

A proposal for the kinematic modelling of W-dipping subductions – possible applications to the Tyrrhenian–Apennines system

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ABSTRACT

In W-dipping subduction zones there is a general eastward progression of the back-arc basin–accretionary wedge–foredeep complex. With the forward progression, early stages of the complex are revealed by slices of upper crust and sedimentary cover abandoned to the west left floating above a new section of mantle. A major shear zone should form at the new Moho separating upper crust slices of earlier accretionary stages and the eastward flowing mantle. The mantle wedging at the top of the subduction plane could be responsible for the uplift of the central parts of the belt. The retreating of the subduction hinge is interpreted as due to the push generated by the 'eastward mantle flow detected in the hot spot reference frame. The foredeep depth is mainly a function of the radius of curvature of the subduction hinge. The frontal wedge is constructed from the stacking of the upper layers of the subducting plate and the syntectonic clastics that fill the foredeep which are progressively involved in thrusting and later by extension. In order to preserve volume balance, the lithosphere of the eastern plate before subduction has to be the same size as that which has been subducted: due to the longer length of the arc with respect to the original length of the linear margin between the two converging plates, laterally stretched subducted lithosphere is predicted at depth. W-dipping subductions usually have a short life probably due to their inherent capability to produce new lateral heterogeneities of the lithosphere (the thin back-arc) which are a key factor in controlling and generating new subductions (both E- and W-dipping). This model is applied to the Apennines–Tyrrhenian Sea system.

part of the crust is involved in the frontal accretionary wedge. In fact accretionary wedges related to W-dipping subductions show low structural and morphological relief, involve shallow upper crust rocks, show a very consistent foredeep generated by the roll-back of the subduction hinge (i.e. W-Pacific accretionary wedges, Barbados, Carpathians, Apennines) and produce back-arc extension which is eastward (*sensu lato*) propagating and cross-cuts the accretionary wedge (Doglioni, 1990; 1991).

KINEMATIC CONSTRAINTS OF W-DIPPING SUBDUCTIONS

A W-dipping subduction can start only if there is originally a thinner lithosphere to the east relative to a thicker one to the west (Doglioni, 1991). This is independent of the nature of the subducted lithosphere (whether oceanic or continental). However, as much of the lithosphere is thin and/or oceanic, more subduction is facilitated. Lateral thickness variations are a first-order factor in controlling the amount and style of subduction. Moreover, longitudinal lithospheric variations in thickness and composition are able to produce strong asymmetry along the subduction zones, as in the Apennines whose eastern border faces both the relatively thin crust of the Ionian sea and the thicker crust of the Adriatic sea.

West-dipping subductions are compensated by mantle flow which fills the 'hole' left by the subducted lithosphere that originally covered the space in which the back-arc basin developed (Fig. 1). This observation leads us to hypothesize that the abandoned complexes formed by off-scraping of the upper layers of the eastern subducting plate (back-arc basin–thrust belt–foredeep) are floating above a 'new'

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INTRODUCTION

The aim of this paper is to suggest a few kinematic considerations about the back-arc basin–accretionary wedge system. Back-arc basins are associated with W-dipping subduction zones, in other words subductions contrasting the mantle flow (Nelson and Temple, 1972; Uyeda and Kanamori, 1979; Doglioni, 1990). It has recently been demonstrated that the westward drift of the lithosphere with respect to the man-

tle (Le Pichon, 1968; Bostrom, 1971; Nelson and Temple, 1972) is a real physical observation which can be produced in a toroidal field by lateral heterogeneities both in the mantle and in the lithosphere (Ricard *et al.*, 1991; O'Connell and Hager, 1991). Due to the relative westward (*sensu lato*) drift of the lithosphere in W-dipping subductions, the base plate decollement of the eastern downgoing plate is folded and subducted itself and only the superficial

FORWARD PROGRESSION \Rightarrow
 of the back-arc extension - thrust belt - foredeep system

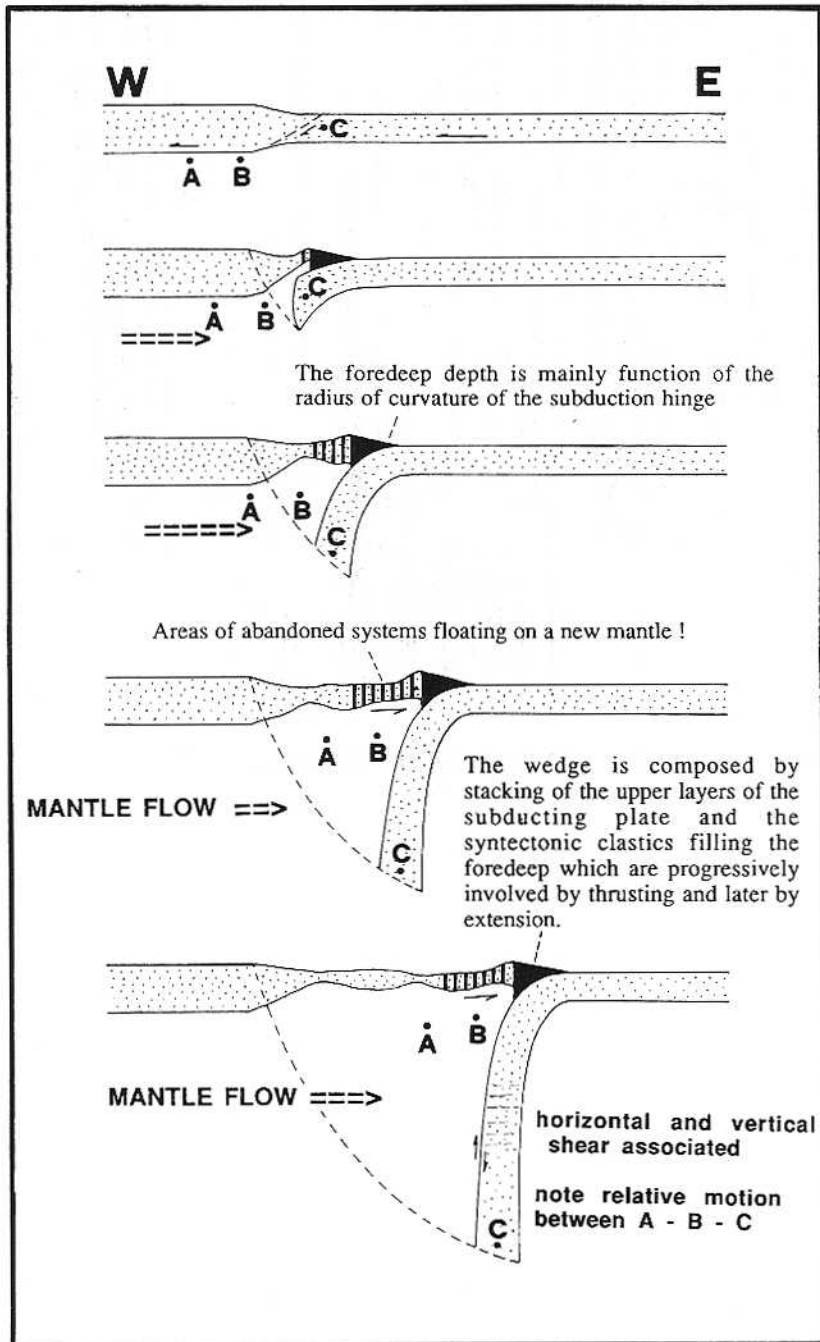


Fig. 1. W-dipping subductions produce a volume problem: the lack of lithosphere which has been subducted is compensated for in the back-arc by the mantle flow. Several consequences can be traced: the foredeep depth is a direct function of the radius of curvature of the lithosphere and is placed at the subduction hinge which is eastward-retreating due to the mantle push. The material accreted on the thrust-belt and later cross-cut by the back-arc extension is remaining behind to the west, floating above a new eastward flowing mantle. Note the relative motion between the three reference points A, B and C: they suggest the coexistence of both horizontal and vertical shear.

mantle and no longer on the original substratum of the lower crust and lithospheric mantle of the eastern subducted plate (Fig. 1). A real delamination (Channell and Mareschal, 1989) occurs. With such kinematics both horizontal and vertical shear develops along the subduction: note the relative motion between the reference points, A, B and C in Fig. 1. From this picture we also note that the foredeep geometry is controlled by the radius of curvature of the subduction.

The length of the lithosphere at the onset of subduction should be maintained: this will tend to produce lateral stretching in the subducting slab due to the bending of the lithosphere (Fig. 2). A sort of comb should form at depth, with a fragmented slab. The horizontal extension should decrease upward; however, minor grabens with a comb distribution may be seen at the surface and they could testify to the disruption of the lithosphere.

In arcs in which subduction is contrary to the mantle flow (W-dipping), the northern arm of the accretionary wedge is characterized by counterclockwise rotations and general sinistral transpression. Dextral transension occurs in the northern arm of the back-arc basin. The southern arm is instead deformed by clockwise rotations and dextral transpression. Sinistral transension has to be in the southern part of the back-arc basin (Fig. 3). A neutral line of separation between extension and compression progrades forward. Grabens perpendicular to the belt with a comb disposition may be related to the stretching of the lithosphere due to bending of the retreating lithosphere (Fig. 2). Second order arcs, undulations of the main arc trajectory appear to be related to high heterogeneities in the subducting slab (horsts, grabens, seamounts, facies changes) able to produce minor oblique and lateral trajectories of the maximum stress. Local transpressions along these regional arcs generate second order rotations which might increase or decrease the rotational values of the first order rotations of the main arc. These tectonic observations are valid in all the West Pacific W-dipping subductions, in the Barbados-Caribbean system, in the Sandwich arc, in the Carpathians and in the Apennines.

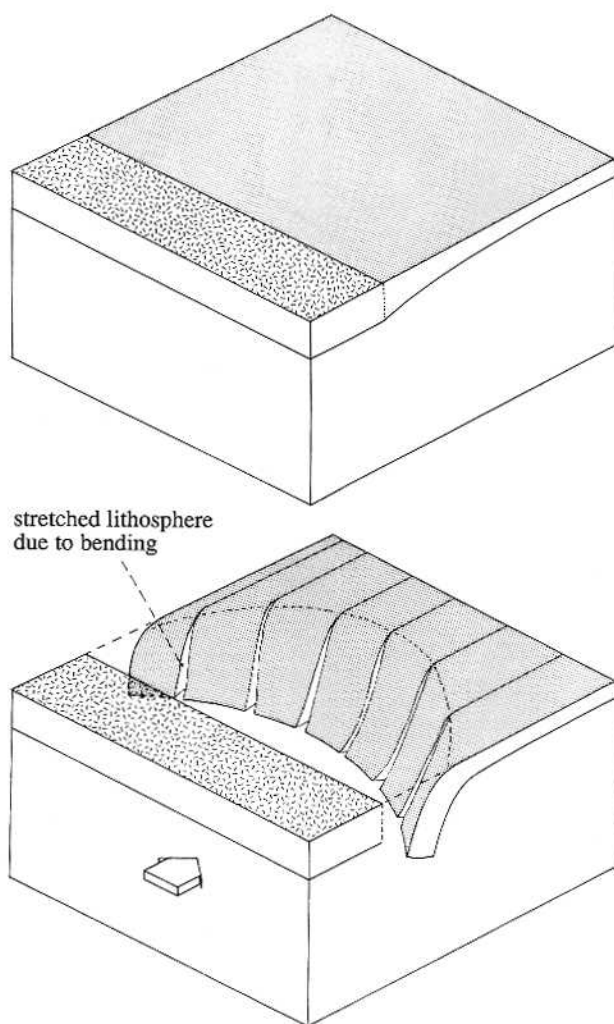


Fig. 2. In order to maintain the original length of the lithosphere before the onset of the subduction, horizontal shear, boudinage and stretching should occur in the downgoing slab. This would produce horizontal extension increasing downward. Minor superficial extension should be perpendicular to the arc producing comb graben disposition.

West dipping subductions are characterized by an eastward migrating tectonic 'wave', comprising back-arc extension to the west with compression to the east. Extension continuously propagates and cross-cuts the previously formed thrust belt (Figs 4 and 5). The area of active compression in this kind of thrust belts is very narrow (a few tens of km) and usually forms below sea-level. In the active compressive area the tangent to the fold hinge of one given pre-deformation reference bed is inclined toward the trench. The base-

ment monocline is always well pronounced and should represent the hinge of the subducting slab. The extension is controlled by a major W-trending detachment between upper slices of crust accreted in the frontal thrust belt which are then cross-cut by the back-arc extension, and the underlying eastward mantle flow. Note the position of the reference point X in Fig. 4: the mantle formerly underlying it is now subducted with the corresponding Moho, and it is now floating above a new mantle. The amount of material dragged into the

frontal accretionary wedge and later cross-cut by extension should be equal to the amount of material eroded from the top of the subducted lithosphere. Remnants of the stretched crust of the western plate could be passively transported in the eastern margin of the back-arc basin, and laterally associated with the upper crustal slices.

The decollements related to frontal accretion and detachments related to back-arc extension are consequently separated and independent (Fig. 4). Their sense of motion is opposite to that of gravity gliding from an asthenospheric high. Note in Fig. 4 that extension is the product of the relative westward motion of the abandoned upper slices of crust relative to the eastward flowing asthenospheric mantle and contemporaneously, in the highest elevation of the chain, to the uplift generated by the mantle wedging at the top of the subduction hinge. Variations in the amount of decollement at the base of the anomalous allochthonous crust will induce internal deformation, both extension and compression as a function of the relative westward velocity. This could explain observations of alternating episodes of extension and compression in back-arc settings, a sort of intraplate deformation, without any local plate subduction. Neogene-Quaternary compressive episodes in a back-arc setting have been proposed in the north-east Tyrrhenian Basin by Bernini *et al.* (1991). Such lateral variations in decollement activity at the base of the lithosphere appear to be significant in order to produce intraplate tectonics (especially compression) only below given thicknesses. Fig. 4 could be applied also to the northern or southern arms of the arc (Fig. 3), but in these cases the frontal compression is rather a transpression and the extension is a transtension with opposite displacements. Moreover, the amount of subduction decreases toward the arc margins and the corresponding frontal accretionary wedge and back-arc extension quantitatively decrease.

The flow of mantle into the wedge just at the top of the Benioff plane might be responsible for the greatest uplift of the internal parts of the chain where maximum extension is operating (Fig. 4).

The accretionary wedge is mainly formed by stacking the upper layers of

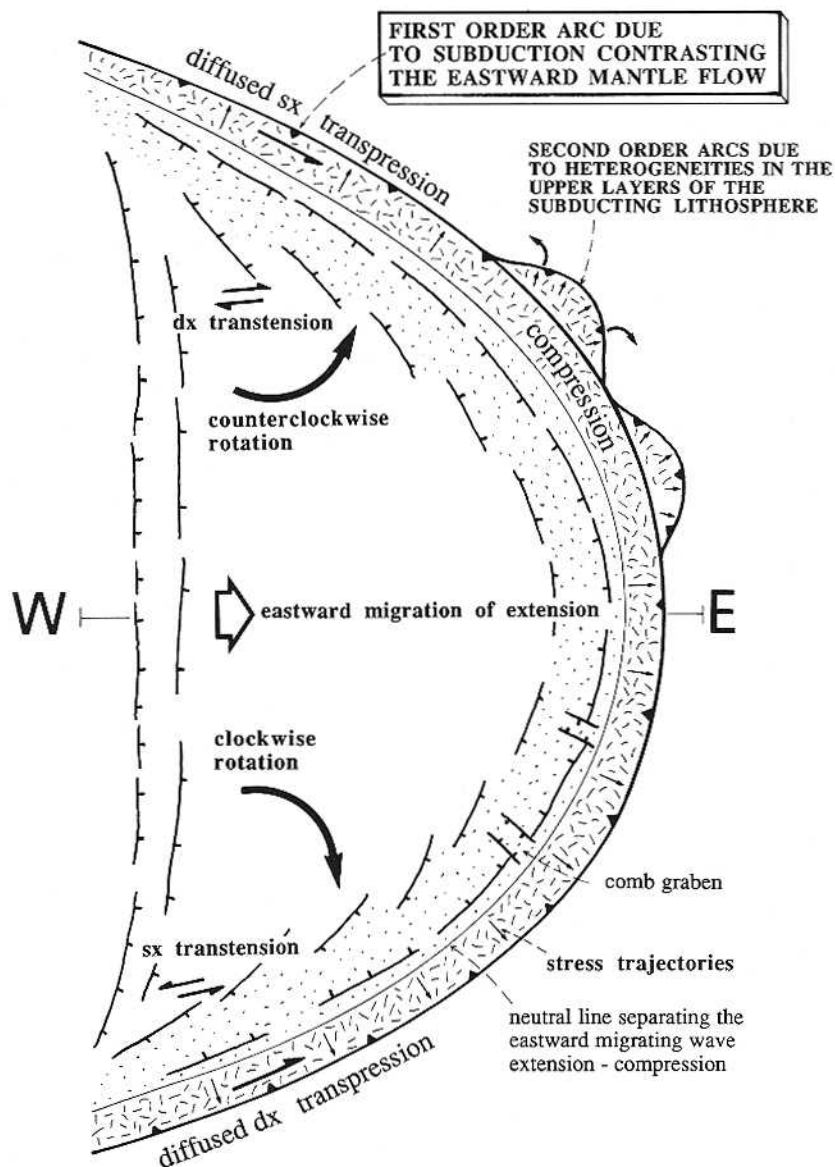


Fig. 3. Main superficial tectonic features due to a W-dipping subduction in a simplified map view. Back-arc basin progrades mainly eastward from a point in an arcuate shape. Frontal compression is limited to a narrow area (10–100 km) that progrades eastward. Note the coexistence at the arc margins of opposite shear (i.e. dextral transpression and sinistral transtension). See Fig. 4 for a schematic section of the system.

the eastern subducting lower plate (Fig. 4). Deep rocks may be involved in this type of accretionary wedge only if they were in a high structural and morphological position before the onset of the W-dipping subduction (i.e. the granulite rocks of Calabria which were emplaced during an earlier 'alpine' E-dipping subduction). Thrust belts related to subduction zones contrasting the mantle flow present an arcuate shape, revealing that they are an obsta-

cle to the lithospheric counterflow like a tree-trunk standing in a river. Arcuate shapes for thrust belts related to subduction zones that follow the mantle flow are more unusual (i.e. the Alps) and seem to be connected to the inherited Mesozoic fragmentation of the lithosphere which produced irregular continental margins able to produce 'indenter' collisions, such as the Laubscher 'Push-arc' (1988).

APPLICATIONS TO THE TYRRHENIAN SEA–APENNINES SYSTEM

The kinematics so far proposed could be considered as a working hypothesis for the Tyrrhenian–Apennines system. The Mediterranean has always proved a complicated challenge for investigators to unravel (Tapponnier, 1977; Rehault *et al.*, 1984; Stanley and Wezel, 1985; Mantovani *et al.*, 1987; Gealey, 1988; Dewey *et al.*, 1989). Recently, Doglioni *et al.* (1991) proposed an eastward–north-eastward directed mantle flow below a Mesozoic disrupted lithosphere as a possible explanation for the complicated Mediterranean geodynamics. This flow appears to be in agreement with recent satellite geodetic information (Smith *et al.*, 1990). The section shown as Fig. 4 is proposed as a picture of the Tyrrhenian–Apennines system in its southern sector. A point X in the western Apennines should stand above a new asthenospheric mantle: its original Moho has to be subducted. However, it should be noted that Fig. 4 is a model, and that the shape, depth and dip of the subducting lithosphere beneath the Apennines are extremely variable. Moreover, the model proposed as Fig. 2, if it exists, should probably be modified in the Tyrrhenian–Apennines system, where the subducting lithosphere is not regularly disrupted and shows an asymmetric arc.

The model of Fig. 3 (the main tectonic features in a map view of the back-arc basin–accretionary wedge system) is applied to the Tyrrhenian–Apennines system as Fig. 6. We note several features in common: counterclockwise rotations in the northern arm and stronger clockwise rotations in the shorter southern arm (Catalano *et al.* 1976). Counterclockwise rotations (20–60°, up to 90°) have been pointed out in the central-northern Apennines (i.e. Hirt and Lowrie, 1988), while strong clockwise rotations ranging between 90° and 140° have been found in the Sicilian thrust belt (Channell *et al.*, 1990) which represents the southern arm of the Apennines, characterized by dextral transpression inland (Ghisetti and Vezzani, 1982; Ghisetti *et al.*, 1982; Boccaletti *et al.*, 1984) and by sinistral transtension in the southwestern

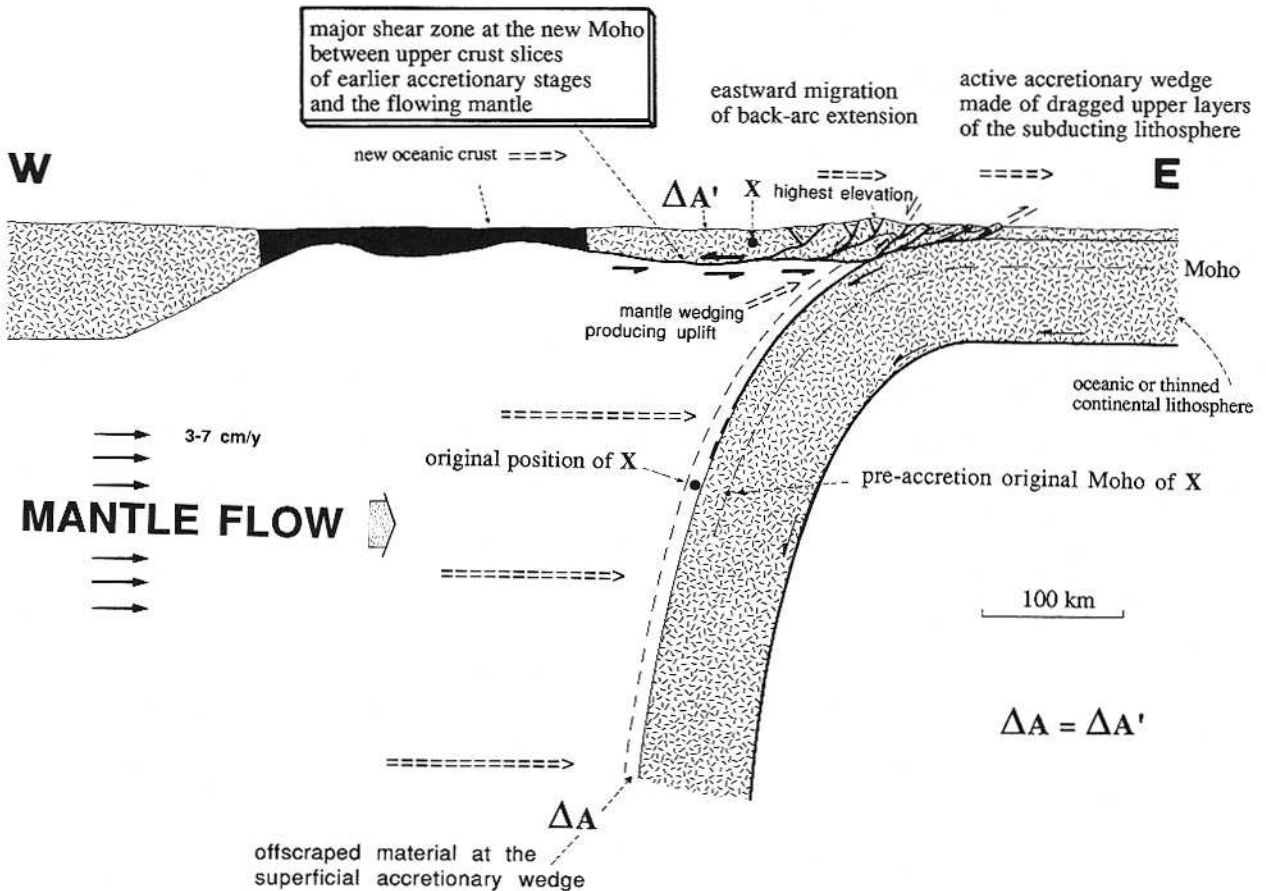


Fig. 4. Subductions contrasting the mantle flow (namely W-dipping) generate active frontal accretionary wedges which are later cut by the eastward propagation of back-arc extension. The amount of upper lithosphere dragged into the accretionary wedge should be equal to the amount of material composing the entire crustal slices floating on top of the eastward flowing mantle. Note the original position of X, its original Moho and the present relationship with the new mantle. The wedging of the mantle at the top of the Benioff plane could be responsible for the uplift of the highest internal zones of the belt. This figure is a section of the arc shown as Fig. 3. Ideally the deepest part of the subducted plate should be reconnected to the western plate. Consequently the mantle flow progressively compensates for the volume lost in the back-arc area. This section is a model and its shape should be adapted to particular regional cases through variations of thickness, composition, depth and dip of the subducting lithosphere, and with the amount of stretching in the back-arc which can very often be in a pre-oceanic crustal stage. Remnants of the stretched crust of the western plate could also be passively transported into the eastern margin of the back-arc basin.

Tyrrhenian sea (Catalano *et al.*, 1989; Torelli *et al.*, 1990; Tricart *et al.*, 1990). Extensional tectonics is forward prograding just behind the narrow compressive belt. Moreover lateral variations in the vector of shear between the eastward flowing new mantle and the allochthonous crust in the back-arc setting could provide a mechanism for localized inversions of graben in the Western Apennines–Eastern Tyrrhenian Sea.

Second-order arcs due to inherited Mesozoic horsts and grabens or facies changes can produce several fans (second-order arcs) with dispersion of the

maximum stress trajectories. The major undulations occur in the northern and southern parts of the arc, at the intersection with inherited N–S trending features, i.e. the big undulation of the Ionian Sea at the Iblean Plateau–Malta escarpment intersection, or the Adventure Bank, etc. Similar undulations occur in the buried northern Apenninic chain along the Po Plain (Pieri and Groppi, 1981; Castellarin *et al.*, 1985). Comb grabens, perpendicular to the belt seem to occur in Calabria. Sinistral transtension is present in the Sardinia Channel while dextral transpression is

operating inland in Sicily.

For the Tyrrhenian Sea (Scandone, 1980; Calcagnile *et al.*, 1981; Moussat *et al.*, 1986a,b; Kastens *et al.*, 1988; Sartori *et al.*, 1989) the Tortonian onset of extension postdates the Burdigalian collision of Sardinia/Calabria with the continental margin of Adria. The extension is therefore superimposed on an arc/continent collision zone (Scandone, 1980; Zitellini *et al.*, 1986; Carmignani and Kligfield, 1990). Throughout the Apennines (Elter *et al.*, 1975) the eastward migrating extension is coeval with compression in adjacent thrust-fold belts to

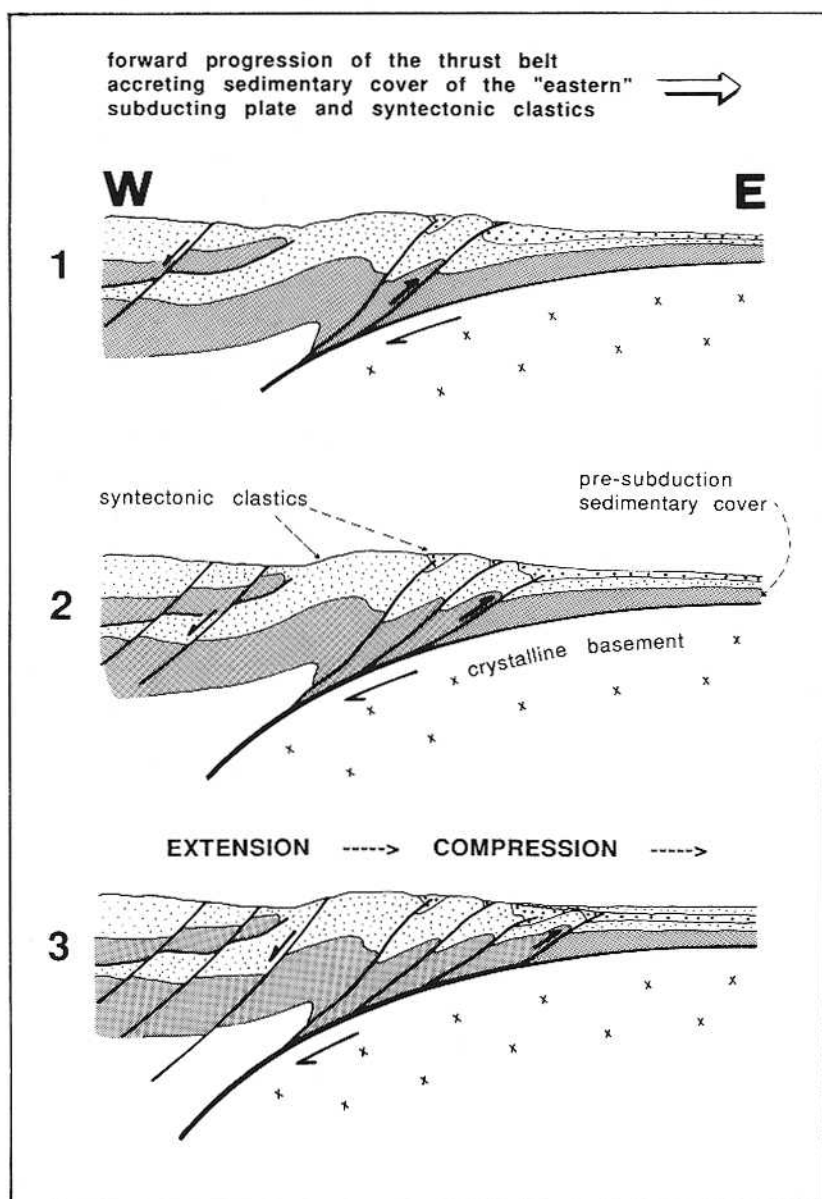


Fig. 5. Schematic progradation toward the foreland of the compressional and extensional wave in the W-dipping subduction-related thrust belt. The area of active compression is very narrow (a few tens of km) where the upper layers (usually the only sedimentary cover) of the subducting plate are scraped. The coeval eastward migration of the back-arc extension continuously cross-cuts the abandoned thrust sheets. Note the basement monocline which is connected to the subduction hinge. The biggest depressions of the foredeep are usually located laterally or behind the front of the thrusts. Accretionary wedges associated with W-dipping subductions show low structural and morphological elevations and pronounced foredeeps (i.e. W-Pacific accretionary wedges, Barbados, Apennines, Carpathians), in contrast with those accretionary wedges generated by E-dipping subductions.

the east (Malinverno and Ryan, 1986; Laubscher, 1988; Lavecchia, 1988). The Mesozoic extension provided a subdivision in the Tethys realm (Bernoulli and Lemoine, 1980; Dercourt *et al.*, 1986; Lemoine *et al.*, 1987; Ziegler, 1988; Bo-

riani *et al.*, 1989) of areas with different lithospheric thicknesses (Calcagnile and Panza, 1981), a key factor in controlling the amount and type of subduction in later times. The lack of easily subductable lithosphere beneath the central

northern Apennines and Sicily confine the region of oceanic rifting and maximum extension to the Tyrrhenian Sea, giving rise to a sinistral transtension at its southern margin and dextral transpression in the Sicilian thrust belt. The eastward migration of rifting is apparent from the Ligurian/Balearic basins to the Tyrrhenian Sea, but there is a clear eastward migration of rifting in the Tyrrhenian itself, from Tortonian ages in the western part to Plio-Pleistocene in the east (Finetti and Del Ben, 1986). Similarly, continental rifting and related magmatism in Tuscany show an eastward migration. The extension westwards of the Apennines thrust belt may be a consequence of the obstacle to the eastward (northeastward) mantle flow produced by the W-dipping lithospheric subduction (Fig. 6). The obstacle constitutes a more effective anchor in the Tyrrhenian/Calabrian region, where a well defined lithospheric slab is present deeper than 500 km, with respect to the central-northern Apennines where a more limited subduction of continental lithosphere has occurred. The differences in composition and thickness of the Apennines' subducting slab are also recorded by the periTyrrhenian magmatism (Barberi *et al.*, 1974; Locardi, 1984; Beccaluva *et al.*, 1989; 1991; Serri, 1990) and by the present seismicity (Console *et al.*, 1989). The topographic load of the Apennines has been shown to be insufficient to explain the deepening of the foreland (Royden *et al.*, 1987; Moretti and Royden, 1988). Royden and Karner (1984) obtained the same conclusions in the Carpathians foredeep (Royden and Horvath, 1988) where subduction is also W-dipping. The requested additional force that has been interpreted as an already subducted slab could be also the mark of the mantle flow.

The Apenninic accretionary wedge (Treves, 1984) is disrupted by extensional tectonics and has mainly been formed by the stacking of the Apulian sedimentary cover (Mostardini and Merlini, 1986) without affecting deep structural levels, which is in agreement with the kinematic model proposed in Figs 4 and 5. This should result because the base plate (Apulia) detachment is folded and subducted itself, and not connected to the surface, inhibiting the uplift of deep seated rocks in active W-

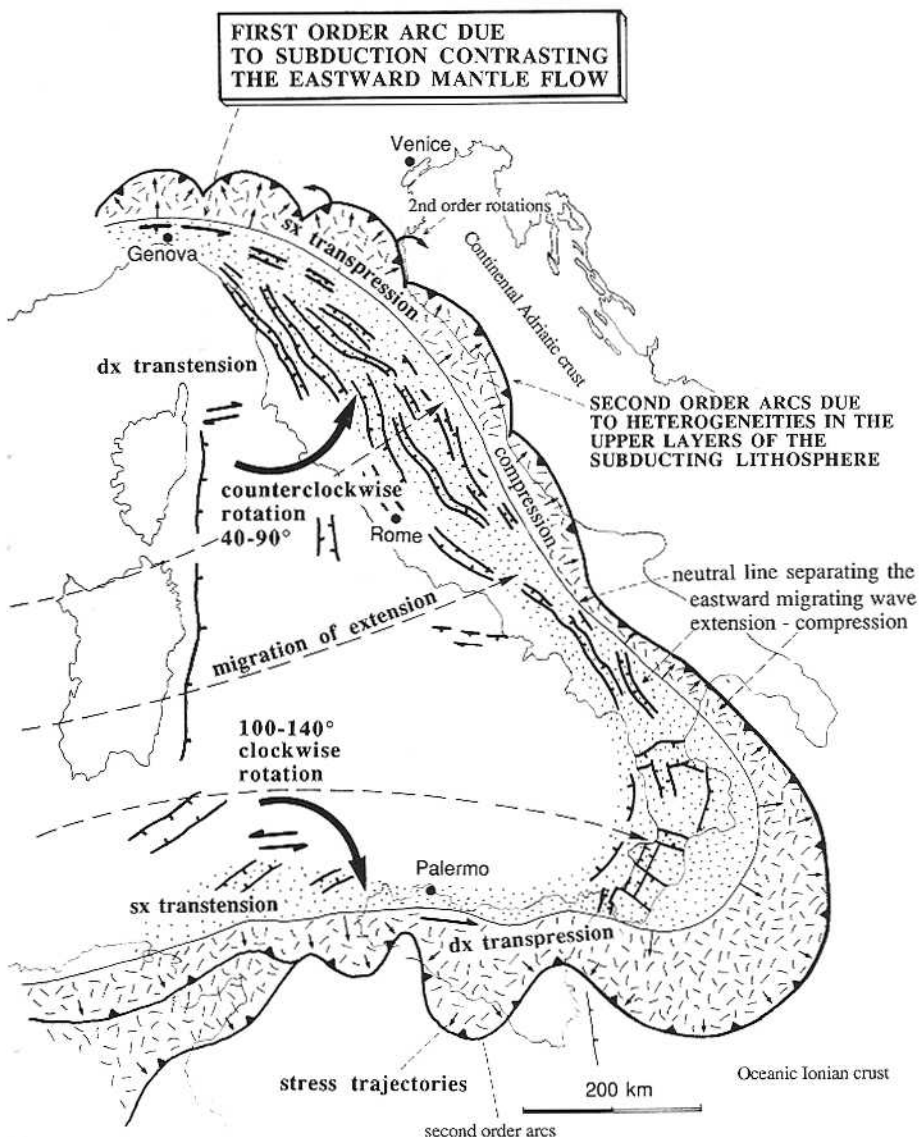


Fig. 6. Application to the Tyrrhenian–Apennines system of the kinematic constraints proposed as Figs 3 and 4. Note that the main asymmetric shape of the arc is controlled by the composition and thickness of the subducting lithosphere: the Ionian part is thinner and oceanic, in other words more subductable with respect to the thicker and more continental Adriatic crust, Fig. 7. Second-order arcs occur in response to inherited downgoing horsts and grabens or facies changes in the upper layers of the crust. Note that they are more pronounced in the northern and southern parts of the arc (Po plain and Sicily) because compression is almost parallel to the N–S trend of the Mesozoic horsts and grabens (i.e. Iblean plateau, Adventure Bank, etc.). Rotations along second-order arcs at transpressive zones may enhance or decrease the rotations (clockwise or counterclockwise) due to the main arc. Note the main directions of maximum stress which are regularly perpendicular to the main arc. Beneath the central western Apennines there should be a new eastward flowing mantle according to Fig. 4, and the main uplifted areas of the Italian peninsula should stand above the mantle wedge.

dipping subductions (Fig. 1).

Following the former general considerations about W-dipping subductions, the western Apennines should float above a new mantle which replaced the subducted lithosphere (Figs 1 and 4). This seems to be in agreement with recent data concerning the Moho in the Apennines (Locardi and Nicolich, 1990). Moreover heat flow data show a strong positive thermal anomaly beneath the western Apennines and the Tyrrhenian Sea (Mongelli *et al.*, 1988) which may be interpreted as a dramatic and diffused mantle wedging at the subduction hinge.

Forward migration of the foredeep in the Neogene evolution of the Apennines has been pointed out several times (Boccaletti *et al.*, 1974; Ricci Lucchi, 1986; Pescatore and Senatore, 1986; Vai, 1987) and this may be the result of the retreat of the subduction hinge due to the eastward mantle push proposed as Fig. 1. An application to the Apenninic foredeep could be the eastward migration of the Macigno, Cervarola and Marnoso Arenacea basins.

It has been pointed out that extension in the Apennines is small compared with the amount of shortening (i.e. Bally *et al.*, 1986). Compression and extension are two products of a common geodynamic environment but, as it is possible to observe in Fig. 4, their relative decollement planes are clearly separated and they can have different amounts of motion: the compression is a direct function of the amount of subduction, but while extension cross-cuts earlier thrust sheets, its displacement is not directly correlatable with the amount of subduction. Note in Fig. 4 that extension is the product of the relative westward motion of the abandoned upper slices of crust relative to the eastward flowing asthenospheric mantle and contemporaneously, in the highest elevation of the chain, to the uplift generated by the mantle wedging at the top of the subduction hinge. Note in Fig. 1 as the empty space left by the subducted lithosphere is replaced by the mantle asthenosphere, there is no possibility for the survival of superficial reference points in both sides of the back-arc basin because the eastern margin is subducted. Consequently, once oceanic lithosphere outcrops in the back-arc, separating the continental margins, the amount of extension is a function of

the retreat of the subduction hinge, mantle push in the upper wedge of the subduction hinge and the amount of decollement at the new shear zone at the base of the upper crustal slices, all factors which may be strongly different from the amount of subduction. Moreover, if the convergence rate between eastern and western plates is a positive value ($Dv > 0$), the compression at the frontal accretionary wedge may be greater with respect to the back-arc of extension. Note also in Figs 1 and 4 that horizontal shear (Giardini and Woodhouse, 1986) and compressive regimes may develop in depth along the subducting lithosphere, at the same time a superficial (0–30 km) extension. This could explain the present Apenninic seismicity.

DISCUSSION

Several models have been proposed to explain the opening of the Tyrrhenian Sea. They can be separated into two main groups: (1) a back-arc basin associated with subduction and (2) an asthenospheric plume without subduction. For models of subduction beneath the Apennines see, for instance, Caputo *et al.* (1970), Gasparini *et al.* (1982), Suhadolc and Panza (1988), Giardini and Velonà (1991), Panza and Prozorov (1991). Van Bemmelen (1972) proposed a mantle diapir from which gravity gliding was responsible for the Apenninic compression to the east without subduction. However, the kinematics indicated in Fig. 4 show motion of the mantle relative to the crustal slices which is opposite to that necessary for gravity gliding. Moreover, the mantle diapir model cannot explain why extension and compression are limited only to the east of the mantle high all over the Earth. Finally recent seismological and tomographic studies of Italy (Spakman, 1989) confirm the presence of subduction beneath the Apennines (Suhadolc and Panza, 1989; Panza *et al.*, 1990; Giardini and Velonà, 1991) also in their northern sector (Cattaneo and Eva, 1990a,b; Amato and Alessandrini, 1991).

The Italian peninsula and Sicily are mainly formed by an asymmetric disrupted thrust belt (the Apennines) surrounding a corresponding asymmetric back-arc basin (Fig. 6). We note, how-

ever, that the present Apenninic ridge is mainly an extensional regime, while compression is confined to a frontal zone below sea-level (Figs 6 and 4). The Italian asymmetry may be interpreted as the result of an irregular subduction beneath the northern and southern Apennines (Fig. 7): in fact the Adriatic lithosphere (Panza, 1984; Rapolla, 1986; Sabadini and Spada, 1988; Suhadolc and Panza, 1989) is continental in origin and thicker than the Ionian lithosphere which might be oceanic in origin (de Voogd *et al.*, 1991), and possibly a relict of the Mesozoic Tethys, although this is not universally accepted (Farrugia and Panza, 1981; Calcagnile *et al.*, 1982). For a review and a discussion of the crustal and lithospheric characters of the area in the Mediterranean context see, for instance, Cloetingh *et al.* (1979), Calcagnile and Panza (1981), Panza *et al.* (1980, 1982), (1990), Nicolich (1989) and Cassins *et al.* (1990). We could interpret the northward decreasing extension of the Tyrrhenian Basin to be a function of the northward decreasing capability of subducting the thicker northern Adriatic continental litho-

sphere. The main transition is between parallels 40° and 41°, along the Taranto–Naples alignment, separating two major magmatic provinces. The differences in composition and thickness of the Apenninic subducting slab are in fact also recorded by the peri-Tyrrhenian magmatism (Locardi, 1984; 1988; Beccaluva *et al.*, 1989; Serri, 1990) and by the present seismicity (Console *et al.*, 1989). The Apennines result in a greater shortening in the Calabrian arc and a corresponding maximum back-arc extension in the southern Tyrrhenian sea (Malinverno and Ryan, 1986). In the central-northern Apennines (Lavecchia *et al.*, 1984; 1988) shortening shows a linear northward decrease from 170 to 35 km according to Bally *et al.* (1986); extension in the Tyrrhenian Sea decreases linearly northward as well (Zitellini *et al.*, 1986), confirming that extension and compression are genetically linked. In summary the present shape of Italy could reflect an asymmetric Late Miocene–Quaternary subduction controlled by the inherited Mesozoic lateral thickness and composition variations of the Adriatic–Ionian lithosphere

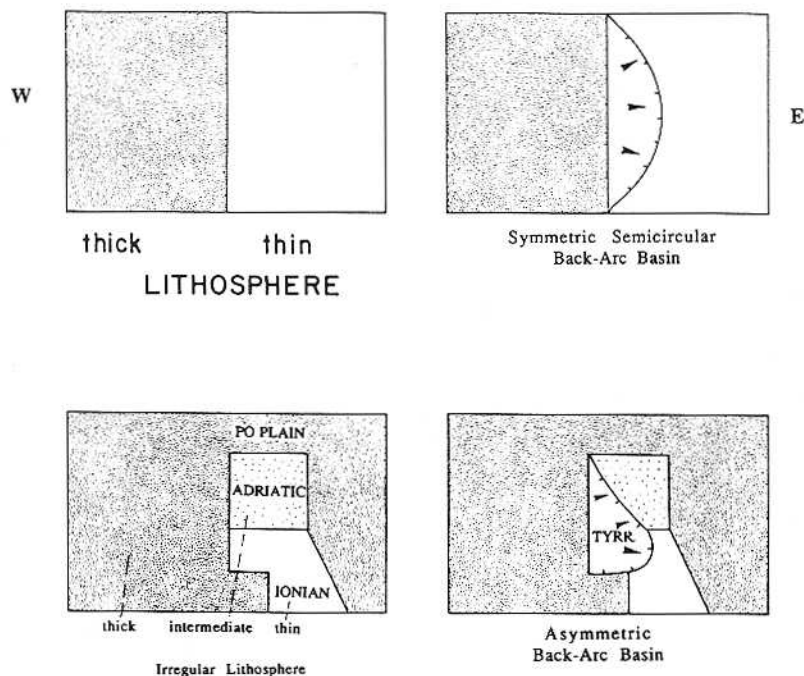


Fig. 7. A subduction contrasting the mantle flow (W- or SW-dipping) between two plates separated by an originally linear margin will produce a trench and an eastward-migrating back-arc basin with semicircular symmetric shape. If lateral heterogeneities are also introduced along the subduction margin (i.e. with intermediate thickness, as in the Adriatic plate) an asymmetric system like the Italian peninsula and the Tyrrhenian Sea will result.

(Fig. 7).

One question arises from the model proposed on this paper: why is there extension in the Aegean Sea if this is associated with a NE-dipping subduction? The Aegean sea is generally considered a back-arc basin and in this model it would represent an exception because it is linked to an opposite type of subduction in the Hellenic trench (Le Pichon and Angelier, 1979). However, the Aegean sea is characterized by a relatively thick crust (20–25 km) according to Makris (1978), in spite of a long standing subduction, probably active at least since Late Cretaceous times (Meulenkamp *et al.*, 1988). Extension and associated magmatism are south-southwest migrating (Jackson and McKenzie, 1988). 'Normal' back-arc basins are associated with west-dipping subductions, and they usually open very fast (10–20 myr). Moreover they are characterized by oceanization and eastward migration of extension and related magmatism, features directly surrounded by a frontal accretionary wedge. Instead the accretionary wedge of the Hellenic subduction is the southeastern prolongation of the Dinaric thrust belt, where no back-arc extension occurs. For these main reasons Doglioni *et al.* (1991) tried to interpret the Aegean sea as a major sinistral transtension in terms of relative differences in base-plate detachment between Turkey and Greece within the frame of the global tectonic flow, rather than as a classic back-arc basin.

CONCLUSIONS

In conclusion the main factors controlling the back-arc basin–accretionary wedge system are as follows: (1) presence of a subduction zone contrary to the 'eastward' mantle flow which is initiated as a result of the presence of a thinner lithosphere to the east; (2) distribution of asthenospheric and lithospheric viscosity anisotropies; (3) convergence rate between the two plates ≥ 0 ; (4) thickness gradient between the two plates $\neq 1$; (5) compositional gradient between the two plates (i.e. continental and oceanic contrast); (6) longitudinal heterogeneities; (7) sediment supply in the foredeep. The mantle wedging at the top of the subduction hinge appears to be responsible

for the extension and uplift of the main topographic relief in the subduction hanging wall (i.e. Apennines).

Back-arc basin–accretionary wedge systems usually have a short life (10–40 myr). Theoretically, when a W-dipping subduction reaches a locked position (i.e. no more subduction of the eastern plate is possible due to the arrival of thick continental crust at the trench) the greatest thickness gradient enabling subduction should shift to the margins of the back-arc basin, producing either a new E-dipping subduction at the eastern margin of the back-arc basin, which will close the back-arc crust (Fig. 8), or a W-dipping subduction at the western margin of the back-arc basin. These factors could induce a sort of yo-yo in these kinds of geodynamic environments. Therefore the rheological characteristics

of the lithosphere (Ranalli and Murphy, 1989) and its lateral thickness variations seem to be crucial arguments in controlling subductions. It is only in W-dipping subductions that lateral heterogeneities of thickness and composition of the lithosphere develop due to the formation of the new and thin oceanic lithosphere in the back-arc basin. This enables the formation of new subductions at the western (W-dipping) or at the eastern (E-dipping) margins of the basin. Once the back-arc basin is consumed and closed by an E-dipping subduction, and if a thinner oceanic lithosphere (i.e. Eurasia–W-Pacific) exists to the east, a new W-dipping subduction may develop. This could also help us to understand why W-dipping subductions have much shorter life with respect to E-dipping subduc-

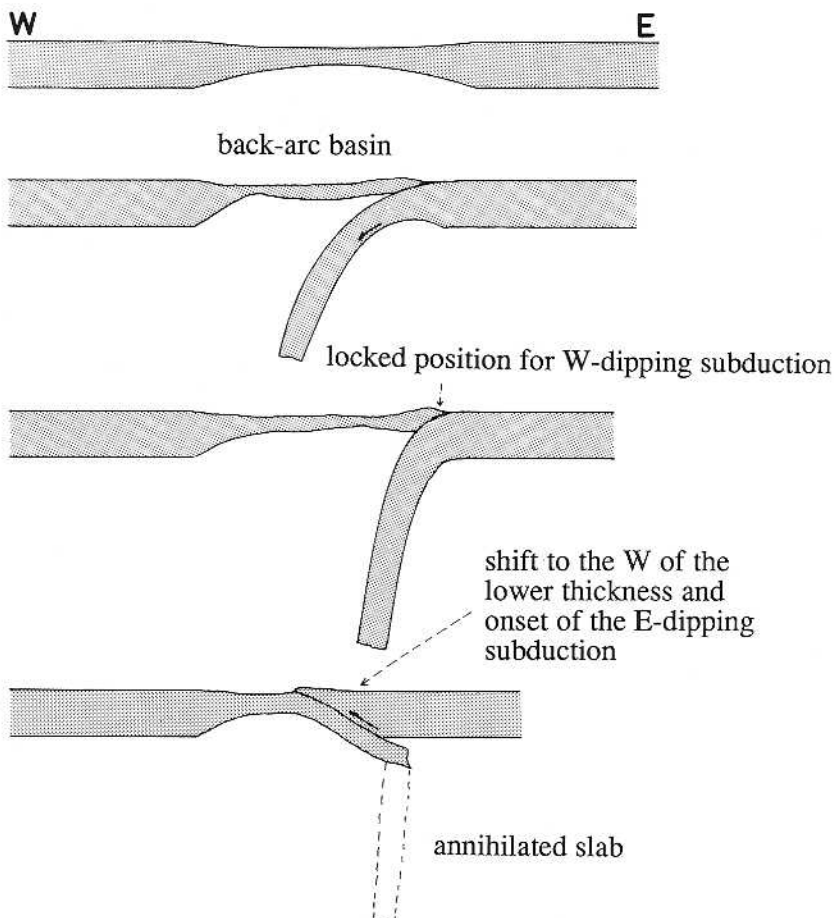


Fig. 8. W-dipping subduction may occur when a thinner lithosphere is present to the west. When the subduction arrives at a locked position (i.e. continental crust is too thick to the east) the subduction may shift and become E-dipping, because the back-arc crust is relatively thinner and enables opposite subduction. In this case, the oceanic crust of the back-arc may be obducted at later collisional stages.

tions (i.e. American Cordillera).

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