Thrusting and extensional exhumation in an Accretionary Wedge: The Paleogene evolution of the Northern Sporades (Greece)

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Introduction and geological setting

Nappe stacking and subsequent extension in the Aegean region related to the final closure of the Neotethys ocean has been a subject of intensive researchs in regions like Rhodopia and the Cyclades (e.g. Brun and Sokoutis, 2007; Jolivet and Brun, 2010, Brun et al. 2016). This contrasts with the region of the Northern Sporades, which have not yet been thoroughly studied in the light of subduction-exhumation processes. We present a study on the latest Cretaceous - Paleogene tectonic evolution of the Northern Sporades islands (Greece) using multi-scale structural analysis and white mica Ar/Ar dating. We show new geological maps, cross sections, and kinematic datasets from the islands of Skiathos and Skopelos. Structural observations are supplemented by the Ar/Ar dating of mylonitic sericite foliations.

The Northern Sporades are part of the Pelagonian zone that experienced burial and exhumation related to the Aegean subduction system in Late Cretaceous-Paleogene times. The islands largely consists of metasediments that belong to 1) a Paleozoic to Jurassic passive margin succession (Pelagonian and Eohellenic units), and 2) an Albian to Paleocene succession that transgresses the older formations (Mesoautochtonous and Palouki units).

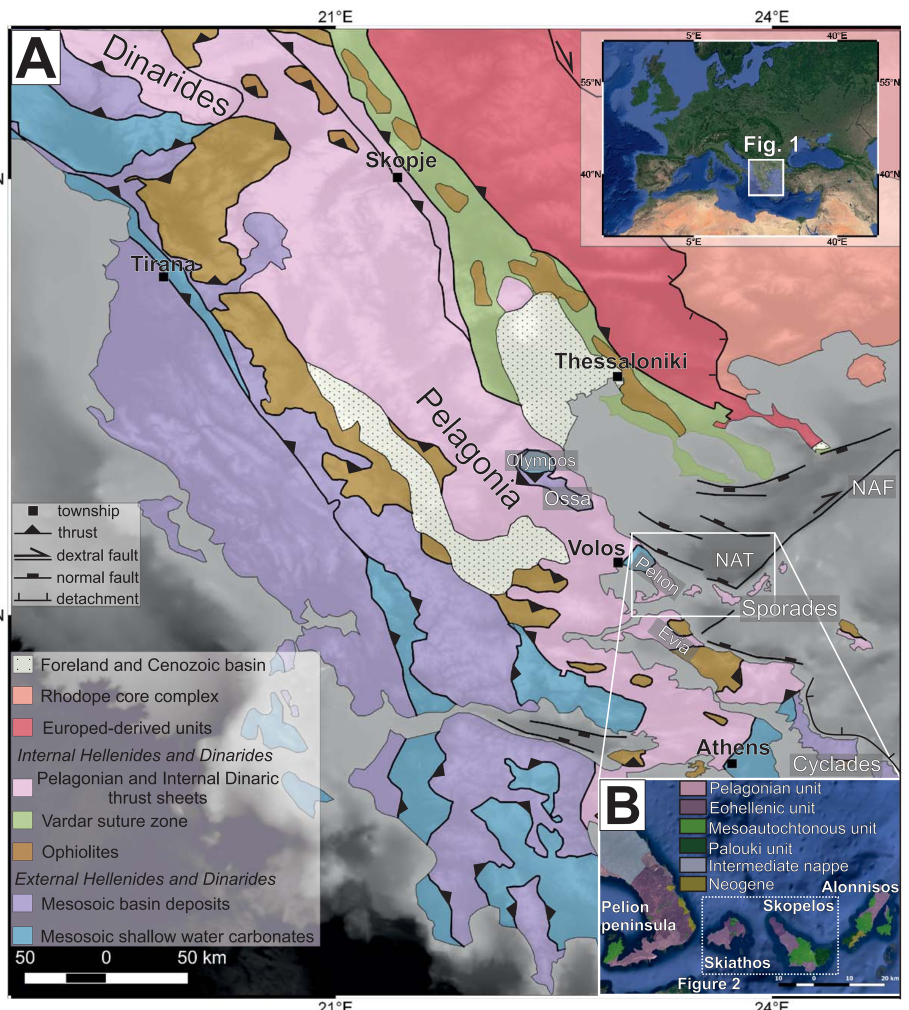


Figure 1. Geological map of the Hellenides and its surroundings. NAF=North Anatolian Fault, NAT=North Aegean Trough. Modified after Burg et al. (2012).

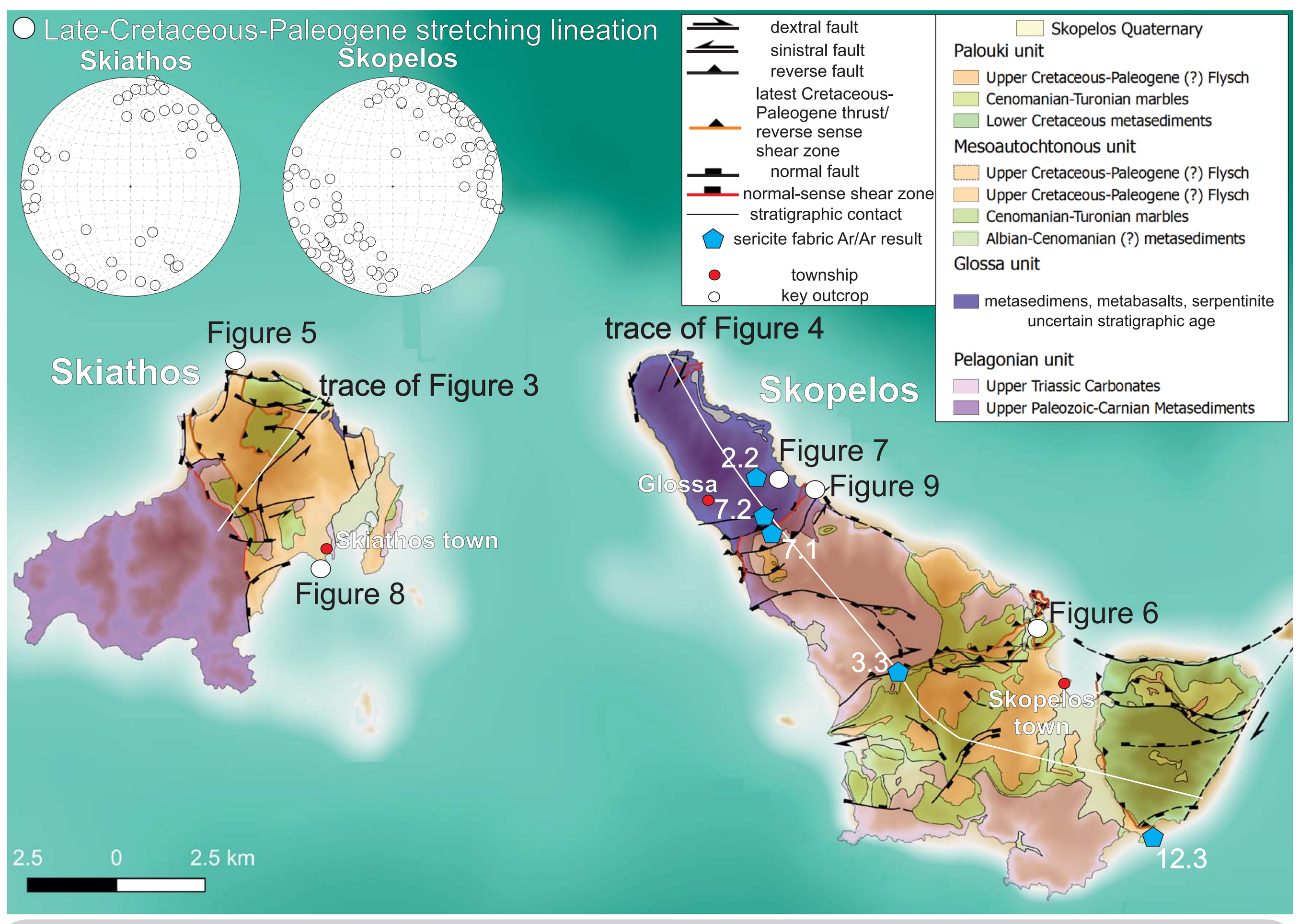


Figure 2. Geological map of Skiathos (modified after Vidakis, 1995) and Skopelos (modified after Matarangas (1992)). Stereoplots show the azimuth and dip angle of Late Cretaceous-Paleogene stretching lineations on both islands.

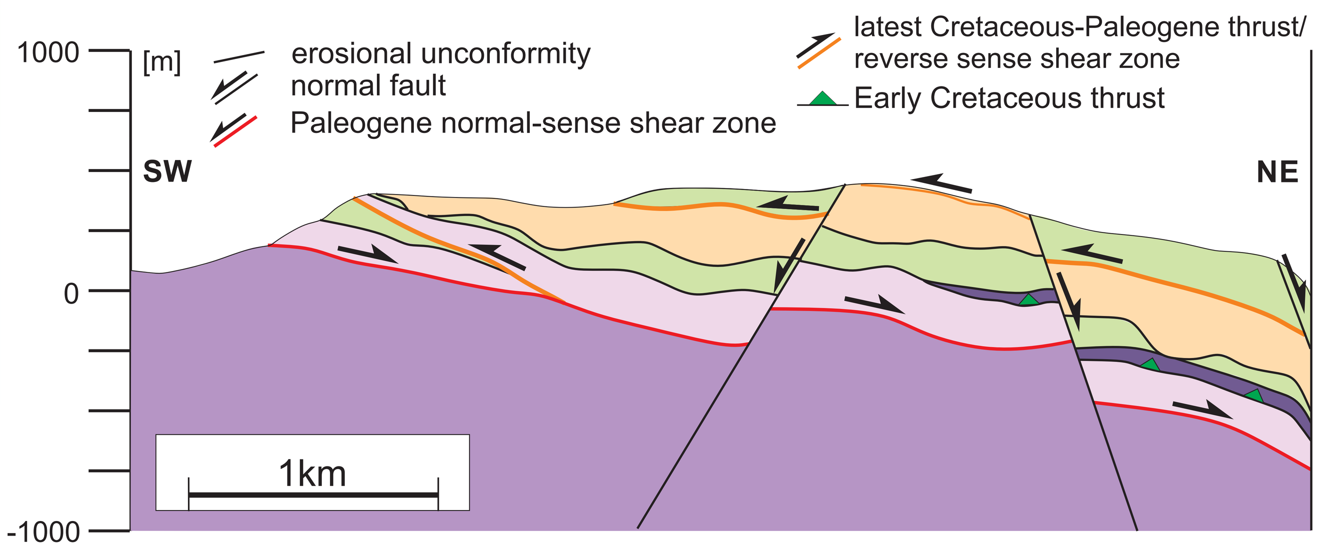


Figure 3. SW-NE cross section of NE-Skiathos. The formations of the island are stacked on top of each other by top-S to SW thrusts. The thrusts produce thin slices of rocks explaining the observed repetition of the formations. **Thrusting was largely accomodated by the formation of carbonate mylonite zones (Figure 5)** that were acting as weak decoupling layers under greenschist facies metamorphic conditions. These shear zones are sub-parallel with the main foliation and were confused with stratigraphic boundaries in previous works from Skiathos (e.g. Vidakis, 1995). The contact between the low-grade metamorphic cover units and the medium-grade Paleozoic is a top-E to NE normal-sense shear zone formed during the exhumation of the units, and explains the difference in metamorphic grade.
The color code of the cross section is the same as on Figure 2.

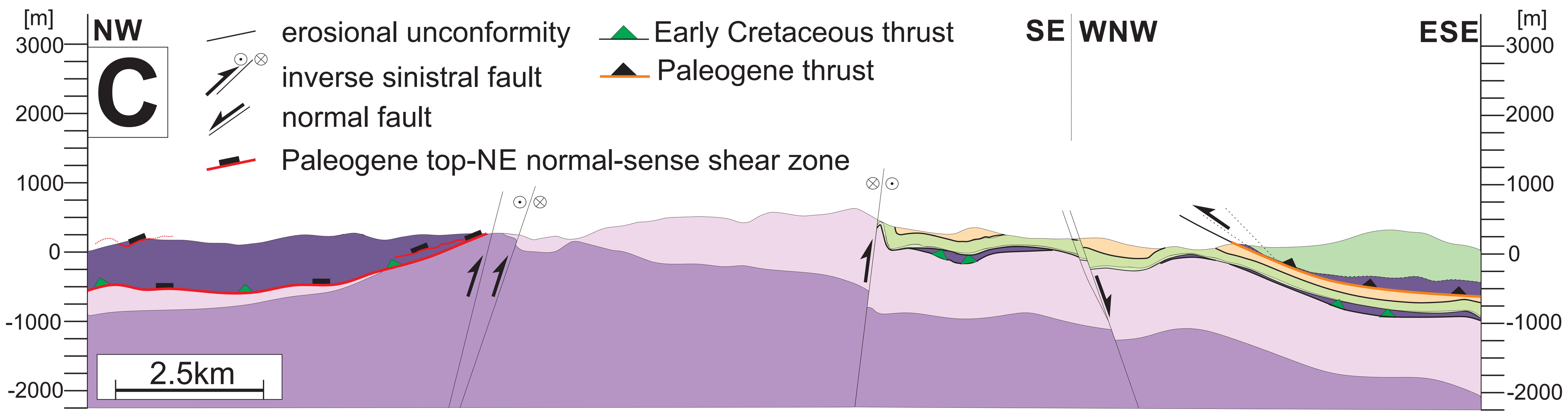


Figure 4. NW-SE cross section of Skopelos showing the somewhat larger scale geology that characterize the Northern Sporades. The bottom Pelagonian unit is overthrust by the Glossa unit in the NW and the Palouki unit in the SE. Field relations indicate that emplacement of the Palouki unit occured after or during the deposition of the Paleogene Flysch. Skopelos exhibits many top-NE, normal sense shear zones that run parallel to sub-parallel with the main foliation. In between the shear zones distributed top-NE shearing developed that can be found in many outcrops on Skopelos.
The color code of the cross section is the same as on Figure 2.

Key outcrops: from top-SW thrusting to top-NE exhumation

Figure 5. Top-SW reverse-sense shear zone on Skiathos emplacing the Albian-Cenomanian marbles on top of the latest Cretaceous-Paleogene Flysch. Deformation is localized at the base of the marble unit which resulted in the formation of a 5-10 m thick carbonate mylonite zone.

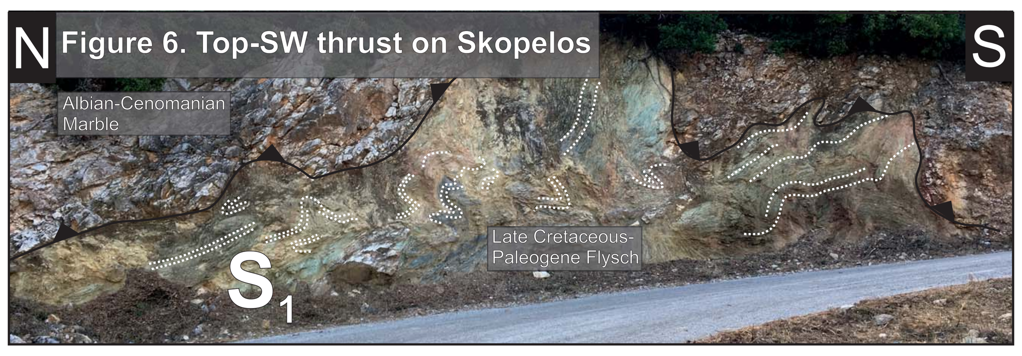


Figure 6. Top-S-SW thrust on Skopelos exhibiting both brittle and ductile deformation mechanisms. The thrust separates the same units as on Figure 5.

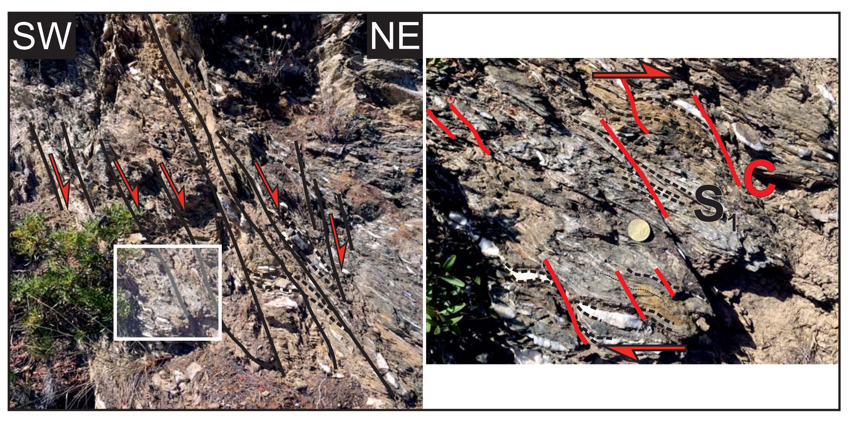


Figure 7. Ductile top-NE shearing is gradually replaced by top-NE brittle normal faulting. Initial shearing is characterized by flowing quartz and isoclinal folding. Ductile structures are cut by the faults afterwards.

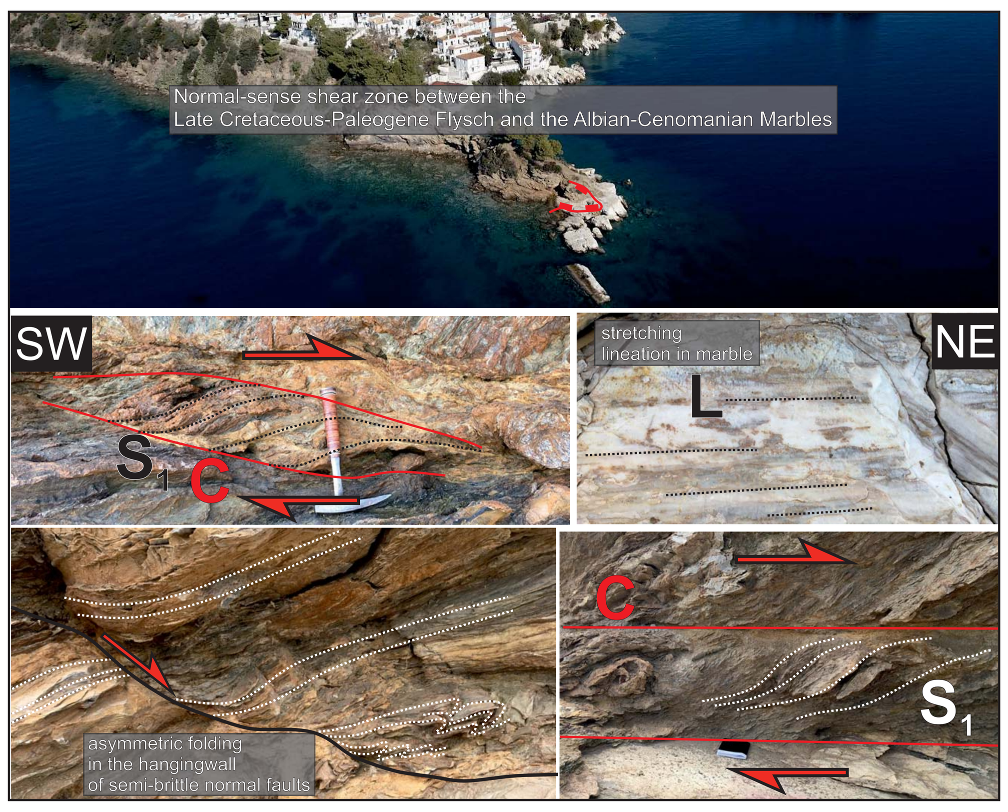


Figure 8. Top-NNE normal-sense shear zone on Skiathos separating the Albian-Cenomanian marbles at the bottom and the latest Cretaceous-Paleogene Flysch on top. The marbles are mylonitic below the contact with strong stretching lineations. The Flysch is deformed first by ductile, top-NNE shearing which is gradually replaced by top-NNW semi-brittle and brittle normal faulting. Semi-brittle shearing is accompanied by tight, asymmetric folding.

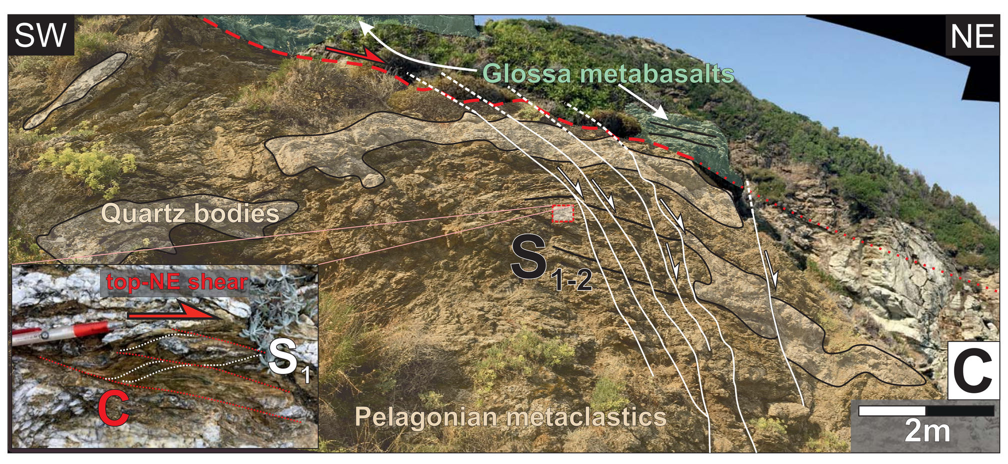


Figure 9. Ductile top-NE shearing is localized along a pre-existing thrust contact on Skopelos. The shear zone is 9-15m thick, and is cut by semi-brittle and brittle top-NE to top-NW normal faults.

Sericite Ar/Ar dating

Tectonic burial due to top-SW thrusting resulted in low-grade metamorphism in all the formations. Deformation induced the crystallization of a main foliation that is largely defined by fine grained sericite. Formation of sericitic fabrics took place under greenschist facies conditions at ~400 °C. Consequently, Ar-loss in these sericites was related to deformation-induced crystallization, and not thermal diffusion. Our Ar/Ar sericite ages thus provide direct time constraints for the deformation-event.

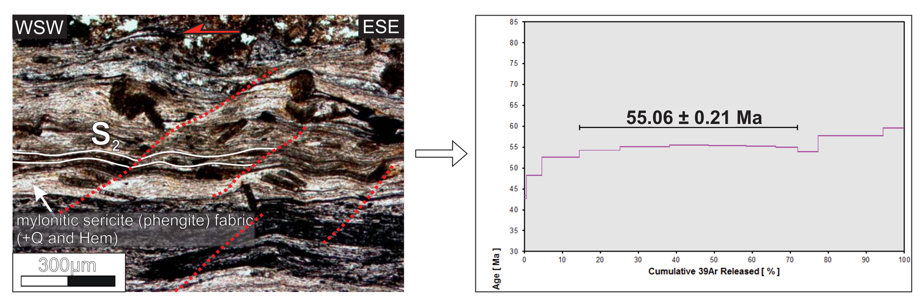
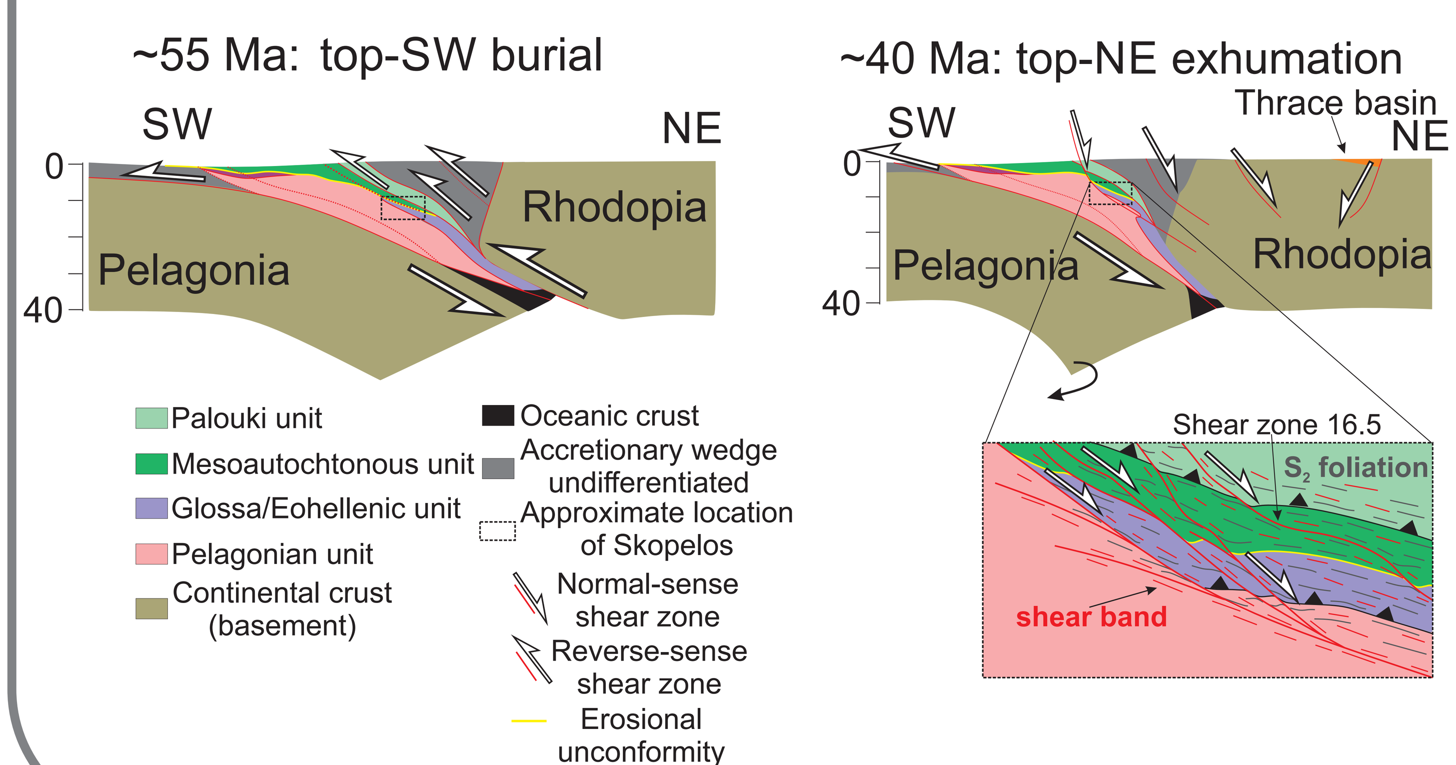


Figure 10. Thin section image of sample 3.3 showing a mylonitic sericite foliation that yielded the age plot on the left side.

Sample ID	Age [Ma]	±1σ error [Ma]
2.2	74.75	0.39
3.3	55.06	0.21
7.1	62.22	0.45
7.2	64.09	0.5
12.3	53.22	0.34

Table 1. Table of Ar/Ar sericite age results.

Geodynamic implications and conclusions



Concluding remarks:

- Tectonic burial by top-SW thrusting initiated in the latest Cretaceous – Early Paleocene, and resulted in the stacking of the outcropping geological units of the islands.
- All the formations were buried to greenschist facies conditions, where shortening was largely accommodated by the formation of reverse-sense shear zones.
- Tectonic burial resulted in the formation of a fine-grained sericite foliation which yields Ar/Ar ages between 74 and 53 Ma.
- .Top-SW thrusting was followed by top-NE shearing related to the extensional exhumation of the formations. Top-NE shear zones localized at pre-existing stratigraphical and tectonic contacts, and are subparallel with the main foliation.
- Ductile top-NE shearing was gradually replaced by normal faulting which was driven by both NE-SW and NW-SE extensional directions. Normal faults are characteristic features of the whole Northern Sporades and are linked to the formation and evolution of the North Aegean Trough.

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