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CHAPTER 1

The Island of Elba: tectonic setting and geological evolution

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1.1 INTRODUCTION

Since last century several studies focused in the geology of Island of Elba have been carried out. Nevertheless, the deformation history, relationship between tectonics and metamorphism and part of the stratigraphical record in Island of Elba are still open to debate, especially when placed in a larger regional context.

The following brief description of the Island of Elba is based on the tectono-stratigraphic complexes identified by Trevisan since 1950. The tectonic evolution of Elba is presented and discussed in the optics of accretionary processes developed on an orogenic wedge. This wedge was part of a trench-subduction zone system where the Thetyan oceanic crust was being consumed along a subduction zone dipping toward the west.

Accretion and underplating of oceanic material to the migrating prism occurred probably during the Middle Cretaceous and went on until the Middle Eocene. During Oligo-Miocene times collision of the tectonic wedge with the continental margin of Tuscany occurred and the latter was overthrusted by oceanic crust.

During this collisional stage low-grade metamorphic conditions were generated and affected terrains like the Complex II in Elba, while shortening caused an out-of-sequence thrust to place Complex III on top of a sliver of serpentinites that already overlaid Complex II. In the third stage extensional faults overprinted the previous stacked structures and led to the present geological setting of the area.

Having started probably as early as in the Lower Tortonian extension created conditions which favoured the generation of magmas of «granitic» composition.These magmas later on intruded the thinned continental crust as seen in the case of the Mt. Capanne and Valdana zones.

1.2 GEOLOGICAL SETTING OF ISLAND OF ELBA

The island of Elba can be broadly divided in two domains, a central-eastern and a western one.

The central-eastern domain is represented by a stacked system of thrust sheets of both oceanic (ophiolites) and continental affinity whereas in the western side the nappes are only of ophiolitic material and their sedimentary cover that were largely intruded by a granodioritic stock.

As a result structural geometries and relationships are only seen on a thin ring around the stock itself. Thus most of the field

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data about the structural evolution came from the central-east domain.

Following Trevisan's work (1950) the embricated stack in central-eastern Elba consists of five different complexes with different lithologies and metamorphic facies (Fig. 1).

Complex I - The rocks of this Complex outcrop in the southeasternmost portion of the island covering the entire Calamita peninsula. Lithologically they consist of muscovitebiotite schists that may also show andalusite and porphyroblasts of plagioclase (Barberi *et al.*, 1967a) which are topped by quartz conglomerates and dolomitic carbonate rocks. The age of the uppermost part of the basement schists is supposed to be Palaeozoic (possibly Permian according to Barberi *et al.*, 1967a), whereas the quartzitic rocks correspond to the Verrucano formation of Tuscany and the dolomitic carbonates on top of it may be related to the late Triassic carbonate evaporitic formation. A characteristic feature of this complex is the presence of an extremely complicated array of late granitic veins and dykes (mineralogy: quartz, orthoclase, plagioclasc, biotite, muscovite and tourmaline) that are only seen on the eastern side of the schistose body.

Complex II - It crops out on the eastern part of Elba around the town of Rio Marina and the best place to see its lithological sequence is in the valley of Ortano. It comprises a series of rock formations that have been correlated with the Tuscan Metamorphic sequences in he Apuane Alps, Montagnola Senese and Monti Pisani (Trevisan, 1953; Dallan-Nardi and Nardi, 1974; Burgassi *et al.*, 1980). The lowermost formation is a schistos rock, varying rom dark brown to a clear green-greyish colour, with a very thin and penetrative foliation and linear fabric («Porfiroidi and Scisti Porfirici»). The age of this formation has been referred to be Permian (Barberi, 1966; Barberi *et al.*, 1967a). However, paleontological findings inside calcareous lenses in the same formation in the Apuane Alps (Vai, 1970) gave a Silurian age. Further researches based on comparisons with similar rocks in Sardinia (Carmignani *et al.*, 1986) suggest a more appropriate age of Middle Ordovician for this formation. Such fact implies that the Porfiroidi Schists represent a portion of Lower Paleozoic basement with an important unconformity separating the schists from their sedimentary cover.

On the top of the schists are rests of a thin layer of metamorphosed vuggy dolomitic limestone breccia equivalent to the Grezzoni formation in the Apuane core. The age of these carbonates is believed to be Triassic (Norian - Rhaetian). They are medium-coarse grained white marble of Lower Liassic age that in turn are covered by a thick sequence of calcschists and quartzites.

The marbles are believed to be the metamorphic correspondent of the carbonate platform sequence of Tuscany (Calcare Massiccio Auct.) whereas the calcschists are the equivalents of the pelagic sequence of Calcare Selcifero and Marne a Posidonia. Boccaletti *et al.* (1977) identified a paleosurface of erosion with ferruginous material between the marbles and the calcschists formations. On the uppermost part of the calcschist sequence thinly foliated mica rich quartzitic horizons have been observed and studied. These quartzites could correspond to Pseudomacigno that Dallan-Nardi and Nardi (1974) described in the Apuane Alps (foliated metamorphic quartzites that in many occasions do not show clear evidences of vertical grading) of Oligocene age. Thus, a complete (but condensed) Apuane Alps sequence, including most probably the Scisti Policromi, seems to be present in the Complex II.

Complex III - It crops out along a narrow stripe with N-S trends all along the northeast side of Elba from Cavo to Mte. Arco. It consists of a phyllitic basement of Carboniferous age and of a sedimentary cover sequence with an age that encompasses all the Mesozoic going until the Oligocene. The first formation of the cover is the Verrucano, classically consisting of pink conglomerates and purple schists that in Elba form a series of

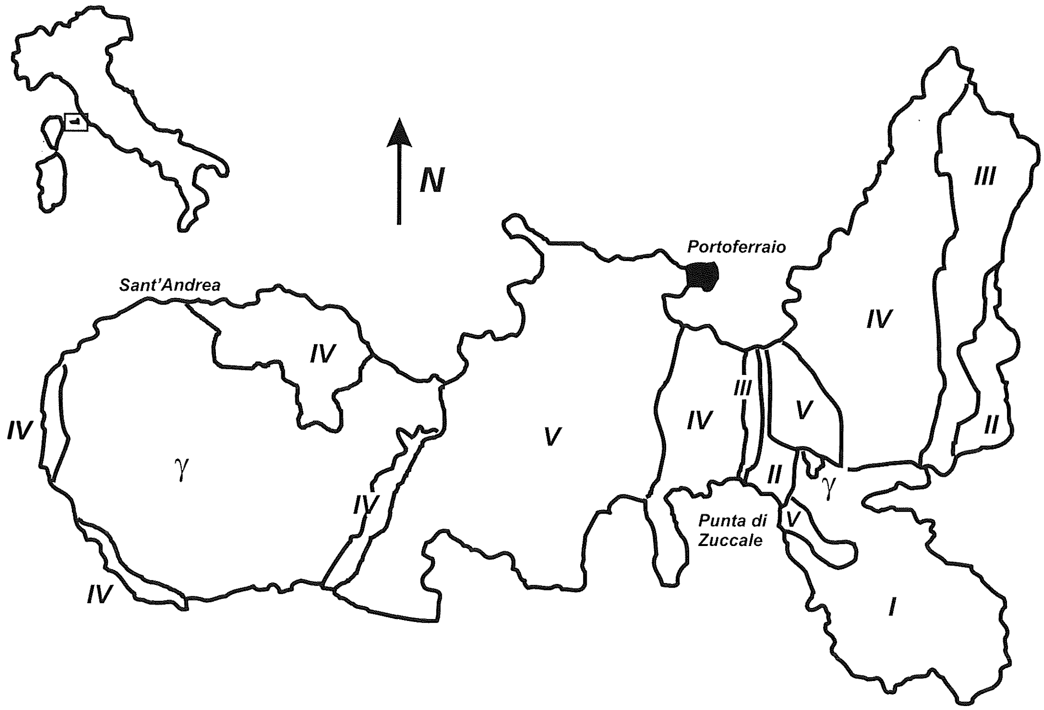

Fig. 1 – Location map of Elba and of the sites mentioned in the text. The distribution of Trevisan's tectonic complexes (from I to V) and late monzogranite and quartz-monzogranite (γ).

cliffs to the north of the town of Rio Marina. It has a Middle-Upper Triassic age (Ladinian-Carnian) with on top the evaporitic vuggy dolomitic limestone formation of Norian age which in turn is followed by limestones with Rhaetavicula contorta. The next formations are white massive limestones related to the Calcare Massicio of Lower Liassic age and a sequence of pelagic nodular and cherty limestones from the Middle-Upper Liassic. The latter underlies a series of marls with Posidonia alpina of Dogger age. Boccaletti *et al.* (1977) refer to the existence of a paleosurface of erosion between the Liassic nodular limestones and the Dogger marls. New data from the Cavo area suggest that on top of the marls Eocene sediments are present, being represented by lenses of nummulitic limestones. In addition, horizons of turbiditic sandstones equivalent to the Macigno formation of Oligocene age were found in the same area.

Complex IV - It comprises the ophiolitic sequence that has been correlated to the ophiolites of the Ligurian domain of the Northern Apennines. This sequence is composed of a basement of serpentinitic rocks, gabbros and pillow basalts that are overlain by a pelagic sedimentary cover. The cover consists of radiolarites and Calpionella limestones whose age is respectively Malm and Upper Jurrassic-Lower Cretaceous.

Classically in the Northern Apennines Ligurian ophiolites, the uppermost formation is represented by the shales of the Argille a Palombini (from the Lower-Middle Cretaceous) that rest on the Calpionella limestones. In contrast, both in central and eastern Elba, such situation is never seen as the

Palombini shales are always overthrust by the basal serpentinites. Hence, the entire ophiolitic unit overlies the Palombini shales. Another characteristic of the Palombini shales in Elba is that blocks and/or olistoliths of ophiolitic material (serpentinites and/or basalts) are found inside the formation.

Complex V - The highest Complex comprises the Flysch formations with the best exposures being found in the Central part of Elba. Two different types of flysch are present in the studied area, an Upper Cretaceous argillo-calcareous Flysch (Helminthoid Flysch Auct.) and the Paleocene- Middle Eocene sequences of Lanciaia formation (clay and calcareous rocks).

The latter mainly represented by shales, calcarenites, sandy marls and breccias that usually contain ophiolitic material. Of the two flysch formations the Upper Cretaceous one prevails. The Upper Cretaceous flysch, in turn, can be divided into two parts: the basal part with sandstones (in Elba defined with the name Ghiaieto Sandstones) and the top part consisting of calcareous marls (calcareous turbidites and calcarenites), shales and thin sandstone beds representing turbiditic sands (the Marina di Campo Formation).

The two parts continue one into the other, having no sign of tectonic disruption along the contact. Aiello *et al.* (1977) pointed to corsica-Sardinia Massif as the source for these sandstones. Perrin (1975) correlated the arenaceous portion of Elba to the Monte Gottero sandstones and the upper portion to the Monte Antola formation. The Tertiary flysch consists of shales, calcarenites, sandy marls and breccias that usually contain ophiolitic material. The ophiolitic material can form blocks ranging from tens of cent meters to tens of meters (olistoliths), found inside the shales and marls. The age of these sediments is probably Paleoocene/Eocene based on fossil findings. Collet (1934) assigned a Lutetian age to nummulitic breccias in P.ta della Contessa. Raggi *et al.* (1965) dated breccias to the west of Mt. Orello as Middle Eocene whereas Lanteaume *et al.* (1976) attributed ophiolitic breccia horizons found inside this formation to the Lower Eocene on the basis of Nummulites.

We found indications that this flysch is still older, since the dating of nannofossils found in flysch samples collected in the locality of Colle Reciso (to the west of Mte. Orello) showed a fauna from the Lower Paleocene. The relationship between the Paleocene/ Eocene flysch and the Upper Cretaceous one is represented by a thrust contact that puts the Cretaceous formation on the top of the younger Paleocene/Eocene flysch. This thrust has an eastward sense of movement.

In the Northern Apennines the flysch sequences rest on the Palombini shales with a sedimentary contact, whereas in Elba the only place where this situation can be seen on the field is in the area of Ghiaieto (Aiello *et al.*, 1977). All the other basal contacts of the flysch unit are of tectonic character with the Calpionella limestones of the fourth Complex.

1.3 TECTONIC EVOLUTION OF ELBA

The tectonic history of Elba is related to the evolution of the Corsica-Apennines system. Usually the geologic literature separates the Apenninic orogenic belt from the Corsican (or Alpine) one. Often, the arguments presented to justify such a division are centered on the opposite vergences of folds and thrusts (towards the west in the Corsican nappes and towards the east in the Northern Apennines), and the ages of the deformation (Middle Cretaceous-Upper Eocene in Corsica and Oligocene-Miocene in the Northern Apennines).

A clear limit between the two orogens as the Sestri-Voltaggio (Haccard *et al.*, 1972) or the Villalvernia-Varzi-Levanto (Elter and Pertusati, 1973) lines also had to exist since the two mountain belts had different structural geometries and age. Using the same criteria of above Perrin (1975) divided Elba in an Alpine realm (the west portion of the island) and an Apenninic one (the central-east side). The limit of the two domains was located in the central part of Elba (passing near Pta. della Contessa and to the west of Portoferraio) and continued northwards in the Tyrrhenian Sea to join the Sestri-Voltaggio line

Elba in this context represents an internal part of a tectonic wedge which was part of a system with a subduction plane dipping to the west under the Corso-Sardinian block. As the orogenic wedge moved to the east accretion of new material to the tip as well as underplating in the deeper parts occurred. Shortening and thickening in the innermost part of the prism caused backthrusting with obduction to the west of the deepest part of the orogenic wedge (represented by HP-LT terrains) over the Corsican block. Structural piling in the ophiolitic unit with eastward direction in the more external areas of the wedge was coeval with the west directed backthrusts of the internal zone described above.

This means that the movement of the thrust sheets to two opposite directions happened during the same event and was due to the same tectonic process. Movement continued to the east of both the Corsican block and the prism itself leding it to collide with the Apulian plate and overthicken, thus destabilizing the wedge. Soon after the collision extensional collapse started to affect the wedge to bring it back to a more stable configuration (Platt, 1986).

Thus, we divide the evolution history of Elba from the Cretaceous onwards in three main stages namely:

1.3.1 Accretionary stage

The olistholiths of ophiolitic material and nummulitic calcarenites of Paleocene-Middle Eocene age (Raggi *et al.*, 1965; Lanteaume *et al.*, 1976) inside the Palcocene-Eocene Flysch to the west of Mte. Orello and Pta. della Contessa, respectively, and the mélange facies deposits (Chaotic Unit) in the Fetovia area of western Elba, where olistostromes and blocks from the ophiolitic unit and sandstones blocks from the Cretaceous Flysch are found support the hypothesis of an Upper Cretaceous beginning of the collision and continuing until Upper Eocene.

The Paleocene/Eocene Chaotic Unit in Fetovaia containing blocks of arenaceous flysch point out to active thrusting just after the deposition of the Cretaceous Flysch. The continuation of the thrusting phase can then be dated in the Paleocene Flysch in Pta. della Contessa where the ophiolitic olistoliths and the nummulitic calcarenites probably indicate its continuation during both the Paleocene and the Eocene. It is probable thrusting and imbrication to have started even earlier than described above. Internal stacking of the ophiolitic unit could have happened in the initial deformational stages of the orogenic wedge when compression was being accomodated by thrust faulting of the oceanic crust.

Overthrusting of serpentinites on Argille a Palombini as seen on the base of the ophiolites of the fourth Complex is another structure that could indicate active tectonism as early as the Middle Cretaceous, much before the ophiolites were accreted to the Apulian continental crust. According to Coehn *et al.* (1981) the overthrusting of the meta ophiolitic nappes over the Corsican margin happened during the Middle Cretaceous. This particular event can still be considered as part of the accretion stage because the highly metamorphic ophiolites (HP-LT) of the internal part of the prism are obducting with a backthrust direction the Corsican block to the rear of the wedge as pointed out by Principi and Treves (1984). In fact no clear collision of the frontal part of the prism with continental crust can be recognized before or during this period.

This means that the Corso-Sardinian block worked as a rigid buttress and the subduction of the slab to the west generated the necessary force to move the tectonic wedge towards the east (slab pull). Accretion of oceanic crust and related sediments in what will be the future Northern Apennines and obductive movements onto Corsican block went on almost simultaneously during Paleocene and Middle Eocene as documented by transgression on deformed substratums of Lanciaia fm. and of Ranzano sequence in N. Apennines and by the «mise en place» of Centuri terraines onto the Upper Schists Lustres Nappe and of non-metamorphic Ligurides onto the Nappe Superieure in Corsica (Dallan-Nardi and Nardi, 1984).

1.3.2 Collisional stage

Collision starts to occur when the prism itself encounters the west side of the Apulian plate and the continental margin is overthrust by the frontal part of the tectonic wedge. This event is clearly marked in east Elba where the ophiolitic unit (or Ligurian Nappe) overlies both Complex II and III of continental affinity. The most probable age for the start of the collision is the Upper Oligocene/Lower Miocene, due to the presence of Macigno sandstones (in Complex III) and Pseudomacigno (Complex II) in the footwall of thrust contacts that have ophiolites in the hangingwall. As collision progressed the wedge started to be shortened to the point that not only internal thrusts formed but late out of sequence thrusts developed breaching the basal serpentinites in order to accomodate the extra shortening strain. In fact, this can be seen in the area from M.te Arco to Rio Marina where the breached serpentinitic slab with Complex III and the ophiolitic succession resting on top of Complex III is found.

Compression continued and caused significant shortening to both the sedimentary and ophiolitic units which deformed originating local thrust imbrications and folding. Kinematic indicators associated with these structurcs point to a direction of movement towards the ESE. Compressive stresses were still building up inside the wedge causing the strain to be accommodated through backthrusting, as in the central-eastern side of Elba where the overshortened ophiolites have undergone backthrusting directed to the WNW (west of Volterraio and M.te Orello).

The progression of the movement of the prism together with the continuous accretion of new materal to the wedge front causes it to thicken and grow. As the wedge advances the accreted material is buried and progressively transported to depressed zones inside the prism.

In Elba the overthrusted Complex II was buried and carried down to depths were the loading pressure was great enough to generate greenschist metamorphic conditions. Such a process could explain the presence of a unit with a higher metamorphic grade (the second Complex in Elba) underlying a less or even non metamorphosed sequence (Complex III).

We believe that this sort of mechanism is a more likely cause for the metamorphism present in the basal units of the Tuscan Nappe in Elba than the one used by Carmignani *et al.* (1978) for the Apuane Alps. These authors have suggested that in the Apuane Alps much of the metamorphism was due to the effect of a shear zone that generated frictional heating high enough to reach greenschist facies conditions. This shear zone was formed during the emplacement of the Tuscan Nappe over the Apuane Sequence in the Apuane area. Thus, the shear heating caused by this overriding plate could explain the higher grade of the metamorphism of the rocks in the footwall whilst the hanging wall suffered much less metamorphic influences.

An extra amount of heat generated in simple shear environments was not needed in Elba probably because there the thickness of the orogenic wedge was greater (since it was located in a more internal position) and hence enough to cause the metamorphic conditions to change. Similar tectonic processes could also account for the deformation and metamorphism of more external units of the Apennines (e.g. Montagnola Senese) as the tectonic wedge migrated further eastwards over the Tuscan mainland.

Assuming this hypothesis is valid, we could expect a younging in the age of metamorphism in the more external areas. In fact, the overall structure and stratigraphy of Complexes II and III of Elba show many correspondences with the areas of the Apuane Alps and La Spezia respectively even though differences in lithology do exist.

Thus, with an equivalence between Elba and the Apuane Alps, the Montagnola Senese structure would represent a more external (and younger) tectonic and metamorphic event. On the other hand, if we assume a correspondence between the Apuane Alps and the Montagnola Senese zone the tectonism in Elba should be considered to have happened earlier than in the other two areas.

1.3.3 Extensional stage.

Extension is the last tectonic event active in Elba where a system of normal faults overprints all previous structures and geometrically dip both to E and W with a N-S trend (Fig. 2). The E dipping ones cut down all the stratigraphical sequence with dips of 12 to 15 degrees. The W dipping faults usually bound different formations creating gaps in the stratigraphy and probably reactivating old thrust planes. The E dipping faults seem to have a major role in the extension of the area and a large detachment fault outcrops along the southwest coast of Elba. In this area a very well exposed extensional shear zone puts in contact Cretaceous Flysch on the hanging wall with Triassic Verrucano conglomerates on the foot wall. This normal detachment is here called Zuccale Fault. An average thickness of 2 to 3 meters of extremally foliated fault gouge is developed in the fault zone displaying a series of shear indicators like shear bands and slickensides that show a clear direction of movement to the ESE (100 to 115).

The gouge itself is mainly composed of both calcareous and argillaceous portions probably originated from the foot and hanging walls. The Zuccale Fault zone can be followed to the north of the island separating a second pile of units identical to the one already described (on the foot wall) to the west, from the imbricated pile seen in eastern Elba.

Another system of E dipping low angle extensional faults can be seen in the southeast coast of Mte. Calamita where they displace pegmatitic aplites which have intruded the schists of the Complex I.

The extensional stage in Elba consisted of a series of events as the emplacement of Mte. Capanne intrusion around 7 m.a. (Ferrara and Tonarini, 1985) together with related vertical normal faults and brecciation around its margins. This event was preceded by the intrusion of precursory dykes and sills in the flysch formations (Trevisan, 1952) when they were still on the place where the granodioritic stock would intrude later on.

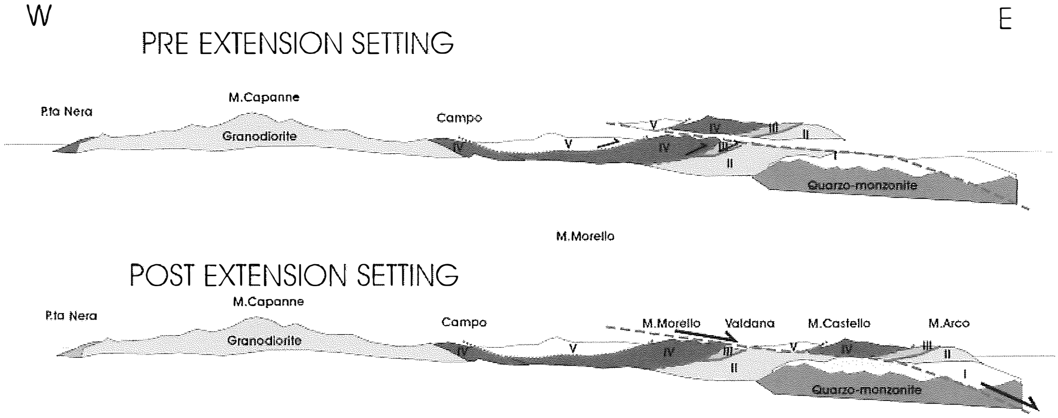

Fig. 2 – General cross-section Island of Elba from the western coast to the eastern coast where the ophiolitic unit and the flysch are found. This section then, passes through most of the complexes or nappes from the basal portion of Complex II to the highest of them all Complex V. It is clear on the section the effect of the extensional detachment fault displacing a sliver of the entire sequence to the ESE.

Dykes and sills were deformed by younger events as: 1) the intrusion of the stock itself, and 2) by the low angle extensional faults created by the Tyrrhenian rifting.

In the eastern part of Elba a second intrusion of quartz-monzonitic composition is present. This stock generated a swarm of aplitic dykes that intruded the Calamita schists and were studied and dated by Saupé *et al.* (1982). The relationships between the dykes and the intrusion according to field and geochronological data point to an earlier intrusion of the aplite swarm than the quartz-monzonite body. Consequently the aplites were cut and uplifted by the intruding body. A comparison between the succession of events given above for the Mte. Capanne and the chronology of phases for the intrusion is another strong evidence of the fact that the dykes around Mt. Capanne were emplaced before the intrusion of the main granitic body. Extension in the Northern Tyrrhenian Sea began in pre- Tortonian times; in mainland Tuscany extensional basin of Tortonian age are known. Taking into account that tensile stresses migrated towards the east after having started in the internal zones of the orogenic area, we are forced to assume that extension was occurring in Elba probably as early as in the Lower-Tortonian.

Tortonian extension and related basins in the Northern Tyrrhenian Sea also indicate that extension immediately followed compression; the former then continued to be active contemporaneously with compression as it migrated towards the more external zones. This fact envisages a scenario where the overthickening of the tectonic wedge and continental crust caused the stack of Elba and Apenninic nappes to became unstable and collapse. The collapse of the destabilized pile of nappes caused the extension and thus the formation of the low angle detachment extensional faults before the Upper Miocene, that stretched and thinned the crust.

Consequently, the granitic intrusions present in many of the islands of the Tuscan Archipelago could have originated because the Northern Tyrrhenian crust was thinned, which caused melting in the crust and generated the granitic magmas that intruded the thin continental crust.