Interactive geodatabase for Sikinos and Ios islands

Introduction
Sikinos and Ios islands are located in the southern Cyclades in the Aegean Sea, part of a metamorphic core complex and a component of the larger Hellenic subduction zone. Two units are exposed on these islands: 1) the Cycladic Blueschist Unit and 2) the Basement. The Cycladic Blueschist Unit is a metasedimentary unit deposited in a passive margin from Triassic to Late Cretaceous and has age modes from Paleoproterozoic to Early Cretaceous. The Basement is a composed of granitic gneisses, crystallized in the Carboniferous, and Late Neoproterzoic to Carboniferous metasedimentary units.

Since these are metamorphic units, the initial sedimentary features have been overprinted and the sequence has been re-ordered through subduction and/or exhumation processes, hence it is essential to set time constraints on the provenance and maximum depositional ages of the metasedimentary units, as well the crystallization ages of the Basement. We use zircon U-Pb geochronology to determine the ages mentioned above.

The Basement underlies the CBU, however the nature of contact between the two is controversial and different scenarios have been proposed. Zircon (U-Th)/He cooling ages can elucidate the cooling and exhumation history of the CBU and Cycladic Basement in Sikinos and the nature of the contact between the two units.

Project
The purposes of this project are:
1) To create maps of Sikinos and Ios islands. They will be use in poster presentations as well as in publications.
2) Build an interactive geodatabase, in which Sikinos and Ios geologic maps will show sample locations (on both islands, both geologic units). Each sample in the database will contain information about the maximum depositional ages or the crystallization ages as well as the zircon cooling ages. Additionally, a photo of each sample will be also accessible. This interactive database will allow viewers to visualize the distribution of ages across the islands.
3) Create geologic cross sections parallel to each island's stretching lineations with sample positions to help us visualize (U-Th)/He ages (i.e. exhumation ages) and determine the nature of the contact.

Data Collection and Preparation

- *Geologic map of Sikinos*

Source: *Exhumation kinematics of the Cycladic Blueschists unit and back-arc extension, insight from the Southern Cyclades (Sikinos and Folegandros Islands, Greece)* from Augier et al. (2014)

- *Geological map of Ios*

Source: *Thrust or detachment? Exhumation processes in the Aegean: Insight from a field study on Ios (Cyclades, Greece)* from Huet et al. (2009)

- *Digital elevation model of the islands from the nasa*

Source: Aster DEM files downloaded from NASA website: LP DAAC Global Data Explorer.

- *Basemap*

Light gray canvas by ESRI Information and Technology Services in ArcMap version 10.3

- *Photos and data for each sample:*

Collected from Eirini Poulaki and Megan Flansburg during personal field seasons and laboratory work at UTChron.

Creating maps and geodatabases

1) GEOREFERENCING

Georeference and rectify the maps of the two islands:

I georeferenced the already published maps (TIFF files) to the basemap 'gray canvas'. I set the spatial reference in UTM system 'WGS_184_UTM_zone_35S'.

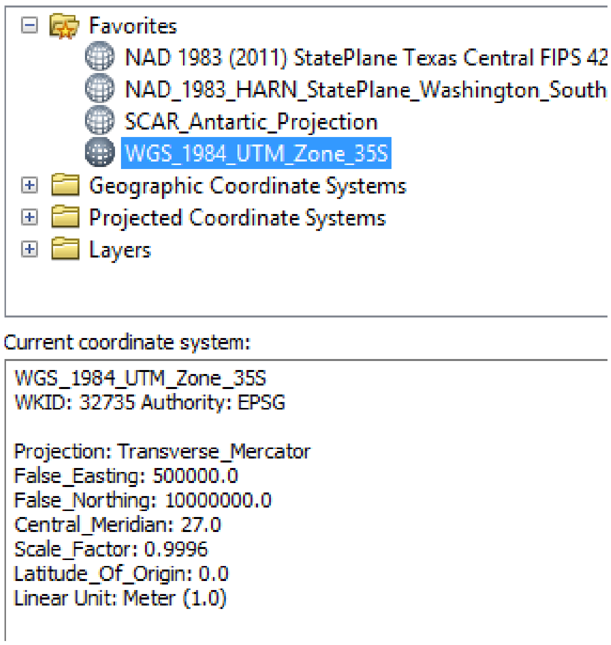


Figure 1: Screen shot from the Properties window of the georeferenced maps showing the spatial reference of the layer.

I rectified the two maps by using the nearest neighbor and a cell size of 1 meter.

2) GEODATABASES AND FEATURE CLASSES

The next step was to create a geodatabase to include all the files essential for the maps.
In the project folder I created a new personal geodatabase within ArcCatalog. This geodatabase (Sikinos_ios) contains several feature classes and databases.
The domains required for the maps are the following:

Island	Sikinos, Ios
Lines	Contact, thrust fault, normal fault
Unit	CBU, Basement
Lithologies	Young Carapace, Old Carapace, Basement, Metabasites, Quartz-mica schist, Alluvium

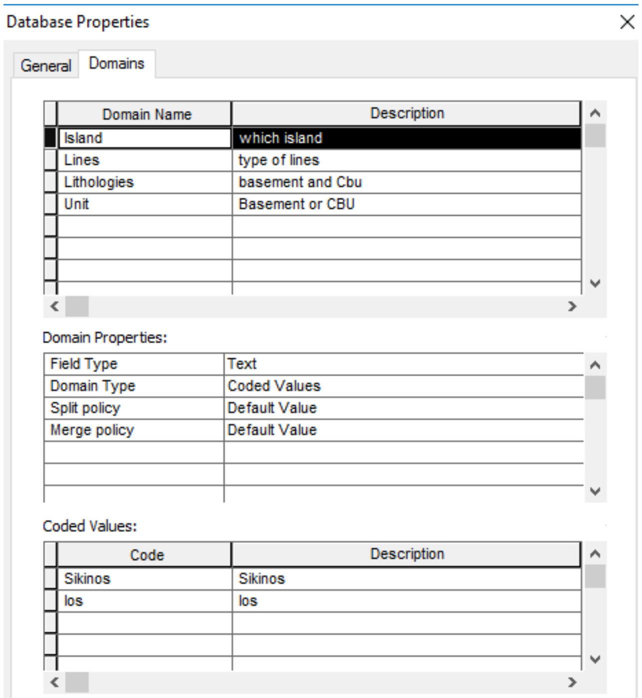


Figure 2: Screen shot from the Properties tab of the personal database, showing the domain properties and the coded values of the "Island domain"

1) The most important feature class is the Coastline of the islands, since it will contain the boundaries of the islands.

Type	Line
Data type	Text
Default value	Island

2) An additional feature database is the 'geology'.
This database contains all the geological features as feature classes:

   a) The contacts and the faults

type	Line		
Field(1)	Line type	Domain:	Lines
Field(2)	Island	Domain	Island

   b) Rock units

type	Polygons		
Field(1)	lithologies	Domain:	lithologies
Field(2)	island	Domain	Island
Field(3)	unit	Domain:	unit

It is important to mention that all new databases and feature classes have the same spatial reference as the georeferenced maps.

3) DIGITIZING

a) The boundaries of both islands.

b) The contacts between different lithologies and faults.

c) To digitize the geological units, I had to enforce topology and fix the errors. The new topology was created inside the personal geodatabase. The errors I cared about were: "-they must not have dangles – they must not self-intersect –they must not self-overlap". When all the errors were fixed, I created the polygons from the existing lines by using the feature to polygon tool.

When I created the polygons, I had to individually define within the attribute table the domains for the island, the unit, and the lithology of each polygon.

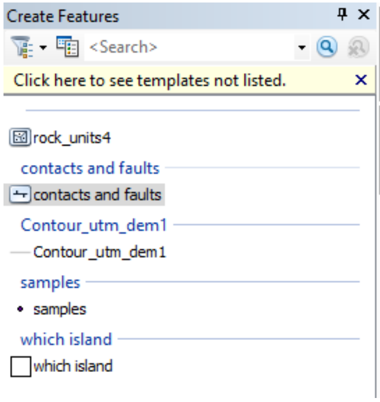


Figure 3: Screen shot of the create feature window showing all the layers that were edited (digitized).

Table

OBJ	SHAPE *	FID_	Island	SHAPE_Length	SHAPE_Area	Lithologies	Unit
28	Polygon	-1	Sikinos	688.246611	8783.910074	Granite	Basement
29	Polygon	-1	Sikinos	830.91971	11406.841959	Granite	Basement
31	Polygon	-1	Sikinos	969.166036	13729.866336	Granite	Basement
32	Polygon	-1	Sikinos	1675.491798	26292.40548	Granite	Basement
33	Polygon	-1	Sikinos	44.299751	54.301213	Granite	Basement
35	Polygon	-1	Sikinos	1505.486056	25152.668382	Granite	Basement
52	Polygon	-1	Sikinos	2192.34962	151972.161177	Granite	Basement
138	Polygon	-1	Ios	51225.786541	58502672.9349	Granite	Basement
158	Polygon	-1	Ios	9751.151481	3115757.406998	Granite	Basement
20	Polygon	-1	Sikinos	2242.957143	90918.759227	Marble	CBU
37	Polygon	-1	Sikinos	1128.298869	28675.51262	Marble	CBU
40	Polygon	-1	Sikinos	2852.95905	204451.684584	Marble	CBU
43	Polygon	-1	Ios	2118.78953	99639.042632	Marble	CBU
47	Polygon	-1	Sikinos	772.888501	20571.274157	Marble	CBU
48	Polygon	-1	Sikinos	2222.671425	78043.980096	Marble	CBU
54	Polygon	-1	Sikinos	3172.980666	234045.141126	Marble	CBU
55	Polygon	-1	Sikinos	34009.944315	3694349.811641	Marble	CBU
57	Polygon	-1	Ios	1057.086946	71868.926716	Marble	CBU
58	Polygon	-1	Sikinos	7295.706262	257127.442725	Marble	CBU
61	Polygon	-1	Sikinos	2905.309241	102840.141817	Marble	CBU
63	Polygon	-1	Sikinos	3001.825991	83918.576244	Marble	CBU
64	Polygon	-1	Sikinos	3842.748354	83709.420625	Marble	CBU
69	Polygon	-1	Sikinos	2153.002206	46561.947024	Marble	CBU
74	Polygon	-1	Sikinos	2153.756	62721.898093	Marble	CBU
76	Polygon	-1	Sikinos	23671.263111	6557066.806529	Marble	CBU
82	Polygon	-1	Sikinos	6839.483435	361467.794743	Marble	CBU
84	Polygon	-1	Sikinos	3622.068045	119787.975412	Marble	CBU
85	Polygon	-1	Sikinos	3541.042279	192630.885001	Marble	CBU
87	Polygon	-1	Sikinos	2831.92245	64251.921791	Marble	CBU
89	Polygon	-1	Sikinos	1207.717642	20056.115632	Marble	CBU
90	Polygon	-1	Sikinos	1879.614254	55739.492529	Marble	CBU

1 (0 out of 180 Selected)

Figure 4: Screen shot of the attribute table of the rock units feature class showing polygons represent different lithologies with the different domains.

4) SYMBOLOGY

In the properties window of the rock units I symbolized were:

- The polygons, based on the lithology.
- The lines, based on the type of line (contact, normal or thrust fault).

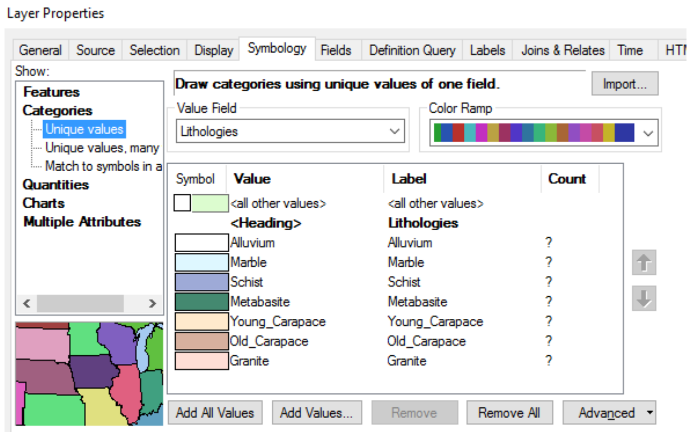


Figure 5: Screen shot of the rock units layer properties, showing the different symbology for each lithology

5) *SAMPLE LOCATIONS*

All the samples collected during person field seasons and the coordinates recorded by GPS. I transferred the coordinates in Google Maps, to import them in the ArcMap file I had to use the 'KML to Layer' tool.

The sample locations are in a new feature class with points in the personal geodatabase.

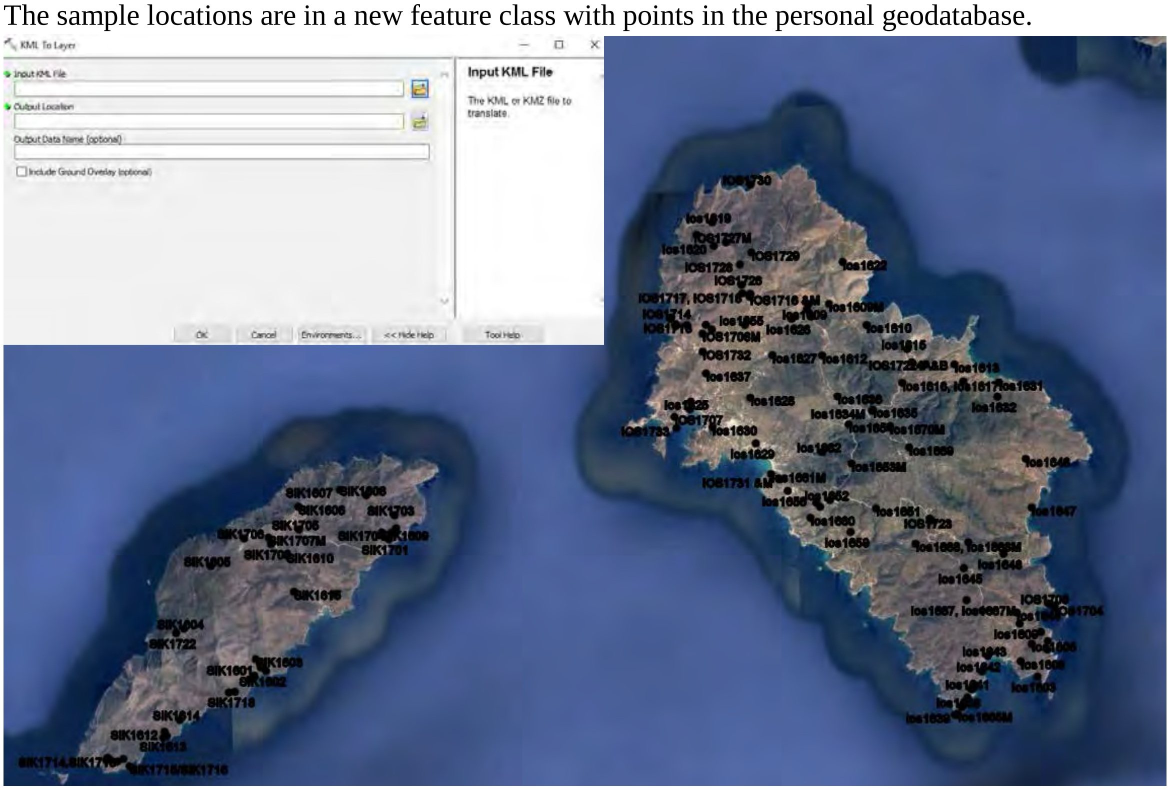


Figure 6: screen shot from google maps (KML file) with all the sample locations and of the KML tool which import the google map file into Arc-GIS.

6) LABELING

Since I imported the samples from google maps, each sample has its own name. Consequently, when I select 'label features' the labels appear but they are overlapping.

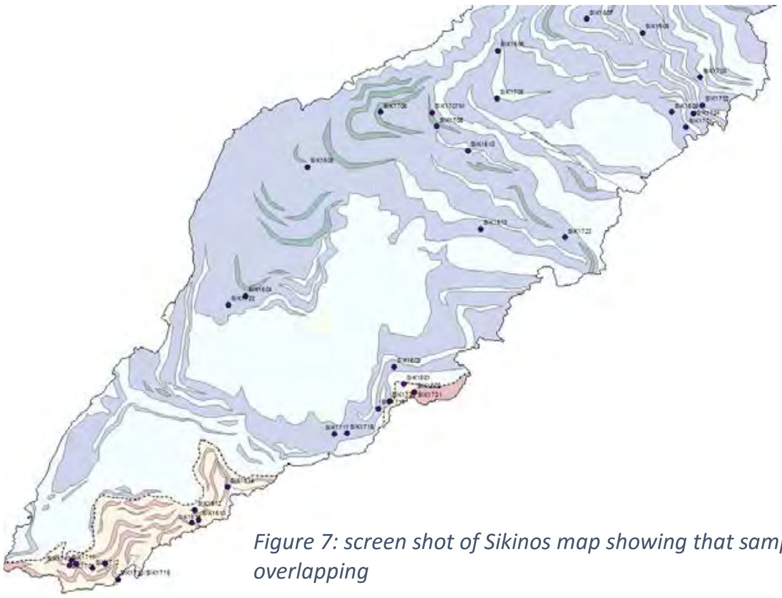


Figure 7: screen shot of Sikinos map showing that samples' labels are overlapping

To be able to change positions, adjust, and delete the labels, I had to convert the dynamic labels into an annotation group.

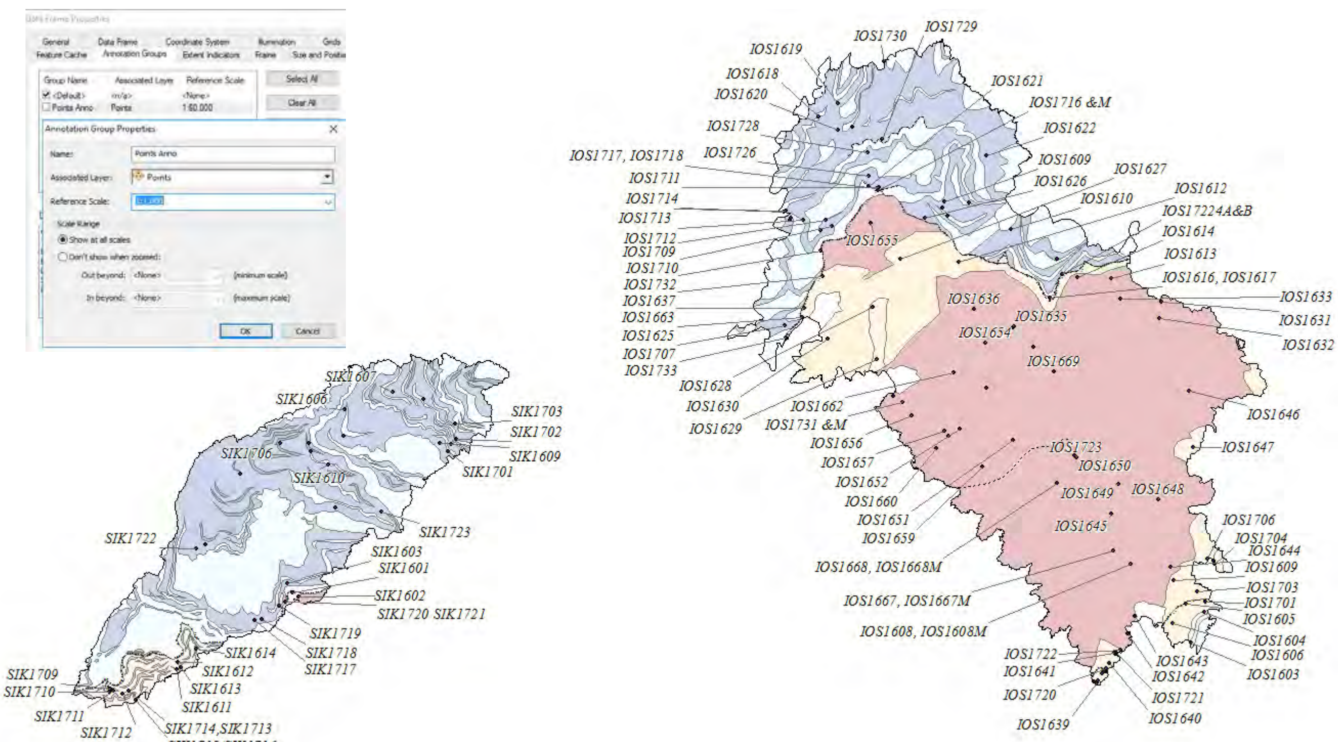


Figure 8: Screen shot showing both maps of the islands with the activated annotation group

7) DIGITAL ELEVATION MODEL (DEM)

A 30 meters' aster gDEM v3 is available for both islands. The first thing that needed to be done was to extract the DEM file around the islands' boundaries by using the extract by mask tool.

I had to define the spatial reference of the gDEM and converted the linear unit to meters.

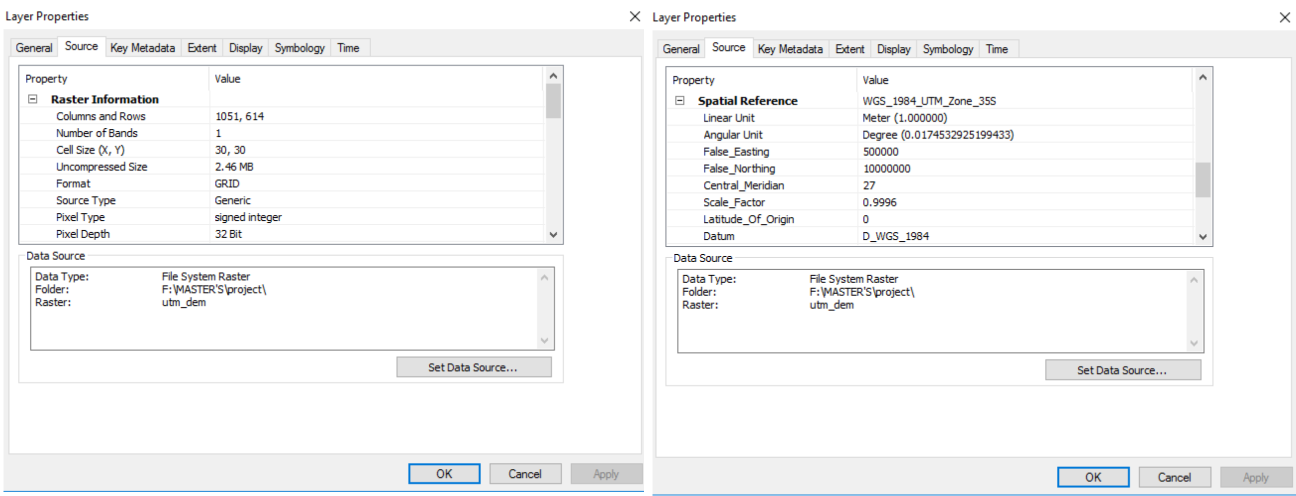


Figure 9: Screen shot of the properties of the DEM file after setting spatial references and converting the linear unit into meters.

a) CONTOURS

Once I imported the DEM file I created the contours.

To create the contours from the DEM file, I used the spatial analysist tool (contour interval=50). The contours are a new feature class located in the personal geodatabase.

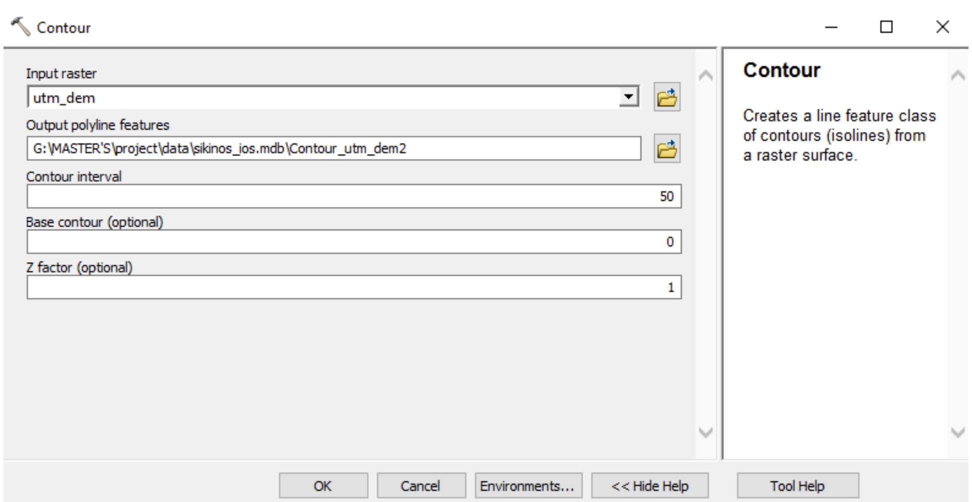
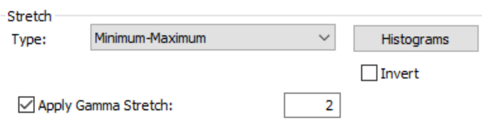


Figure 10: Screen shot of the contour tool, showing the 50 m interval and the 1 Z factor.

b) HILLSHADE

A hillshade of the DEM was created in order to visually see each sample's elevation. This was done by setting the map layer on top of the created Hillshade and setting 30% transparency.

The symbology is stretched with minimum maximum type and applied gamma stretch of 2.



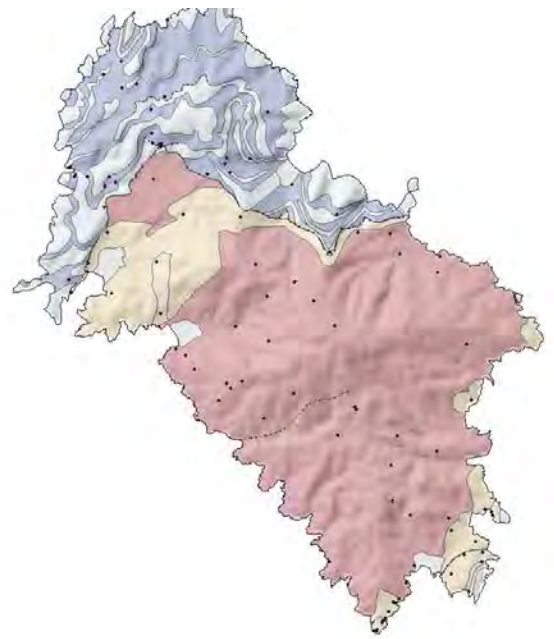


Figure 11: Screen shots showing the maps of the islands with the Hillshade effect. Sikinos Island (left) has only the Hillshade layer, Ios Island (right) has both Hillshade and rock units.

c) MOSAIC of RASTER

*This data will be essential for the creation of the 3D map.*First I had to create a Mosaic of Raster Data from the DEM file. I used the tool 'mosaic to a new raster' and I set the following parameters.

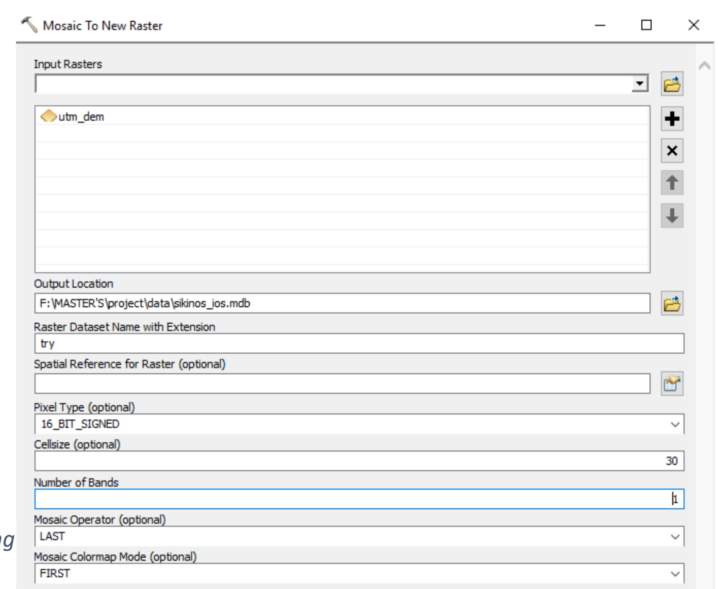


Figure 12: Screen shot of the 'mosaic to new raster' tool showing the parameters I used to create the mosaic layer.

Next I extracted by mask only the boundaries of the two islands

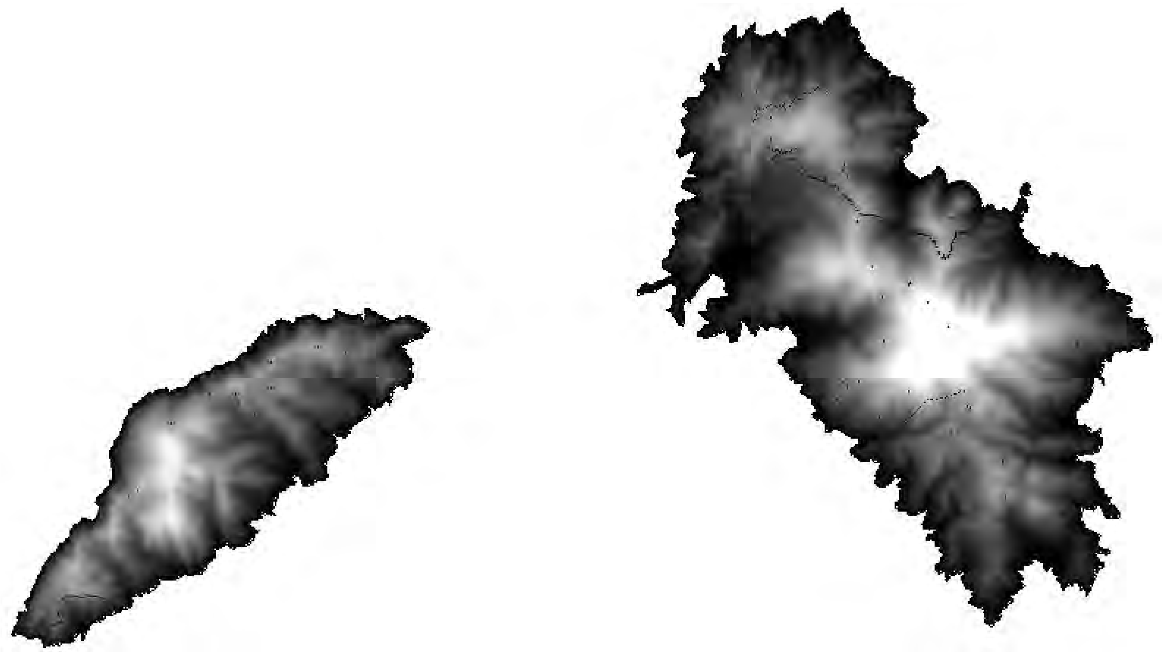


Figure 13: Screen shot of the mosaic layer from both islands

8) *ATTACHING INFORMATION IN THE SAMPLES*

In this step I hyperlinked photos and data collected from each sample. In order to do this I had to enable the attachments for the 'samples' feature class' and then start editing.

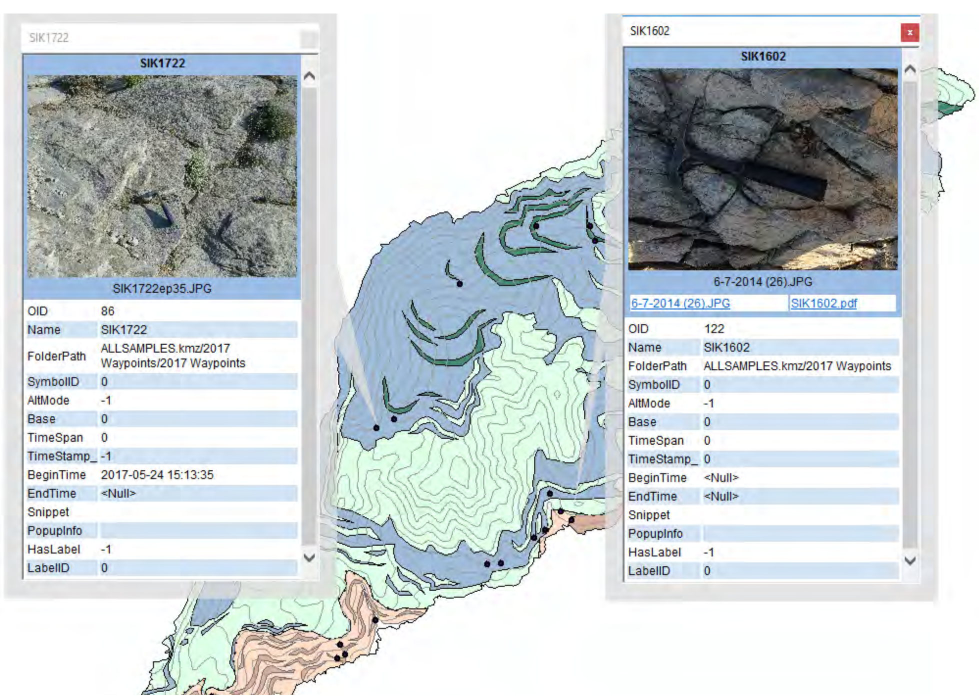


Figure 14: Screen shot of Sikinos Island showing available attachments from two samples

Extra material:

1) 3D map preparation

Topography in cooling and exhumation history of geological is very important. As a result 3D maps are very useful to visualize the elevation of samples.

I imported in arc-scene the mosaic DEM file, the sample locations, the lithologies and the contours. For all the files selected in the Base heights tab, the properties were adjusted as in the figure below.

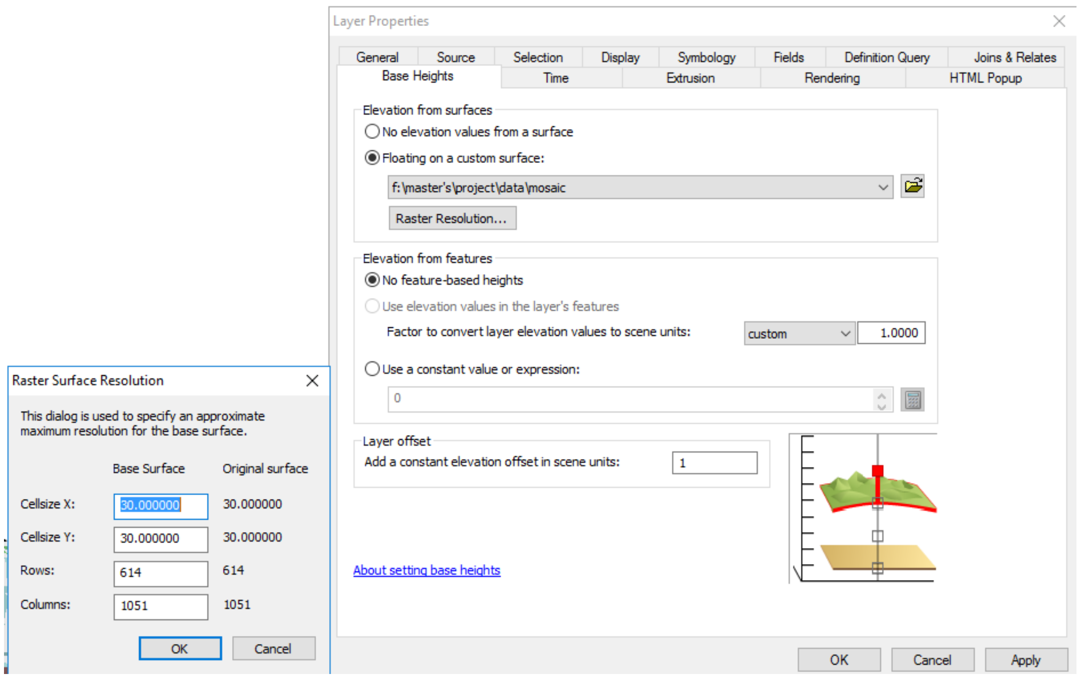


Figure 15: Screen shot of the properties of the DEM file in ArcScene

Figure 16 Screen shot of Ios and Sikinos Islands in 3D perspective from ArcScene

2) 3D cross section

I extracted the elevations from the DEM file along a polyline. This transect is running along the stretching lineation. To do this I had to make a new feature class called cross section and digitize the line. The stack profile tool in the functional surface toolbox creates table which contain the line features

Finally using Adobe Illustrator I was able to create a 3D topographic profile.

Discussion/ Conclusions

The purpose of this project is three-fold:

1) **Create maps of both islands with samples collected for geochronology and thermochronology which will be used in poster presentations as well as publications.**

Geological maps of Sikinos and Ios Islands

Eirini M Poulaki

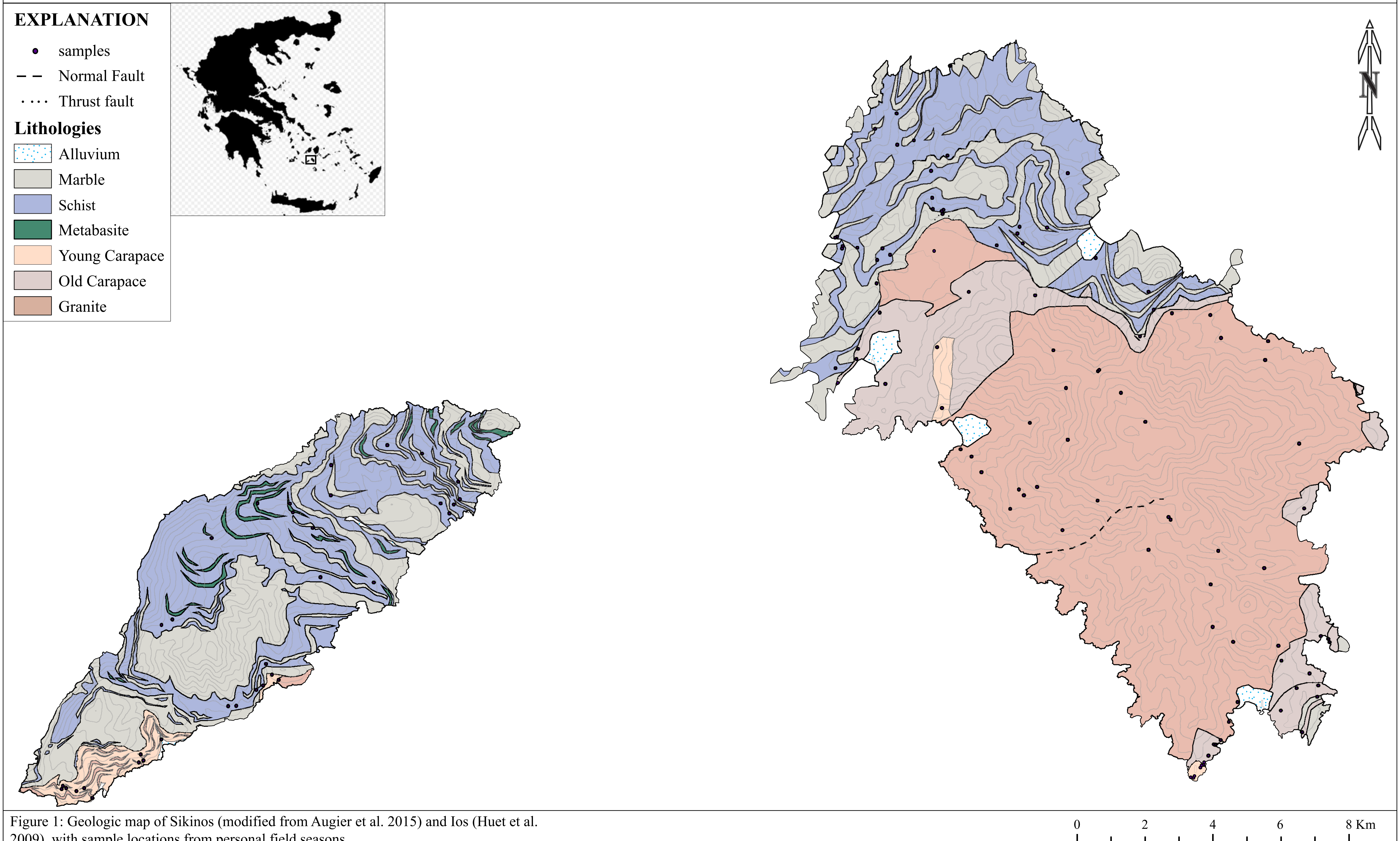


Figure 1: Geologic map of Sikinos (modified from Augier et al. 2015) and Ios (Huet et al. 2009), with sample locations from personal field seasons.

GEOLOGICAL MAP OF SIKINOS ISLAND

Eirini M Poulaki

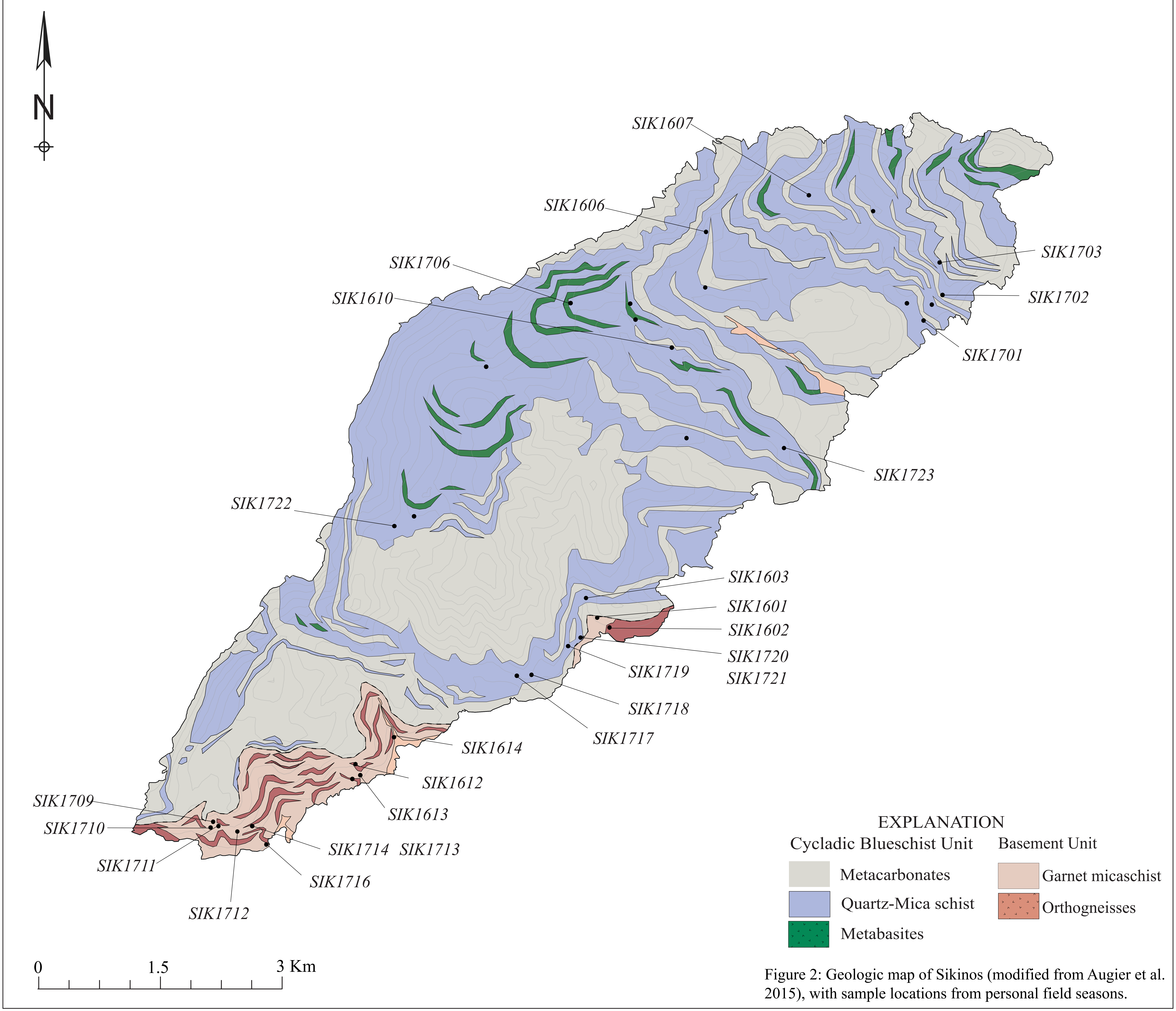


Figure 2: Geologic map of Sikinos (modified from Augier et al. 2015), with sample locations from personal field seasons.

Unravelling the Formation and Exhumation of the Cycladic Blueschist Unit and Basement in the Southern Aegean, Sikinos Island, Geece

TEXAS Geosciences
The University of Texas at Austin
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National and Kapodistrian UNIVERSITY OF ATHENS

INTRODUCTION

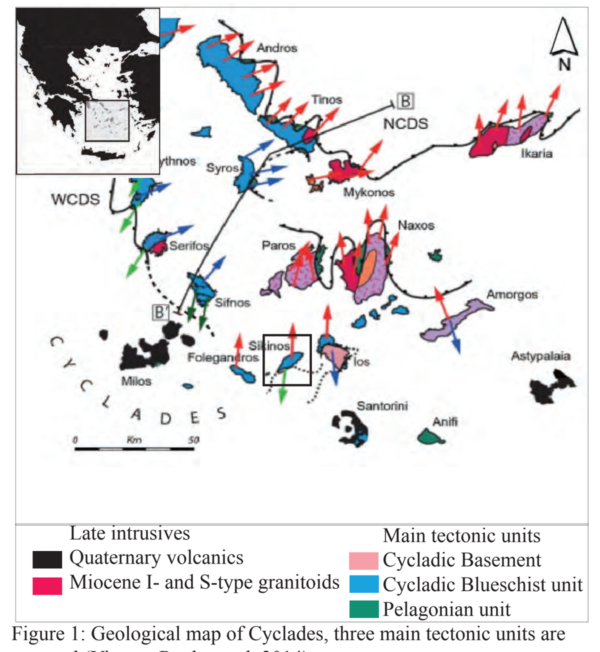


Figure 1: Geological map of Cyclades, three main tectonic units are exposed (Vincent Roche et al. 2014).

Sikinos island is part of a metamorphic core complex (MCC) located in the Southern Cyclades located in the backarc of the Hellenic subduction zone. The Cycladic MCCs are the result of the continuous subduction of the African plate (continental blocks separated by oceanic or hyperextended basins) beneath the southern margin of Eurasia since the late Cretaceous, and are broadly characterized by two stages of formation/exhumation:

1. Eocene: rocks were subjected to high pressure/low temperature (HP/LT) metamorphism followed by the partial exhumation of metamorphic rocks within the subduction channel.

2. Oligocene-Miocene: post-orogenic exhumation of the MCC by low-angle normal faults contemporaneous with the intrusion of arc-related Miocene granitoids, causing local contact metamorphism.

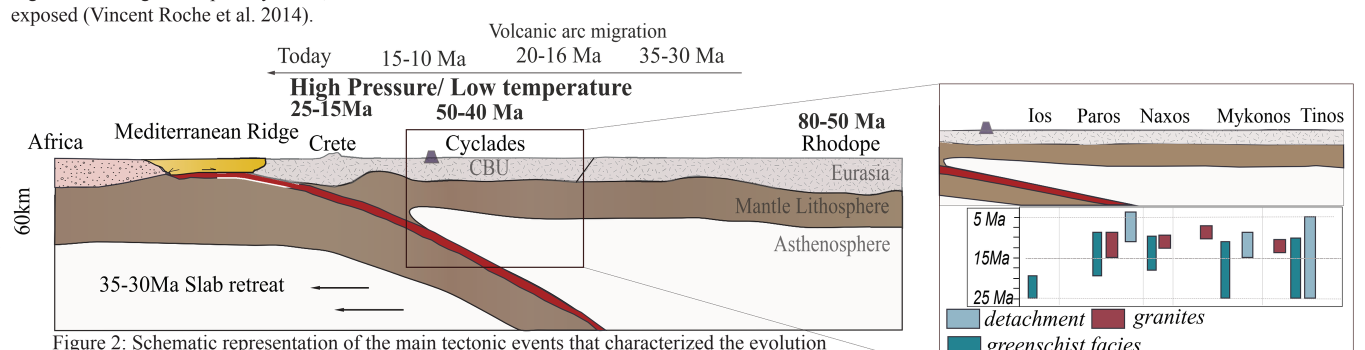


Figure 2: Schematic representation of the main tectonic events that characterized the evolution of the Hellenic subduction zone from 100Ma to present.

SIKINOS

Cycladic Blueschist Unit:
Metamorphosed under blueschist-eclogite conditions and retrograded into greenschist facies. Composed of Triassic to late Cretaceous carbonates, clastic sediments, and volcanic rocks.

Crystalline Basement (and Carapace):
Strongly deformed granitic gneisses (Crystalline Basement) intruded garnet mica schists and paragneisses (Carapace) during Variscan orogeny.

Contact between CBU and Basement
1) A pre to syn-blueschist facies thrust plane localized along an older erosional surface or unconformity (Vander, 1980).
2) A north dipping low angle normal fault reactivated as a south dipping low angle normal fault (Lister 1999).
3) A thrust fault formed during HP/LT metamorphism and reactivated as a low angle normal fault during exhumation.

Figure 3: (A) Marble boudin in quartz mica schist from the Cycladic Blueshist Unit on Sikinos Island (B) Mylonitized orthogneiss from the Crystalline Basement on Sikinos Island intruded in phyllitic Carapace (C) Contact between CBU and Basement on Sikinos Island

MOTIVATION/RESEARCH QUESTIONS

There are few constraints on the timing of deposition and sediment sources for the CBU exposed in the southern Cyclades.
(1) What is the maximum depositional age and provenance of the CBU?
(2) Has the CBU stratigraphy been structurally re-ordered through subduction- and/or extension-related processes?

The nature of the contact between the CBU and the underlying Cycladic Basement on Sikinos Island is debated.
(1)What is the age of the overlying CBU and the underlying Basement on either side of this contact?
(2) Were these units together during Eocene subduction-related metamorphism?
(3) Do these units share a thermal history and when were they exhumed?

METHODS

-*Zircon U-Pb* dating by high resolution laser-ablation inductively coupled plasma mass spectrometry (HR-LA-ICP-MS) to determine detrital provenance, maximum depositional ages (MDAs), constrain protolith ages for the Crystalline Basement and metatuffs, and quantify the timing of HP-LT metamorphism.

-*Zircon U-Pb dating by Split-Stream LA-ICP-MS* to simultaneously determine U-Pb ages and trace element compositions and hence to distinguish between magmatic and metamorphic zircon ages. This is critical for determining both MDA and the age of metamorphism in the CBU.

- *Zircon (U–Th)/He dating*, based on the decay of 238U, 235U, 232Th, and 147Sm by alpha (4He nucleus) emission. Parent isotopes collected with isotope dilution methods on a ThermoFisher Element2 ICP-MS.

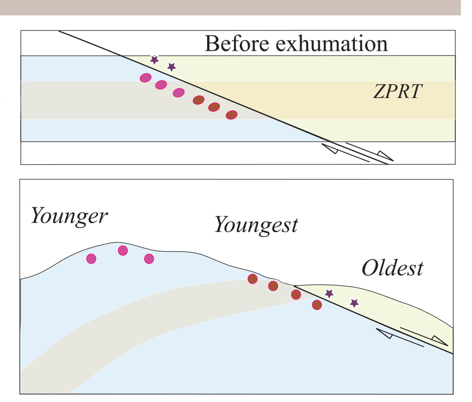


Figure 4: Simplified model showing the expected zircon cooling ages in the hanging-wall and footwall of a low-angle normal fault after exhumation of a metamorphic core complex. (Modified from Stockli et al. 2000)

RESULTS

GEOLOGIC MAP OF SIKINOS

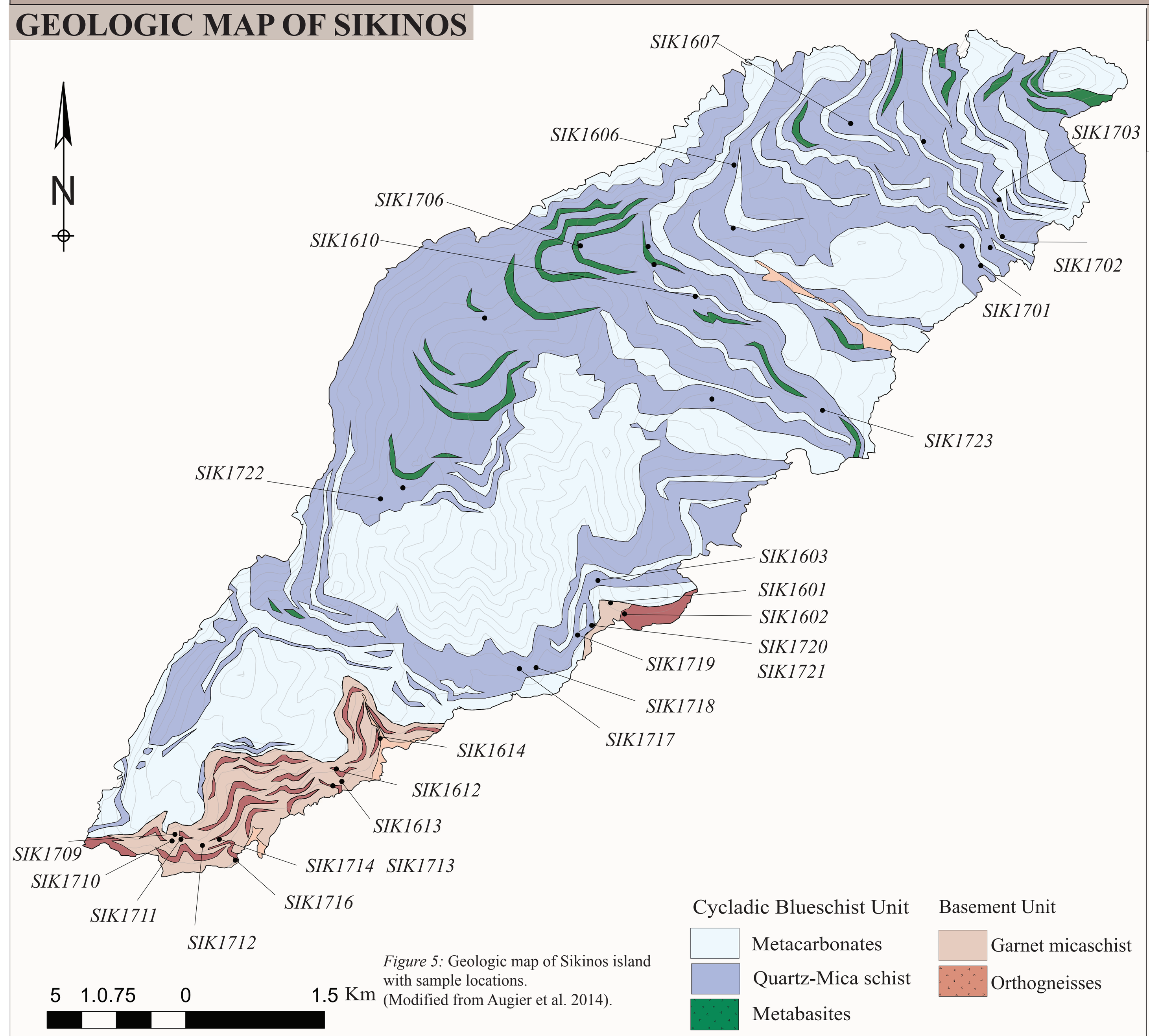


Figure 5: Geologic map of Sikinos island with sample locations. (Modified from Augier et al. 2014).

MAXIMUM DEPOSITIONAL AGES/OVERGROWTHS

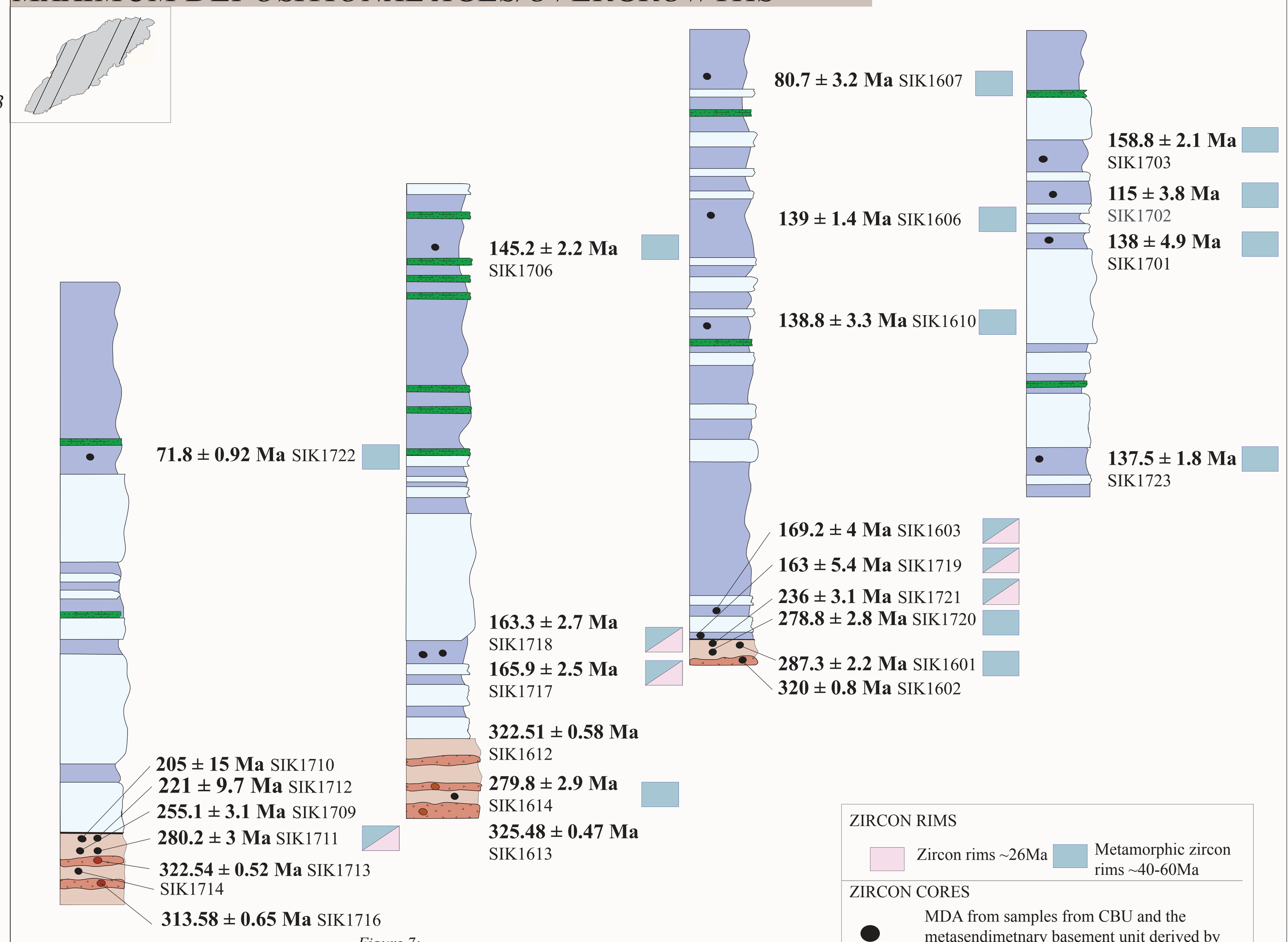


Figure 7:
Structural transects from Sikinos island based on the pre-existing map [e.g. Augier 2014] from SW to NE, showing relative sample locations, interpreted maximum depositional ages, crystallization ages, and metamorphic zircon rims.

Detrital zircon provenance

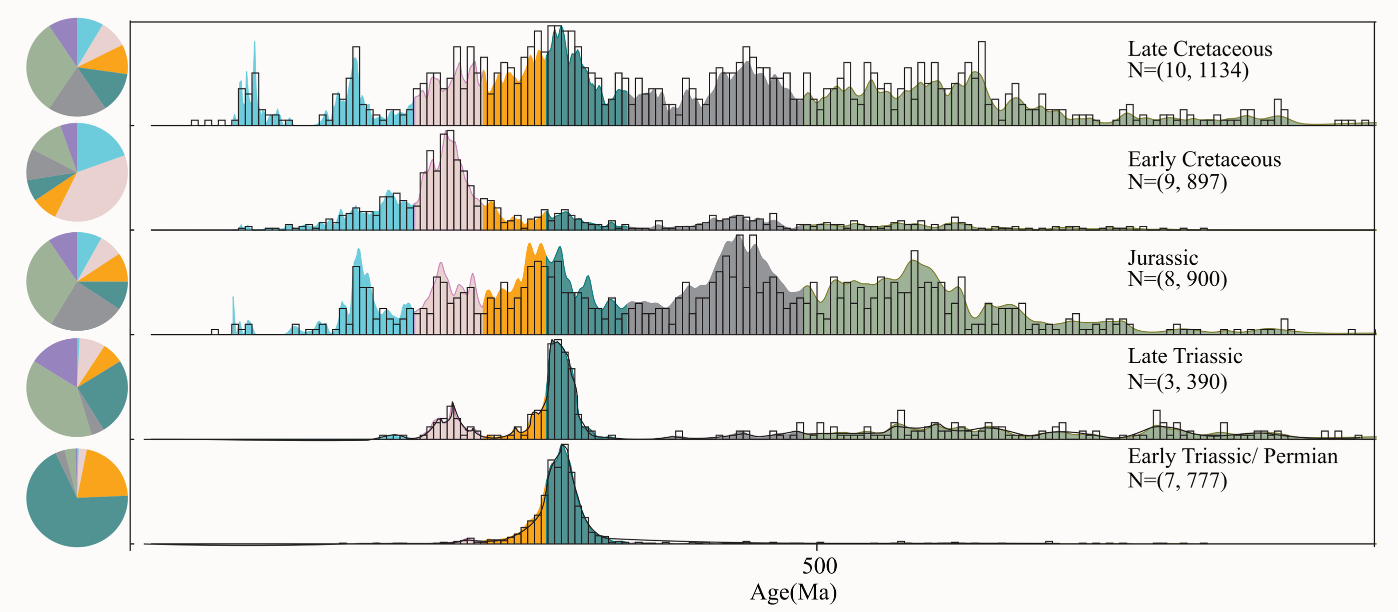


Figure 6: KDE of detrital samples collected from Sikinos and Ios island from the CBU. KDEs represent multiple samples categorized based on the Maximum Depositional Ages, each sample has n>80 grains. Prominent age modes are represented by different colors and include Mesoproterozoic-Paleoproterozoic (900-2200 Ma), Cambrian-Neoproterozoic (500-700 Ma), Silurian-Ordovician (400-450 Ma), Carboniferous-Devonian (300-400 Ma), Permian (250-300 Ma), Triassic (200-250 Ma), and Cretaceous-Jurassic (70-200Ma). Samples are categorized based on the MDA and are plotted progressively from old at the base to young at the top.

Zircon (U-Th)/He

Closure temperature of He is 190-220 °C in zircon. The geothermal gradient during Miocene greenschist facies is ~25 °C/km, hence the partial retention zone is 6-7.5 km beneath the surface.

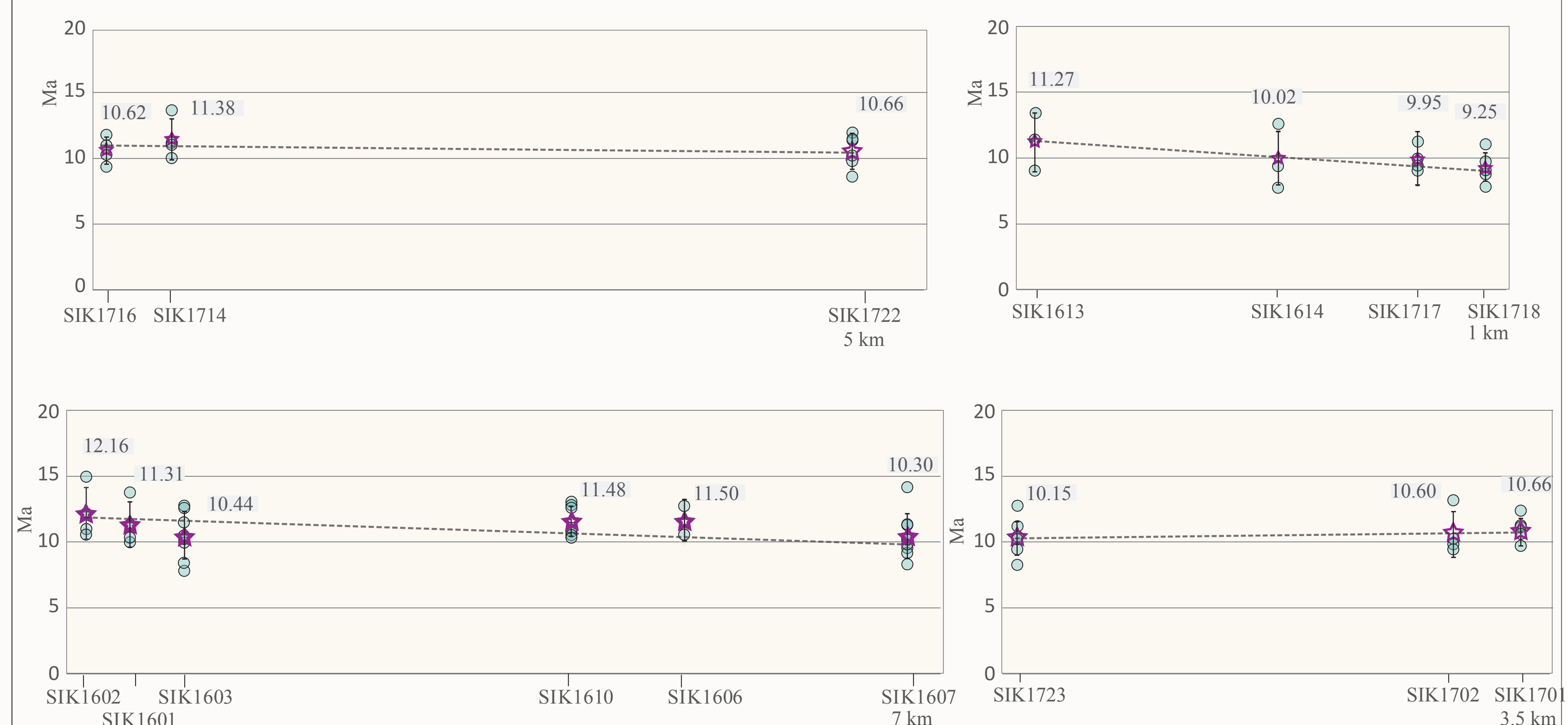


Figure 8: Transects across Sikinos Island run parallel to the stretching lineation and aliquots represent individual grains. Whiskers represent the standard deviation. The ages tend to be older in the South and younger in the North.

Trace elements in zircon

Known Observations:
Metamorphic/Metasomatic grains:
-Richer in LEE/ steeper patterns
-Th/U> 0.1

Magmatic grains:
-Flatter patterns in LEE
-Eu, Ce is pronounced
-Th/U<0.1

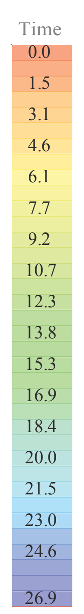
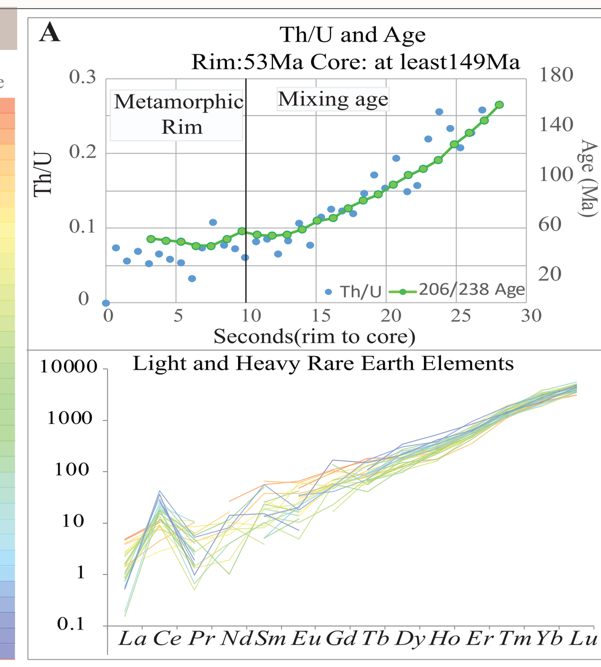
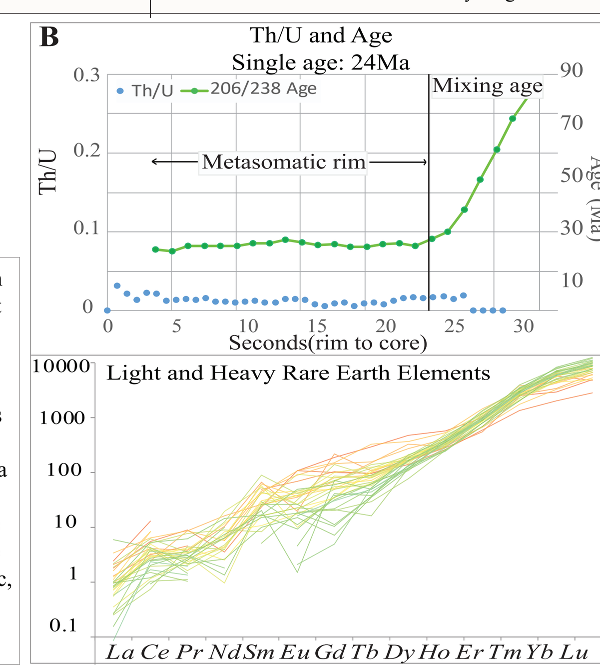


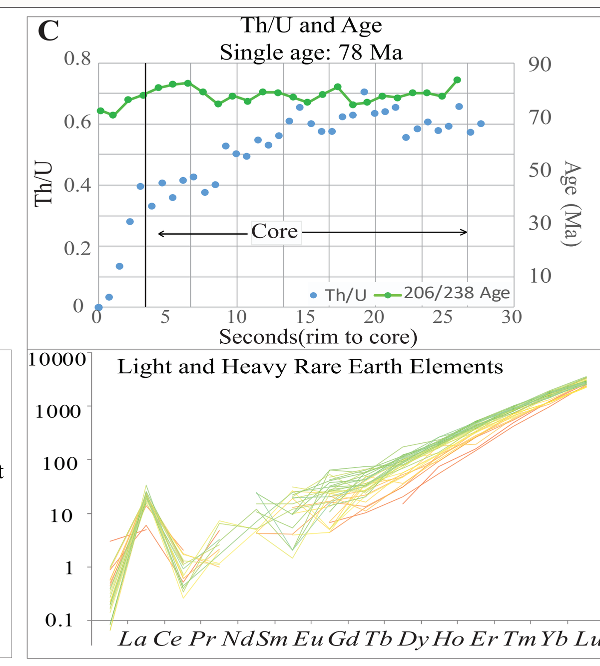
Figure 9: Graphs show individual grains from the SIK1613 sample analyzed with Split Stream LA-ICP-MS depth profiling. The Th/U and 236/238 Age graphs are plotted against seconds of ablation on the zircon grain. The LHREE plot shows the temporal evolution of ablation on individual grains. The signal from the surface of the grain is shown in red, and transitions to blue towards the grain center.



Graph A. The 53 Ma rim has Th/U < 0.1 and is not enriched in Eu and Ce, therefore is likely **metamorphic**. The profile does not flatten as ablation time progresses, hence the 149 Ma age is a mixing age between the metamorphic rim and the magmatic core. This age is not solely metamorphic, since Th/U > 0.1 and Ce is pronounced.



Graph B. The 24Ma single age (0-23 sec) is a metasomatic rim and it has Th/U<0.1 and steep LEE pattern. The profile does not flatten (25-30 sec) as ablation time progresses, hence the 90Ma age is a mixing age between the metamorphic rim and the magmatic core.



Graph C. The 78 Ma single age (5-30 sec) has Th/U>0.4 and pronounce Ce, therefore is magmatic.

CONCLUSIONS/DISCUSION

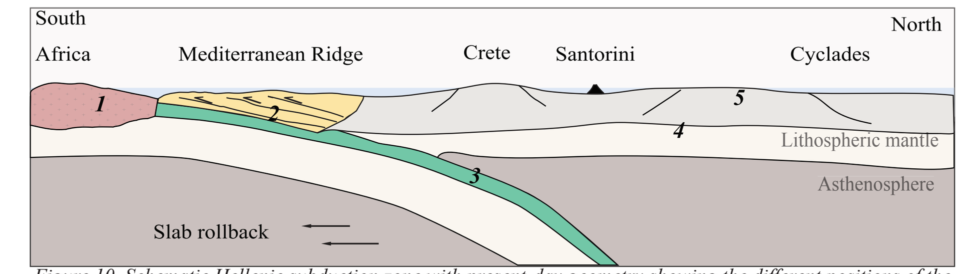


Figure 10. Schematic Hellenic subduction zone with present-day geometry showing the different positions of the CBU and Basement as they progressed from subduction to exhumation.

Paleoproterozoic-Cretaceous

1) The spread of detrital zircon U-Pb ages of the CBU can be explained by both volcanic and fluvial input from a combination of Gondwana and Peri-Gondwana terrains and Eurasia. Both MDAs and detrital zircon age distributions suggest the CBU was deposited in an early syn-rift to syn-convergent environment.

Cretaceous

2) On Sikinos island, samples taken across the mapped contact yield MDAs grading from old to young. Since no time hiatus has been observed, this progression from old to young can be interpreted as an initial depositional contact.

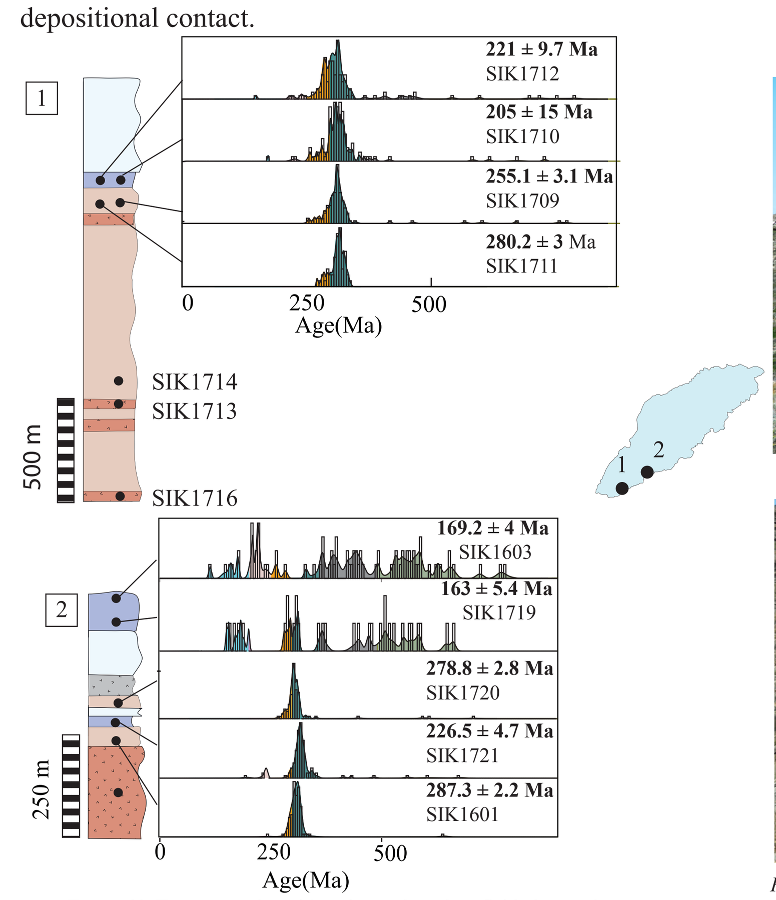


Figure 11: Tectonostratigraphic columns based on field observations from positions 1 and 2 on Sikinos island including sample locations, detrital zircon age distributions plotted as KDEs, and MDAs derived using the YC1sigma (5+) method.

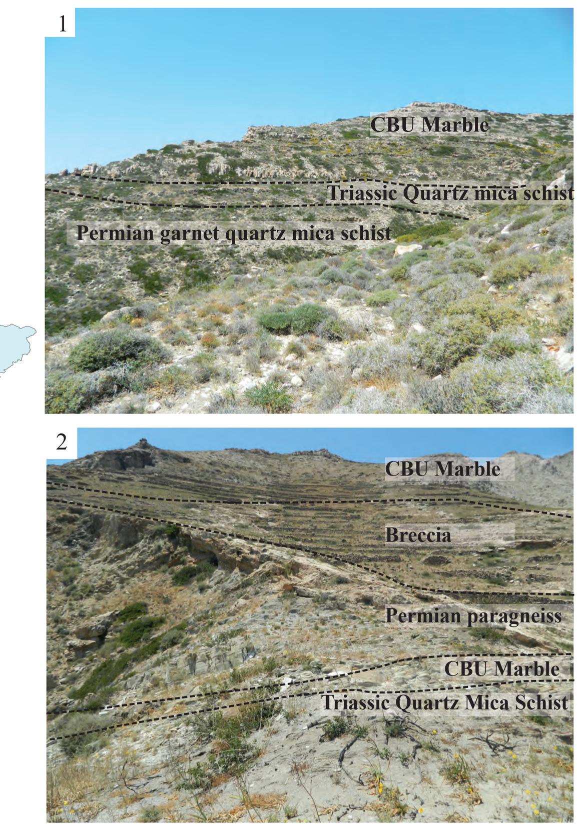


Figure 12: Selection of field photos: (1) Large-scale view of the Cycladic Basement/CBU contact on the southern coast of Sikinos island (position 1). (2) Contact between Cycladic Basement and CBU on the SE coast of Sikinos island (position 2).

Eocene-Miocene

3) Both Basement and CBU experienced the HP-LT metamorphism during Eocene
4) Samples along the contact show 20-26 Ma zircon overgrowths, likely from fluid circulation along the contact.
5) Zircon (U/Th) – He ages from both units trend from old to young towards the stretching lineation (N-S), hence the Basement and CBU were likely exhumed together. **We propose that both units were exhumed due to a low-angle normal fault located north of the island.**

	SIK1602	SIK1601	SIK1721	SIK1719	SIK1603	SIK1610	SIK1606	SIK1607
Z rims 50 Ma		●	●	●	●	●	●	●
26Ma			●	●	●			
ZHe	12.16 Ma	11.31 Ma			10.44 Ma	11.48 Ma	11.5 Ma	10.3 Ma

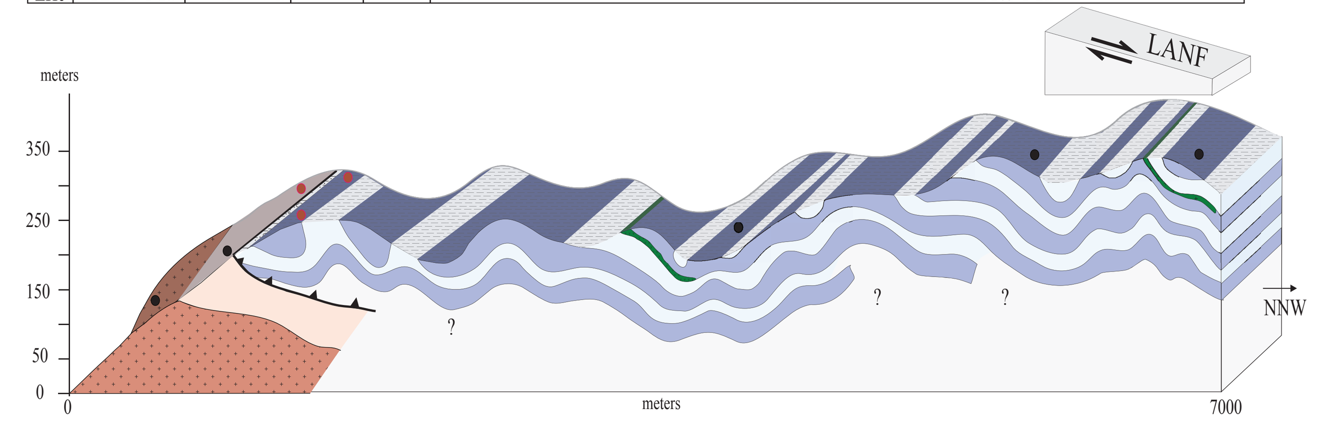


Figure 14: Schematic 3-D diagram summarizing the tectonometamorphic evolution of the island from the initial stages of subduction to exhumation and subsequent exposure on the surface.

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2) Create a complete geodatabase from samples collected on Sikinos and Ios with zircon U/Pb and U-Th/ He ages.

Samples' data and pictures have been attached in the GIS file, but due to the large number (>100) of samples, further work is required to finish the geodatabase.

3) Create geological cross sections along the islands with the samples positions to help us visualize the U-Th/He ages and determine the nature of the contact.

Closure temperature of He is 190-220 °C in zircon. The geothermal gradient during Miocene greenschist facies is ~25 °C/km, hence the partial retention zone is 6-7.5 km beneath the surface.

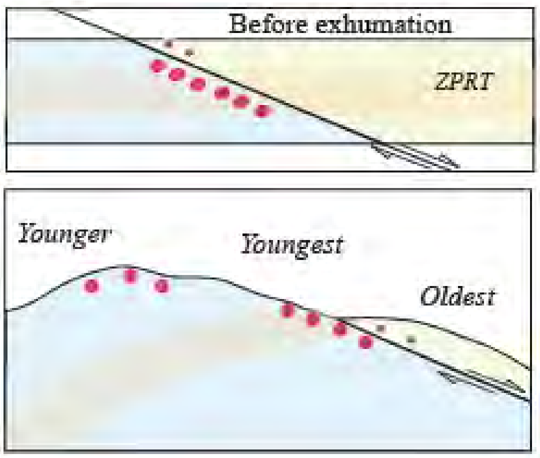

Figure 17: Simplified model showing the expected zircon cooling ages in the hangingwall and footwall of a low-angle normal fault after exhumation of a metamorphic core complex. (Modified from Stockli et al. 2000)

Zircon U/Th – He from both units trend from old to young towards the stretching lineation (N-S), hence the Basement and CBU were likely exhumed together. If the CBU was the hangingwall unit and the Basement was the footwall unit of a low-angle normal fault, we would expect to see older ages in the CBU and younger ages in the Basement, but this is not the case as is evident in the cross-section created in ArcMap and modified in Adobe Illustrator, shown below. We propose that both units were exhumed together via a low-angle normal fault located north of the island.

	SIK1602	SIK1601	SIK1721	SIK1719	SIK1603	SIK1610	SIK1606	SIK1607
Z rims 50 Ma								
26Ma								
ZHe	12.16 Ma	11.31 Ma			10.44 Ma	11.48 Ma	11.5 Ma	10.3 Ma

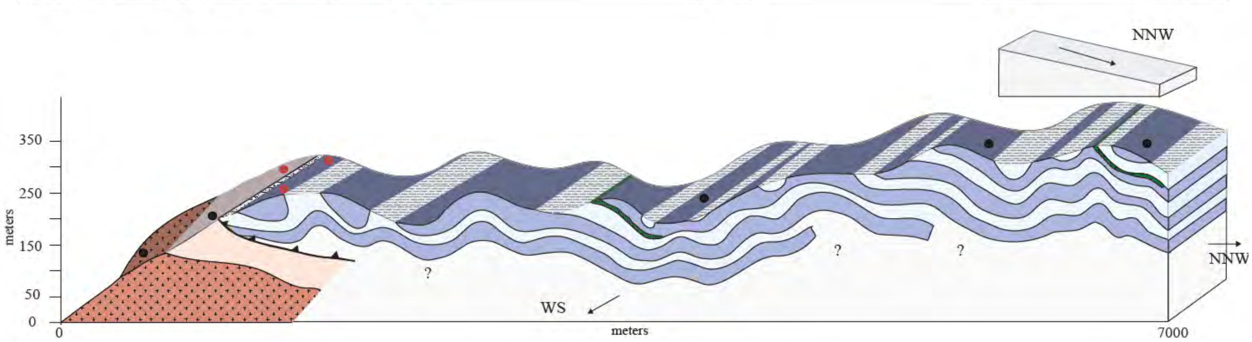

Figure 18 Schematic 3-D diagram summarizing the tectonometamorphic evolution of the island from the initial stages of subduction to exhumation and subsequent exposure on the surface.

REFERENCES

Augier et al. 2014 Exhumation kinematics of the Cycladic Blueschists unit and back-arc extension, insight from the Southern Cyclades (Sikinos and Folegandros Islands, Greece) from

Huet et al., 2009 Thrust or detachment? Exhumation processes in the Aegean: Insight from a field study on Ios (Cyclades, Greece).

https://www.nasa.gov/

And labs created from Mark Helper for the GEO 327G class