Geomorphological observations concerning the evolution of the Basin of Athens

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Abstract. Tectonism is an important element in the determination of the present landscape of Greece. It has shaped and is shaping the numerous highlands and depressions and consequently settlement patterns of the country. One such area is the Greater Athens region, a triangular basin, opening to the sea in the southwest and surrounded by four mountain masses.

The presence of an old planation surface on the surrounding mountains; of thick lateritic soils in the basin overlain by Miocene and Pliocene marls, marly limestones, sands and conglomerates; Pleistocene fluviotorrential deposits; alluvial fans; and fluvial and marine terraces, enabled the authors to put together the Tertiary and Quaternary tectonic and geomorphic evolution of the Greater Athens area.

The paleogeographic evolution goes back to a probable mountainous topography before the Miocene with near tropical climatic conditions. In the Early Miocene, the breaking up of the highland area and the formation of today's basin begins or has already begun. During the Late Miocene, a transgression of the sea occurs, particularly in the western half of the basin. This is followed by regression, erosion and Late Pliocene transgression. During the Neogene and Quaternary we have continuous fluviotorrential deposition intercalating with marine sediments. In the Quaternary, the tectonic activity in the area slowly subsides and climate, particularly in the late Pleistocene and Holocene and eustatism, especially along the coastal zone, affect more readily the depositional and erosional regime and geomorphic processes.

Introduction

Numerous studies of intermountane basins have been done in almost all parts of the world. There have always been a few locations of particular interest, however, which for various reasons have not been studied as thoroughly as necessary. One such basin is that of Athens (Fig. 1).
The intermountane Basin of Athens is one of the oldest inhabited by man in Greece. The oldest permanent settlements known thus far are about 5,000 years old and were situated near a spring on the northwest slopes of the Acropolis (Camp II, 1977, p. 33).

Fig. 1. Topographic map of the Basin of Athens
One of the reasons that made the Basin of Athens a favourable settlement location was its physical setting. It is trending northeast-southwest, has a plain sloping gently towards the sea, and is surrounded by three mountain masses. In the east, there is the elongated Ymittos with its highest elevation, 1026 meters, in its northern half. The mountain is divided in a northern higher mass and in a southern lower one. In the northeast of the basin, there is a more massive mountain, though smaller in extent, named Pendeli. The highest peak, 1107 meters, is near the middle. In the north-northwest, there is the third and highest area, Parnitha, with a height of 1413 meters, although it is a little farther from the plain than the previous two. A fourth lower “mountain” mass is Egaleo, 468 meters, located in the west and much closer to the plain than Parnitha.

In addition to these important highlands surrounding the Athens basin, there is a group of alligned hills in the basin trending northeast-southwest with decreasing elevations to the southwest. These are Tourkovounia (323 meters), Lykavitos (265 meters), Acropolis (142 meters) and Filopappou (161 meters). It is around these hills that the first permanent settlements occurred, particularly around Acropolis where a number of springs were issuing.

The present study attempts to reconstruct the physical environment of the Basin of Athens from ancient geologic time to the present day. It is apparent that, as one moves to more recent times, the geo-evolutionary stages become more and more detailed and better documented. Hence, this study concentrates more heavily upon the Neogene and Quaternary evolution of the basin and the surrounding mountains.

Most of the study was done in the field (city). Almost the whole basin has been built up today. This is unfortunate because it is impossible to get a general picture of the topography “au naturel” but also fortunate because a large number of buildings, new roads, sewerage systems, and underground tunnels are under construction providing a relatively good picture of the subsurface geology and landforms that exist in the basin. In addition to field work, various geologic maps, old and new topographic sheets having scales ranging from 1:5,000 to 1:200,000, and airphotos were utilized. Some laboratory analysis of sediment samples and fossil identifications were also carried out.

Many scientists have studied the geology and tectonics of Attica. The most important studies are considered to be those by Lepsius (1893), Ktenas (1907), Negris (1912-1915), Kober (1929), Sindowski (1949), Philipsson (1954), Renz (1955), Trikalinos (1955), Marinou (1955, 1956), and Katsikatos (1976). The main geologic formations recognized in the Basin of Athens are (Fig. 2):

1. The Metamorphic system (Ymittos)
2. The Sedimentary system (Egaleo, Parnitha)
3. The Athenian schists and Cretaceous limestones, and
4. The Neogene and Quaternary deposits

The structural relations between these units have not been fully understood or explained. Lepsius (1893), Trikalinos (1955) and others maintain that the age of the metamorphic system is pre-Paleozoic because it underlies Paleozoic formations (Parnitha). Kober (1929), who was the first to describe Attica as a tectonic window, believed to the mesozoic age of the metamorphic system, as the more recent scientists Marinou (1955) and Katsikatos (1976) did.

Few scientists have studied the geomorphology of the basin of Athens and the surrounding highlands. Reniers (1933, 1937, 1938) studied the lateritic and terra-rossa soils of the Attiki area in general. But more importantly, it was Mistardis (1954, 1959/61a, 1959/61b, 1964a, 1964b, 1964c) who studied the Quaternary formations of the basin and the adjacent areas. In both cases, however, the studies were mostly descriptive. Other studies related to the geomorphology and evolution of the Athens area are by Roubanis (1961), Higgins (1962), Vande Weerd (1972), Mitsaki (1973), De Bruijn and Vande Meulen (1975), Symeonidis and Zapfe (1977), Symeonidis and De Vos (1977) and K. Doukas (1981).
Fig. 2. Geologic and geomorphologic sketch map of the areas studied in the basin of Athens
Geology, tectonism and geomorphology of the basin of Athens

Geology

The Basin of Athens is surrounded by the metamorphic system of Attica (Ymittos, Pandeli) in the east and northeast, and by the sedimentary formations of Egaleo and Parnitha in the west and northwest.

The lithostratigraphy of the basin of Athens, from bottom to top, is as follows:

1. The Athenian schists (mica, chloritic and argillaceous schists) of probable Maastrichtian age (Geological Map of Athina-Pireas, 1:50.000, I. G. M. E.). Within the Athens schists we find thin limestone layers. The Athenian hills (Lykavitos, Acropolis, etc.) are Upper Cretaceous limestones, thrust over the Athenian schists (Kober, 1929).

2. Unconformally overlying formations composed of fluvio-torrential deposits and over them Upper Miocene sediments (Papp et al., 1978) in the northeast of the basin, and limestones with marls in the northwest (Freyberg, 1951).

3. Pliocene formations rich in characteristic fossils (Leptius, 1893) unconformally overlain by sandstones, marls and conglomerates which extend to the south of the basin. At Palio Faliro (Fig. 3), along a small cut, it is possible to observe alternating layers of sands, marls and conglomerates. Going up the layers of the series it appears that the depth of the sea increases. The upper layers are composed of relatively fine sediments (thin-bedded marls, sands and thin limestone intercalations). These Pliocene formations with rich fauna (Rafina) are very widespread and are found along the eastern coasts of Attica.

4. The Pleistocene sediments are fluvio-torrential and we find them mainly in the southwestern area of the basin (Nea Smyrni). They are composed of alternating layers of conglomerates, sands and yellow to brown sandy marls (Fig. 4).

5. In the Middle and Upper Pleistocene we have fluvio-torrential deposits, old cones (Nea Smyrni) and red clayey soils in small faulted openings (Tourkoumi-Doukas, 1981). Furthermore, we have the more recent alluvial sediments of both terrestrial and marine (beachrocks) and anthropogenic (Lykavitos) origin.

Fig. 3. Stratigraphic column and section at Palio Faliro
The recent evolution of the Basin of Athens in the result of discontinuous deformation (faults and joints) which followed the Alpine tectonism.

In the pre-Upper Miocene period we have a fault tectonism with normal faults (direction mainly NE, NNE for Ymittos and Egaleo), sinking of the region and transgression of the Miocene sea. Consequently, we have the unconformably lying Pliocene sediments. In the latter, we frequently observe reverse faults or open folds, which is an indication of a slight compression during the post-Pliocene period (Palio Faliro, Fig. 3). Following this we have normal faults, indicating extensional forces.

The Pleistocene sediments (Fig. 4) show a dip towards the north which should not be primary but due to tectonic deformation. Moreover, normal faults are observed in these sediments (Nea Smyrni) but also in the relatively younger deposits (Kifissia, Fig. 5). In summary, we can say:

1. Normal faulting following extension before the Upper Miocene.
2. Compression with reverse faults in the Plio-Pleistocene.
3. Normal faulting, following the compressional phase, during the Pleistocene.

Evidently, many cones found along the footslopes of the surrounding mountains are the result of deposition along faults of the Quaternary as, for example, the fault between West Ymittos (direction N 30°) and the corresponding alluvial cones.

Finally, the main directions of the joints in the region surrounding the Athenian schists are NNE-SSW, NE-SW, E-W and NW-SE. In the hills of the Athens basin (Tourkovounia, Lykavitos, Acropolis, Filopappou) the predominant directions are N 50° to N 70°.

Geomorphology

The physiography of the intermountane basin of Athens can be divided into three units (Fig. 2). The first is the surrounding mountain masses, Ymittos, Pendeli, Parnitha and Egaleo; the second includes the plain of Athens which can be further subdivided in the peri-
pheral piedmont slopes and the lower basin proper; and third, the four inselberg-like formations in the plain, namely Tourkovounia, Lykavitos, Acropolis and Filopappou.

The mountains: Ymittos, in the east and south, is elongated but not continuous. The southern third is severed from the northern part, appears to have moved to the east and is at a lower elevation. The whole mass exhibits a flat surface along its ridge ranging in height from 600 to 900 meters. It is believed to represent a pre-Quaternary erosional cycle before faulting set in this area. It is also possible to divide Ymittos along a NNE-SSW axis passing a few hundred meters west of the peak but no tectonic evidence has been found to exist yet. Along the western middle part of the mountain there are two deep gorges having depths of 300 meters or more, the longest being three kilometers, cutting through the erosional surface at an elevation of 750-800 meters. Within some of the more gently sloping valleys, an alluvial terrace of 5-6 meters is observed, too.

Pendeli is located in the northeast of the Basin of Athens. It is a symmetrical mountain with steep slopes, especially on the northeastern side. The southwestern part has steep-sided but not deep valleys which end in a bajada-like apron of fluvio-torrential sediments.

Parnitha mountain in the north-northeast is much more extensive and higher. A relatively extensive erosional surface is observed between 800 and 1,000 meters. There are three deep gorges with depths of up to 300 meters that seem to converge near the 400 meter contour. All three reach the erosional surface.

Egaleo is an elongated hilly ridge flattening at an elevation of a little more than 300 meters. In this case too, like Ymittos, Egaleo is divided in two parts, the southern being somewhat higher that the northern. The whole area is steeper from 100 to 200 meters, and becomes more gently sloping from 200 to 300 meters.

The plain of Athens and the "piedmont" slopes: Between the surrounding highlands and the plain of the basin of Athens there is a "piedmont" zone with gently sloping surfaces dipping towards the plain. This zone is composed of fluvio-torrential sediments but also Neogene marine, brackish and lacustrine deposits in the lower, southern portion of the basin near Egaleo and southwest of Ymittos.

Below the "piedmont" slopes there extends the plain of Athens which covers the lowland areas below 300 meters. Most of this area is found along the western side of the basin, in front of Parnitha and Egaleo. The average NNE-SSW slope is about 2° but the upper parts, from 100 to 300 meters are deeply dissected, more than 10 meters in some places. This is believed to be related to the climatic change of the last glacial period. The lower parts of these deeply dissected vallyes are "drowned" and filled with recent sediments. Deposition in the plain of Athens seems to have been continuous, at least during the Quaternary, although some hiatuses can be identified with some accompanying tectonism (Fig. 5).

The low hill ridge. The four hills outcropping in the plain of Athens are rock remnants of a previous landscape in the early formation of the Athens depression. It is certain that the Neogene sea reached as far as the Acropolis area and may have surrounded it for a short period of time. Pliocene marls have been found just west of Lykavitos at an elevation of about 120 meters. The Pliocene deposits are much more extensive west of the southern half of Ymittos. This area is rich in terrestrial cone and fan deposits, too. In Tourkovounia, several scientists have discovered fossil remains of rodents in reddish, clayey sediments found in faults and joints of the marbles (Symeondis and Vos, 1977; Symeondis and Zapfe, 1997; Doukas, 1981). These were dated as Lower to Middle Pleistocene. Finally, a recent sediment cover is found on ancient Greek structures which is eroding quickly today, and uncovering the underlying old roads and buildings. This cover is located north and west of the Acropolis.

Of special significance, for the better understanding of the evolution of the Basin of Athens, are some landforms that need a more detailed description.

Alluvial cones and fans: The more distinct ones are located along the eastern portion of the basin and are related to Ymittos which has been affected most by tectonism. These fans are composed of medium to well cemented sediments, reddish and greyish in colour, very little weathered, displaying some layering but poor sorting and indicating a fluvio-torrential ori-
gin of the sediments. The size of the transported material varies from medium sand to large boulders close to one cubic meter in size. They are medium to well rounded. The lithologic composition is marbles, dolomites, schists and limestones. The oldest of these probably underlie the Pliocene marls, sands and gravels, but most of them overlie them. No fossils have been found in them, yet. Most of these fans are eroding today and the modern drainage network follows their sides.

"Piedmont" slopes: A typical section is that of Kifissia (Fig. 5). It is made of alternating sands and gravels or conglomerates and has at least six soil horizons in between. The paleosols are reddish-brown, prismatic and include chert gravels. The sands and gravels are medium to well cemented, very little weathered, greyish in colour but reddish near the soil horizons. The lithologic composition is marbles, limestones, dolomites and schists. In some cases large boulders, more than half cubic meter, are included. The matrix in the conglomerates is very limited, composed of medium to coarse sands. The dip of the Kifissia deposits is steeper than today's topographic slope indicating either recent tectonism, which is clearly visible in the road cut, or an intense erosional phase in the upper reaches of Kifissia. All these deposits are deeply dissected today.

The coastline: It should be noted that a large part of the Saronikos coastline is retreating today, following the most recent transgression until the Middle Holocene. Since then, only the portion between Palio Faliro and eastern Pireas seems to have reversed this process. An appropriate proof of the active erosion of most of the coastline is the presence of beachrocks. These are Holocene layered formations composed of well cemented sands and gravels, many times including pieces of ancient Greek pottery but also Coca Cola tops. In many locations the beachrocks have been breached by the advancing sea and the loose sand behind them is eroding. Finally, we have two marine terraces on the Neogene deposits, one at an
elevation of 18-20 meters and the other near 40 meters. It is believed that these were formed during the last two interglacial periods. No deposits or fossils have been found to sustain this view yet.

Evolution of the basin of Athens

Combining all the geologic, tectonic and geomorphic observations it is possible to reconstruct the evolutionary stages through which the basin of Athens passed to reach its present form.

In pre-Neogene times, the resultant landscape at the end of the Alpine orogeny (mostly folding) was a mountainous physiography very unlike today’s landscape.

Before the Upper Miocene, the area was affected by extensional tectonism, with normal faults forming the basin with its surrounding mountains. Part of the basin was covered by sea, particularly the western part which had sunk more than the eastern. Preceding this transgression (Tortonian) we have a period of intense erosion, deposition mainly of conglomerates, along the periphery of the newly formed mountains — first erosional phase.

During the Messinian Crisis of the Mediterranean basin (end of Miocene, 5-7 m. y. ago) in a warm sub-tropical climate there was a rapid regression of the sea accompanied by active erosion — second erosional phase. This process resulted in the erosion of extensive parts of the Miocene deposits and the deposition of fluvi-torrential sediments, in the form of alluvial cones and fans, on most of the remaining.

The Messinian regression was followed by the Pliocene transgression with marine deposits found today at an elevation of more than 120 meters. These deposits are sometimes intercalated with fluvi-torrential sediments, indicating shallow marine conditions.

During the end of the Pliocene and early Pleistocene a weak compressional phase occurred, resulting in open or reverse faults. In the lower half of the Pleistocene there was a gradual drop of sea level accompanied by erosion and deposition in the form of alluvial cones and fans — third erosional phase.

From the Middle to Upper Pleistocene a period of rapid transgressions and regressions due to the glacial and interglacial periods took place. In this period we have the formation of marine and fluvial terraces — fourth erosional phase, together with continuous extensional tectonism.

Finally, in the Holocene, we recognize at least one depositional phase with the most recent, post-Hellenistic erosional phase — the fifth, forming the present 5-6 meter terrace in the older valleys.

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