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Samos Island, Part II: Ancient history of the Samos fossils and the record of earthquakes

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Abstract: This second part of our field trip guide deals with the Miocene fossils found near Mytilini. Those fossils have already been interpreted by some of the Greek philosophers and are the main reason why Samos is a famous island for Earth Scientists.

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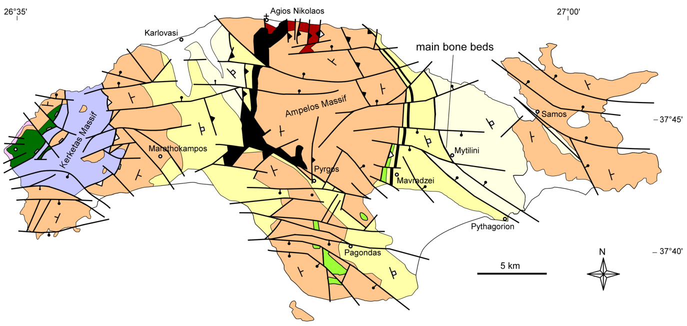
Historical and Mythological Views

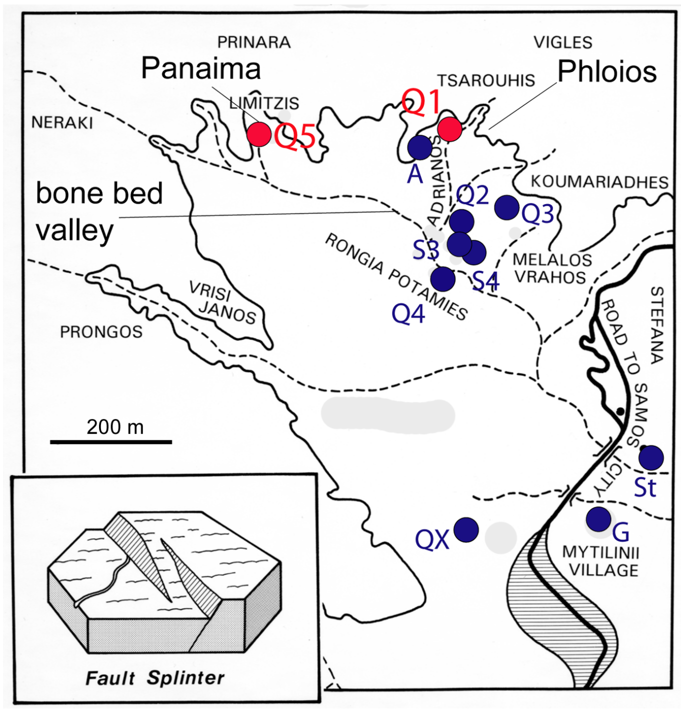
Samos is a famous place for palaeontology. Most of the fossils are found in the Mytilini basin N of the village Mytilini and E of the Ampelos massif (Figs 1 and 2). Numerous fossils of mammals have primarily been found on Samos but there are other groups of animals and plants. A cartoon of the species is presented as the Samos family portrait (Fig. 3). The cartoon shows the species reconstructed in a simple manner. Many scientific excavations and studies have been conducted on Samos fossils. In addition, Mayor (2000) has shown that ancient people were aware of the presence of fossils in various locations and often correctly interpreted them. Myths and legends were used as explanations of the fossils. Fossils were dragons, sea monsters or Cyclops. The ancient Greeks had written two myths trying to interpret the Samos fossils and the occurrence of earthquakes at Samos. Solounias and Mayor (2004) have expanded on these ancient myths and their interpretations and a summary is given here.

Figure 1. Map showing outcrops of bone beds.



Map showing outcrops of bone beds NNW of Mytilini in upper series of graben fill.

Figure 2. Detailed map showing bone bed valley NNW of Mytilini.



Dashed lines are creek valleys; major excavations sites are near Panaima (quarry Q1) and Phloios (quarry Q5); other quarries are indicated in blue.

Figure 3. Samos family portrait.

Imaginary cartoon of species in so-called Samos family portrait.

In about 200 BC, a Greek geographer named Euphorion wrote about monsters called the Neades. His works are now lost, but the natural historian Aelian (3rd century AD) quoted him: ‘Euphorion says in his memoirs that during the very very old times, Samos became deserted; deserted due to very large and fierce beasts which appeared on it [on

Samos], they caused sufferings and were called Neades, and their mere roar could fracture the earth; thus there is a proverb on Samos "to scream louder than the Neades". The same writer [Euphorion] says that their big bones for years are now displayed.

Comments and interpretations

Euphorion says in his memoirs that …during the very old times. This indicates a definite sense of the great antiquity, which implies indirectly the antiquity of the fossils. Neades: Their mere roar could fracture the earth. The mere roar or their strong sound would fracture the earth is interpreted as earthquakes and which were thought to be caused by the fossils (the Neades). The same writer [Euphorion] says that their big bones for years are now displayed. Displayed means exhibited (same word in Greek) suggesting a public display of the bones. We emphasize that the meaning is directly about the bones on display and not a meaning of the bones found in the countryside. The remains of the Neades were displayed as in a museum or a shrine. This agrees with the original concept of a museum as a place where curious things are kept. "Museum" in Greek means the place of the muses. In 1988, German archaeologists discovered a large fossil thighbone of an extinct animal that had been placed by the ancient altar of the Temple of Hera (Heraion or Ireon) on Samos sometime during or before the 7th century BC (Kyrieleis 1988). Ireon was an important temple of its day and maintained, in addition to the ceremonial grounds, an extensive collection of natural wonders and exotic animals. Their mere roar could fracture the earth. It is clear that the strange animals were believed to cause earthquakes. The bones are found at a major fault zone and we assume that the Greeks made the connection between earthquakes and fractures on the ground. Thus, faults were recognized and related to earthquakes. To scream louder than the Neades. The proverb seems to refer to vivid memories of the roar that accompanied an earthquake.

Plutarch, in his Greek Questions (~100 AD) addressed the question: What is the reason that on Samos there is a region called Panaima [all bloody place or bloodbath]? The answer is the Amazons, fleeing from Dionysus, fell [or were trapped] on Samos [fleeing] from the land of the people of Ephesos. Dionysus constructed ships, passed [from the mainland to Samos] and fought the Amazons, killing most of them, in various locations [on Samos]. Such a vast amount of blood spilled that people who noticed the red-stained earth called the place by the name Panaima. Some of the ϕ [letter phi changed later to elephants] died near the place called Phloios and their bones can still be seen there. Some say that they fractured Phloios because of their prodigious bellowing.

Comments and interpretations

Panaima in Greek means 'all bloody place' or 'bloodbath'. This is clearly due to the colour of the ground after a battle. There are other grounds where the red colour has been used in folklore to mean blood and some type of sacrifice. Most of the bones at Samos are beige, and the sediments beige-white. There is however a notable exception. There is a small area, which contains many beige-coloured bones, where the sediment is notably reddish. Figure 1 shows the red sediment near a fossil locality (Limitzis District). The red sediment sharply contrasts with the surrounding prevalent beige-white sediments. We suggest that Panaima was a true geographic landmark there in ancient times (Solounias and Mayor 2004). A 17th century map of Samos (copper engraving), popularly sold on Samos to tourists, also shows the word "Guerrari" at the place of the bone beds. In Latin this means 'the place where the battles have taken place'. Various crusaders and Venetians were stopping in most of the Greek islands. It may be possible that Panaima was transformed to Guerrari (perhaps a renaming in Latin of Panaima); a renaming emphasizing the battle aspect which would result in a bloodbath. The answer is the Amazons, fleeing from Dionysus, fell [or were trapped] on Samos [fleeing] from the land of the people of Ephesos. Dionysus constructed ships that passed [from the Turkish mainland to Samos] and fought the Amazons, killing most of them, in various locations [on Samos]. That the text says in various locations is interpreted to mean various locations of bones. There are at least 15 bone beds on Samos and this early citation is in agreement with this fact. Such a vast amount of blood spilled that people who noticed the red-stained earth called the place by the name Panaima. Some say that they fractured Phloios because of their bellowing. The bellowing of the Amazons or the elephants fractured the thick crust.

Amazons: Ancient commentators interpreted that the fossils at Panaima or Phloios as those of fallen [warrior] Amazons. Interestingly, Amazons were mythical horse-riding warriors. It is possible that the ancients recognized the fossil Hippotherium-Hipparion skulls (most abundant fossil on Samos) as a horse and related this observation to the Amazons who were horse-riding warriors. In antiquity, as in modern Greece, people would have been familiar with the appearance of the basic skeletons of dead, domesticated animals. Horses have characteristic teeth and ancients would most certainly recognize such teeth from observation. We suggest that the identification of Amazons could be related to the recognition of fossil hipparions as horses ridden by the Amazons in battle (Solounias and Mayor 2004).

Phloios, presented hints as to its geographic location: some of the elephants died near a place called Phloios – near indicates that the bones were not on or at Phloios, but close to that place. We identify Phloios as the big block of faulted limestone next to Brown's quarry Q1 (Figs. 2 and 4). The limestone is a local landmark and is the only prominent feature near a fossil bone deposit at Q1. The limestone block forms a prominent high cliff and its face is the fault surface (Fig. 5). Phloios is about 30 m high, measuring from the Adrianos ravine and the bone bed to the topographic top. The width of that rock face is about 80 m. The current local name of the Phloios region is Tsarouhis. This is a modern Greek word meaning 'thick sole'. Tsarcuchia are characteristic Greek farmer shoes in the 18th and 19th century, with very thick leather soles studded with horseshoe nails. It is possible that the massive limestone block Phloios was renamed Tsarouhis in more recent times. There is a chain of additional limestone blocks in the area and two of the prominent ones have names. The prominent limestones of the region are part of the Kokkarion Formation and make up the footwalls of several faults. The next visible rock south of Phloios is Megalos Vrahos ('Big Rock' in Greek). Brown's quarry Q3 was located below Megalos Vrahos. One block of limestone further southeast is called Stefana ('wreath' in Greek). The limestone cap of the hill resembles a wreath. Forsyth Major excavated below Stefana Hill and the fossils are stored in the University of Lausanne, Switzerland. Since Tsarouhis, Megalos Vrahos, and Stefana are named today, it makes sense that the ancients named prominent rock outcrops.

Figure 4. Outcrop of red sediments

Outcrop of red sediments near quarry Q1 at Panaima near Limitzis; Panaima means 'bloodbath'; the ancient Greeks interpreted the red sediment surrounding the fossil sites as stained by blood from battles.

Figure 5. Photographs of outcrop at fossil site.

Outcrop photographs at Q1 fossil site near Tsarouhs; massive limestone has been interpreted by Plutarch as thick crust covering fossil site; note slickensided fault scarps in limestone.

Earthquakes: Some say that they fractured Phloios because of their prodigious bellowing. Here again we have the recognition that a fracture formed in Phloios during an earthquake and the noise associated with earthquakes is interpreted as bellowing. It is possible that such a major earthquake took place on that fault forming the high limestone block and ancient locals witnessed it and related it to the fossil bones nearby. We see the fracture as an earthquake caused by the Amazons or elephants. There is a major normal fault next to Phloios and to quarry Q1.

Adrianos: A geographic name with significance in Roman history. Adrianos is one of the few named gullies and ravines in Greece. It is especially rare that a specific proper foreign name was used and for a very small stream (1 km long and 1 m wide having water only part of the year). Consequently, the use of such a foreign name becomes even more interesting. Adrianos is a rather specific proper Latin name; so it is interesting that the ravine with the fossils has this name in a remote and poorly inhabited region. The name of the Roman Emperor Hadrian (Hadrianus in Latin) is Adrianos in Greek instead of Hadrianos. Hadrian was in Athens and visited several places in Greece. The well known Arc of Hadrian located in Athens is known as Pili of Adrianos (same spelling as the Samos ravine). Hadrian was interested in natural history and he visited Athens and Troy among other places. Hadrian (76-138 AD) sailed across the Aegean to reach Troy, which is 200 kilometers north of Samos on the Turkish mainland. The trip probably utilized the frequently fished and sailed eastern Aegean corridor of the coastline (Lydia and Ionia) and the islands of Lesbos, Chios, Samos, Ikaria and Kos. In Troy, he visited a fossil bed with huge bones, which he interpreted as bones of the Greek warrior Ajax from the Trojan War. He established a shrine for these bones. There is also literary evidence that Hadrian went to Egypt to see fossils, probably at Wadi Natrum S of Alexandria, and that he kept natural curios in his archives. Although there is no direct proof that Hadrian visited Samos, it is very likely that he would have paid a visit to the island, a well-known stop for Roman travelers on their way to Asia Minor – where big cities such as Miletos and Ephesos were located a few kilometers from Samos City. He may have collected bones near Phloios. As Emperor, he may have named the area after himself, a typical indication of power and Roman renaming. In support of the proposed visit, we know that other emperors visited Samos. For example, Marc Anthony (83-30 BC) and Tiberius (42 BC-37 AD) visited Samos probably because of the large and celebrated Temple of Hera near Ireon. In it fossil bones were probably displayed, such as the femur of a giraffid (Samotherium), which was discovered near the ceremonial altar of the Temple of Heraion. Augustus (63 BC-14 AD), Tiberius, and Hadrian all had a strong interest in unusual natural objects and phenomena; Augustus displayed so-called giants' bones in Capri and Rome, and Tiberius received a giant tooth from the Black Sea area after an earthquake. It is possible that these emperors went to Samos to collect fossil bones (Solounias and Mayor 2004).

In summary: The ancient Greeks interpreted these fossils as the remains of Neades, strange exotic beasts, or of the Amazons who perished in battle. Some of the fossils have been found in the ruins of the Temple of Heraion where they had been gathered for display. The red soil in which the fossils were found was explained as from blood spilled during a bloodbath. Furthermore, the Greeks had correlated geologic faults to earthquakes. The myths clearly state that they also had a sense of deep time (the great antiquity of the fossils). They named two bone beds because of the fossils: Panaima and Phloios. These are proper names given in upper case letters in the myths. In Greek, Panaima means bloodbath and Phloios means thick and hard crust. Phloios is located in a ravine named Adrianos, which is a non-Greek name. Small ravines rarely have names in Greece and we explain the name as the renaming of Phloios by the Roman emperor Hadrian. Hadrian is known to have collected fossils near Troy and may have visited Samos.

The Palaeontological Excavations on Samos: a historical perspective

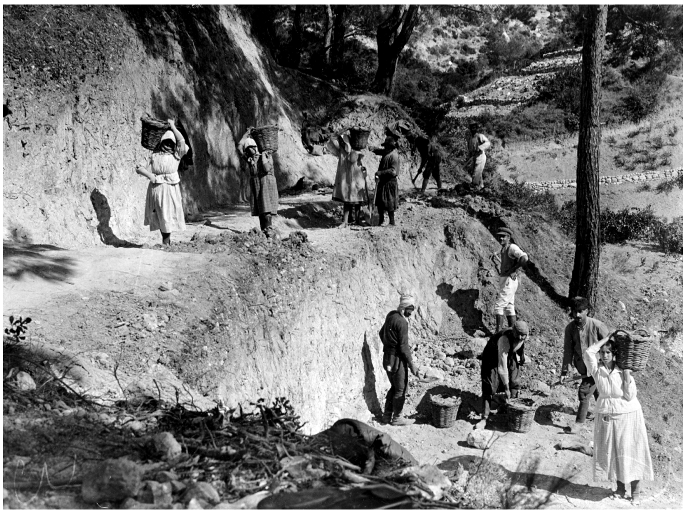
The fossils were discovered and extensively studied in the early part of the 19th century. Many excavations have taken place on Samos Island and fossils have been brought to collections of various natural history museums in the cities of Berkeley, Chicago, New York, New Haven, Cambridge, Washington (all USA), London (England), Frankfurt, Darmstadt, Hamburg, München, Berlin (all Germany), Lausanne, Basel, Geneva (all Switzerland), Vienna (Austria), Budapest (Hungary), Padova (Italy), Athens and

Mytilini on Samos. The 84 mammalian species are well-preserved and most are almost known from skulls. The fossils were found in about 12 bone horizons.

Before 1852 travelers brought fossils from Samos to the University of Padova. This collection which is still in Padova was forgotten. The Samos fossils were rediscovered by Charles Immanuel Forsyth Major in 1887. He claimed to have used the two ancient myths a suggestive indication that there were fossils on Samos. Major was part of an expedition of natural history to the Aegean Archipelago which was funded by the family Barbey-Boissier (hence the giraffid Samotherium boissieri in honor of Madame Boissier). Major deposited most of the collection in the Geological Museum of Lausanne. This collection has now moved to the University of Lausanne. Some bones were also given to the museum of Geneva and Basel by Major. Major excavated on Samos twice; the first excavation was in 1887, the second in 1889.

T. Stützel and A. Hentschel collected for the museum in München from 1897 to 1902. The antelope fossils housed in München were described by Schlosser (1904) and the giraffes were described by Schlosser (1921) and Bohlin (1926). The collections in Frankfurt, Darmstadt and Hamburg are particularly extensive and interesting. Many of the Vienna specimens have receipts from Karl Acker. Acker was an ambassador of Austria on Samos when Samos was an independent country. Acker was also a wine merchant. He knew that the value increased by the completeness of the fossil and he collected and prepared carefully. Acker's specimens have exquisite preservation. The last major collection was made by Barnum Brown for the American Museum of Natural History (AMNH) during 1921-1924 and Brown was a professional excavator. The AMNH fossils from Samos are well prepared. Brown opened at least seven quarries (Q1 to Q6 and QX, Fig. 1) whose numbers have nothing to do with age or stratigraphy. Brown concentrated on the fossil bones of Q1 (Brown 1927) (Fig. 6). While on Samos, he was accompanied by his wife Lillian who even wrote a book about their excavations and life on Samos (Brown, L. 1951: Cleopatra slept here. Dodd-Mead Press, New York). After the completion of the excavations in 1924, Brown had difficulty bringing the collection to the American Museum of Natural History in New York because Greek palaeontologists tried to prevent him from exporting the fossils. However, after some type of official court case Brown was eventually allowed to take the entire collection to the US. This was achieved by the influence of an American, Maria Tsipouras, who was married to a Greek who was high up in the army hierarchy in Greece. In a letter Brown mentioned a sizable collection from a private collector which he was contemplating in purchasing. Certain specimens at the AMNH without locality data may be from that collection. Sixty crates of fossils were shipped by Brown to New York.

Figure 6. The 1921 excavation



Photograph of 1921 excavation at Q1.

After 1924, the excavations continued by K. Acker in 1935. J. Melentis in 1963, excavated primarily at Q1 (Melentis 1968). He incorporated his finds to other finds in the possession of Stelios Ligizos, a pharmacist. Solounias in 1976 was the only one who excavated for small mammals. They were found in locality S3. The small mammal material is at Carnegie in Pittsburg and in University of Colorado Museum in Boulder (Black et al. 1980). Besides the Lausanne and the New York collections, no stratigraphic or locality data exist for any other museum collection. More recently, Dimitrios Kostopoulos, George Koufos and other scientists have been excavating various localities from 1990-2006 (Kostopoulos et al. 2003). For example they have collected bones from Q1 and S4 (Koufos et al. 1997).

Published Works on the Samos Fossils

There are over 200 publications, which deal directly or indirectly with species from Samos. Major (1888, 1892) reports on the discovery and first species lists; Solounias (1981a) and Bernor et al. (1996) published reviews of the fauna; Black et al. (1980) on the rodents; Werdelin and

Solounias (1990) on the hyaenids; Schlessiger (1922) on the probosicdeans; Weber (1904, 1905) and Heissig (1975) on the rhinoceroses; Sondaar (1971) on the hipparions; Bohlin (1926), Hamilton (1978), Geraads (1977, 1979, 1986), and Solounias et al. (1988) on the giraffids; Schlosser (1904), Andree (1926), Gentry (1971), and Solounias (1981a) on the bovids. The mammal species sampled at Samos include 1 species of a bat, 5 species of rodents, among the carnivores, one remotely similar to pandas, 2 bears, 2 mustelids, 7 hyenas of various sizes, 1 felid and 3 sabertooths, 1 aardvark, 3 mastodons, 1 dinothere, 2 hyraxes, 6 species of three toed horses (hipparions or hippotheria), one chalicothere, 5 rhinoceroses, 2 suids, 1 tragulid, 1 muntjac, 1 deer, 6 species of giraffids (some similar to the living okapi, some unique, and one similar to the living giraffe) and approximately 30 species of bovids (antelopes) (Solounias 1981a, b; Bernor et al. 1996).

The Mytilini Basin

The subdivisions of the Mytilini basin are described in some detail from bottom to top (note that formation names do NOT agree with the location of the namesake villages as Hora is built on Pythagorion Formation, Mytilini on Hora Formation and Kokkarion on Mytilini Formation; note also that we describe some localities in detail and those localities might be visited in the course of an excursion to Samos Island). Our description largely follows Weidmann et al. (1984).

(1) The Basal Conglomerate Formation restricted to the western part of the basin is made up by reddish conglomerates and locally mudstones. The type section is a road cut between Mavradzei and Mytilini in the Kazani district. The contact to the basement is either a fault or an angular unconformity. Some of the boulders above this unconformity reach a size of ~1 m3 indicating that the local relief resulting from mid-Miocene extensional deformation was pronounced. At the top of the formation are brown to yellow silts with thick palaeosoils, the latter of which are commonly incised by channel deposits. The Basal Conglomerate Formation is not dated but has been assigned a Serravallian age (Weidmann et al. 1984).

(2) The Pythagorion Formation is mostly thick-bedded limestone with layers of grey to black mudstone and lignitic horizons. The limestone contains fresh-water gastropods, stromatolites and onkolites. Dessication cracks and wave ripples are common indicating very shallow water levels. Rare clastic horizons contain tuffaceous sands, silts and conglomerate layers containing basement clasts. The Pythagorion Formation is best exposed near Mavradzei and at its type section on the Spilani Hill E of Pythagorion. To the west, the thick-bedded limestone interfingers with bituminous limestone (locally referred to as the Mavradzei beds). They are well exposed in the road cut S of Mavradzei and contain a rich fauna of freshwater molluscs, charophytes, phragmites, grey-green lignitic clays and 1-2 cm thick lignite beds. Because the exposed sediments are extensively oxidized it is impossible to recognize the fine lignitic beds anymore. Burrows and desiccation cracks are common. At the top of the Pythagorion Formation occurs the Basalt and Tuff Member (Weidmann et al. 1984), whose type section is the road cut from Pagondas to Spatherei. The top of the thick-bedded limestone is overlain there by a 3-8 m thick basalt flow. The basalt flow is overlain by beige to light grey lahar tuffs, which may reach 50 m and can be followed to the E as far as Hora, where they only measure 1-2 m. Sedimentary structures indicate a fluvial deposition of the tuff. Within the Pythagorion Formation near Pagondas there is a basaltic sill dated by the 40Ar-39Ar method at 11.2 Ma (see previous paper, Fig. 3), a lahar tuff yielded 10.9-10.8 Ma (Weidmann et al. 1984).

(3) The base of the Hora Formation contains thinly bedded fresh water limestones, which frequently contain cherts and 1-2 m thick beds of white, chalky pure limestone. Fresh-water molluscs and stromatolites occur. Above that sequence follow thin-bedded limestones and marls. In turn above follow yellow-green marls with subordinate lime-rich or siliceous shale. The marls contain frequent slump structures similar to those described at stop #2.7. The slump structures included meter-scale disharmonic folds and breccias of unsorted limestone fragments in a shale matrix. Gastropods, ostracods, diatoms and plant debris are common throughout the sequence. On top of the Hora Formation follow thinly-bedded limestones. 40Ar-39Ar dating of a tuffaceous turbidite ~1.7 km W of Mytilini yielded an age of 9.0 Ma (Weidmann et al. 1984). All three so far described formations are folded and affected by reverse faults of the D4 deformation (Ring et al. 1999a).

(4) Above the Hora Formation is the Mytilini Formation which contains all the known mammalian fossils. In the northwestern parts of the Mytilini basin the Mytilini Formation is a few metres thick and undifferentiated. The Mytilini Formation reaches its maximum thickness of up to ~200 m 2-3 km NNW of the village of Mytilini. There, several horizons can be distinguished: (a) The Old Mill

Beds within which two bone beds have been identified: quarries QX and G at Smakia. The Old Mill Beds are a 15-80 m thick sequence of sands, silts, marls and water lain tuffs (grey or tan-reddish). A few layers of massive, gravelly tuffs contain channels with rounded basement clasts capped by palaeosoils. The age of the Old Mill Beds is 8.6-8.0 Ma (Weidmann et al. 1984). (b) The Gravel Beds above the Old Mill Beds contain numerous gravels and sandy marls and are of variable thickness. Channel fills are deep (up to ~5 m) and have little lateral extend. They are interpreted as deposits of immature rivers. The clasts are mainly from the basement but also from the Pythagorion and Hora formations. (c) The White Beds are silty or chalky lacustrine limestones and their exposure is limited to the Rongia and Potamis districts. Beds of poorly sorted limestone breccia occur and occasionally reach 8-15 m in thickness and suggest a marked palaeorelief. These breccias commonly constitute small hill tops or ridges. The White Beds contain fresh-water gastropods and one bone bed (Q4) at its very top. (d) The Main Bone Beds, above the White Beds, contain most of the fossil horizons, mainly near the base and near the top of the beds. The Main Bone Beds itself are tuffaceous marls, silts, sands and mudstones sprinkled with small gravels and reach 60-110 m in thickness. Palaeosoils are common and also may contain bones. Many of the gravels in the Main Bone Bed contain pebbles of the Hora Formation and the basement of the Ampelos nappe. The lowest bone bed is Q4 situated at the uppermost part of the White Beds. The next sequences are Q2, S3, S4 and S6. (4b) Above the Mytilini Formation are the Marker Tuffs containing bone bed L in thick-bedded marl. The quality of bone preservation suggests rapid burial and minimum transport. Radiometric dating indicates an age of 7.6-6.9 Ma for the Main Bone Beds and 6.7-6.5 for the Marker Tuffs above them (Weidmann et al. 1984).

(5) Above the Mytilini Formation, and locally interfingering with it, is the Kokkarion Formation. Thick-bedded and porous limestone containing abundant oncolites, stromatolites and fresh-water gastropods are most common. The Kokkarion Formation was deposited in lakes encroaching from the southeast. Its top is an erosional surface.

The Mytilini and Kokkarion formations show no do not show any sign of contractional deformation indicating that Samos Island is undergoing wholesale extension since 8.6 Ma.

The Fossils

Seventy eight species of mammals and 18 species of reptiles, birds and snails have been discovered on Samos. The majority of the fossils were found clustered in nine small regions (a few meters each) which have been termed bone beds or bone horizons. Within a bone bed, the animal bones were all mixed together and piled on top of each other. We know this from other bone beds found elsewhere on Earth (Bernor et al. 1996). Thousands of bones were also found at Pikermi (Miocene near Athens). In the Natural History Museum of London there are two blocks where jumbled bones were left intact. No pictures were ever taken of the fossils in situ during the numerous excavations on Samos. There are however a few unprepared blocks of bone masses. For example, block Y at the American Museum of Natural History, and two smaller blocks in Lausanne show a mass of jumbled bones. The pattern is similar to other bone beds from other regions of the world. Often a hippotherium (fossil horse) jaw will be open and a long bone of a giraffe limb will be passing through the jaw. Piles of long bones and ribs are all stuck together in dried mud (marl sediment). Bones of different sizes are found together. A massive deinotherium (elephant) skull (50 cm wide) will contain sediment in which a tiny bat skull (0.5 cm wide) is preserved. Tiny heel bones (astragali) are deposited next to an elephant tibia. Limbs and skulls are all packed together often so tight that museum technical preparators often had to destroy a bone to retrieve adjacent bones.

There are several scientific values of the fossils found on Samos. (1) They represent ancestors of many of the modern species and consequently they have been used to understand the evolution of modern taxa. (2) The fauna is located between three continents and has species which can be related mostly to those of central Africa (rainforest and savanna) and secondarily to those of Asia. The fauna is least similar to species from central Europe. Thus the zoogeographic value is that it enables us to better understand the Late Miocene distribution of taxa between these three continents. (3) The fauna was discovered early in the 19th century and hence many species have systematic types established from Samos specimens. The type of a species is the first, the template, which is used to name a newly discovered species. Other specimens of the same species found in other localities later, were based on types from Samos. (4) The fossils from Samos are well preserved. Most species are represented by complete skulls which is also untypical of fossil localities where fossils are fragmentary. In addition several species are known from many skulls. (5) The fauna is very rich for any standards (78 species of mammals). Modern African savanna faunas have less species of mammals than Samos although in East Africa the savannas are several hundred km2 wide. On Samos the richer faunas are sampled in an area no more than 1 km2.

How did bone beds form? One explanation is extensive and catastrophic death of taxa during droughts. This happens in Africa today where 30 or so animals cluster around a water hole. They stay there until they die. It is frequent that rains follow droughts and bones can be transported by water in small rivers. In torrential rains sheets of water can traverse the land outside river banks sweeping bones. These are termed flash or sheet floods. Subsequently, some of the bones can be washed into a low spot by floods. Bones would accumulate due to periodic droughts. Another explanation is that bones accumulating in a region where numerous animals live or pass by. Depressions in areas where animals live would enhance burial. Many of the Samos fossils are well preserved and often are skulls which are fragile. This implies rapid burial after death. Such burial would prohibit hyenas and other scavengers from destroying the bones. Burial in silt and limy marl is what is observed on Samos. Small depressions were present on the ground and probably bone beds are formed in such depressions. Evidence of the depressions can be found in quarries Q1, Q2 and Q4 where two massive layers of bone are superimposed on each other. Superposition of bone implies that a depression was persistent and a second layer of bone was deposited above the first before the depression filled up. These layers represent two primary bone accumulation events which could be separated even by thousands of years. Bones remaining on the surface have a short life span. They are either chewed up by carnivores or they form sun crack and break up.

The vegetation was rich with both forests and plains and the climate was subtropical and the forests were probably mild climate subtropical evergreen sclerophyllous (hard waxy coated leaves) (Axlerod 1975; Solounias et al. 1999). Orgetta (1979) described a scelorphyllous flora from Pikermi near Athens, which is a rich locality with many similarities to the fauna of Samos. Solounias et al. (1999) proposed a proto-savanna for Samos and Pikermi which was a precursor to modern savannas. There is a flora from Samos found below Mavradzei. The collection was made on a fresh road cut where exquisite details of layers were found. Now the surface of the road cut has oxidized preventing to see the published sedimentary details. Ioakim and Solounias (1985) sampled: Pinus, Tsuga, Taxodium, Sequoia, Quercus, Ulmus and Zelkova (which is the most abundant) near Mavradzei. They also found in less abundance: Alnus, Eucommia, Jungans and Carya – Platanaceae, Salicaceae, Cyrillaceae, Aquifoliaceae, and Nyssacaeae. Bushes of Amaratheceae-Chenopodiaceae, Graminae and Compositae were also identified. Ferns and Palmae were also present. This flora is similar to that of Pikermi and hence it was assumed that the flora changed little in the Samos region from 11 to 7 Ma (Ioakim and Solounias 1985).

The diversity of animal fossil life is unique (Solounias 1981a and 1981b; 1991; 1994). The most common fossils are mammalian ungulates (hoofed mammals). Many species are known from only 3-8 specimens. The majority of species, primarily ungulates, are known from 20 or more specimens each. For example hyena, hippotheria, rhinoceroses, the giraffid Samotherium and species of antelopes were common.

The ostriches were larger than the recent species in East Africa. There were small land tortoises and a very large one, Colossochelys, which was the size of a small car. There were small rodents and a bat similar to an Asian species. The bears were similar to modern species but were typical of Miocene bear species. There were dassies or hyraxes that were very large compared to their modern counterparts. The ant eating aardvark Orycteropus was smaller that the modern African species. The African like porcupine Hystrix was very similar to the one found on Samos. The species of pigs were a few and were basically very similar to the European wild boar (Sus). The mustelids (minks) were common and similar to modern species. The diversity of hyenas is characteristic of other Miocene localities from Asia. The hyenas are many and in various sizes. The majority are similar to modern dogs and foxes. The large hyena was a bone crusher (Adcrocuta) and was probably ancestral to the stripped and brown hyenas of Africa. The smaller species were similar to foxes and jackals (gracile) and are grouped into Hyaenotherium and Ictitherium. One species (Lycyaena) had long slender limbs like modern Chrysocyon (the maned wolf) and features resembling felids. Hyenotherium was basically like a modern coyote. The smallest hyenas were similar to civets. It is possible the modern aardwolf of Africa evolved from Ictitherium and modern brown and striped hyena from

Adcrocuta. A very small hyena was similar to modern civet cats (viverids) and was named Plioviverrops. The felids (cats) were similar to modern taxa. There was a wild cat similar to modern wild cats (Felis). In addition there was a saber-toothed cat (Machairodus) which was abundant in the Miocene. Small saber-toothed felids (Metailurus) were also found on Samos. There were three species of elephants (proboscids): a large mastodon, a small mastodon and a deinothere. The mastodons had molar teeth shaped like breasts (hence their name mastobreastdont tooth) and four tusks two above and two on the jaw. Deinotherium had a small head and two down turned tusks on the lower jaw. They were distant relatives of the elephants.

The perissodactyls (odd toed ungulates) were many. Three toed horses dominated the mammalian fauna. Many species commonly known as hipparions or hippotheria are found on Samos. Hippotherium had three hooves per foot or hand whereas the modern horse has one. The central hoof bore the primary weight as in the modern horse. The side hooves were reduced but still functional. One difference in Hippotherium is a depression in front of the eye on the face. These were similar to depressions to those found in modern pigs, deer and antelope duikers and oribi today. The prevailing theory is that the depressions of Hippotherium had muscles supporting very large upper lips. There is also a possibility that these depressions had face glands as do duikers and oribi. If they had lip muscles, they may also have had a small proboscis as tapirs. Various hippotheria differ is size and the number and shape of skull depressions in front of their eye. One of the hippotheria was small. Most species were the size of a donkey. Ancylotherium was a bizarre species. It had an inclined back like a hyena but it was a herbivore and a close relative to the horses and the rhinoceroses. It also had, instead of hooves, huge clawed hands. Its snout was very delicate and slender and it had broad teeth for browsing.

The rhinoceroses were of two types. There were species without horns. These species had a very broad lower lip and were called chilotheria (lip mammals). They also had lower tusks reminiscent of those of pigs and hippopotamuses. The rest of the rhinos are similar to the modern African black and white rhino but they have many differences and hence are ancestral to them. They had two horns marks of which can be discerned on the profile of the nasal bone. There was also a Dicerohrinus which is still extant as the Sumatran rhino. Dicerohrinus was a common genus during the Middle and Late Miocene.

The deer were similar to the European roe deer (Pliocervus) but there were also species of more primitive deer such as a muntjack and even a tragulids (Muntiacus and Dorcatherium). There were many giraffes. Palaeotragus and Samotherium were both large species (the former the size of a large deer or an elk and the later even larger than a moose). Their horns were straight and had an unusual feature. Often the skin of the horn peeled off and bare bony tips were exposed. This is an unusual feature for any animal to have bone exposed to the air. Palaeotragus and Samotherium had medium in length necks like a modern gerenuk. Their limbs were short in comparison to the limbs of modern giraffe. There were two sivathere species of giraffes which were even larger than Samotherium and they had short necks and stalky limbs. None of these giraffids were ancestral to modern giraffe. In addition there was a species (Bohlinia) which resembled the modern giraffe in that it had long limbs and a long neck. This species may not actually be related to modern giraffe and in that case the long neck would be due to parallel evolution. If that was the case, then there would be no ancestor of the modern giraffe found on Samos. Schansitherium is a species similar to Palaeotragus. Birgerbohlinia was like a sivathere but it was different in the limbs.

Many antelope bovids were found on Samos (Gentry 1971). The majority of the antelopes were similar to modern tragelaphines (kudus) and deer in dentition. They presumably browsed most of the time. There were several relatives of the modern Indian nilgai and chusigha. The most common ones were Miotragocerus and Tragoportax. There were antelopes similar to the Indian black buck and to other spirally horned species. The most common ones were Protragelaphus and Prostrepciceros. The gazelles were small and most similar to those found in Sudan (Gazella dorcas). There were early ancestors (Samokeros) of the bovine group (bison, cows and buffaloes). There were distant ancestors (Palaeoryx) to the modern sable and oryx antelopes. There were undisputable ancestors (Pachytagus) to the modern goats. The goat ancestors had many similarities with modern goats such as short premolars and simple teeth. But they also had differences like primitive horns which did not have sinuses in them and long metapodials unlike the short modern goat metapodials. Perhaps these are adaptations for climbing mountains and Pachytragus would be more of a species inhabiting. Criotherium and Parurmiatherium were distant relatives of modern musk oxen and takins. Palaoeoreas was a spiral antelope of unclear affinities.

Bone beds, museums and sites of ancient technology on Samos Island

Day 6: Fossil and ancient sites around Mytilini and Pythagorion

Stop#6.1: Bone beds NNW of Mytilini

Figure 1 shows a detailed map of the famous fossils sites near Mytilini; Q1 and Q5 are probably the most interesting ones. Start walking in the creek from the second road bridge N of Mytilini to the NW. You are in the Mytilini Formation of the Upper series (see previous paper, Fig. 3). The sequence is basically dipping at 10-25º to the E: however, small-scale faults are abundant and cause locally dips into other directions. Near Smakia, the Old Mill beds consisting of marls and water lain tuffs (grey or tan-reddish) are exposed. They contain at least two bone beds. Above the Old Mill beds follow the Gravel Beds with numerous gravel layers and sandy marls. The thickness of the Gravel Beds is highly variable and the might locally pinch out completely.

Bear N and walk up the Potamies valley, which brings you into the White Beds with their whitish to grey limestones. The lowest bone bed is situated at the uppermost part of the White Beds. The Main Bone Beds follow above the White Beds. They host most of the fossil horizons. The Main Bone Beds itself are marls and mudstones sprinkled with thin layers of gravel. Most of the gravels in the Main Bone Bed contain pebbles of Hora Formation and basement of the Ampelos nappe. The Main Bone Beds also contain numerous water lain tuffs and palaeosols. Fossils have been found both in the White Beds and the overlying sandy sediments of the Main Bone Beds. Outcrop photographs of the famous Panaima and Phloios localities (Figs 4 and 5) can be found in Solounias and Mayor 2004, their fig. 4). At Phloios, a well-exposed NW-striking fault scarp is exposed in greyish limestone. Those striated scarps and the rugged topography had inspired the ancient Greek philosophers to think about ancient earthquakes.

Stop#6.2: Palaeontological Museum of Mytilini

The museum was established in 1965 and is in the Municipality building. The museum basically exhibits, amongst others, the fossils of bones from animals that lived 7-3.5 Myr ago. They belong to middle and large sized mammals and also smaller vertebrate terrestrial mammals. Most important are the fossils of Samokeros (ancient type of cattle), Samotherion (wild beats of Samos), Gomphotherion, Dinotherion, Macherodon, Metelouros and large carnivorous mammals. The exhibits come mainly from the excavations of J. Melentis that were conducted in 1963 in the area of ‘Adrianos’ near the village of Mytilini. In the past, excavations were also conducted in 1832, 1885, 1887 and 1925 but the findings of these excavations were forwarded to museums in Lausanne, London, New York, Budapest, Frankfurt and elsewhere (see above).

Stop#6.3: Efpalinus tunnel of Pythagorion

The famous tunnel of Efpalinus (Fig. 7) was the "8th wonder" of the ancient world. It is one of the Polycratian constructions, constructed ~550 BC by Efpalinus, an engineer from Megara. It is an aqueduct, a masterpiece of engineering device, the most important of the antique era.

Figure 7. The Efpalinus tunnel.

Photograph.

The way the tunnel is constructed often comes as a surprise even to modern experts. Given the primitive tools (hammer and chisel) available at the time the success of the enterprise is astonishing. This tunnel is the middle section of a major aqueduct to supply Polycrate's town, i.e. the ancient city of Samos, the modern Pythagorion, with water. Its construction took about 10 years and the tunnel has a length of 1036 meters. A total of 7000 cubic meters of natural rock had to be removed for the conduit. The section of the tunnel is on average 1.8 m by 1.8 m, and is cuts through the mountain at a depth of 180 m below its summit. This ancient tunnel is constructed with rectangular stones which are very skillfully fitted one on top of the other. It is roofed with a triangular vault, made with the same kind of stones.

The ancient Greek builders first had to hollow out the mountain and then constructed in it the wall and vaulted corridor as a passageway. The water was channeled through clay pipes which were installed in the aqueduct below the part of the tunnel in the direction of the source and alongside it in the direction of the town. These pipes, which remained in many places, are so well made that they appear as put in yesterday.

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