Farnham Geological Society

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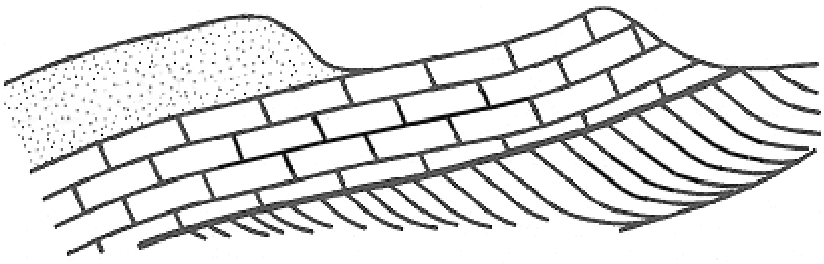

A local group within the GA

Vol. 22 No.1 **Newsletter** February 2019

Issue No: 101

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Editorial

I hope that you have all had a good Christmas and will have a very healthy and successful 2019. The Society has had a good year – we still have almost 100 members and many of these attended our end of year gathering.

Thanks to Janet Catchpole, we had a great and very varied selection of talks covering topics which ranged from fossils (and fraud) varying from plants to dinosaurs, to earthquakes, faults, volcanoes & magnetism to space research and quarrying. These were from locations as varied as Farnham and Godalming to Mull, Italy and Greece. Accordingly the talks were well attended throughout the year.

Similarly the FGS Field trips were well attended and varied from Godalming, Guildford & Albury, to Sheppey and Salisbury and to Devon & Cornwall, and, Glamorgan. The highlights of these trips included superb fossil locations, sedimentation, metamorphism and interesting tectonics. Thanks have to go Graham Williams and his team for the organization of these trips.

Retirement - Mike Weaver, who has been a committee member of FGS for ~20 years, and who has run the FGS Website for many years plans to retire from that job. Mike Hollington has helped him in the past and we are pleased to know that Mike will join the committee and take over now in 2019. However, for the moment, Mike will continue to finalize and supply the Society's newsletters.

Some people have had problems when attending our meetings, especially when the Maltings have particularly popular (and often noisy) events on the same evening. I can assure members that it is extremely difficult to find suitable venues in Farnham, which have adequate and pleasant facilities with safe and easy parking. Members may not be aware of the 'overflow' part of the car park at the far end of the Maltings car park, but it is large, quiet and very easy to park in.

I want to thank John Stanley who created (and has unstintingly kept up-to-date) a full record of all the articles which have been written for the Society's newsletters. These date back to the first, produced in July 1970. This full record includes, date, author, key words and Society numbering – it can be found on the web site and is accessible to all.

We can all now look forward to a successful season this year, as you will see from the list of talks and field trips which have been planned.

Obituaries - Sadly, Roslyn Linse (better known to all as Lyn), a member of FGS for more than 25 years died this year. She was an active FGS member, not only as a regular attendant to meeting but also as a former committee member and frequently seen on field trips – a truly lovely lade who will be sorely missed by us all.

The Geologists Association's Festival of Geology at University College London, November 3rd, 2018

FGS have been attending the GA Festival of Geology since 2010 and this year 23 Farnham members attended. Sally Pritchard again put together an excellent display for the Society and was supported on the day by Janet Catchpole, Judith Wilson, Jonathon and Jean Davies, Christine and Peter Norgate, John Williams and myself, which was very welcome.

The organizers introduced a 'quiz' for children who had to 'collect' a stamp from certain stalls - FGS was given a 'trilobite image' and a 'rubber stamp' and the children flooded in with their cards in an attempt to collect all the images / stamps. It made it fun and gave an excellent ambience to the event.

Liz Aston

Field trip to Old Sarum and Salisbury Cathedral, Wednesday 10th October, 2018

The weather gods were with us for the visit to Old Sarum and Salisbury Cathedral, under the guidance of John Williams and Mike Rubbra, both FGS Members. The sun shone and we saw both sites to their best advantage. Poor John had made his recce on a very wet and windswept day!

Old Sarum is the site of the earliest settlement of Salisbury in England. It was occupied from as early as 3000B.C. until about 1514 A.D. when Henry VIII authorized the use of the whole site for stones (Figures 1, 2, 3).

Fig. 1: A close-up of the walls of Old Sarum

Fig. 2: Outline of Old Sarum site

Fig. 3: A more distant view of Old Sarum walls.

Mike Rubbra gave us a very comprehensive and interesting description and history of the site. Old Sarum was originally an Iron Age fort strategically placed on the conjunction of two trade routes and the river Avon. It was later used by the Romans, becoming the town of Sorviodunum. The Saxons used the site as a stronghold against marauding Vikings, and the Normans built a stone curtain wall around the Iron Age perimeter and a centrally placed castle on a motte protected by a deep dry moat. Later a royal palace and a cathedral were built.

This site proved very inconvenient, particularly as there had been a serious falling out between the church and the military, so it was decided to relocate the cathedral to level land beside the river Avon. Water had also been an issue with the Old Sarum hill site. Construction began in 1220 A.D. and was completed in 1284. Throughout ashlar masonry was of 'Chilmark' stone with Purbeck marble for the columns and smaller shafts around the doors and windows.

Chilmark stone has been used to the present day for repairs. Medieval work utilized the following stones:- Chilmark stone, Purbeck marble, Hazelbury oolitic limestone, Chalk, Tufa, and Upper Greensand limestone. Also to be seen in later repairs and monuments are Purbeck Limestone, Portland Limestone, Bath stone, Devon marbles, Forest of Dean sandstone, English alabaster and various Belgian and Italian marbles.

 

Figs. 4a, 4b: Views of the outside and chancelry of the iconic Salisbury Cathedral

*Reported by Gill Clarke***.**

Volcanoes and humans: a story of love, fear and respect

Summary of February 2018 lecture to FGS given by Dr. Chiara Maria Petrone, Natural History Museum

Volcanoes are one of the most powerful and fascinating forces of nature. Human history strongly depends on the presence of volcanoes, which play an extremely important role on our planet. Our atmosphere, for instance, is the result of volcanic activity, and human evolution, its adaptation and migration, has been strongly influenced by volcanic eruptions.

Fig. 1: Popocatepetl Volcano (Mexico, 5545 m a.s.l.) as seen from Paso De Cortes at 3,800 m.

All 3 Photos credit @ C.M. Petrone

Fig. 2: Pumice deposits of Plinian eruption at Popocatepetl Volcano. From top to bottom: white layer = 1,000 years ago Plinian eruption; black layer = volcanic ash; yellow layer = 2,000 years ago Plinian eruption; bottom black layer = black ash.

We look at volcanoes with fear, respect and utter fascination. We can exploit the many benefits volcanoes provide, from fertile soil, to geothermal energy, construction materials and mineral resources. However, when volcanoes erupt they pose a big threat to the nearby population. There are more than 800 million people living very close to an active volcano and there are about 1,500 potentially active volcanoes worldwide with about 500 of them that have erupted in historical time (from USGS website).

Popocatépetl volcano in Mexico (Figure 1) is one of the most active volcanoes on Earth and it also ranks very high in terms of threatened population, with more than 20 million people living within 70 km from the crater. Continuously active since 1994, the present-day edifice has been shaped by voluminous lava flows punctuated by at least five major Plinian eruptions in the last 23,000 years, with the ~14,000 years old "Pumice with Andesite" Plinian eruption, the most powerful on record at Popocatépetl, reaching as far as Mexico City.

Figure 3 - Human remains at Herculaneum (Italy) destroyed by the 79 AD eruption of Vesuvius Volcano.

From the rock record (Figure 2), we know that about 2000 years ago another large Plinian eruption took place at Popocatépetl. The eruptive column rose between 20 and 30 km before depositing a large volume of pumices estimated as at least 3.2 km^3, covering an area of at least 25 km east of the volcano's crater and over 1m thick even at 20 km from the crater (Siebe, 2000). Pumice and ash completely buried the village of Tetimpa, a farming village on the northeastern flank of the volcano, obliterating the life of its inhabitants, but at the same time preserving the traces of their every-day life activities that scientists are now able to reconstruct and interpret.

From the dispersion of the tephra eastward, scientists concluded that 2000 years ago the Plinian eruption took place during the dry season, from October through May when the prevailing winds blow west to east. Archaeological evidence (Plunket and Uruñuela, 2008) also supports this interpretation, indicating that the agricultural fields were not planted and there was a shortage of food supply in the domestic storage facilities, a clear sign that most of it had been already used.

The short- (e.g., loss of seeds for the next season) and long-term (e.g., destruction of hunting area and agricultural soil) effects of the eruption were devastating, prompting thousands of people to move north, toward Teotihuacan, and east, toward Cholula. With time, Teotihuacan saw a huge population increase, also aided by another devastating eruption of Popocatépetl around 1000 years ago, becoming the most powerful city of pre-Hispanic Mexico.

The story of Tetimpa and many other archaeological sites, with their remains, testify to the powerful force of volcanic activity and at the same time the resilience of the community living in the vicinity of an active volcano. The area of Tetimpa, as well as the more famous Pompeii and Herculaneum in Italy (Figure 3), both destroyed by the 79AD eruption of Vesuvius, are currently populated. Their history is punctuated by many cycles of abandonment and repopulation as a consequence of volcanic eruptions.

The main challenge faced by scientists consists in understanding how volcanoes work, interpreting the warning signals and clearly communicating the hazards to the authorities and the communities. At the same time, people living nearby a volcano have another major challenge to face: to understand and respect the nature of the volcano via well-planned urban development and emplacement of a serious evacuation plan, based on scientific results.

Although scientists, local communities and civil authorities have different expertise and play very different roles, in order to successfully manage the emergency and the aftermath of a volcanic eruption, trust, respect and clear communication are fundamental.

References and further Reading

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How To weigh a dinosaur

Summary of October 2018 talk given to FGS by Dr Susannah Maidment, Natural History Museum, London

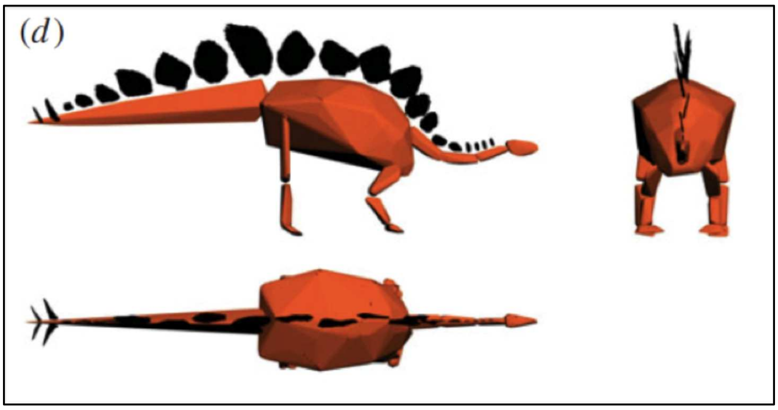
In the media, we often see reports of "the World's largest dinosaur" being discovered. But is the size of a long-extinct animal actually important? Does it actually mean anything for our understanding of their biology? And how do we measure how 'large' an extinct animal was?

In extant herbivores, body mass is known to correlate with factors such as home range size and migration ability. Large size among living animals has even been interpreted as an adaptation to aridity, because body mass scales with the 0.75 to a variety of physiological processes, meaning that larger animals need less sustenance than their smaller relatives. It seems that body mass may actually be rather important for understanding an animal's biology, and that if we could reliably estimate it in extinct animals, it might be rather useful to help us understand their lifestyles.

Palaeobiologists estimate body mass in two main ways. The first is by use of a linear bivariate equation. If the circumference of the upper arm bone (humerus) and upper leg bone (femur) are measured and added together in extant animals of different sizes, and plotted against body mass on a log-log scale, a straight line relationship between the two emerges. This means that in living animals, if we know the humerus + femur circumferences, we can predict body mass with a small error. Palaeobiologists have applied this simple relationship to fossils, by measuring the limb bone circumferences, plotting them onto the graph based on living animals, and reading off body mass. This is a simple method, doesn't require a complete skeleton to be found, and doesn't require any flash computing. But the problem is that the largest extant animal (the African elephant) weighs just six tonnes: an order of magnitude smaller than the largest dinosaurs. Is it reasonable to extrapolate the data beyond the range of our living sample?

The second way that palaeobiologists measure body mass in extinct animals is using the volumetric method. This method takes a 3D computational model of a dinosaur skeleton and 'shrink wraps' it using a method called convex hulling to produce a minimum volume estimate of the skeleton. The density of soft tissue (which we know from living animals) can then be applied to the convex hull volumes, and body mass calculated. When we carry out this method on living animals for which we already know the body mass, we find that if we increase the minimum convex hull volume by 21%, this accurately reflects the amount of soft tissue found, and we can apply this same reasoning to dinosaurs. So we take a dinosaur skeleton, shrink-wrap it, increase the hull volume by 21%, and calculate body mass. The problem with this method, however, is that we need a complete or nearly complete skeleton to use it.

We compared these two methods in two different case studies. The first was for a dinosaur called *Dreadnoughtus*, which when discovered received a lot of media attention for being the heaviest dinosaur ever found. The linear bivariate equation had estimated its mass at 60 tonnes. We produced a digital model of its skeleton, applied the volumetric method, and calculated that it weighed 30 tonnes. We are unable to explain this discrepancy, but suspect that it suggests the extrapolation of the linear bivariate method outside of the body range size of extant animals is invalid.



A computational model of Sophie the Stegosaurus, shrink-wrapped in a convex hull, which is then enlarged by 21% of its volume to represent the amount of soft tissue that the animal probably had surrounding its skeleton (from Brassey, C. A., Maidment, S. C. R. and Barrett, P. M. 2015. Body mass estimates of an exceptionally complete Stegosaurus (Ornithischia: Thyreophora): comparing volumetric and linear bivariate mass estimation methods. Biology Letters 11: 20140984).

Second, we investigated the body mass of a specimen of the World's most complete *Stegosaurus*, Sophie, which is on display at the Natural History Museum. We calculated Sophie's body mass using the linear bivariate method to be about four tonnes. But using the volumetric method, we calculated it to be about half that, around two tonnes. However, during our study of the skeleton, we noted that the specimen was not fully-grown when it died. The linear bivariate model is built on adult animals, so this might have been having an effect. We applied a method called developmental mass estimation, which calculates how big the animal might have got to based on the largest known individual of that species, calculates body mass from that, and then scales relative to the length of the limb bones to back-calculate the body mass of immature individuals. When we applied this correction to the linear bivariate method, it brought the mass estimate down to about two tonnes, and well within the error bar of our volumetric estimation.

So it seems the two methods can come up with similar results, as long as the animals whose mass we are estimating are fully grown adults, and they are within the size range of living animals. Since the methods are based on entirely different data, we can feel reassured that our mass estimates are not wildly wrong. However, the linear bivariate method has very large error bars: for Sophie, the mass estimate is anywhere between two and six tonnes. With this sort of level of error, it's virtually impossible to infer anything meaningful about the lifestyle of an extinct animal. And the level of uncertainty around these mass estimates is never given in the media. So next time you see a headline about the 'world's largest dinosaur', take it with a pinch of salt!

A geological snapshot of the Greek Islands

Summary of November 2018 talk given by Liz Aston, CGeol, FGS

Greece and its Islands

The Greek Islands comprise >6,000 islands & islets covering much of the E Mediterranean. Only about 230 of the islands are inhabited. The most common sedimentary rock is limestone or where metamorphosed, marble, and exploitation of this marble has been important for 100s of years. Other metamorphic and volcanic rocks have an important role to play geologically and from the associated minerals & metals that have been economically important to Greece.

The largest Greek island is Crete at the S edge of the Aegean Sea, next is Euboea (separated from mainland Greece by just 60m). The 3rd and 4th are Lesbos and Rhodes, the rest of the islands are all smaller. Cyprus is also large but not included in this geographical area.

The smaller islands are traditionally grouped into 6 major clusters (Figure 1a):

- Ionian (6 islands): off NW coast of mainland Greece - Corfu, Kefalonia and Zante.
- Saronic (7 main islands): in Saronic Gulf near Athens with islands of Aegina and Poros.
- Sporades: A small, tightly-knit group of many, very small, islands just off the E coast of Greece.
- North Aegean: A loose group of ~30 islands, NE of Greece.
- Dodecanese: A long string of ~160 islands parallel to the Turkish coast including Rhodes.
- Cyclades: A large, dense group of ~220 islands in the central Aegean Sea, including Mykonos & Santorini.

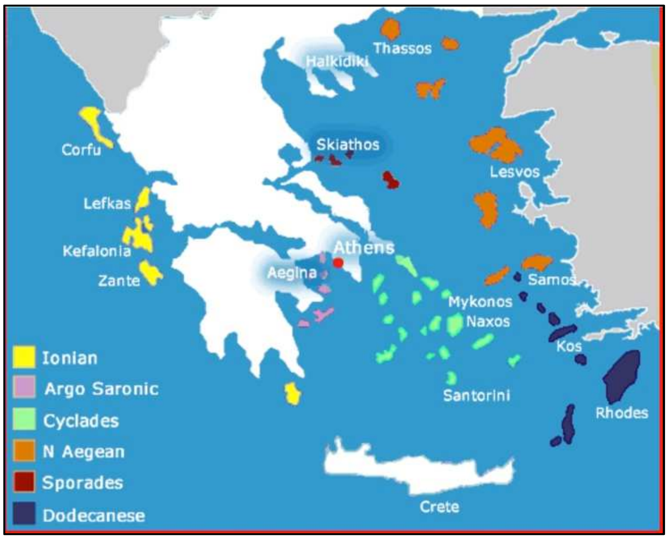


Fig. 1a: Map of the Greek Island Clusters

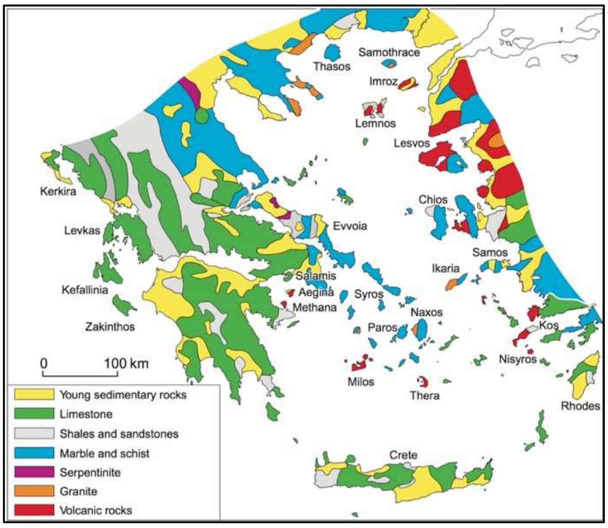


Fig. 1b: Geology of Greek Islands. From Higgins, 2009

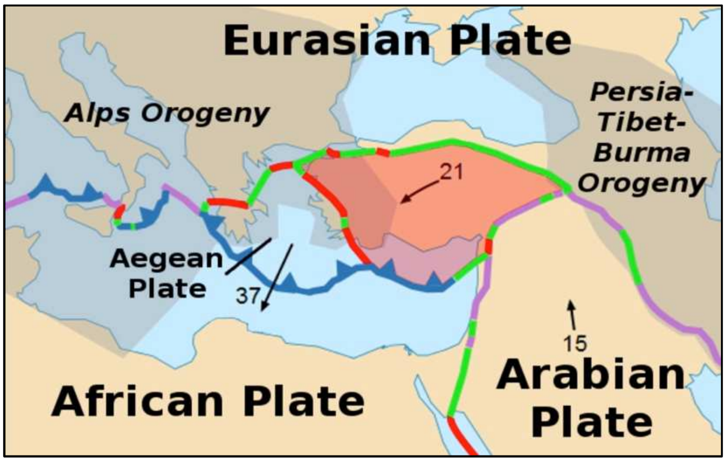
However these groupings are not really geological (see Figure 1b); a better geological grouping is:

1. The northernmost N Aegean Islands – Thasos, Samothrace – geology as S Europe;
2. The Islands of the Central Aegean – The Sporades islands (in W) & Lesbos, Chios (in E);
3. The Cyclades – with the Saronic islands (geology as E side of mainland Greece with volcanics), Ikaria, Samos & N Dodecanese islands ('crystalline area' with marbles & schists akin to E Greece & Alps; including an important section with blueschists and eclogites);
    - S Aegean – complexes of plutons and metamorphics with large detachments;
4. Volcanic Arc along, and generally to the N of, the subduction zone;
5. The Ionic islands (geology as W side of mainland Greece), Rhodes, S Dodecanese islands and Crete – fore-arc with marbles & schists and with Alpine thrusts & detachments.

The geology of the Greek islands reflects a long, complex interaction between 3 tectonic plates – the Eurasian (Europe–Asia), Mediterranean (African), Anatolian (Turkey–Middle East) plates (Figure 2). Their various movements have generated the numerous volcanic eruptions and earthquakes. The dominant force has been that of the Alpine orogeny, as Africa drifted into Eurasia.

Modern Tectonic Situation of the Aegean Plate (Figures 2a, b)

- The Anatolian plate is moving into the W part of the Aegean region.
- The Mediterranean (African) plate is subducting N under the area & melts at ~100 km to feed active volcanoes.
- Movements along these plate boundaries create earthquakes; Greece is the most seismically active part of Europe.
- The Alpine mountain system extends from W Greece through the Cyclades and Dodecanese islands to join up with the Taurides in Turkey.
- Faulting and folding have changed ground and/or sea levels over time.
- The faults allow surface water to descend deep into the Earth and rise as hot springs.



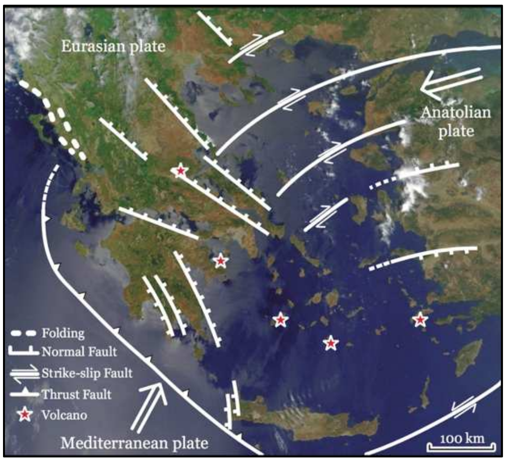


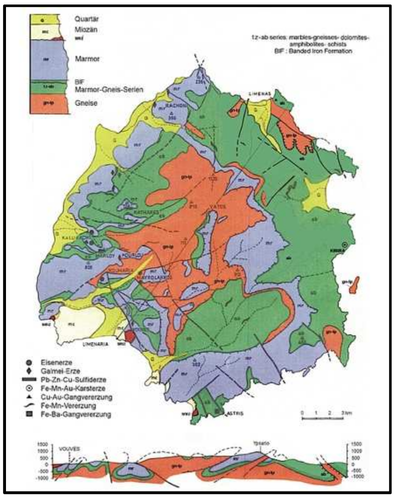
Figure 2a, b: Plate tectonics of Aegean region

2a: From: Alataristarion [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons

2b: From: Michael Higgins, Geology of the Greek Islands

https://www.researchgate.net/publication/256975462_Geology_of_the_Greek_Islands

Geology of Greek Islands



1. Islands Of The Northern Aegean – these islands lie to the N of the North Aegean Fault Zone & Trough, a major suture & extension of the sinistral transverse North Anatolian Fault Zone which traverses through Turkey. Thasos (Figure 3: Geological map. *From: Demadis, Epitropou, Tsopos 1989, modified by Epitropou 2001 and 2006 - IGME Xanthi / Greece*) comprises schist, gneiss, and marble and is an extension of the Rhodope metamorphic massif on the mainland 8km N. The W part of the island has many small metallic mineral deposits, including silver and gold. The oldest mines exploited red ochre in Palaeolithic times and were some of the largest in Europe at that time. White marble was also important historically.

Samothrace is a horst block between faults to the N and S. It comprises ophiolites formed ~150Ma ago, late Jurassic. Volcanism occurred 45Ma ago and was followed 20Ma later by more volcanism and the emplacement of granite that now makes up some of the highest parts of the island.

2. The Islands of the Central Aegean – The Sporades islands (in W) & Lesbos, Chios (in E)

The Sporades Islands, along E coast of Greece comprise Jurassic limestones, which have undergone several phases of orogeny and metamorphism. Skopelos is part of the Pelagonian Mountain Chain with volcanic, sedimentary & metamorphic rocks, similar to the Greek mainland. There are 3 units: the central part of the island comprises the basement; a folded and faulted Glossa Unit is thrust over it in the NW; and a structurally higher Palouki Unit is thrust over the central complex in the SE.

Lesbos comprises schists and marbles, serpentinite & ophiolite with Mg minerals and Miocene volcanics, lavas & tuffs, 16-18Ma old. The volcanic province extends ~150km E into Turkey. **Chios** has bedrock of sandstones & shales and pink marbles with red & white inclusions and meta-limestone breccias**.**

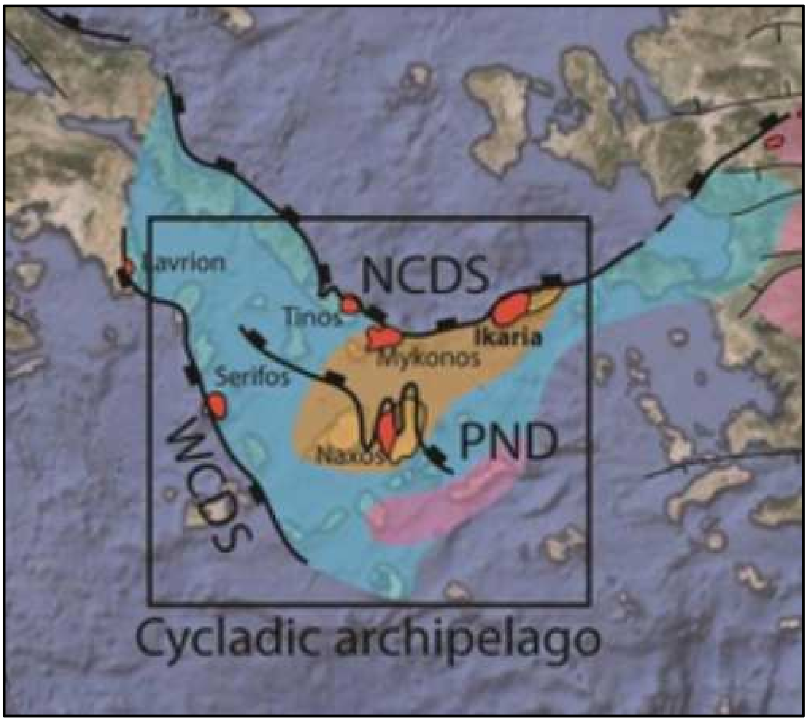
These are part of the mountain chain, which in turn is part of a massive W-E mountain chain system extending from the Atlas Mts, in the West, through the Alps and Aegean Islands to the Turkish Taurides and E to the Himalayas. The whole mountain chain formed as the African Plate moved N into Eurasia and the Tethys Ocean closed.

3. The Cyclades, Saronic, Ikaria, Samos & N Dodecanese islands and S Aegean Complexes of Plutons and Metamorphics With Large Detachments

Islands Of The Saronic Gulf - The Saronic and Corinthian Gulfs are broad rifts produced by extension of the crust (refer back to Figure 2b). The oldest rocks are hard, grey Mesozoic limestones (250-65Ma old) deposited in the shallow seas of the Tethys Ocean. Relatively recent volcanic eruptions of lavas and tuffs started 4Ma ago on Aegina and have continued on Methana and Poros, close to the Peloponnese.

The Cyclades are part of a complex metamorphic terrain that stretches N to Greek mainland and Euboea. Marble and schist dominate, but blueschists, with blue metamorphic amphibole (glaucophane), are widespread.

Glaucophane forms under very high pressures and is related to subduction zones. Closure of small ocean basins have thrust segments of ocean floor over these metamorphic rocks, forming ophiolite complexes.
Granite, intruded into the metamorphic rocks, is abundant on Naxos, Mykonos and Delos. Jadeite from Syros may have been used in Neolithic times to make axe heads; corundum from Naxos was used to shape and polish marble. White marble from Naxos and Paros was exploited; the translucent nature of the latter was prized. The distinctive geology of the Cyclades region (Figure 4, below) connects the geology of mainland & E Greece to W Turkey and the Taurides.



Figs. 4 & 5 From Laurent, et. al., 2015

Across the area it is possible to trace 3 main units –

Upper Cycladic Unit, darker ochre;
Miocene Granites, bright red in figure;
***Metamorphic core**: -*
HT-LP Cyclades, pale ochre in the figure;
UHP-LT Blueschist Unit, blue right across area;
UHP-LT Phyllites, greenish in the figure;

Menderes (Miocene massif W Turkey) - pinkish in the figure to L;

These units are associated with major detachments): N Cycladic (NCDS), W Cycladic (WCDS), Paros-Naxos (PND).

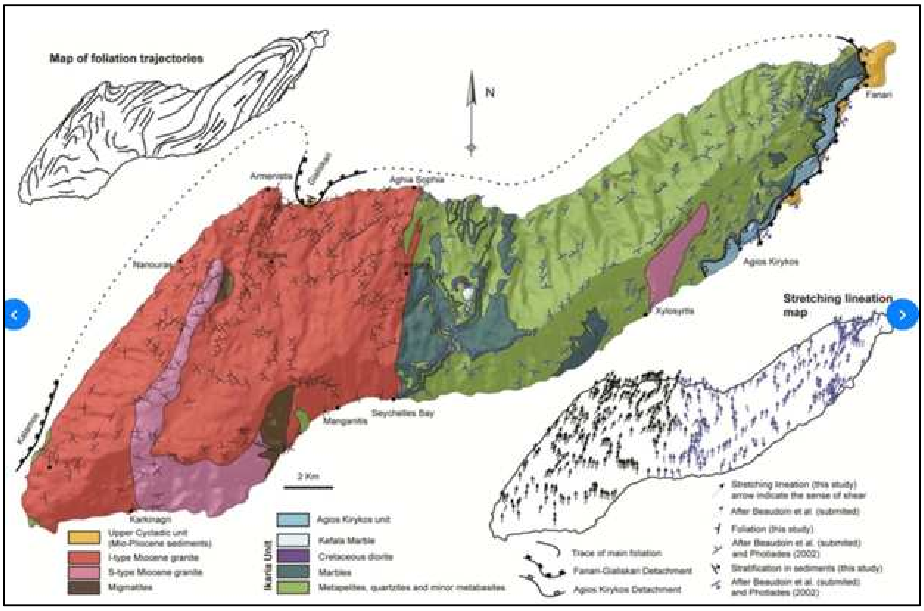


Fig. 5: Geological map of Ikaria
There are 3 tectonic units:

- *Upper unit of ophiolites & LP-HT marbles & phyllites;*
- *Intermediate unit of marbles and phyllites;*
- *Lowest unit of gneisses & meta-sedimentary rocks.*
- *The rocks of the E part are separated from the W part by a décollement surface.*

Ikaria (Figure 5) comprises metamorphic rocks in the E (migmatite, gneiss, marbles and high grade muscovite schists, often with corundum, andalusite, sillimanite). Two Miocene granites crop out in the W, with tourmaline, biotite, titanite, ilmenite, hematite, rutile, zircon. These are the Raches and Xylosyrtis granites, similar to those of Naxos and Mykonos. The granites form the largest plutonic body in the Aegean. Younger Neogene conglomerates, sandstones and clays complete the stratigraphy.

The same scenario is present on Tinos, Mykonos. Typical photos of the rocks of the Aegean are shown below Figures 6a, 6b).

Fig. 6a: Gneiss & marble

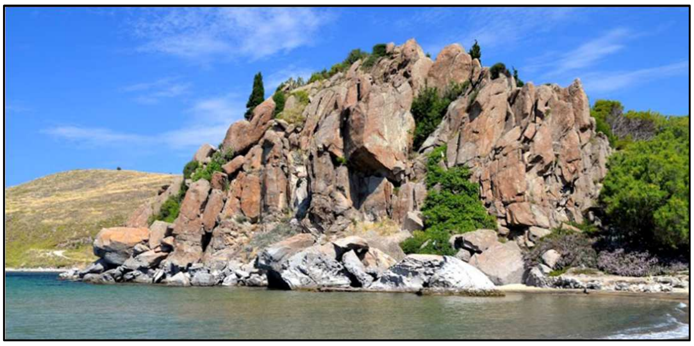


Fig. 6b: Granite (above)

The Cyclades Detachments and Nappes – The E part of the Aegean back-arc experienced ~50km extension in early Miocene resulting in detachments. At this time, the Turkey Menderes massif was in upper crust.

- Detachments form with parallel thrusting along a plane of décollement (or detachment) - like a rug on the floor, which slides and forms upward folds. Numerous folds, lying on top of each other (duplexes) and secondary thrusts can form.
- Nappes can also occur, these form when the root of an area is completely separated from its substratum and thrust for miles along a plane of décollement (or detachment). The beds of the nappe are often compressed, or even underthrust, below surrounding tectonic units.

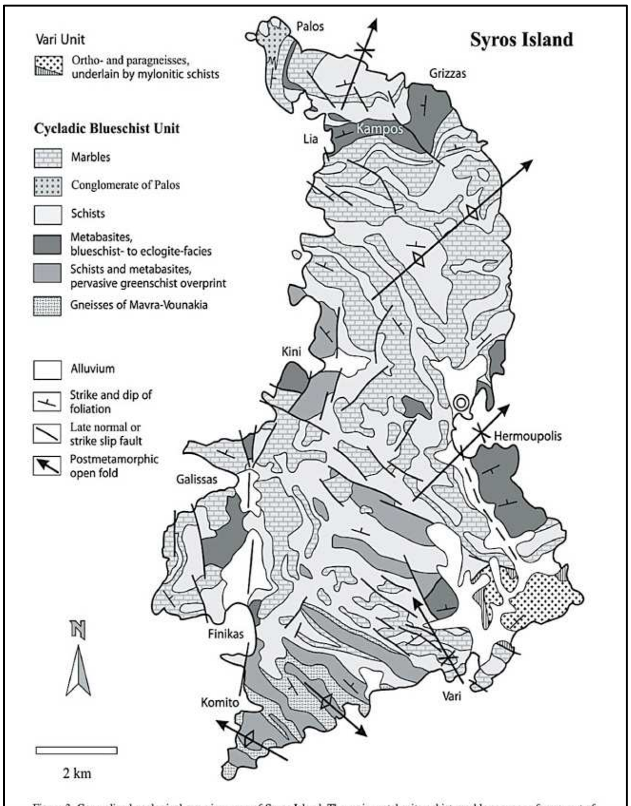


Figure 3. Generalized geological overview map of Syros Island. The main metabasite-schist-marble sequence forms part of the Cycladic Blueschist Unit; the Vari Unit, part of the allochthonous Upper Unit, is confined to the southeast of the island.

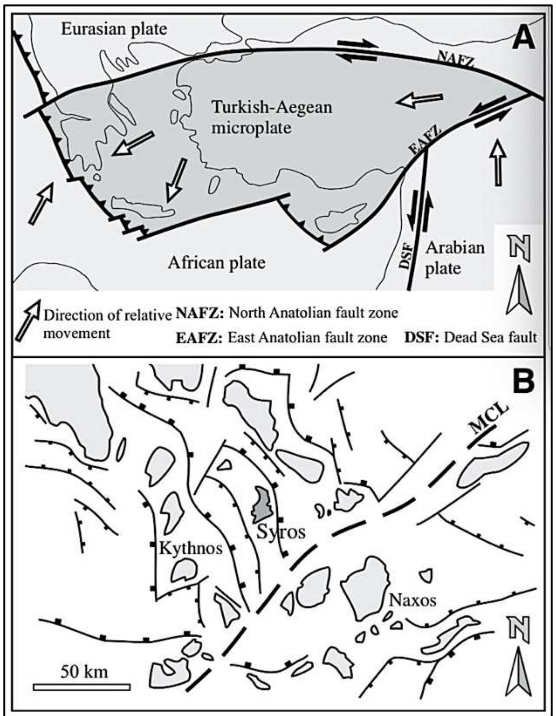


Figure 2. (A) Present-day plate tectonic situation in the eastern Mediterranean. Simplified after McKenzie (1970) and Walcott and White (1998). Position of the Hellenic trench after Le Pichon and Angelier (1979). Arrows mark the directions of movement relative to a fixed Eurasia. (B) Offshore fault pattern in the Cyclades after Walcott and White (1998) and references therein. The mid-Cycladic lineament (MCL) separates domains of postmetamorphic rotation; with clockwise rotation in the northwest, and anticlockwise rotation southeast of the MCL, respectively.

Fig. 7, above: Geology of Syros
Fig. 8, to Right: Modern tectonics in E Mediterranean.
Figures from Keiter et. al.

Syros and the blueschist-eclogite facies - The Island of Syros (Figure 7) has exceptionally well preserved blueschist- to eclogite-facies metamorphic lithologies, showing highly variable lithological assemblages, as well as a complex structural evolution. The Cycladic Blueschist Unit on Syros, includes meta-ophiolites and meta-sediments, which can retain primary depositional features. The structural evolution of the Cycladic Blueschist Unit comprises multiphase isoclinal folding and ductile thrusting, regarded as essentially burial related and terminating close to peak metamorphic conditions. The origin of the metamorphic facies of ophiolites-blueschists-eclogites is discussed below.

There is also **retrograde evolution**, this was accompanied by variously distributed, weakly developed extensional tectonics and episodic, contractional deformation, followed by intense brittle transpressional and transtensional tectonics, disrupting the rock sequence since Miocene. *(Transpression & transtension has lateral pressure as well as normal compression or tension).*

The mid-Cycladic lineament (MCL) separates domains of postmetamorphic rotation; with clockwise rotation in the NW, and anticlockwise rotation SE of the MCL, respectively (Figure 8).

The Cyclades islands have **huge mineral wealth** which has been exploited for millennia. Notably Milos from which there was the early transport of 'flint' (actually obsidian) to all Aegean and today still export barytes, clays (perlite, bentonite, Ca- reacting pozolani). The other economic minerals and rocks include Fe, Mn, Cr, Ag, Pb, Zn, asbestos, corundum, marbles, granite and bauxite.

4. Volcanic Arc along the subduction zone

Volcanism has been dominant since early Miocene, 21.5Ma ago. **Milos** and surrounding islands are dominated by volcanic rocks from ~4Ma ago with the eruption of tuffs and lavas and recently by phreatic explosions. In Paleolithic to Neolithic times, natural volcanic glass obsidian was used. More recently, the volcanic clays (perlite and bentonite) have been exploited.

Aegini & Methana - Volcanism started in Pliocene (4.4Ma ago) - rhyodacitic ashes and pumice. The stratovolcano grew with andesite-dacite flows, plugs & volcanoclastic flows until 2Ma ago. Latterly cones with minor amounts of pyroclastics & basaltic andesites have occurred. There is a subcrop of Permian to Up. Cretaceous limestones, covered by flysch and ophiolities. **Kos Island** has warm springs of Therma with beneficial minerals for well-being relaxation and stress-relief.

The current or **recent volcanic activity** comes from a modern volcanic arc. **Nisyros** – in 1888 the volcano erupted with a 4-km long caldera with 5 small craters in centre. It is supposedly the best preserved hydrothermal crater, and recent phreatic explosion craters now release sulphuric fumes.

Santorini Volcano (Island of Thera) - The most famous and spectacular volcano in the Aegean was built on a foundation of marble and schist, now exposed on the hills around Ancient town of Thera. Volcanism started 1.5Ma ago in the S part of the island, but the main phase only dates from 200Ka ago. There have been many major eruptions, which are exemplified by the Minoan eruption. This started with the rapid eruption of 333km^3 of volcanic ash, which buried a Bronze Age town in the S part of the island near Akrotiri. The volcanic summit then collapsed, leading to the formation of a caldera that now makes up the N part of the Bay of Thera. Construction of a new volcano started shortly afterward with the eruption of lavas in the centre of the bay. Volcanic activity continues on the Kameni Islands, which last erupted in 1950. The Colombo Bank underwater volcano, located only 10km NE of Thera, erupted in 1650. It will probably make a new volcanic island in a few thousand years.

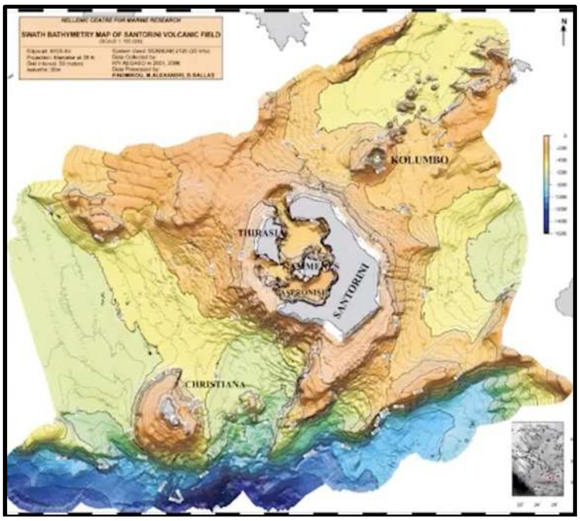
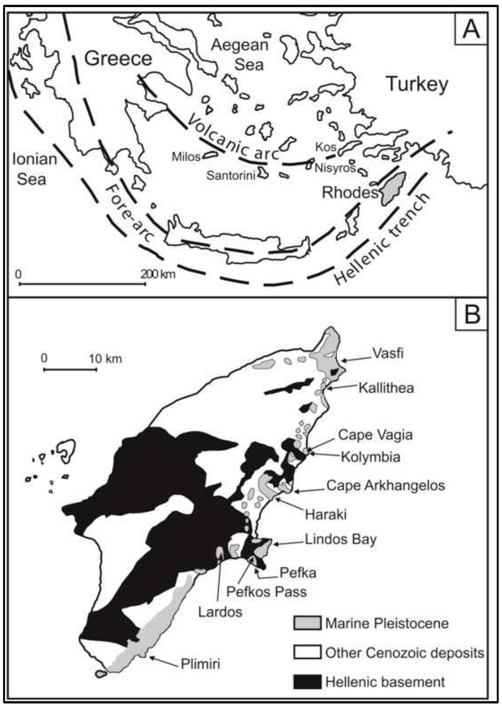


Fig. 9a: Map of the Island of Thera and the volcanic caldera of Santorini.

http://mem.lyellcollection.org/content/19/1/NP.2 & Scientific Reports

Fig. 9b: The caldera walls of Santorini volcano. From Higgins, M, 2009

5. Ionian & S Dodecanese islands, Rhodes & Crete – fore-arc with thrusts & detachments.



The **Ionian islands** lie to the E of the N part of the subduction zone and the W coast of Corfu drops sharply 1000m to the sea floor. The oldest rocks are hard, grey Triassic to Jurassic limestones. The S Ionian islands have younger limestones, cut by many faults and frequently experience earthquakes. Gypsum, which formed when Mediterranean almost completely dried up 6Ma ago, occurs in these islands. There are also natural pools of bitumen (pitch) but no significant oil deposits.

The **Dodecanese Islands** are part of the external Hellenides form an elongate arc located on the Aegean Arc front, extending from Epirus to the Dodecanese islands comprising alpine rocks in various nappes.

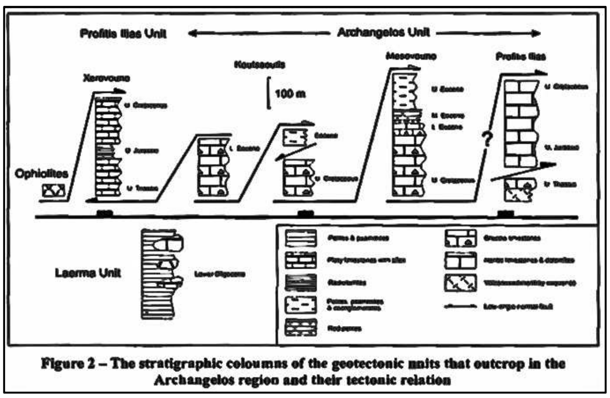
The Alpine nappes can be traced from NW to SE through Epirus, Mainland Greece, Peloponnesus and Crete, but cannot be traced through the Dodecanese, due to limited outcrop; to significant stratigraphic variations within the units; and to post-alpine deformation (with Neogene basins of thick clastics). Correlations & stratigraphic/tectonic units within the islands have been proposed to equate to units in Rhodes, Crete, Mainland Greece, SW Turkey, Taurides, and Asia Minor.

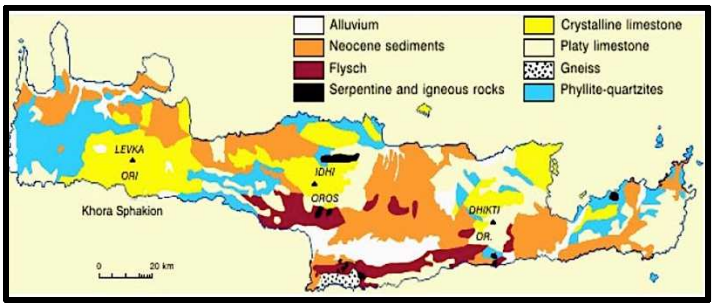
Rhodes (Figure 10 above) has good outcrops of alpine rocks with 6 tectonic units - thrusts and nappes which correlate to units of the External Hellenides, seen in Crete, mainland Greece and SW Turkey.

The rocks vary from pelagic sediments (thin platy limestones, cherts, reddish marls & radiolarites) of Up. Triassic to Up. Cretaceous age; to limestones (Up Triassic-Lo Eocene); and to flysch units (Mid-Up Eocene). The uppermost nappe comprises ophiolites of Up. Cretaceous age & correlate to ophiolites in SW Turkey.

At ~15Ma ago, tectonic activity uplifted the whole region, but between 4-3Ma ago, the land sank and left just the mountaintops above water.

Crete formed as the African plate subducted beneath the Aegean. The plate boundary is immediately to the S, which accounts for the frequency of earthquakes. The lowest rocks are partly recrystallized limestones (250-210 Ma old); limestones of a similar age are thrust along horizontal faults over them. About 12 Ma ago, subduction started to the S and, in response, the Aegean sea to the N expanded. Crete was faulted into many blocks, which moved independently. Some blocks became the mountains, whereas others dropped down, leaving troughs that filled with sedimentary rocks.



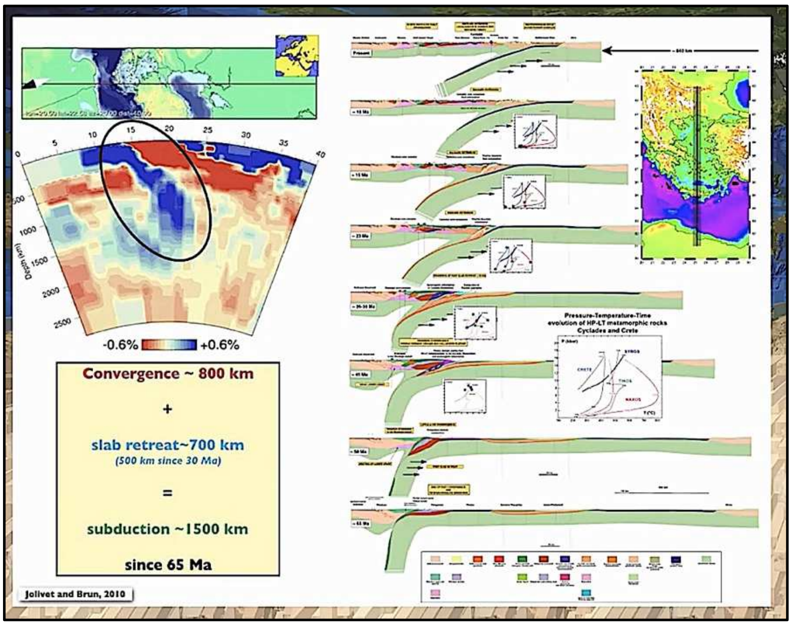


Left - Fig. 11: Succession of detachments in Rhodes, from Lefkas et.al.
Top - Fig. 12: Geological map of Crete from Cretan Beaches.com

Earthquakes have been common and continue today: The harbour at Phalasarna was uplifted 7m, probably during a single earthquake in the 5th century.

Comparison with Rhodes, shows there are at least 7 types of similar units in Crete, the largest number in Greece, including ophiolites. In Turkey & Taurides, the Alpine chain includes continental, slope-basin, oceanic units & ophiolites in three belts - as nappes and overthrusting as a whole entity over the underlying platform units from Up Cretaceous onwards.

Figures 13 & 14 are from European Geoscience Union (EGU), Geoscience Information for Teachers (GIFT) Workshop, The Mediterranean. Faccenna, Claudio, et. al. Shaping the Mediterranean from the Inside Out; and Jolivet., L., et. al. Tectonics of the Mediterranean Sea and Subduction of the African Plate; from basins to mountains, from mountains to basins .



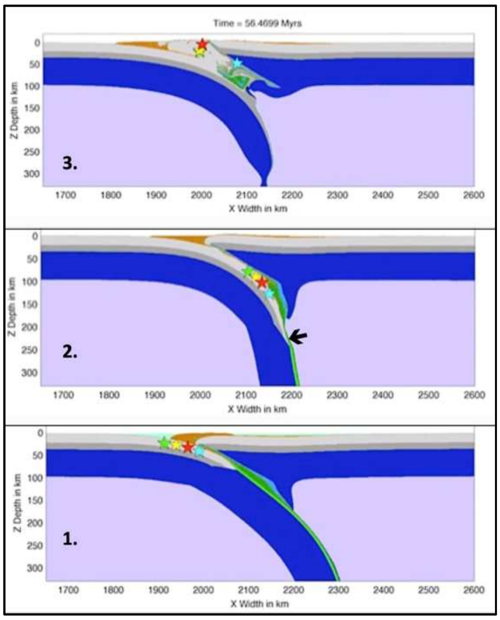


Fig. 13: Left is North (Aegean Plate) & Right is South (Africa Plate); Africa (brown blob on far R of plate) gradually moves towards the left Seismic tomography shows the plate to go down to 1500m and then come back up 700m. All of this over last 65Ma

Fig. 14: African oceanic plate subducts below Aegean plate with accretionary wedge sediments. Ultra-high pressure metamorphism creates blueschists; the slab retreats with mantle xenoliths (eclogites).

Subduction History and Slab Retreat

The theory of slab retreat (Figure 14) for the Aegean is that the African plate subducts below the Aegean Plate taking with it the sediments formed in & around the trench (an accretionary wedge) and in places ophiolites which may have been obducted onto the top of the trench/sedimentary wedge.

Subduction takes this mixture of sediments and ophiolites deep down into the mantle and the plate melts sufficiently that part detaches and allows the upper section to retreat back up the subduction zone, this may be assisted by regional extension.

As the slab retreats back up, it brings the ophiolites (sometimes metamorphosed) the sediments (now with blue glaucophane rather than green hornbende, i.e. blueschists) and 'xenoliths' of mantle - eclogite (garnet-olivine rock).

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Images (in addition to citations above)

- **Aegean Plate**: Alataristarion - https://commons.wikimedia.org/wiki/File:Tectonic_plates_boundaries_detailed-en.svg
- **African (N):** Alataristarion - https://commons.wikimedia.org/wiki/File:Tectonic_plates_boundaries_detailed-en.svg
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- **Rhodes,** https://earthobservatory.nasa.gov/images/77079/rhodes-greece

Ancient cholesterol in Dickinsonia, Ediacarian Fossil
The Geological Society of America and reported in an article in Science News, 21 September, 2018


Dickinsonia with rib-like segments

Near the shore of the White Sea in Russia, a Dickensonia fossil has been found. 'If Dickinsonia was an animal it may have been a very odd one' apparently (according to the discoverers Nicole Law & Scott McKenzie of Mercyhurst University, Pennsylvania). Dickinsonia lived 558Ma ago years ago, in the Ediacaran period, 3-40Ma before the 'Cambrian explosion'. Fossils were first discovered in Australia 75 years ago, ranging in size from 1cm up to 140cm and had been described as animals, fungi, lichen and jellyfish. Dickinsonia is a large genus which includes 2000 species.

Little is known about the creature which may not have a mouth and it is thought that it was a seabed grazer, absorbing matter through the skin from the algal mat on which it was found.. It is just few mm thick as a fossil, but was probably longer, wider and taller in life – having probably shrunk when dead.

The new find was so well preserved, some organic matter was still intact. This enabled analysis which showed the presence of fat which proved to be cholesterol, which is specific to animals. The fat molecules in this specimen prove that animals were large and abundant in the Neoproterozoic.

Noted by Judith Wilson and John Stanley, FGS Members