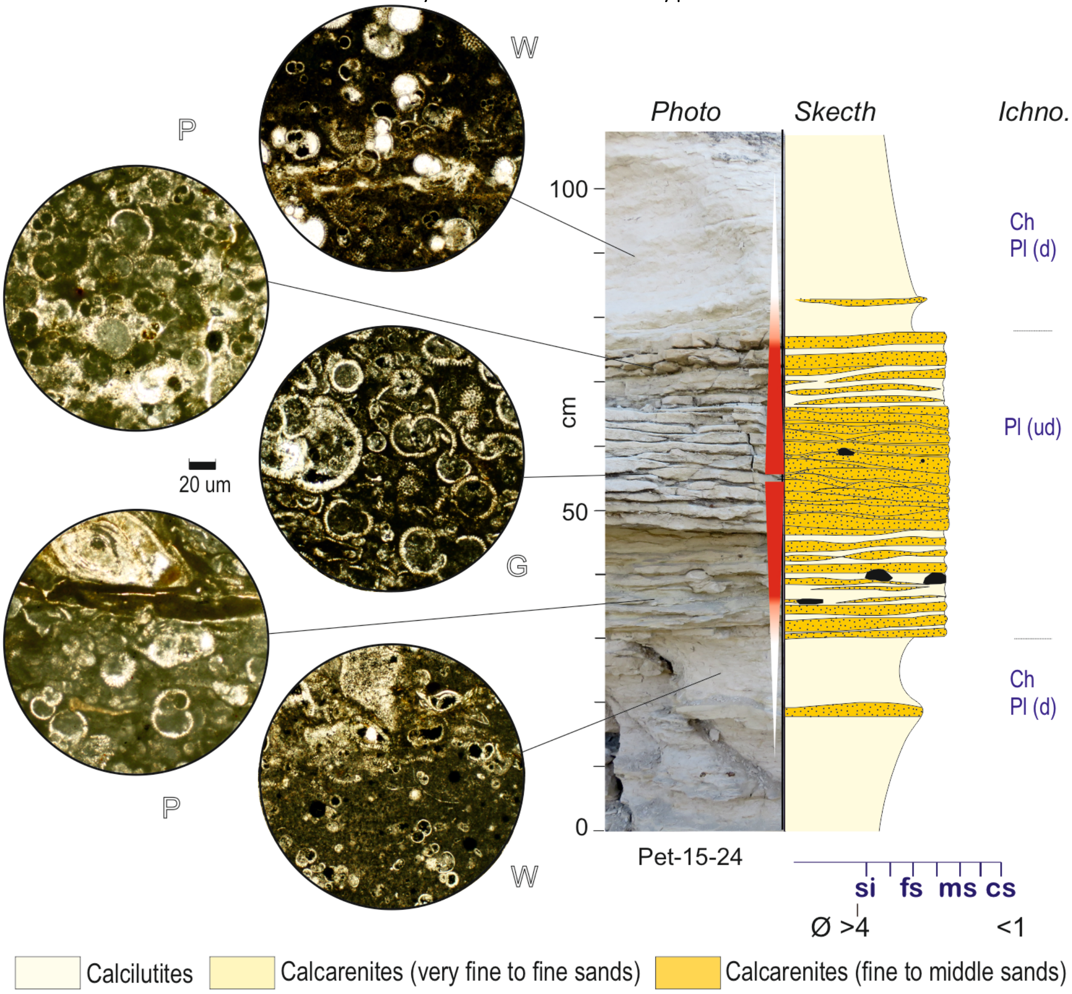
The 4th Deep Water Circulation Research Conference

Edinburgh, 24 - 26 May 2023

Post-conference Field Trip

Contourites and reworked turbidites from the Eocene to Miocene deposits of the Lefkara and Pakhna formations (Cyprus): distinguish criteria and implications

4th Deep Water Circulation Research Conference (4DWC)
28 May – 2 June 2023 - Cyprus



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Contourites and reworked turbidites from the Eocene to Miocene deposits of the Lefkara and Pakhna formations (Cyprus): distinguish criteria and implications

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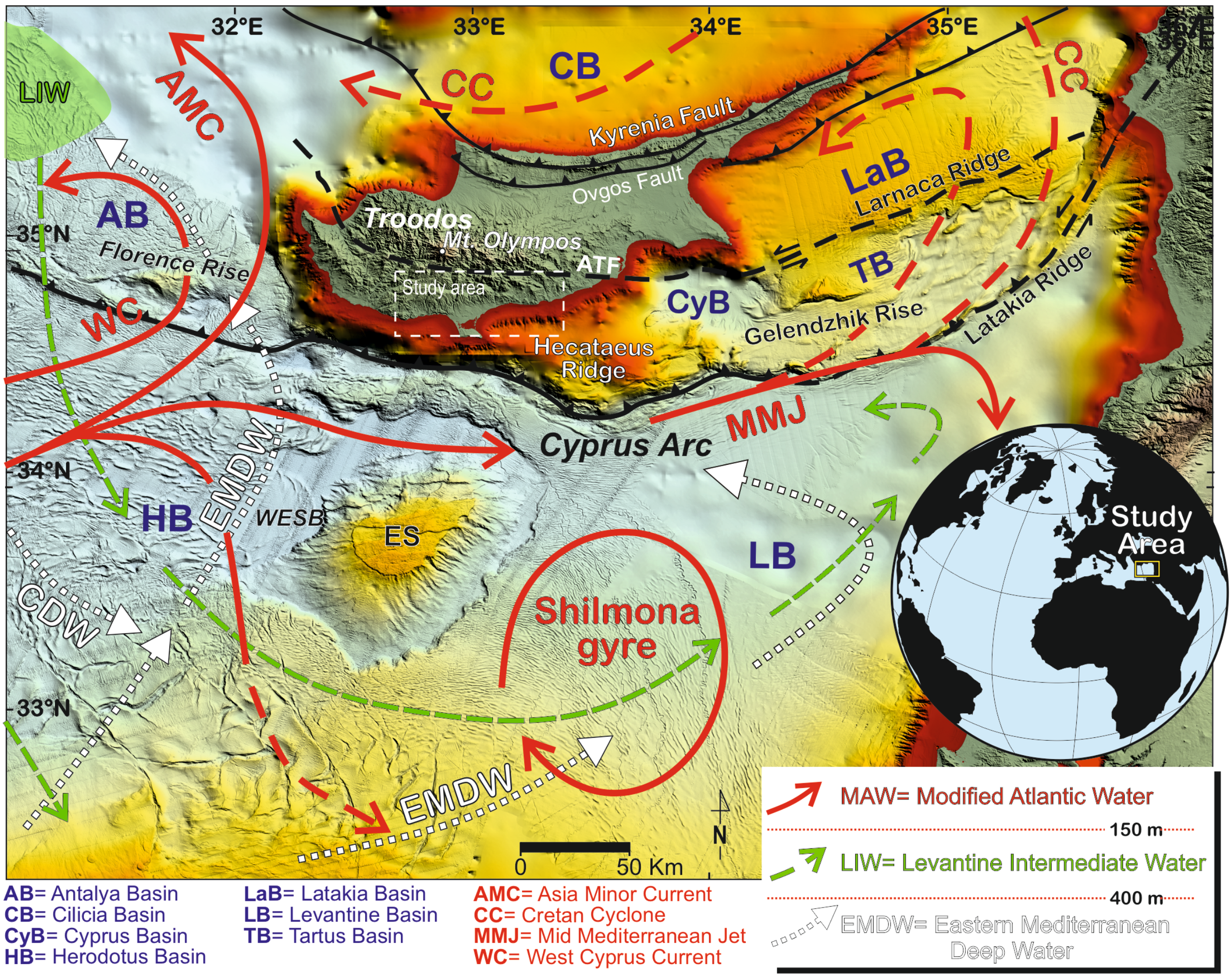
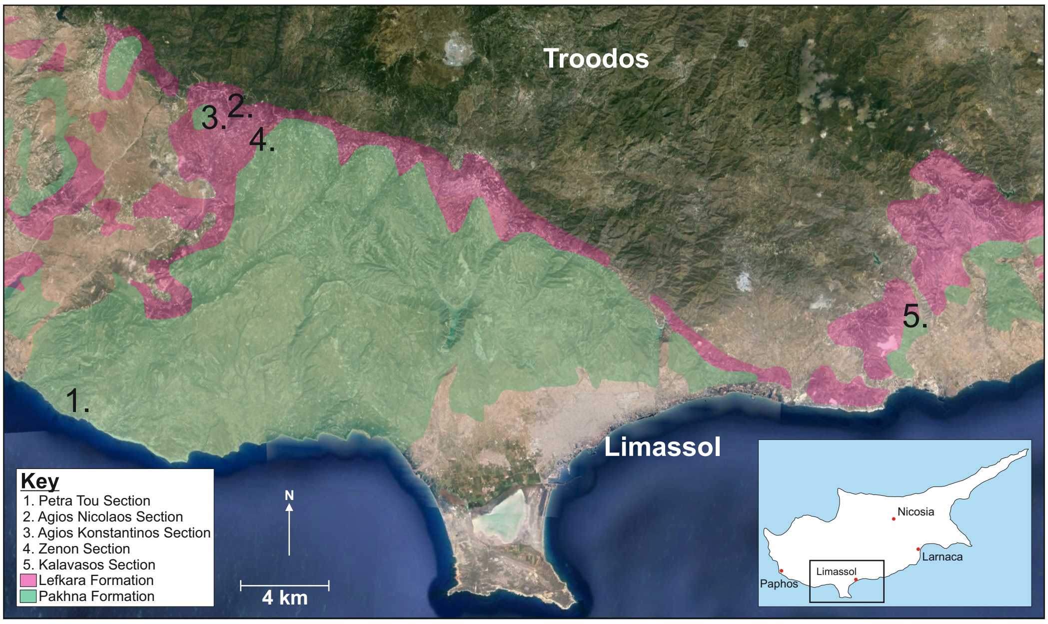
Objectives

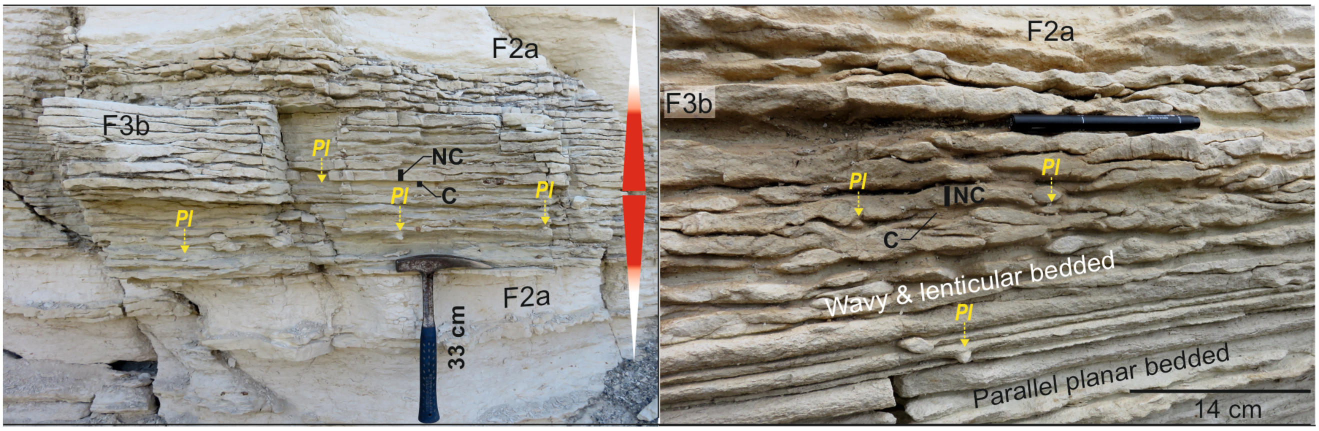
During this field trip we will visit key field localities that showcase some of the best-known examples of Eocene to middle Miocene bottom current deposits in the Lefkara and Pakhna formations (Cyprus). Sedimentary facies, ichnological information, microfacies and sedimentary models and the stratigraphic position of the contourites deposits will be discussed and associated with analogue deposits in modern / recent deepwater environments and compared to other deepwater deposits (i.e., reworked turbidites, turbidites, mass transport and pelagic/hemipelagic deposits) in the same outcrops, and their conceptual significance will be examined.



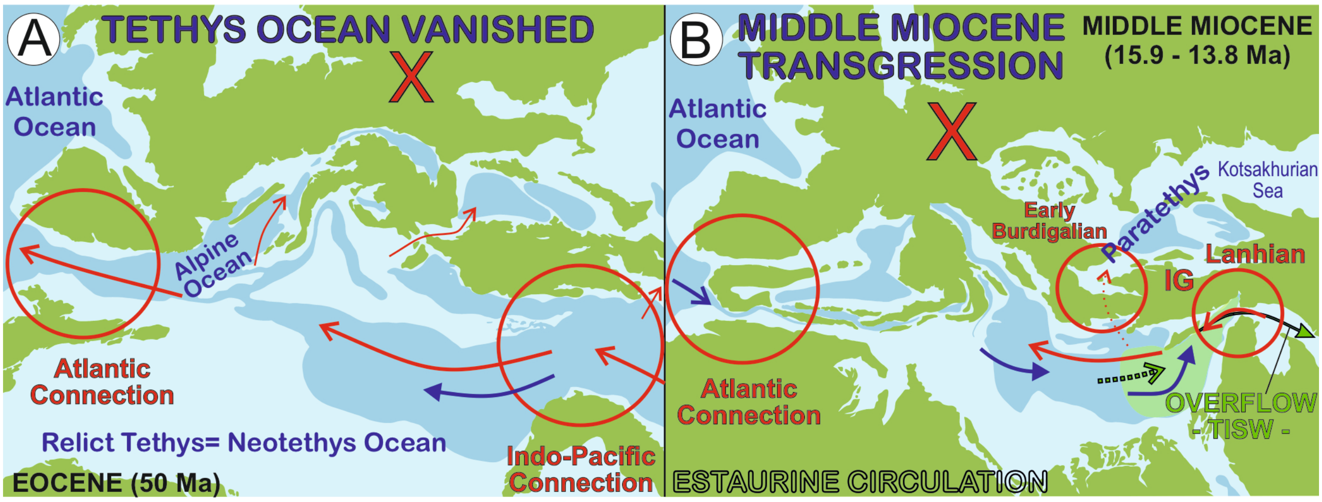
Bottom currents and their deposits (contourites) are now widely recognised as a major component of continental margins and abyssal plains sedimentation throughout the world oceans. Contourite features generated by bottom currents, provide strong diagnostic evidence for bottom-water circulation patterns and associated sedimentary processes, which have proven to critically control the sea-floor morphology and sedimentary evolution of continental margins and offer important insights for marine geohazards. Sandy contourites and mixed turbidite-contourite deposits can form extensive sand-rich deposits in deepwater settings, which provide a play for CO2 storage and hydrocarbon exploration, already evidenced in several key discoveries.



Contourite deposits in Cyprus appear in late Eocene to middle Miocene intervals interstratified with pelagic/hemipelagic sediments, turbidites and mass-transport deposits (MTDs). These deepwater deposits developed along a slope basin located on the upper plate of an active margin, evolving from a wide basin formed during a period of tectonic quiescent into a series of shallowing-upward, segmented sub-basins affected by compressional stress. The long-term evolution of the contourites reflects tectonic events that enhanced subduction processes south of Cyprus as well as exchange between the Neotethys Ocean and the Indian and Atlantic oceans —until the final closure of the Indian Gateway by the end of the middle Miocene, when a new circulation pattern was established with the formation of the Mediterranean Sea.



The proposed field trip will provide an opportunity to: a) *visit key field localities to characterise facies associations of deep-marine systems and identify contourite deposits*; b) *compare these deposits with other examples recognised in modern deep-marine environments and discuss about the sedimentary model*; c) *determine why, when and how these deposits formed by assessing long-term tectonic history and the* *formation and evolution of the nearby Indian Gateway*; and d) *participate in lively discussion sessions on contourite and mixed systems and evaluate their scientific and economic significance*.



Itinerary / Program

28th May Sun	Time	29th May Mo	30th May Tu	31st May Wed	1st June T	2nd June F
Travel to Limassol (Cyprus)	8:30 – 16:00	***Field trip***				Back from Limassol (Cyprus)
		Travel to ***Petra tou Romiou*** *section*	Travel to ***Agios Nicolaos*** *section*	***The Troodos Ophiolite Complex*** and ***Troodos Geopark*** *visiting Center* *(Lead by the Cyprus Geological Survey)*	Travel to ***Kalavasos*** *section (2h)*	
	17:00-17:30	*General group discussion sessions (30')*			Visit to archaeological sites	
		Bottom-current deposits in Cyprus	*Contourites & reworked turbidites: distinguish criteria and implications*			
	17:30	*Travel back to Hotel*				
	20:30	*Dinner*				

Registration / Cost

Field trip = **875** Euros (*including accommodation, breakfast and lunches (no dinner), local transport/ coaches for Airport to hotel and field days, field guide, but not flight travel in and out to Cyprus*)

Registration and flights / accommodation booking via: *Mar Avendaño (Airbus Travel Agency)*

mar@airbusgalicia.com / 0034 986432000

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THE TROODOS OPHIOLITE COMPLEX

31st MAY 2023

FIELD TRIP GUIDE

Cyprus Geological Survey

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1. Brief introduction to the Geology of Cyprus

The island attracted a lot of attention during the 1960's when Gass and Smith (1964) reported on a large positive anomaly beneath Troodos which Gass (1968) later interpreted as a piece of Tethyan oceanic crust. Nevertheless, the island of Cyprus consists of a mosaic of topographic terranes which are very much controlled by four distinct geological terrains and their associated tectonic structures: the Troodos Terrane, an autochthonous bedrock terrane which consists of Middle - Upper Turonian to uppermost Santonian ophiolite sequence, the Arakapas Transform Sequence, an off-axis ophiolite sequence, the Mamonia Terrane consisting of Upper Triassic – Cretaceous sedimentary rocks and basalts and finally the Keryneia Terrane, consisting of Carboniferous – Cretaceous limestones and Cretaceous – Pliocene carbonate sediments and greywackes. All four terranes are covered by autochthonous sediments, commonly referred to as the Circum-Troodos sedimentary succession.

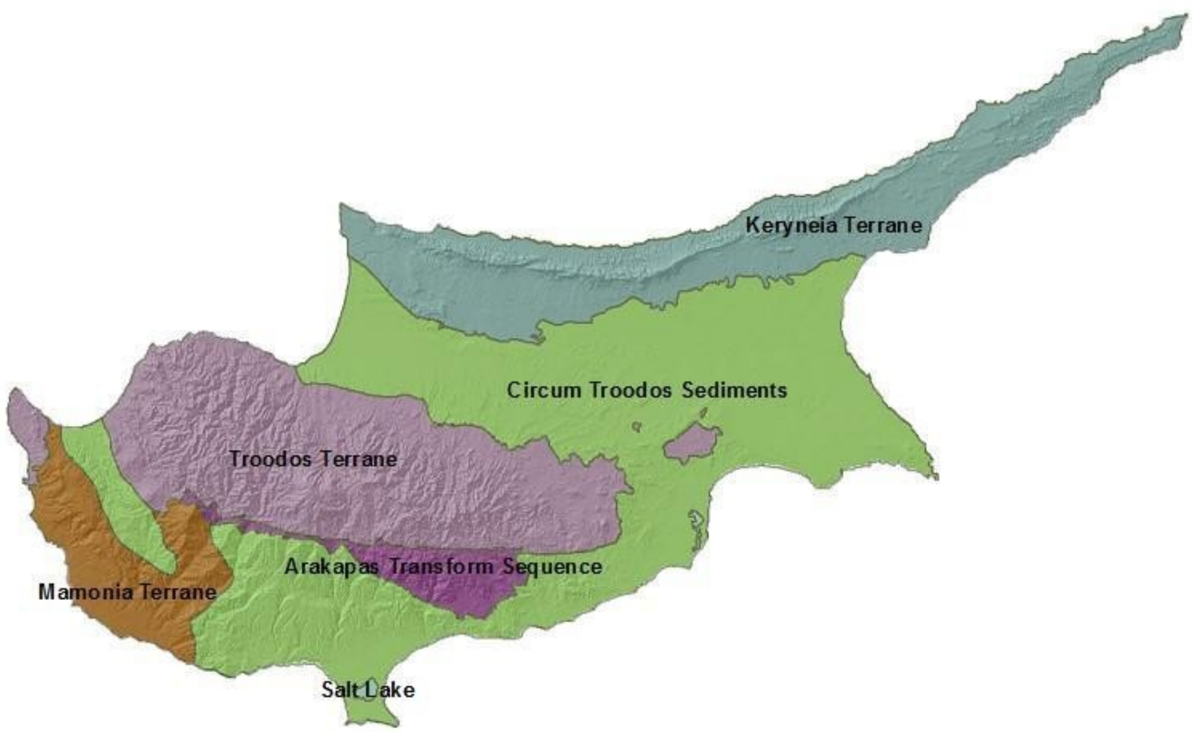

Fig. 1. Major geological terranes of Cyprus.

Cyprus is no doubt one of the first, copper producers in the world, where metallic copper was produced through mining and smelting of cupriferous sulphide deposits. Early archeological investigations at Ambelikou, in the Skouriotissa mining area dated mining activities back to 2760 B.C. whereas the first copper artefact found on the island, a hair ornament, dates to around 2.800 B.C.

Ample ancient historical references and archaeological findings evident the early development and gradual expansion of the copper industry in Cyprus which lasted for more than 3,000 years. Ancient mining workings such as shafts and galleries can be found scattered across the island. However, the most impressive evidence of the extent of the ancient copper industry in Cyprus is the widespread occurrence of ancient slag heaps. More than 110 such heaps have been found, scattered mostly on the pillow lava outcrops in the periphery of the Troodos Ophiolite.

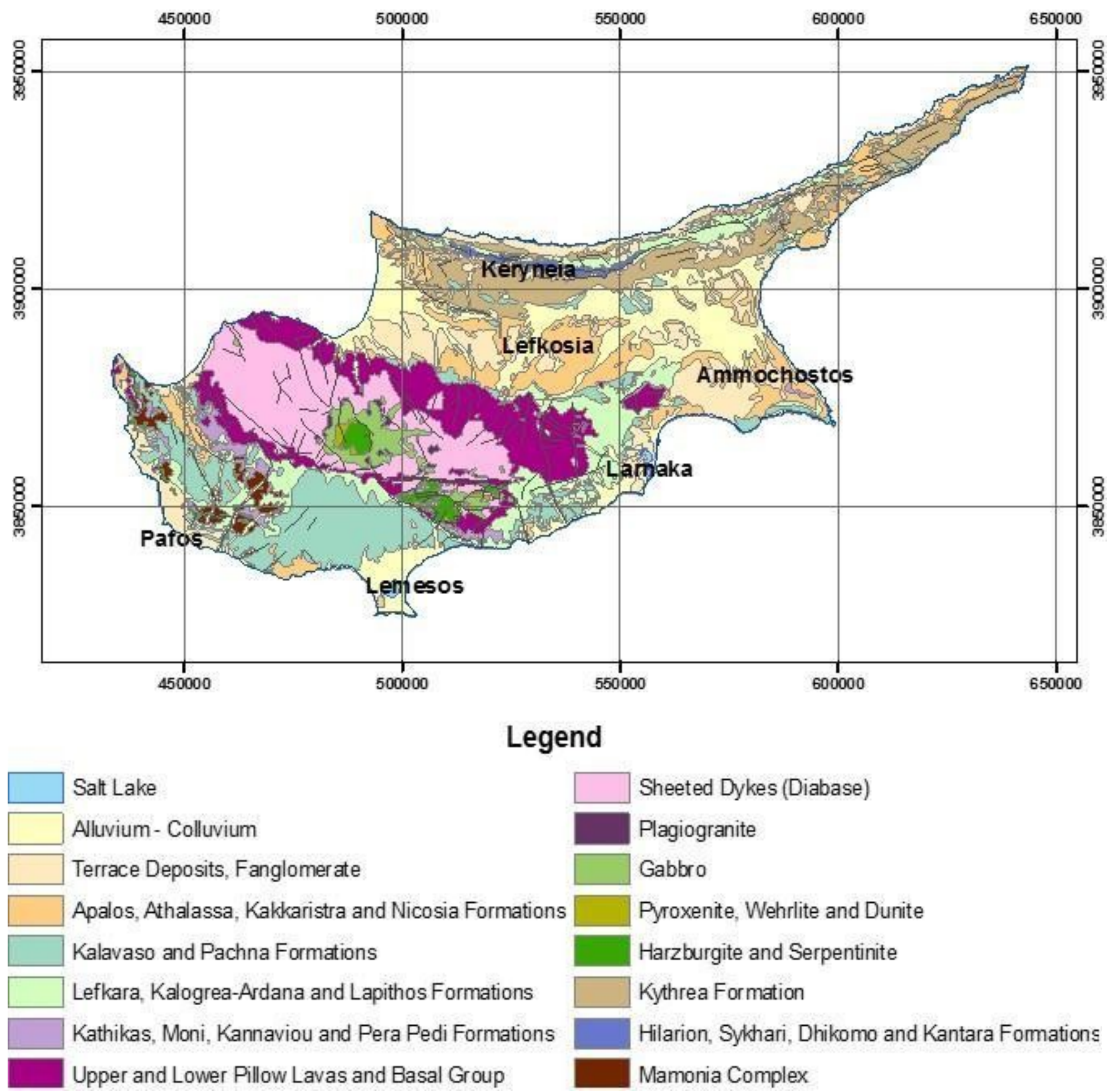

Fig. 2. Simplified geological map of Cyprus

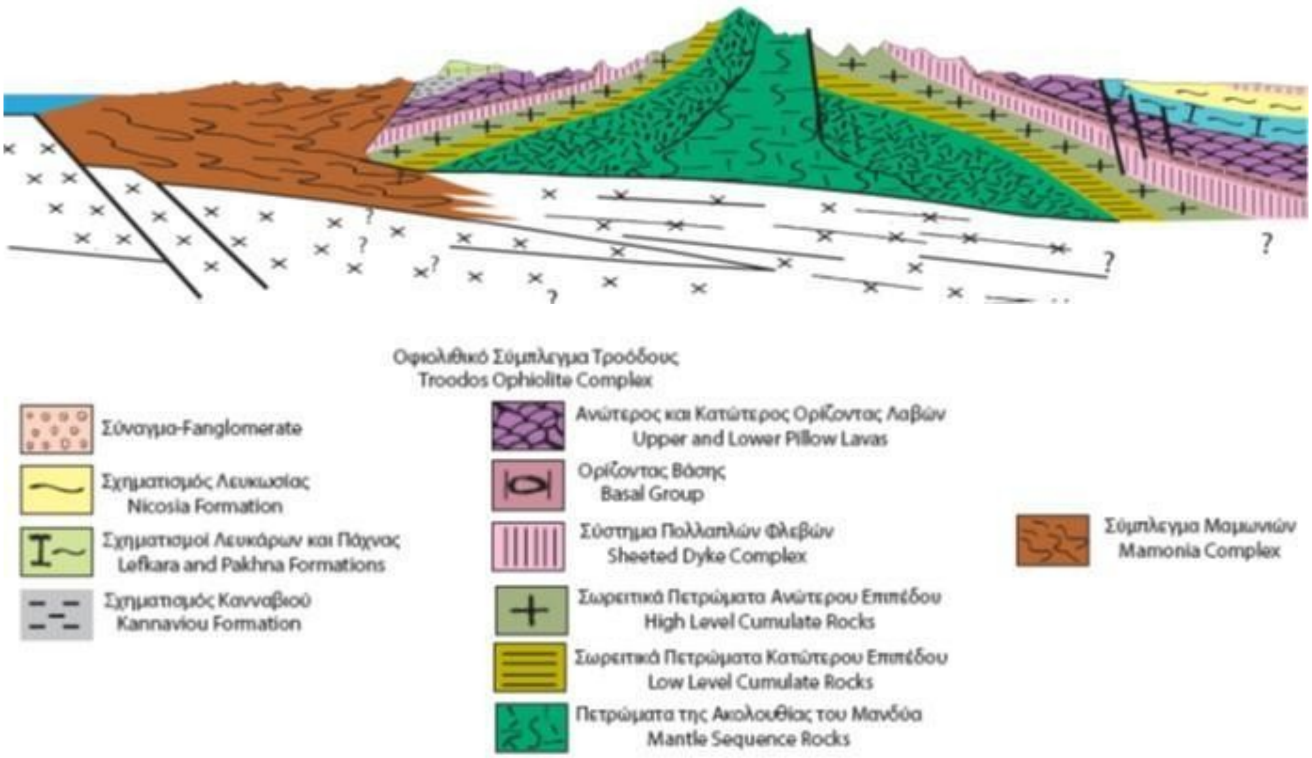

Fig 3. Simplified cross section from Pafos (left) to Lefkosia (right) through Troodos

Note: Some parts of this guidebook are extracts from the “Field Excursion Guidebook”, Symposium TROODOS 87, OPHIOLITES AND OCEANIC LITHOSHERE, hosted and published by the Cyprus Geological Survey and the field trip guides “The Troodos Ophiolite” by Malpas J., Xenophontos, C. and Cann J and “The Geology of Southwest Cyprus” by Malpas J., Xenophontos, C. and Robertson, A., 2 field trip guides for the 3rd International Conference on the Geology of the Eastern Mediterranean held in Cyprus in 1998, organized by the Cyprus Geological Survey.

The Circum - Troodos Sediments Stratigraphy

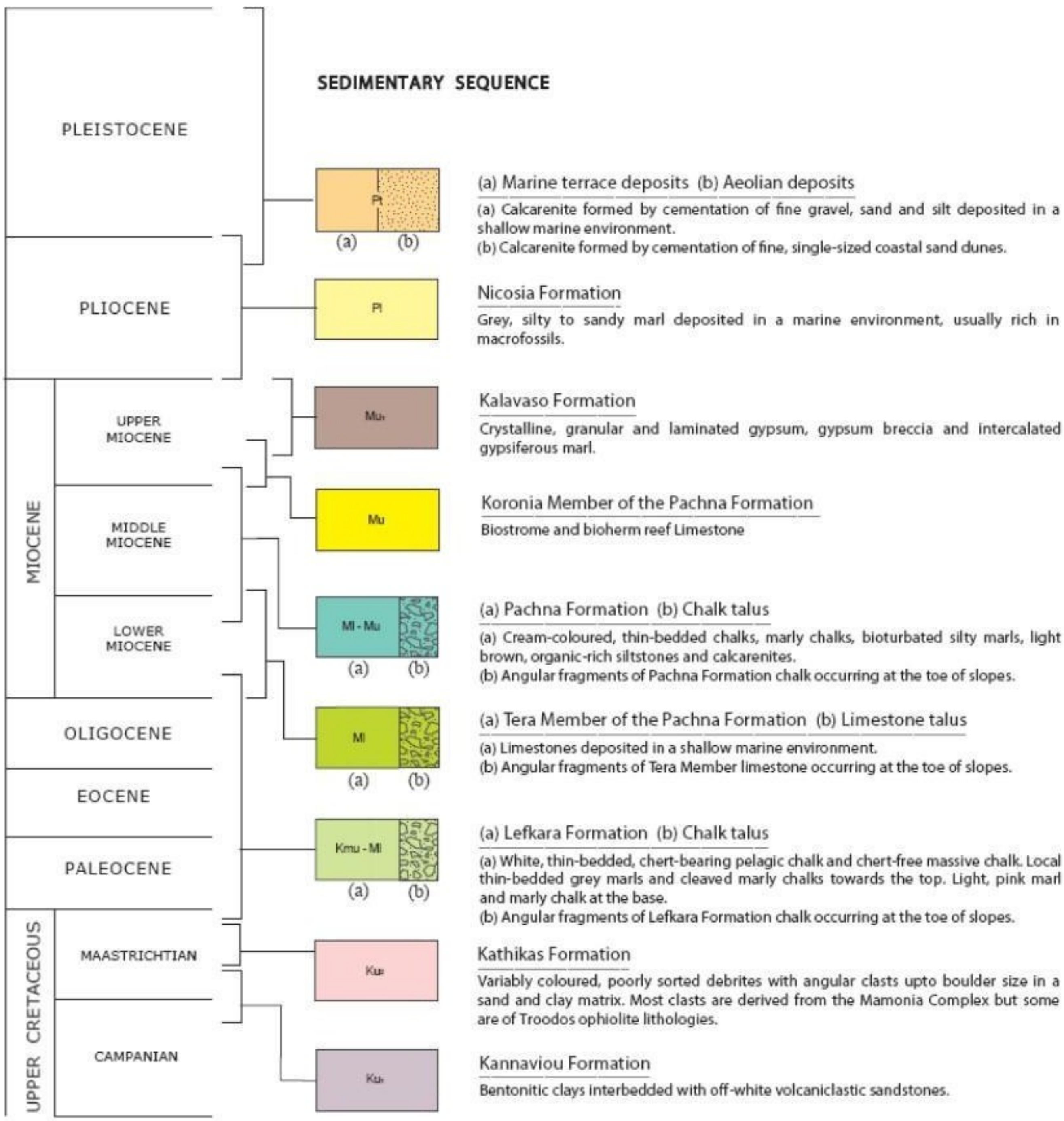

Fig 4. Simple Stratigraphy of the Circum – Troodos sediments

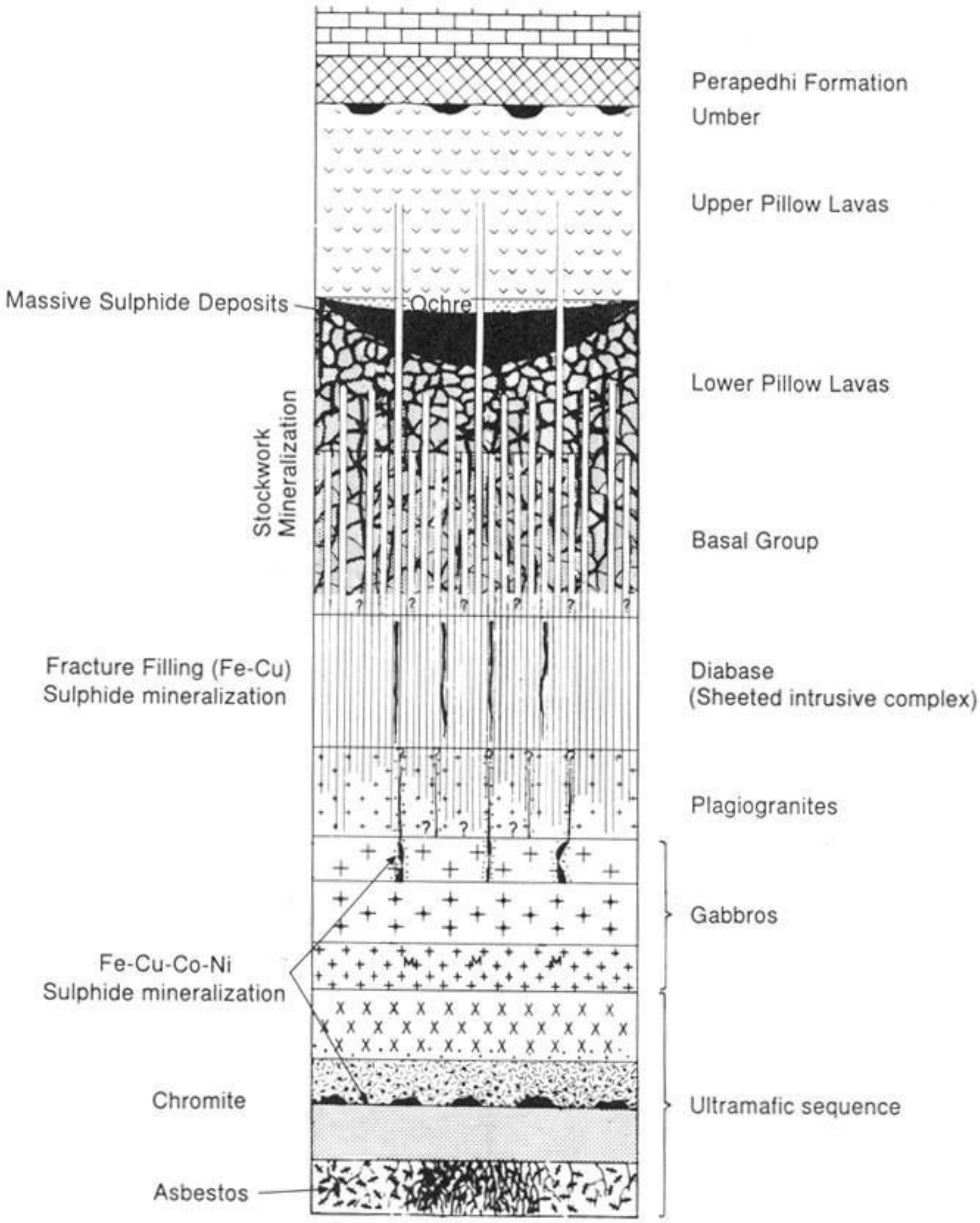

Fig 5. Stratigraphic column of the Troodos Ophiolite Complex

2. The Troodos Ophiolite Complex

The Troodos Mountain Range is the main geomorphologic feature of the island of Cyprus. It covers an area of about 3200 km^2 and its highest peak, Olympus, has an elevation of 1951 m. Formed in a Neotethyan supra-subduction zone by seafloor spreading at a constructive plate margin during the Turonian to uppermost Santonian, the Troodos ophiolite terrane forms the central geologic zone and terrane on the island of Cyprus. It consists of a relatively intact and complete ophiolitic rock sequence. Its well-preserved structure and rock sequence makes the Troodos ophiolite unique in relation to the other Tethyan ophiolites. It includes all components of an ophiolitic sequence, an ultramafic core consisting mainly of serpentinized harzburgite, plutonic ultramafic and mafic rocks, a sheeted-dyke complex, a volcanic sequence of mostly pillowed lava flows and topped with iron- and manganese-rich hydrothermal sediments. Our trip will make a progression upwards through the ophiolitic crustal sequence.

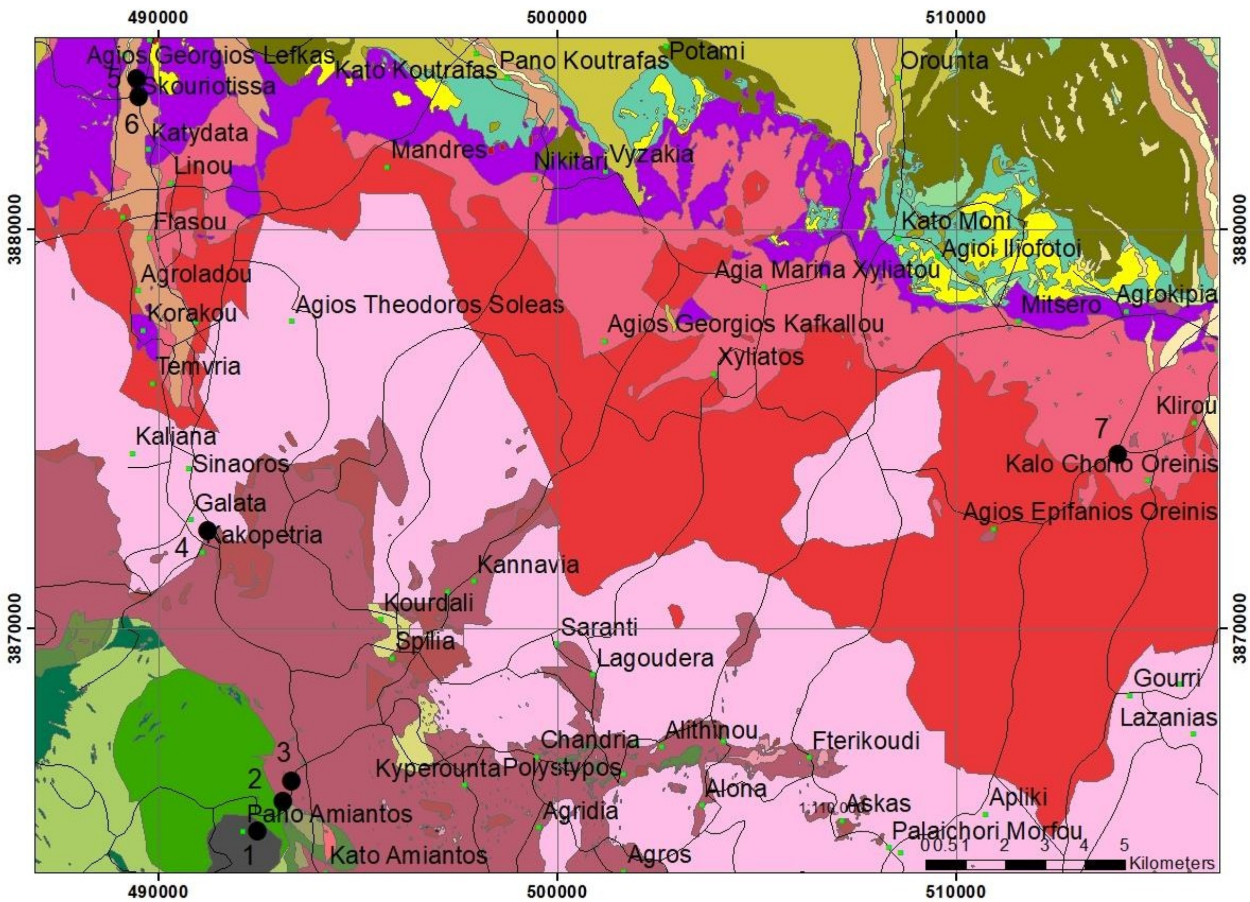

Fig 6. Geological map portraying the location of the stops for the field trip.

Fig 7. Illustration of the geological formations displayed in the geological map of Fig. 6.

3. Description of Stops

Stop 1 (09:30): Troodos Unesco Global Geopark Visitor Centre, 492482E - 3864925N

Visit at the Troodos Unesco Global Geopark Visitor Centre. There you will have the opportunity to watch the film on the geologic evolution of the Troodos ophiolite followed by a guided tour on the exhibits of the centre and the geological garden.

Stop 2 (10:45): Amiantos Fault, 493110E - 3865673N

At this point you can observe the Amiantos Fault, which is exposed in the broader area of the Asbestos Mine. The fault brings in tectonic contact highly serpentinized rocks of the upper mantle sequence (left) with intensively fragmented gabbro of the cumulate sequence (right).

Stop 3 (11:15): Geosite 34 - Layered and massive gabbro, 493422E-3866316N (optional)

At this outcrop very thin layers of gabbro at the base of the roadcut are overlain by massive gabbro and are cut by pegmatitic gabbro (very coarse-grained gabbro) indicating the complex geological procedures that took place within a magma chamber. The alternating white (plagioclase-rich) and dark (pyroxene-rich) gabbroic layers have been formed either due to the interruption of the process of fractional crystallization by the repeated ascend of new magma into the magma chamber, or by the diffusion of minerals to the bottom of the magma chamber as a result of thermal activation of their kinetic properties. Diffusion is the mineral transportation process from places of higher concentration to places of lower concentration within the magma chamber.

Stop 4 (11:45): Sheeted Dyke Complex, Galata village, 491240E - 3872420N

Stop at the bakery parking lot on the main road and walk back about 60m where you can view sheeted dykes on the east side of the road. The sheeted dyke complex represents the solidification of the ascending magma into channels, through which magma was transported from the magma chamber to the seafloor. It is a successive series of dykes which represent the filling up of space created from plate diversion at the spreading axis. The sheeted dyke complex is very extensive across the Troodos mountains. These intrusive rocks, locally referred to as diabase, have a doleritic to basaltic composition, their dyke orientation is NW – SE and are almost vertical except from areas that are affected by subsequent tectonism.

In tectonized areas, the dykes are not vertical but rotated by detachment faults on both sides of the spreading axis after the solidification of the magma in the transportation conduits. At this stop the dykes strike about 320^{o} and dip 45^{o} to the east. Besides the diabasic dykes which are by far the most abundant rock types with well-preserved chilled margins, there is also a number of small basaltic dykes 20-50 cm wide which are seen intruding into the other two type of dykes. The intrusion of these dykes is the best indication of continued spreading.

. Stop 5 (12:20): Upper Pillow Lavas, Lower Pillow Lavas and Sulphide Deposits outside Skouriotissa mine, 489460E - 3883800N

This location offers a panoramic view of Skouriotissa mine, which up until 2019 was actively producing pure copper metal. In addition, it is a unique mining heritage site with continuous exploration at the same location since antiquity. The massive ore is located in the pillow lavas.

Based on colour, mineral composition and degree of dyke intrusion, the volcanic rocks of Troodos ophiolite are divided into two horizons, the Upper and the Lower pillow lavas. The geochemistry of the lavas points to a supra-subduction zone environment of the Neotethyan Ocean domain. The Upper Pillow Lavas (UPL) consist of 80-90% of pillow lavas and 10-20% of dykes. The lavas are commonly olive-phyric basalts with some picrite basalts but also rarer olivine-free basalts.

At this location the lavas are olivine-phyric basalts with olivine being replaced by carbonates and red iron oxides. These iron oxides cause the characteristic red color of the UPL. The space between pillows is usually occupied by altered glass, calcite, zeolites (analcime) and interlava sediment. The pillows are flattened and elongated with their diameters ranging from 30-170 cm. The pillow periphery is glassy as a result of abrupt cooling on the ocean floor. The internal texture is vesicular due to the abrupt release of gas due to the sudden drop of temperature and magma pressure during the eruption of lava. The vesicles vary in size and shape and do not connect.

Lower Pillow Lavas and Sulphide Deposits

The sulphide deposits of Cyprus, rich in pyrite and chalcopyrite, are closely associated with the Troodos ophiolite and in particular with the Lower Pillow Lava horizon. At Skouriotissa the ore body was estimated approximately at 6 million tons with an average copper content of about 0,5-2,5% and sulphur at 47%.

These deposits have been formed on the Neotethys sea floor along sea floor spreading axis by the circulation of metal-rich hydrothermal fluids. The source of sulphur is seawater, which percolates through the oceanic rocks via a network of fissures that are formed in the zone of seafloor spreading. The percolating seawater is heated by ascending magma, washes out metallic elements from the surrounding rocks and ascends. Once the hydrothermal fluids reach the seafloor in the form of “black smokers”, precipitation of sulphide minerals such as pyrite and chalcopyrite occurs due to the fall in temperature and other physicochemical conditions (e.g. pH, Eh). Such deposits are formed today in the Atlantic, Pacific and Indian Oceans and are known as “Cyprus-type” deposits.

The differential uplift of Troodos in conjunction with the erosion that followed, exposed the deposits to the surface, where they were oxidized, forming gossans (iron cap) of iron oxides and hydroxides with spectacular red and yellow colours. These attracted the ancient inhabitants and resulted in their discovery and extensive exploitation in antiquity from 2760 BC to AD 500.

Stop 6 (12:50): Slag Heap, 489512E-3883315N

The slag heaps which can been found around the Troodos mountains form the most irrefutable evidence for copper mining and smelting on the island in antiquity. The Skouriotissa area contains more than half of the total slag present in Cyprus. The slag heap which has been sectioned by modern quarrying activities has been dated to the Late Roman or Early Byzantine period (4th-7th centuries AD).

Stop 7 (14:00): Lower Pillow Lavas, Maroulena River, 514027E-3874360N

One of the most important and spectacular exposures of the Lower Pillow Lavas is the slope of a gorge in the Akaki river showing the lower part of the volcanic sequence. This outcrop is the classic reference locality for the study of these types of rocks.

In this section there is a lower unit of hyaloclastites (black color) and an upper unit of pillow lavas cut by swarms of near vertical dykes (70°- 80°) with an approximately N-S direction. These dykes make up approximately 30 percent of the section and are cut by younger inclined light brownish dykes. This area shows the stratigraphically lower part of the volcanic sequence, where the number of dykes increases abruptly in the volcanic rocks near the boundary with the Basal Group.

Chalcedony occurs infilling vesicles and cracks, both in the lavas and in some of the intrusions. It is probable that solutions rich in silica—derived, perhaps, from the decomposition of some of the silicates in the lava itself—percolated through the rock and deposited a siliceous gel in the interior of the vesicles and cracks.