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The Puglia uplift (SE Italy): An anomaly in the foreland of the Apenninic subduction due to buckling of a thick continental lithosphere

Carlo Doglioni
Centro di Geodinamica, Università della Basilicata, Potenza, Italy

Francesco Mongelli and Piero Pieri
Dipartimento di Geologia e Geofisica dell'Università, Bari, Italy

Abstract. The Apenninic foreland shows two distinct structural signatures comparing the central Adriatic Sea and the Puglia region. During the Pliocene-Pleistocene the central Adriatic underwent high subsidence rates due to the eastward rollback of the hinge of the west dipping Apenninic subduction. The Puglia region and the Bradanic foredeep are located southward along strike in the same foreland, but, in contrast with the central Adriatic, after Pliocene-early Pleistocene subsidence they underwent uplift since the middle Pleistocene. The geometry and the kinematics of the frontal accretionary wedge and related foreland changed from that moment on between the two areas. At the front of the central northern Apennines, off scraping and subsidence continued, whereas the foredeep and foreland of the southern Apennines were buckled. Those differences are interpreted as being due to the larger subduction hinge rollback rate since middle Pleistocene of the central Adriatic lithosphere (70 km thick) with respect to the thicker Puglia (110 km). The different thicknesses of the continental crust and lithosphere were inherited from the Mesozoic rifting that disrupted the Adriatic plate. The different thicknesses appear to have controlled the variable degree of flexure of the lithosphere and its asthenospheric penetration rate. The Tremiti E-W alignment is the right-lateral lithospheric transfer zone of those different tectonic regimes. The consequent different dip of the subduction in the two sections (steeper west of Puglia) could also explain the lower elevation of the southern Apennines, compared to their central-northern sector.

Introduction

Puglia is a region of southeastern Italy and is part of the Apulia swell, a NW trending, narrow ridge of continental crust, running from central Italy to offshore Greece (Figure 1). Puglia constitutes the southwestern margin of the Adriatic plate in the central Mediterranean, and it is considered a poorly tectonized area in the Apenninic foreland (Figure 2). The region is marked by an anomalous late Pleistocene uplift [e.g., *Hearty and Dai Pra*, 1992], in contrast with adjacent foreland areas such as the central and northern Adriatic where subsidence occurred at the same time [*Bigi et al.*, 1989]. This paper deals with main geological and geophysical constraints of the late Pliocene-Pleistocene history of the Apenninic foreland, and it proposes to link those variable subsidence/uplift rates (Figure 3) to different behaviors of the Apenninic subduction.

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Regional Setting

In Puglia there is outcropping of an authocthonous carbonate platform developed on top of the Apulian swell throughout the Mesozoic. Slope-to-basin transition occurs on the eastern side of the Gargano [*Masse and Luperto Sinni*, 1987] and in the eastern Puglia offshore southwestern Adriatic Sea [*De Dominicis and Mazzoldi*, 1987], as shown in Figure 4. This platform margin is displaced with right-lateral sense by the Tremiti Line and the Mattinata Line [*Doulcet et al.*, 1990]. Puglia represents the foreland of both the Apenninic and Dinaric orogens, active during the Neogene. This foreland is weakly deformed and consists of an emerged area (the Gargano, Murge, and Salento areas) and of a submerged area in the Adriatic Sea and in the Ionian Sea, or Apulian swell [*Auroux et al.*, 1985]. The Apulian foreland shows a rather uniform structure with a Variscan crystalline basement and an approximately 6 km thick Mesozoic sedimentary cover. This was drilled by exploration wells. In particular, the Puglia 2 shows a classic succession of Permo-Triassic red beds (fluvial-deltaic terrigenous facies, i.e. Verrucano), evaporites (Burano Anidrite, about 1 km thick), and well-bedded Jurassic-Cretaceous carbonates of generally restricted platform or back-reef facies 3-5 km thick [*D'Argenio*, 1974]. This succession is overlain by thin, discontinuous Tertiary deposits. These latter are represented by organogenic and/or calcarenitic facies of Paleocene-Oligocene age and by thin carbonate-terrigenous deposits of Neogene and Quaternary age.

From a general point of view, Puglia corresponds to the most uplifted portion of a wide antiform structure WNW-ESE trending and segmented by several, parallel normal faults and related transfer zones. The antiform shows down faulted blocks both toward the Bradanic trough to the west and toward the Adriatic (Figure 4). Transfer faults striking oblique or perpendicular to the main WNW trending normal faults segmented the Puglia in three main blocks with different

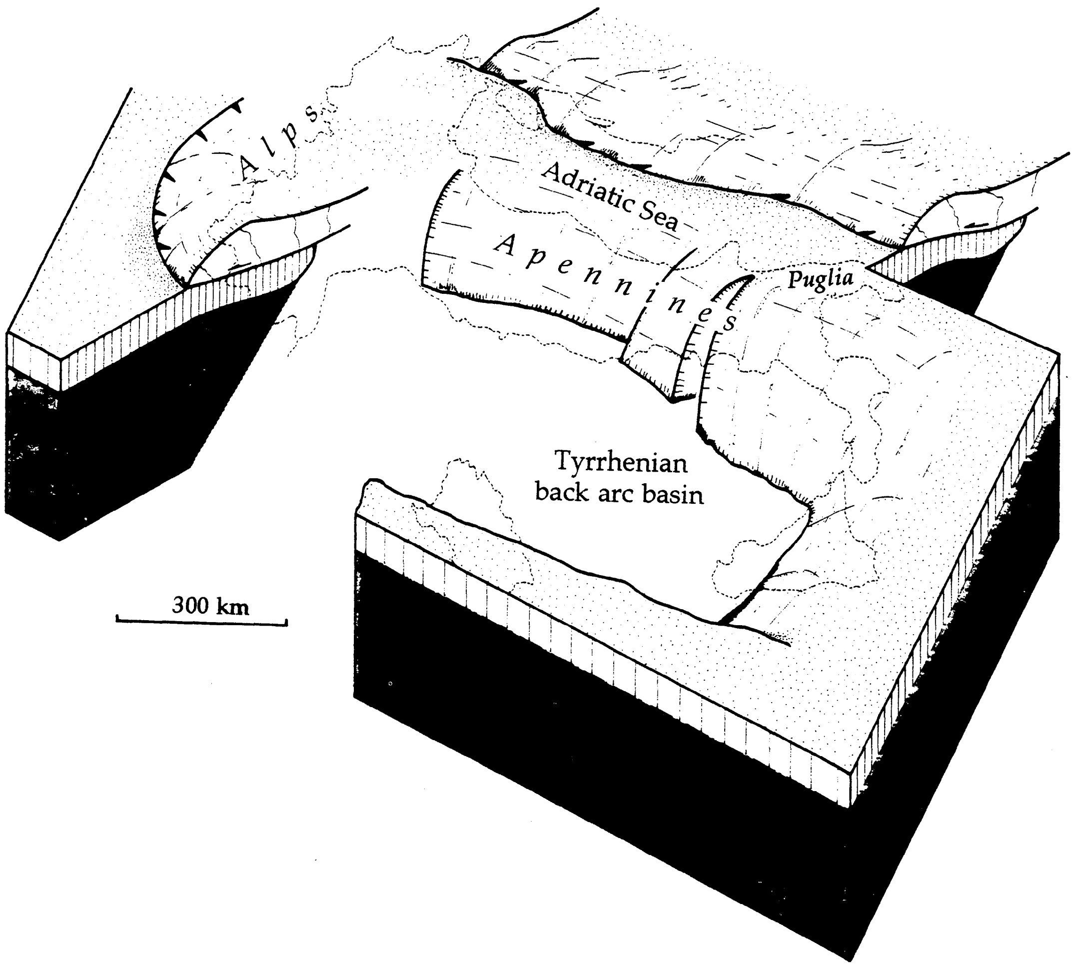

Figure 1. The Adriatic plate is subducting westward underneath the Apennines, and east-northeastward underneath the Dinarides, while it is overthrusting the European plate toward the west, generating the Alps.

degree of uplift (from the highest Gargano, Murge, and to the lowland of Salento toward the southeast).

The stratigraphy of the Apenninic foreland shows similar evolution until the lower Pleistocene comparing the foredeep sediments of the central Apennines and southern Apennines fronts. Up to 3-to-6 km thick Pliocene and Pleistocene sands and shales filled the Apenninic foredeep in both areas. The Argille subappennine filled the Bradanic foredeep at the front of the southern Apennines, showing an eastward migration of their depocenter, like all around the Apenninic arc [*Boccaletti et al.*, 1990]. They were deposited during high subsidence rates, similar to those of the central Adriatic during the same time span (late Pliocene-middle Pleistocene). The subsidence was controlled by the eastward rollback of the subduction hinge of the Adriatic plate. However, since middle Pleistocene, the Puglia foreland, in front of the southern Apennines, began to uplift, in contrast with the northern foreland in the central Adriatic where subsidence continued regularly. The two different settings may be illustrated by four representative stratigraphic columns of the Apenninic foreland, two from the Adriatic Sea and two from the Puglia region (Figures 3 and 4, locations 1 to 4). Comparing the stratigraphic sections of the north central Adriatic (locations 1-2) with the Puglia region (locations 3-4), we do observe the thick pile of clastic Pleistocene sediments in the northern-central Adriatic, whereas thin outcrops (a few tens of meters) of these sediments are only locally preserved owing to the erosion in Puglia (both Gargano promontory and Murge) where middle-late Pleistocene uplift occurred (Figures 3 and 4).

In site 1 along the Ancona offshore, at about 50 km from the coastline, the Barbara well [*Pacchiarotti*, 1982] shows 1600 m of Pleistocene clastics (shales, sandstones, and siltstones) overlying a few tens of meters of Pliocene calcarenites that, in turn, are discordantly covering a Mesozoic-Paleogene carbonate platform. At site 2, 20 km from the coastline in the Vasto offshore near Pescara, to the west of the Gargano promontory (Figures 3 and 4), and on the structural high of the Rospo Mare field [*Doulcet et al.*, 1990], 70-100 m of Miocene deposits are discordantly overlying the Mesozoic carbonate platform. The Miocene is, in turn, covered by 1250 m of Plio-Pleistocene shales and siltstones. The structural and morphologic high of the Rospo Mare is bounded by faults E-W, NW-SE trending to the south and southwest, whereas it is limited by the carbonate platform margin to the north and northeast. Site 3 is a schematic column representing a typical setting of the Gargano promontory that is the most uplifted block of the Apulian foreland (1050 m above sea level). Late Pliocene-Pleistocene

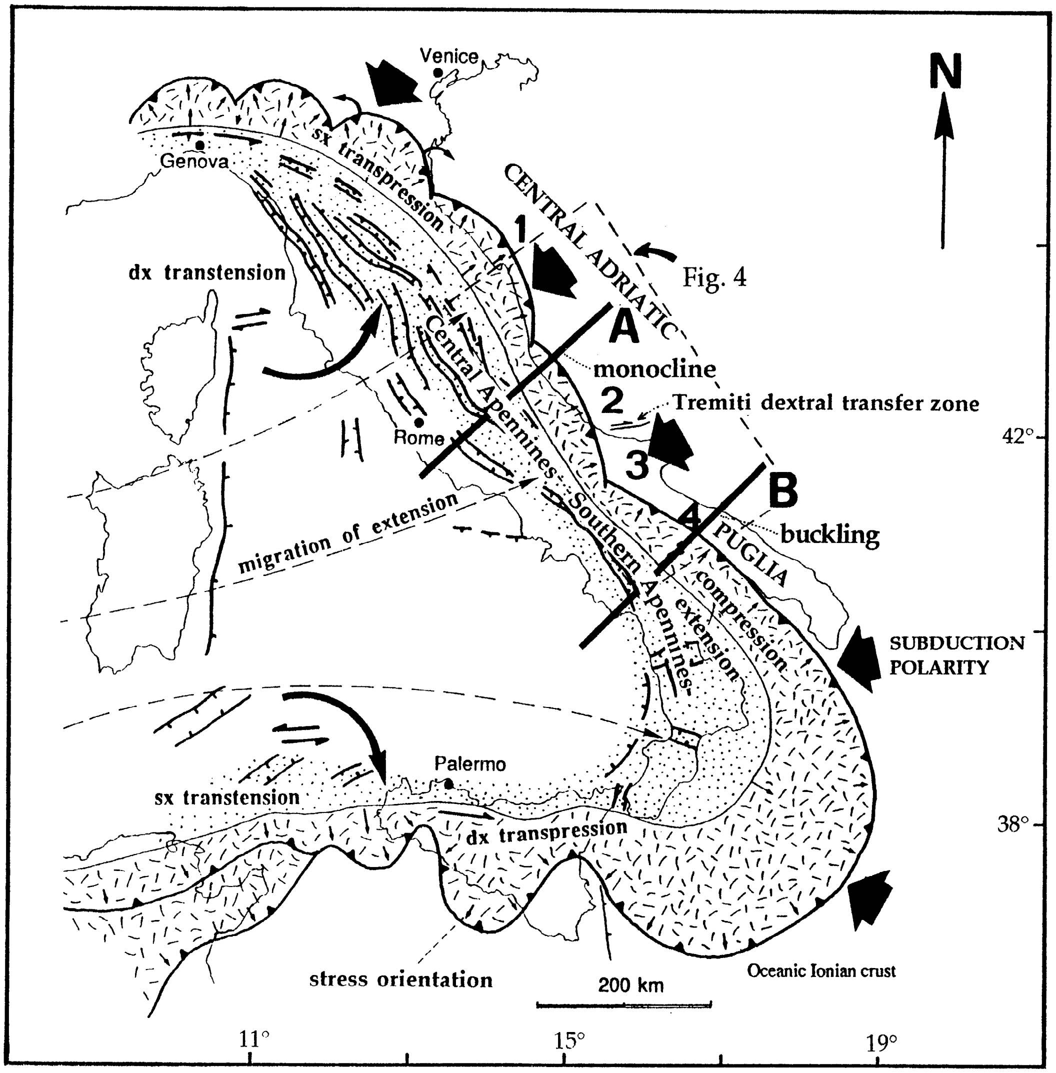

Figure 2. Main Plio-Pleistocene "eastward" moving tectonic fields of the Apennines arc [after *Doglioni*, 1991] and location of the sections shown as Figures 6 and 7. Numbers refer to the locations of the stratigraphic sections of Figure 3; dx is right lateral; sx, left lateral.

calcarenites [*D'Alessandro et al.*, 1979] are discordantly overlying the Mesozoic carbonate platform sequences. The Plio-Pleistocene deposits are a few tens of meters thick, and they occur at 200-250 m above sea level. Site 4 is located in the Murge that is the elongated antiform characterizing the strike of Puglia. The Murge (or Murgia) is elongated NW-SE, and it is the largest uplifted area of the Apenninic foreland. Late Pliocene-lower Pleistocene calcarenites (Gravina Calcarenite) a few meters thick discordantly cover the Cretaceous carbonate platform sequences (Bari and Altamura Formations). This Cretaceous-Pleistocene contact occurs in several localities up to 400 m above sea level. If we consider as datum plane the contact between the Mesozoic carbonate platform and the Plio-Pleistocene sediments in the four stratigraphic sites, we observe two clearly distinct settings between the Adriatic Sea and Puglia. The four sites are distributed along about 400 km, and they indicate that the Apenninic foreland is separated in two areas along the Tremiti lineament. To the north, subsidence was operating throughout the Pliocene and Pleistocene, whereas to the south, subsidence occurred until the lower Pleistocene. From that moment on, the Puglia (or Apulian swell) was inverted in uplift.

Geophysical Setting

The lithospheric thickness of Italy and the surrounding regions shows frequent lateral variations [*Calcagnile and Panza*, 1981; *Babuska and Plomerová*, 1990]. In particular, the thickness of the continental lithosphere of the central Adriatic region is lower (an average of 70 km) with respect to the Puglia swell (110 km), as shown in Figure 5. Those thickness variations should be related to the Mesozoic rifting that affected the Adriatic plate during the Tethyan history [e.g., *Ziegler*, 1988]. In fact, the Puglia region shows Mesozoic carbonate platform facies, whereas the central Adriatic is mainly characterized by pelagic facies during the late Mesozoic. The lithosphere to the west of Puglia, now lost

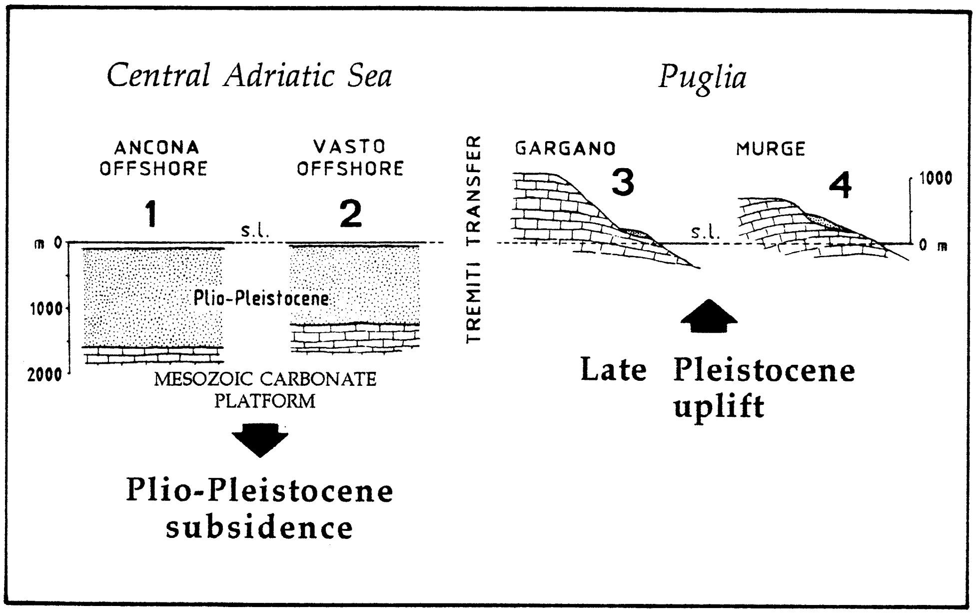

Figure 3. Schematic stratigraphic columns of the Apenninic foreland in the north central Adriatic and Puglia. For locations, see the relative numbers in Figures 2 and 4. Columns are very similar until the top of the Pliocene, but in the Adriatic the subsidence continued throughout the Quaternary, whereas the Puglia region underwent uplift since the middle Pleistocene. Scattered outcrops of Plio-Pleistocene gravels and sands are lying on the Mesozoic carbonate sequence in the Gargano and Murge areas.

in subduction underneath the southern Apennines, had to be thinner than 100 km and possibly oceanic in origin, according to the pelagic facies of the Lagonegro Units. Southwest of Puglia, seismic and heat flow studies clearly indicate that the Ionian Sea is floored by oceanic lithosphere [*Finetti*, 1982; *Della Vedova et al.*, 1989; *de Voogd et al.*, 1992]. The Ionian Sea is a Mesozoic oceanic-trapped crust and, most likely, this basin continued to the north-northwest, west of Puglia. The pelagic cover of this oceanic lithosphere might be considered the Lagonegro Unit of the southern Apennines.

The shape of the Bouger gravimetric profiles in the two sections of Figure 2 clearly differ [see *Mongelli et al.*, 1975; *Royden*, 1988]. The southern section shows a gravimetric high in correspondence to the Puglia relief, and the hinge zone is located more to the west. This is absent in the central Adriatic, where the gravimetric profile is smoother and regularly bending underneath the Apenninic foredeep.

The Moho depth [*Nicolich*, 1989] ranges between 25 km (Gargano) and 30 km (Murge) in Puglia and between 30 km in the central Adriatic and 35 km below the Chieti basin. In the central Adriatic the Moho dips underneath the Apennines, as we may expect from the subduction, whereas in the Puglia region, particularly in the Gargano promontory, the Moho shows an anomalous uplift, in contrast with the high elevation of the area.

Royden [1988] studied the flexural behavior of the Adriatic continental lithosphere, taking into account vertical forces and bending moments that act on the plate in static state, and she concluded that the shape of the basal Pliocene surface may be explained by a terminal force supplied by anomalously dense material of the subducted lithosphere.

Apenninic Subduction

The Adriatic plate [*Channell et al.*, 1979; *Anderson*, 1987] is subducting westward and generating both the frontal accretionary wedge of the Apennines and the internal Tyrrhenian back arc basin. The Adriatic plate was also subducting eastward underneath the Dinarides and thrusting the European plate toward the west, producing the Alps (Figure 1). Geophysical evidence for the Apenninic subduction have been proposed by several authors [*Caputo et al.*, 1970; *Mongelli et al.*, 1975; *Panza et al.*, 1982; *Gasparini et al.*, 1984; *Anderson and Jackson*, 1987; *Spakman*, 1989; *Amato et al.*, 1993]. These data confirm or are in agreement with other geologic data and interpretations about the Apenninic geodynamics [*Ricchetti and Mongelli*, 1980; *Cristofolini et al.*, 1985; *Malinverno and Ryan*, 1986; *Peccerillo*, 1985; *Royden et al.*, 1987; *Patacca and Scandone*, 1989; *Serri*, 1990; *Doglioni*, 1991; *Lobkovsky and Matveenkov*, 1991; *Van Dijk and Okkes*, 1991]. The Apenninic subduction was active since at least the early Miocene. The subduction hinge migrated "eastward" (but also northeastward in the northern Apennines and southeastward in Calabria and Sicily) all around the Apenninic arc at rates of 1-7 cm/yr, which are the lower values located at the two (northern and southern) subduction tip lines. The subducting slab is, in fact, deeper beneath the southern Apennines, whereas it is linearly decreasing in depth both northwestward (northern Apennines) and southwestward (Sicily). In contrast with other classic west dipping subduction-related arcs (Carpathians, Barbados, Sandwich, Banda, Marianas, Aleutians, Ryukyu, and Japan) the Apenninic arc is particularly asymmetric, having its tighter bending in the southern sector, i.e., the Ionian Sea. This has

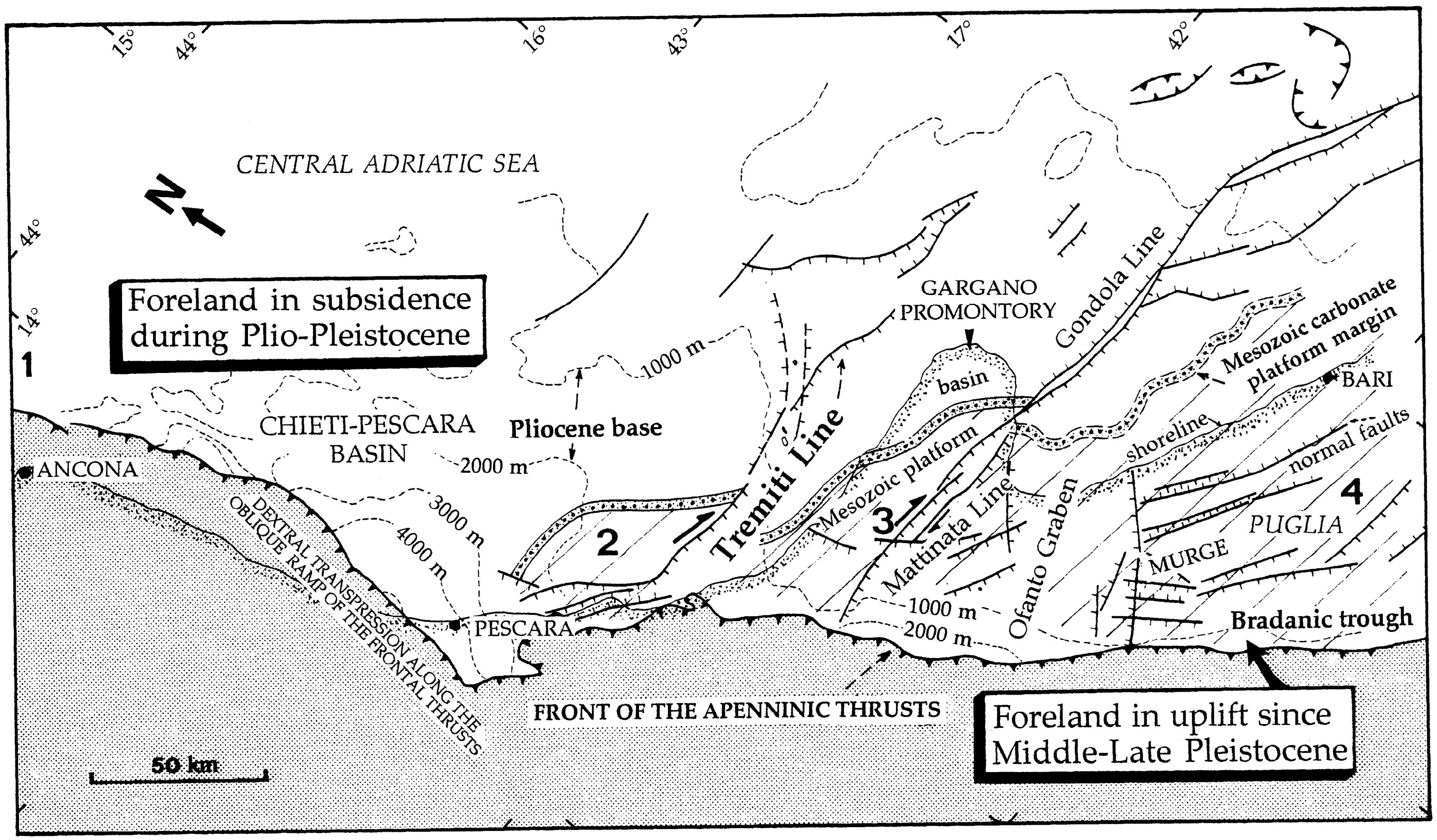

Figure 4. Structural map of the Apenninic foreland between the central Adriatic Sea and northern Puglia, based on data by *De Dominicis and Mazzoldi* [1987], *Bigi et al.* [1989], *Doulcet et al.* [1990], *De Alteriis and Aiello* [1993], and *Argnani et al.* [1993]. Note the Tremiti right-lateral transfer zone separating the two realms. Numbers refer to the stratigraphic columns of Figure 3.

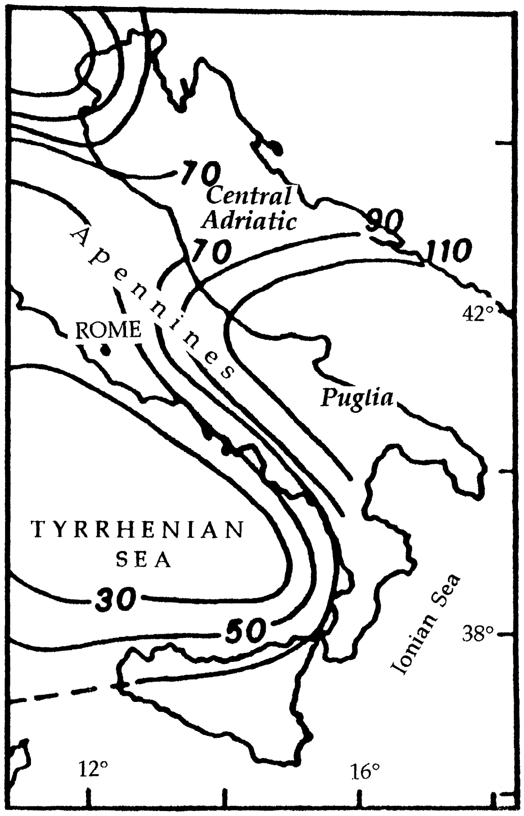

Figure 5. Lithospheric thicknesses of the Apennines, Puglia, and Adriatic Sea region, after *Calcagnile and Panza* [1981].

been interpreted to be a result of the inherited framework of the Mesozoic rifting; the easier subduction of the Ionian Mesozoic oceanic lithosphere with respect to the Adriatic continental lithosphere appears to have controlled the larger expansion of the Apenninic arc over the Ionian Sea and the wider opening of the Tyrrhenian Sea, in comparison, for example, with the shorter northern Apennines where it is subducting the Adriatic continental lithosphere [*Doglioni*, 1991]. In contrast with the western Pacific west dipping subduction zones, the Apenninic subduction doesn't have convergence rate between the foreland (e.g., the Adriatic and Puglia) and the western margin of the back arc basin (e.g., Sardinia), like the Carpathians, Barbados, Sandwich, and Banda west dipping subduction zones. Western Pacific subduction zones regularly show an outer rise or bulge, whereas the Apennines show a bulge only along the Apulian swell [see *Ricchetti and Mongelli*, 1980].

Apenninic Front

The Apennines have an active accretionary wedge that may be followed from the Monferrato, across the Po Plain, throughout the western side of the central Adriatic Sea, the Bradanic trough, the Ionian Sea, and Sicily. This active wedge is structurally and morphologically lower (usually below sea level), with respect to the real Apenninic mountains, that are located to the west and are characterized by pervasive extensional active tectonics. The pair extension to the "west" in the Apennines and compression to the "east" at the base of the Apenninic slope (Po Plain, western Adriatic Sea, Bradanic trough, Ionian Sea, and southern Sicily) constitutes a wave moving eastward throughout the Neogene and the Quaternary (Figure 2). The Apenninic frontal accretionary wedge shows imbricate fan geometries. The frontal active compression can be documented through seismic information all around the arc [*Pieri*, 1983; *Ori et al.*, 1991; *Schwander*, 1989] and by field data at the western margin of the Bradanic foredeep. The vitality of the compression is manifested by thrusts cutting the Quaternary at the buried front of the Apennines in the Po Plain and in the western Adriatic Sea. Moreover, an active thrust, folding and cutting the Quaternary, is visible at the rear of the accretionary wedge (often running parallel to the base of the eastern Apenninic slope) with out-of-sequence kinematics. The frontal, buried imbricate fan is poorly developed in the Bradano foredeep [*Casnedi*, 1988; *Sella et al.*, 1988] at the front of the southern Apennines [*Casero et al.*, 1988], but at its western margin the internal out-of-sequence thrust remains active, as documented by deformation of Pleistocene deposits at the western margin of the Bradano foredeep [*Loiacono and Sabato*, 1987]. The activity of the southern Apennines frontal thrusts is also supported by 23° counterclockwise rotation of middle-late Pleistocene deposits [*Sagnotti*, 1992; *Scheepers et al.*, 1993].

The most external thrusts of the Apenninic accretionary wedge are buried in the western side of the central Adriatic, offshore Pescara and Chieti, and they parallel the coast. They deviate southward and enter onshore at the southern margin of the Chieti basin (Figures 2 and 4), west of the Gargano promontory. They return to strike with the Apenninic trend NW-SE along the western side of the Bradano foredeep. This undulation indicates a dextral transpression characterized by oblique ramps at the intersection of the superficial decollements of the accretionary wedge and the E-W trending Tremiti Line, a lithospheric discontinuity separating a thicker lithosphere to the south, with respect to its northern counterpart (Figures 4 and 5).

The kinematics of the frontal part of the Apennines are different between north central Apennines [*Bally et al.* 1986; *Ori et al.*, 1991], in comparison with the sections of the front of the southern Apennines [*Mostardini and Merlini*, 1986; *Pescatore and Senatore*, 1986; *Casero et al.*, 1988], however, both fronts were alive throughout the Quaternary. This separation between the two structural styles occurs at the dextral undulation of the arc to the west of the Gargano promontory (Figure 4). The impressive difference between the two realms is underlined by the active subsidence in the Adriatic Sea [*Colantoni et al.*, 1989] and the coeval uplift to the south in the Bradano trough and Puglia [*Cosentino and Gliozzi*, 1988, *Dai Pra and Hearty*, 1988; 1989]. Evidence for this uplift is given by uplifted shorelines and the uplift of the sediments that filled the Bradano foredeep, e.g., the Pleistocene Argille subappennine and the late Pleistocene Irsina Conglomerate that is now at about 500-600 m altitude. According to *Cosentino and Gliozzi* [1988], *Dai Pra and Hearty* [1988; 1989] subsidence rates in the Apenninic foredeep located in the western Adriatic Sea are in the order of 3.5 m/kyr, whereas uplift rates in Puglia are of the order of 0.2-0.3 m/kyr. Average subsidence rates in the Apenninic

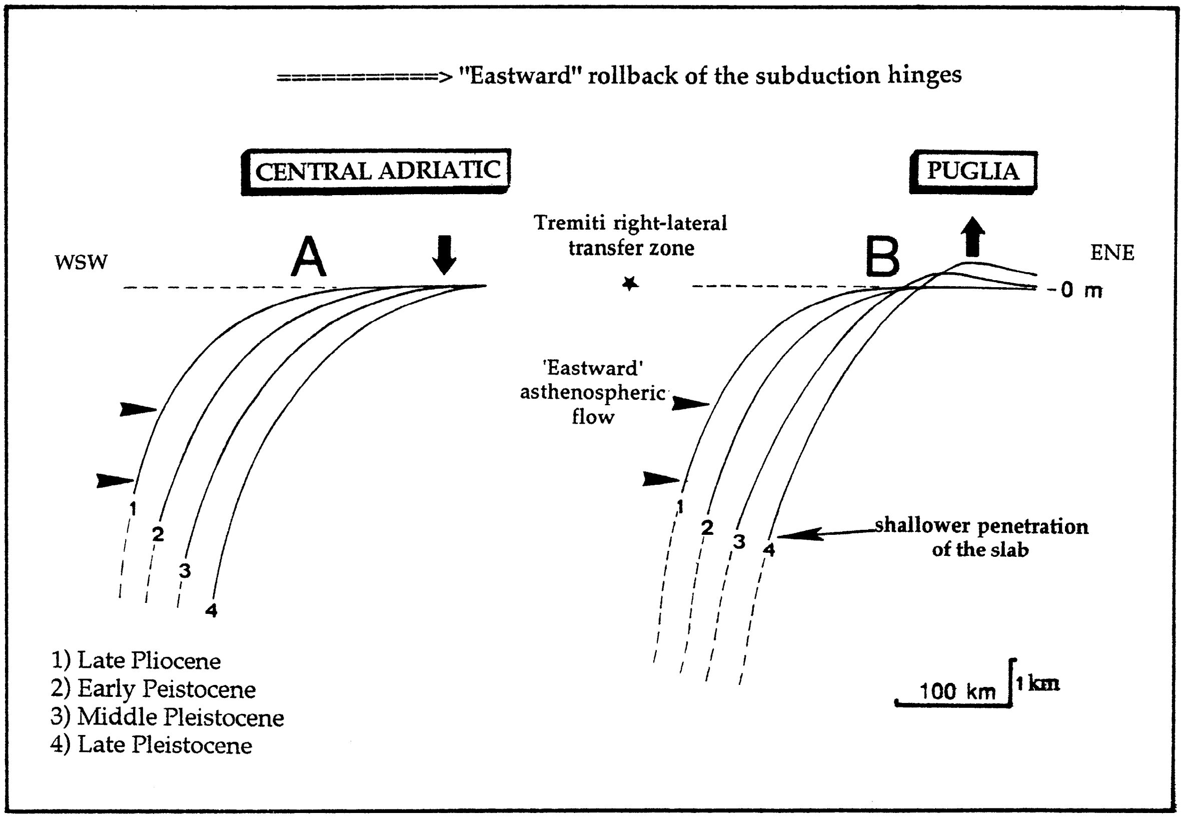

Figure 6. Comparison of the different evolutions of the subduction hinge rollback of the central Adriatic and Puglia. The existence of Puglia, as present land, may be interpreted as being caused by the uplift of the lithosphere as a consequence of the lower penetration of the slab, which is due to the thicker continental lithosphere reached the subduction zone; this is compensated by buckling of the lithosphere.

foredeep during the Pliocene and Pleistocene is of the order of 1.0-1.6 m/kyr [*Doglioni*, 1992, 1994]. The subsidence is primarily interpreted as being due to the rollback of the subduction hinge [*Malinverno and Ryan*, 1986; *Royden et al.*, 1987] but also influenced by the load of the Apenninic thrust sheets and the load of the sediments filling the foredeep sourced by the Po river and other minor rivers.

Active NW-SE trending normal faults outcrop in Puglia and eastern Bradano trough [*Ciaranfi et al.*, 1988; *Ricchetti et al.*, 1988, and references therein]. They dissect the entire Puglia but also the submerged Apulian swell to the southeast [*Auroux et al.*, 1985]. This extension has been accompanied by the uplift of the region. This deformation does not appear (at least in such an evident way) to the north, in the central Adriatic that is the natural prolongation of the Apenninic foreland.

Tremiti Transfer Zone

The two different tectonic realms are separated by an E-W or ENE-WSW trending shear zone, known as Tremiti Line (Figures 2 and 4). This alignment runs offshore to the north of the Gargano promontory [*Finetti et al.*, 1987; *Doulcet et al.*, 1990; *Correggiari et al.*, 1992; *Argnani et al.*, 1993], it deforms the sea bottom [*Mosetti and Mosetti*, 1984], and it is seismically active [*Favali et al.*, 1993]. On the basis of this seismicity and other data, *Mongelli* [1975] and *Console et al.* [1993] interpreted this alignment as a lithospheric rupture separating the Adriatic plate into two blocks (northern and southern). Subparallel or E-W trending active faults run in the southern part of the Gargano promontory, e.g., the Mattinata Line, [*Funiciello et al.*, 1988; 1991; *Guerricchio and Wasowski*, 1988] and in its offshore prolongation [*Finetti et al.*, 1987; *De Dominicis and Mazzoldi*, 1987; *Argnani et al.*, 1993; *De Alteriis and Aiello*, 1993]. Focal mechanisms and structural data indicate a right-lateral sense of motion for the Tremiti alignment [*Funiciello et al.*, 1991]. This is consistent with the dextral displacement of 10-20 km of the eastern margin of the lower Cretaceous Apulian carbonate platform [*Doulcet et al.*, 1990], as shown in Figure 4. En échelon undulations or steps of these faults generated both pull-aparts (right steps) or push-ups (left steps) along the Tremiti and Mattinata alignments. Left-lateral movements along the Mattinata fault have also been indicated [*Funiciello et al.*, 1991], but they could be related to other factors such as the transfer zone allowing the clockwise Tertiary rotation of Puglia relative to the Gargano promontory [*Tozzi et al.*, 1988] and the left-lateral transtensional opening of the northern border of the Ofanto Graben, and/or they could represent an inherited Mesozoic transfer fault related to the rifting processes that acted in the lower Adriatic Basin between Puglia and Albania.

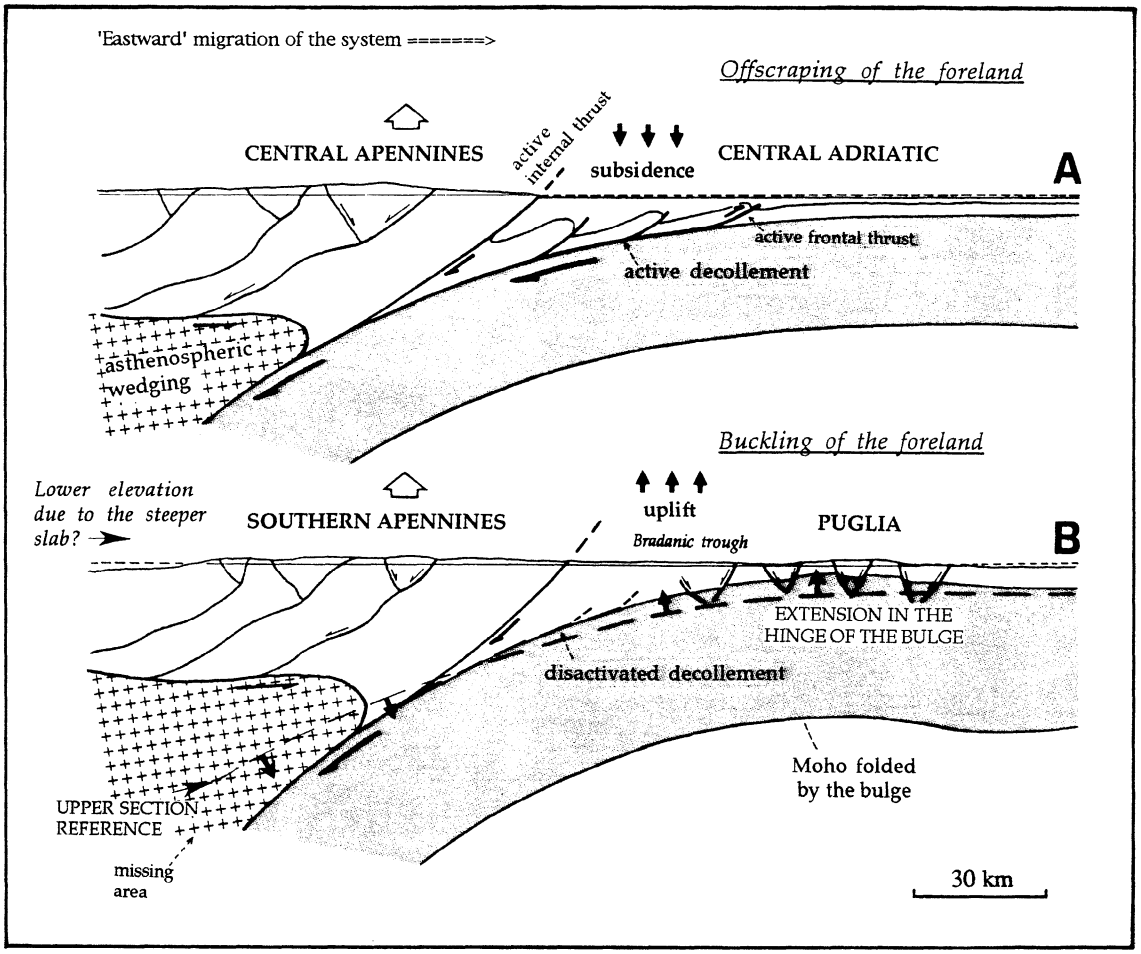

Figure 7. Two schematic cross sections interpreting the differences between central and southern Apennines. During the late Pleistocene evolution the geometry and kinematics of the "eastward" migrating accretionary wedge and foredeep differ between the two sectors. (A) In the northern section the accretion continues through off scraping of the upper layers of the "westward" downgoing subducting Adriatic plate. (B) In the southern section the lower rollback of the subduction hinge is compensated by buckling and formation of the Puglia bulge. The Bradanic trough was inverted from subsidence to uplift from middle Pleistocene on. Comparing the top of the crystalline basement (shaded areas) of the upper section with that of the lower section, the "upper section reference" plotted in Figure 7B is lower in the foreland and in the foredeep where, in fact, there is ongoing uplift, whereas it is deeper and steeper underneath the southern Apennines. Therefore the southern section in Figure 7B needs a steeper monocline of the top of the subducting plate in depth. This may have controlled the lower elevation of the southern Apennines due to the wider available room occurring in the hanging wall.

Geodynamic Considerations

The larger eastward rollback of the Apenninic subduction hinge in the central Adriatic lithosphere with respect to the Puglia lithosphere needs a right-lateral transfer zone which can be identified with the Tremiti alignment. This feature is, in fact, active in the foreland of the Apenninic front, and it has an eastward propagating tip line in the eastern side of the lower Adriatic basin. In other words, this system of faults exists in order to accommodate the different behavior of the subduction of the Adriatic plate underneath the Apennines, separating two segments with different rollback rates. In fact, the subduction of the lithosphere to the west of Puglia below the southern Apennines is slower with respect to the segments to the north (central Adriatic) and to the south (Ionian Sea). In this sector the rollback of the Ionian lithosphere presents the highest value (5-7 cm/yr). The transfer zone is located in the Taranto Gulf. Also, in the Ionian Sea, high subsidence rates are observed.

In conclusion, the entire Apennines are the consequence of the subduction of three types of lithosphere with different characteristics, but pertaining to the same Adriatic plate. (1) In the north central Apennines, thin continental lithosphere at the surface in the foreland, and probably thinner at depth, occurs. (2) In the southern Apennines, thick continental lithosphere occurs in the foreland, whereas probably old oceanic lithosphere constitutes the slab at depth to the west (northern prolongation of the Ionian Mesozoic basin). (3) In the southern sector, offshore Calabria, old oceanic Ionian lithosphere occurs both in the foreland and at depth.

If we accept the existence of an eastward moving asthenosphere relative to the lithosphere, as evidenced by the hot spot reference frame [*Le Pichon*, 1968; *Ricard et al.*, 1991; *Doglioni*, 1993], then there should be an eastward oriented push acting on the Adriatic slab in depth (Figure 6). This means that in addition to the forces generally considered in the study of the flexural behavior of the lithosphere, this other force has to be taken into account. Moreover, the observed split into subsidence and uplift settings since the middle Pleistocene in different sectors means that (1) the regime is transient and (2) the acting forces and physical parameters are different in the three sectors.

The history of the Apenninic subduction may be reconstructed in the following way. At the beginning of the subduction the Adriatic lithosphere is flexed by the weight of the overriding plate, its own weight contrasted by the buoyancy forces, and the horizontal push of the asthenospheric flow. The progressive flexure generates the rollback of the hinge and the continuous subsidence of the area above the hinge (i.e., the foredeep). The slope of the subduction is increasing by the weight of the slab and by the asthenospheric horizontal push, these forces being contrasted by the flow induced in the asthenosphere by the slab. These conditions do not favor the formation of the bulge. Once the subduction is on, the overriding plate is abandoned to the west. No significant difference occurs between the subduction of the north central Apennines in comparison with the southern sector, apart from the amount of penetration that is larger for the latter, down to 500-600 km, during 20 Ma. During the middle Pleistocene the thick continental lithosphere of the Apulian swell arrived at the subduction hinge, offering larger resistance to the flexure, so that the eastward rollback of the subduction hinge and the penetration of the slab slowed. The pressure of the asthenospheric flow generated an increase of the slab slope and favored the increase of the bulge in the foreland. This buckling is responsible for the uplift of the foreland and of the Moho (Figures 7 and 8) that is missing in the adjacent Adriatic and Ionian segments. The arrival of the Puglia thicker lithosphere at the subduction hinge is coeval with the deviation toward the southeast of the

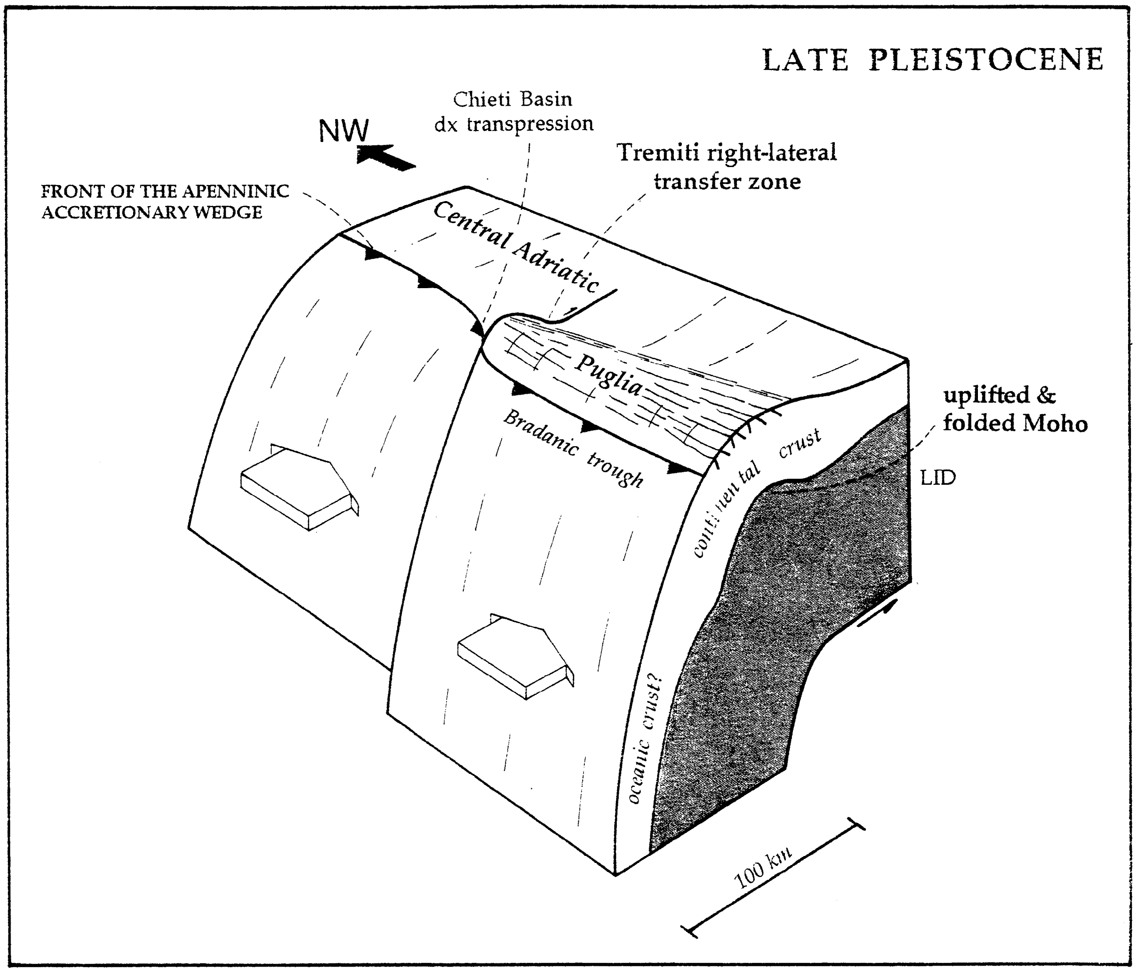

Figure 8. Block diagram showing the different behavior of the Adriatic and Puglia lithosphere. The E-W trending Tremiti tectonic alignment should be the right-lateral transfer zone between the larger eastward rollback of the subduction hinge of the Adriatic lithosphere characterized by a thinner lithosphere (70 km) and the uplifting Puglia, where the lithosphere is thicker (110 km) and shows a lower penetration rate.

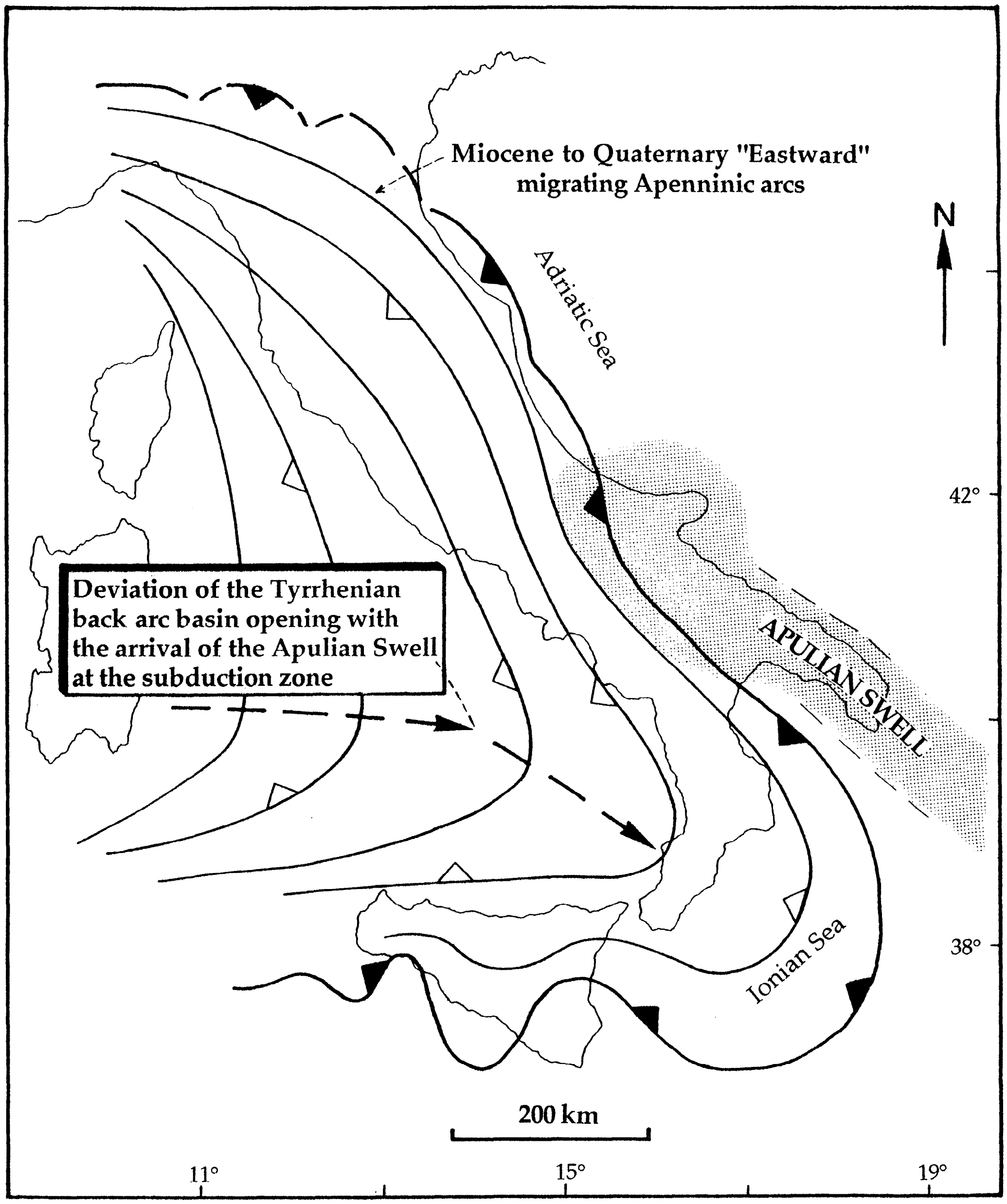

Figure 9. The Apenninic arc migrated "eastward" during Neogene and Pleistocene times, associated with the rollback of the subduction hinge. The arrival of the thick continental lithosphere of the Apulian swell to the subduction hinge probably controlled the larger southeastward deviation of the Ionian arc and of the Tyrrhenian back arc spreading.

Tyrrhenian rifting, suggesting a common denominator for the two phenomena. The more rigid obstacle represented by Puglia could be responsible for the larger expansion toward the more subductable Ionian oceanic lithosphere, forming the large Apenninic arc in the Ionian Sea (Figure 9). This deviation generated an apparently independent subduction which is the most seismically active in southern Italy [*Anderson and Jackson*, 1987] and which led *Patacca and Scandone* [1989] to interpret the Apenninic arc as controlled by two separated subduction directions, toward WSW in the central northern Apennines and toward NW underneath the southern Apennines and Calabria.

The buckling of the Adriatic lithosphere has several dramatic consequences for the structural evolution of the southern Apennines. The relative lower subduction with respect to the other Apenninic sectors has to control a lower detachment between the sedimentary cover and the crystalline basement in comparison with the other parts of the Apenninic accretionary wedge. In other words, the regular off scraping of the sedimentary cover is more inhibited at the front of the southern Apennines relative to the adjacent areas, due to the slower descent of the lithosphere. Therefore rather than off scraping and active decollements, the front of the southern Apennines (i.e., the Bradano trough and the Puglia foreland) is characterized by buckling, and the shape and kinematics of the accretionary wedge change with respect to the north central Apennines and the Ionian arc. The first difference is that the foreland is uplifting, whereas in the adjacent areas this is subsiding. The second difference is that the shape and propagation of the thrust planes are inhibited and lower at the front of the southern Apennines, even if the system is clearly alive. Probably, the compressive belt is presently concentrated in the "out-of-sequence" thrust located at the western margin of the Bradanic trough.

The buckling of the foreland should be compensated by a steeper slab underneath the southern Apennines (Figure 7). The top of the crystalline basement has a smoother shape in the section between central Apennines and central Adriatic, in comparison with the southern Apennines and Puglia cross section (compare the "upper section reference" in Figure 7B). The latter section shows a large-scale crustal folding (80-100 km), with a relative uplift of the top of the basement, with respect to the central Apennines section. However, this uplift is compensated by a deepening of the top of the basement (corresponding to the top of the downgoing Adriatic lithosphere) more to the west underneath the southern Apennines; this has the consequence of expanding the available area above the subduction zone in this section, with respect to its northern counterpart. The consequence of this larger available room may be the lowering of the entire crust and asthenosphere in the southern Apennines section, responsible for the lower elevation of the southern Apennines, with respect to the central Apennines, where the highest mountains (Gran Sasso, Maiella, etc.) are located in spite of a shallower subduction. In fact from the maximum depth underneath Calabria (about 600 km), the subduction decreases northwestward to 0 in western Piemonte, northern Italy.

The buckling of the foreland may explain why that at the highest morphologic elevations of Puglia (e.g., the Gargano promontory) there corresponds the shallower Moho (25 km), suggesting an uncompensated isostatic setting (Figures 7 and 8). The highest altitudes are located in northern Puglia, close to the Tremiti transfer zone. This structural high could be related to transpressional tectonics. We note a gradual decrease in the structural and morphologic elevation moving southeastward along the Puglia region and its offshore prolongation, the Apulian swell between the southern Adriatic Sea and the Ionian Sea. It is interesting to note that this 500-km ridge is oblique, with respect to the subduction hinge, and the highest elevation is located at the intersection of the ridge with the Apenninic front. The obliquity of the ridge arriving at the foredeep should induce a diachronous buckling of the foreland, with a wave propagating both eastward and southeastward, and may have controlled clockwise rotation of the Salento peninsula [*Tozzi et al.*, 1988].

A complication in the system is generated by the increase of the length of the Apenninic arc due to the eastward rollback of the subduction hinge. This should control the development of "comb" grabens perpendicularly oriented with respect to the arc. A major feature that could be related to this extension is the Ofanto graben (Figure 4), about E-W trending and located to the south of the Gargano promontory.

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C. Doglioni, Centro di Geodinamica, Università della Basilicata, V. Anzio, 85100 Potenza, Italy

F. Mongelli and P. Pieri, Dipartimento di Geologia e Geofisica dell'Università, Via Orabona 4, Campus, 70125 Bari, Italy

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