Despite of pre-Tertiary ages that have been suggested long time ago, radiometric determinations from Cycladic rocks and from the external Hellenides have coined the idea in the last two decades that blueschist facies metamorphism in the Hellenides was of Tertiary age.

However, a pre-Tertiary age for the onset of HP/LT metamorphism is supported by the occurrence of detrital blue amphiboles found within Paleocene flysch deposits of the Othrys Mountain that lie over karstified, occasionally strongly eroded Upper Maastrichtian limestones. These deposits contain frequently minor amounts (<10%) of blue amphiboles. Analyses of these detrital grains were compared with published analyses of blue amphiboles from known blueschist terrains in order to reveal their potential provenance.

Blue amphiboles from Pelagonian rocks (Olympos and Ossa) show a very wide variation that does not coincide with that of the detrital grains. This is mainly due to the widely varying bulk composition and their incomplete overprinting relations. For example, in many cases, blue amphiboles have been reported as overgrowths over green amphiboles, suggesting incomplete HP/LT overprinting of greenschist or amphibolite facies precursors. A Pelagonian source for the detrital grains is also excluded because this incomplete HP/LT overprint took place in post-Paleocene times.

Most Cycladic sources show a narrow compositional variation that generally coincides with that of the detrital blue amphiboles. However, currently available evidence suggests that the Cycladic islands reached the erosion surface at Miocene times. This precludes the Cyclades as sources of the detrital blue amphiboles in the Paleocene flysch deposits. We therefore suggest the following:

1. Blueschist facies metamorphism in the Hellenides started at pre-Tertiary times.
2. The source of the detrital blue amphiboles in the Paleocene flysch deposits of the Othrys Mountain is presently not exposed, but may have been covered tectonically during the Tertiary. It has been exposed to erosion during Maastrichtian/Paleocene times.
3. This source as well as the Cycladic blueschists and those of the Ambelakia unit were slices of HP/LT rocks that (a) originated by subduction of the Pindos ocean at the external active margin of the Pelagonian and (b) were extruded from the orogenic wedge at different times.

The new Metamorphic Core of Serifos (Western Cyclades, Greece)

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The Southern Aegean area of the Cycladic islands is characterized by a N-S directed extension since the Miocene. This extension led to the formation of metamorphic core complexes (Naxos, Paros, Ios in the eastern Cyclades). In most cases, the shallow dipping extensional detachments show a top-to-N directed movement. This work presents a similar, but S-directed structure exposed on the western Cycladic island of Serifos.

Serifos is dominated by a Hbl + Bt-granodiorite that intruded before 8-9 Ma a low-grade metamorphosed volcano-sedimentary series comprising marbles as well as metabasic and lesser metapelitic rocks. The intrusion induced conduct phenomena and extensive formation of Ca-Fe-Mg-skarn and Fe-ore deposits. The metasomatic and hydrothermal processes have been extensively studied by Salemink (1985). The position of Serifos within the tectonic framework mentioned above is, however, less clear.

Based on extensive structural and geologic mapping, it can be convincingly shown that the island of Serifos corresponds to the foot wall of a metamorphic core that is characterized by S-directed movements. Parts of the ductile detachment zone comprises commonly lineated sericite±graphite schists and marble mylonites and occur in form of patches exposed mostly at the margins of the island. The shallow-dipping mylonitic foliation follows the shape of the island and underlines its dome structure. Well-developed stretching lineations strike firmly NNE-SSW and numerous kinematic indicators (scc' fabrics, σ- and δ-clasts, flanking folds, mica-fish etc.) suggest unequivocally S-directed extensional movements. Relic patches of the hanging wall are restricted only at the SW part of the island. They occur above a thick cataclasite horizon and comprise allochthonous serpentinites and ankeritic limestones.

The granodiorite shows a rather unstrained core. Towards its southern margin, it becomes more intensively foliated. It finally has been wrapped by the detachment zone and evolved to an ultra-mylonite. Its northern margin lies markedly below the detachment zone and shows clear intrusive contacts against the country rocks. These features suggest that the granodiorite is syn- to post-kinematic.

The foot wall rocks form the northern part of the island. They are folded and show persistent E-W directed stretching lineations that pre-date the formation of the detachment zone. Towards the detachment zone, these structures become overprinted by younger N-S directed extensional movements.

The latest evolution of Serifos is documented by conjugate WNW-ESE striking brittle faults that are associated with sub-volcanic vein intrusion. These veins are mostly unstrained and cross-cut the granodiorite as well as the detachment zone. These features are consistent with the N-S extensional regime still prevailing in the Southern Aegean region.

Salemink, J., 1985: Skarn and ore formation at Seriphos, Greece, as a consequence of granodiorite intrusion. PhD Thesis, University of Utrecht.

Alpine structures and their evolution: numerical modeling and natural examples

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Recent geophysical investigations have highlighted the crustal structure of the Swiss Alps: a bivergent orogen, in which upper crustal units were stacked northwards and southwards above an asymmetric subduction geometry involving lithospheric mantle and lower continental crust. Numerical dynamic modeling explains how upper crustal material from thinned crustal sections can be subducted to greater depths, whereas in normal crustal sections the upper crust detaches from the lower crust and becomes accreted to the upper plate.

A simple conceptual model for modes of accretion, erosion and subduction at convergent margins can be described in terms of the mass flux among four components: the accretionary wedge (pro-wedge); plug uplift; retro-wedge; and the subduction zone, the latter consisting of a conduit of slowly-deforming material and a rapidly-deformed subduction channel. The subduction conduit widens or narrows in response to flexural loading of the downgoing plate and the relative fluxes of tectonic erosion, accretion and underplating. Crustal-scale models span a continuum of behaviour from single-vergence, with development of a landward dipping (pro-)shear zone, to double-vergence with formation of a seaward dipping (retro-)shear zone. Results show that single-vergent deformation occurs whenever the mass flux lost by subduction is equal to or greater than incoming mass flux. This mode can develop dynamically by flexural compensation and/or subduction retreat.

The combined action of pro-shear (nappe stacking) and retro-shear (back-thrusting) uplifts a plug between the two shear zones. Subsequent focusing of shear along the retro-shear zone results in rotation of the plug and overlying units, leading to crustal-scale backfolds. Heterogeneities in the pro-crust focus shear and lead to the development of “nappe structures“. Accretion of small continental terranes within a model subduction zone can cause crustal-scale fold nappes and shear zones to develop, with accompanying tectonic underplating and/or frontal accretion. In the case of the Swiss Alps, the entrance of the European margin into the Alpine subduction zone triggered back-thrusting along the Insubric Line and the adjacent units ultimately leading to the development of a bivergent thrust belt. Underplating and plug-uplift between pro- and retro-shear accompanied by erosion led to the exhumation of high-grade rocks in the core of the orogen. The model experiments predict features relevant to Alpine dynamics, including (1) similar crustal thicknesses and exhumation patterns, (2) continued accretion and subduction of upper crustal fragments allowing high-pressure metamorphic conditions, (3) tilting and exhumation of lower crust when a midcrustal weak zone is present, and (4) “shunting“ of material across the strong lower crustal wedge of the upper plate.

Experiments concentrating on nappe-scale structures suggest that the formation of detachment folds require a high thickness ratio between detachment horizon and the competent unit above. Imbricate thrust sheets evolve in the case where the detachment horizon is thin. Lateral heterogeneities in the cover sediments control the nappe internal structures. For example, discontinuities such as present in passive margin sequences are preferential sites for the nucleation of folds and thrust faults.

Morphogenesis: interaction between crustal and surface processes

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Morphogenesis at convergent plate boundaries reflects material fluxes at the surface and in subsurface. The fate of material entering a convergent margin is many-sided. In the simplest cases it gets subducted into the mantle, or accreted to the margin. Accretion leads to the formation of an orogenic wedge, the growth of which implies internal deformation and the creation of an elevated area (surface uplift), which in turn triggers denudation. Thus,