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Geometry and kinematics of extension in Alpine Corsica

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ABSTRACT

The geometry of the most recent deformation in Alpine Corsica is discussed in terms of reactivation of thrusts as normal faults and crustal extension, following crustal thickening in late Cretaceous and Eocene time. A cross section interpreted in terms of obduction in previous works is shown here to be a result of ductile and brittle extension in late Oligocene and Early Miocene time. This new interpretation is based on field observations of the brittle and ductile structures and their relations to the metamorphic history in the Tenda–col de Teghime and Centuri regions, as well as additional observations in other parts of Alpine Corsica. The following geological features are observed: (1) The recent deformation was partly achieved during a top-to-the-east ductile shear close to the brittle–ductile transition and was later superimposed by brittle shear indicating a transition in time from ductile to brittle regime. (2) Extensional brittle structures in the Early Miocene Saint Florent limestone and sense of tilt are compatible with the eastward sense of shear observed in the ductile rocks. (3) The movement along major "thrust" contacts is associated with retrograde metamorphism which overprinted the early high-P–low-T paragenesis at less severe P–T conditions. They also bring tectonic units with contrasted metamorphic evolutions into close contacts. (4) There is a regional correlation between retromorphosis and recent deformation since the high-P–low-T paragenesis are better preserved in southern of Alpine Corsica where the recent deformation is less pervasive. (5) Highly non-coaxial deformation is localized along east-dipping shear zones close to brittle normal faults which bounds tilted Miocene basins; in between the geometry is more symmetric and the finite strain therefore more coaxial. (6) Late extensional brittle structures are observed at many sites in the metamorphic rocks. In the present paper we discussed these first-order observations and describe the geometry of crustal extension in Alpine Corsica. We analyze the progressive formation of a crustal-scale tilted block in Cap Corse and propose that the normal faults are localized by asymmetric boudinage of the crust. The asymmetry of this crustal-scale boudinage is controlled by the position of early thrust planes.

1. Introduction

Reworking of compressional structures during large-scale extension has been described in the Basin and Range province [1–4] and the Aegean Sea [5] where very large extension has occurred shortly after the end of compression. However, in many cases the initial compressional structures have been highly reworked and it is difficult to decipher the influence of the pre-existing compressional geometry on the mechanism of the later extension. Deep seismic profiling in the Caledonian orogen of northern Europe shows that early thrusts were reactivated as normal faults which control asymmetric sedimentary basins [6,7]. Does extension rework pre-existing flat-lying discontinuities and how does it rework them? Can asymmetry of extension (e.g. simple shear model of extension) be controlled in some cases by such pre-existing discontinuities?

Alpine Corsica is a part of the Alps where compression ceased in Late Oligocene time when it was isolated from the main Alpine belt by the extension and the opening of the Liguro–Provençal basin and the Tyrrhenian sea. Alpine Corsica forms a metamorphic core complex superimposed on the previous Alpine compressional orogen and it is an example where field observations can be made on the reactivation of thrust faults during ductile extension [8]. Deep crustal hot material such as migmatites are not observed in the core complex as opposed to Naxos for instance [5,9], but it is possible to study there extensional deformation in the upper part of the ductile crust and its evolution through time during crustal thinning. Furthermore the distribution of deep ductile struc-

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tures with respect to more superficial ones is clear there. We describe in this paper the geometry of the Oligo-Miocene extension. We show that the recent ductile deformation has a regional distribution which can only be interpreted in terms of extension: domains with highly non-coaxial strain are localized close to the most recent brittle normal faults which bound the Miocene basins, and the deformation is more coaxial in between; this suggests that the formation of the tilted blocks and normal faults corresponds to asymmetric boudinage of the crust.

2. Regional setting and previous studies

The ductile deformation in the Schistes Lustrés nappe of alpine Corsica (Fig. 1) as well as in the autochthonous basement has been interpreted in terms of obduction and collision under high-P–low-T conditions. Mattauer et al. [10] and Warburton [11] proposed that ductile structures observed along a representative cross section between the Tenda massif and Bastia (Fig. 1) are related to the obduction toward the west of oceanic material (Schistes Lustrés) on the continental margin of Europe (Tenda massif). The most remarkable features are a stretching lineation and sheath folds which strike consistently E–W [12,13]. Jolivet et al. [8] proposed instead that two stages can be recognized along the same cross section: an early compressive westward shear stage contemporaneous with the high-P–low-T metamorphism, and a younger eastward shear during crustal extension, contemporaneous with the retrograde metamorphism which began at greenschist conditions and terminated under subsurface conditions. A major thrust plane of Mattauer et al. [10] is shown to be reactivated as a detachment fault in late Oligocene and early Miocene time (Fig. 2). The east-vergent shear event was associated with retrogression in the greenschist facies whose age lies between 30 and 40 Ma [14]. Middle Eocene sediments were affected by high-P–low-T metamorphism and compressional deformation [15]. Phengites in the east-Tenda shear zone yielded ages of 32 Ma corresponding this eastward shear [16]. The Early Miocene basal conglomerate of the Saint Florent limestone is cut by east-dipping normal faults which are the youngest evidences of eastward shear. Eastward ductile shear thus began during the Oligocene and ended during the Early Miocene. The early Miocene Saint Florent limestone has been tilted above the detachment. The extensional ductile deformation is distributed throughout the nappe stack, but is predominantly localized along the early thrust contacts. Extension following crustal thickening in Corsica can also explain the abnormal juxtaposition of poorly metamorphosed rocks of the Balagne nappe directly above the highly metamorphosed rocks of the Schistes Lustrés nappe as is typical to metamorphic core complexes.

3. Stacked tectonic units

3.1. Southern Cap Corse

A cross section from the Tenda massif to Bastia (Fig. 2) shows the major geological characteristics of Alpine Corsica. The nappe pile is folded into broad anticlines (Tenda and Cap Corse–Castagniccia) and synclines (Nebbio and Balagne) and comprises:

The early Miocene Saint Florent limestone which rests unconformably upon the underlying alpine units [17,18]. Except at its base the limestone is almost non-deformed and shows an average tilt toward the west.

The Balagne–Nebbio nappe [18–21] (Balagne nappe in the following). It is a complex association of Mesozoic ophiolitic rocks (pillow lavas and radiolarites) and terrigenous deposits of probable Eocene age [16,22]. It lies upon the autochthonous basement of western Corsica and its Eocene cover (Balagne nappe), as well as upon the metamorphosed Schistes Lustrés (Nebbio nappe and the Macinaggio small klippes) with a sharp contact. It shows neither pervasive ductile deformation nor intense metamorphism.

The Schistes Lustrés nappe [22] made of metamorphosed oceanic rocks consists of the following rock units [10,23–26]: (a) Gabbro and serpentinite forming massive lenses showing strong gradient of deformation toward upper and lower contacts; (b) para- and orthogneiss of continental affinity with a sedimentary cover of a probable Mesozoic age (Sera di Pigno–Oletta–Farinole). The original lithology is similar to that of the para-autochthonous Tenda massif; (c) a first unit of calc-schists; (d) basic rocks which contain relics

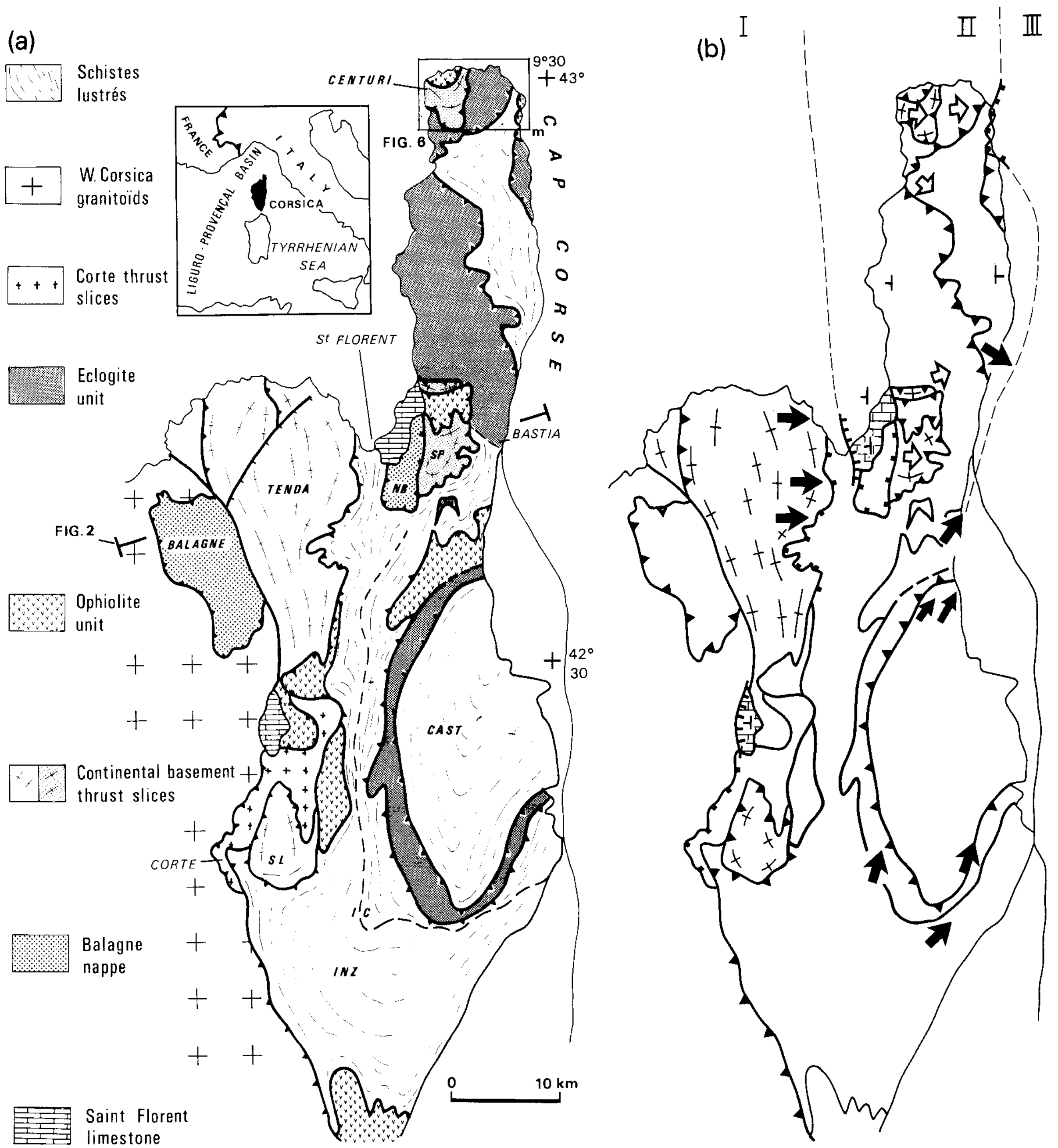

Fig. 1. Geological map of Alpine Corsica (a) (m = Macinagio), and sense of shear during the late stage (b). Filled arrows = noncoaxial eastward shear, open arrows = noncoaxial eastward shear and pure shear).

eclogites; and (e) a second unit of calc-schists which forms the core of the Castagniccia anticline.

The entire Schistes Lustrés nappe has been metamorphosed under high-P–low-T conditions with abundant characteristic minerals such as glaucophane, carpholite, jadeite and lawsonite [8,11,23,25–28,30–32] but the basic rocks and some orthogneiss intercalated in the calc-schists show more severe P–T conditions typical to the eclogite facies [25,27,31].

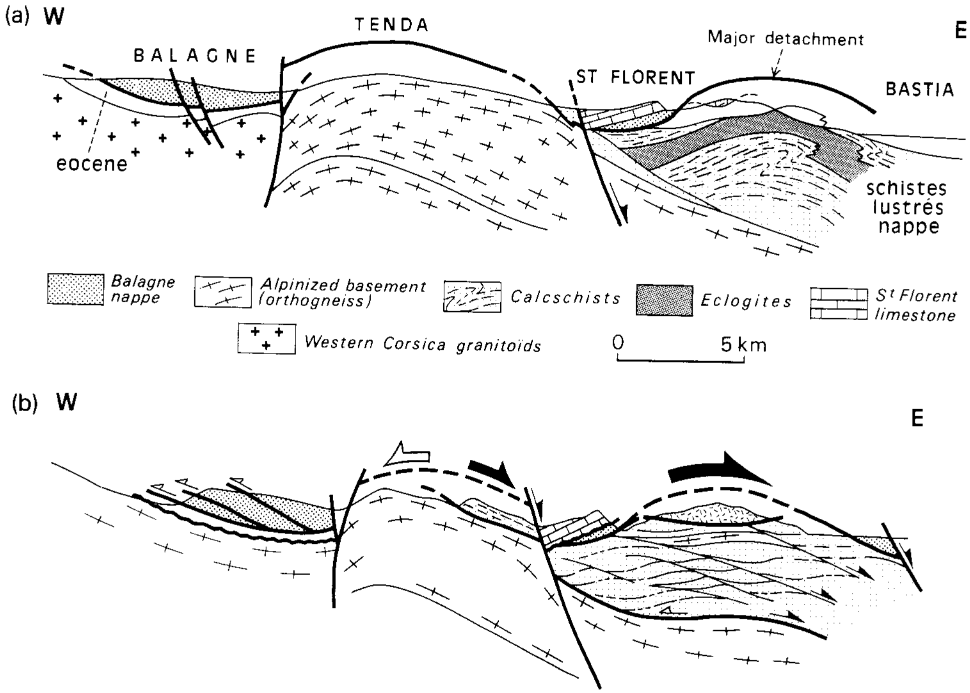

Fig. 2. (a) Synthetic E–W cross section at the latitude of Bastia with indications of the two successive tectonic episodes, compression and extension, modified after Jolivet et al. [8]. (b) Idealized cross section based on (a) with the geometry of the Schistes Lustrés nappe deduced from the observations described in the paper.

The para-autochthonous Tenda massif which is a part of western Corsica displaced westwards and deformed under intermediate pressure conditions [28,29]. It contains a Paleozoic continental basement with intrusive granodiorites and its Mesozoic sedimentary cover (Santo Pietro di Tenda sequence, quartzites and marbles).

Except for the Miocene limestone and the Balagne nappe, all units show a penetrative ductile deformation with strong gradients toward the contacts between units. The eastern boundary of the Tenda massif shows progressive transition from undeformed granodiorite with static crystallization of crossite to highly deformed gneisses with synkinematic minerals. This section was described by Mattauer et al. [10] as the result of a continuum of deformation during the westward obduction of the Schistes Lustrés.

3.2. Northernmost Cap Corse

The geology is similar (Figs. 3 and 4) with lenses of alpinized orthogneiss which contains good strain markers. Previous studies of the deformation in this part of the island [32] concluded that a regional non-coaxial eastward shear affected the base of the orthogneiss lense. In Centuri Malavieille [33] described eastward sense of shear opposite to that described near Bastia and therefore proposed a complex thrust model. Previous studies of the metamorphic evolution showed that this region also underwent high-P-low-T metamorphism [26,30] even though retrogression in the greenschist facies is more pervasive than in the south and the high-P minerals are preserved mostly in less deformed parts of the structure. From top to base one can recognize:

Small klippes of the Balagne nappe along the eastern coast [19,20] at Macinaggio. They contain unmetamorphosed sedimentary rocks which range from carbonate flysch-type deposits to sedimentary breccia and very coarse conglomerate.

The Monte Maggiore serpentinites and peridotites [24], highly foliated near the base and poorly deformed at the top. They are equivalent to the upper unit of the Schistes Lustrés nappe described above.

The Centuri gneiss which form a lense on the western limb of the antiform. They include both

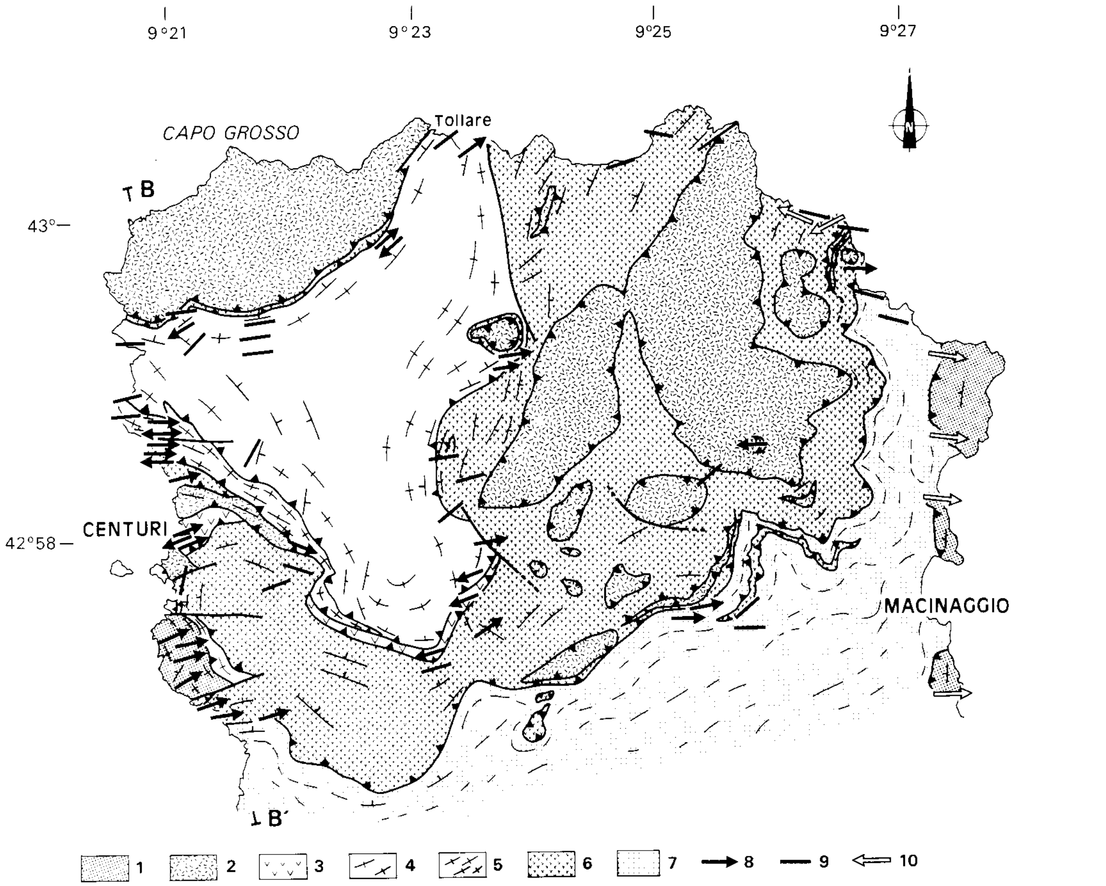

Fig. 3. Structural map of the northern Cap Corse. Geological contours are after Daniel et al. (in prep.), Malavieille [37] and Guillou [56]. **1** = Balagne nappe; **2** = serpentinite; **3** = gabbro; **4**, **5** = orthogneiss; **6** = greenschist with high pressure relicts; **7** = calcschists; **8**, **9** = strain in the metamorphic rocks (**8** = stretching lineations and sense of shear, **9** = stretching lineations with unknown sense of shear); **10** = brittle sense of shear in the non-metamorphic rocks.

acidic and basic gneiss which are unevenly deformed and are similar to the Serra di Pigno–Oletta orthogneiss.

A thick unit of greenschists, including metagabbros, metabasalts and serpentinite.

Calc-schists in the core of the antiform.

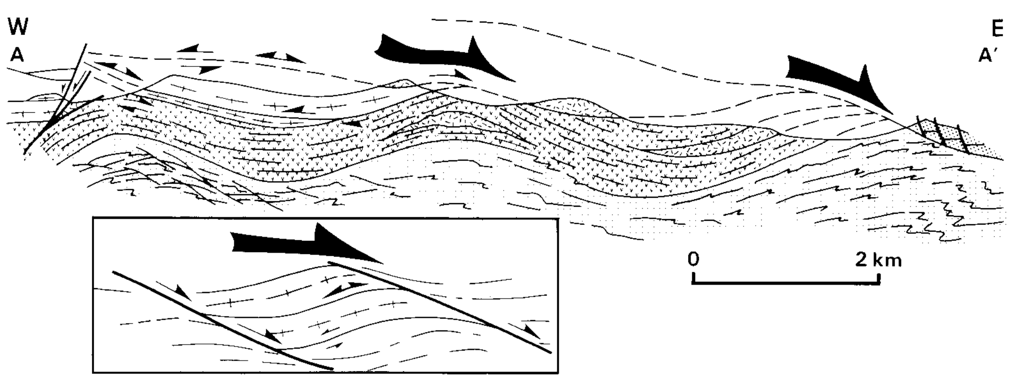

Fig. 4. Cross section near Centuri. Top: synthetic E–W cross section. Bottom: N–S cross section from the village of Centuri northward along the shore. Box: idealized geometry of an asymmetric boudin bounded by two east-dipping shear zones which model the orthogneiss lense of Centuri.

4. Evidences of ductile extension

We studied the deformation on a regional scale using simple shear sense criteria such as shear bands [34–36] or asymmetric pressure shadows [34,35,37]. No quantification of the finite strain was made. The attitude of the principal strain axes ($X > Y > Z$) was determined using measurements of stretching lineation (X) and foliation plane (XY). We investigated in details the symmetry of small-scale structures in the XZ plane, simply assuming that the more asymmetric the structure is, the more important was the simple shear component with respect to the pure shear. Our observations in various lithologies in the entire area show consistent eastward sense of shear. Near Farinole, the limestones show extensional brittle structures (Fig. 5) with east-dipping normal faults affecting only the base of the basin. These normal faults shown in Fig. 5 imply an eastward sense of shear at the base of the faulted blocks consistent with the sense of ductile shear and confirms the direct link between the ductile and brittle extension described in Jolivet et al. [8].

The most frequent ductile structures are oblique shear bands with a millimetre to kilometre scale (Fig. 6). They occur either as a single set of parallel surfaces showing the same sense of offset or as two conjugate sets. Following Berthé et al. [34] or Platt and Vissers [35] these structures were used as shear criteria: a single set has been interpreted as indicating a large component of simple shear and conjugate set, as indicating more coaxial strain with a flattening component. Recent experimental studies [36,38] confirm this interpretation of shear bands.

At the latitude of Bastia an E–W trending stretching lineation observed in all units is the most striking manifestation of this ductile deformation. It is however not the result of a single continuum of obduction but of, at least, two successive progressive phases: an obduction and crustal thickening stage and an extensional stage later. The ductile extensional deformation is predominantly localized along the major thrust contacts (for details see Jolivet et al. [8] and Fournier et al. [39]). The best example is the east-Tenda shear zone where almost all criteria indicate an eastward sense of shear at rather low-P metamorphic conditions [16] (Fig. 6). Evidence for the early westward shear is preserved only in the core of the massif far from the main shear zone. East-vergent shear planes are often parallel to an early strain slip cleavage described in [16] and were formed during and after the greenschist facies overprint [39]. The deformation evolved from a ductile to a more brittle toward the top of the shear zone, approaching the east-dipping normal fault which bounds the Saint Florent limestone to the west. The same is true for the Schistes Lustrés nappe where structures produced by the westward shear in high-P–low-T conditions are observed only in the core of more competent units (Fig. 7). Elsewhere the sense of shear is predominantly toward the east with however a larger component of pure shear shown by the coexistence of westward and eastward shear (both post dating high-P–low-T) within the most competent units. All contacts show breccia post-dating the ductile structures and flat-lying normal brittle faults are observed showing that the deformation evolves from ductile to brittle.

Highly non-coaxial strain is localized along the east-Tenda shear zone which we interpret as a flat-lying detachment. The Saint Florent limestone is bounded by a steeply east-dipping normal fault which must cut the detachment at depth given their respective attitudes. The westward tilt of the limestone is compatible with the dip of the normal fault and the eastward sense of shear along the detachment fault.

The major conclusion of this preliminary study is that extensional ductile deformation affected the whole region but is preferentially localized along the major thrust contacts (especially the east-Tenda shear zone) where it shows a large component of non-coaxial shear toward the east. In other places the deformation is more coaxial but with predominating eastward shear bands. The normal fault which bounds the asymmetric Miocene basin is located in the region of highly non-coaxial strain.

In Centuri region the Balagne nappe (Maccinagio) shows only brittle extensional structures, while the underlying units show normal faults which are superimposed on ductile structures (Fig. 5). Sedimentary rocks of this nappe are cut by normal faults on various scales which bound small tilted blocks (Fig. 5). The normal faults are predominantly inclined toward the east whereas strata

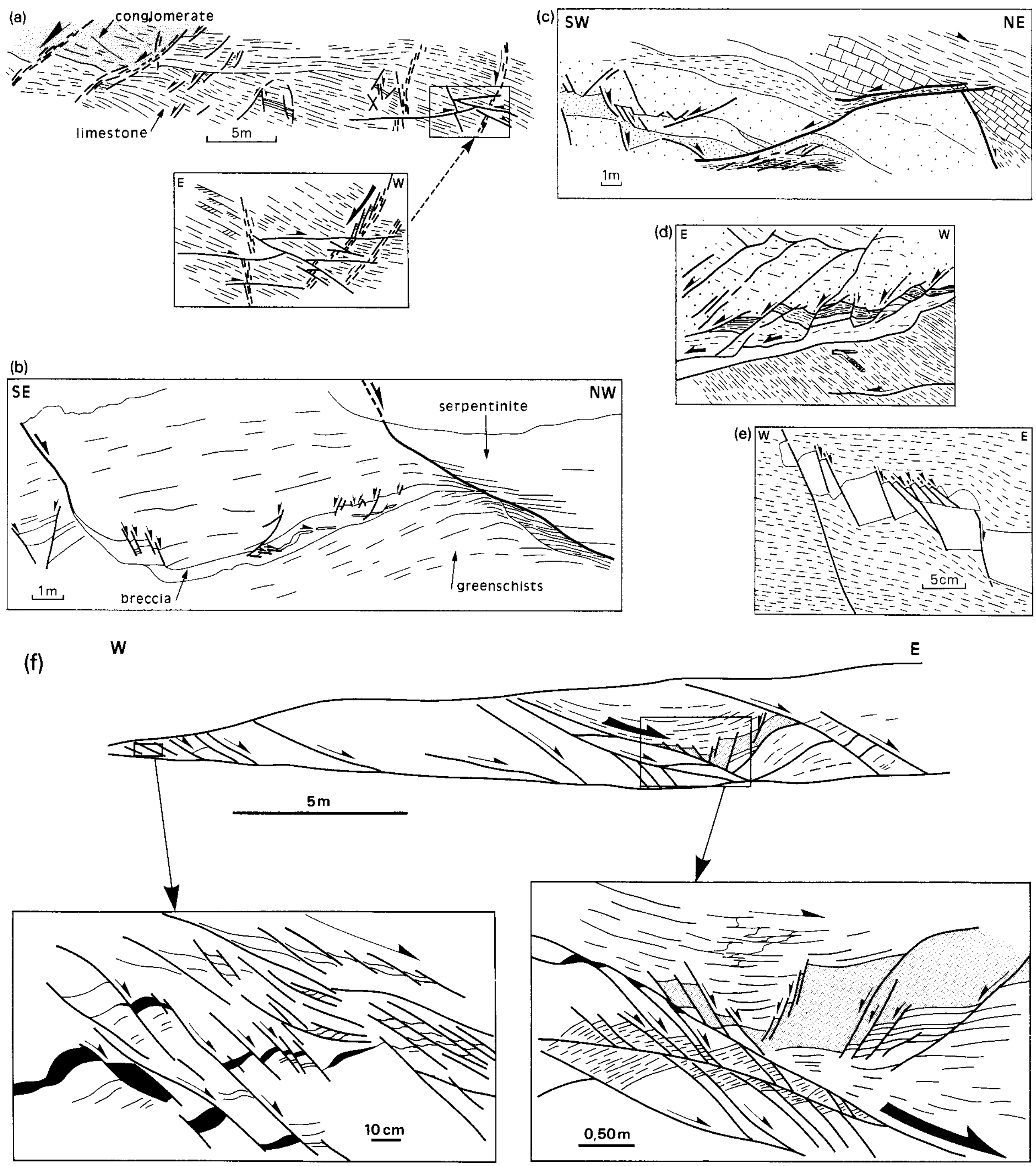

Fig. 5. Field examples of brittle extensional deformation. (a) Early Miocene Saint Florent limestone (Farinole); (b) Schistes Lustrés (Cap Corse); (c) Macinaggio klippe (Cap Corse); (d) basal contact of the Macinaggion klippe (Tamarone); (e) base of Saint Florent limestone; (f) Schistes Lustrés near the contact with western Corsica (San Quilico pass near Corte).

dip to the west. The basal contact of the nappe with the underlying calc-schists is a sharp and flat fault with a fault gouge a few tens of centimeters thick fault gouge (Fig. 5). Normal faults rooted in the décollement dip consistently eastward.

The underlying units are cut by N–S trending

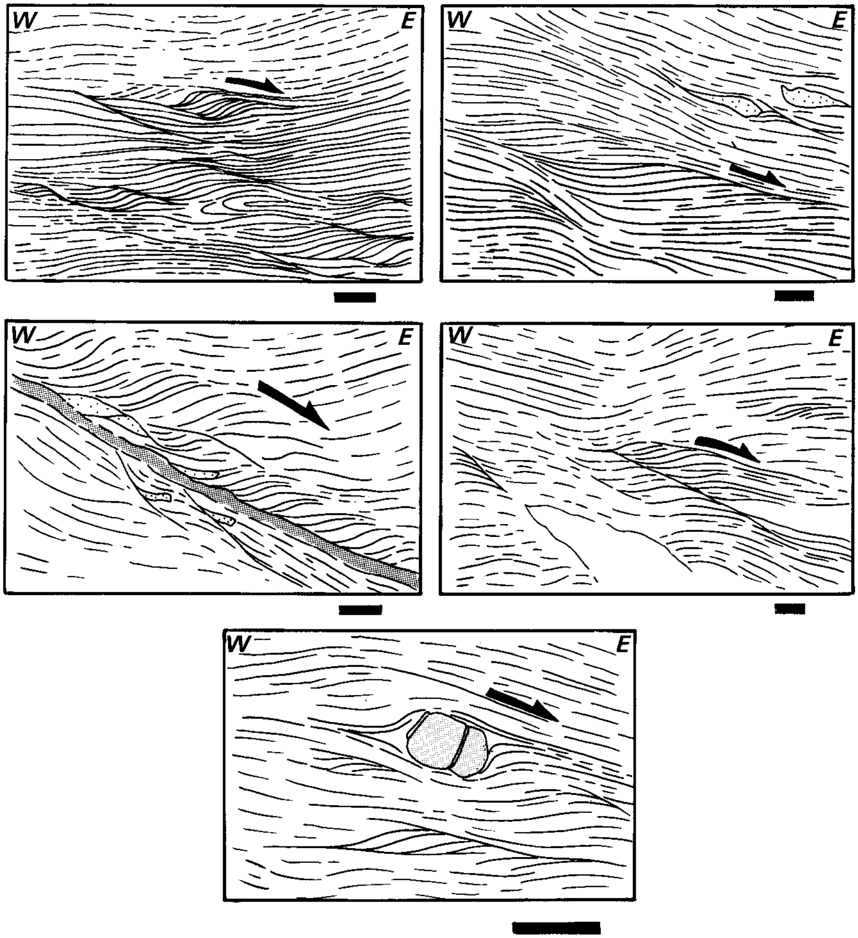

Fig. 6. Examples of ductile and semi-brittle eastward shear bands along the east Tenda shear zone, scale bar represents 10 cm. The lower example is a Late Cretaceous conglomerate with asymmetric stretching of pebbles.

normal faults which cut all lithologies. Contacts between units are reworked by flat-lying brittle faults parallel to the foliation. The foliation is folded by east-vergent folds of all scales from a few tens of cm to several tens of meters and is most obvious in the schists in the east of the area. The greenschists, gneisses and schists display a strong stretching lineation which strikes E–W in the entire area. X–Z sections show frequent and non-ambiguous shear sense criteria such as oblique shear bands and asymmetric pressure shadows.

High shear strain is localized along the major contacts between thrust sheets and the basal contact of the basement unit is a good illustration of such a strain localization. Very high shear strain is observed in the underlying units, greenschists and calc-schists. The sense of shear is in places predominantly eastward as shown mainly by oblique shear bands. A strain-slip cleavage parallel to the long axis of the strain ellipsoid indicates a component of flattening. In many occurrences both shear senses are observed on a single outcrop, like conjugate shear bands, eastward and westward [26]. The base of the basement unit is made of acidic orthogneiss with amphibolite lenses. A very prominent strain gradient is observed from top to bottom toward the basal contact and the amphibolites show a gradient of metamorphic recrystallizations. Blue amphiboles are preserved far from the contact and are progressively replaced by actinolite toward the base. This shows that the present-

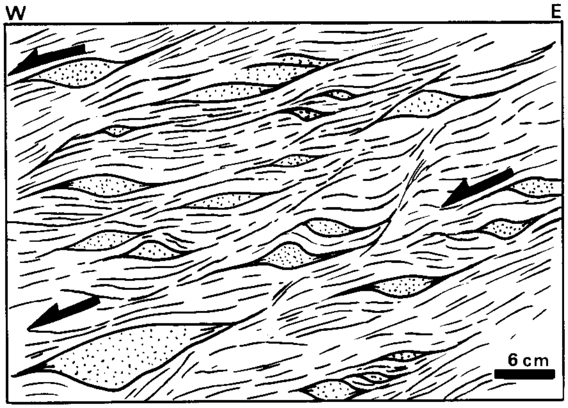

Fig. 7. Example of westward shear criterais associated with blueschist recrystallization (Schistes Lustrés nappe, Lancone Gorges). The deformed material is a pillow breccia. Stippled asymmetric lenses represent clasts of pillow lavas stretched during the high-P thrusting event. The foliation between them is mainly made of glaucophane, lawsonite, epidote and garnet. Glaucophane also recrystallized in the rim of stretched pillow clasts.

day contact is a late feature which postdated the high-P–low-T metamorphism. Generally speaking, structures contemporaneous with the high-P recrystallizations are not frequent and all the major structures are more recent and contemporaneous with the retrogressive metamorphic stage. The base of the basement klippe shows conjugate shear bands, eastward and westward. East-dipping shear bands were frequently opened and filled by quartz, whereas the west-dipping ones were not. This shows a foliation-parallel extension with a minor component of eastward shear. Toward the top the late deformation becomes less penetrative and syn-high-P structures are observed in thin section. They show a westward sense of shear contemporaneous with the crystallization of blue amphiboles. Upward the deformation decreases and pre-alpine structures and high-T metamorphic recrystallizations are observed.

High ductile shear strain is predominantly concentrated within acidic lithologies while more basic lithologies are generally affected by normal faults, with the hanging blocks downfaulted both to the east and west. These basic layers are both less deformed and less recrystallized comprising massive amphibolites with static crystallization of blue amphiboles. This is another illustration of the link between the recent ductile deformation and the retrogressive metamorphic stage. The recent deformation was localized in the less competent lithologies, schists, gabbro and acidic gneiss, where it enhanced the retrogression in the greenschist facies. Based on smaller-scale structures one can assume that the large basic layers represent large boudins of competent material extended within the regional shear zone. In the poorly deformed orthogneiss, late deformation is concentrated along bands of ultra-cataclasites, a few tens of centimeters thick with clear westward shear sense (near Tollare).

The following points can be stated: (1) The major part of the ductile deformation occurred subsequent to the high-P–low-T metamorphism during and after the greenschist facies overprint. (2) The ductile structures has been reworked by more brittle structures such as ultra-cataclasites in the foliation planes and normal faults which cut through the foliation. (3) The recent ductile deformation is the result of a foliation-parallel extension with a minor component of eastward shear. (4) the brittle deformation of the upper plate (Balagne nappe) on the eastern side of the antiform is consistent with this eastward sense of shear.

These observations explain the apparent contradiction noticed by Malavieille [33] considering the eastward sense of shear at Centuri: it does not correspond to the same tectonic event as that represented by the westward shear observed in southern Cap Corse.

Careful examination of the structural map (Fig. 3) reveals the following distribution of shear senses: at both the eastern and western tips of the orthogneiss lense, where it is thinner, shear is essentially toward the east, while it is either coaxial or westward in other areas. This suggests that the entire lense is a large-scale asymmetric boudin bounded by two east-dipping flat normal shear zones.

Scattered observations along several cross sections in the Schistes Lustrés south of Bastia (Fig. 1) reveal that fresh high-P minerals such as carpholite and lawsonite are confined to the southwest of Alpine Corsica. Elsewhere only relics or pseudomorphs are observed in schists, while fresh glaucophane and epidote are frequent in basic lenses. The foliation is folded into a broad antiform. Outcrop scale shear sense criteria such

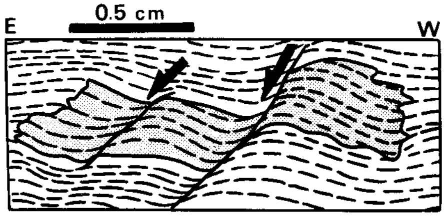

Fig. 8. Sketch of a thin section in metabasalts of Lancone Gorges (Schistes Lustrés nappe). The high-*P* foliation is overgrown by albite (stippled), which is in turn deformed by eastward shear bands. The eastward ductile shear is here post-greenschists overprint. Other thin sections in the same unit show that eastward shear is syn- to post-greenschist.

as oblique shear bands or en échelon cracks are frequent. All of these are late features which postdate the high-*P* foliation. Shear bands show a consistent eastward or northeastward shear sense and they are most frequent in the eastern limb of the antiform. The geometrical relation of the foliation and the shear bands are identical throughout, and both structures are folded by the broad antiform, which is thus more recent.

Jourdan [16] and Egal and Caron [22] describe N–S trending east-dipping normal faults which cut through the Balagne nappe (s.s.). Egal and Caron [22] further shows that the base of the early Miocene conglomerate at Francardo suffered an extensional deformation. The western boundary of this basin is an east-dipping normal fault, which is consistent with the general westward dip of the Miocene sedimentary rocks [16]. In the underlying rocks, south of this basin, the early thrust plane is reworked as flat-lying brittle normal shear zone with a clear top to the east sense of motion (Fig. 5).

5. Conclusions

Several conclusions, which are significant at the scale of Alpine Corsica, can be drawn out of the observations described (see idealized cross section, Fig. 2b).

(a) The most obvious deformation in the Schistes Lustrés nappe and the basement units which were involved in the alpine thrusting, is related to a late tectonic event which postdates the high-*P*–low-*T* metamorphism and followed the deformation related to obduction and collision which resulted in crustal thickening. This tectonic stage occurred subsequently to the late Eocene and presumably lower Oligocene compression and high-*P* metamorphism and was still active during the deposition of Saint Florent limestone in the Early Miocene. The depositional contact seen in the northeast part of the basin does not imply that all ductile deformation ceased with the deposition of the limestone. There is no depositional contact on top of the east Tenda shear zone which might have been still at depth when the easternmost part of the nappe stack had already reached the surface.

(b) The deformation is ductile and evolved in time toward more brittle conditions. It cannot be compared to the ductile deformation of the Aegean Sea metamorphic core complexes where migmatites are seen. The deformation was thus achieved in less deep levels, most likely in the upper part of the ductile crust, within or below the brittle–ductile transition.

(c) High ductile strain is localized in particular lithologies such as calc-schists and greenschists, as well as acidic gneiss. More competent lithologies, such as amphibolites, show less penetrative strain and are affected only by brittle faults. They form regional scale resistant boudins within a more acidic less resistant matrix.

(d) There is an evolution in time from ductile to brittle conditions along the major shear planes suggesting that the shear planes have been progressively uplifted during the deformation [40].

(e) This deformation brought units with very different metamorphic evolutions into close contacts.

(f) Highly non-coaxial strain is regionally localized along the east-Tenda shear zone and Castagniccia schists. The deformation is elsewhere more coaxial with a strong component of foliation parallel extension. The base of the Balagne nappe in the east is a flat-lying normal fault with an eastward sense of motion. The east-Tenda shear zone and the base of the upper nappe are the two major extensional shear zones which are superimposed on earlier thrust planes. The east-Tenda shear zone also controls the asymmetry of the early Miocene Saint Florent basin. The observation of shear bands an a thin section to a kilometre scale on either sides of the Cap Corse can be used as a further argument to relate this ductile deformation to extension during an overall eastward normal shear.

(g) Brittle normal faults which bound the Miocene basins cut through these domains of highly non-coaxial strain having the same sense of shear (eastward down).

(h) The Francardo and Saint Florent basins show extensional deformation and indicate regional tilt which are compatible with a general eastward sense of shear. The geometrical relation of the sense of tilt in the brittle domain and sense of shear in the ductile field at depth is similar to what is observed in the Caledonides of northern Europe where asymmetric Devonian basins were formed above reactivated thrusts [6,41,42]. Similar observations were described in the Massif Central where Stephanian basins [43,44], or the Cyclades with Mio-Pliocene basins [9] and sand-silicone experiments also suggests this relation in the laboratory [45–47].

(i) The rate of extension increases northward: the most obvious evidences are: (1) the divergence toward the north of the axes of the Tenda and Castagniccia–Cap Corse antiforms toward the north; (2) thinner crust in the north [48]; and (3) the fact that Miocene basins are continental in the south (Francardo) and shallow marine in the north (Saint Florent).

(j) The retrogressive metamorphism which was enhanced by the extensional deformation becomes more pervasive toward the north.

6. Discussion

We now discuss these conclusions and propose a model for the deformation of the Corsican crust during the Oligo-Miocene extension (Fig. 9).

We begin with a thickened crust which contains planar heterogeneities inherited from early thrust planes with a geometry similar to that described in Jolivet et al. [8]. The burial depth of the Schistes Lustrés at the end of the crustal thickening is constrained by the last high-P–low-T paragenesis. Adria represents the upper plate overthrusted on the Schistes Lustrés during compression [11]. Its only remains after extension are the klippes of the Balagne nappe (Balagne s.s, Nebbio and Macinagio). When extension begins, either in response to extreme crustal thickening or to a regional kinematic change or both, the thrust planes are reactivated as normal faults which localize the strain. The two main thrusts zones are at the base and top of the Schistes Lustrés nappe. Normal faults shown on Fig. 9 are similar to those observed in active extensional domains such as Greece [49–51]. Normal faults are plane and dip steeply down to 10 km where they root in a zone with much shallower (20°). This zone may be the brittle and ductile transition. Below this level, deformation is essentially ductile with flat-lying shear planes. In the upper part of the ductile domain, and in the transition, eastward directed shearing strain is localized along early thrust planes. In between, extension results in a more coaxial thinning. In the upper crust, westward block tilting occurs between east-dipping normal faults. During extension, the thicknesses of both the upper and lower crusts decrease, the previously ductile domain approaches the surface and the deformation in it becomes progressively more brittle. Brittle faults are localized in the domain of high shear strain and cut through the ductile detachment. The intervening ductile domain is progressively incorporated in the tilted block. This deformation proceeds until the upper surface is low enough to be covered with seawater and shallow marine limestone are deposited in half grabens. The antiformal shapes of the Tenda and Cap Corse have been acquired during this complex evolution: they were first formed by stretching of the ductile crust between the shear zones, and then as roll-over antiforms during and after the deposition of the limestones. This illustrates the formation of tilted blocks and the localization of the upper crust normal faults by asymmetric boudinage of the crust. The asymmetry is controlled by the position of the earlier thrust planes.

The transition from compression to extension is apparently very short, the last compressive high-P–low-T events appear to be almost contemporaneous with the inception of extension. It is thus sometimes difficult to conclude with much certainty that a given structure is linked to extension or to compression. We tried to consider first order facts which have a regional significance and thus our conclusions are only valid at a regional scale. One might argue that individual structures which we have attributed to extension are in fact related to compression.

We did not address here the reasons for this drastic change in the tectonic regime. Alpine Corsica was separated from the main body of the

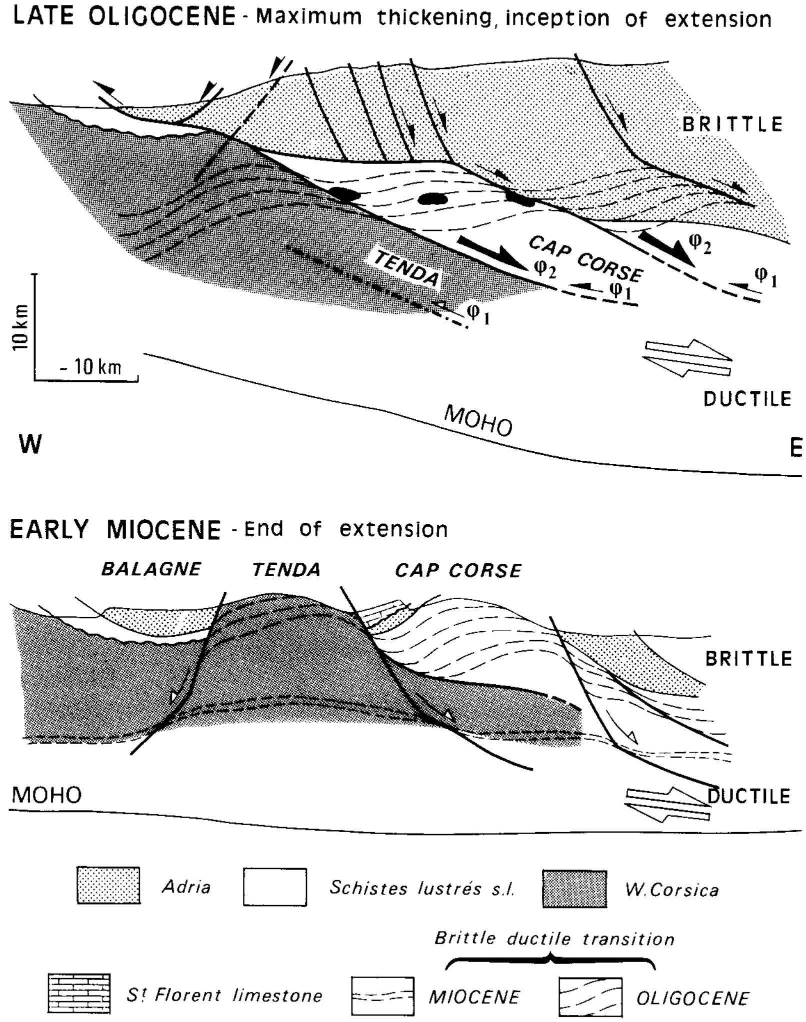

Fig. 9. Formation of tilted blocks and evolution of the ductile–brittle transition during post-orogenic collpase through time in the Cap Corse area.

Alps and compression stopped because the regional extension which led to the opening of the Liguro–Provençal basin and Tyrrhenian Sea and formation of oceanic crust began. There are in our case two possible causes for the extension: (1) It is a response to extreme crustal thickening, with collapse of the thickened crust as the most significant driving mechanism [2,52], but it does not explain the opening of a basin opened of alpine Corsica. (2) Extension is a result of back-arc extension behind the Appenine and Calabrian subduction zones which were already active at that time, as shown by the occurrence of subduction-related volcanics in Corsica and Sardinia [19,20]. The sudden change of the boundary condition to the east induced crustal extension which favored crustal collapse.

The model of uniform sense normal simple shear based on observations in the Basin and Range province [1,2,53] or Aegean Sea [5] has been applied to passive margin formation [53–55]. The structure of Alpine Corsica shows that in some cases pre-existing structures strongly control the kinematics of extension and particularly its asymmetry (regional sense of shear and block tilting) at least during the early stages of crustal stretching. This suggests that comparison between passive margins and collapsing orogens should be made with caution. The Basin and Range or Aegean Sea regions were deformed by thrusting before extension started. It implies (1) that the crust was much thicker, the ductile/brittle ratio was higher and the crust consequently less resistant, and (2) that planar heterogeneities existed which may have localized the strain and controlled the asymmetry of extension. These two conditions differ greatly in classical passive margins.

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