Plattenkalk Unit of the Psilorites Mountains

View of the Psilorites Mountains as seen from the Skinakas Peak Observatory looking westwards. In the foreground the Petradolakia area displaying karstic erosion of the the Tripoliza nappe. In the background mountain ridges consisting of platy marble. [Source: Psiloritis Geopark WebGIS]

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Berlin, January 2024

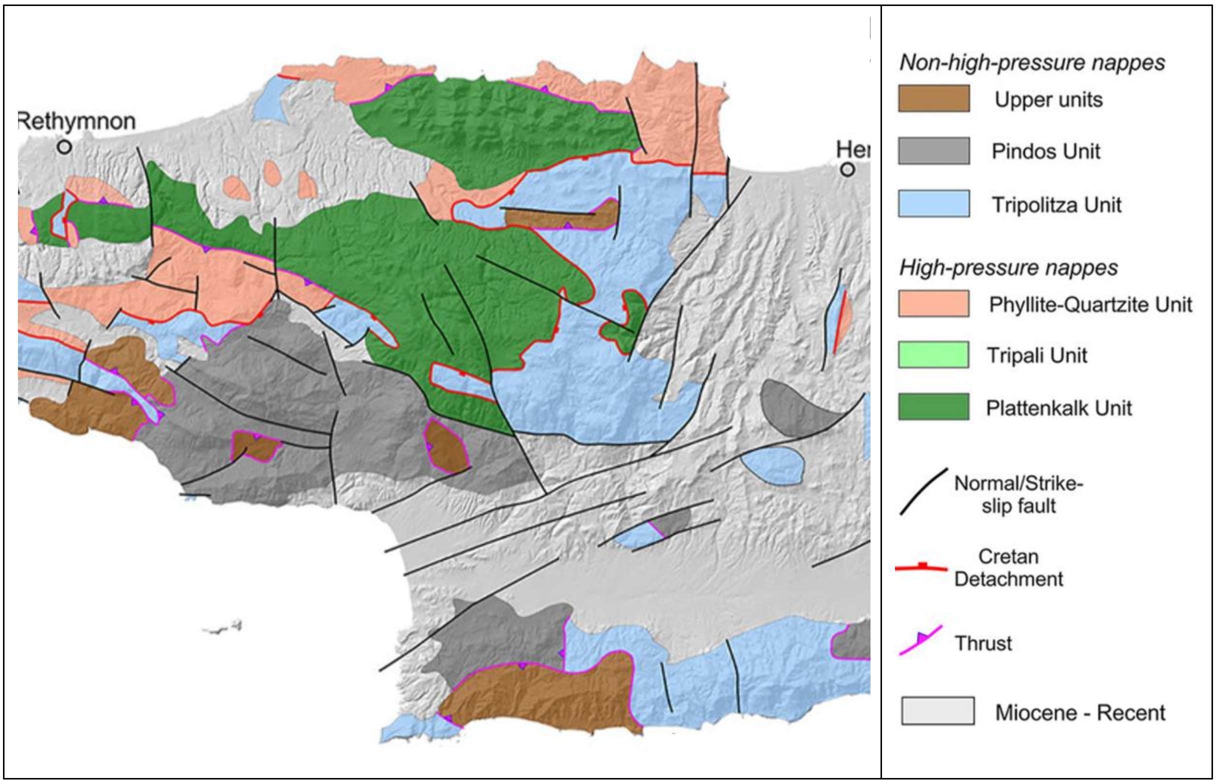
Contents

Appendix

1 Introduction - Plattenkalk Unit

The following introduction on the general Geology of Crete was taken from Thomson's paper on the high-pressure metamorphic rocks of Crete regarding his "rapid exhumation by buoyant escape theory". The other sections of the field guide are primarily based on a field guide created by Rahl J. et. al. titled "Exhumation of high-pressure metamorphic rocks within an active convergent margin, Crete, Greece". In addition to my observations, I have also included information from other authors. Photographs were taken by me.

The island of Crete is situated above the present-day Hellenic Subduction Zone of the eastern Mediterranean Sea and is one of the few places in the world where very young (Miocene) HP-LT metamorphic rocks are recognized as having been juxtaposed by extensional detachment (Fassoulas et al. 1994; Kilias et al. 1994; Jolivet et al. 1996) against non-metamorphic rocks within a convergence zone dominated by oceanic subduction. From simple stratigraphic relationships, Crete has been shown to be composed of a series of thrust sheets, which were formed by collision of the northern margin of the Adria microcontinent with the southern margin of the Eurasian Plate during Oligocene and Miocene time at a convergent plate boundary dominated by subduction (Robertson et al. 1991).



Geological Map of Central Crete defining high pressure metamorphic and non-high pressure metamophic nappes. Source: Ring U. et al, 2022. Modify legend (Uppermost Nappes and HT/LP, LT/HP respectively)

On Crete two main rock groups can be identified: a lower group comprising rocks that show pervasive Oligocene-Miocene HP-LT metamorphism, and an upper group that shows no evidence of Tertiary metamorphism. This major metamorphic break in the sequence has long been difficult to explain (see Robertson & Dixon 1984, p. 47). However, Lister *et al.* (1984) proposed a model where the HP-LT metamorphic rocks of Crete were exhumed along a shallow dipping extensional detachment from under a stretching and fracturing upper plate composed mainly of unmetamorphosed sedimentary rocks and ophiolite suite rocks. More recent studies by Fassoulas *et al.* (1994), Kilias *et aL* (1994), Jolivet et al. (1996) and Thomson *et al.* (1998a) also concluded, albeit with an opposite sense of motion along the extensional detachment, that the two rock groups must have been juxtaposed by a major low-angle extensional detachment sometime during the Miocene.

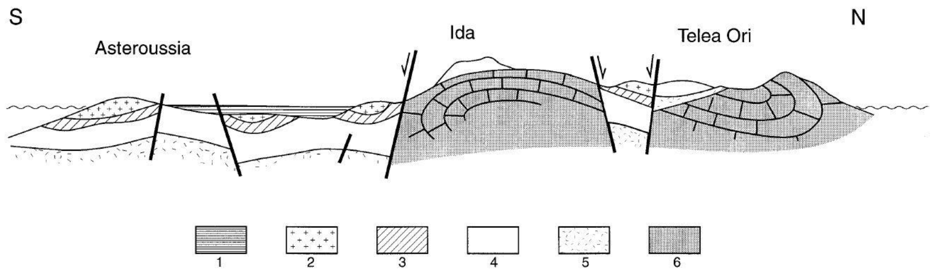
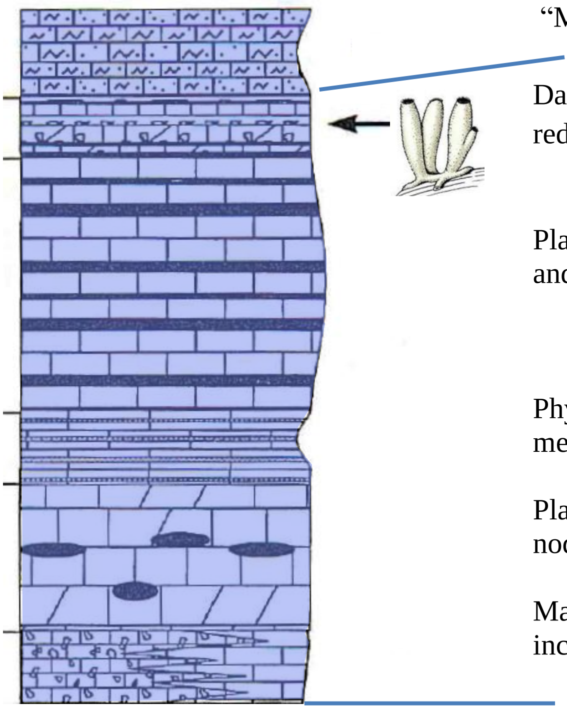


Fig. 2. N–S cross-section redrawn from Bonneau *et al.* (1977) showing the most important fault and fold features, as well as the stacking of tectonic nappes. 1 = Neogene basin fill, 2 = Ultra Mafic Series, 3 = Pindos Series, 4 = Tripolitza Series, 5 = Phyllite–Quartzite Unit, 6 = Plattenkalk Series.

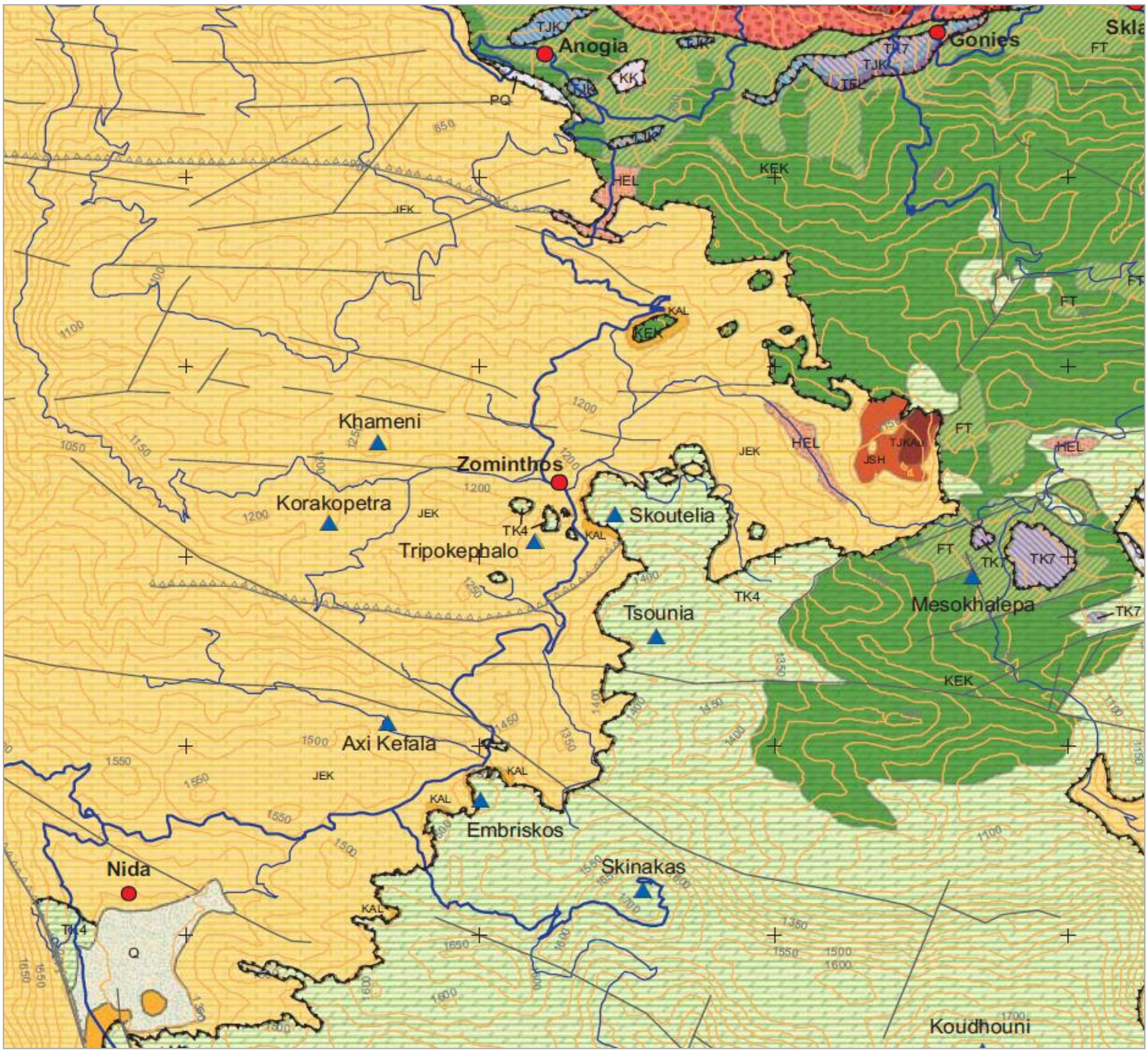
Idealized N-S section through Central Crete showing the tectonic structure of the various nappes. [Source: Middle and Late Miocene outer-arc basin evolution, Crete JH ten Veen]

Three main thrust sheets occur in the 'upper plate' (above the detachment fault; see Lister & Davis (1989)). These are labelled, from top to bottom, the Uppermost, Pindos, and Tripolitza units. These units represent a shallow accretionary sequence formed before and during the Oligocene to Miocene collision of the Adria microcontinent with Eurasia. The Uppermost unit is generally considered to represent a mélange or olistostrome formed at the southern leading edge of the Eurasian Plate during northward directed subduction of the Pindos branch of the Neotethys Ocean (Robertson *et al.* 1991) and before the collision of Adria. It contains elements derived from both the Jurassic-Cretaceous Pindos Ocean, such as oceanic pillow basalts, gabbros, deep-water carbonates and cherts, and serpentinized mantle fragments, as well as bits of the overriding Eurasian Plate, which comprise Jurassic HP-LT metamorphic, and Late Cretaceous high temperature-low pressure (HT-LP) metamorphic and plutonic rocks. The rocks of the Pindos unit represent the accreted distal parts of the northern continental margin of the Adria microcontinent, and comprise largely deep-water Mesozoic to early Tertiary carbonates and cherts. The Tripolitza unit contains rocks of similar age that were accreted from the more proximal shallow-water platform carbonates of the colliding Adria microplate. From Palaeocene to Eocene time onwards, both the Pindos and Tripolitza units are dominated by terrigenous flysch deposits derived from the overriding Eurasian Plate (Hall *et al.* 1984).



Stratigraphic section of the Platy Marble Group (Aloides Fm.)

Directly below the main extensional detachment HP-LT metamorphic rocks of the Phyllite- Quartzite (PQ) unit are found, and below this, representing the deepest tectonostratigraphic unit seen in Crete, is the Platy Marble or Plattenkalk (PK) unit, which also shows evidence of an HP-LT metamorphic overprint (Seidel *et al.* 1982). The PQ unit contains largely Carboniferous to mid-Triassic clastic sedimentary rocks, with some local carbonates and evaporites (Krahl *et aL* 1983). This unit is thought to represent the older stratigraphic continuation of the carbonate Tripolitza unit, as originally proposed by Bonneau (1976). Whereas the Tripolitza unit underwent accretion at shallow depth, the PQ unit would then have continued its downward subduction, probably underthrust along a weak mid-Triassic evaporite horizon, and subsequently accreted at much greater depth. It is also likely that these evaporites, now largely seen as large gypsum bodies within the upper parts of the PQ unit, formed a weak zone allowing the development of the main extensional detachment during the subsequent exhumation of the HP-LT lower plate of Crete. The PK unit is dominated by Permian to Eocene, initially shallow-water, but mainly deep-water carbonates and cherts, with a minor Eocene to Oligocene calcareous flysch in its uppermost part (Seidel *et al.* 1982). These rocks are thought to represent the sedimentary cover of the southern continental margin of the Adria Microplate, and have been correlated with the carbonates of the Ionian Zone of western mainland Greece by Bonneau (1984). The crystalline continental basement, which must have underlain many of these accreted sedimentary units or thrust sheets, is generally not seen in Crete, although a few small outcrops of Hercynian metamorphic rocks are exposed associated with PQ unit rocks in eastern Crete (Wachendorf *et al.* 1974; Seidel *et al.* 1982). See Appendix for the “Rapid exhumation by buoyant escape model” by Thomson. N et. al., 1999 *[Thomson S., 1999].*



Quartär und Tertiär

- AL — Holozän: alluviale Ablagerungen, v.a. Kiese, Sande, Schluffe
- HEL — Holozän: Terra Rossa und eluviale Ablagerungen
- Q — Quartär: Konglomerate, Sande, Tone
- PP — Plio-Pleistozän: Mergel, Sande, Tone, Brekzien
- MT — Mittleres - oberes Miozän: Brekzien, Tonsteine, Mergel
- Mbr — Unteres Miozän: Kalkbrekzien

Allochtone Serien (OPH)

- JSOP — Oberer Jura - untere Kreide: tektonische Melange mit Mergeln, Kalk- und Sandsteinen
- OP — Ophiolithischer Komplex: Peridotite, Pyroxenite, Amphibolite, Gneisse, Gabbros, Dolerite

Pindos-Serie

- KK — Obere Kreide: Kalksteine
- TK7 — Oberer Jura - obere Kreide: klastische Sedimente, Tonsteine, Cherts
- TJK — Obere Trias - mittlerer Jura: Kalksteine, Brekzien, Mergel
- TFL — Obere Trias: Sand- Kalk- & Tonsteine, Mergel

Tripolitza-Serie (TK)

- FT — Oberes Eozän - Oligozän: Flysch (schiefrige Mergel, Pelite)
- KEK — Obere Kreide - Eozän: Kalksteine, Dolomite (stark verkarstet)
- TK4 — Perm - obere Kreide: Kalksteine, Dolomite (stark verkarstet)

Phyllit-Quarzit-Serie (PQ)

- PQ — Perm - Trias (?): Pelite, Quarzite, Phyllite, Schiefer

Plattenkalk-Serie (PK)

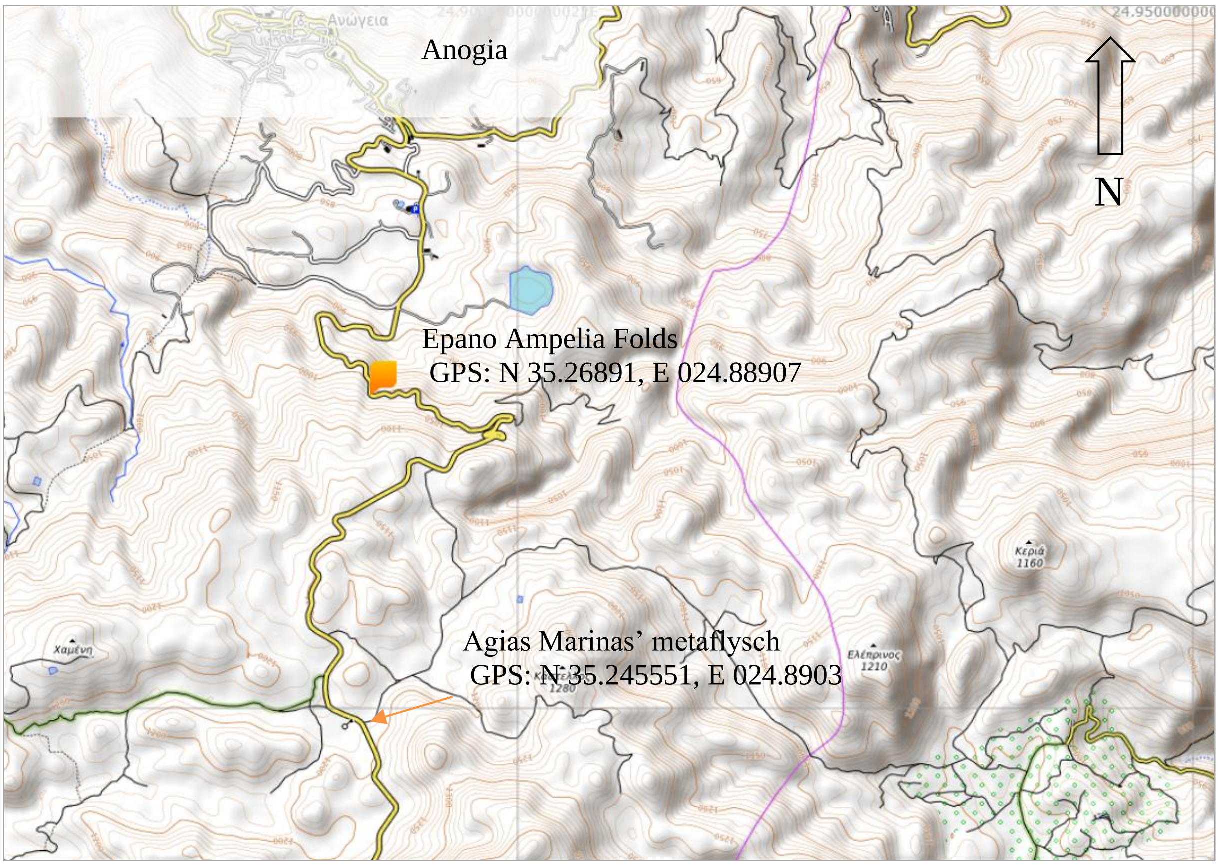
- KAL — Oberes Eozän - unteres Oligozän: Kalkschiefer, Kalke, Mergel, z.T. von geringmächtigem Flysch überlagert
- JEK — Oberer Jura - oberes Eozän: Plattenkalk, Chertlagen
- JSH — Mittlerer - oberer Jura: Tonsteine, Cherts, Kalk, Schiefer
- TJKA — Mittlere - obere Trias: Pantokratora-Kalkstein

Ortsnamen **Gipfel** **Straßen**

Deckenüberschiebung **Störung** **Verwerfung**

2 The Petradolakia Area

2.1 Epano Ampelia Folds



Location of outcrops folds near Epano Ampelia and exposed Agias Marinas' metaflysch

The Plattenkalk Group is the deepest tectonostratigraphic unit exposed on Crete. It consists of a Permian to Oligocene sequence of marbles, dolomites, and platy limestones that represent the sedimentary cover of the southern continental margin of the Adria microcontinent. These characteristic beds can be seen along the road from Anogia to the Psiloritis Mountains.

While driving South through the village of Anogia one passes through the Cretan Detachment (Psiloritis Thrust), which represents the contact between the Upper and Lower Nappes. At this location Tripoliza limestone lies on top of Plattenkalk. Unfortunately, the contact zone is quite diffuse due to scree and vegetation, but cataclastic rock is exposed in some places. After leaving Anogia elevation increases and the hillslopes to the east and west are exposed displaying Plattenkalk and Tripoliza limestone. The Plattenkalk is platy and more subdued, whereas the Tripolitza, lying above the detachment is lighter and rockier.

Location of outcrops I and II displaying Epano Ampelia Folds [Source of image: Google Maps]

Overview of outcrop I displaying folds in Platy Marble (Plattenkalk)

Outcrop I. Close up (see arrow on previous picture)

Contact between two Platy Marble beds. 1: Fine grained dark marble, 2: Coarse grained marble, which is reported to be the result of fluids travelling along bedding planes, 3: White chert nodule

Sample of fine grained Plattenkalk from the Outcrop I shown above (1)

Sample of coarse grained Plattenkalk from the Outcrop I shown above (2)

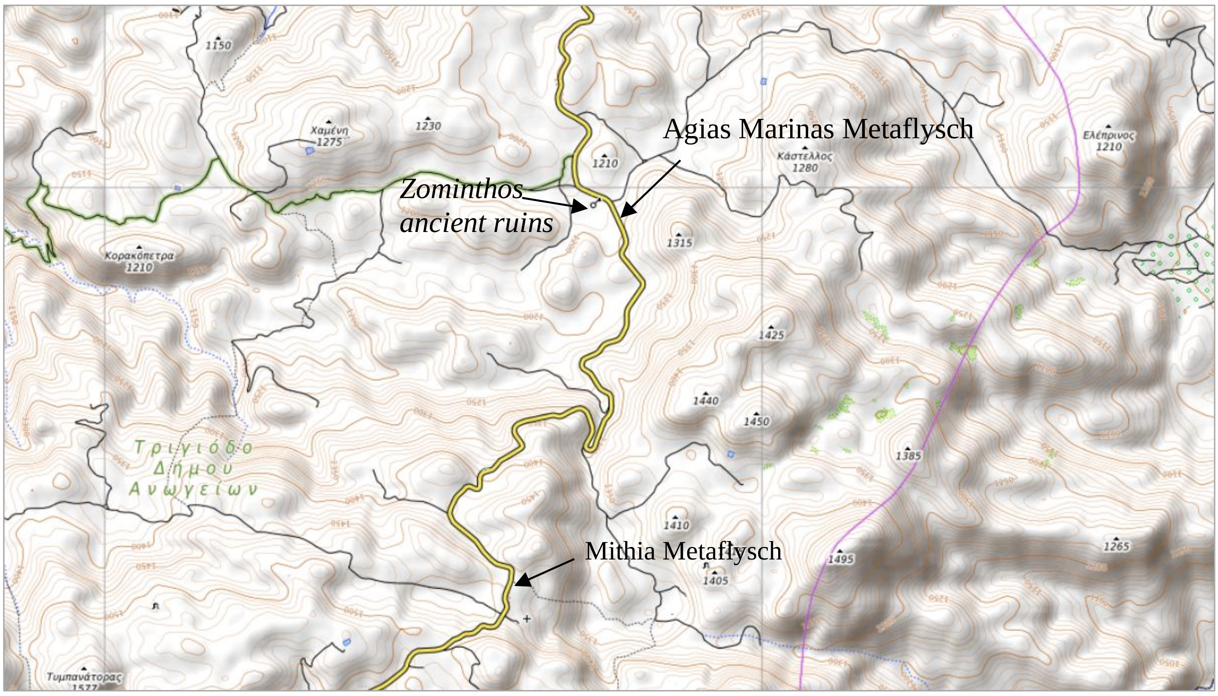
Generally, the Plattenkalk rocks have a fine-grained texture. However, recrystallization and an increase in grain size are commonly observed around cracks and at bedding contacts. These features may mark pathways for fluids that promoted metamorphic recrystallization. The bulk of the Plattenkalk must have been very dry, because there is little evidence for metamorphism in the platy limestone horizons despite the fact that these rocks reached maximum PT conditions estimated at 0.8 GPa and 350°C (Theye and Seidel, 1991). *[Rahl J.M., 2004]*

Overview of Outcrop II

Sparse undeformed fossils found in the area, indicate that this part of the section was deposited in the Eocene (Bizon et al., 1976). The Plattenkalk is characterized by tight to isoclinal mesoscale and map scale folds. The folds generally have east-west trending axes and are asymmetric with southward vergence. Here, the folded layers of the Plattenkalk generally maintain their thickness, indicating that the folds have developed primarily by flexural shear. Note that the cleavage-bedding intersection is the same on both the upright and overturned limbs, with a geometry consistent with the top-S vergence of the folds. The deformation in the limbs was apparently dominated by an outcrop scale top-S shearing. Note that this deformation could be due to shear in a limb of larger fold, especially given the fact that folds with amplitudes of 500 m and greater are recognized in the Plattenkalk. Folding obviously took place after deposition of the youngest Plattenkalk at about 29 Ma. The folding is commonly attributed to a first phase of thrusting during late Oligocene accretion at the Hellenic subduction zone (see phase D1 after Chatzaras, 2006). *[Rahl J.M., 2004]*

Closeup of Outcrop of II (see arrow on previous picture) showing thick white chert layer.

2.2 Agias Marinas Metaflysch



Following the road southward towards the Nida Plateau, one moves stratigraphically up section within the Plattenkalk. At Agias Marinas you will have reached the youngest rocks of the group, and a facies change occurs from the well-bedded platy limestones with chert interbeds to an approximately 10 m - 30 m thick package of metamorphosed calcareous turbidite sandstone (calcilutites) and siliciclastic deposits intercalated with limestone. The metaflysch as it is locally called, is well foliated having the appearance of a schist or phyllite. The metaflysch interval is the youngest part of the Plattenkalk Group, and is thought to represent an influx of siliciclastic continental material as the Plattenkalk carbonate platform approached the subduction zone (see Section: 1 Introduction and Appendix) *[Rahl J.M., 2004]*.

View from the metaflysch outcrop looking South. The outcrop lies at the left side of the road (arrow).

Outcrop of Agias Marinas metaflysch, displaying carbonate rich siliciclastic schist.

Closeup of previous picture

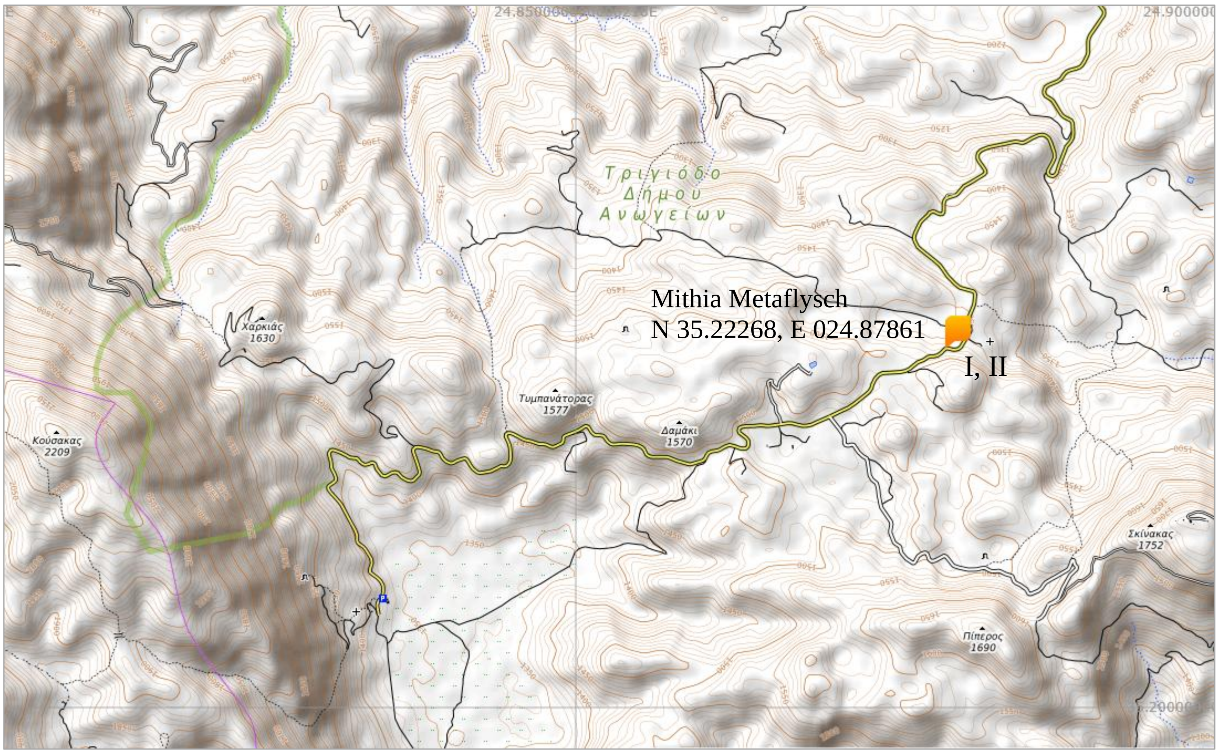
1: Carbonate rich siliciclastic schist, 2: Intercalated limestone layer

2.3 Mithia Metaflysch

Near Mithia at about 1433 m above mean sea level there is one of the largest outcrops of Plattenkalk metaflysch in the area. The metaflysch is intensely deformed revealing small scale folds. Foraminifera (Globigerina) within the metaflysch have been dated at 29.3 to 28.3 Ma (Bizon et al., 1976). The flysch has a weak, gently dipping bedding. A penetrative cleavage dips towards the north, as well as a spaced pressure-solution cleavage that dips to the south. Minor boudinage in the carbonate layers indicate that the rocks have experience some degree of layer parallel extension *[Rahl J.M., 2004]*.

Above the metaflysch outcrop lies Tripolitza limestone, which owing to the missing Phyllite-Quartzite Unit, represents a major unconformity. The tectonic contact that is a thrust plane and/or an extensional flat lying normal fault is regarded as the Cretan Detachment.

With time the Plattenkalk and the overlying Tripoliza limestones have formed a system of acquirers due to extensive karstic erosion. The metaflysch layer, that is offset in some places by faults, acts as an aquiclude enabling groundwater to emerge as springs. They can be observed at several places within the Psiloritis mountains *[GeoPark]*.

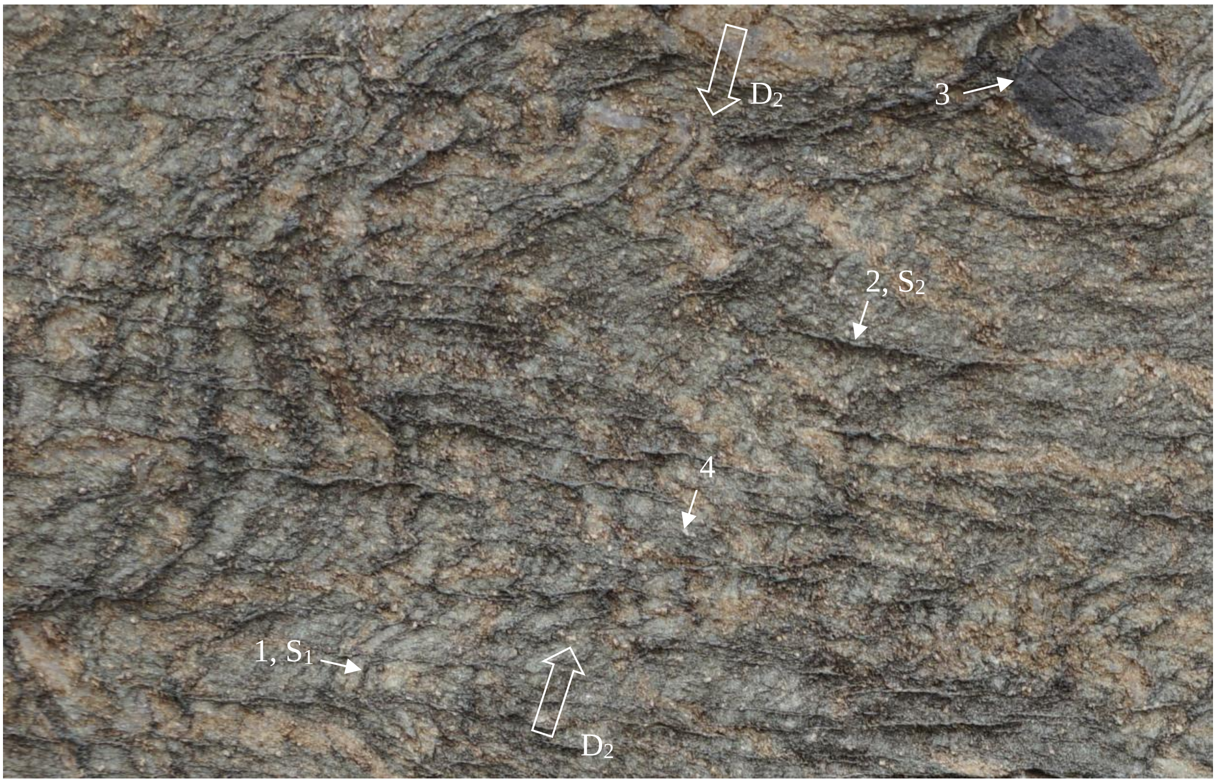


Outcrop location of the Oligocene Mithia Metaflysch at the top of the Plattenkalk

Mithia Metaflysch outcrops

Outcrop I: A calcschist is a form of metamorphosed argillaceous limestone that has a schistose structure. The term carbonate-silicate schist should be used in preference if the non-carbonate mineral content is more than 50 vol. % [Alex Strekeisen]. The schistosity is produced by the parallel orientation of the platy minerals during metamorphism.

Outcrop I: Closeup of the previous picture (see arrow). 1: Micro folds and parallel, second phase cleavage, 3: part of a former carbonate boudin.



Outcrop I: Closeup of previous picture showing a weathered surface. 1: First cleavage (S_1) deformed during second phase of deformation, 2: Second phase cleavage (S_2) that is parallel and more or less equally spaced; in this case foliation is attributed to "pressure solution" and foliation planes are perpendicular to compression (see arrows). 3: Part of a former carbonate boudin, 4: Sand grains that may have been deposited by a turbidity current.

Outcrop I: 1: Highly deformed carbonate boudin indicating a former bedding plain, 2: Calcschist displaying second phase cleavage (S_2).

Outcrop I: Closeup of previous picture. 1: Highly deformed carbonate boudin, 2: Presumed fold surface revealed by weathering. 3: Second phase cleavage attributed to "pressure solution" (S_2)

Outcrop I: Sample of dark limestone taken from a carbonate body/layer within the outcrop interpreted as a matrix supported carbonate breccia.

Overview of Outcrop II. 1: Marble layer indicating bedding plane, 2: Calcschist displaying two cleavage planes (see close up next picture)

Outcrop II, Box A. 1:Marble layer, 3:bedding plane, 2: Pressure solution cleavage (S_2)

Outcrop II, Box B. 1: First cleavage (S_1), 2: Pressure solution cleavage S_2 (see Appendix for description of cleavage types).

Outcrop II. Closeup of previous picture showing 1: finely spaced black platy minerals representing first cleavage (S_1). 2: The more widely spaced foliation created by pressure solution (S_2). The presents of two cleavages indicates two phases of deformation. 3: Notice the fine light-coloured dots that are sand grains.

Outcrop II: Slightly green coloured calc-silicate schist exposed a few meters further on. Calc-silicate schist is a metamorphosed calcareous rock, commonly derived from argillaceous limestone or calcareous mudstone, containing calcium-bearing silicates (such as chlorite, diopside and wollastonite) *with a schistose structure produced by parallel orientated platy minerals. At this spot the cleavage surfaces appear to be of sericite, which reflects the light very well and is white.*

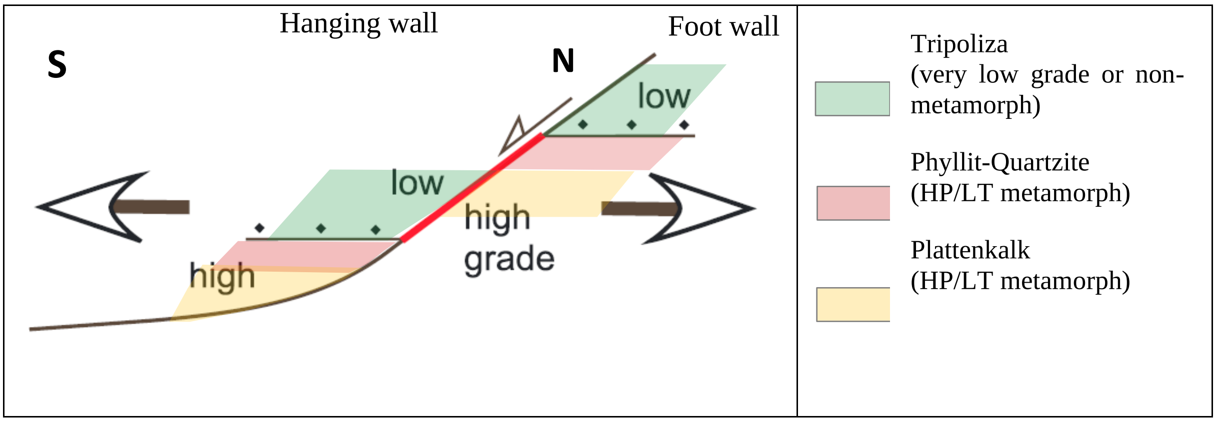
Outcrop II. At this spot the cleavage surfaces are shiny green, which could be due to the formation of chlorite along cleavage planes.

Outcrop II: Hand sample of marble from the same location as the previous picture. The marble is slightly green and displays minute grains of sand.

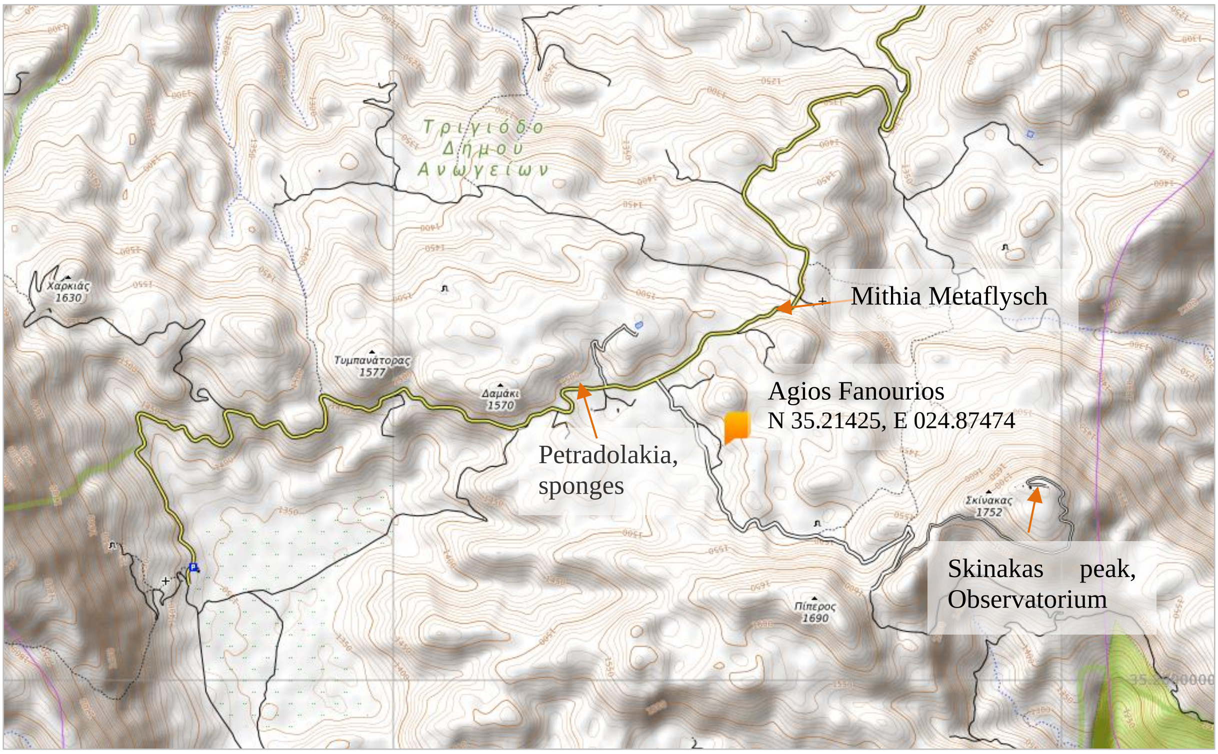
For further examples of Plattenkalk meta-flysch see My GeoGuide “No.7: Platy Marble Flysch, Triassic Gypsum and Andesite Lava, Mochlos to Kalavros”.

2.4 The Cretan Detachment - Church of Agios Fanourios

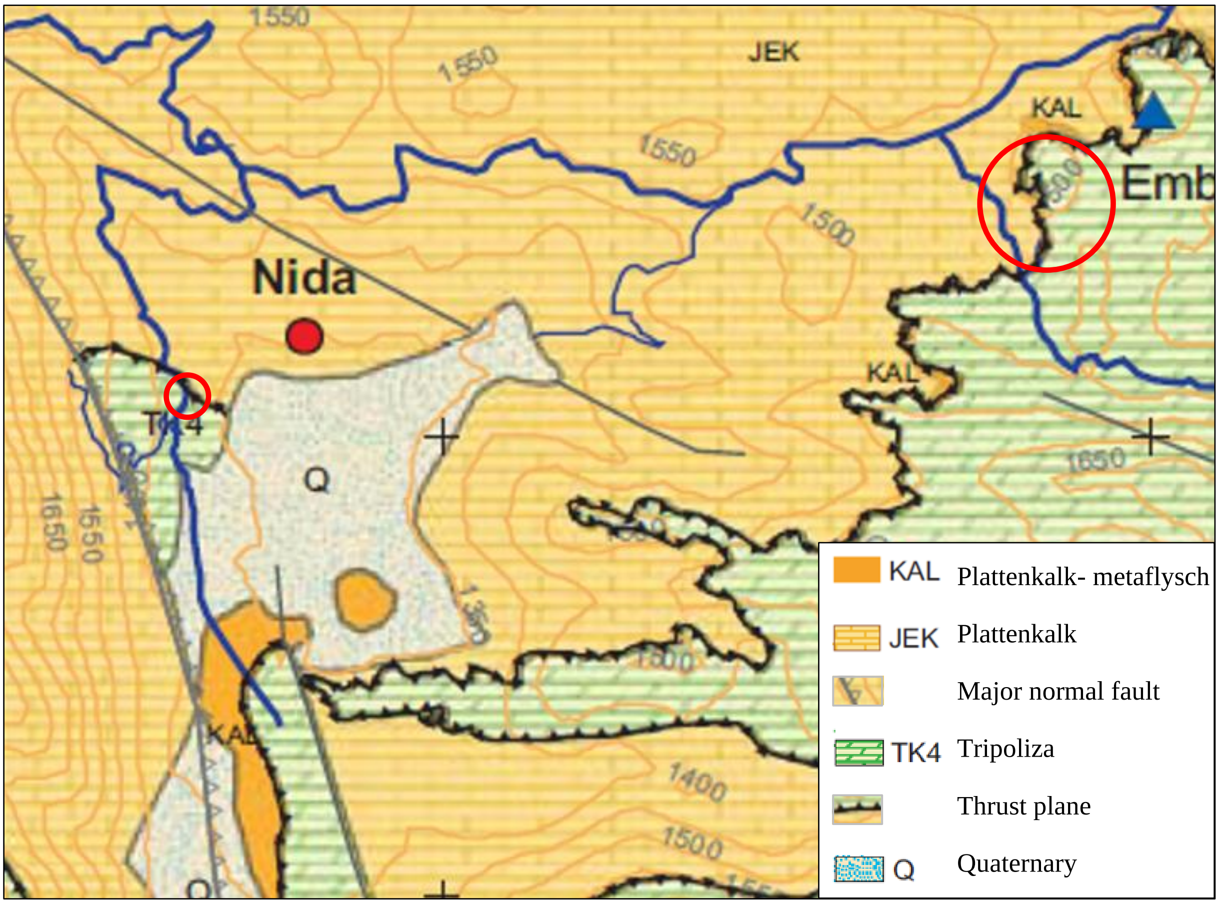
In central Crete, the HP-LT metamorphic Plattenkalk rocks are tectonically covered by non-metamorphic limestones of the Tripolitza Group. These units are separated by the Cretan detachment, a significant Miocene flat lying normal fault, which has cut out approximately 20 km of structural section – the Phyllite Quartzite Unit. An excellent exposure of the detachment can be found behind the Chapel of Agios Fanourious. The fault zone is nearly horizontal at this location. The footwall consists of Oligocene Plattenkalk “metaflysch”, and the hanging wall is made up of Tripolitza limestone. The relatively weak “metaflysch” preserves brittle structures that indicate top-S motion at this location on the detachment fault. Brittle, low-angle shear zones dip into the detachment zone. A schistosity has developed parallel to the detachment, and a steep, northward dipping foliation is present in the fault gouge. *[Rahl J.M., 2004]*.



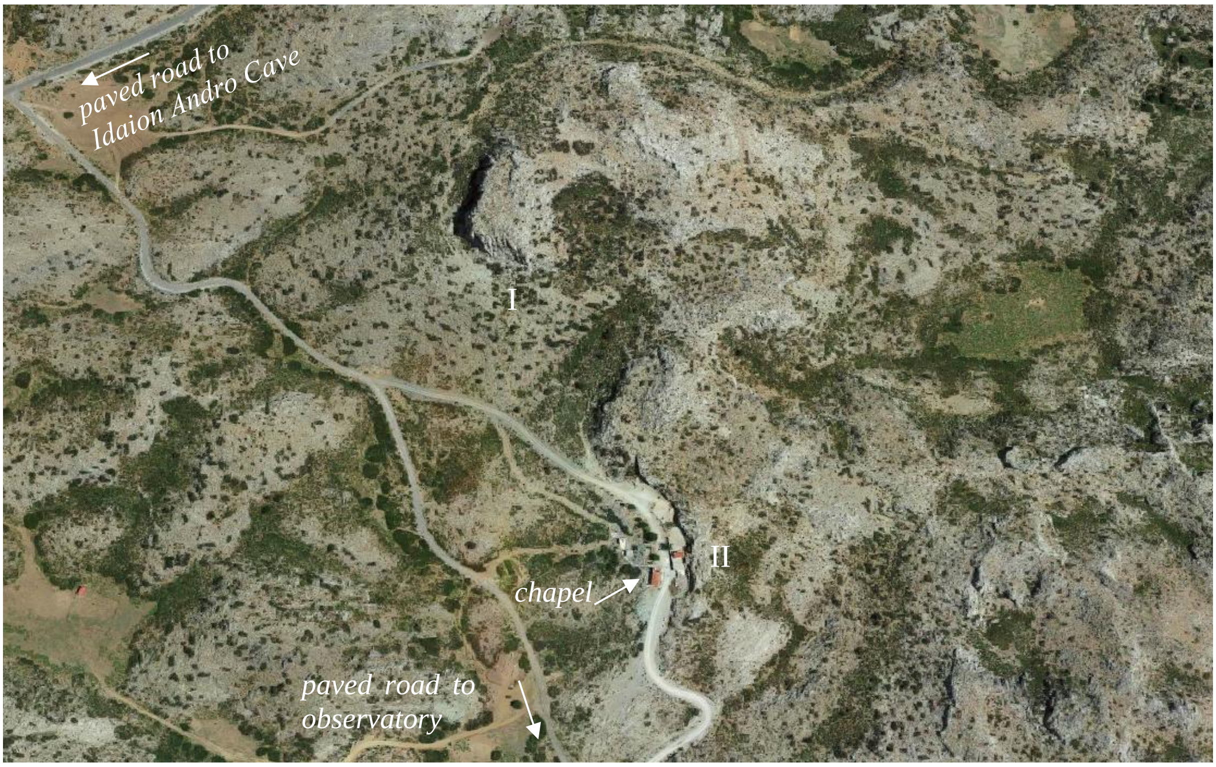
A normal extensional fault as a model for placement of Tripolitza on Plattenkalk. Note that the fault is thought in reality to have been very flat. There are also a number of other models involving compressional strain and wedge extrusion not discussed here [modified after Ring U., 2022].



Some of the locations described in this field guide



Geological map of the area. The large red circle shows the location the Cretan Detachement at the Agios Fanourios Chapel (thrust plane displaying Tripolitza on Plattenkalk metaflysch). The small red circle represents the Nida Plateau, View Point



Location of outcrops

Outcrop I. 1: Tripoliza, 2: Plattenkalk "metaflysch", 3: Plattenkalk

Outcrop I. Metaflysch from outside of the fault zone displaying foliation. It is presumed to be either a calcschist or calc-sicilic schist.

Outcrop II: Detachment fault at road cutting leading to the chapel (wall on the far left for scale). 1: Tripoliza limestone, 2: Highly sheared Plattenkalk metaflysch

Outcrop II: Agios Fanourios detachment fault. At this location the detachment fault is nearly horizontal. Limestones of the Tripolitza Group in the hanging wall rest upon the metamorphic Plattenkalk "metaflysch". 1: Tripoliza limestone, 2: Shear zone consisting of olive-green "metaflysch", 3: fault zone consisting of olive-green "metaflysch", 4: Highly foliated grey-green "metaflysch" outside of fault zone. Top of man made wall for scale.

Outcrop II, Box A. 2: Sigmoidal curvature of shear bands in the shear zone. Sigmoidal shapes developed within the "metaflysch" indicate top to the South motion at this part of the detachment.

Outcrop II. 2: Olive-green coloured calcschist or calc-sicilic schist. Hand sample taken from underneath the shear zone (resting on hammer head). The light olive-green colour appears to be superficial resulting from weathering.

Outcrop II. 3: Grey-green coloured calc-sicilic schist with two cleavage planes indicated by the rhomboid pattern of cleavage.

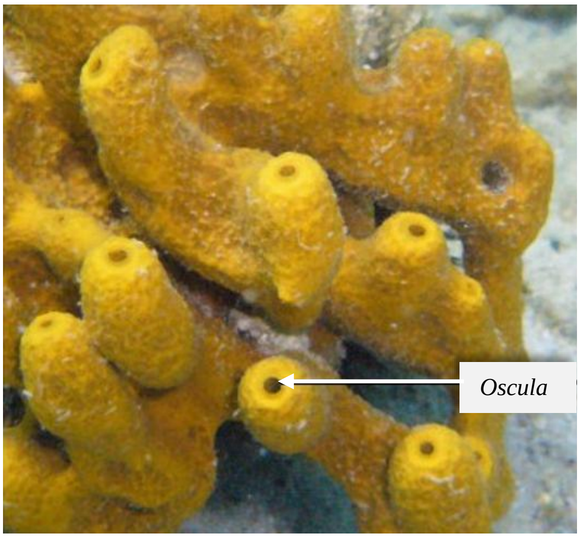
The Tripolitza rocks hold groundwater which is trapped by the impervious "metaflysch" layer. At the Almyros spring, which is one of a number of springs it seeps out of the detachment fault.

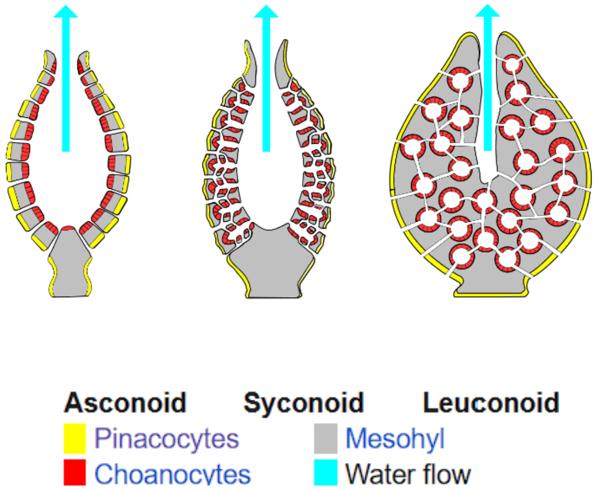
2.5 Petradolakia Sponges

Part of the Petradolakia area. 1: Sponges, 2: Doline, 3: Mitata (traditional stone hut) [Source of image: Google Maps]

The Petradolakia area possesses a large number of small plateaus (dolines) which have been formed by karstic weathering of the Plattenkalk marble and Tripolitza limestone. At this particular location the Plattenkalk Group that normally forms platy grey marble with interlaced white silica nodules and layers exhibits uniquely preserved sponges. The fossil sponges, that are reported to be between 50 to 100 Ma old, provide evidence for the origin of the white layers of chert within the Plattenkalk (Aloides Fm.). The findings are in contrast with a theory suggesting that the white chert is the result of the accumulation of silicious microorganisms such as radiolarians (Epting et al. 1972, Krahl et al. 1988 and Bruhn et al. 1993).

The presents of fossil siliceous sponge colonies (identified as lithistid Demospongiae) allows an assessment of the sedimentary environment in which they lived. Based on their maximum distribution the water depth was probably no more than approximately 300-400 meters. The depositional environment is therefore thought to have been at the edge of the carbonate platform, at the transition to the continental slope. The sponges have a rigid skeleton of an irregular type of specular called desmas, but the poor state of preservation does not allow a more precise taxonomic classification other than that there is a close resemblance to the family Siphoniidae and the suborder Rhizomorina. *[Manutsoglu E., 1995].*



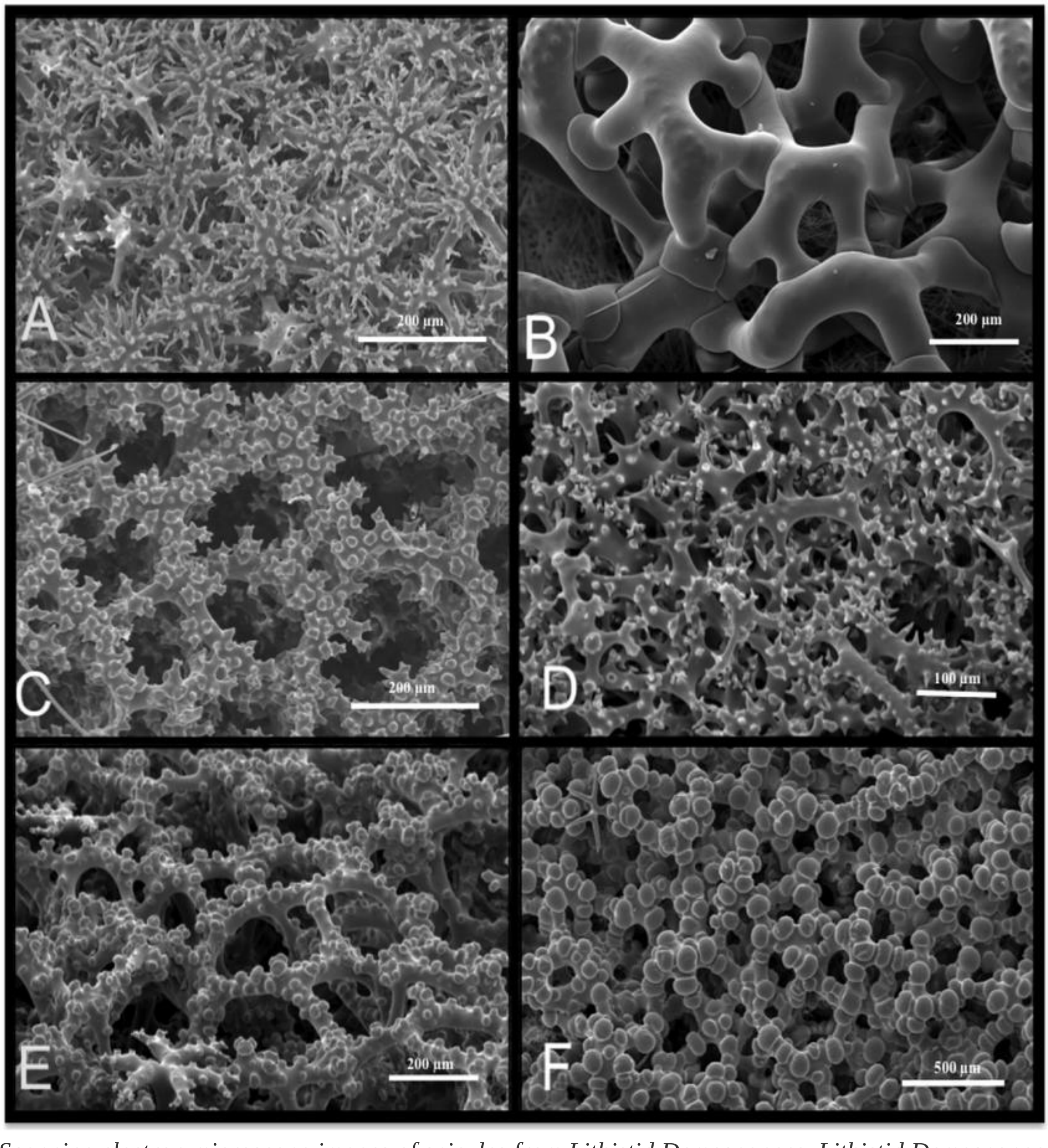


[Source: Wikipedia, Sponge - Wikipedia]

Fossil remains of silica sponge colonies attached to the top of a steeply dipping Plattenkalk bed. It is interpreted to represent the sea bed within the Tethys Ocean at that time. The individual Porifera colonies are closely interlinked, creating a stable framework. Unfortunately, numerous geologists and or tourists have already chipped away some of the fossil sponges.

Small flat sponge reef. The colony is characterized by multiple large openings (Oscula), which were the outlets of the sponges' water-current-system. Most sponges draw water and food (plankton) through pores within the sides of their walls. The water is ultimately ejected through the Osculum (see Appendix).

The main skeletal component of Demospongiae sponges is silica as opposed to calcium carbonate or fibrous organic materials. More than 95 percent of all known recent and fossil sponge species have a siliceous skeleton. The siliceous skeleton is usually composed of discrete elements known as spicules that vary greatly in size and shape from species to species and are hence often used to aid species identification.



Scanning electron microscope images of spicules from Lithistid Demosponges. Lithistid Demosponges are defined by the common possession of peculiar siliceous spicules called desmas that characteristically form rigid articulated skeletons. Lithistid sponges differ from other demosponges by the unique possession of desmas. (A) sphaeroclone desmas (Vetulinidae); (B) megaclone desmas (Pleromidae); C–D rhizoclone desmas (Scleritodermidae, Azoricidae, Siphonididae); E–F dicranoclone desmas (Corallistidae). [Schuster A. et al. 2014]

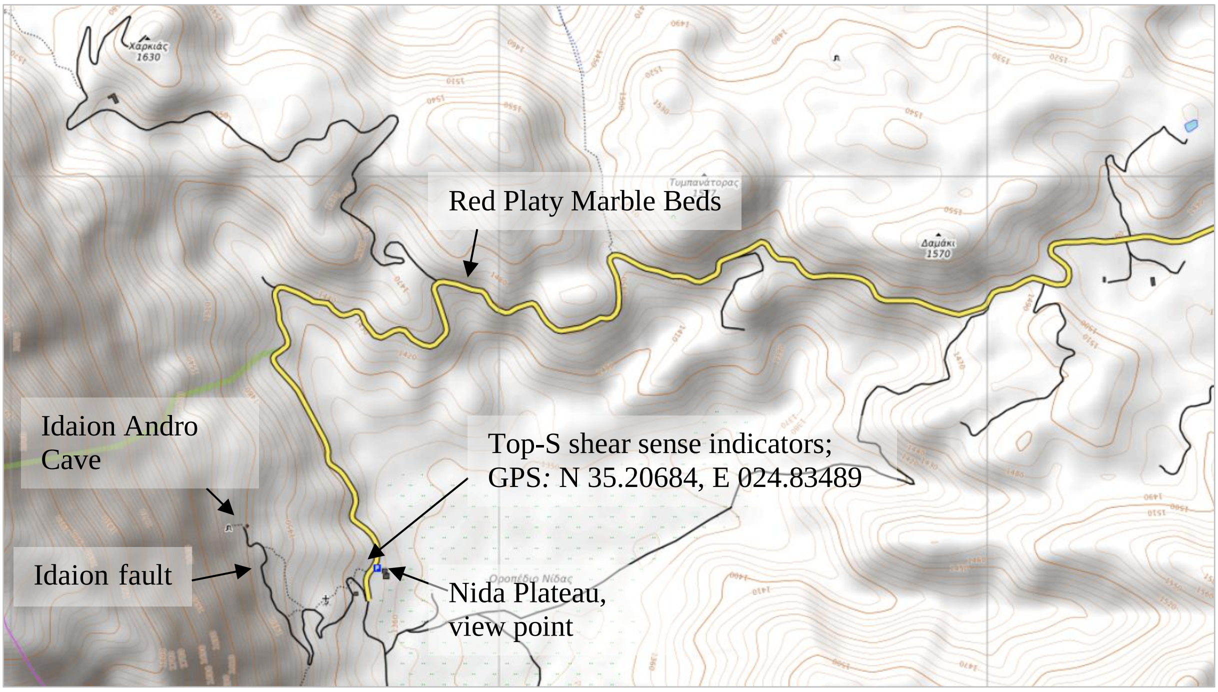
White silica layer sandwtched between grey Plattenkalk. The chert layer still bears some of the former features of the sponges after compression and metamorphism.

A distinctive landmark of the area are the abundant mitata, the traditional circular dry-stone constructions built by shepherds.

3: *A traditional shepard's hut called a "mitato" located next to the sponge outcrop.*

3 Nida Plateau

3.1 Red Plattenkalk Beds



Overview of the Nida Plateau area showing outcrop locations

Overview of the Plattenkalk containing red coloured beds (rucksack at edge of the road for scale).

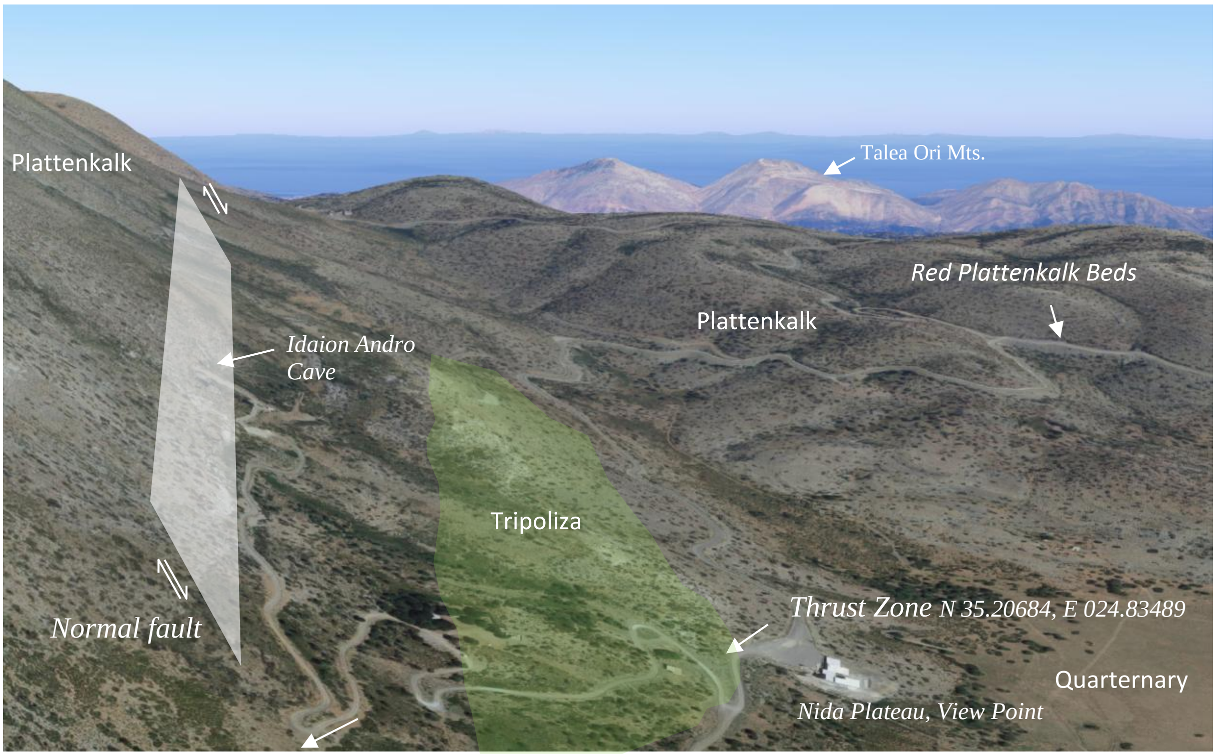
Closeup of previous picture. 1: platy marble, 2: white chert layer, 3: white chert nodules. The red-coloured beds, which can also be observed in north-eastern Crete (Mochlos, Kalavros), seem only to occur within the upper part of the Platy Marble section.

Closeup of the weathered surface of the red coloured beds.

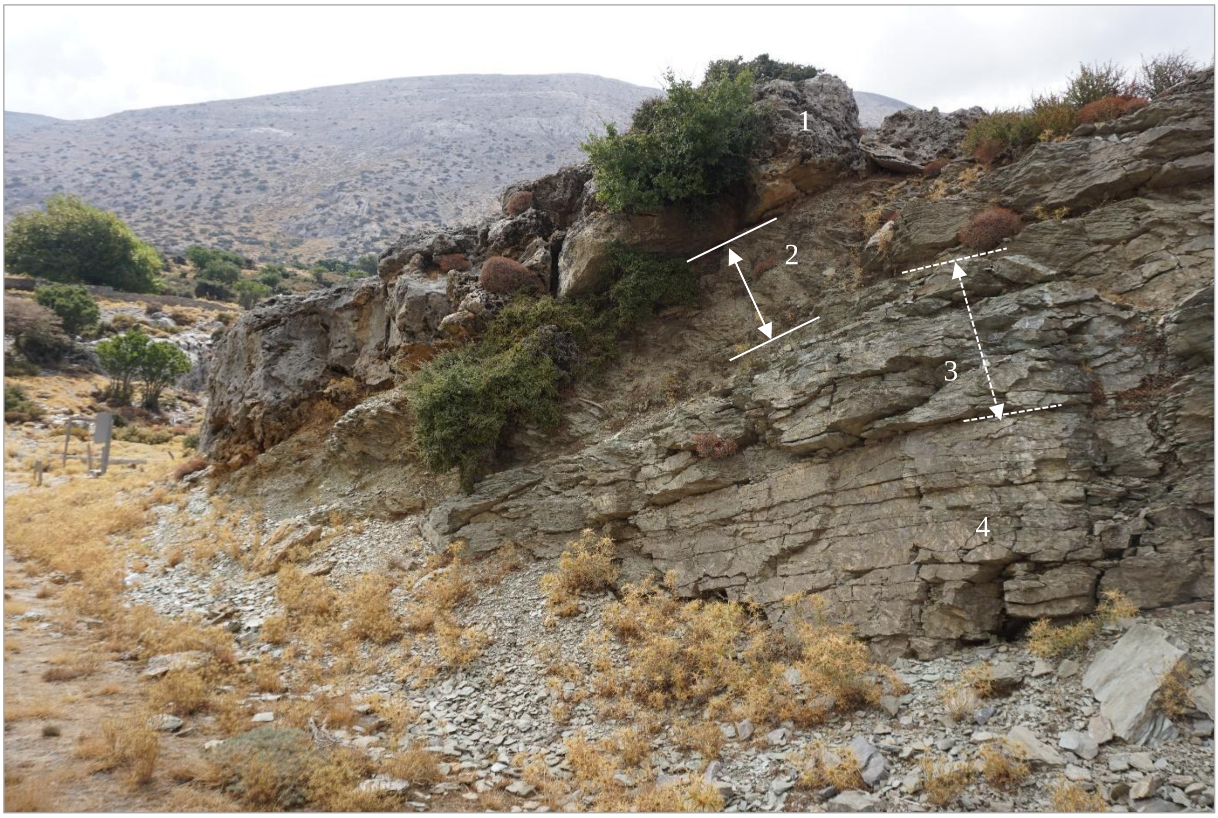
Hand sample from the red-coloured beds. The red colour is thought to be due to the presents of Fe-III. The light specks within the marble appear, to be calcareous clastic material.

3.2 Cretan Detachment - Top-to-the South Shear Sense Indicators

Just to the west of the Nida Plateau View Point is another good exposure of the detachment. Fault zone structures are well developed in a one- to two-meter-thick zone directly below the stratigraphic break that marks the detachment surface. The structures, including kink folds and S-C structures, are consistent with a top-S motion on the detachment fault *[Rahl J.M., 2004]*.



Overview of the area showing geological features, and the location of the Idaion Andro Cave, which is mentioned in Greek mythology. At this location the thrust zone, also known as the Cretan Detachment, is part of the hanging wall of a much younger normal fault. [Source of image: Google Maps]



Exposure of the Cretan Detachment between Tripoliza and Plattenkalk "metaflysch" at the Nida Plateau View Point. 1: Tripoliza limestone, 2: highly shear fault zone, 3: damage zone consisting of Plattenkalk "metaflysch", 4: "metaflysch" host rock.

View of the fault zone. 1: Tripoliza limestone, 2: highly sheared „metaflysch"

Highly sheared and foliated „metaflysch" within the fault zone.

Weathered surface of the "metaflysch" host rock displaying penetrative foliation.

3.3 Idaion Antro Cave and Major Normal Fault

The Idion Antro Cave is one of the most important archaeological sites on Crete. According to Greek mythology it is the cave where Zeus spent his childhood and was therefore a place of worship during the Minoan era. Archaeological excavations unearthed several important artifacts including a bronze shield that is kept today at the Archeological Museum in Heraklion.

The cave, which was formed within the Plattenkalk by karstic erosion, is relatively small. It was initially part of a larger cave system from which it was separated by a major normal fault. The normal fault can be observed today at the entrance to the cave. The extensive hydrogeological tunnel system from which it was separated has been detected below the Nida Plateau.

View of the major normal fault within the Plattenkalk (arrow). 1: on the bottom right a path leading up to the cave. The fault can be traced northwards all the way along the mountain side.

Fault scarp next to the cave. On the left scaffolding from restoration works. Reactivation of the fault since its occurrence during the Neogene is indicated by the exposed fault scarp surface. The fault is reported to be still active today.

View of the Nida Plateau as seen from the Idaion Antro Cave looking eastwards. Plattenkalk limestone surrounds the plateau. The Skinakas mountain peak, that is the location of the observatory, is just visible in the background (see arrow).

3.4 Regional Tectonics and the Cretan Detachment Fault

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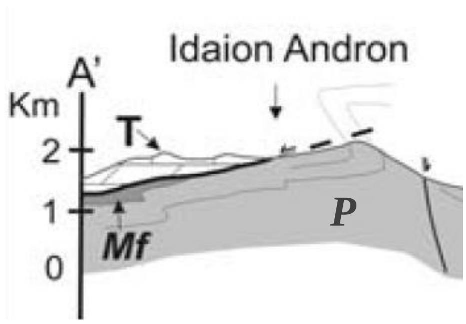
View of the Nida Plateau looking westwards [Source: GeoPark, Website]

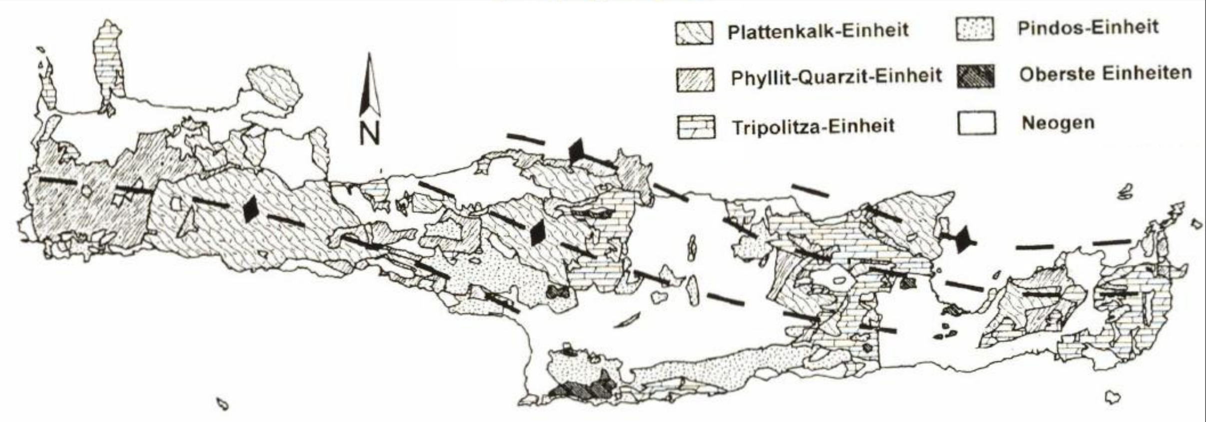
A panorama of the Psiloritis Mountains above Nida Plateau. [Source: Rahl J.M., 2004]

The picture shown above gives a scenic west-facing view of the Cretan Detachment cutting through the landscape. The tallest peaks of the Psiloritis Mountains lie to the west behind the mountain ridge. Towards the south a sharp low-angle fault called a detachment forms the contact between the Tripolitza nappe, seen here as the mountain peak (Mavri Korifi), and the whitish rocks of the Plattenkalk nappe below it. In addition, the mountain is cut along its length by an east-side down normal fault, which offsets the nappes and the detachment fault. Remains of the continuation of the detachment can be found in the hanging wall approx. 400m lower down near the base of the mountain.

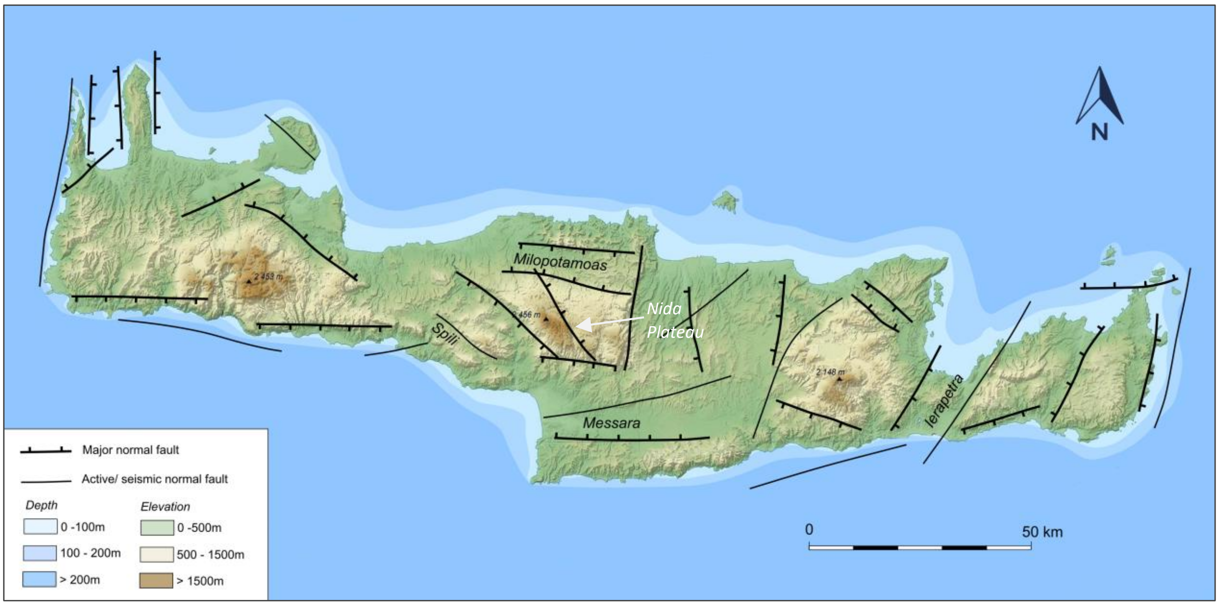
The picture below provides a good view of a large recumbent fold in the Plattenkalk. One of the limbs of the fold runs along most parallel to the of the ridge, towards the northern end of the mountain ridge where it is folded into a large, asymmetric, south-verging fold. These folds are larger versions of what is described in the following Section as "Livadia Folds". The folds are attributed to the Oligocene accretion of the nappes. *[Fassoulas, C. et al., 2004]*

View of the western face of the Psiloritis Mountains. 1: Map scale folds within the Plattenkalk, 2: Fault scarp running along the foot hills of the mountain, 3: Psiloritis summit (2456 m) [Source: GeoPark, Website]

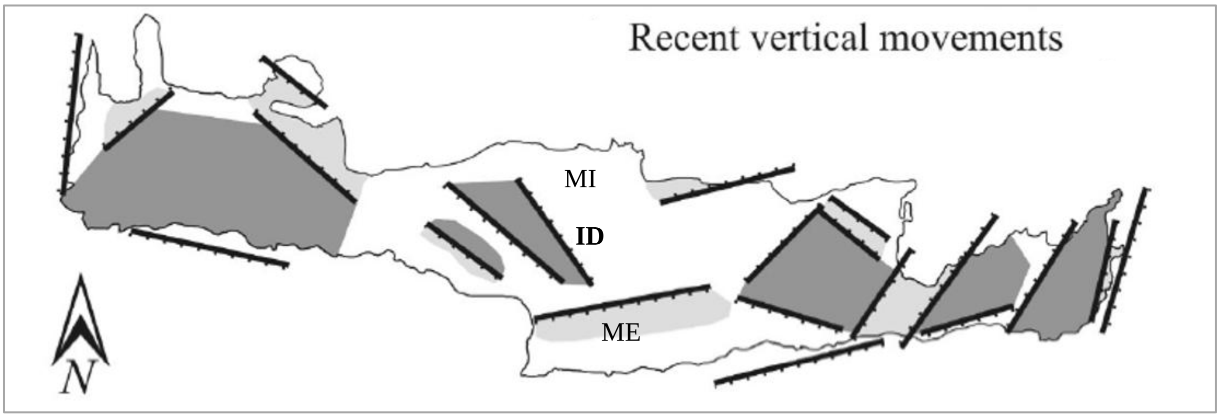
	Pl: Plattenkalk; Mf: Plattenkalkmeta-flysch; T: Tripolitza nappe *Schematic drawing of the Tripolitza Nappe and the reconstructed continuation of an asymmetric, south-verging fold within the Plattenkalk [Fassoulas, C. et al., 2004]*



Geological map of Crete showing four major anticlines extending along the length of the island [Hinsbergen & Meulenkamp 2006]. These in turn are made up of parasitic second and thirds order folds and have been termed "anticlinoria".



The major Neogene and Recent fault zones and geomorphological features of Crete. Data are after Creutzburg et al. (1977), Delibasis et al. (1982, 1999), Papoulia et al. (1996) and Pirazzoli et al. (1982).. Image modified after Fassoulas C., 2000



Recent (Quaternary to Present day) vertical movements at major faults on Crete. The faults shown are are either active or possibly active faults. Horsts are indicated in dark shading and graben (depressions) in light shading. ***ID****: Idaion fault, ME: Messara Basin, MI: Milopotamos valley [Fassoulas, 2000]*

The Idaion normal fault (ID), described above is one of several third phase extensional faults on Crete. It starts from the Messara basin (ME) in the south, crosses the main body of Psiloritis mountains and continues further northwest to the Milopotamos valley (MI). The major fault divides the eastern slopes of Psiloritis Mts. from the Petradolakia area and the Nida plateau.

Nida Plateau looking South.

The Plateau is the highest in Crete with a mean altitude of 1360 meters. Resulting from vertical displacement, it was formed by smaller surface depressions (dolines) joining together to form a much larger structure called a polge. Like the nearby Petradolakia dolines, it occurs just at the place where the Tripolitza limestone comes into contact with the underlying Plattenkalk "metaflysch". The thin layer of "metaflysch" formed a barrier to infiltrating rainwater, which in time due to dissolution of carbonate formed the dolines. Many dolines or sinkholes lie at the northern part of the plateau. The depressions are often filled with fertile reddish soil called "Terra Rosa" that is the residue of dissolution processes. The sinkholes receive surface run-off directing it into an extensive underground system of karstic tunnels. In the nearby Tafkoura cave, east of the Nida Plateau, the tunnels reach a depth of 950 m below the surface *[GeoPark]*.

4 Skinakas Peak, Observatory

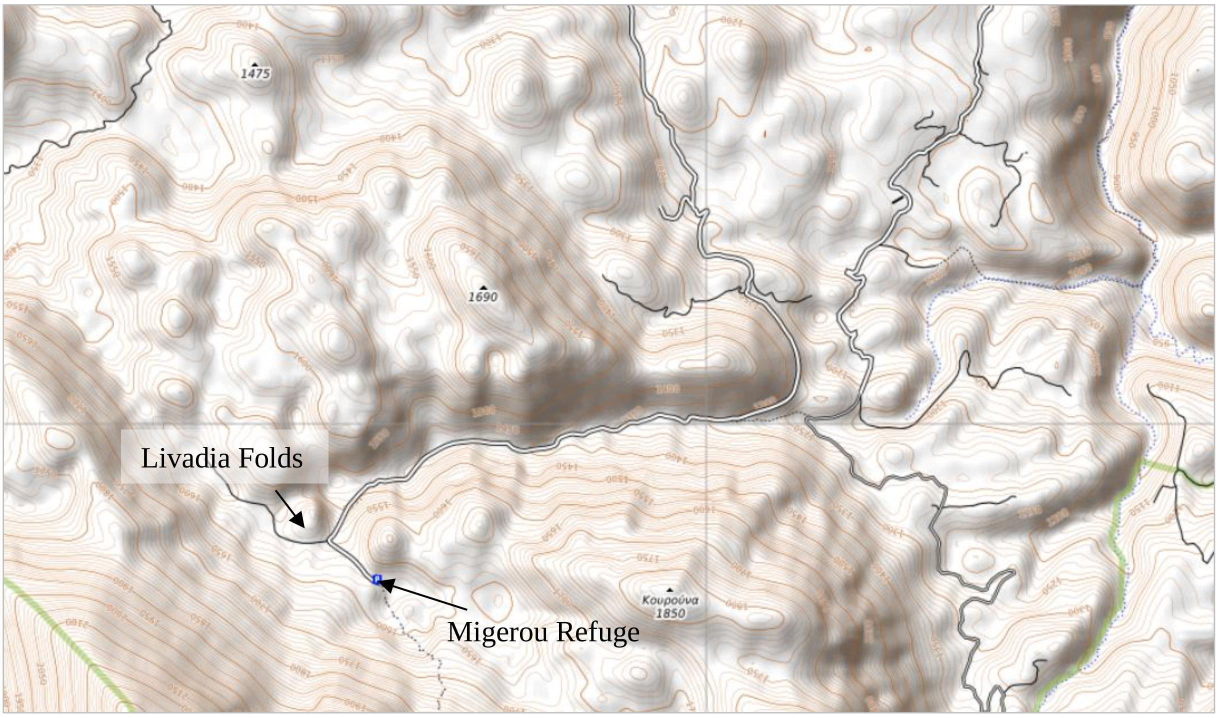
The peculiar karst landscape formed within the Tripolitza limestone of the area can be admired from the Skinakas Peak, Observatory. The morphology is due to the good solubility of the limestone in slightly acidic rainfall resulting in the formation of dolines, sinkholes and potholes that are the hallmark of karstic weathering.

One of a number of telescopes at observatory belonging to the Max Plank Institute for Extraterrestrial Physics. In the foreground Tripoliza limestone.

View of the Petradolakia area from the Skinakas Peak Observatory looking North. In the foreground karstic erosion of the Tripoliza nappe. In the background the eastern part of the the Talea Ori Mountains.

5 Migerou Plateau

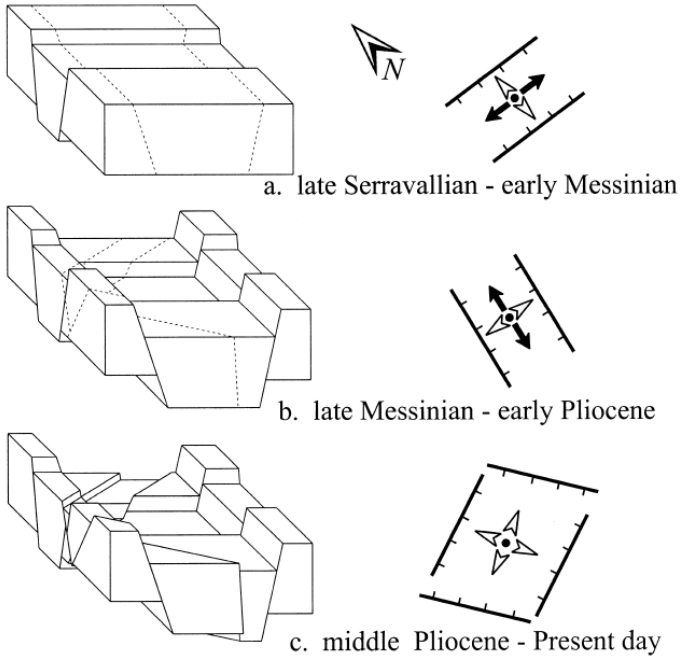
The Migerou Plateau is an area that lies below the highest Psiloritis mountain at an altitude of 1700 meters AMSL. It consists of a series of small and larger dolines that have evolved along a major fault that cuts across the northern part of Psiloritis mountain range. From the Migerou Refuge a path leads to the summit of Psiloritis mountain. At the western end of Migerou Plateau there is a small hill displaying are number of nicely formed small zigzag folds within the platy marble (Plattenkalk). A minor fault, which is antithetic to the main normal fault forming the northern slopes of Psiloritis in this area, can also be observed.



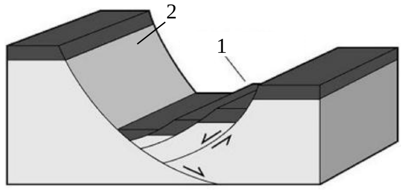
Location of outcrops

View of the Migerou Plateau looking westwards. 1: In the centre a hill with outcropping Livadia Folds. 2: On the far right the Migerou Refuge [Source of image: GeoPark].

1: Major normal fault probably late Serravallian to early Messinian, 2 & 3: possible younger major normal faults middle Pliocene to Recent, 4: presumed antithetic fault associated with 2, 5: Livadia Folds [Source of image: Google Maps)



[Fassoulas, 2000]



1: Antithetic fault. 2: Synthetic fault. Antithetic faults are minor, secondary faults, usually one of a set, whose sense of displacement is opposite to its associated major and synthetic faults. Antithetic-synthetic fault sets are typical in areas of normal faulting and are the result of extensional stress.

5.1 Livadia Folds

5: Location of zig zag folds outcropping next to an antithetic fault at the Migerou Plateau. 1: Livadia Folds, 2: presumed antithetic fault, 3: Mitato

The zig zag folds within the platy marble indicate brittle conditions and therefore strain within shallow depth of the earth's crust [Source: GeoPark]

The folds mainly have sharp edges indicating slightly less ductile condition that in the Talea Ori mountains.

1: Presumed antithetic fault. 2: Well indicating underground karstic erosion and groundwater system.

Well near the "Livadia Folds" location (see previous picture)

Well near the "Livadia Folds" location.

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GeoPark: Geo | Psiloritis Natural Park - UNESCO Global Geopark

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6 Appendix

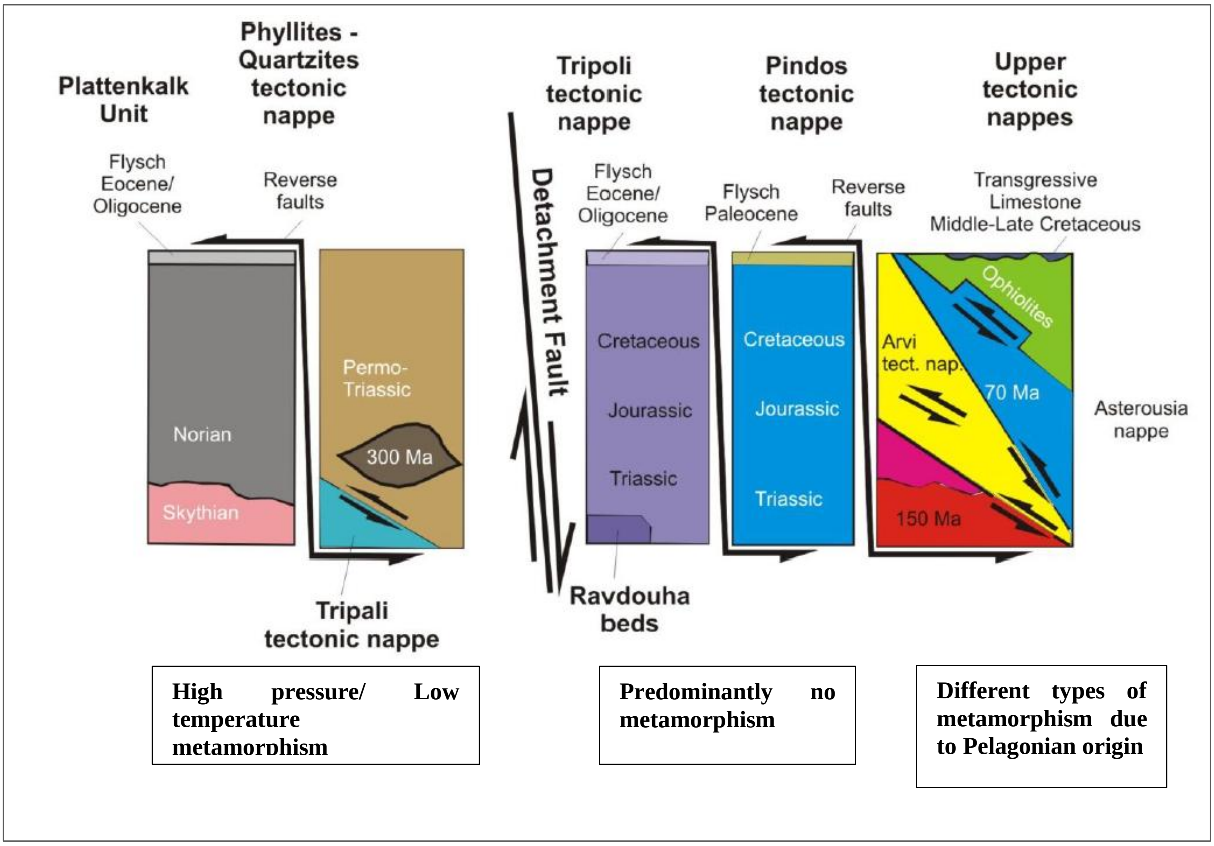
Geological Time Scale

Eonothem/ Eon	Erathem/ Era	System/ Period	Series/ Epoch	Stage/ Age	mya[1]
					2.58
Phanerozoic	Cenozoic	Neogene	Pliocene	Piacenzian	3.600
				Zanclean	5.333
			Miocene	Messinian	7.246
				Tortonian	11.63
				Serravallian	13.82
				Langhian	15.97
				Burdigalian	20.44
				Aquitanian	23.03
		Paleogene	Oligocene	Chattian	27.82
				Rupelian	33.9
			Eocene	Priabonian	37.8
				Bartonian	41.2
				Lutetian	47.8
				Ypresian	56.0
			Paleocene	Thanetian	59.2
				Selandian	61.6
				Danian	66.0
	Mesozoic	Cretaceous	Upper	Maastrichtian	72.1 ± 0.2
				Campanian	83.6 ± 0.2
				Santonian	86.3 ± 0.5
				Coniacian	89.8 ± 0.3
				Turonian	93.9
				Cenomanian	100.5
			Lower	Albian	~113
				Aptian	~125.0
				Barremian	~129.4
				Hauterivian	~132.9
				Valanginian	~139.8
				Berriasian	~145.0

Eonothem/ Eon	Erathem/ Era	System/ Period	Subsystem	Series/ Epoch	Stage/ Age	mya[1]
						~145.0
Phanerozoic	Mesozoic	Jurassic		Upper	Tithonian	152.1 ± 0.9
					Kimmeridgian	157.3 ± 1.0
					Oxfordian	163.5 ± 1.0
				Middle	Callovian	166.1 ± 1.2
					Bathonian	168.3 ± 1.3
					Bajocian	170.3 ± 1.4
					Aalenian	174.1 ± 1.0
				Lower	Toarcian	182.7 ± 0.7
					Pliensbachian	190.8 ± 1.0
					Sinemurian	199.3 ± 0.3
					Hettangian	201.3 ± 0.2
		Triassic		Upper	Rhaetian	~208.5
					Norian	~227.0
					Carnian	~237.0
				Middle	Ladinian	~242.0
					Anisian	247.2
				Lower	Olenekian	251.2
					Induan	251.902 ± 0.024
	Paleozoic	Permian		Lopingian	Changhsingian	254.14 ± 0.7
					Wuchiapingian	259.1 ± 0.5
				Guadalupian	Capitanian	265.1 ± 0.4
					Wordian	268.8 ± 0.5
					Roadian	272.95 ± 0.11
				Cisuralian	Kungurian	283.5 ± 0.6
					Artinskian	290.1 ± 0.26
					Sakmarian	295.0 ± 0.18
					Asselian	298.9 ± 0.15
		Carboniferous	Pennsylvanian[2]	Upper	Gzhelian	303.7 ± 0.1
					Kasimovian	307.0 ± 0.1
				Middle	Moscovian	315.2 ± 0.2
				Lower	Bashkirian	323.2 ± 0.4
			Mississippian[2]	Upper	Serpukhovian	330.9 ± 0.2
				Middle	Visean	346.7 ± 0.4
				Lower	Tournaisian	358.9 ± 0.4

Regional Tectonic Models for Crete

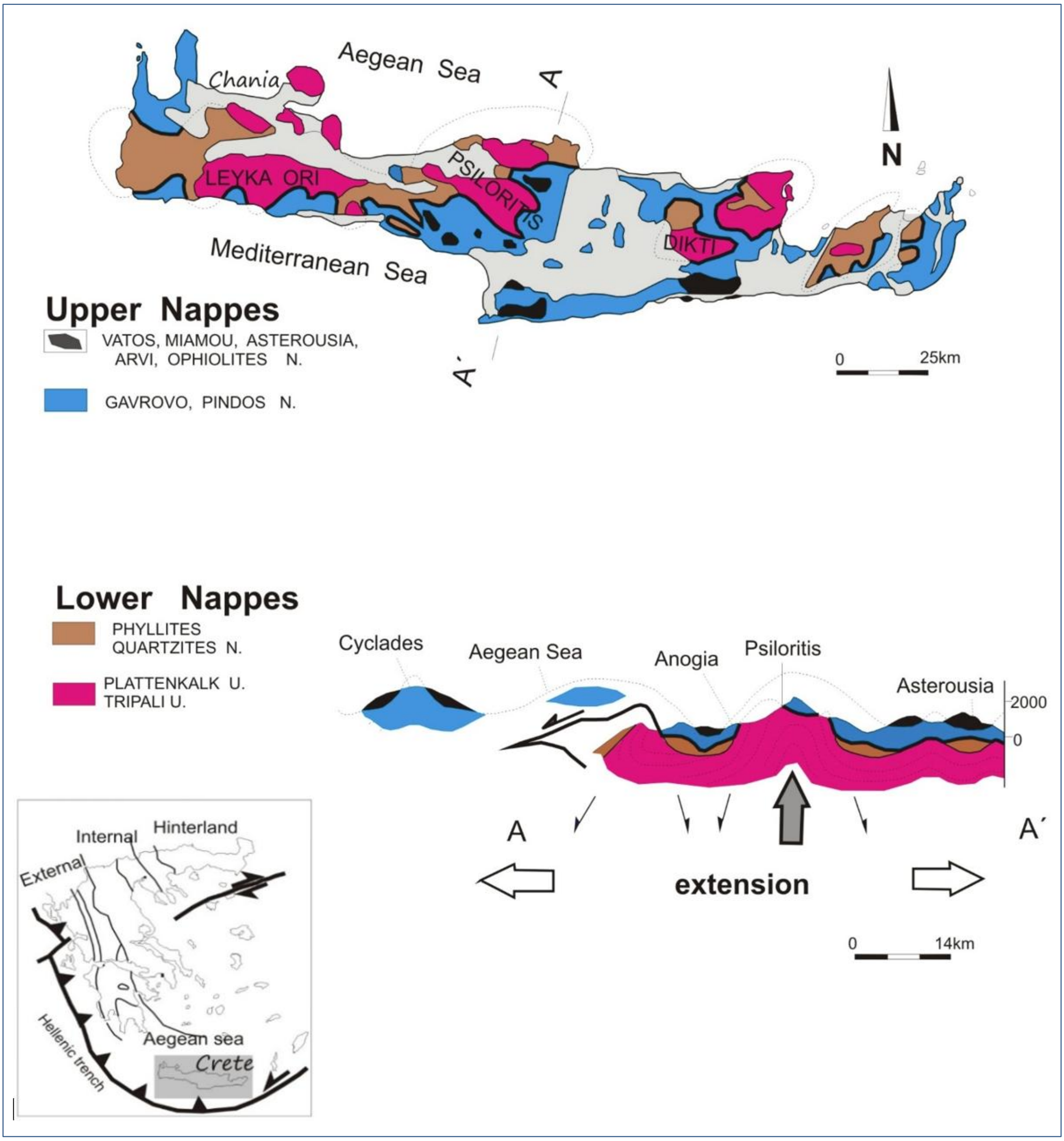
Nappe Tectonics



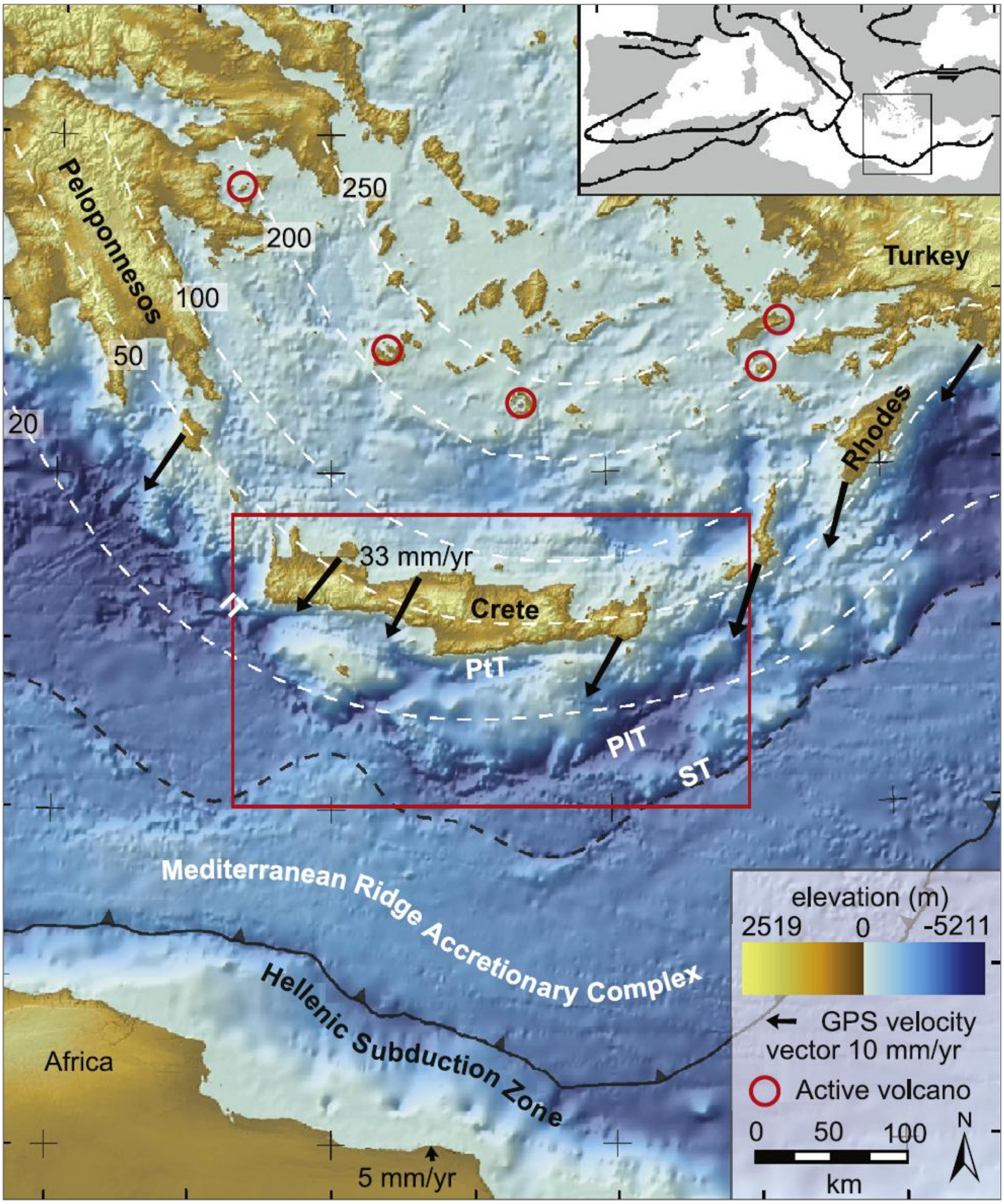
The nappes of Crete were stacked on top of each other during the Alpine orogeny from Eocene to Miocene time. A major compressional regime arising from subduction resulted in younger nappes being stacked onto older ones during the formation of an accretional wedge. The subduction of the lower and older part of the nappe pile to greater depths (30 km and more) subjected the Plattenkalk and Quartz Phyllite Units in particular to high pressure low temperature metamorphism during the Upper Oligocene to Lower Miocene (Seidel *et al.*, 1982).

Compression and nappe stacking were followed during Lower-Middle Miocene by a period of extensional thinning of the overriding plate causing exhumation of the lower high-pressure nappes. According to the Thomson N., 1999 exhumation was driven by buoyancy of the less dense nappes within the much denser lithosphere.

The lower nappes appear today in a series of tectonic windows such as in the Psilorities and Talea Ori Mts. An important feature is the formation of horst and graben structures due to uplift and extensional stresses (Fassoulas *et al.*, 1994, Kilias *et al.*, 1994, 2002). The lower tectonic nappes were affected by ductile deformation, while the upper tectonic nappes display brittle low-angle extensional shear zones. During this period, the first Neogene basins of the island were formed, often bordered by major syn-sedimentary normal boundary faults. The main compression migrated southwards towards the Mediterranean ridge, where today's active subduction zone lies and where eastern Mediterranean lithosphere is being subducted beneath the Aegean microplate. From the Middle Miocene onwards the Aegean microplate began to thin out due to initial almost N-S sub-horizontal extension. Based on GPS measurements the Aegean Plate is moving today at a velocity of approx. 33mm/y southwards, while the convergent African plate is moving at about 5mm/y northwards.



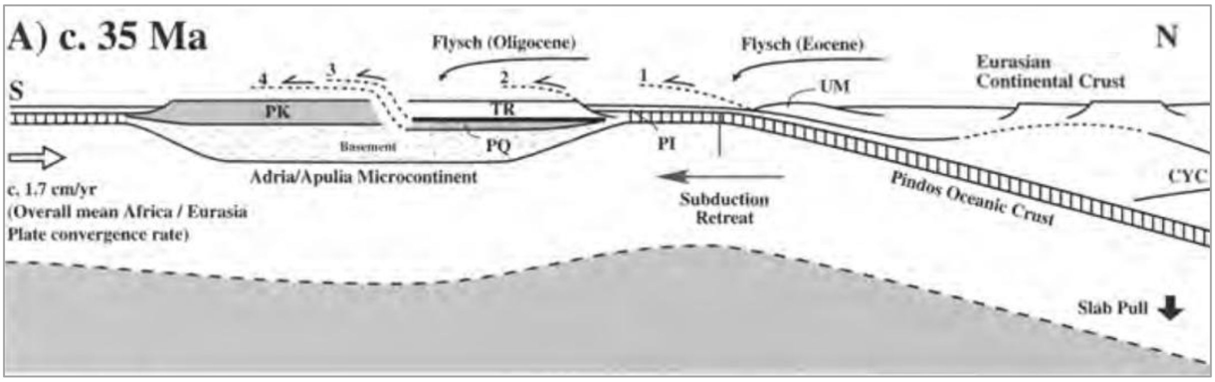
[Mountrakis D. et al., 2012, [http://virtualexplorer.com.au/]](http://virtualexplorer.com.au/)



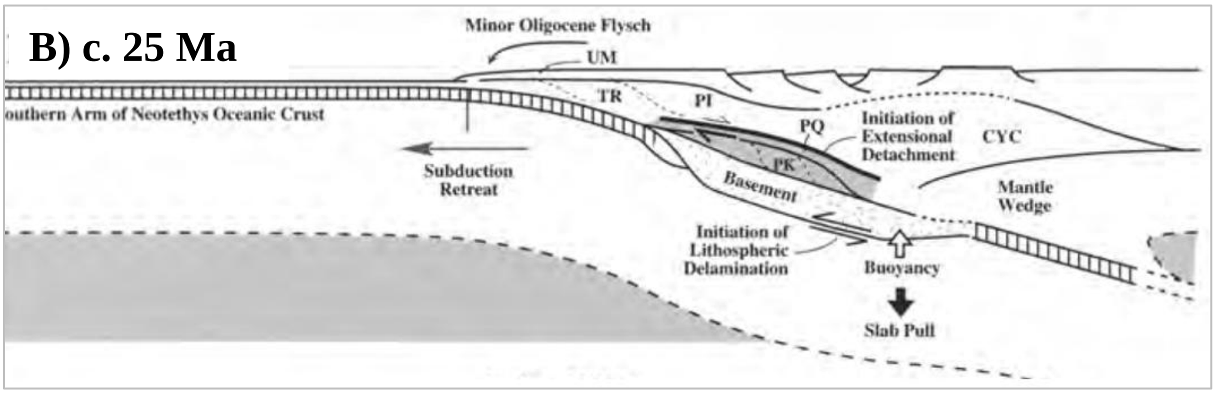
Tectonic setting of the eastern Mediterranean in the vicinity of Crete, Greece. Inset: map of the major active and inactive convergent boundaries in the Mediterranean region and the North Anatolian Fault. The box highlights the area of the larger map. The Hellenic troughs, including the Ionian (IT), Ptolemy (PtT), Pliny (PlT), and Strabos (ST) are labeled. The location of the Hellenic Subduction zone in the south and back thrust (black dashed line) to the north that define the boundaries of the Mediterranean Ridge Accretionary complex is from Kreemer and Chamot Rooke (2004). The GPS velocity vectors (black arrows) are resolvable into a total convergence rate of~36mm/yr (Reilinger et al.,2006). Depth (km) to the subducting plate (dashed white lines) is from Benioff-zone seismicity (Papazachos et al.,2000), mico-seismicity (Meieretal.,2004; Becker et al.,2006), and an upper mantle seismic velocity model (Gudmundsson and Sambridge,1998). [Gallen S.F. 2014]

Rapid Exhumation by Buoyant Escape Model - Thomson N., 1999

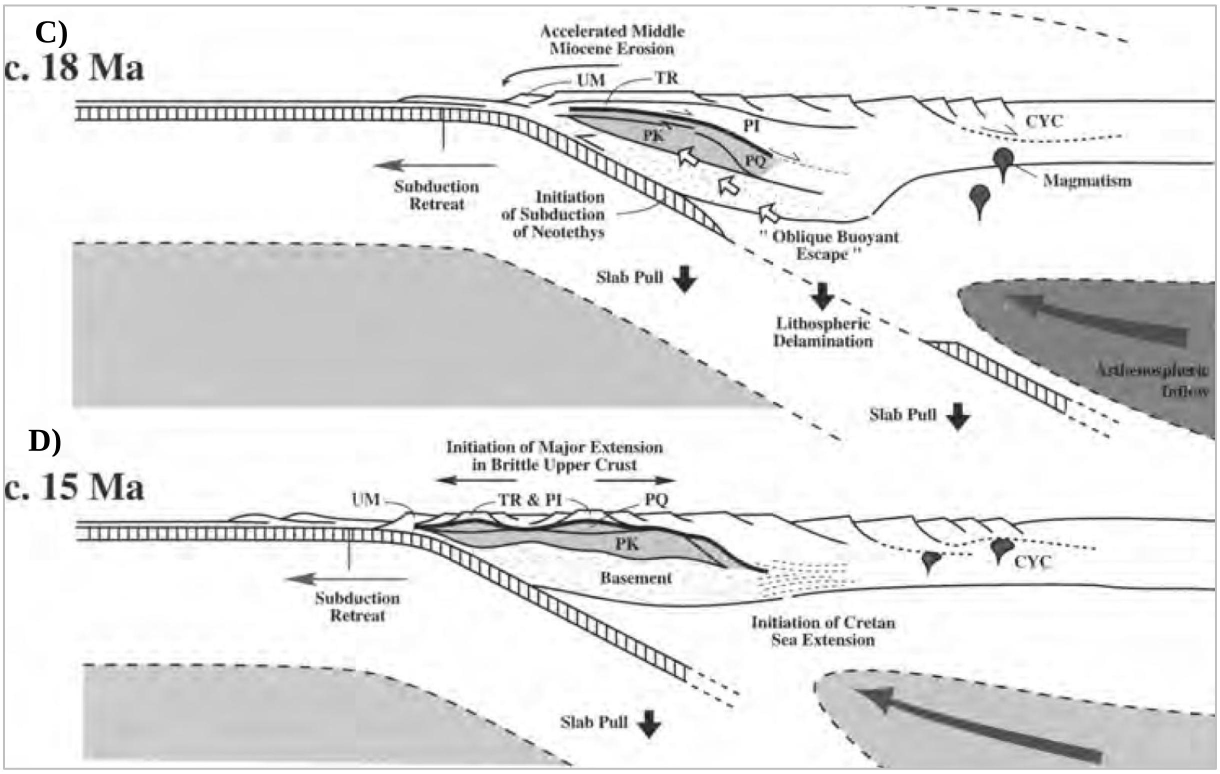
Schematic N--S cross-sections that illustrate Thomson's, 1999 preferred model for the late Eocene to mid-Miocene tectonic development of the Cretan segment of the Hellenic convergent boundary. The details are described in the text. Vertical exaggeration is c. 3 x, with the crustal layers further exaggerated for clarity. The age sequence of accretion of the different tectonic units of Crete is numbered in (a).



Model of nappe stacking according to Thomson N. Schematic N-S cross-section that illustrates the late Eocene to mid-Miocene plate tectonic development of Crete. (Vertical exaggeration is approx. 3 x) with the crustal layers further exaggerated for clarity. The sequence of accretion of the different tectonic units is numbered 1 to 4. The HP-LT lower plate rocks exposed at present on Crete are shaded grey for clarity. PK, Plattenkalk unit; PQ, Phyllite-Quartzite unit; TR, Tripolitza unit; PI, Pindos unit; UM, Uppermost unit; CYC, present-day rocks of the Cyclades. [Thomson N., 1999]



Model illustrating the subduction of nappes and the initiation of an extensional detachment, which emplaced the less metamorphic upper nappes onto the higher metamorphic lower nappes [Thomson N., 1999]


C)
c. 18 Ma
Accelerated Middle
Miocene Erosion
UM
TR
PI
PK
PQ
CYC
Magmatism
Subduction
Retreat
Initiation
of Subduction
of Neotethys
" Oblique Buoyant
Escape "
Slab Pull
Lithospheric
Delamination
Slab Pull
D)
c. 15 Ma
Initiation of Major Extension
in Brittle Upper Crust
UM
TR & PI
PQ
PK
Basement
CYC
Subduction
Retreat
Initiation of Cretan
Sea Extension
Slab Pull

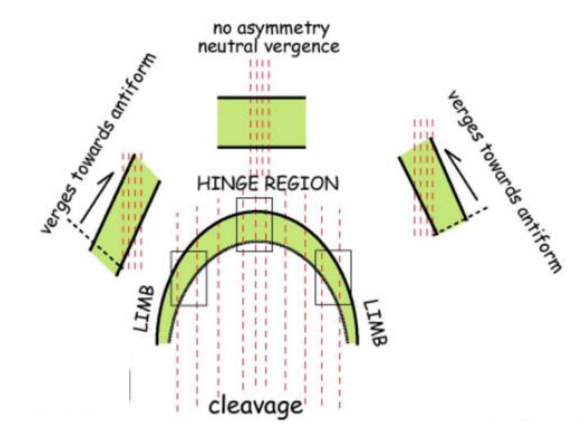
Types of Cleavage

https://www.see.leeds.ac.uk/structure/minor/cleavage/index.htm

Cleavage is a new fabric that develops in rocks during deformation. There are several ways in which cleavage can form. Probably the most famous type is "slatey cleavage" - so called because it is characteristic of slates. In slates the cleavage can come to dominate the rock so that you have to look really hard to find features like bedding. In these situations, the cleavage is said to be "penetrative". Slatey cleavage results from the mechanical realignment or growth of platy minerals such as clays and micas, essentially so that they are flattened perpendicular to the direction of maximum compression. In folded sequence slatey cleavage is commonly found to be parallel to fold axial surfaces (this type of arrangement is termed "axial planar cleavage" and is useful for determining vergence. When rock layers with different mechanical properties are interlayered, cleavage is often found to refract through the layers. Cleavage planes can also form by dissolution of material - although in these situations it is commonly spaced. This type is called "pressure solution cleavage".

Cleavage and Folds

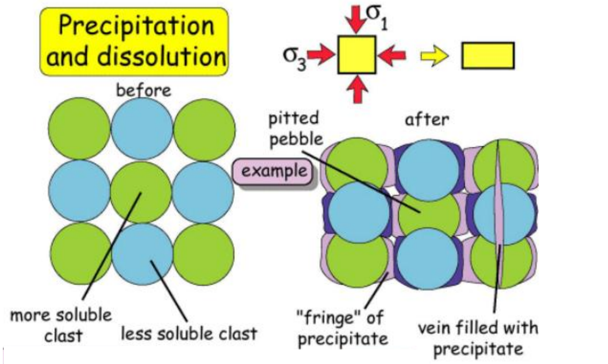
Cleavage often goes hand in hand with folding. However, the neat thing about cleavage is that in ideal cases its orientation is parallel to the axial surface of local folds - when it is referred to as "axial planar cleavage". In this ideal situation, and even if it fans a bit, the intersection of cleavage planes with the bedding planes (the intersection of two planes is a line of course) will be parallel to the hinge line of the fold. Cleavage-bedding relationships can also be used to help unravel large-scale structure using the vergence concept.



Cleavage vergence

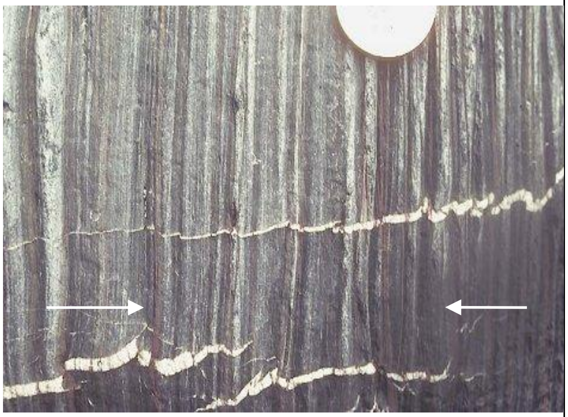
Pressure Solution

Dissolution and reprecipitation of minerals are important mechanisms by which rocks can change shape (i.e. deform). The process is generally termed Diffusional Mass Transfer (DMT) - although some people refer to the dissolution part as "pressure solution". The key idea is that materials tend to dissolve when compressed (like carbon dioxide gas in a fizzy drink with the cap on) and come out of solution when the pressure is released. So the direction of maximum compression in rocks is normal to planes of maximum solution with precipitation in the direction of minimum compressive stress. In fine grained rocks the surfaces of dissolution are commonly wavy. These features are called stilolites. Pressure solution is also an important way to form cleavage. There are different types of reprecipitation sites.



https://www.see.leeds.ac.uk/structure/minor/dmt/index.htm

1: indenting clast; 2: dissolving/pitted clast; 3: veins indicate extension



Example of pressure solution cleavage in silts from south Devon. The cleavage here is aligned vertically and has generated the characteristic "stripes" of this form of cleavage. Notice that the white vein has been dissolved across the solution seams and is locally buckled (indicating that the vein is less soluble than the original silt - possibly because the mineral grains in the vein are bigger). The vein can be related to the same deformation, opening up vertically as the maximum compression acted horizontally (see arrows).

Schist

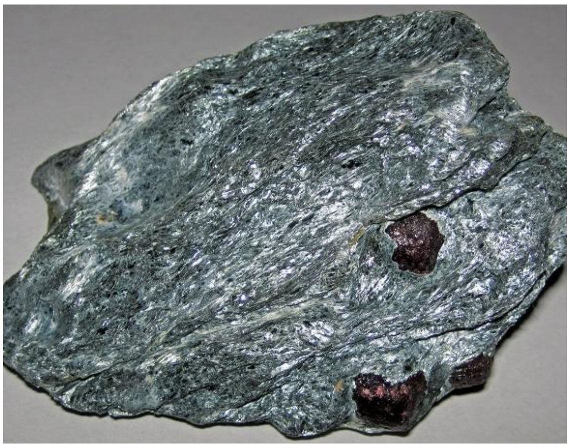
https://www.alexstrekeisen.it/english/meta/chloriteschist.php

The word schist is derived from the Greek word schízein meaning "to split", which is a reference to the ease with which schists can be split along the plane in which the platy minerals lie. Schist is a medium-grained strongly-foliated crystalline metamorphic rock, formed by dynamic metamorphism, that can be readily split into thin flakes or slabs due to the well-developed parallelism of more than 50% of the minerals present, particularly those of lamellar or elongate prismatic habit, e.g., mica and amphiboles. Individual mineral grains are discernible by the naked eye, and this property sets it apart from slate. There are many varieties of schist and they are named for the dominant mineral comprising the rock, e.g. mica schist, green schist (green because of high chlorite content), garnet schist, actinolite schist, biotite schist etc.

Schistosity is a type of foliation, characterized by the preferred orientation of elongated or platy mineral grains (which are abundant in schistose rocks). Schistosity is a result of pressure in the crust which forces the grains to align perpendicular to the force applied. This force may be compressive (in mountain ranges) or simply caused by the weight of the overlying rocks. Metamorphic reactions between minerals upon increased burial will lead to the loss of schistosity because feldspar increases in abundance as micas become unstable. This process will lead to the formation of high-grade metamorphic rock gneiss (and gneissose fabric which can be described as a poorly developed schistosity).

The mineral assemblages and textures of the schist change with the temperature and pressure of recrystallization. With increasing metamorphism, the grain size usually increases and, depending on appropriate chemical availability, minerals such as chloritoid, garnet, staurolite, cordierite, andalusite, and kyanite crystallize as large crystals (called porphyroblasts) in a foliated micaceous matrix. Many porphyroblasts contain inclusions, indicating that they crystallized by replacement of some other mineral or rock. *[Alex Strekeisen]*

Chlorite schist. Michigamme Mine, Upper Peninsula of Michigan, USA. From James St. John.



Garnet-chlorite schist. Lake Martin, Alabama, USA. From James St. John. [Alex Strekeisen]

Chlorite

https://www.alexstrekeisen.it/english/meta/chloriteschist.php

Chlorite is the group name for about 10 related minerals. However, the term chlorite can be used both to describe the group in general, or as a specific term to describe any green member of the Chlorite group whose exact identity is not practical to be determined. The chlorite group minerals are mostly monoclinic (also triclinic or orthorhombic) micaceous phyllosilicate minerals with a structure consisting of T-O-T layers with two layers having their silicate tetrahedral apices pointing towards each other, separated by an interlayer that may be simple octahedrally coordinated cations or which may be a brucite-like layer of two sheets of closely packed OH groups with the interstices between sheets providing the octahedral cordination site.

Chlorites can be described by the following four endmembers based on their chemistry via substitution of the following four elements in the silicate lattice:

- Clinochlore: $(Mg_5Al)(AlSi_3)O_{10}(OH)_8$
- Chamosite: $(Fe_5Al)(AlSi_3)O_{10}(OH)_8$
- Nimite: $(Ni_5Al)(AlSi_3)O_{10}(OH)_8$
- Pennantite: $(Mn,Al)_6(Si,Al)_4O_{10}(OH)_8$

In addition, zinc, lithium, and calcium species are known. The great range in composition results in considerable variation in physical, optical, and X-ray properties. Similarly, the range of chemical composition allows chlorite group minerals to exist over a wide range of temperature and pressure conditions. For this reason chlorite minerals are ubiquitous minerals within low and medium temperature metamorphic rocks, some igneous rocks, hydrothermal rocks and deeply buried sediments.

Chlorite is an important constituent of many contact and regional metamorphic rocks of low to medium grade, usually with temperatures of to 400°C and pressures up to a few Kb. It is also found in amygdules, fractures in altered volcanic rocks, hydrothermal vein deposits and soils. Chlorite is often found with biotite, garnet, staurolite, andalusite, muscovite, chloritoid, and cordierite in pelitic rocks. In mafic rocks, it occurs with talc, serpentine, actinolite, hornblende, epidote, and garnet. It can also be found with feldspars, quartz, calcite, dolomite, olivine, plagioclase, rutile, ilmenite, titanite, magnetite, chromite, sulfides, zircon, and zeolites.

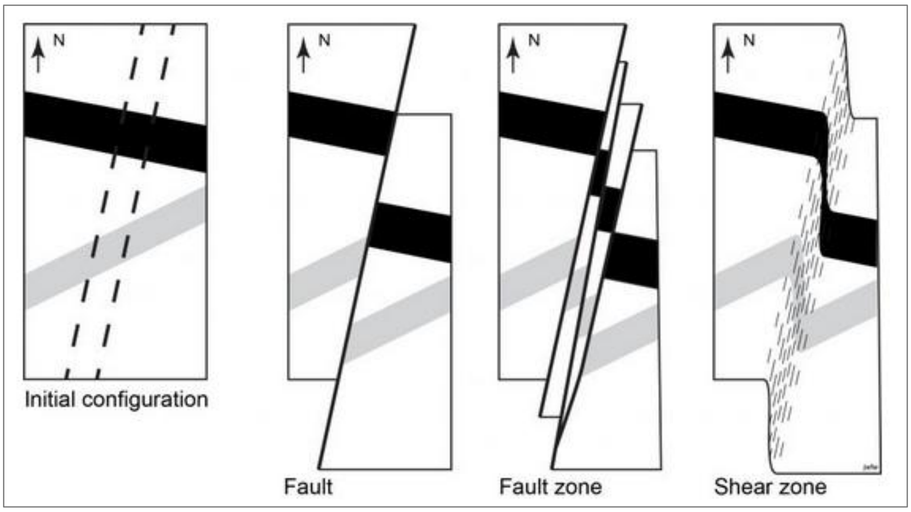
Chlorite forms by the alteration of mafic minerals such as pyroxenes, amphiboles, biotite, staurolite, cordierite, garnet, and chloritoid. Chlorite can also occur as a result of hydrothermal alteration of any rock type, where recrystallization of clay minerals or alteration of mafic minerals produce chlorite.

[Alex Strekeisen]

Shear Zones and Faults

https://openeducationalberta.ca/introductorystructuralgeology/chapter/m-shear-zones/

Shear zones are zones of intense ductile deformation that are thin relative to their lateral extent. Shear zones, like faults, typically show offsets of older structures, but unlike faults, they lack through-going brittle fractures.



Fault, fault zone, shear zone

Deformation in the earth’s ductile mid and lower crust (typically at a depth of around ~15 kilometres in continental crust) results in the formation of shear zones. These ductile shear zones feature characteristic deformation structures which may be used to determine sense of shear.

Shear Bands

https://structuredatabase.wordpress.com/ductile-shear-sense-indicators/

C-Type Shear Bands

Preferred orientation of micas or distinct compositional layering (foliation) may be transected at a small, oblique angle by sets of sub-parrallel minor shear zones. These small scale shear zones (millimetre to centimetre) are known as shear bands. Foliation is often denoted as S (for schistosity) or "schistosite") and shear bands as C (French for "cisaillement"). Well foliated mylonitic rocks often feature single sets of C (shear bands) that form at an oblique angle (between 25-45°) to S (schistosity), with the relationship between the two indicating sense of shear. Sigmoidal curvature of shear bands in shear zones serves as the most direct shear sense indicator, however shear bands may form relatively late during the evolution of a shear zone and may only reflect part of the deformation history (Fossen, 2010; C. W. Passchier & Trouw, 1996; Ramsay, 1980)

C'-Type Shear Bands

If shear strain is significantly high in a shear zone, the angle between C and S becomes sub-parallel and indiscernible. This forms a composite foliation consisting of rotated S and C surfaces. Simple S-C relationships typically seen in mylonites are also disturbed by heterogeneities in the deforming rock and slip along micaceous elements in the foliation. High strain fabrics result in the formation of C' shear bands oblique to shear zone margins, this second generation of shear bands is only distinguishable from C where their orientations in relation to shear zone boundaries is known (Fossen, 2010; Ji et al., 2004) (Hanmer & Passchier, 1991; Platt, 1984)

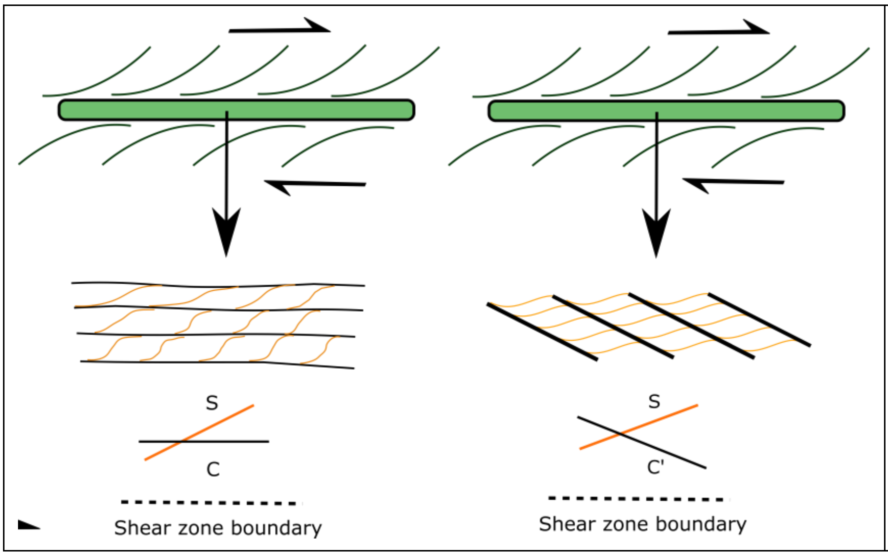
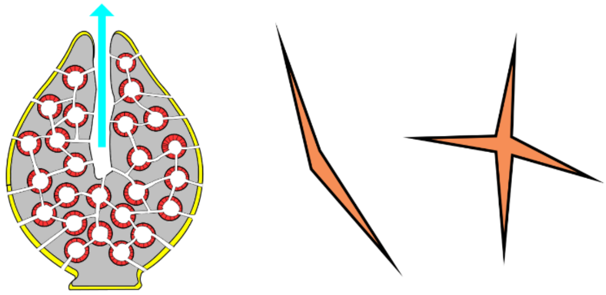


Figure 2: Foliation pairs common in ductile shear zones. C-type and C'-type shear bands in relation to schistosity (S) and shear zone boundaries. Adapted from (C. W. Passchier & Trouw, 1996) [Website: Structure Database]

Phylum Porifera (Sponges)



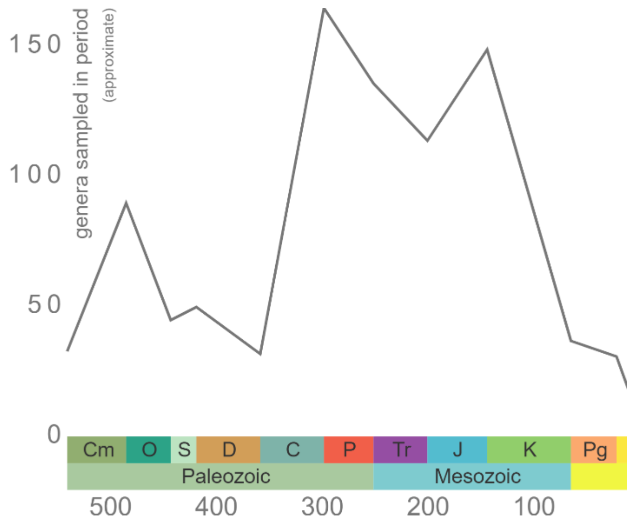
Leucon Body Form

Monoaxon and Tetraxon Spicules

Class Demospongiae

Sponge leucon body plan modified from original image by 'Philcha' (Wikimedia Commons; Creative Commons Attribution-Share Alike 3.0 Public Domain Dedication). Spicule image by Jaleigh Q. Pier is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License

[*Demospongiae - Digital Atlas of Ancient Life*]



Demospongiae has a long fossil record dating to the Early Cambrian. Fossil demosponges are prevalent in Permian and Cretaceous rocks.

Phanerozoic genus-level diversity of Demospongiae (graph generated using the Paleobiology Database Navigator).

Demospongiae - Digital Atlas of Ancient Life

https://www.britannica.com/animal/sponge-animal/Form-and-function

A simple saclike sponge has a surface perforated by small openings (incurrent pores) formed by tubelike cells (porocytes), which open into the internal cavity. A gelatinous middle layer contains the skeletal elements (spicules and spongin fibers) as well as amebocytes active in digestion, waste removal, and spicule and spongin formation. Flagellated collar cells (choanocytes) line the internal cavity, create currents to move water containing oxygen and food into the sponge, and engulf and digest food particles. Water and wastes are expelled through the ostium opening, whose size can be altered to regulate water flow through the sponge. *[Encyclopædia Britannica, Inc.]*

Early naturalists regarded the sponges as plants because of their frequent branching form and their lack of obvious movement. The animal nature of sponges, first described in 1755, was confirmed in 1765 after observations of their water currents and the changes in diameter of the openings into their central cavity. In structure, function, and development, sponges are distinct from other animals; one of their most noticeable features is that they lack organs. Many zoologists have regarded sponges as occupying an isolated position in the animal kingdom and classify them in the subkingdom Parazoa; however, molecular data suggest that both sponges and more-complex animals evolved from a common ancestor. Probably they are bona fide animals that gave rise to no further evolutionary lines.

The phylum Porifera may be divided into three classes on the basis of the composition of the skeletal elements. Together, the classes Calcarea and Hexactinellida make up about 10 to 20 percent of the known species of sponges; the remaining 80 to 90 percent are placed in the class Demospongiae.

The classes mainly defined according to the composition of their skeletons:

- Hexactinellida (glass sponges) have silicate spicules, the largest of which have six rays and may be individual or fused. The main components of their bodies are syncytia in which large numbers of cell share a single external membrane.
- Calcarea have skeletons made of calcite, a form of calcium carbonate, which may form separate spicules or large masses. All the cells have a single nucleus and membrane.
- Most Demospongiae have silicate spicules or spongin fibers or both within their soft tissues. However, a few also have massive external skeletons made of aragonite, another form of calcium carbonate. All the cells have a single nucleus and membrane.
- Archeocyatha are known only as fossils from the Cambrian period.

Water-Current System

The essential elements of the water-current system include the pores, or ostia, through which water enters the sponge (incurrent system); the choanocytes, or collar cells, which are flagellated cells that generate water currents and capture food; and the oscula, openings through which water is expelled (excurrent system).

Size Range and Diversity of Structure

https://www.britannica.com/animal/sponge-animal/Form-and-function

Most sponges are only a few centimeters in size, but some urn-shaped or shapeless ones are less than a centimeter; others, shaped like vases, tubes, or branches, may be one to two meters tall, and broad rounded masses may be one to two meters in diameter. Size within a species may vary with age, environmental conditions, and food supply.

Sponges vary greatly in external appearance. Some are bushy or treelike and have fingerlike projections. Others, particularly in the class Demospongiae, are shapeless, or amorphous, masses that form thin encrustations on objects or are cushion shaped. A few species in the Demospongiae have well-defined spherical shapes as in *Tethya aurantium*, the sea orange; others may be cup- or fan-shaped. Calcareous sponges of the genus *Scypha* are shaped like tubular sacs, with an opening (osculum) at the tip. Members of the Hexactinellida are erect or cylindrical, with a stalklike base.

Distribution and Abundance

Sponges are present at all water depths, from the tidal zone to the deepest regions (abyss). They occur at all latitudes and are particularly abundant in Antarctic waters. Members of the Calcarea and Demospongiae are found mainly on the rocky bottoms of the continental shelf, and members of the Hexactinellida are characteristic of the deepest muddy bottoms of oceans and seas. In some environments, sponges are the dominating organisms; sometimes they cover wide areas, especially on rocky overhangs and in the caves of the littoral, or shore, zone. A restricted number of species are adapted to brackish waters; and members of the family Spongillidae (class Demospongiae) populate the fresh waters of rivers and lakes.

Reproduction

Most species use sexual reproduction, releasing sperm cells into the water to fertilize ova that in some species are released and in others are retained by the "mother." The fertilized eggs develop into larvae, which swim off in search of places to settle.

Asexual Reproduction

A few species reproduce by budding. When environmental conditions become less hospitable to the sponges, for example as temperatures drop, many freshwater species and a few marine ones produce gemmules, "survival pods" of unspecialized cells that remain dormant until conditions improve; they then either form completely new sponges or recolonize the skeletons of their parents.

Regeneration

Besides the sexual and asexual reproduction sponges are able to regenerate. Sponges are known for regenerating from fragments that are broken off, although this only works if the fragments include the right types of cells.

The extraordinary capacity of sponges to regenerate is manifested not only by restoration of damaged or lost parts but also by complete regeneration of an adult from fragments or even single cells. During unfavourable conditions, sponges are reduced to small fragments that may consist only of masses of archaeocytes covered by layers of pinacocytes. A complete sponge forms from these fragments when favourable conditions return.

Fossil Sponges

http://www.sepmstrata.org/Terminology.aspx?id=skeletal%20grains

Sponges were extremely important as reef builders in the Permian and the Mesozoic. Some forms produce sediment during bioerosion of reefs and other hard substrates. Most sponges live in water less than l00m deep on hard bottoms where there is some water circulation. Sponge spicules are commonly all that is preserved. These are composed of silica, but they may be calcite or spongin. Spicules vary in size and shape depending on their position within the sponge and their function as structural framework or as protection. Sponge spicules have smooth and simple geometrical shapes and a hollow central axis; in contrast, spicules of other organisms usually have a more complex shape.

Sclerosponges are calcareous sponges that precipitate a massive aragonite skeleton and have siliceous spicules. These sponges are important contributors to the formation of deepwater reefs, living mainly in crevices and caves. Another important group of sponges are the boring varieties, such as Cliona, which produce large quantities of silt-size carbonate sediment that collects near reefs and on hard bottoms. The excavating cells of the sponge form characteristic hemispherical-shaped chips.