

**THE DADIA–LEFKIMI–SOUFLI FOREST NATIONAL PARK, GREECE:
BIODIVERSITY, MANAGEMENT AND CONSERVATION**

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Illustrations by
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The geology of the Dadia–Lefkimi–Soufli Forest National Park

Stylianos Skias

The currently available geo-scientific information, referring particularly to the Dadia–Lefkimi–Soufli Forest National Park (DNP), is limited. Consequently, most of the bibliography used in this article refers to it indirectly. An outline of the geological history and structure of Greece is presented first, with emphasis on Thrace where the oldest rocks in the country are found. The particular features of the geological zones comprising the south-eastern Rhodope area where the DNP is situated, are described. The geotectonic structure and rock composition of the DNP are mainly derived from volcanic and tectonic activity in the mid-Eocene to Miocene, but possibly earlier. Rock formations in the north-west belong to the Rhodope massif zone (Rh), and are mainly metamorphic and igneous-volcanic, those in the larger south-eastern part belong to the Circum-Rhodope zone (CR) and are igneous and sedimentary. Other rocks of low-lying areas consist of molassic series of conglomerates, sandstones and marls of the Middle Eocene – Oligocene, as well as Miocene marine sediments of coastal facies. Yellowish, sandy marls, loams and clays of Pliocene age occur in the flat areas in the south-east.

Keywords: Geology of Greece/Thrace/Rhodope, Rhodope massif zone, Circum-Rhodope zone

An outline of the geological history and structure of Greece

It is acknowledged by the international geoscientific community that the geo-environment of Greece exhibits extreme inherent complexity in all respects of materials, processes, structure and history, and has a unique and continuing geodynamic activity manifested by abundant earthquakes and extreme seismicity. These are mainly the result of the collision between the African and the Eurasian geotectonic plates and the associated subduction processes along the so-called Hellenic Arc (Fig. 1).

The Hellenic area consists of two smaller plates (belonging to the Eurasian plate) known as the North and South Aegean plates, respectively, which are divided by the North Anatolian Fault. These are in turn surrounded and affected by three additional plates, the Adriatic or Apulian (to the west), the African (to the south) and the Anatolian (to the east) (Fig. 1). In general, the Hellenic area represents a very active and complex geological system which constantly attracts international scientific

interest (Le Pichon and Angelier 1979, Burchfiel 1980, Makropoulos and Burton 1984, Papanikolaou 1986).

Greece or, geologically, the Hellenic orogen, is part of the Mediterranean section of the Alpine-Himalayan orogenetic system to which all of the most recent and highest mountain chains belong. It is also where the major part of the Earth's geotectonic energy in the form of earthquakes and volcanic activity is released through tectonic plate movements. This system originated during the destruction of the Tethys Sea by the convergence of Gondwana and Laurasia (the two huge continents of the early Earth). The Alpine-Mediterranean section of the Alpine-Himalayan system represents the youngest parts of the European continent (Italy, the Alps and the Balkan Peninsula, with central Europe being of intermediate age, and northern Europe the oldest), and is one of the most complex geodynamic settings on Earth. Until the beginning of the Mesozoic era (250 my ago), Greece and the larger Alpine-Mediterranean area were submerged under the Tethys Sea, which at that time extended parallel to the equator from the present Atlantic ocean to the Pacific (Malpas 2000). The Tethys basin



Fig. 1. Schematic illustration of the principal movements affecting active tectonics in the Greek Aegean and the eastern Mediterranean. Thick arrows indicate the direction of the motion relative to Eurasia. The values (mm yr^{-1}) are shown near each arrow (Source: McClusky et al. 2000.)

was a huge trough with a bed of alternating small ridges and troughs called the Alpine Geosyncline. During the Mesozoic (lasting 190 my) and the Cenozoic (lasting 60 my), the cyclic Alpine orogenic processes took place here resulting in the gradual and successive disappearance of parts of the Tethys Sea eventually ending in the formation (orogenesis) of the present Alpine system of mountain chains. All of the new sediments that were deposited in the Alpine geocyncline (now present in various parts of the mountain chain) are named Alpine sediment rocks and the pre-existing older ones, Pre-alpine sediment rocks (Durand et al. 1999).

Most of Greece (except the north-eastern part of Macedonia and Thrace) was formed by successive cycles of the Alpine orogenic processes, and its mountain chains, called the Hellenides, belong to the larger Alpine system, including the mountains of Albania and the former Yugoslavia (the Dinarides) as well as the Taurides of southern Turkey (Jacobshagen 1994, Downes and Vaselli 2001; Fig. 2).

Rocks of Alpine origin predominate in Greece (Alpine Greece) and only a small area consists of pre-Alpine (older) rocks. The latter are in Thrace and represented by the Rhodope Massif (Rh) geotectonic zone (Fig. 3).

Most geoscientists agree that the geologic territory of Greece is composed of successive geotectonic zones (the Hellenides zones), which at present lie in a NW – SE direction. These were originally created about 200 my ago during the Triassic period in the form of alternating submarine ridges (geo-anticlines) and troughs (geo-synclines), collectively called isopic zones (Aubouin 1965). The Hellenides are subdivided into two main groups. One represents the External Hellenides (western and central Greece). From west to east these are: Paxos, Ionian, Gavrovo-Tripolitza, Olonos-Pindos and Parnassos-Ghiona. The other represents the Internal Hellenides, which follow the External Hellenides and, arranged in a sequence from west to east, are: Sub-Pelagonian, Attico-Cycladic, Pelagonian, Almopian, Paiko and Peonian. These constitute the Axios-Vardar zone, the Circum-Rhodope (CR) zone, the Serbo-Macedonian zone and the Rhodope massif (Rh) (Fig. 3).

The Rhodope massif and the Serbo-Macedonian zone might constitute the hinterland of the Hellenides by being the ancient core rocks of pre-Alpine origin. Consequently, the older rock systems of Greece are found within these latter zones.

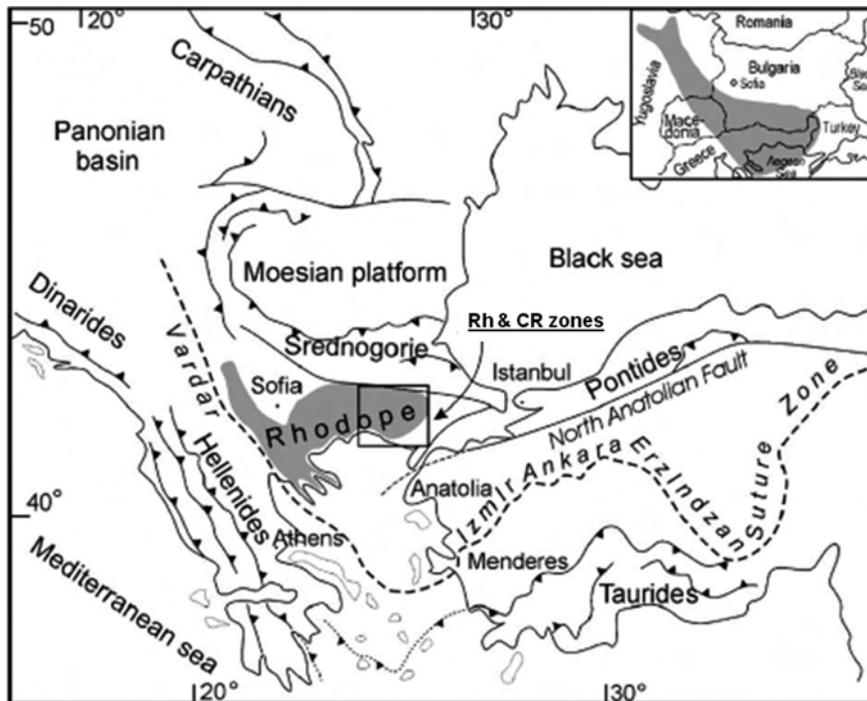


Fig. 2. The shaded area indicates the position of the Rhodope Massif (Rh) and Circum Rhodope (CR) geotectonic zones, in relation to the main tectonic units of south-eastern Europe. In the inset, the shaded area represents these two zones in the Greek and Bulgarian parts of Thrace. The majority of this area is occupied by Eocene-Oligocene magmatic rocks. (Source: Marchev et al. 2004.)

The rocks of Greece: main types and distribution

Relative to its size, Greece exhibits an enormous variety of rock formations, belonging to all three basic petrological categories: igneous, sedimentary and metamorphic. This is due to the extremely complex geological processes which have occurred in this region during geologic time. According to their relative ages, the rock formations of Greece are divided into pre-Alpine (older), Alpine (intermediate age) and post-Alpine (younger) (Higgins and Higgins 1996).

The pre-Alpine formations are mainly metamorphic, with small areas of sedimentary and igneous rocks. The Alpine and post-Alpine formations include most of the sedimentary cover of Greece, together with large igneous outcrops.

Greek metamorphic rocks are found mainly in the Internal Hellenides zones, i.e. in Central and Eastern Macedonia, Thrace and on the islands of the North Aegean, and are mainly Palaeozoic schists, slates, gneisses, marbles and amphibolites. These also occur in southern Greece (Papanikolaou 1984).

The sedimentary carbonate rocks (mainly limestones but also dolomites) were mostly formed during the Mesozoic. The mountains of the Ionian Islands, Epirus and Akarnania (Adriatic-Ionian region), Pindos, Agrafa, Tymfristos, Tzoumerka, the Aetolean, Tripoli and Parion mountains, and most of the mountains in Crete are predominantly limestones (with lesser amounts of dolomites).

Flysch is a complex sedimentary formation of a very thick sequence (of the order of hundreds of metres) of sandstone strata, rich in quartz, alternating with clay shales, siltstones, mudstones and, rarely, conglomerates. It occupies a huge area in Greece, covering entire regions to a depth of up to 1000 m. The largest Paleogene flysch region extends from the Greek-Albanian border through western Greece and Epirus, south to southern Peloponnese and the south Aegean island of Rhodes. It is also prominent in the Ionian, Gavrovo-Tripolitza and Olonos-Pindos geotectonic zones. Molasse formations are similar to the flysch sequences (as far as the constituting rocks are the same) and cover considerable areas, notably in northern and western Greece (Papanikolaou 1986).

The youngest rocks (Neogene age) and soils in Greece are sedimentary, of marine, riverine or lacustrine ori-

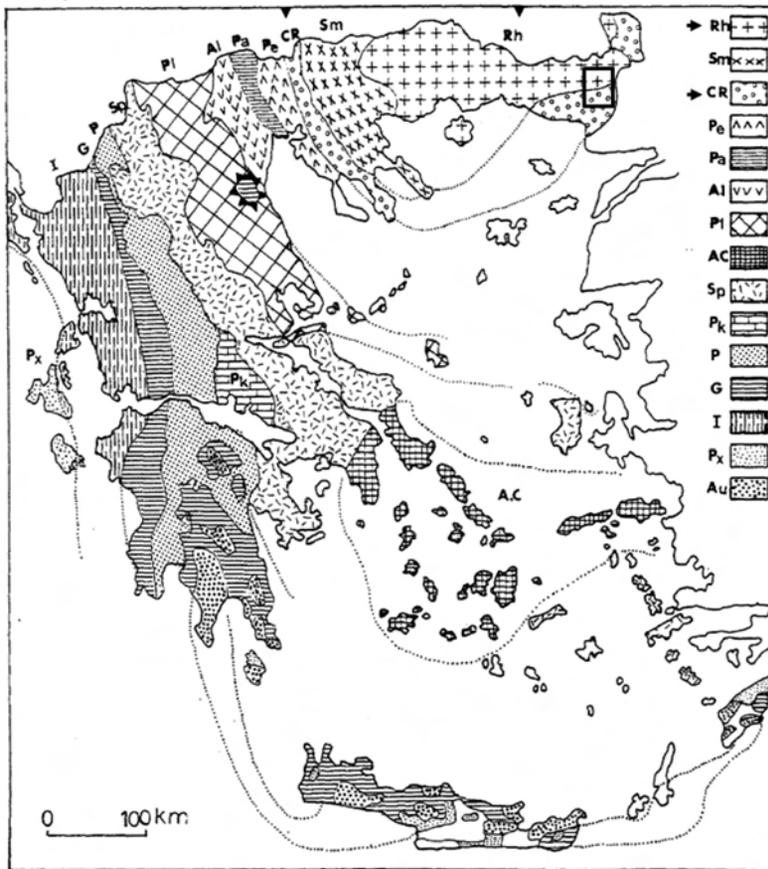


Fig. 3. The spatial distribution of the main geotectonic zones of Greece, the internal and external Hellenides. The Dadia–Lefkimi–Soufli Forest National Park (rectangle, upper right) is geologically represented by the Rhodope massif (Rh) and the Circum Rhodope (CR) zones, small rectangle in the upper right of the map. (After Mountrakis 1986.)

gin, and consist mainly of sands, clays, conglomerates, marls, travertines, peat, lignites and porous limestones. They cover large areas of low-lying land and appear in horizontally oriented strata. They occur mainly on the north coast of Peloponnesus and in Corinth, Attica, the Kassandra peninsula in Chalkidiki, in the north of the island of Evia, in Crete, in the area between Kalambaka and Kastoria and in the highest levels of the Serres-Sidirokastro-Nigrita and Drama depressions, and in many other parts of the country. The lignites are of particular economic importance to Greece, since 70% of its total electric energy production is based on them.

Igneous rocks (divided into sub-groups of volcanic, plutonic and dikes) occupy considerable areas, chiefly in northern Greece where they appear as domes, napes or flows, and only rarely as dikes. Extensive volcanic and plutonic rocks exist in Rhodope, Thrace and Almopea, while volcanic rocks are abundant, particularly in the Aegean islands. Plutonic rocks (granite, diorite and gab-

bro) outcrop chiefly in Macedonia. The granite outcrops of Vrontou, Florina and Xanthi are important because of their size. Most igneous rocks in Greece are of Tertiary age (< 65 my), though some are Paleozoic (> 250 my). Volcanic rocks are closely associated with the presence of geothermal energy fields and in Thrace (e.g. Xanthi, Evros, Samothrace) considerable fields of high potential are present which have not yet been seriously exploited (Mountrakis 1986, Pe-Piper and Piper 2002).

The geo-tectonic history and structure of north-eastern Greece, south-eastern Rhodope and the central Evros area

A dominant geographical, geological and ecological feature of Thrace is the Rhodope mountain chain, which is shared between Bulgaria and Greece and exhibits an

east-west orientation. A larger geographical area, which includes the mountain chain and the neighbouring plains, is also called Rhodope. Rhodope covers 14,737 km², of which 12,233 km² are on Bulgarian territory. The mountain chain is c. 220 km long and 100 – 120 km wide, with an average altitude of 785 m asl. It represents an ancient massif (geologically one of the oldest in Europe) now eroded to a wide, undulating plateau. Uplift of the massif has regenerated the erosion cycle, which is still on-going. Eastern Rhodope is divided into northern and southern parts by the River Ardas, a tributary to the River Evros. The Dadia–Lefkimi–Soufli Forest National Park (hereafter DNP) covers an area of ca 420 km² at the southern margins of the south-eastern Rhodope, in Greek Thrace, adjacent to the Greek-Turkish border represented by the River Evros. The Dadia, Gianouli and Lefkimi villages are included in the Park and the town of Soufli touches its perimeter (Fig. 4).

The present geotectonic structure and existing composition and distribution of rocks in the wider area of the DNP are mainly expressing effects of mid Eocene to Miocene volcanic and tectonic activity. The volcanic rocks of this area are connected with fault-controlled basins, such as the Feres-Dadia-Soufli basin, formed under tensional tectonics. The development of this basin began in the Lutetian (c. 52 my ago) and lasted to the Pliocene (Agemoglou 1997).

Most of the area in which the DNP lies consists of formations belonging to the geotectonic zones of the Rhodope massif (Rh), encountered in the smaller, north-western part of the park, and of the Circum-Rhodope zone (CR), represented in the remaining, larger south-eastern part. These two zones appear with slight differences in Fig. 2 and Fig. 3. The differences between the maps represent differences in the scope and mapping criteria, and differences in scientific opinion among those who carried out the research.

Fig. 4 shows all the main types of geologic formations which occur in the geographical area covered by the DNP, with their petrological characteristics and age. At present, there is no large-scale geologic map of the area, thus more detailed information is lacking. A specialised geological map of the DNP area is presented in Fig. 5.

The Rhodope massif zone (Rh)

The Rhodope massif (Rh), underwent several phases of continental subduction, collision, thrust, extension and widespread granitoid magmatism in Cretaceous and Tertiary times. Rh covers the largest part of Greek

Thrace (Rhodope chain), Eastern Macedonia and the island of Thasos, as well as part of southern Bulgaria (the Rila chain). In the Evros Prefecture it is mainly represented in the central part (Fig. 3). Together with the Serbo-Macedonian massif zone, the Rhodope massif is considered to have been the hinterland of the whole Hellenides system. It is also believed to have originated from the ancient continental plate of Laurasia and is thus considered part of paleo-Europe.

The importance of the Rhodope Massif for the geology of Europe and the whole world comes mostly from (1) its position between the “two branches of the Alpine orogenic belt” and its behavioural role during the consecutive phases of folding and thrusting and during the considerable plate movements associated with the closure of the Tethys Sea; (2) the presence of pre-Alpine metamorphic complexes and tectonic units and their behaviours during the Alpine orogenes; (3) the present thickened continental crust and its evolution, its recent increasing seismicity and its status as a seismic hazard; (4) the possibilities it presents for the application and perfection of existing methods in the study of complex metamorphic terrains.

There still exist serious controversies regarding the interpretation of the geological evidence for the Thracian region as represented by the Rhodope massif, which stem mostly from restricted field and laboratory data. The solution to most of the problems may be achieved through a wider involvement of the international geological community, as well as through the application of modern methods in the domains of radio-geochronology, deep seismic sounding, palaeomagnetism, deep structural boreholes, etc. (Fytikas et al. 1984, Mposkos et al. 2001).

The Rh zone is mainly metamorphic (schists, gneisses, marbles, amphibolites and phyllites) and igneous-volcanic (mainly granites and volcanic andesites, trachytes and lavas), which reach a maximum thickness of about 24 km. In several places, large masses of Tertiary granitic and volcanic rocks have intruded into the metamorphic rocks. This magmatism is possibly related to the creation of sedimentary basins (e.g. the Xanthi-Komotini basin) during the Eocene. Most of these intrusive rocks are Oligocene or younger. The diverse rock types appear as coherent blocks or sequences of strata with maximum widths or depths ranging from 10 to 20 km. Their ages can differ greatly, from less than 65 my (Tertiary period) to more than 240 my (Palaeozoic era). Most formations at great depths are of pre-Alpine age (> 240 my). In general, the rocks belonging to the Rh zone are much older than those of the Circum-Rhodope zone, because of the

spatial and temporal differences between the two zones, which in turn are related to the geotectonic processes they have undergone.

The Circum-Rhodope zone (CR)

Within the geotectonic system of Greece, the Circum-Rhodope zone (CR) constitutes the main internal zone

of the Hellenides. As is evident from Fig. 3, it “embraces” the Rhodope and Serbo-Macedonian zones. The rock sequences of the CR zone have been thrust over bedrock masses of the Rhodope zone. In Thrace, the Circum-Rhodope Belt is divided into two units: the Makri unit (also known as the phyllite series) and the overlying Drimos-Melia unit (Kouris 1980, Papadopoulos 1982).

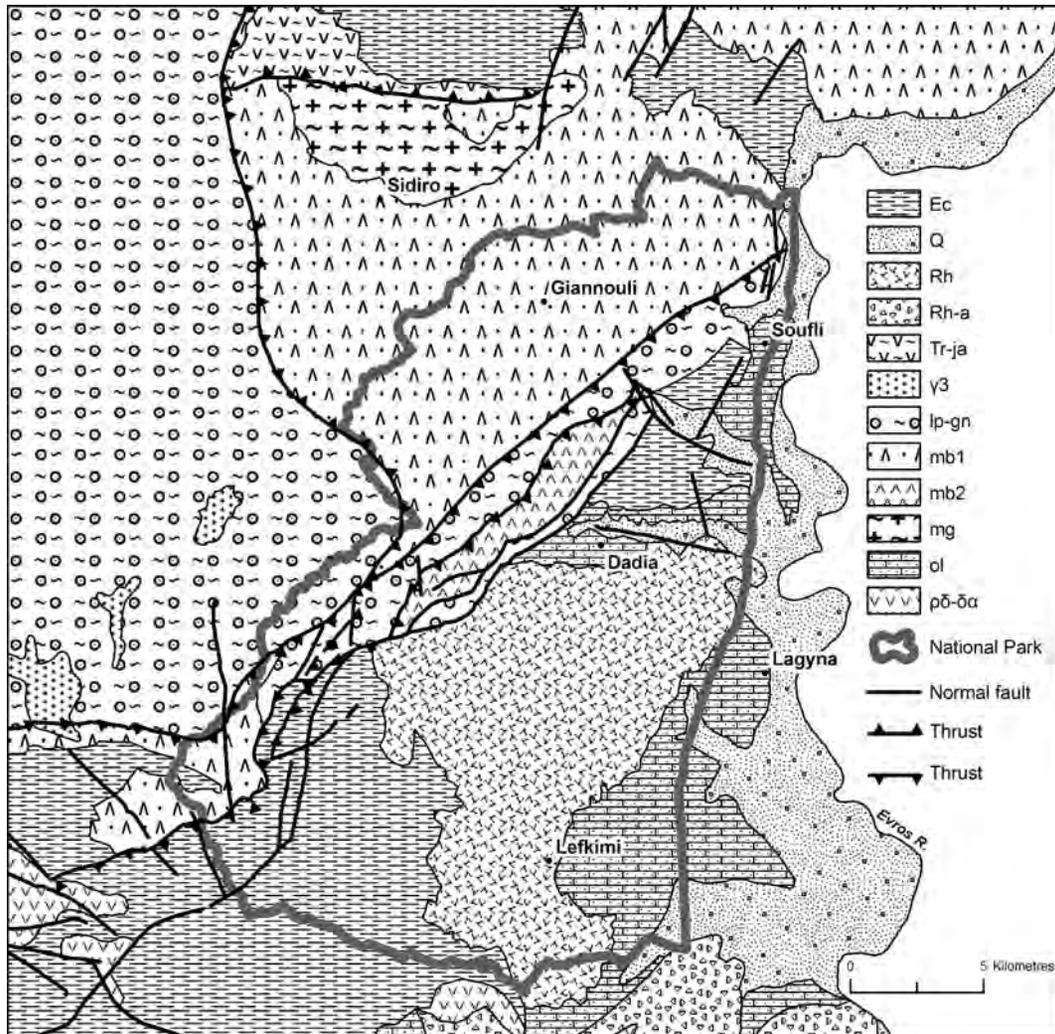


Fig. 4. Geological map of the central Evros region with the Dadia–Lefkimi–Soufli Forest National Park (modified from Dimadis and Zachos 1986). Quaternary: Q = Terraces (river, marine), pebbles and cobbles, alluvial deposits, coastal sands; Oligocene: Koula formation (Rh): Rhyolite and ignimbrite; Kaloticho and Feres – Melia formations (Rh-α): volcano-sedimentary series (rhyolite, andesite, tuff and argillaceous sandstone); ol = Coastal facies: Conglomerate and sandstone. Eocene (Lutetian-Preabonian?): Ec=Iasmos and Aisimi formations: flysch. Mesozoic-Circum Rhodope Zone Metamorphic formations: Tr-ja = Maronia series. Meta-volcano-sedimentary greenschist facies, composed of tuff and dacitic lava; Palaeozoic Rhodope Zone: lp-gn =Augengneiss, Nea Santa series. Metavolcanic series of acid composition: leptinite, biotite-gneiss with intercalations of ortho-Augengneiss; mg=Augengneiss, Gneissgranite. Tertiary – Subvolcanic and plutonic rocks: ρδ-δα = Rhyodacite and dacite; γ3 = Granodiorite. Ophiolite complexes: mb2 = Metabasite ultrabasite: second cycle; mb1 = Metabasite ultrabasite: first cycle. Marbles and amphibolites

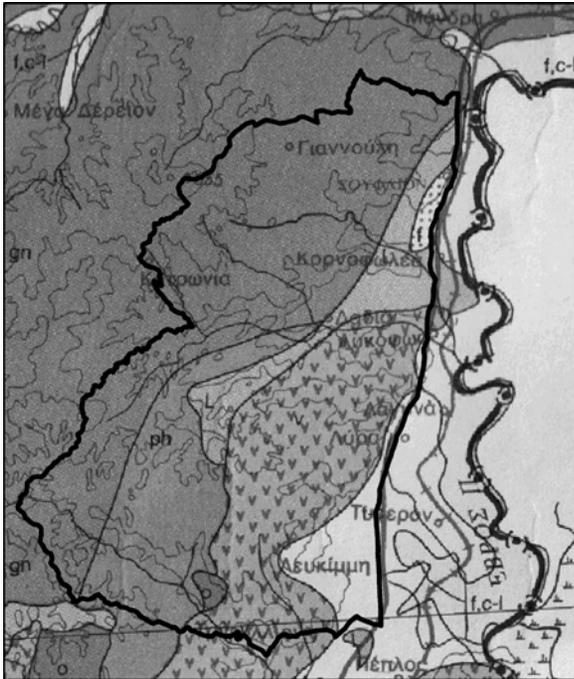


Fig. 5. Engineering geological map of the Dadia – Lefkimi – Soufli Forest National Park area. (Source: Andronopoulos et al. 1993.) Symbols: **gn**: metamorphic rocks, mainly gneisses and schists; **ph**: semi-metamorphic rocks, mainly phyllites; **L**: limestones, compact and often crystalline; **o**: ophiolites; **v**: volcanic rocks (lavas); **f**: neogene soil deposits, mainly fine-grained, and molassic sediments of Thrace (clays, silts, marls); **f-c**: neogene soil deposits of mixed phases (clays, sands, marls, sandstones, conglomerates); **f,c-l**: quaternary loose soil formations of mixed sizes and phases (clayey silts, sands, grits, gravels and cobbles of varying gradation and proportion, resulting from erosion of older rocks of varying composition).

The rock types within the CR belong to all the three main categories (igneous, metamorphic and sedimentary). The prevailing exposed rocks are igneous ones of the volcanic sub-group (pyroclastic conglomerates, andesites, trachytes, etc.) and sedimentary rocks (shales, sandstones, limestones and conglomerates, but also constituents of molasse formations). However, exposed, slightly metamorphosed rocks also occur (as phyllites and green schists) (Maganas 1988).

Apart from the rock formations belonging to the Rh and CR zones, there exist other rock and soil formations close to the DNP. These are found particularly in the flat, low-altitude areas and consist of c. 2000 m thick molassic series of conglomerates, sandstones, marls and marly limestones, with lignite horizons dating from the Middle Eocene – Oligocene and probably to the base

of the Miocene (Papadopoulos 1980, Katsikatsos 1992, Lalechos and Savoyat 1979). In addition, Miocene marine sediments of coastal facies (white, porous limestones, sandstones, marls and clays) as well as lacustrine deposits (alternating layers of sandstones, sands and sandy clays) cover the flat areas both within the DNP and in its surroundings.

Finally, Pliocene soil formations occur in the flat areas to the south-east of DNP, right up to floodplains of the River Evros. These are mainly yellowish, sandy marls, loams and clays of varying thickness and spatial distribution.

Paleontological evidence: The Evros petrified forest

In the large, low-lying, flat, south-eastern area adjacent to DNP that extends to the River Evros, abundant fossils of animals and plants have been discovered within tertiary volcano-sedimentary formations, which represent the climatic (sub-tropical) and geological conditions c. 20 – 25 my ago. Apart from certain fish teeth and bones, the most impressive findings of the paleontological studies in the area are well preserved parts of fossilized (silicified) trees (up to several metres long). These were part of a huge forest ecosystem of great biodiversity and are considered to be remnants of the oldest petrified forest found in Greece. Trees so far identified are pines, sequoias, cypresses and palms. Ongoing research in the surrounding area has also discovered coral reefs and numerous molluscs, evidence of a past shallow marine environment. The petrified forest of Evros was investigated gradually, from 1960 onwards, in the vicinity of the village of Fylakto (Municipality of Tycheron). It is covered by rock and soil of volcanic origin (mostly andesitic lavas) and has become known through the long and intensive research by many scientists and especially by Prof. E. Velitzelos (Velitzelos 1998, 2000).

Scientific research has also provided evidence to show that the area of the north-eastern Aegean has undergone large sea-level fluctuations from the upper Pleistocene to the present time (successive sea regressions and transgressions during the glacial and post-glacial periods, respectively). The last regression took place about 16,000 years ago and amounted to c. 90 – 125 m; it was followed by the final (Flandrian) transgression. Eventually, the sea level in this region stabilized, more or less, to its present level about 7,500 years ago, during which time large river deltas formed (such as that of the River Evros) through the deposition and accumulation of huge

quantities of fine sediments: sand, silt and clay fractions (Kraft et al. 1982).

Seismic activity

The tectonic history and seismic activity in southern Thrace and the northern Aegean Sea are caused, and controlled, by the presence of the North Anatolian Fault and the North Aegean Trough systems (Papanikolaou 1992, Sodoudi 2005). Their occurrence and influence are confirmed by geo-morphological data from Eastern Macedonia and Thrace on the development of the hydrographic network and the river basins (Lalechos and

Savoyat 1979). Although seismic activity is very strong in the North Aegean Sea region, it is mainly expressed as submarine earthquakes, and only a small number of seismic epicentres have been located in Thrace. The most widely known historic earthquakes manifested in Eastern Macedonia and Greek Thrace are the following (Mougiaris 1994, Papazachos and Papazachou 1997), given together with their Richter scale magnitudes (M):

52 A.C.: The first known large earthquake reported in the area of Kavala and which destroyed Philippi. M = 5.6.

1784: An earthquake that struck the region of Komotini. M = 6.3.

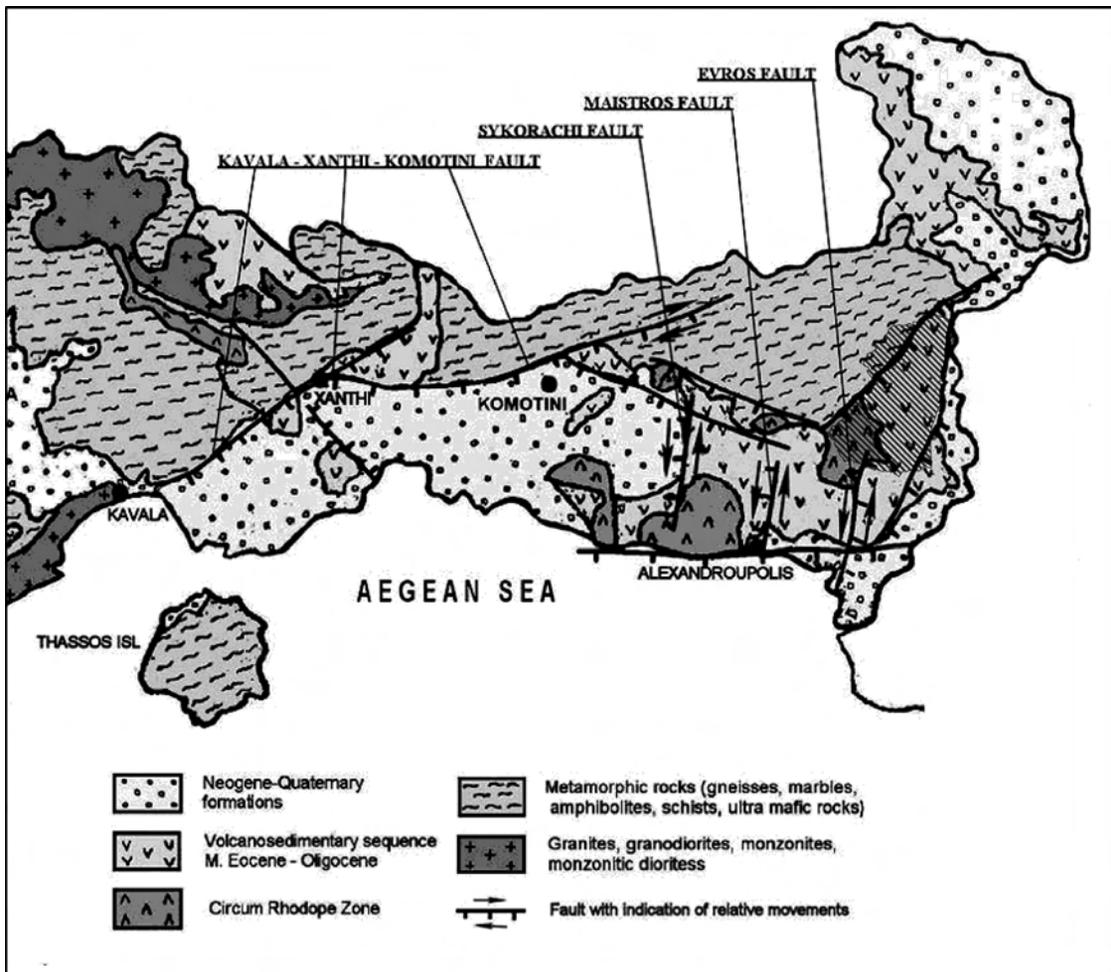


Fig. 6. Simplified geological map of eastern Macedonia-Thrace, where all major faults and their identified relative movements are presented. (Source: Rondoyanni et al. 2005, modified after Katsikatsos 1992).

1829: This earthquake had its epicentre near Drama, which was totally destroyed. It also struck the wider region of Eastern Macedonia, causing significant damage in Kavala, Xanthi, Eleftheroupolis and Edirne. $M = 7.3$.
1867: The epicentre of this earthquake was in the area of Drama, causing widespread damage. Strong shocks were reported all over the area from Thessaloniki to the Dardanelles and Edirne.

The most important neotectonic structure in the Greek regions of Eastern Macedonia and Thrace is the fault zone of Kavala-Xanthi-Komotini (c. 120 km), clearly visible in satellite images and aerial photos, which ends (more or less) in the valley of the River Evros. In addition, three other visible fault zones of much less importance, but still possessing considerable seismic potential for earthquakes of low to medium strength, are found in south-eastern Thrace and are therefore the nearest ones to the DNP, viz. Sykorachi (c. 21 km), Mastros (c. 9 km) and Evros (c. 11 km) (Fig. 6). They all have a general N – S direction and are characterized as active or potentially active faults, given their morpho-tectonic characteristics.

With respect to seismic hazard, Greece is divided into three zones (I low, II moderate, III high). The whole region of Thrace belongs to zone I (low risk). Nevertheless, lessons from recent destructive earthquakes, which have occurred after long periods of quiescence both in Greece (Athens in 1999) and in other countries (e.g. Kobe, Japan in 1996), stress the necessity for further research and proper civil protection measures in areas with moderate or even low seismicity, such as Eastern Macedonia and Thrace.

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