Fragments of Pre-alpine rocks and Tyros Beds at the Vai Peninsula

View of Tripitos beach and an outcrop of pre-alpine basement East of Sitia

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Introduction:

Pre-alpine Basement

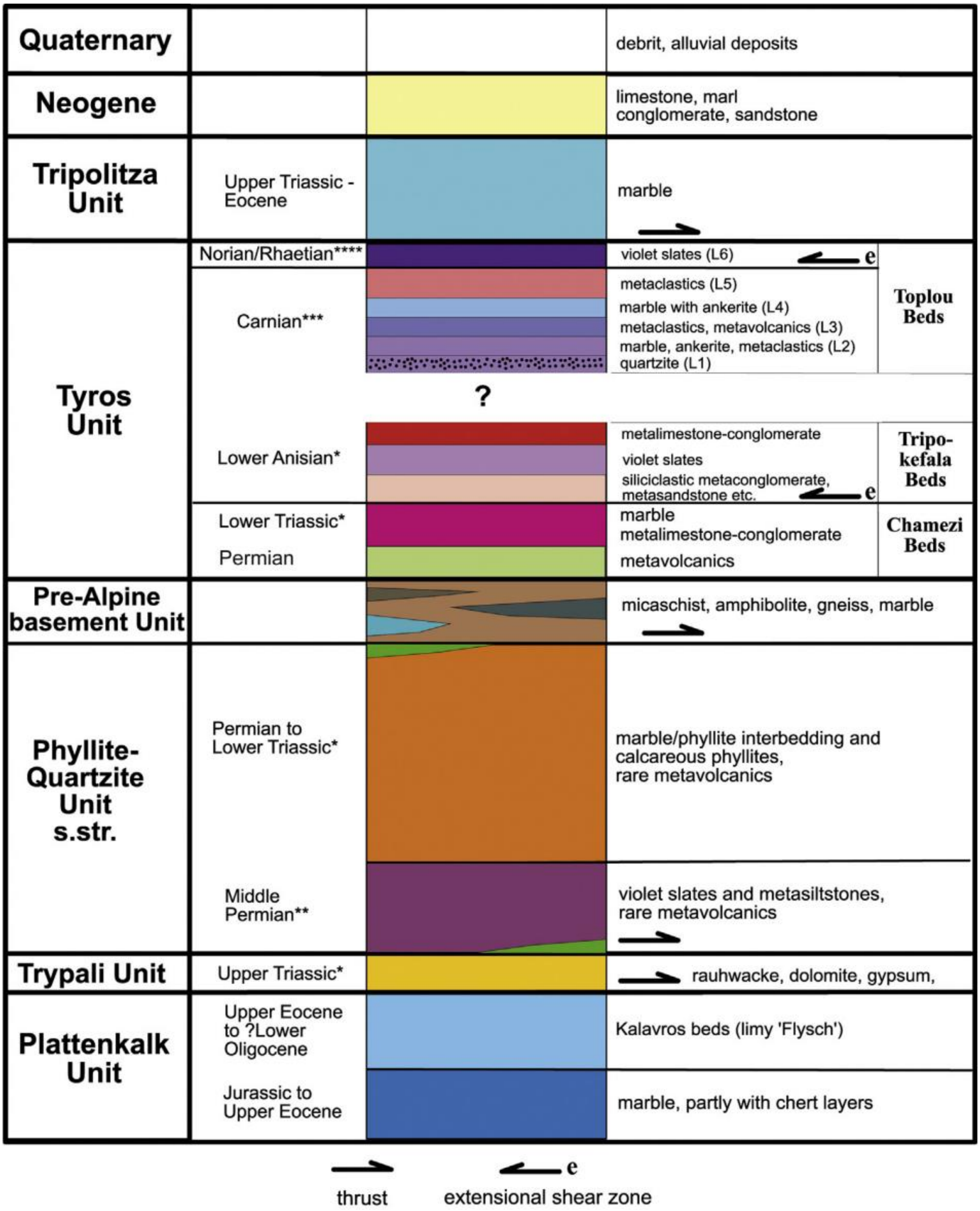
The variscan metamorphic rocks that represent the pre-alpine basement occur at the north eastern part of Crete (see My GeoGuide: “Remnants of a Variscan Basement lodged between Alpine Nappes, Mochlos to Chamezi”). They consist of a succession of gneisses, micaschists, amphibolites, marbles and quartzites (Romano et al., 2002) and minerals assemblages point to Barrovian type metamorphism in amphibolite facies. Metamorphism is reported to have reached temperatures ranging from 500 to 630°C and pressures between 5.5 and 8 Kb. U-Pb radiometric dating on zircon, monazite and titanite indicate ages ranging from Cambrian to Triassic. East of Sita only small outcrops of gneisses and micaschists may be encountered.

Tyros-Einheit

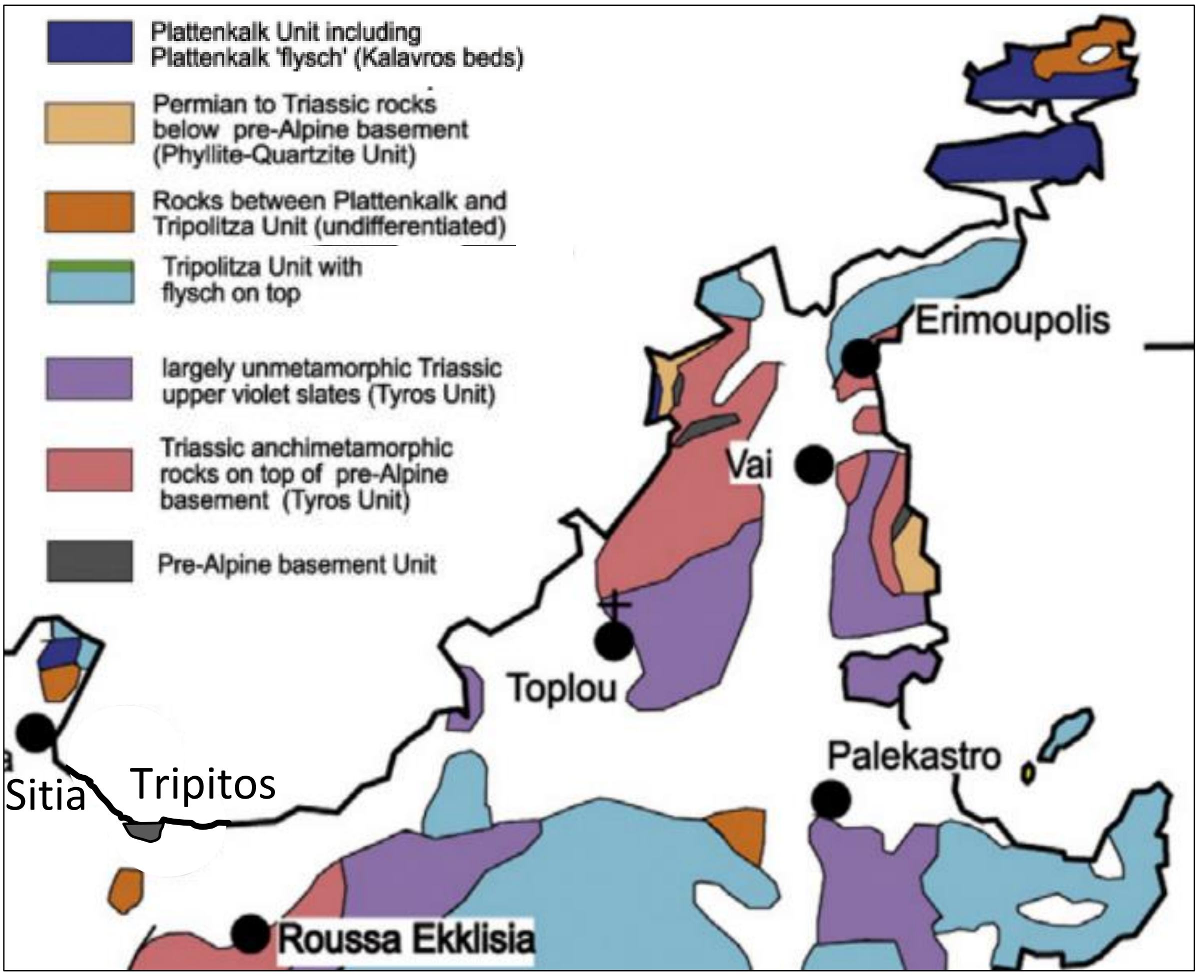
The Tyros unit is named after a similar stratigraphic sequence on the Peloponnese. It is a shallow marine sequence - and therefore deferrers from the phyllite-quartzite unit s. str. In Crete, the age of the Tyros unit is Upper Triassic and the rocks consist of slates or phyllites, limestone and dolomite marbles, sandstones and quartzites as well as andesitic metamorphic volcanites (Seidel 1978). There is no evidence of HP/LT metamorphism in the upper most portions of the Tyros unit (Wachendorf et al.). The uppermost parts of the Tyros unit probably originally formed the base of the Tripolitza unit, which became tectonically independent as a result of competence differences (i.e. Tyros slate is more easily deformed than Tripoliza limestone). In eastern Crete, the pre-alpine basement is considered to be the base of at least the lower parts of the Tyros unit, although the stratigraphic association is disturbed.

The stratigraphic sequence begins with the Chamezi strata and the Tripokefala strata. Conodonts indicate Scythian/Lower Anisian age. Above them follow a disturbed sequence of sedimentary rocks known as the “Upper Violet Slates”, comprising red to violet slates with intercalated quartzites and metasandstones. Their lower part belongs to the higher Ladinian/Carnian. The uppermost part of the “Upper Violet Slates” did not undergo HP/LT metamorphism and is separated from the lower part by faults *[Kull, 2012]*.

The sequence between the Tripokefala Beds and the Tripolitza Unit is also referred to as the Toplou Beds. In eastern Crete the Toplou Beds are exposed near Roussa Ekklisia, Toplou and Vai. Haude, 1989 has subdivided the Toplou Beds into six layers (from base to top) as follows: quartzite (T1), marble, ankeritic dolomite and metaclastic rocks (T2), metaclastic rocks and metavolcanics (T3), marble with ankeritic dolomite (T4), metaclastic rocks (T5), and violet slates and siltstones intercalated with quartzite (T6).

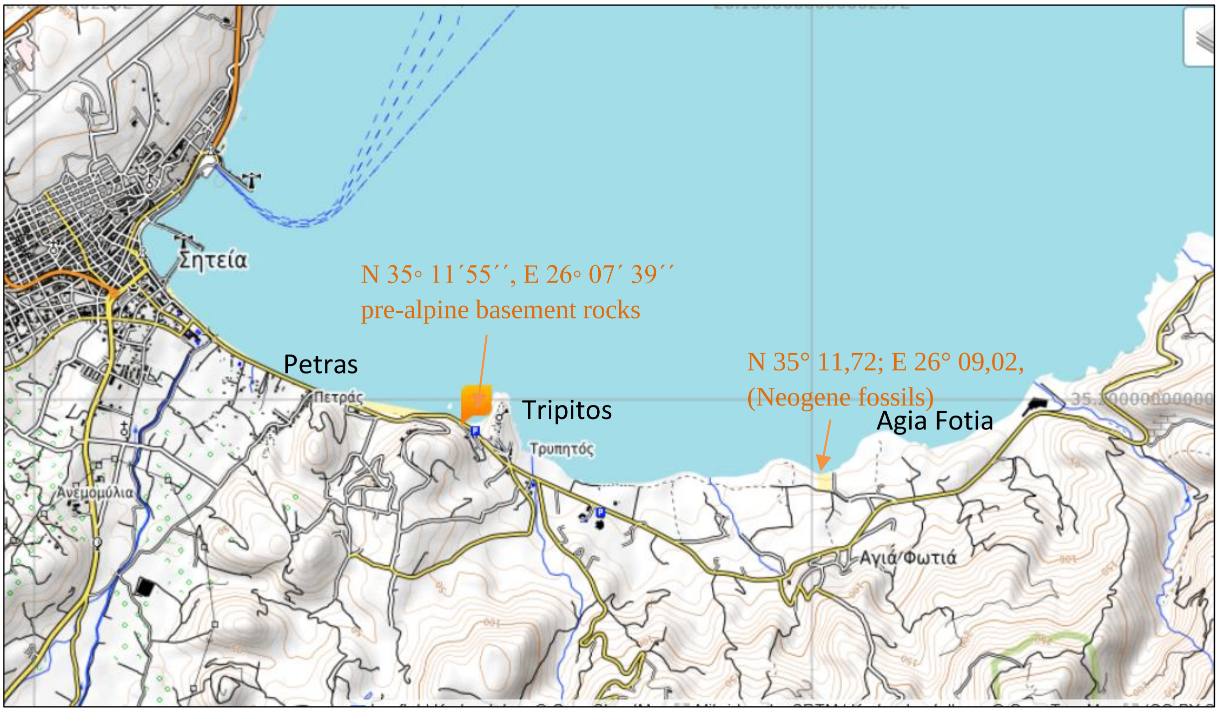


Tectonostratigraphic sequence of the rocks located between the Plattenkalk and the Tripolitza Unit in eastern Crete (Wolfgang Dörr et. al., 2014, after Zulauf et. al., 2008)



Geological Map of the Vai Peninsula [Source: Tonian basement in the eastern Mediterranean, W. Dörr, G. Zulauf]

Fragments of Pre-alpine Basement, Tripitos


N 35◦ 11´55´´, E 26◦ 07´ 39´´
pre-alpine basement rocks

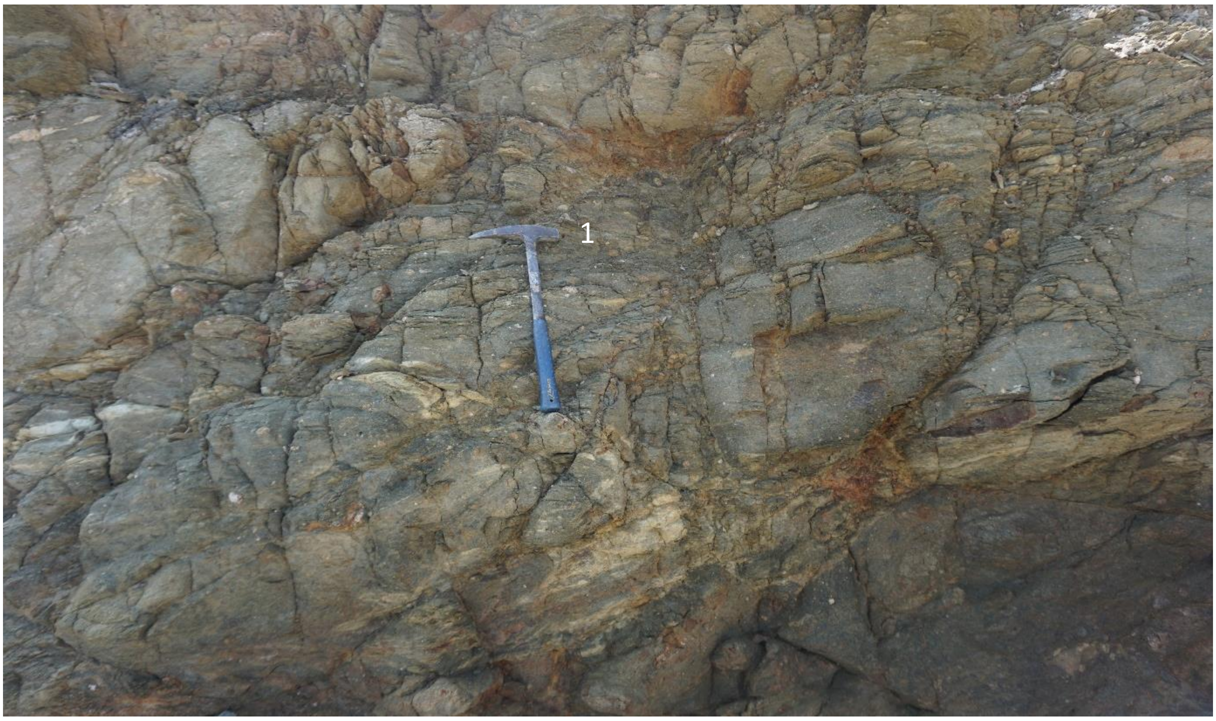
N 35° 11,72; E 26° 09,02,
(Neogene fossils)

Location of Paragneiss (Meta-greywacke) near Tripitos. (Neogene fossil finds near Agia Fotia)

Paragneiss (meta-greywacke)

Paragneiss/meta-greywacke belonging to the easternmost part of the Precambrian Basement Units can be observed at Tripitos beach (35◦ 11´55´´ N, 26◦ 07´ 39´´ E). There are a few boudins within the paragneiss (an aplite gang within the gneiss has also been reported) *[Zulauf 2008 (Mirsine Mulde)]*.

Pre-alpine basement outcropping at Tripitos beach. 1: Paragneiss, 2: Mica schist, 3: Garnet-mica schist



1: Highly sheared and weathered outcrop along the beach thought to be a mylonitic Paragneiss

1: Closeup of previous picture.

2: Micaschist

2: *Closeup of previous picture*

3: *Garnet-mica schist*

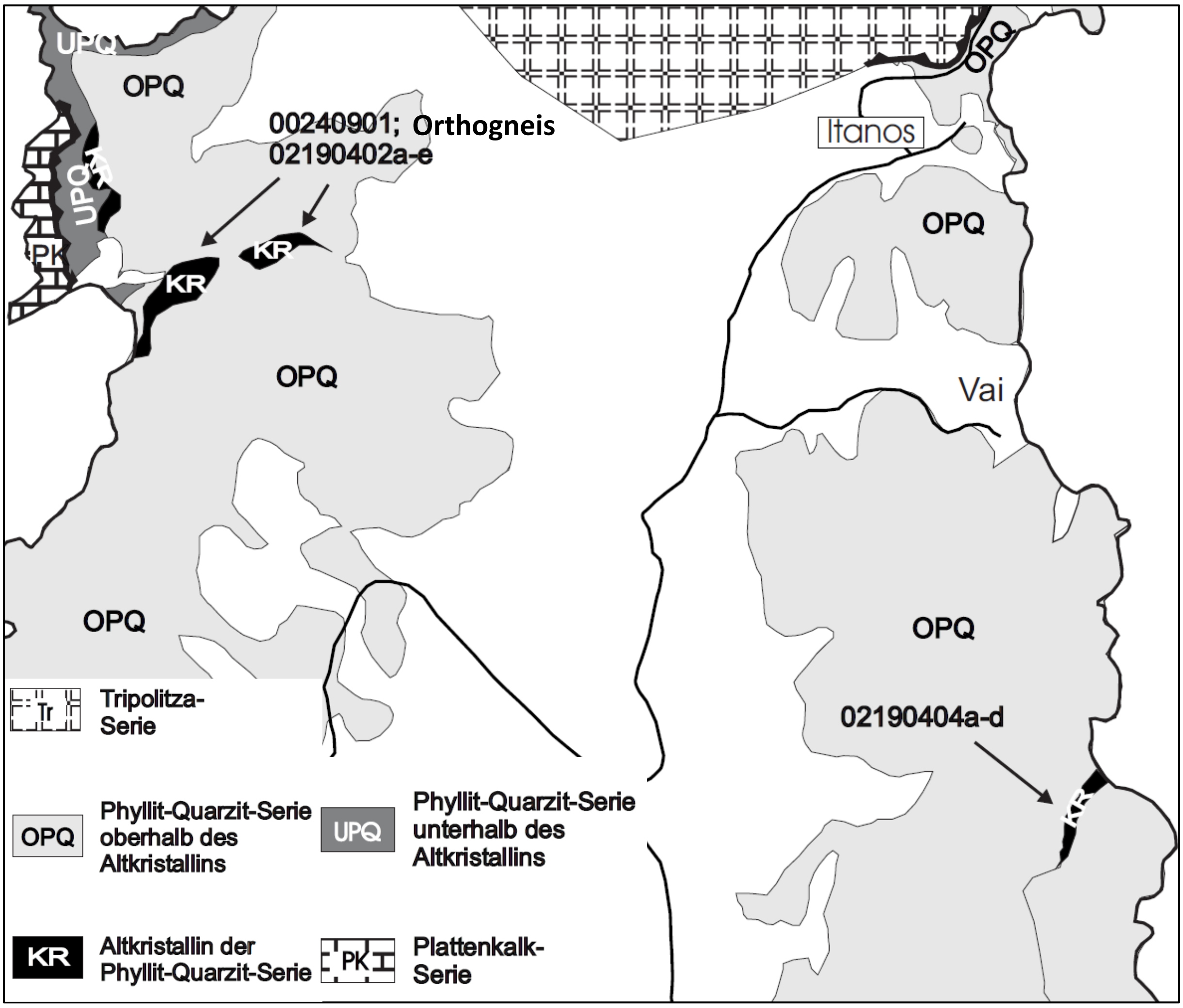
3: Grab sample from the outcrop above. 3a: probably garnet, 3b: white mica

Tyros Beds and Pre-alpine Basement at the Vai Peninsular

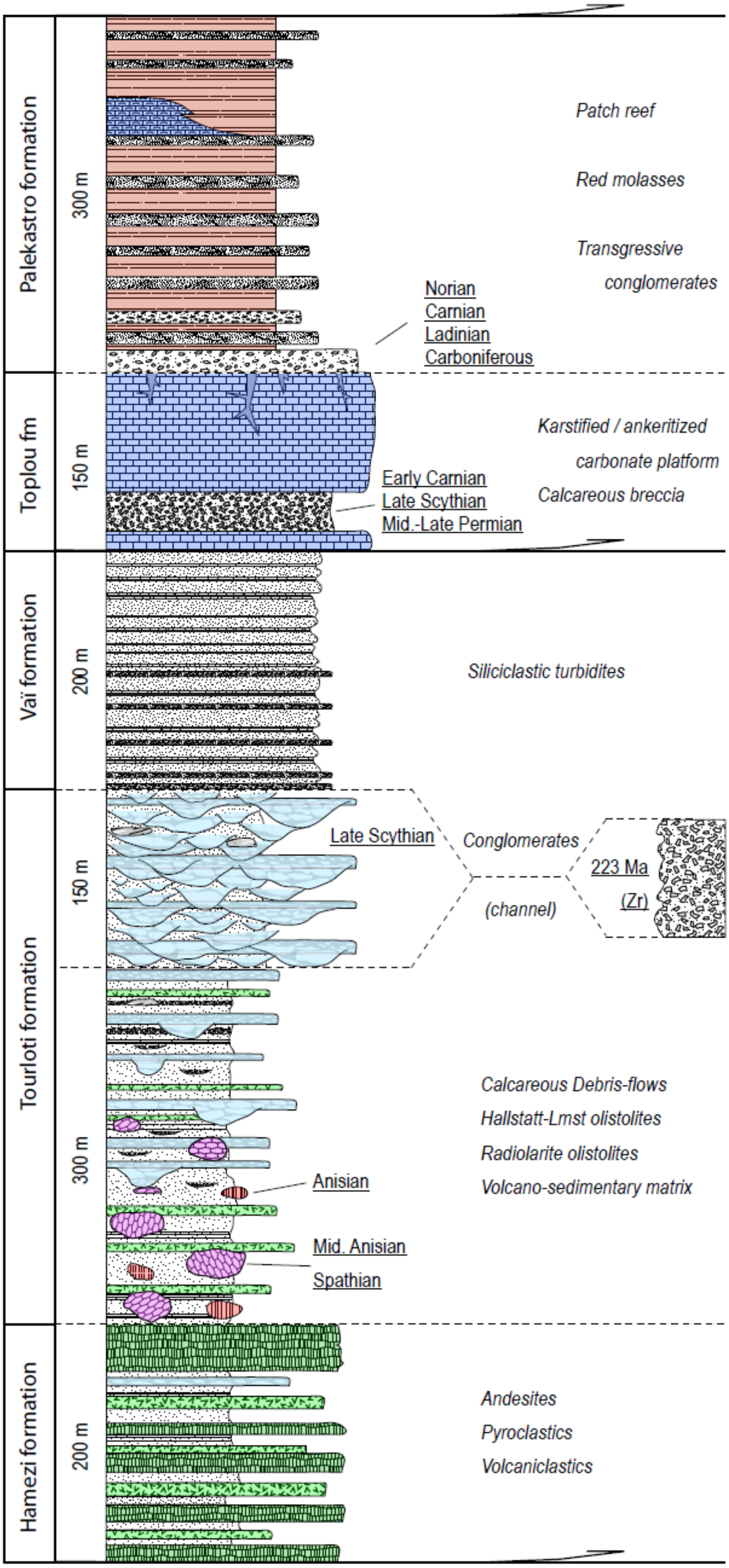
Meta-andesites, Pink Marble and Orthogneiss at the Chordarkis Quarry

Vai-Kristallin

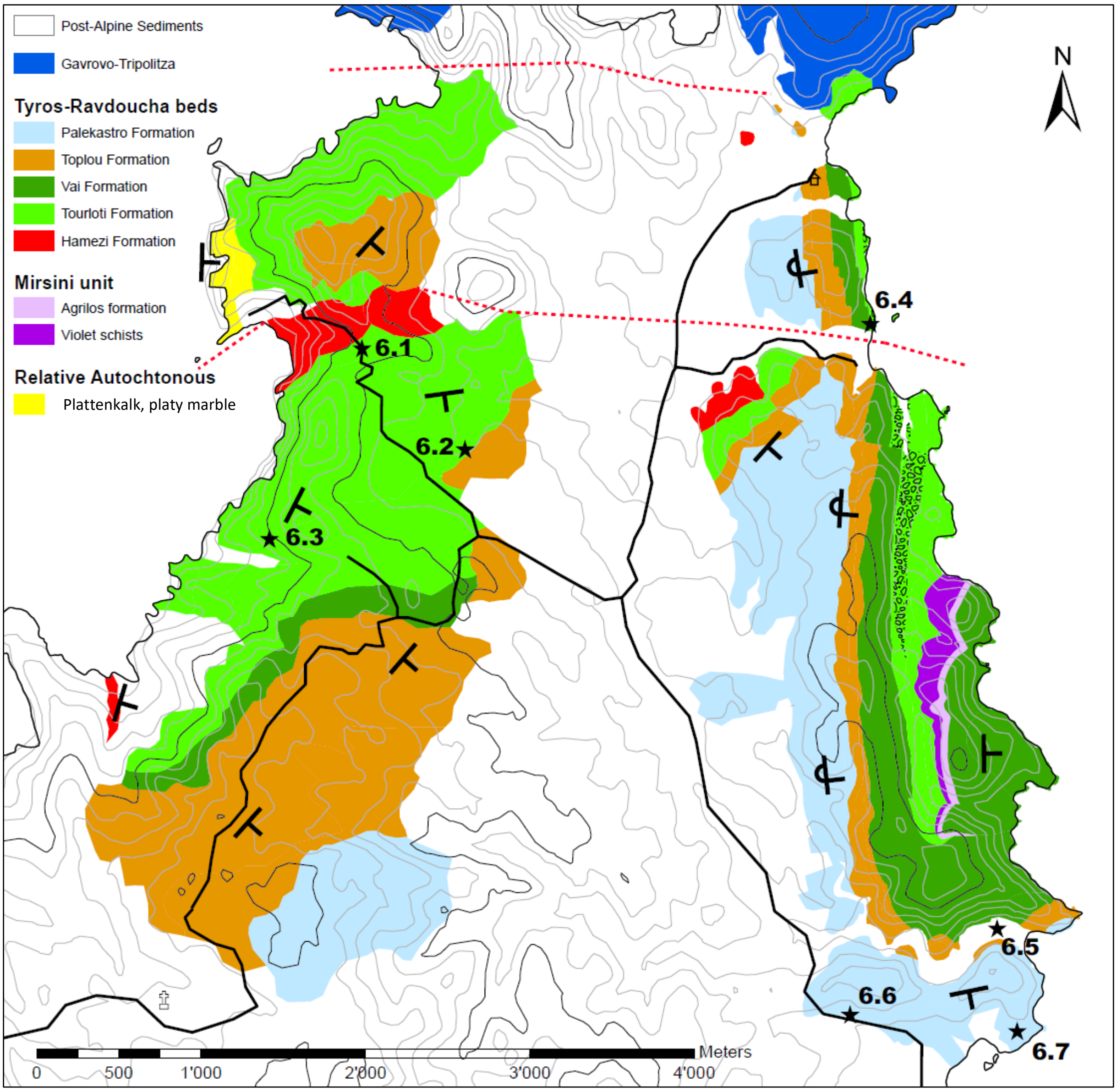
North of the Toplou monastery near the coast, on Vai beach and on the road north of Itanos, there are small crystalline outcrops of pre-alpine basement. The muscovite-biotite-mica schists and albite-muscovite gneisses occurring at the Vai peninsula are named Vai Crystalline Complex (VCC). The deposits at Vai and Itanos are only a few dm thick and also strongly altered. The pre-alpine basement deposits at the Chordakis quarry, on the other hand, are several tens of metres thick. They consist of slightly altered amphibolites, mica schists and gneisses. The tecto-stratigraphic position of the VCC is not well known, but granite is thought to have been intruded into sediments and metamorphic rock during the Triassic approx. 223 Ma ago. A later phase of amphibolite facies overprint indicates top-to the NW shearing. The rapid ascent of the rocks is documented by Jurassic zircon fission track ages of 184 Ma *[Romano, 2005]*.



[Source: Romano, 2005]



Synthetic log of the Tyros-Ravdoucha Beds in Eastern Crete [Source: Stampfli, 2010]



Geological map of the Vai peninsula modified after Matti & Mazzardi (2001) and Romano (2005) [Source: Stampfli, 2010]. Note: the Map does not show outcrops of the pre-alpine basement.

Tourloti formation (6.1, 6.2 and 6.3)

Based on the classification by Stampfli the Tourloti formation is made up of limestone debris-flows with abundant olistolites of up to 30m in diameter. Volcanic material is present, but mainly as volcano-sedimentary matrix, in which small lenses of quartzite and quartzite breccias occasionally occur. According to Stampfli the olistolite blocks consist mostly of pink Hallstatt-limestones and red radiolarites, but grey or brown limestones and volcanic rock are also present *[Source: Stampfli, 2010]*.

The Hallstatt limestone/marble located within the Tourloti Fm. was once exploited at a former quarry called "Chordakis" (N 35° 15.31; E 26° 13.97). The limestone/marble is predominantly red, but is also grey. Fossils are still recognizable in the marble and hexa-corals indicate Middle Triassic age or younger. Another marble deposit in the area has yielded Triassic conodonts and radiolarite blocks contain Anisian radiolarians. Green meta-volcanites and basalt/andesite also occur in the area around the quarry and just south below the quarry an outcrop of Variscan crystalline (VCC) consisting of orthogneiss is exposed (N 35° 15.20; E 26° 13.93) *[Kull, 2012]*.

1: Overview of the Tourloti formation, which is interpreted by Stampfli as a calcareous debris flow. It often contains pink marble or radiolite blocks up to 30m in diameter. Blocks of grey or brown limestones and volcanics are also present. The large blocks are thought to be olistolites that were deposited by marine gravity flows. The submarine rock slides are usually triggered by earth quakes. Note that the rock is anchi-metamorphic and displays foliation. 2b: basalt or andesite flow/olistolite

1: *Close up of the Tourloti formation, which is interpreted by Stampfli, 2010 as a calcareous debris flow. The matrix is reported to be volcano-sedimentary, while the clasts are mainly calcareous and sometimes of clastic or volcanic origin.*

2a: Location of a basalt/andesite outcrop as seen from the road looking south

2a: Basalt/andesite shown on the previous picture

2a: Closeup of the previous picture

3: View of the small Chordarkis quarry looking north-east. It is a source of red Hallstatt limestone/marble, which is thought to be an olistolith. 5: Orthogneis (Romano 2005)

5: Orthogneis, which is reported to be part of the pre-alpine basement (Romano 2005)

5: Closeup of previous picture (see arrow). The light grey to white rock is composed of 35 % quartz, 40 % feldspars, 20 % muscovite and 5 % opaque phases. The pink crystals are probably of potassium feldspar.

The orthogneiss occurrence is only 15 m thick. The light grey to white rock is composed of 35 % quartz, 40 % feldspars, 20 % muscovite and 5 % opaque phases. The protomylonitic gneiss consists of a quartz-muscovite substructure in which max. 1 mm large magmatic potassic feldspar, plagioclase and albitised plagioclase porphyroclasts are embedded. Besides a weak SC-structure, the potassic feldspars show asymmetric pressure shadows of muscovite, so that top-NW-transport can be determined. In addition, dynamic recrystallisation of the plagioclase took place. During the Alpine overprinting, shear paths with bulging recrystallisation (BLG) of quartz were established. In these highly stressed areas, the biotites and muscovites broke up or were replaced by chlorite, sericite and opaque phases *[Romano, 2005]*.

5: Highly foliated orthogneis

5: Closeup of previous picture

5: Highly foliated and partly mylonitic orthogneis 4m further down the road from previous picture, 3: Red Hallstatt marble boulders

3a: Red Hallstatt limestone/marble. Notice the violet rock overlying the pink marble, 3b: Overlying violet rock. The Hallstatt limestone possesses irregular shaped calcite veins and linear cemented joints which indicates different phases of stress.

The red Hallstatt limestones contain pelagic conodonts of ages between Oelenekian (Spathian) and the Middle Anisian (Stampli). At other locations such as at Hallstatt, Austria and Theokafta, Eastern Peloponnese this limestone horizon contains abundant cephalopod fossils. The pink hemipelagic limestones display calcium carbonate nodules (3c) floating in a carbonate Fe-oxide enriched matrix (F.A. Pomoni1, 2013).

3b: Closeup of the violet rock overlying the Hallsatt limestone.

Grey limestone/marble overlying the Hallstatt marble assumed to belong to the Tyros beds.

Closeup of the grey limestones/marble overlying the red Hallstatt limestone/marble. There are at least two generations of fissures which have been cemented together indicating tectonic deformation (stress).

The Chamezi formation (6.1)

The most common facies of the RTB is the basal sequence of volcanogenic rocks (Chamezi formation), which can reach 200m thickness. It is mainly composed of green pyroclastic and andesitic flows, alternating with yellow-green volcano-sedimentary rocks (arkosic sandstones and shales). Igneous textures can be observed, like magma-mixing figures or pyroclastic breccia with dacitic to rhyolitic blocks.

The rocks are very differentiated, with composition between andesitic basalts and trachy-andesites. The geochemical analysis of these volcanics yield a bimodal signature, with calk-alkaline and within-plate tholeiitic signatures. Unfortunately, no dating of this formation could be undertaken except for ages obtained in the upper formation that indicate Middle Triassic. The Paleotethyan volcanic arc is therefore considered as the geodynamic setting of this formation.

4: Meta-andesite (Chamezi Fm) displaying distinct foliation.

4b: Closeup of previous picture. Notice the reflective sheen and wrinkled surface due to the parallel alinement of minute white mica grains. The meta-andesite has a creamy slightly greenish colour that may be due to the presents of chlorite. Cleavage surfaces also sometimes display very small phenocrysts that were probably pyroxenes (Diopsite or Augit) now brown due to formation of Fe-oxides during weathering.

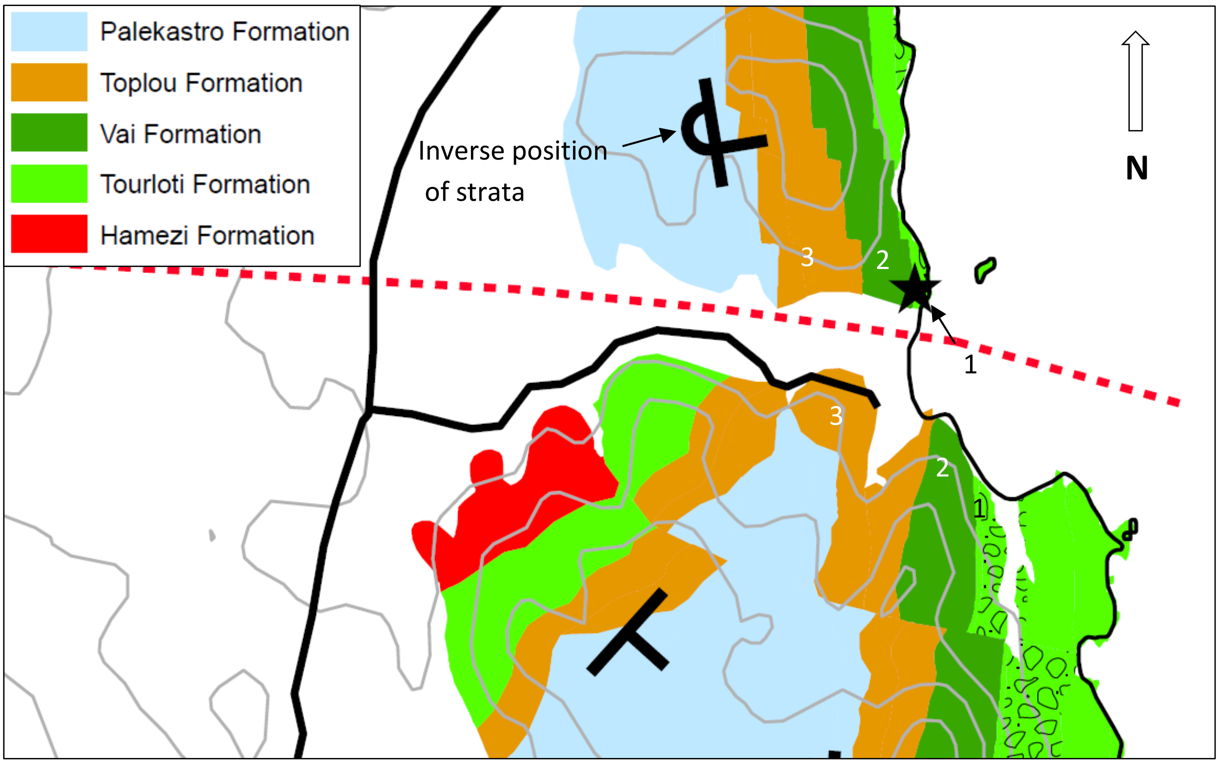
The Toplou Beds nach Haude, 1989

The sequence between the Tripokefala Beds and the Tripolitza Unit is referred to as the Toplou Beds. Rocks of the Toplou Beds are exposed near Roussa Ekklisia, Toplou and Vai. Haude, 1989 subdivided the Toplou Beds into six layers as follows (from base to top):

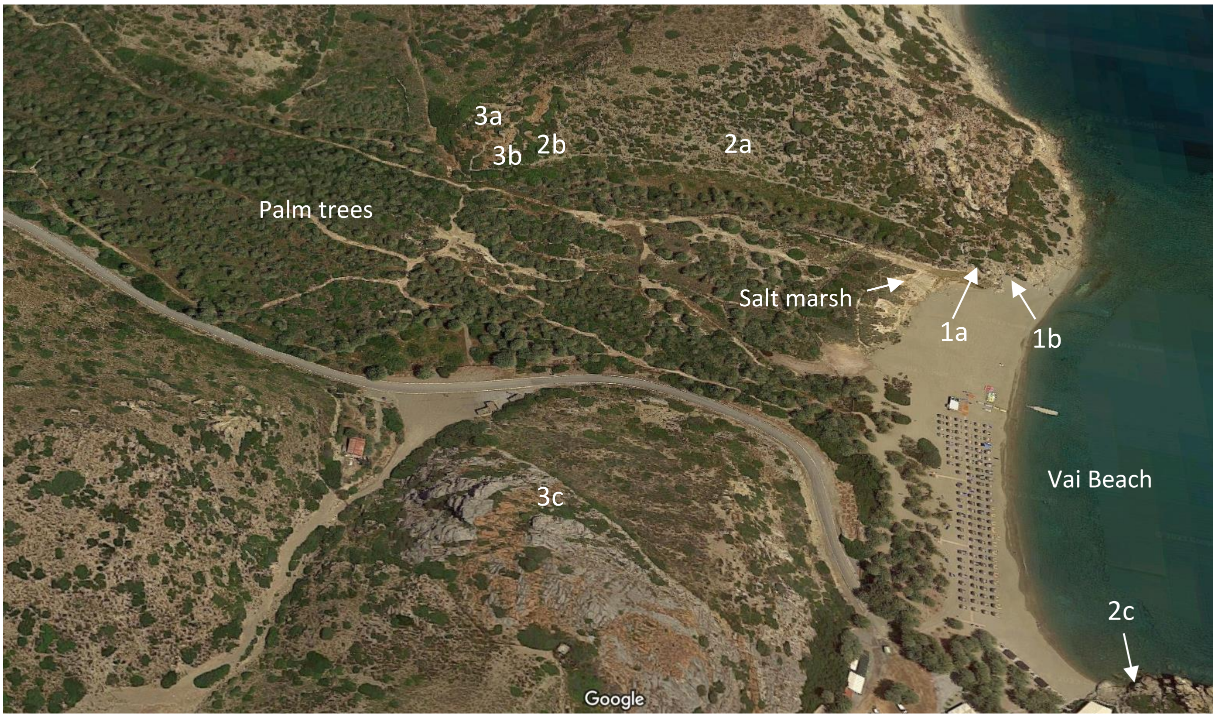
- T1 - Violet quartzite,
- T2 - marble, ankeritic dolomite and metaclastic rocks,
- T3 - metaclastic rocks and metavolcanics,
- T4 - marble with ankeritic dolomite,
- T5 - metaclastic rocks,
- T6 - violet slates and siltstones intercalated with quartzite.

Vai Beach

Outcrops of the Toutloti and Vai Formation (Tyros Series) can be seen at the northern and southern end of the beach and along the sides of the valley. At the northern side of the beach there is a metaconglomerate consisting mainly of quartzites and quartz, but also of marble and occasional angular components of gneiss. The crystalline components of the conglomerate are thought to be pre-alpine basement clasts, which have been differently interpreted by various authors i.e. Haude 1989, Stampfli et al. 2003, Robertson 2006, 2008 *[Kull]*.



Geological map of Vai Beach and vicinity showing inverse position of the strata along the coast. 1: meta-conglomerate (after Stampfli, 2010)



Overview of Vai Beach and valley: 1a: Base of the Tourloti Fm (volcano-sedimentary deposits) displaying a regressive sequence, 1b: Conglomerate partly with pre-alpine basement clasts belonging to the Tourloti Fm, 2a: Vai formation consisting of siliciclastic turbidites, 2b: conglomerate at top of the Vai Fm., 3a, 3b & 3c: Orange ankeritic limestone of the Toplou Fm.

1a: Siltstone to conglomerate sequence within the Tourloti Fm displaying a "coarsening up sequence". As the outcrop is indicated to be upside down (see geological map) it is really a "fining up sequence", which may be interpreted as a transgression.

1a: Close up of previous picture showing the transition from gravel sized clasts to silt sized particles

1b: Conglomerates of the Tourloti Fm overlying the transgressional sequence (see previous picture)

1b: Closeup of the previous picture. The conglomerate is highly deformed often displaying disc-shaped clasts. The clasts consist mainly of quartzite and quartz, but some are of marble and gneiss (A). The gneisses are reported to have been derived from a pre-alpine basement displaying an age of 223 Ma yr (Romano, 2005). The conglomerate itself is indicated to be younger and represents the filling of a wide erosional channel (Stampfli) that is within the Tourloti Fm.

The Pre-alpine Basement Conglomerates within the Tourloti Fm

Intercalated within the Tourloti formation, there is a layer of terrigenous conglomerates. It is characterized by poorly sorted pebbles and clasts of basement rock (up to 40 cm), such as garnet-bearing mica schists, meta-sandstones and pink quartz. It crops out as a lens of 3 km length and a maximum thickness of 100m. According to Stampfli, it is thought to have been a channel bringing material from nearby Variscan basement outcrops. However, based on Carnian zircons from an orthogneiss clast some authors interpret the meta-conglomerate as a tectonic slice of Variscan basement (Romano, 2005).

Based on the Tourloti Fm facies and the erosional channel model Stampfli suggests there to have been significant subsidence and inundation of area during the Middle Triassic. Turbidites, debris-flows and olistolites indicate the presence of steep marine slopes, probably caused by faulting. The tectonic activity would have led to extensive faulting and ultimately erosion of covering strata down to the basement. In a plate tectonic model this would correspond to a syn-rift setting, close to a volcanic arc. The paleogeographic position and the ages relate to the opening of the Pindos back-arc basin (see Appendix for plate tectonic model) *[Stampfli,]*.

The Vai formation (6.4)

Overlying the volcano-sedimentary deposits (Tourloti Fm), there is a thick sequence (at least 200m) of terrigenous turbidites called the Vai formation. It consists of a series of quarzitic sandstones, siltstones, clay stones, and rare layers of breccia, with yellow to red colors. The beds exhibit turbiditic structures, with decimeter to meter thickness (but 5m thick layers of breccia occur at the base). The whole sequence displays fining upwards. The lower contact is reported to be sedimentary, while the upper contact is interpreted to be tectonic. The Vai formation was previously regarded as early Cimmerian flysch, occurring at the closure of the Paleotethyan ocean (Matti and Mazzardi, 2001; Stampfli et al. 2003). However, due to its position on top of the syn-rift Tourloti formation, it can be regarded as a post-rift sequence.

2a: Closeup of the Vai Formation at the north side of the valley

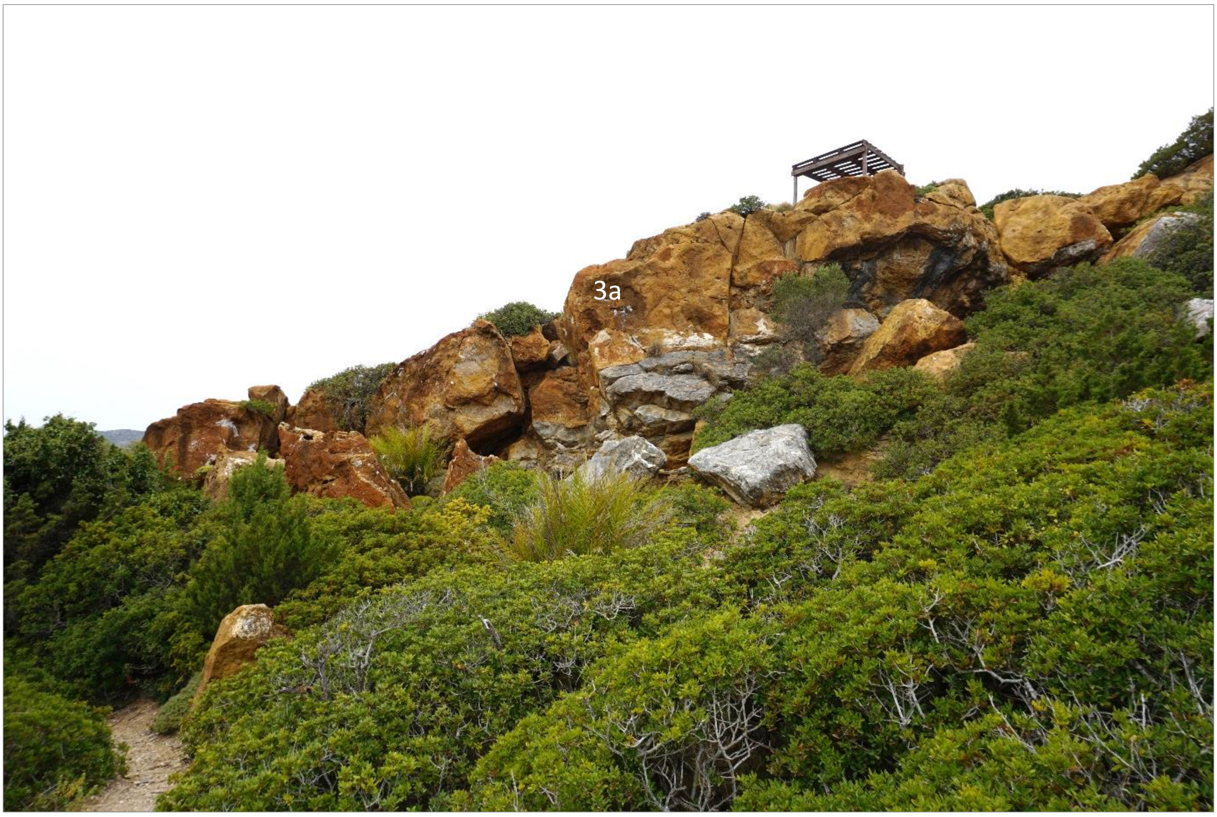
2c: Folded rocks of the Vai Formation consisting of sicilic-clastic turbidites at the south side of the valley.

2c: A conspicuous fold within the Vai Formation at the south rim of the valley. The folding is due to ductile deformation deep within the earth's crust. A second phase of brittle deformation at shallow depth is indicated by joints cross cutting the fold (B).

2b: Conglomerate located between the Vai Fm and Toplou Fm at the north side of the valley.

The Toplou Formation (6.4 and 6.5)

This formation represents a small carbonate platform of max. 150m thickness that is intercalated by a horizon of calcareous breccia. The limestones are frequently orange due to ankeritic alteration and often display karstification. Breccia clasts within the limestone contain conodonts and foraminifera of different Permian (shallow water) and Triassic ages. Based on the youngest clasts the platform is considered to be of Carnian age (see Appendix for stratigraphic ages) *[Stampfli]*.



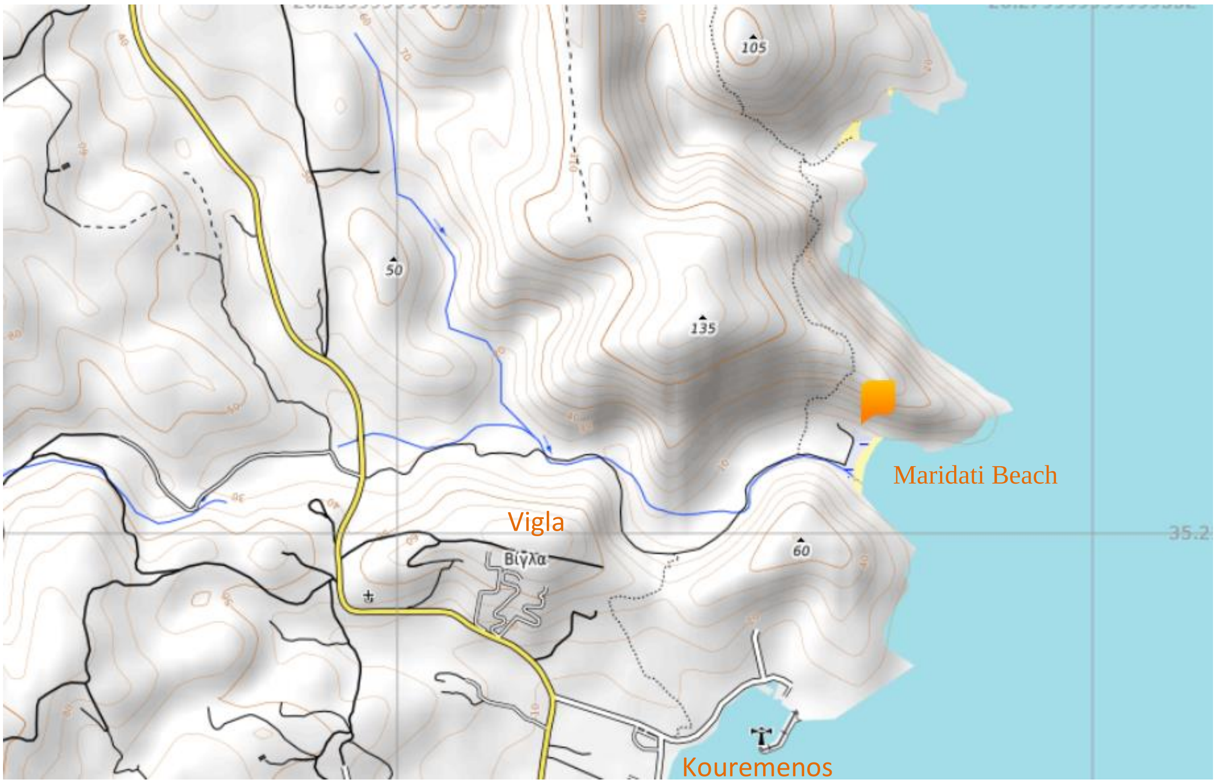
3a: Overview of the Toplou Formation at the north side of the valley. Notice the distinct orange surface colouring of the marble which is normally grey.

3a: Close up of the orange-stained marble (Toplou Fm.). The orange colouring of the marble is mostly superficial. Ankerite is a calcium iron carbonate with the formular: $CaFe[CO_3]_2$. In composition it is closely related to dolomite, but differs from dolomite in having magnesium replaced by varying amounts of iron II. When manganese is present Kutnohorite may also occur ($CaMn[CO_3]_2$).

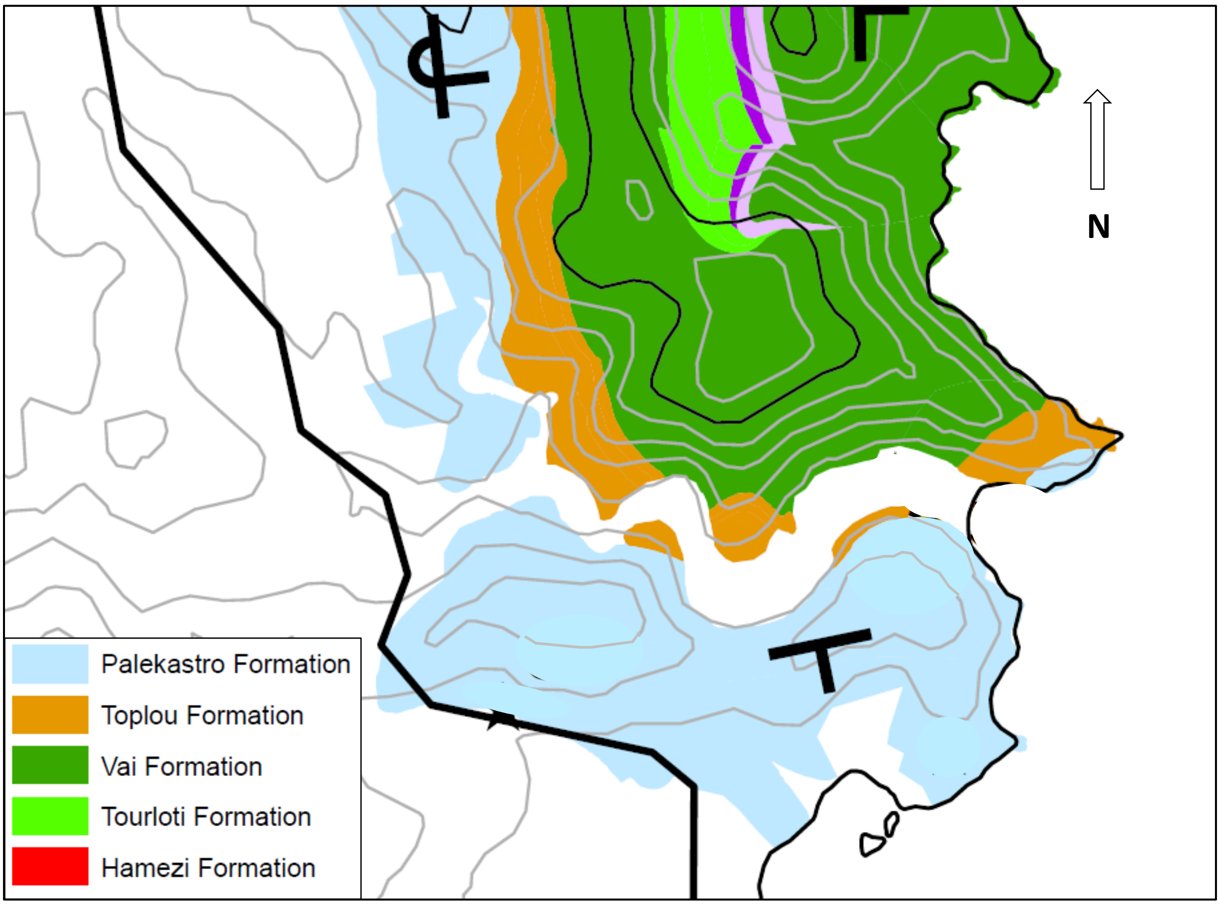
3c: View of the Toplou Fm. looking south across the valley that is filled with palm trees. A: ankeritic area, white line indicates a normal fault.

A salt marsh has formed between the beach and the palm trees.

Maridati Beach, Ankeritic Dolomite



Location of Maridati Beach south of Vai Beach



Geological map of Maridati Beach displaying the Tyros Beds (Stampfli)

Outcrops of the Tyros Beds at the Maridati Beach (image from Google Maps)

The Maridati Beach is a protected landscape (NATURA GR4320006, GR4320009) and is a natural coastal wetland that is wet throughout the year. The ecological environment relies on the presents of groundwater, surface water and the influence of the sea to create brackish water conditions. The Maridati wetland is an important resting place for migratory birds (see Appendix).

1a: View of the small peninsular at the northern side of Maridati Beach displaying the Palekastro Fm. (after Stampfli)

2a: Toplou Fm at the north side of the beach showing the typical orange colouring of the limestone/dolomite. The limestone originates from a small carbonate platform that is considered to be of Carnian age (Stampfli).

2a. Closeup of the Toplou Fm limestone/dolomite

3a: Carnian red metasandstone (T1 after Haube); 2a: Ankeritic dolomite (T2 after Haube) [Zulauf, 2014]

3a: Closeup of the Carnian red metasandstone/metasiltstone shown on the previous picture

Palekastro Formation (6.6 and 6.7)

A transgressive conglomerate, with limestone clasts coming from the ankeritized platform occurs at the base of the Palekastro Formation. Carboniferous, ladinian, carnian and norian conodonts have been found in the conglomerate (Krahl et al, 1986). It is followed by a very thick series of yellow to red sandstones and pelites, with a calcareous matrix. Erosive structures and cross-bedding stratification suggest a shallow water environment such with beach or delta facies. This is supported by several isolated patch reefs with oolithic sands, corals, crinoids, bivalves, and gastropods (not exposed at this location). The Palekastro formation is regarded as once being the transition to the overlying Tripolitza platform, which is now a nappe. There is a radical change of depositional environment between the Tourloti-Vai formations, which represent marine slopes with turbidity currents and the Toplou-Palekastro formations displaying shallow water facies with carbonate platform and deltas. The change to shallow water conditions is probably due to tectonic activity, rather than to eustatic sea level change. The Norian ages suggest some relation to the Eo-cimmerian mountain building during the closure of the Paleotethys. Consequently, red terrigenous deposits (not exposed at this location) can be interpreted as molasse *[Stampfli,]*.

1b: view of the south side of Maridati Beach displaying the Palekastro Fm.

1b: A: conglomerate, B, graded sandstone

1b: top side of a conglomerate bed within the Palekastro Fm showing rounded but poorly sorted clasts in a carbonate matrix.

1b: Section of a similar conglomerate bed (see previous picture) displaying foliation and partly oval - shaped clasts.

1b: Yellowy sandstone beds with red colouring.

1b: Closeup of previous picture showing graded bedding of sandstone. Direction of arrow indicates a coarsening upwards texture, which can be attributed to an increase in water velocity.

1b: A: foliated pelite bed (slate), B: Sandstone beds displaying cross bedding.

1b: closeup of previous picture, A: crossbedding in sandstone indicates a shallow, flowing water environment e.g. estuary, delta or shoreface, B: bedding plane, C: cleavage of slate

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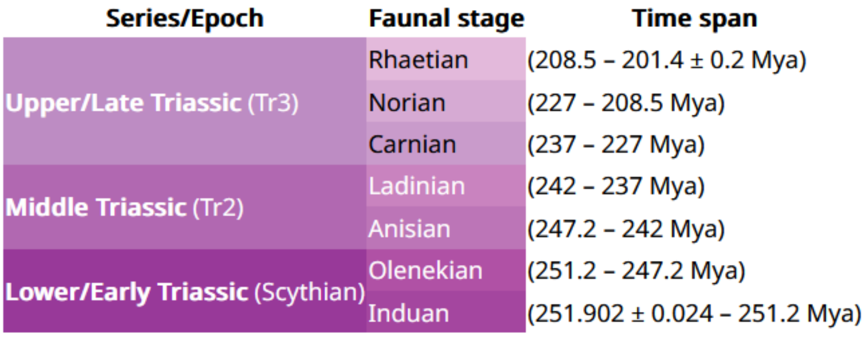
Appendix

Stratigraphic Table and Paleogeography of the Triassic Period (Source: Wikipedia)



Series/Epoch	**Faunal stage**	**Time span**
Upper/Late Triassic (Tr3)	Rhaetian	(208.5 – 201.4 ± 0.2 Mya)
	Norian	(227 – 208.5 Mya)
	Carnian	(237 – 227 Mya)
Middle Triassic (Tr2)	Ladinian	(242 – 237 Mya)
	Anisian	(247.2 – 242 Mya)
Lower/Early Triassic (Scythian)	Olenekian	(251.2 – 247.2 Mya)
	Induan	(251.902 ± 0.024 – 251.2 Mya)

During the Triassic, almost all the Earth's land mass was concentrated into a single supercontinent, Pangaea (lit. 'entire land'). This supercontinent was more-or-less centered on the equator and extended between the poles, though it did drift northwards as the period progressed. Southern Pangea, also known as Gondwana, was made up by closely-appressed cratons corresponding to modern South America, Africa, Madagascar, India, Antarctica, and Australia. North Pangea, also known as Laurussia or Laurasia, corresponds to modern-day North America and the fragmented predecessors of Eurasia.

The western edge of Pangea lay at the margin of an enormous ocean, Panthalassa (lit. 'entire sea'), which roughly corresponds to the modern Pacific Ocean. Practically all deep-ocean crust present during the Triassic has been recycled through the subduction of oceanic plates, so very little is known about the open ocean from this time period. Most information on Panthalassan geology and marine life is derived from island arcs and rare seafloor sediments accreted onto surrounding land masses, such as present-day Japan and western North America.

The eastern edge of Pangea was encroached upon by a pair of extensive oceanic basins: The Neo-Tethys (or simply Tethys) and Paleo-Tethys Oceans. These extended from China to Iberia, hosting abundant marine life along their shallow tropical peripheries. They were divided from each other by a long string of microcontinents known as the Cimmerian terranes. Cimmerian crust had detached from Gondwana in the early Permian and drifted northwards during the Triassic, enlarging the Neo-Tethys Ocean which formed in their wake. At the same time, they forced the Paleo-Tethys Ocean to shrink as it was being subducted under Asia. By the end of the Triassic, the Paleo-Tethys Ocean occupied a small area and the Cimmerian terranes began to collide with southern Asia. This collision, known as the Cimmerian Orogeny, continued into the Jurassic and Cretaceous to produce a chain of mountain ranges stretching from Turkey to Malaysia.

Pangaea was fractured by widespread faulting and rift basins during the Triassic—especially late in that period—but had not yet separated. The first nonmarine sediments in the rift that marks the initial break-up of Pangaea, which separated eastern North America from Morocco, are of Late Triassic age; in the United States, these thick sediments comprise the Newark Supergroup. Rift basins are also common in South America, Europe, and Africa. Terrestrial environments are particularly well-represented in the South Africa, Russia, central Europe, and the southwest United States. Terrestrial Triassic biostratigraphy is mostly based on terrestrial and freshwater tetrapods, as well as conchostracans ("clam shrimps"), a type of fast-breeding crustacean which lived in lakes and hypersaline environments.

Because a supercontinent has less shoreline compared to a series of smaller continents, Triassic marine deposits are relatively uncommon on a global scale. A major exception is in Western Europe, where the Triassic was first studied. The northeastern margin of Gondwana was a stable passive margin along the Neo-Tethys Ocean, and marine sediments have been preserved in parts of northern India and Arabia. In North America, marine deposits are limited to a few exposures in the west.

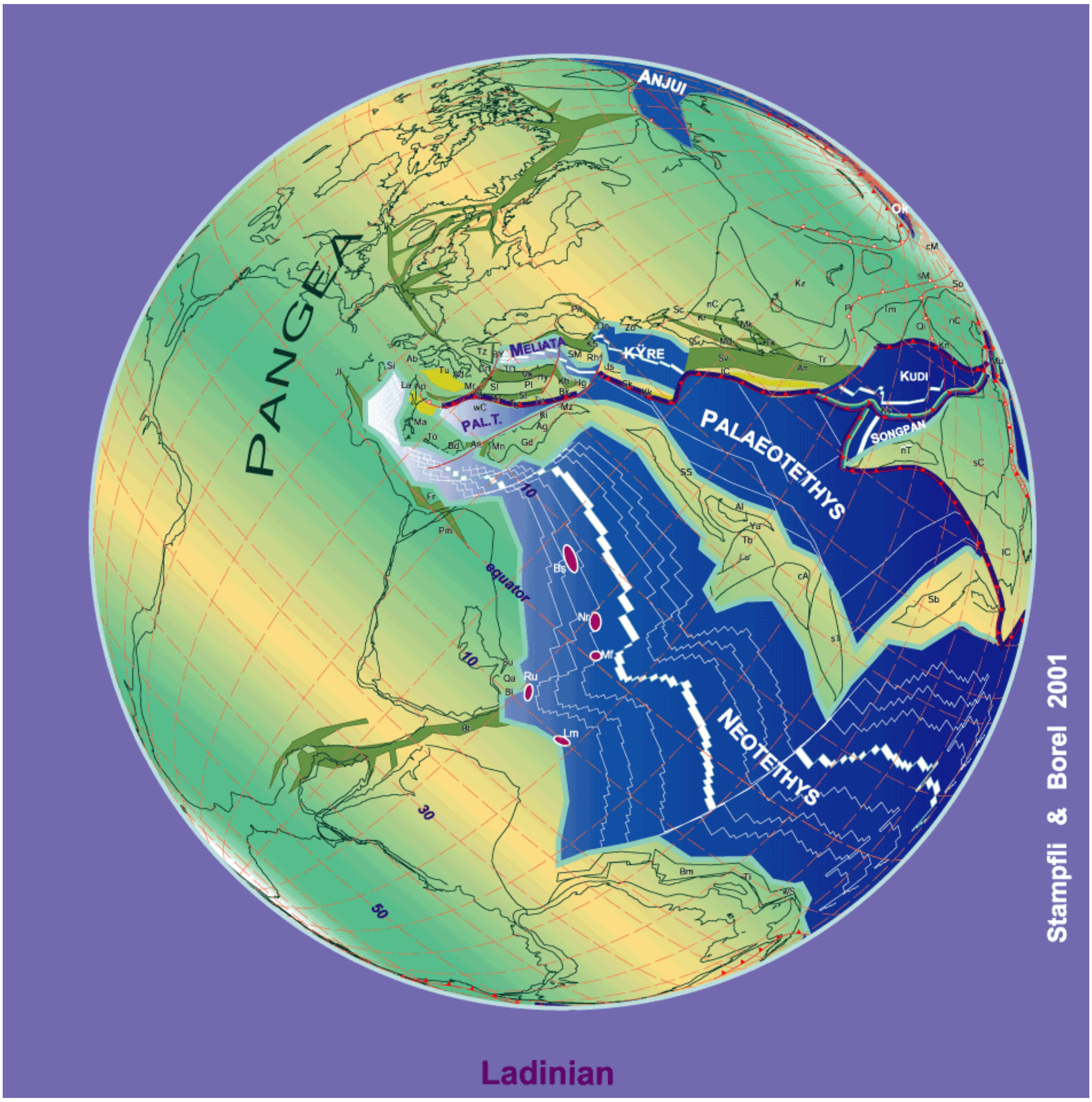


Plate tectonic Model for the Pre-alpine Period (Romano 2005)

The pre-Alpine basement was thrust on top of the Phyllite–Quartzite Unit (s.str.), which consists of metavolcanics, violet slates, metasiltstone and quartzite (at the base), and phyllite/marble interbeds (at the top). Thin marble layers in the upper part of the violet slates yielded a pelagic fauna of Middle Permian age (conodonts and radiolaria, Kozur and Krahl, 1987). The phyllite/marble interbeds yielded an Early Olenekian conodont fauna (Krahl et al., 1986). As amphibolite facies rocks of the basement have been thrust on top of anchimetarmophic rocks of the Phyllite-Quartzite Unit s. str., thrusting occurred under brittle to semi-brittle conditions. Apart from the uppermost part of the Tyros Unit, all rocks, from Plattenkalk to Tripolitza flysch underwent Oligocene–Miocene subduction and related high-pressure/low-temperature metamorphism (Seidel et al., 1982; Feldhoff et al., 1991; Theye et al., 1992; Zulauf et al., 2002; Klein et al., 2008, 2013). The peak conditions of the Alpine metamorphism in eastern Crete are 4.5–6.0 kbar and 250–310 °C (Seidel et al., 1982; Franz et al., 2005). As the temperature is below the zircon fission-track annealing zone, zircon fission-track ages do not reflect the Alpine overprint, but the cooling of the source rocks of the meta-sediments (Brix et al., 2002). Notably, fission-track ages obtained from detrital zircons of Tyros-Unit quartzites yield Devonian ages (Brix et al., 2002), indicating that these zircons and the source rock did not undergo significant metamorphism during the Variscan, Cimmerian or Alpine cycle.

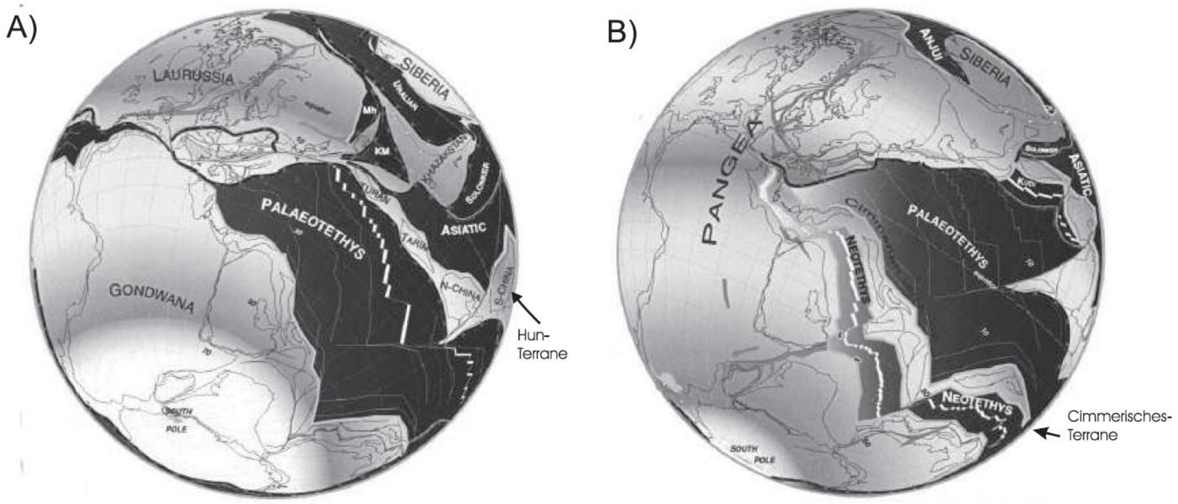
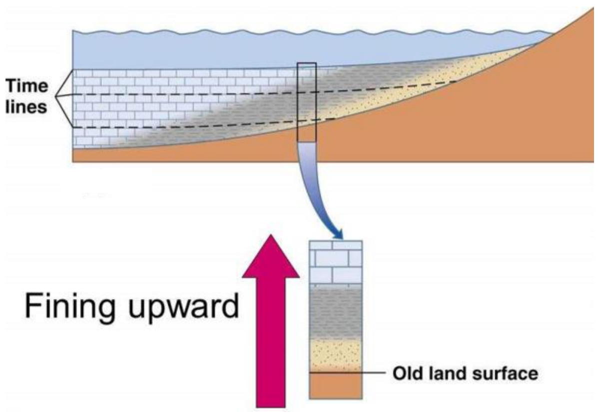
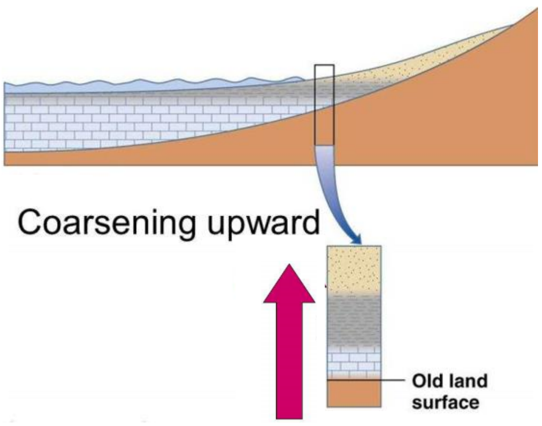


Abbildung 4.11.: Der Nordrand Gondwanas vor a) 320 Ma: hier existieren noch Gondwana und Laurussia; b) 260 Ma: Pangea, showing the initial separation of the Cimmerian-Terranes (Stampfli and Borel 2002).

Based on the zircon spectra and the direction of tectonic transport, the pre-alpine crystalline complexes are interpreted to be fragments of Gondwana. In late Pan-African times plutons intruded, followed by rifting and separation of several fragments. In Carboniferous to Permian times the collision and accretion of the crystalline complexes (MCC, CCC and KCC) was caused by top-to-the-N shearing. The magmatic intrusion of plutonites into the host rocks of the Vai Crystalline Complex (VCC) occurred in Triassic times, therefore the metamorphic overprint is younger. The basement cooled to > 350 °C in Jurassic times. During this phase of cooling the VCC was exhumed first, followed by the other basement units.

Transgression and fining up sequence

A Marine **Transgression** is a geologic event during which sea level rises relative to the land and the shoreline moves toward higher ground, resulting in flooding. Transgressions can be caused either by the land sinking or the ocean basins filling with water (or decreasing in capacity). Transgressions and regressions may be caused by **tectonic events** such as orogenies, severe climate change such as ice ages or isostatic adjustments following removal of ice or sediment load. In either case, sea water rises farther up onto land than it did before.

Transgression	Regression
	
In this case deeper sea sediments (shales and limestones) are deposited on top of continentally-derived beach sediments (sand). This forms a sequence (from bottom to top) of: ***sand-shale-limestone****.*	*In this case we will have deeper sea sediments (shales and limestones) being deposited on top of continentally-derived beach sediments (sand). This forms a sequence (from bottom to top) of:* ***sand-shale-limestone****.*

Note that a complete sequence does not necessarily have to exit. Transgressions and regressions can sometimes have occurred even when not all the rock types are present (due to an unconformity) or where coarser sediment is deposited from farther inland. In other words, instead of limestone conglomerates and breccias can be present landward.

Saltmarsh morphology