sea): Implications for the Drepano Thrust Front. *Tectonophysics* **2005**, *409*, 1–18. [CrossRef]
166. Carmignani, L.; Decandia, F.A.; Fantozzi, P.L.; Lazzarotto, A.; Liotta, D.; Meccheri, M. Tertiary Extensional Tectonics in Tuscany (Northern Apennines, Italy). *Tectonophysics* **1994**, *238*, 295–315. [CrossRef]
167. Casula, G.; Cherchi, A.; Montadert, L.; Murru, M.; Sarria, E. The Cenozoic Graben System of Sardinia (Italy): Geodynamic Evolution from New Seismic and Field Data. *Mar. Pet. Geol.* **2001**, *18*, 863–888. [CrossRef]
168. Cocco, F.; Funedda, A.; Patacca, E.; Scandone, P. Plio-Pleistocene Extensional Tectonics in the Campidano Graben (SW Sardinia, Italy): Preliminary Note. *Rend. Online Della Soc. Geol. Ital.* **2013**, *29*, 31–34.
169. Massironi, M.; Zampieri, D.; Caporali, A. Miocene to Present Major Fault Linkages through the Adriatic Indenter and the Austroalpine-Penninic collisional Wedge (Alps of NE Italy). *Geol. Soc. Lond. Spec. Publ.* **2006**, *262*, 245–258. [CrossRef]
170. Pola, M.; Ricciato, A.; Fantoni, R.; Fabbri, P.; Zampieri, D. Architecture of the Western Margin of the North Adriatic Foreland: The Schio-Vicenza Fault System. *Ital. J. Geosci.* **2014**, *133*, 223–234. [CrossRef]
171. Bressan, G.; Snidarcig, A.; Venturini, C. Present State of Tectonic Stress of the Friuli Area (Eastern Southern Alps). *Tectonophysics* **1998**, *292*, 211–227. [CrossRef]
172. Galadini, F.; Poli, M.E.; Zanferrari, A. Seismogenic Sources Potentially Responsible for Earthquakes with $M \geq 6$ in the Eastern Southern Alps (Thiene-Udine Sector, NE Italy). *Geophys. J. Int.* **2005**, *161*, 739–762. [CrossRef]
173. Placer, L.; Vrabec, M.; Celarc, B. The Bases for Understanding of the NW Dinarides and Istria Peninsula tectonics. *Geologija* **2010**, *53*, 55–86. [CrossRef]
174. Ben Avraham, Z.; Boccaletti, M.; Cello, G.; Grasso, M.; Lentini, F.; Torelli, L.; Tortorici, L. Principali Domini Strutturali Originatisi Dalla Collisione Neogenico-Quaternaria Nel Mediterraneo Centrale. *Mem. Soc. Geol. Ital.* **1990**, *45*, 453–462.
175. Lentini, F.; Carbone, S.; Catalano, S. Main Structural Domains of the Central Mediterranean Region and Their Tectonic Evolution. *Boll. Geofis. Teor. Appl.* **1994**, *36*, 103–125.

176. Sulli, A. Structural Framework and Crustal Characteristics of the Sardinia Channel Alpine Transect in the Central Mediterranean. *Tectonophysics* **2000**, *324*, 321–336. [CrossRef]
177. Gueguen, E.; Tavarnelli, E.; Renda, P.; Tramutoli, M. The Geodynamics of the Southern Tyrrhenian Sea Margin as Revealed by Integrated Geological, Geophysical and Geodetic Data. *Boll. Soc. Geol. Ital. Vol. Spec.* **2002**, *1*, 77–85.
178. Civile, D.; Lodolo, E.; Accettella, D.; Geletti, R.; Ben-Avraham, Z.; Deponte, M.; Facchin, L.; Ramella, R.; Romeo, R. The Pantelleria Graben (Sicily Channel, Central Mediterranean): An Example of Intraplate 'Passive' Rift. *Tectonophysics* **2010**, *490*, 173–183. [CrossRef]
179. Civile, D.; Brancolini, G.; Lodolo, E.; Forlin, E.; Accaino, F.; Zecchin, M.; Brancatelli, G. Morphostructural Setting and Tectonic Evolution of the Central Part of the Sicilian Channel (Central Mediterranean). *Lithosphere* **2021**, *2021*, 7866771. [CrossRef]
180. Molli, G. Northern Apennine-Corsica Orogenic System: An Updated Overview. In *Tectonic Aspects of the Alpine-Dinarides-Carpathians System*; Siegesmund, S., Fugensheu, B., Froitzheim, N., Eds.; The Geological Society: London, UK, 2008; Volume 298, pp. 413–442.
181. Malusà, M.G.; Danišík, M.; Kuhlemann, J. Tracking the Adriatic-Slab Travel beneath the Tethyan Margin of Corsica-Sardinia by Low-Temperature Thermochronometry. *Gondwana Res.* **2016**, *31*, 135–149. [CrossRef]
182. Finetti, I.R.; Lentini, F.; Carbone, S.; Del Ben, A.; Di Stefano, A.; Forlin, E.; Guarnieri, P.; Pipan, M.; Prizzon, A. Geological Outline of Sicily and Lithospheric Tectono-Dynamics of its Tyrrhenian Margin from New CROP Seismic Data. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 15; pp. 319–376.
183. Grasso, M.; Pedley, H.M. The Pelagian Islands: A New Geological Interpretation from Sedimentological and Tectonic Studies and Its Bearing on the Evolution of the Central Mediterrranean Sea (Pelagian Block). *Geol. Romana* **1985**, *24*, 13–34.
184. Kim, Y.S.; Peacock, D.C.P.; Sanderson, D.J. Mesoscale Strike-Slip Faults and Damage Zones at Malsalform, Gozo Island, Malta. *J. Struct. Geol.* **2003**, *25*, 793–812. [CrossRef]
185. Boccaletti, M.; Cello, G.; Tortorici, L. Transtensional Tectonics in the Sicily Channel. *J. Struct. Geol.* **1987**, *9*, 869–876. [CrossRef]
186. Cello, G. Structure and Deformation Processes in the Strait of Sicily "Rift Zone". *Tectonophysics* **1987**, *141*, 237–247. [CrossRef]
187. Catalano, S.; De Guidi, G.; Lanzafame, G.; Monaco, C.; Tortorici, L. Late Quaternary Deformation on the Island on Pantelleria: New Constraints for the Recent Tectonic Evolution of the Sicily Channel Rift (Southern Italy). *J. Geodyn.* **2009**, *48*, 75–82. [CrossRef]
188. Finetti, I.R.; Del Ben, A. Crustal Tectono-Stratigraphy of the Ionian Sea from New Integrated CROP Seismic Data. In *CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy*; Finetti, I.R., Ed.; Elsevier: Amsterdam, The Netherlands, 2005; Chapter 19; pp. 447–470.
189. Sartori, R. The Main Results of ODP Leg 107 in the Frame of Neogene to Recent Geology of Perityrrhenian Areas. *Proc. ODP Sci. Results Coll. Stn. Tx* **1990**, *107*, 715–730.
190. Savelli, C. Time–Space Distribution of Magmatic Activity in the Western Mediterranean and Peripheral Orogens during the Past 30 Ma (A Stimulus to Geodynamic Considerations). *J. Geodyn.* **2002**, *34*, 99–126. [CrossRef]
191. Cello, G.; Mazzoli, S. Apennine Tectonics in Southern Italy: A Review. *J. Geodyn.* **1999**, *27*, 191–211. [CrossRef]
192. Catalano, S.; Monaco, C.; Tortorici, L. Neogene-Quaternary Tectonic Evolution of the Southern Apennines. *Tectonics* **2004**, *23*, TC2003. [CrossRef]
193. 193. Patacca, E.; Scandone, P. The Plio-Pleistocene Thrust Belt-Foredeep System in the Southern Apennines and Sicily (Italy). In *Geology of Italy: Special Volume of the Italian Geological Society for the IGC 32 Florence*; Crescenti, V., D'Offizi, S., Merlino, S., Sacchi, L., Eds.; Società Geologica Italiana: Roma, Italy, 2004; pp. 93–129.
194. Westaway, R. Quaternary Uplift in Southern Italy. *J. Geophys. Res.* **1993**, *98*, 21741–21772. [CrossRef]
195. Van Dijk, J.P.; Scheepers, P.J.J. Neotectonic Rotations in the Calabrian Arc; Implications for a Pliocene-Recent Geodynamic Scenario for the Central Mediterranean. *Earth Sci. Rev.* **1995**, *39*, 207–246. [CrossRef]
196. Zecchin, M.; Caffau, M.; Tosi, L.; Civile, D.; Brancolini, G.; Rizzetto, F.; Roda, C. The Impact of Late Quaternary Glacio-Eustasy and Tectonics on Sequence Development: Evidence from Both Uplifting and Subsiding Settings in Italy. *Terra Nova* **2010**, *22*, 324–329. [CrossRef]
197. Zecchin, M.; Civile, D.; Caffau, M.; Sturiale, G.; Roda, C. Sequence Stratigraphy in the Context of Rapid Regional Uplift and High-Amplitude Glacio-Eustatic Changes: The Pleistocene Cutro Terrace (Calabria, Southern Italy). *Sedimentology* **2011**, *58*, 442–477. [CrossRef]
198. Zecchin, M.; Praeg, D.; Ceramicola, S.; Muto, F. Onshore to Offshore Correlation of Regional Unconformities in the Plio-Pleistocene Sedimentary Successions of the Calabrian Arc (Central Mediterranean). *Earth Sci. Rev.* **2015**, *142*, 60–78. [CrossRef]
199. Del Ben, A.; Barnaba, C.; Toboga, A. Strike-Slip Systems as the Main Tectonic Features in the Plio-Quaternary Kinematics of the Calabrian Arc. *Mar. Geophys. Res.* **2008**, *29*, 1–12. [CrossRef]
200. Spina, V.; Tondi, E.; Mazzoli, S. Complex Basin Development in a Wrench-Dominated back-Arc Area: Tectonic Evolution of the Crati Basin, Calabria, Italy. *J. Geodyn.* **2011**, *51*, 90–109. [CrossRef]
201. Roda-Boluda, D.C.; Whittaker, A.C. Structural and Geomorphic Constraints on Active Normal Faulting and Landscape Evolution in Calabria, Italy. *J. Geol. Soc. Lond.* **2017**, *174*, 701–720. [CrossRef]
202. Tripodi, V.; Muto, F.; Brutto, F.; Perri, F.; Critelli, S. Neogene-Quaternary Evolution of the Forearc and Backarc Regions between the Serre and Aspromonte Massifs, Calabria (Southern Italy). *Mar. Pet. Geol.* **2018**, *95*, 328–343. [CrossRef]

203. Patacca, E.; Sartori, R.; Scandone, P. Tyrrhenian Basin and Apenninic Arcs: Kinematic Relations since Late Tortonian Times. *Mem. Soc. Geol. Ital.* **1990**, *45*, 425–451.
204. Del Ben, A. Calabrian Arc Tectonics from Seismic Exploration. *Boll. Geofis. Teor. Appl.* **1993**, *139*, 339–347.
205. Tropeano, M.; Sabato, L.; Pieri, P. Filling and Cannibalization of a Foredeep: The Bradanic Trough (Southern Italy). *Geol. Soc. Lond. Spec. Publ.* **2002**, *191*, 55–79. [CrossRef]
206. Santangelo, N.; Di Donato, V.; Lebreton, V.; Romano, P.; Russo Ermolli, E. Palaeolandscapes of Southern Apennines during the Late Early and the Middle Pleistocene. *Quatern. Int.* **2012**, *267*, 20–29. [CrossRef]
207. Zecchin, M.; Donda, F.; Forlin, E. Genesis of the Northern Adriatic Sea (Northern Italy), since Early Pliocene. *Mar. Pet. Geol.* **2017**, *79*, 108–130. [CrossRef]
208. Peccerillo, A. Plio-Quaternary Volcanism in Italy. In *Petrology, Geochemistry, Geodynamics*; Springer: Heidelberg, Germany, 2005; ISBN 978-3-540-25885-8.
209. Nicolosi, I.; Speranza, F.; Chiappini, M. Ultrafast Oceanic Spreading of the Marsili Basin, Southern Tyrrhenian Sea. Evidence from Magnetic Anomaly Analysis. *Geology* **2006**, *34*, 717–720. [CrossRef]
210. Zecchin, M.; Nalin, R.; Roda, C. Raised Pleistocene Marine Terraces of the Crotone Peninsula (Calabria, Southern Italy): Facies Analysis and Organization of Their Deposits. *Sediment. Geol.* **2004**, *172*, 165–185. [CrossRef]
211. Brancolini, G.; Civile, D.; Donda, F.; Tosi, L.; Zecchin, M.; Volpi, V.; Rossi, G.; Sandron, D.; Ferrante, G.M.; Forlin, E. New Insights into the Adria Plate Geodynamics from the Northern Adriatic Perspective. *Mar. Pet. Geol.* **2019**, *109*, 687–697. [CrossRef]
212. Argnani, A.; Barbacini, G.; Bernini, M.; Camurri, F.; Ghielmi, M.; Papani, G.; Rizzini, F.; Rogledi, S.; Torelli, L. Gravity Tectonics Driven by Quaternary Uplift in the Northern Apennines: Insights from the La Spezia-Reggio Emilia geo-transect. *Quatern. Int.* **2003**, *101–102*, 13–26. [CrossRef]
213. Bartolini, C. When Did the Northern Apennine Become a Mountain Chain? *Quatern. Int.* **2003**, *101–102*, 75–80. [CrossRef]
214. Schiattarella, M.; Di Leo, P.; Beneduce, P.; Giano, S.I. Quaternary Uplift vs. Tectonic Loading: A Case Study from the Lucanian Apennine, Southern Italy. *Quatern. Int.* **2003**, *101–102*, 239–251. [CrossRef]
215. Ascione, A.; Cinque, A.; Miccadei, E.; Villani, F. The Plio-Quaternary Uplift of the Apennines Chain: New Data from the Analysis of Topography and River Valleys in Central Italy. *Geomorphology* **2008**, *102*, 105–118. [CrossRef]
216. Cello, G.; Tondi, E.; Micarelli, L.; Mattioni, L. Active Tectonics and Earthquake Sources in the Epicentral Area of the 1857 Basilicata Earthquake (Southern Italy). *J. Geodyn.* **2003**, *36*, 37–50. [CrossRef]
217. Ferranti, L.; Santoro, E.; Mazzella, M.E.; Monaco, C.; Morelli, D. Active Transpression in the Northern Calabria Apennines, Southern Italy. *Tectonophysics* **2009**, *476*, 226–251. [CrossRef]
218. Ferranti, L.; Oldow, J.S. History and Tectonic Implications of Low-Angle Detachment Faults and Orogen-Parallel Extension, Picentini Mountains, Southern Apennines Fold and Thrust Belt, Italy. *Tectonics* **1999**, *18*, 498–526. [CrossRef]
219. Amicucci, L.; Barchi, M.R.; Paola Montone, P.; Rubiliani, N. The Vallo di Diano and Auletta Extensional Basins in the Southern Apennines (Italy): A Simple Model for a Complex Setting. *Terra Nova* **2008**, *20*, 475–482. [CrossRef]
220. Piccardi, L.; Gaudemer, Y.; Tapponnier, P.; Boccaletti, M. Active Oblique Extension in the Central Apennines (Italy): Evidence from the Fucino Region. *Geophys. J. Int.* **1999**, *139*, 499–530. [CrossRef]
221. Galadini, F.; Messina, P. Early-Middle Pleistocene Eastward Migration of the Abruzzi Apennine (Central Italy) Extensional Domain. *J. Geodyn.* **2004**, *37*, 57–81. [CrossRef]
222. Elter, F.M.; Elter, P.; Eva, C.; Eva, E.; Kraus, R.K.; Padovano, M.; Solarino, S. An Alternative Model for the Recent Evolution of Northern-Central Apennines (Italy). *J. Geodyn.* **2012**, *54*, 55–63. [CrossRef]
223. Cello, G.; Mazzoli, S.; Tondi, E. The Crustal Fault Structure Responsible for the 1703 Earthquake Sequence of Central Italy. *J. Geodyn.* **1998**, *26*, 443–460. [CrossRef]
224. Cello, G.; Deiana, G.; Ferreli, L.; Marchigiani, L.; Maschio, L.; Mazzoli, S.; Michetti, A.; Serva, L.; Tondi, E.; Vittori, E. Geological Constraints for Earthquake Faulting Analysis in the Colfiorito Area. *J. Seismol.* **2000**, *4*, 357–364. [CrossRef]
225. Tondi, E.; Cello, G. Spatiotemporal Evolution of the Central Apennines Fault System (Italy). *J. Geodyn.* **2003**, *36*, 113–128. [CrossRef]
226. Piccardi, L.; Tondi, G.; Cello, G. Geo-Structural Evidence for Active Oblique Extension in South-Central Italy. In *The Adria Microplate: GPS Geodesy, Tectonics and Hazard*; Pinter, N., Grenerczy, G., Weber, J., Stein, S., Medak, D., Eds.; Springer: Heidelberg, Germany, 2006; pp. 95–108.
227. Boncio, P.; Bracone, V. Active Stress from Earthquake Focal Mechanisms along the Padan-Adriatic Side of the Northern Apennines (Italy), with Considerations on Stress Magnitudes and Pore-Fluid Pressures. *Tectonophysics* **2009**, *476*, 180–194. [CrossRef]
228. Scisciani, V.; Calamita, F. Active Intraplate Deformation within Adria: Examples from the Adriatic Region. *Tectonophysics* **2009**, *476*, 57–72. [CrossRef]
229. Boccaletti, M.; Corti, G.; Martelli, L. Recent and Active Tectonics of the External Zone of the Northern Apennines (Italy). *Geol. Rundsch.* **2011**, *100*, 1331–1348. [CrossRef]
230. Pace, P.; Scisciani, V.; Calamita, F.; Butler, R.W.H.; Iacopini, D.; Esestime, P.; Hodgson, N. Inversion Structures in a Foreland Domain: Seismic Examples from the Italian Adriatic Sea. *Interpretation* **2015**, *3*, SAA161–SAA176. [CrossRef]
231. Alagna, K.E.; Peccerillo, A.; Martin, S.; Donati, C. Tertiary to Present Evolution of Orogenic Magmatism in Italy. *J. Virtual Explor.* **2010**, *36*, 18. [CrossRef]

232. Milia, A.; Torrente, M.M. Late-Quaternary Volcanism and Transtensional Tectonics in the Bay of Naples, Campanian Continental Margin, Italy. *Mineral. Petrol.* **2003**, *79*, 49–65. [CrossRef]
233. Acocella, V.; Funiciello, R. Transverse Systems along Thee Tyrrhenian Margin of Central Italy and Their Influence on Volcanism. *Tectonics* **2006**, *25*, TC2003. [CrossRef]
234. Ferranti, L.; Burrato, P.; Pepe, F.; Santoro, E.; Mazzella, M.E.; Morelli, D.; Passaro, S.; Vannucci., G. An Active Oblique Contractional Belt at the Transition between the Southern Apennines and Calabrian Arc: The Amendolara Ridge, Ionian Sea, Italy. *Tectonics* **2014**, *33*, 2169–2194. [CrossRef]
235. Volpi, V.; Del Ben, A.; Civile, D.; Zgur, F. Neogene Tectono-Sedimentaty Interaction between the Calabrian Accretionary Wedge and the Apulian Foreland in the Northern Ionian Sea. *Mar. Pet. Geol.* **2017**, *83*, 246–260. [CrossRef]
236. Lodolo, E.; Civile, D.; Zanolla, C.; Geletti, R. Magnetic Signature of the Sicily Channel Volcanism. *Mar. Gephys. Res.* **2012**, *33*, 33–44. [CrossRef]
237. Viti, M.; Mantovani, E.; Babbucci, D.; Tamburelli, C.; Cenni, N.; Baglione, M.; D'Intinosante, V. Belt-Parallel Shortening in the Northern Apennines and Seismotectonic Implications. *Int. J. Geosci.* **2015**, *6*, 938–961. [CrossRef]
238. Costa, M. The Buried, Apenninic Arcs of the Po Plain and Northern Adriatic Sea (Italy): A New Model. *Boll. Soc. Geol. Ital.* **2003**, *122*, 3–23.
239. Pizzi, A.; Galadini, F. Pre-Existing cross-Structures and Active Fault Segmentation in the Northern-Central Apennines (Italy). *Tectonophysics* **2009**, *476*, 304–319. [CrossRef]
240. Pantosti, D.; Valensise, G. Faulting Mechanism and Complexity of the 23 November 1980, Campania-Lucania Earthquake Inferred from Surface Observations. *J. Geophys. Res.* **1990**, *95*, 319–341. [CrossRef]
241. Cinque, A.; Ascione, A.; Chiazzo, C. Distribuzione Spaziotemporale E Caratterizzazione Della Fagliazione Quaternaria in Appennino Meridionale. In *Ricerche Del GNDT Nel Campo Della Pericolosità Sismica (1996–1999), Special Publication of CNR-GNDT, Gruppo Nazionale Per La Difesa Dai Terremoti*; Galadini, F., Meletti, C., Rebez, A., Eds.; CNR-GNDT: Roma, Italy, 2000; pp. 203–218.
242. Calamita, F.; Scisciani, V.; Montefalcone, R.; Paltrinieri, W.; Pizzi, A. L'ereditarietà Del Paleomargine Dell'adria Nella Geometria Del Sistema Orogenico Centro-Appenninico: L'area Abruzzese Esterna. *Mem. Soc. Geol. Ital.* **2002**, *57*, 355–368.
243. Blumetti, A.M.; Guerrieri, L.; Vittori, E. The Primary Role of the Paganica-San Demetrio Fault System in the Seismic Landscape of the Middle Aterno Valley Basin (Central Apennines). *Quatern. Int.* **2013**, *288*, 183–194. [CrossRef]
244. Cerrina Feroni, A.; Leoni, L.; Martelli, L.; Martinelli, P.; Ottria, G.; Sarti, G. The Romagna Apennines, Italy: An Eroded Duplex. *Geol. J.* **2001**, *36*, 39–54. [CrossRef]
245. Vannoli, P.; Basili, R.; Valensise, G. New Geomorphic Evidence for Anticlinal Growth Driven by Blind-Thrust Faulting Long the Northern Marche Coastal Belt (Central Italy). *J. Seismol.* **2004**, *8*, 297–312. [CrossRef]
246. Vannoli, P.; Burrato, P.; Valensise, G. The Seismotectonics of the Po Plain (Northern Italy): Tectonic Diversity in a Blind Faulting Domain. *Pure Appl. Geophys.* **2015**, *172*, 1105–1142. [CrossRef]
247. Chicco, J.M.; Pierantoni, P.P.; Costa, M.; Invernizzi, C. Plio-Quaternary Tectonics and Possible Implications for Geothermal Fluids in the Marche Region (Italy). *Tectonophysics* **2019**, *755*, 21–34. [CrossRef]
248. Babbucci, D.; Tamburelli, C.; Viti, M.; Mantovani, E.; Albarello, D.; D'Onza, F.; Cenni, N.; Mugnaioli, E. Relative Motion of the Adriatic with Respect to the Confining Plates: Seismological and Geodetic Constraints. *Geophys. J. Int.* **2004**, *159*, 765–775. [CrossRef]
249. Nocquet, J.-M. Present-Day Kinematics of the Mediterranean: A Comprehensive Overview of GPS Results. *Tectonophysics* **2012**, *579*, 220–242. [CrossRef]
250. Mantovani, E.; Viti, M.; Cenni, N.; Babbucci, D.; Tamburelli, C. Present Velocity Field in the Italian Region by GPS Data: Geodynamic/Tectonic Implications. *Int. J. Geosci.* **2015**, *6*, 1285–1316. [CrossRef]
251. Altamimi, Z.; Rebischung, P.; Metivier, L.; Collilieux, X. ITRF2014: A New Release of the International Terrestrial Reference Frame Modeling nonlinear station motions. *J. Geophys. Res., Solid Earth* **2016**, *121*, 6109–6131. [CrossRef]
252. Cenni, N.; Mantovani, E.; Baldi, P.; Viti, M. Present Kinematics of Central and Northern Italy from Continuous GPS Measurements. *J. Geodyn.* **2012**, *58*, 62–72. [CrossRef]
253. Mantovani, E.; Viti, M.; Babbucci, D.; Tamburelli, C.; Cenni, N.; Baglione, M.; D'Intinosante, V. Recognition of Periadriatic Seismic Zones Most Prone to Next Major Earthquakes: Insights from a Deterministic Approach. In *Earthquakes and Their Impact on Society. Springer Natural Hazard Series*; D'Amico, S., Ed.; Springer International Publishing: Cham, Switzerland, 2016; pp. 43–80. [CrossRef]
254. Mantovani, E.; Tamburelli, C.; Babbucci, D.; Viti, M.; Cenni, N. Tectonics and Seismicity in the Periadriatic Zones: Implications for Seismic Hazard in Italy. In *Earthquakes—From Tectonics to Buildings*; Salazar, W., Ed.; IntechOpen: London, UK, 2020. [CrossRef]
255. Tamburelli, C.; Babbucci, D.; Mantovani, E. Geodynamic Implications of Subduction Related Magmatism: Insights from the Tyrrhenian-Apennines Region. *J. Volcanol. Geotherm. Res.* **2000**, *104*, 33–43. [CrossRef]
256. Finetti, I.R. Basic Regional Crustal Setting and Superimposed Local Pluton-Intrusion-Related Tectonics in the Larderello-M. Amiata Geothermal Province, from Integrated CROP Seismic Data. *Boll. Soc. Geol. Ital.* **2006**, *125*, 117–146.
257. Tibaldi, A.; Pasquarè, F.; Tormey, T. Volcanism in Reverse and Strike-Slip Fault Settings. In *New Frontiers in Integrated Solid Earth Sciences*; Cloetingh, S., Negendank, J., Eds.; Springer Netherlands: Berlin, Germany, 2010; pp. 315–348. [CrossRef]
258. Guarnieri, P. Plio-Quaternary Segmentation of the South Tyrrhenian Forearc Basin. *Int. J. Earth Sci.* **2006**, *95*, 107–118. [CrossRef]

259. Teofilo, G.; Antoncecchi, I.; Caputo, R. Neogene-Quaternary Evolution of the Offshore Sector of the Southern Apennines Accretionary Wedge, Gulf of Taranto, Italy. *Tectonophysics* **2018**, *738–739*, 16–32. [CrossRef]
260. Rovida, A.; Locati, M.; Camassi, R.; Lolli, B.; Gasperini, P. The Italian Earthquake Catalogue CPTI15. *Bull. Earthq. Eng.* **2020**, *18*, 2953–2984. [CrossRef]
261. Maffione, M.; Speranza, F.; Faccenna, C.; Cascella, A.; Vignaroli, G.; Sagnotti, L. A Synchronous Alpine and Corsica-Sardinia rotation. *J. Geophy. Res.* **2008**, *113*, B03104. [CrossRef]
262. Boccaletti, M.; Coli, M.; Decandia, F.A.; Giannini, E.; Lazzarotto, A. Evoluzione Dell'appennino Settentrionale Secondo Un Nuovo Modello Strutturale. *Mem. Soc. Geol. Ital.* **1980**, *21*, 359–373.
263. Elter, P.; Marroni, M. Le Unità Liguri Dell'appennino Settentrionale: Sintesi Dei Dati E Nuove Interpretazioni. *Mem. Descr. Della Carta Geol. D'italia* **1991**, *46*, 121–138.
264. Feroni, A.C.; Ottria, G.; Ellero, A. The Northern Apennine, Italy: Geological Structure and Transpressive Evolution. *Soc. Geol. Ital. Roma* **2004**, 15–32. Available online: https://www.researchgate.net/publication/292276885_The_Northern_Apennine_Italy_geological_structure_and_transpressive_evolution (accessed on 1 November 2021).
265. Boccaletti, M.; Calamita, F.; Viandante, M.G. La Neo-Catena Litosferica Appenninica Nata A Partire Dal Pliocene Inferiore Come Espressione Della Convergenza Africa-Europa. *Boll. Soc. Geol. Ital.* **2005**, *124*, 87–105.