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ΣΥΝΔΕΣΜΟΣ ΓΕΩΛΟΓΩΝ ΚΑΙ ΜΕΤΑΛΛΕΙΟΛΟΓΩΝ ΚΥΠΡΟΥ

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CYPRUS ASSOCIATION OF GEOLOGISTS AND MINING ENGINEERS

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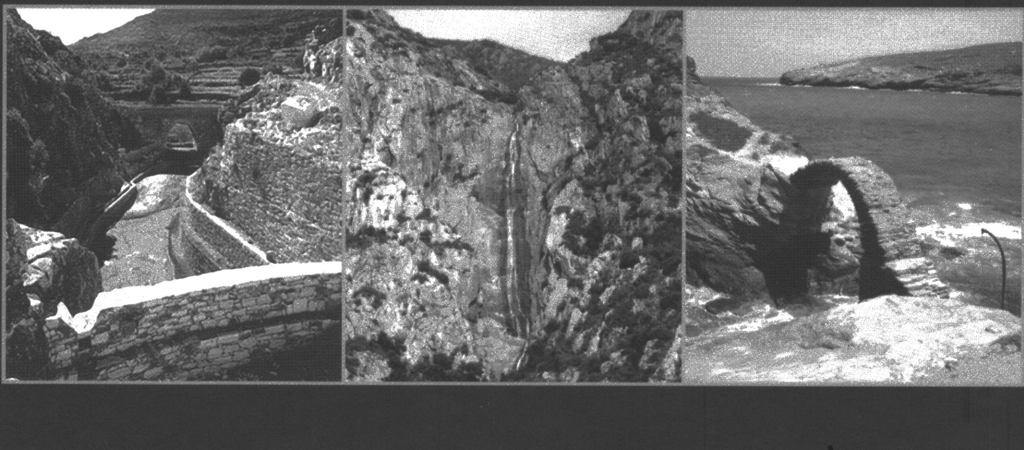

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GEOLOGICAL AND TECTONIC STUDY OF THE FISSURED ROCKS OF THE HELLENIDES AND THEIR HYDROGEOLOGICAL PATTERN

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Abstract
The present contribution is dealing with the outcrops and the hydrogeological behaviour of the fractured rocks (mainly igneous, metamorphic and not karstified carbonate rocks, as they have been defined by the I.A.H Commission of the Hard rock Hydrogeology). The presentation starts with the description of the geotectonic regime of the Hellenic territory into the adopted different geotectonic zones. For each zone a general lithological and structural description is attempted accompanied by the description of the main aquifers and the general features of the groundwater flow related to the formation of the rock mass fractures. Finally, an analytical description of some case studies is presented.

1. Introduction

Hellas from a geotectonic point of view corresponds to the world known Aegean or Hellenic Arc, in which the African plate converges to the European.

The alpine orogenetic system of Hellas, the so-called Hellenides, is composed by a set of geotectonic zones. Hellenides are extended primarily in N-S direction, changing southwards, in an E-W direction amd are subdivided to the following zones, from E to W (Figure 1):

1) Rhodope Massif
2) Servo-Macedonian Massif (or zone)
3) Axios Zone
4) Pelagonian Zone
5) Sub-Pelagonian Zone or Eastern Hellas Zone
6) Parnassos Zone
7) Pindos Zone (or Pindos-Olonos zone)
8) Gavrovo – Tripolis Zone
9) Ionian Zone
10) Paxi Zone.

At this point it should be mentioned that, in the frame of the Alpine orogenetic phase, some tectonometamorpic – tectonic units have been created sub parallel and transverse to the Hellenides structures. These units are partially different from the general system of the Hellenides. The most significant of them is the Atticocycladic Unit.

Hellenides based on different criteria are divided also, from E to W, into Internal and External Hellenides. Internal Hellenides comprise the massif and zones of Rhodope, Axios, Pelagonian, and Sub-Pelagonian, as well as the External contain the zones of Parnassos, Pindos, Gavrovo – Tripolis, Ionian and Paxi. The main criteria of this division, is the presence of the Upper Jurassic – Lower Cretaceous early orogenic phase, which resulted ophiolitic tectonic nappes and the Upper Cretaceous stratigraphical discordance. In the Internal part, the fractured rocks occur in greatest extend than in the External.

At this point it should be mentioned that, in the frame of the Alpine orogenetic phase, some tectonometamorphic – tectonic units, have been created subparallel and transverse to Hellenides structures. The most significant of them is the Atticocycladic unit and the Olympos – Ossa and Almyropotamos tectonic windows, which geotectonically correspond to the external Hellenides. We find that the fractured rocks occur mainly in the Internal Hellenides related to metamorphic rocks and ophiolites (Mountrakis 1985, Ferriere 1982, Katsikatsos et al. 1986, Krasny 2002, Meyer & Pilger 1963).

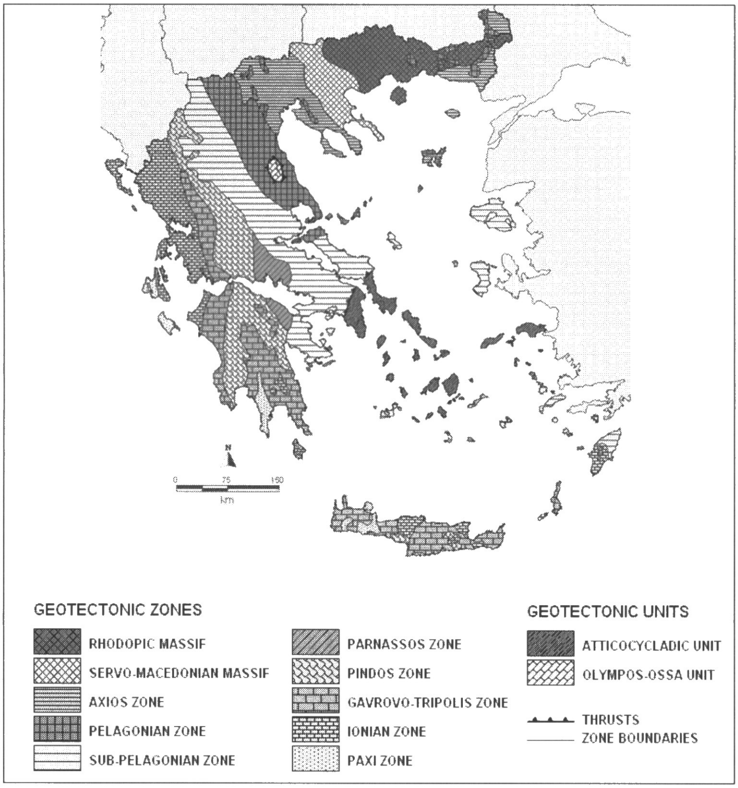

Figure 1. Geotectonic sketch map of Hellenides.

2. Geotectonic zones - Structural pattern - Fissure rocks hydrology

1) *Rhodope Massif* is characterized by the occurrence of gneiss (mainly orthogneiss), schists (mainly mica-schists) and amphibolites, in alterations with marble horizons. It is subdivided in the following two tectonic units (t.u.):

a) Sidironero t.u. where orthogneiss, micaschists, amphibolites and intercalations of marbles occur.
b) Paggaeo t.u., which is composed by three sequences: i) a lower of orthogneiss, micaschists, schists and amphibolites ii) a middle of marbles with intercalations of mica-schist and amphibolites, and iii) an upper with alterations of schists and marbles.

The magmatic rocks are composed of Carboniferous to Cretaceous plutonic masses (granites, granodiorites, monzonites and diorites) and Eocene to Oligocene volcanic rocks (rhyolites, dacides, andesites and dolerites).

Tectonic Analysis

The orientation analysis of the tectonic and microtectonic regime Rhodope Massif is shown on the following Table 1, and on Figure 2.

The aquifers

The main aquifers of the Rhodope massif are located both in Sidironero t.u. and Paggaeo t.u., as these units are composed mainly by metamorphic rocks, which are the typical fractured media included within the considered and examined fractured rocks environment. Even in the case of the marble sequence, where karstification occurs, the horizons of schist into the sequence as intercalations could be included in the fissured rock sequence.

As far as the igneous phase concerns, both plutonic and eruptive rocks are included within the considered and examined fissured rocks.

Regarding the relation between the groundwater storage and flow and the fracturation existed, some comments can be cited, valid for all the outcrops of the discussed formations in all geotectonic zones. For the plutonic rocks, the fracturation is limited in shallow depths except the zones of tectonic events. In the case of the eruptive formations, the secondary porosity becomes denser since before the fracturation induced by the tectonic action, another system of preexistent discontinuities have been induced by the "rapid" cooling of the magma at or near the ground surface.

Table 1. Tectonic elements of Rhodope massif.

Bedding or Schistosity	N70°W/30°-40°NE (main) N50°E/20°-30°NW
Fold axis	
Thrusts	N40°-60°W/30°-40°NE
Shear zones	N45°E/70°-80°NW or SE
Faults / Fault zones	N50°-70°W/60°-70°SW or NE N40°-60°E/60°-70°SE or NW N20°W-N20°E/80°E or W
Diaclases	N40°-50°E/70°-80°SE or NW N50°-60°W/70°-80°SW or NE

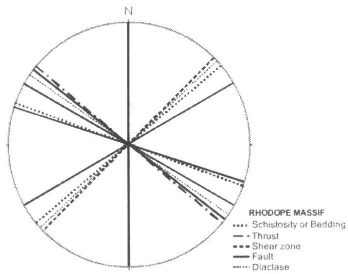

Figure 2. Rose diagram of tectonic elements.

2) *Servo-Macedonian Massif (or zone)* is composed by a thick metamorphic formation of marbles, schists and gneisses. The hall metamorphic sequence is cross cutted by granitic intrusions and is divided in two sub-sequences:

a) The lower one of Kerdilia, consists of alterations of marbles and gneisses, with intercalation of amphibolites. In the marble horizons, gneisses and schists appear frequently.
b) The upper one of Vertiskos, which is composed by alterations of micaschists, gneisses, with thin intercalation of marbles. In the upper part of the sequence metagabbros, metadiabases, amphibolites and bodies of serpentinites are tectonically placed in many cases.

At the western boundary of the Serbo-Macedonian Massif, there are outcrops of very low grade metamorphism Permian -Triassic sediments. Granites also occur, which belong to three different magmatic phases of Upper Paleozoic, Jurassic and Oligocene age respectively.

Tectonic analysis

The orientation analysis of the tectonic and microtectonic regime Serbo-Macedonian Massif is shown in the following Table 2, and in Figure 3.

The aquifers

As it can be seen from the description above, the composition of the Servo–Macedonian Massif (gneisses, schists, amphibolites, granites and Neogene's volcanic rock masses) corresponds to the typical hydrogeological environment of the fractured rock aquifers. The extent of these rocks makes them an important aquifer system for all water uses.

Table 2. Tectonic elements of Serbo-Macedonian massif (or zone).

Bedding or Schistosity	N40°-60°W/30°-40°NE
Fold axis	
Thrusts	N30°-40°W/50°NE
Shear zone	N40°E/70°-80°NW or SE
Faults/ Fault zones	N30°-50°W/80°SW or NE N60°-80°W to E-W/70°N or S N20°-40°E/60°-70°SE or NW N60°-70°E/70°SE or NW
Diaclases	N20°-30°E/70°-80°SE or NW N40°-50°W/70°-80°SW or NE

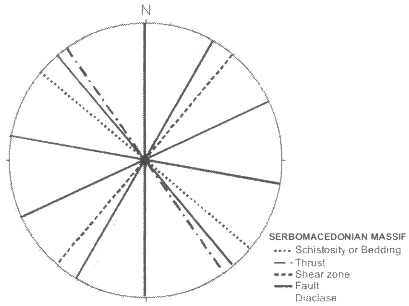

Figure 3. Rose diagram of tectonic elements.

3) *Axios Zone* is characterized by the intense tectonic events, where folding and thrusting occur. Axios zone is subdivided (from E to W) in the following sub-zones: (a) Peonia, (b) Paiko and (c) Almopia Zone.

The formations that occur in the Axios Zone are the following:

a) Sedimentary and volcano – sedimentary formations of Mesozoic age. These formations are composed by cherts, limestones, volcanic beds and intrusions, tuffs and pyroclastics. Additionally, intrusions of quartz-diorites occur.
b) Ophiolitic formations, which are mainly ultra basic rocks, gabbros, pyroxenites and basaltic lavas with intercalations of pelagic sediments.
c) Formations which are composed by alterations of schists, sandstones, conglomerates and limestones. These formations are of Upper Jurassic-Cretaceous age, and are overlying transgressively the previous formations.

Tectonic analysis

The orientation analysis of the tectonic and microtectonic regime Axios Zone is shown on Table 3, and on Figure 4.

The aquifers

Due to the intense tectonics and to the nature of the formations, Axios zone is a typical example of the fractured rocks hydrogeological environment. The extent of the fractured rocks makes them an important aquifer system for all water uses.

Table 3. Tectonic elements of Axios zone.

Bedding or Schistosity	N30°-40°W/30°-40°NE
Fold axis	
Thrusts	N20°W/50°NE
Shear zone	N-S/80°E N50°-60°E/80° SE
Faults/ Fault zones	N40°-50°W/70°SW or NE N50°-60°E/60°-70°SE or NW N-S/70°-80°E or W E-W/70°-80°N or S
Diaclases	N30°-40°E/70°-80°SE or NW N40°-50°W/70°-80°SW or NE

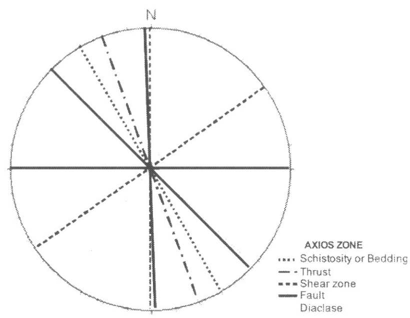

Figure 4. Rose diagram of tectonic elements.

4) *Pelagonian Zone* is composed by the following sequences, from base to top:

a. The crystalline basement, where alterations of gneisses, schists and amphibolites occur.
b. The granites – migmatites of Upper Carboniferous, which are intruding into the crystalline basement.
c. The Perm Triassic meta-clastic sequence, which transgressively overlies the above formation. It is composed by volcanic rocks, acid or basic lavas and tuffs as well.
d. The Triassic-Jurassic carbonaceous sequences, which correspond to the platform sendimentation of alpine system. All previous formations have been metamorphosed during the Upper Jurassic – Lower Cretaceous period in green schist phase.
e. The ophiolitic formations, which constitute an extent tectonic nappe.
f. The transgressively overlie Cretaceous formations composed of crystalline limestones, which ends up to the meta-flysch formation.

Tectonic analysis

The orientation analysis of the tectonic and microtectonic regime Pelagonian Zone is shown on Table 4, and on Figure 5.

The aquifers

Gneiss-schists, schists, granites and ophiolites, are typical example of discontinuous media included within the considered and examined fractured rocks. The extent of the fractured rocks makes them an important aquifer system for all water uses.

Table 4. Tectonic elements of Pelagonian zone.

Bedding or Schistosity	N30°-50°W/40°NE (main) N40°-60°E/60°NW
Fold axis	
Thrusts	N30°-60°W/45°NE
Shear zone	N50°-60°E/60°-80° NW or SE
Faults/ Fault zones	N40°-50°W/70°SW or NE N40°-60°E/60°-70°SE or NW N20°W-N20°E/70°-80°E or W
Diaclases	N40°-50°E/70°-80°SE or NW N30°-40°W/70°-80°SW or NE

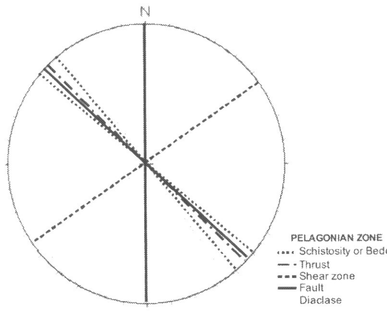

Figure 5. Rose diagram of tectonic elements.

5) *Sub-Pelagonian Zone* (zone of Eastern Hellas) is characterized by the intense lithological transformations within its whole extent. The stratigraphy of the zone is the following:

a) Neo-Paleozoic formations which are composed of sandstones, phylittes and schists.
b) Formations of Lower – Middle Triassic which are composed of i) sandstones, ii) basic volcanic rocks and iii) intercalations of limestones.
c) Neritic limestones of Middle Triassic-Upper Jurassic. Locally, the neritic sedimentation pass to pelagic with radiolarites, pellites, clay schists, etc.
d) Clastic formations of Upper Jurassic - Lower Cretaceous which are composed of radiolites, conglomerates, sandstones and shales with olistostromes of ophiolites.
e) A tectonic nappe of pre-upper Cretaceous age, which is divided in two tectonic units. A lower unit which is composed of volcano-sedimentary formations, and an upper one, which is composed by ophiolites.
f) Formations of upper Cretaceous composed of limestones, which are lying transgressively over the previous formations. Finally flysch of Paleocene occurs.

Tectonic analysis

The analysis of the (micro) tectonic regime Sub-Pelagonian zone is shown on Table 5 and Figure 6.

The aquifers:
The Neo-Paleozoic formations which are composed of sandstones, phylittes, schists and the tectonic cover of pre-upper Cretaceous age, consists the fracture rocks environment of the given zone. The extent of the fractured rocks makes them an important aquifer system for all water uses.

Table 5. Tectonic of the sub-Pelagonian.

Bedding or Schistosity	N30°-40°W/40°NE (main) N70°-80°W/45°NE N50°-60°E/50°SE or NW
Fold axis	
Thrusts	N20°-40°W/40°-50°NE N30°-50°E/50°-60°NW
Shear zone	N45°E/50°-60° NW or SE E-W/70°-80° N or S
Faults/ Fault zones	N60°-70°W/60°-70°SW or NE N40°-60°E/60°-70°SE or NW N10°-20°W/70°-80°NE or SW E-W/70°-80°S or N
Diaclases	N30°-50°E/70°-80°SE or NW N20°-40°W/70°-80°SW or NE

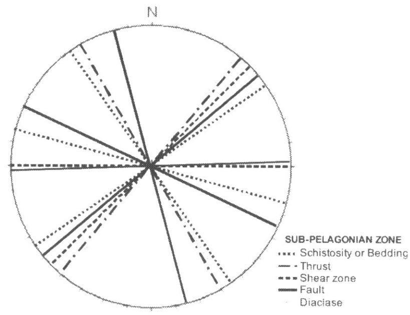

Figure 6. Rose diagram of tectonic elements.

6) *Parnassos Zone* which is characterized by the continuous neritic carbonate formation, typical karst configuration and intense paleogeographic evolution, reflected on the three characteristics bauxite horizons. The carbonate sequence pass upwards to the flysch formation of Upper Cretaceous Lower Paleocene age. Pre-alpine basement is not recognized in this zone, while the eruptive rocks are totally absent.
Tectonic Analysis
The orientation analysis of the tectonic and microtectonic regime Parnassos Zone is shown on Table 6 and on Figure 7.
The Aquifers:
The absence of crystalline or igneous, rocks and the simultaneous presence of karst configuration in the neritic formations, excludes this zone from the typical hydrogeological environment of the fractured rock aquifers.

Table 6. Tectonic of Parnassos zone.

Bedding or Schistosity	N40°-50°W/40°NE
Fold axis	
Thrusts	N10°W/50°-60°NE
Shear zone	N70°-80°E/80° NW or SE
Faults/ Fault zones	N30°W/60°-70°SW or NE N60°W/60°-70°SW or NE N40°E/60°-70°SE or NW
Diaclases	N30°-50°E/70°-80°SE or NW N40°-60°W/70°-80°SW or NE

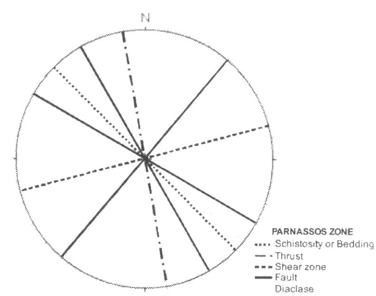

Figure 7. Rose diagram of tectonic elements.

7) *Pindos-Olonos Zone* is considered the "backbone" of the Hellenides Mountain Chain, extending from Epirus area to Peloponnesus. Small outcrops of this zone are located in Crete and in some islands of south Aegean Sea. The main characteristic of this zone is that during the alpine orogenetic process, it was a deep sea. From a geotectonic point of view, Pindos Zone is located between the Sub-Pelagonian and the Gavrovo-Tripolis Zone. Lithologically the older deposits are dolomites and limestones of Middle-Triassic age, which in some cases are lying over clastic rocks (sandstones) of Middle-Triassic age as well. In the Upper-Triassic limestones of pelagic phase are present with some intercalations of cherts and shales. During Jurassic alterations of cherts, clay schists, pelagic limestones and sandstones, occur. At Lower Cretaceous alterations of brescia, conglomerates, sandstones and shales are the dominant formation, with characteristics similar to those of the flysch formation (first flysch of Pindos). A second sequence of thin bedded pelagic limestones is lying over the first flysch, until the start of Paleocene, where the typical flysch (alterations of sandstones, shales, with intercalation of conglomerates) occurs.

Tectonic analysis

The orientation analysis of the tectonic and microtectonic regime Pindos Zone is shown on Table 7, Figure 8.

The aquifers

Despite the absence of crystalline and igneous rocks, in Pindos zone, the thin bedded limestones, the radiolarites and some horizons of flysch (sandstones) due to the intense folding and thrusting, cause a rather quick drainage of the groundwater. The aquifers in those formations present very similar properties with the typical hard rock aquifer especially since the limestone very rarely presents the typical karstic geoforms.

Table 7. Tectonic elements of Pindos zone.

Bedding or Schistosity	N20°W/50°-60°NE
Fold axis	N10°-30°W/20°-40°NW or SE
Thrusts	N20°-40°W/50°NE
Shear zone	N70°E to E-W/70°-80°N or S
Faults/ Fault zones	N10°-20°W/60°-70°SW or NE E-W/70°-80°S or N
Diaclases	N20°-30°E/70°-80°SE or NW N10°-20°W/70°-80°SW or NE

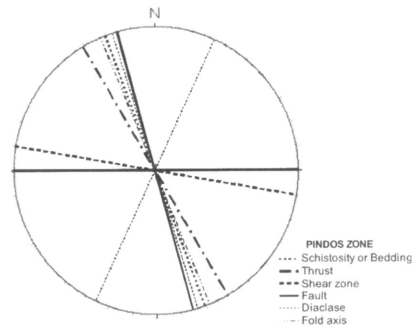

Figure 8. Rose diagram of tectonic elements.

8) *Gavrovo-Tripolis Zone* is composed by continuous neritic carbonate formations from the early stages to the end of Mesozoic. Limestones of thick bedded to unbedded forms presenting typical karst configuration. The carbonate rocks pass upward to the flysch formations consist of sandstones, conglomerates and shales.

Tectonic Analysis

The orientation analysis of the tectonic and microtectonic regime Gavrovo-Tripolis Zone is shown on Table 8, and on Figure 9.

The aquifers

The groundwater flow in this zone is mainly controlled by large karstic conduits.

Table 8. Tectonic elements of Gavrovo-Tripolis zone.	
Bedding or Schistosity	N20°W/40°NE
Fold axis	N20°W/30°-50°NW or SE
Thrusts	N20°W/50°-60°NE
Shear zone	N70°-80°E/80° NW or SE
Faults/ Fault zones	N20°-40°W/70°-80°SW or NE N40°-60°E/70°-80°SE or NW
Diaclases	N40°-50°E/70°-80°SE or NW N20°-30°W/70°-80°SW or NE

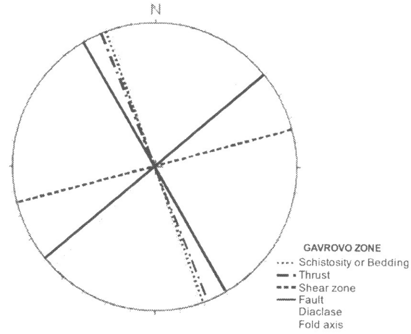

Figure 9. Rose diagram of tectonic elements.

9) *Ionian Zone* is characterized by the presence of evaporates above which there is a thick Mesozoic carbonate sequence, of Permian – Triassic age. Their thickness is 1500m approximately. The Lias member, comprise alterations of cherts with marly limestones and shales. To the west this formation pass trangressively to the red limestones. Typical pelagic limestones occur in the Malm with intercalations of cherts (Vigla Limestones). The last formation before the flysch depository is the pelagic limestone breccia of Upper Cretaceous age. The flysch (Upper Eocene-Lower Miocene) of Ionian zone is composed by alteration of marls and sandstones, at its lower parts, while in upper parts is composed by alterations of marls, marly limestones and conglomerates.

Tectonic analysis

The orientation analysis of the tectonic and microtectonic regime Ionian Zone is shown on Table 9, and on Figure 10.

The aquifers

Despite the fact that this zone is characterized by the absence of crystalline or igneous rocks, some sequences present typical characteristics of hard rock aquifers due to the intercalation of cherts and of marly limestones.

Table 9: Tectonic elements of Ionian zone.	
Bedding or Schistosity	N20°W/50°-60°NE
Fold axis	N10°-20°W/10°-30°NW or SE
Thrusts	N10°-30°W/50°-60°NE
Shear zone	N45°E/50°-60° NW or SE E-W/70°-80° N or S
Faults/ Fault zones	N40°-60°W/60°-70°SW or NE N40°-60°E/60°-70°SE or NW N10°-20°W/70°-80°NE or SW E-W/70°-80°S or N
Diaclases	N20°-40°E/70°-80°SE or NW N40°-60°W/70°-80°SW or NE

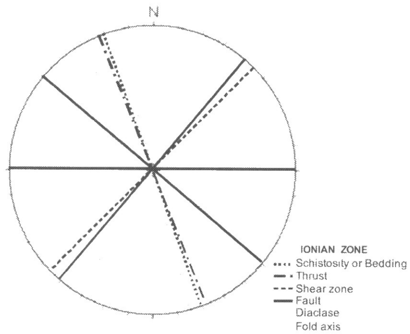

Figure 10. Rose diagram of tectonic elements.

10) *Attico-Cycladic Unit (Complex)* has a tectono-metamorphic character, as it comprises by concatenations of tectonic covers and windows, of ophiolites and metamorphic rocks (schists, gneiss-schists, amphibolites, greenschists, glaucophane schists). These rocks were created under the frame of three metamorphic phases: (i) Greenschist to amphibolitic phase of Palaeozoic age,

(ii) High Pressure-Low temperature phase of Eocene age and (iii) Greenschist Phase of Oligocene-Miocene age.
Additionally plutonitic intrusions of granitic composition are taking place at Miocene.

Tectonic Analysis

The orientation analysis of the tectonic and microtectonic regime Attico-Cycladic Unit is shown on Table 10, and on Figure 11.

The aquifers

The complex tectono-metamorphic frame of Attico-Cycladic Unit corresponds to the typical hydrogeological environment of the fractured rocks. This is very important for the Cyclades Islands, where the fractured rocks represent the main or the unique aquifer in an environment of limited precipitation, of strong evaporation conditions (temperature, wind) and of limited islands surface.

Table 10: Tectonic Elements of Attica-Cyclades unit.

Bedding or Schistosity	N30°W/50°-60°NE N70°E/20-30°NW or SE N40°E/40°-50°SE or NW
Fold axis	
Thrusts	N50°-70°W/50°NE or SW N30°-50°E/40°NW or SE
Shear zone	N60°-80°E/60°-70 °NW or SE
Faults/ Fault zones	N60°-70°W/60°-70°SW or NE N30°-40°E/60°-70°SE or NW N10°-20°W/70°-80°NE or SW E-W/70°-80°S or N
Diaclases	N20°-40°E/70°-80°SE or NW N60°-80°W/70°-80°SW or NE

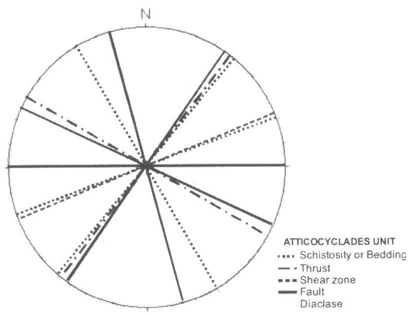

Figure 11. Rose Diagram of tectonic elements.

Summarizing the lithological description of Hellenides, a map of the fractured rocks, was composed in which the fractured rock outcrops is shown. (Stournaras et al. 2007, Figure 12).

3. Case studies

In order to depict the characters of the fractured rocks, comprehensively, five case studies from different regions of Hellas were selected to be presented. These case studies are:

1) Rhodope area
2) Olympus-Ossa Mts.
3) Othrys Mt.
4) Euboea Island.
5) Cyclades island complex
6) Tinos Island.

1) *Rhodope area*

The fractured rocks encountered in the massif of Rhodope (Figure 13) are:

- Metamorphic formations, composed by gneiss, schist, amphibolites, migmatites and marbles.
- Plutonic rocks (granites, granodiorite, monzonites, diorites).
- Eruptive rocks (rhyolites, andesites, dacides, dolerites).

The metamorphic formations constitute the basement of the discussed area, presenting a geotectonic position compared with the East Mediterranean arc. The presence of the eruptive bodies is related to the tectonic regime of the Tertiary (Meyer & Pilger 1963, Kronberg & Raith 1977, etc).

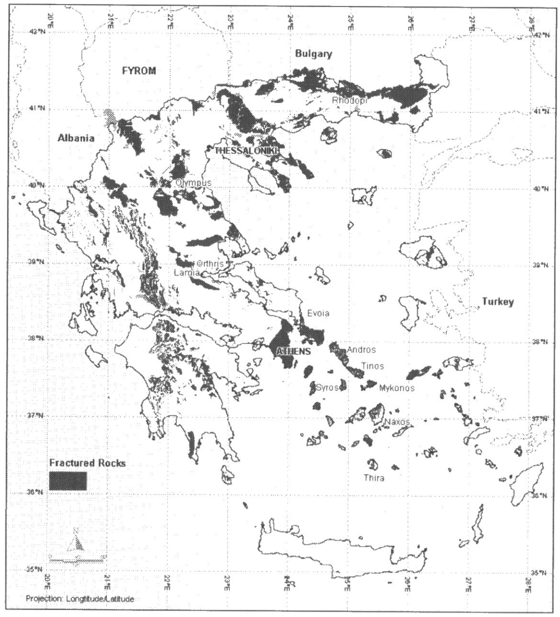

Figure 12. The fractured rock outcrops in Hellas.

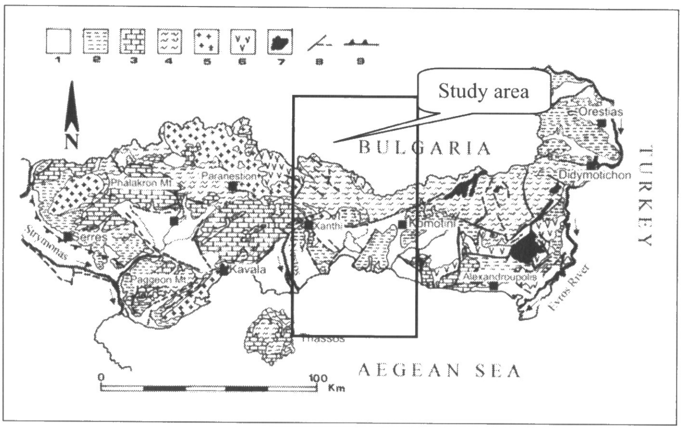

Figure 13. Geological map of Rhodope massif: 1.Quaternary formations; 2.Neogene formations; 3.Marbles; 4.Metamorphic formations, mainly amphibolites, gneisses and schists, with marble intercalations; 5.Granites; 6.Volcanic rocks; 7. Ophiolites, mainly serpentinites and diabases; 8.Faults; 9.Thrusts.

The metamorphic system is divided into two tectonic unit (T.U.). The Paggaeo T.U., is overthrusted on the Sidironero T.U., additionally containing ophiolites, mainly ultra basic rocks. The totality of the igneous and metamorphic rocks, with the exception of the intermediary horizon of the marbles, behave as a typical discontinuous media, adapted to the hydrogeology and groundwater hydraulics of the fissured (hard) rocks. The detailed behavior is connected to the above mentioned tectonics of the area and to the post alpine extensional faulting as well. Consequently, the main rupture lines are related to:

- Folds of direction: (i) N-S, NE-SW and NW-SE as the result of the successive stages of the metamorphism; (ii) NW-SE as the result of the thrust of the Paggaeo T.U. above the Sidironero T.U..
- Main faults of direction N 30°-70° and secondary of direction E-W and N 20°.

From the hydrogeological point of view, the classification that could be established is:

- Relatively high permeable formations: non karstified marbles and Tertiary volcanic rock formations (rhyolites, andesites, dacites, tuffs and pyroclasts).
- Medium permeable formations: granites, diorites.
- Less permeable formations: schists, gneisses, ultra-basic formations.

The amphibolites intercalations within the marble bodies form some difficulties in the frame of the consideration of ground watersheds and of the boundary conditions. The same difficulties appear in the case of the granitic intrusions, where the fracturation and the erosion thickness, connected to the groundwater thickness, depend on the local structural and tectonic conditions.

As it becomes clear from local researches and studies the diaclases, thus the directions of the groundwater flow, originated from the tectonic and structural action are, in general, well organized, while another secondary porosity, originated from the rapid cooling of the magma, presents a chaotic character.

The study area that was chosen for further investigation is the Xanthi area (Figure 14), where springs are emerging from marbles, volcanic rocks, granites and schists. Thermal springs emerging from schists are also located.

Springs emerging from marbles. At the North-Eastern part of Xanthi, schists are characterized by lenticular intercalations of marbles where springs are emerging. Their chemical characteristics are shown at Table 11. Geo-chemically these springs are classified as normal geo-alkaline, (mainly bicarbonate) and belong to the hydrochemical type Ca-Mg-HCO_3. The hardness ranges from 5.4 to 10.4°dH (German degrees), characterizing the water from soft to hard. TDS ranges between 179.6 and 350.0 mg/l, with an average value of 250.0 mg/l. The dominant cations are the calcium and the magnesium the dominant anions are the bicarbonate and the sulftate ones. Generally, the waters are of good quality.

Springs emerging from volcanic rocks. Volcanic rocks springs are characterized by low values of dissolved solids, the low rate of hardness and their alkaline character. These waters contain few metals, and are classified as geo-alcaline, corresponding to the hydrochemical type Ca - Na - Cl - HCO_3.

Springs emerging from granites. The main characteristics of these springs are low values of dissolved solids, the low rate of hardness and the alkaline character. They contain few metals; and are classified as geo-alkaline, corresponding to the hydrochemical type Ca - Na - HCO_3.

Springs emerging from schists. The main characteristics of these springs are low values of dissolved solids, the low rate of hardness and the alkaline character. Their water is classified as normal geo-alkaline, corresponding to the hydrochemical type Ca-Na-Cl-HCO_3. The hydrogeological environment of these springs corresponds to the typical one of fractured rocks. Some of the springs are emerging directly from fractures. In some other cases, groundwater percolates through the weathered mantle to the fractured zone, and emerges through the intersection of the topographical surface and the fractured zone / bedrock contact.

Thermal spring of Thermes. The thermal spring of Thermes (Figure 14, spring S5) is located in Xeropotamos basin, emerging from schists. Its occurrence is strongly related to the fractured pattern of the surrounding area. The water temperature ranges between 33°C and 43°C. The "Thermes" spring has the hydrochemical type Na-Ca-HCO_3. The amount of the dissolved solids runs up to 1200.0 mg/l. The spring has alkaline characteristics and according to the temperature degree it is classified in the category of mesothermal springs.

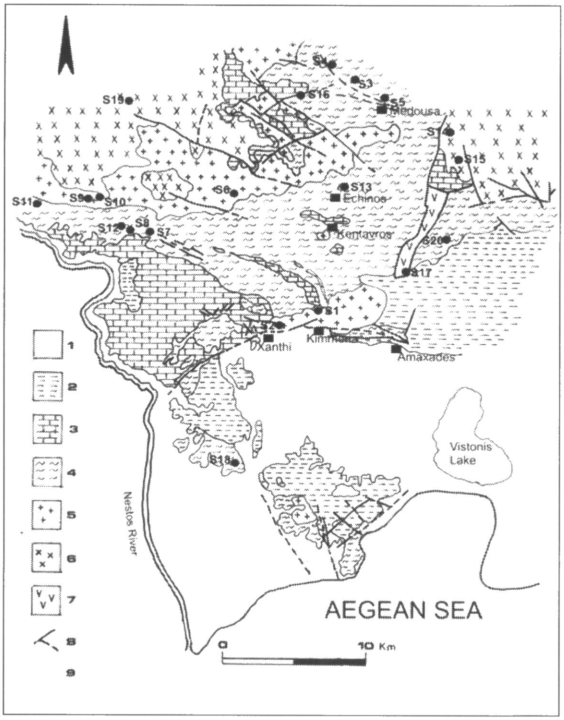

Figure 14. Geological map of Xanthi area (western Rhodope): 1. Quaternary formations; 2. Neogene formations; 3. Marbles; 4. Schists and Gneisses; 5. Granites; 6. Volcanic rocks (Andesites and Dacites); 7. Ophilites (mainly ultrabasic masses); 8. Faults; 9. Springs (S1).

Table 11. Hydrochemical characters of the springs the Xanthi area.

	Marble			Schists			Granites			Volcanic rocks			Thermal water
	min	max	aver	min	max	aver	min	max	aver	min	max	aver	
T °C	14,7	17,3	15,6										33 - 43
pH	7,8	8,7	8,3	8,0	8,1	8,0	8,8	9,1	9,0	7,5	8,1	8,2	7,3
EC (μS/cm)	235	484	332	126	185	156	11,5	19,5	15,5	61	130	96	1369
Ca^{2+}(mg/l)	24,1	54,5	43,1	22,8	27,6	25,2	8,8	13,6	11,2	6,0	15,1	10,7	136,4
Mg^{2+} (mg/l)	6,8	11,9	7,7	2,2	2,4	2,3	1,5	2,4	2,0	1,0	2,2	1,7	10,0
Na^{+}(mg/l)	4,7	12,0	10,5	3,1	4,0	3,6	9,2	18,0	13,6	5,2	6,7	5,8	171,8
K^{+}(mg/l)	1,0	2,2	1,4	0,7	1,3	1,0	4,1	4,3	4,2	0,9	1,4	1,1	19,6
HCO_3^- (mg/l)	79,3	201,3	140,5	67,1	88,4	77,8	32,9	34,2	33,5	12,2	54,9	35,1	652,7
Cl^- (mg/l)	7,8	26,5	13,6	10,6	12,4	11,5	5,3	7,1	6,2	5,7	10,6	7,5	64,5
SO_4^{2-} (mg/l)				0	0	0	2,5	13,2	7,8	38,4	0,0	19,7	144,5
NO_3^- (mg/l)	0,5	32,0	4,7	0,2	17,0	8,6	0	0	0	0,0	17,0	4,3	1,0
TDS (mg/l)	179,6	350,0	250,0	125,0	135,0	130,0	81,5	93,6	87,6	37,9	103,8	75,4	1200
Tot. Hard.*	5,4	10,4	8,2	3,7	4,4	4,0	2,8	4,4	3,6	1,1	2,6	2,1	21,4
Temp.Hard.*	3,6	9,2	7,1	3,1	4,1	3,5	2,8	4,4	3,6	0,1	0,8	0,4	16,7
Perm.Hard*	1,8	1,2	1,1	0,6	0,3	0,5	0	0	0	1,0	1,8	1,7	4,1

2) *Olympos-Ossa Mts.*

The geological composition of Olympos and Ossa mountains (Figure 15) is complicates, composed by several units, which are the following, in a tectonic window structural form (Ferriere et al. 1998, Godfriaux 1962, Katsikatsos et al. 1982, Stamatis 1999, Stamatis & Migiros 2004):

Olympos-Ossa Unit. The formations of this unit, occupy almost entirely Olympus Mt, and Ossa Mt. It is a series of crystalline limestones and dolomites and it is equivalent to the Gavrovo Zone. Their sedimentation occurs in continuation as a neritic environment, from Triassic up to Eocene (Lutetium). This series ends up in slightly metamorphic flysch formations.

Ampelakia Unit. This complex is mainly composed by different rock types of schists, gneiss-schists, gneisses and prasinites, with some intercalations of marbles, meta- basalts, meta-greywacke and meta-pelites, characterized by a blueschist phase of metamorphosis. These formations present an intense degree of folds, faults and alteration phenomena. From hydrogeological point of view, the formations of the sequence present a variable permeability connected to the presence of the gneisses or prasinites, which improve the hydrogeological behavior of the totality of the different lithological phases.

Pelagonian Unit. This complex, entirely metamorphosed, is composed by the following hard rocks sequences:

- The Paleozoic crystalline basement, by gneisses, amphibolites and amphibolitic schists and migmatites, with gneissic character and granitic texture.
- The Neo-Paleozoic - Middle Triassic formations, by gneiss, gneissic schist, mica schist, etc. with intercalations of marbles.
- The Pre-Upper Cretaceous tectonic nappe, by metamorphosed ophiolites (basic and ultra-basic rock formations).

The occurrence of gneiss is also connected with the improvement of the hydrogeological behavior of the totality of the different lithological phases. The case of the basic rocks seems to be interesting related to the folding (syncline structure) although the depth of the diaclases, thus the thickness of the groundwater table, seems to be rather limited.

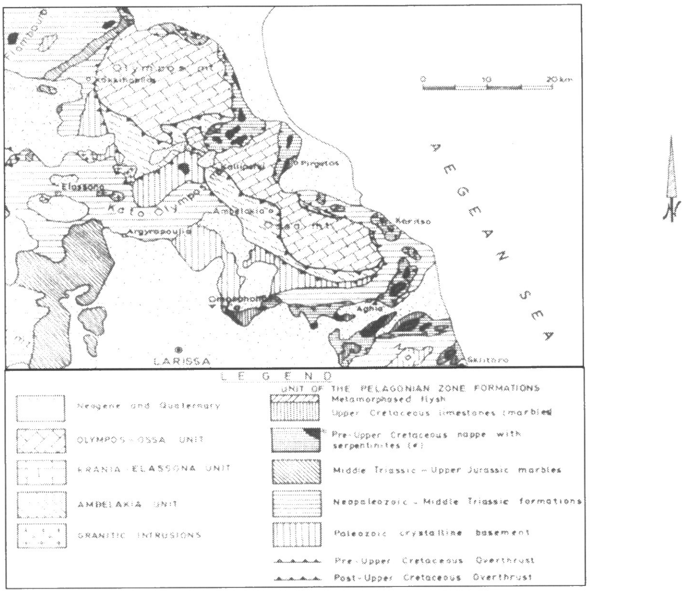

Figure 15. Olympos-Ossa Geological Map (Katsikatsos et al., 1986).

The tectonics of the area is characterized by folds, faults, and thrusts, which their direction is shown in (Figure 16).

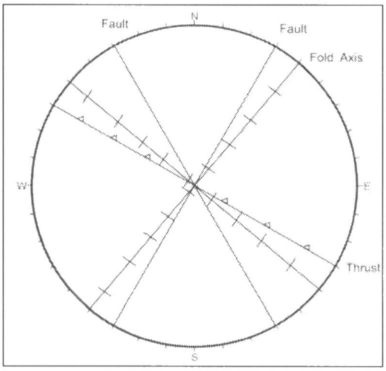

Figure 16. Rose diagram of major fault, thrust and diaclase orientations of Olympos-Ossa region.

The groundwater occurrence is directly related to the depth, where the granitic fracturation and alteration exceeds. The latter can be remarkable within the zones of the tectonic events.

<u>Conclusion originated from the tectonic data</u>

The main tectonic direction is N30°-60°W, which is combined with axes of structures, thrusts and faults. The direction N30°-70°E is another main tectonic direction combined with axes of structures and faults. Secondary directions are also encountered.

Related to the structural geology conditions, guiding the groundwater circulation within the fractured (hard) rocks of the given area, the rose diagram on figure 16 shows that the orientation relation between folds and faults present a remarkable constancy, while the relationship between faults present an analogous constancy.

It should be noticed that lineaments that derived from Landsat - 7 ETM+ images (Figure 17), present the same orientation with fault systems of NE-SW direction. The general orientation of thrusts is NW-SE.

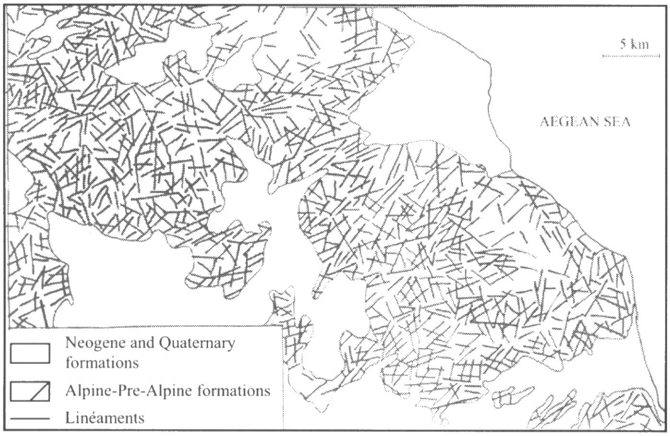

Figure 17. Lineaments of Olympos – Ossa region.

Finally, some hydrogeological and hydrochemical characters of the discussed groundwater manifestations are given in Table 12.

Table 12. Hydrochemical characters of the Olympos – Ossa area.

	Marble			Gneisses			Ultrabasic			Metaflysch			Schists			Serpentinites			Thermal water
	min	max	aver	min	max	aver	min	max	aver	min	max	aver	min	max	aver	min	max	aver	
T °C	11,7	14,9	13,63	11,5	17,6	13,83	6,5	12,3	9,8	9,6	13,6	11,98	11,4	14,6	13,2	7	7,2	7,1	14,5
pH	7,1	7,4	7,2	7,3	7,5	7,43	7,1	7,9	7,48	6,8	8,2	7,3	6,7	7,6	7,3	7,1	7,5	7,3	5,3
EC (μS/cm)	277	465	375	250	375	317	65	436	259	203	582	314	162	505	334	234	348	291	2447,0
Ca^{2+} (mg/l)	38,2	62,4	53,9	25,6	56	41,2	3,4	45	31,2	24	97,6	45,57	8,8	72,8	41,78	9,6	44,8	27,2	408,0
Mg^{2+} (mg/l)	7,5	23	12,8	5,6	12,2	9,1	3,3	23,9	12,75	3,2	16,1	8,06	3,9	21,7	13,27	12,9	20,2	16,55	121,7
Na^{+} (mg/l)	5,3	10,8	7,83	7,2	10,6	8,3	2,4	8,6	4,42	1,3	8,2	5,41	1,9	11,8	7,07	1,6	3,2	2,4	8,4
K^{+} (mg/l)	0,4	1	0,6	0,1	0,7	0,35	0,3	0,5	0,37	0,3	0,8	0,48	0,3	1,4	0,88	0,3	0,5	0,4	1,5
HCO_3 (mg/l)	136,6	262,3	195,6	122	201,3	167,8	26,8	244	146,8	122	353,8	175,3	61	298,9	186,4	122,5	195,2	158,9	1750,7
Cl^{-} (mg/l)	7,1	24,8	15,2	14,2	24,8	18,6	3,5	17,7	12,4	5,3	17,7	12,3	5,3	28,4	14,9	5,3	7,1	6,2	14,2
SO_4^{2-} (mg/l)	17,3	26,9	22,47	2	43	16,13	4	33,5	12,23	4,5	27,5	12,71	6,2	24,1	16,4	8,6	9,5	9,05	4,0
NO_3^{-} (mg/l)	0,2	8,7	3,37	0,4	3,1	1,18	0,2	4	1,07	0,2	3,4	1,04	1	7,2	2,51	0,2	0,3	0,25	0,5
TDS (mg/l)	213	408	312	190	341	262	48	374	221	184	521	260	109	457	283	171,0	270,0	220	2309,0
Tot. Hard. °dH	7,1	14	10,5	6,2	9,5	7,8	1,3	11,8	7,2	5	17,4	8,2	2,8	14,6	9,1	5,6	9	7,3	85,2
Temp. H ard. °dH	6,3	12	8,9	5,6	9,2	7,7	1,3	11,2	6,7	5,6	16,2	8,1	2,8	13,7	8,5	5,6	9	7,3	80,4
Perm. Hard. °dH	0,8	2	1,5	0	0,6	0,3	0	1,1	0,4	0	1,2	0,4	0	2	0,6	0	0	0	4,8

3) *Othrys Mt.*

Othrys is a mountain of Central Hellas, consists of alpine formations witch geotectonically belongs to the Sub Pelagonian zone. From the lithological point of view, the fractured rocks are represented by the intercalations of basaltic lavas within sedimentary rocks, schists - chert sequence. Ophiolites (serpentinites, gabbros e.t.c) and limestones occur as well. More analytical description, concerning the following sequences is encountered (Figure 18):

- Chert-Schist Sequence. Thin bedded formation consisted by alternations of chert, clayey schist, siltstone, intensively tectonised and folded.
- Basaltic rocks. Basic volcanic rocks, fractured and alternated with chert and siltstone intercalations.
- Ultra Maffic Rocks. Peridotites with variable degree of serpentinization intensively fractured. In the base of the system gabbros, laves and amphibolites are encountered. Limestone blocks are often encountered as products of the cover tectonics. When the degree of the serpentinization is extremely high, the discontinuities network is very dense.

Many orogenetic tectonic parameters lead the discontinuities configuration of the above formations, the following:

- Fold plane: Direction N 20°-30° W, Inclination 30°-50° NE.
- Thrusts: Direction N 45° W, Inclination 20 NE.

- Thrust-Reverse faults: Direction N 30°-40° W, Inclination 45°-60° NE.
- Faults: Direction E-W, Inclination 60°-70° N.
- Strike – slip faults: Direction N 50°-70°, Inclination 30°-50° N.

It is evident that there is a nearly stable direction of all the tectonic events within the range of N 20°-70°.

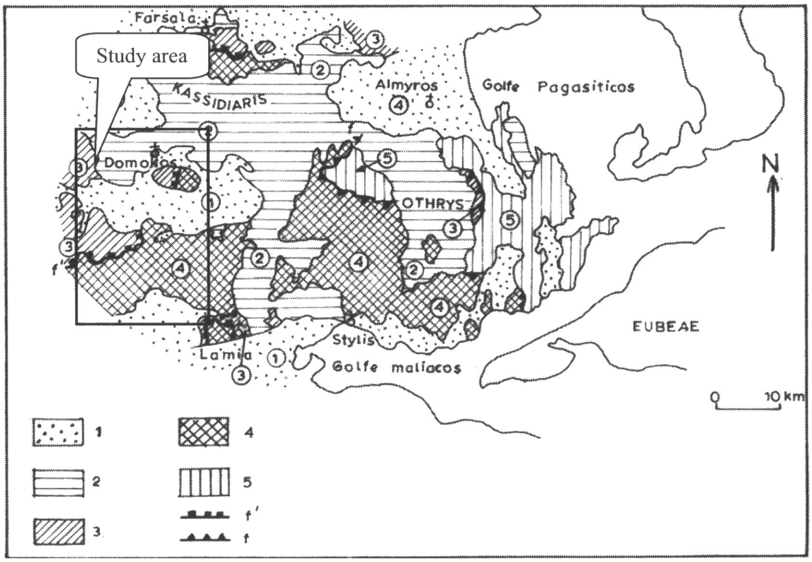

Figure 18. Geological map of Othrys Mt. (1.Post Alpine formations, 2.Cretaceous formations, 3.Ultra basic masses, 4.Sedimentary-volcanosedimentary Triassic-Jurassic formations, 5.Neopaleozoic-Triassic formations, f-f΄: Thrusts).

From the point of view of the post orogenetic tectonics, is that faults and rupture surfaces are induced by the tension stresses. The recapitulation of the rupture surfaces orientation is depicted in Table 13.

Table 13. Rupture surfaces orientations.

Direction	**Details**	**Type of rupture**	**In direction / length**
E-W	N250-290 and/or N70-110	Main rupture	In direction / length
NW-SE	N330-340 and/or N150-160 N310-320 and/or N130-140	Dominant secondary rupture	In direction / length
		Secondary rupture	In direction / length
NE-SW	N30-50 and/or N210-230	Secondary rupture	In direction / length

From hydrogeological point of view, two groups of formations could be distinguished at the base of their permeability. The first group, mainly including the serpentinized peridotites, represents the most permeable sequence of the fractured rocks. The second group, mainly

including the chert-schist sequence and the volcanic rocks, represent the relatively less permeable sequence of the fractured rocks.
Some data concerning the wells and the springs of the given area figure in the following Tables 14, 15 and 16.

Table 14. Hydrogeological characters of the springs in the selected study area.

Springs	Area	Type	Operation	Formation	Discharge (m^3/h)	Use
S1	Agoriani-Ekara	Contact	Seasonal	Peridot./chert	3	Water supply-SPA
S2	Kaitsa	Contact	Permanent	Peridot./chert	<10	Water supply
S3	Trilopho	Contact	Seasonal	Peridot./chert	<1	Unexploited
S4	Pente Vrysses	Overflow	Seasonal	Peridot./chert	80	Water supply
S5	Moschokarya	Contact	Seasonal	Basalte	<1	Unexploited
S6	Archani	Contact	Seasonal	Peridot./chert	20-30	SPA

Table 15. Hydrogeological characters of the wells in the selected study area.

Well	Area	Altitude	Depth (m)	Formation	Discharge (m^3/h)	Use
B1	Perivoli	590	100	Ophiolites	40	Water supply
B2	Aghios Stefanos	500	130	Ophiolites	-	Water supply

Table 16. Hydrochemical characters of the springs in the selected study area.

	S1 A	S1 B	S1 C	S1 D	S1 E
Electrical conductivity (μS/cm)	565	532	540	729	385
pH	11.1	11.1	11.0	10.9	10.8
Water temperature (^{0}O)	22	20.8	19.2	24.2	23.5
Air temperature (^{0}O)	28	28	28	28	29
Discharge (l/h)	226	226	1	960	50-100
Permanent hardness ^{0}O dH	6.18	6.12	5.5	2.13	4.55
Ca^{2+} mg/l/meq/l	43.29/2.16	42.48/2.12	38.48/1.92	15.23/0.76	32.46/1.62
Mg^{2+} mg/l/meq/l	0.49/0.04	0.73/0.06	0.49/0.04	0/0	0/0
Na^+ mg/l/meq/l	21.62/0.94	21.62/2.12	29.44/1.28	111.32/4.84	19.78/0.86
K^+ mg/l/meq/l	0.78/0.02	0.78/0.02	0.78/0.02	2.35/0.06	0.78/0.02
HCO_3^- mg/l/meq/l	0/0	0/0	0/0	0/0	0/0
Cl^- mg/l/meq/l	27.66/0.78	26.60/0.75	30.14/0.85	90.42/2.55	23.05/0.65
SO_4^{2-} mg/l/meq/l	2.4/0.05	3.36/0.07	4.80/0.10	21.61/0.45	3.84/0.08
NO_3^- mg/l/meq/l	0/0	0/0	0/0	6.20/0.10	0/0
NO_2^- mg/l/meq/l	0/0	0/0	0/0	0/0	0/0
OH^- mg/l/meq/l	25.16/1.48	23.80/1.40	23.46/1.38	22.44/1.32	13.77/0.81
SiO_2	4	6	19	36	19
TDS	153	152.97	171.79	345.17	143.28

4) *Euboea Island*

The Euboea presents a complicate geological structure with the Pelagonian formations to the north, Sub-Pelagonian to the center area and the tectonic window of Almyropotamos, equivalent to Olympos-Ossa, to the south. That is the reason why we present the hydrogeological conditions of the fractures rocks in two different areas, Central and Southern parts (Katsikatsos 1977, Stamatis & Gartzos 1999, Stamatis et al. 2005, Figure 19).

Central part of Euboea Island

The Euboea artificial island (Figure 19), especially the central part (Figure 19), corresponds to the typical structure of Sub-Pelagonian zone and is consisted by Palaeozoic basement, covered by non metamorphic Mesozoic formations, which present tectonic intercalations of ophiolites. Among the different lithostratigraphic phases, the potential and existing fractured rocks aquifers on the Central (and North) part Euboea mainly belong to the following sequences.

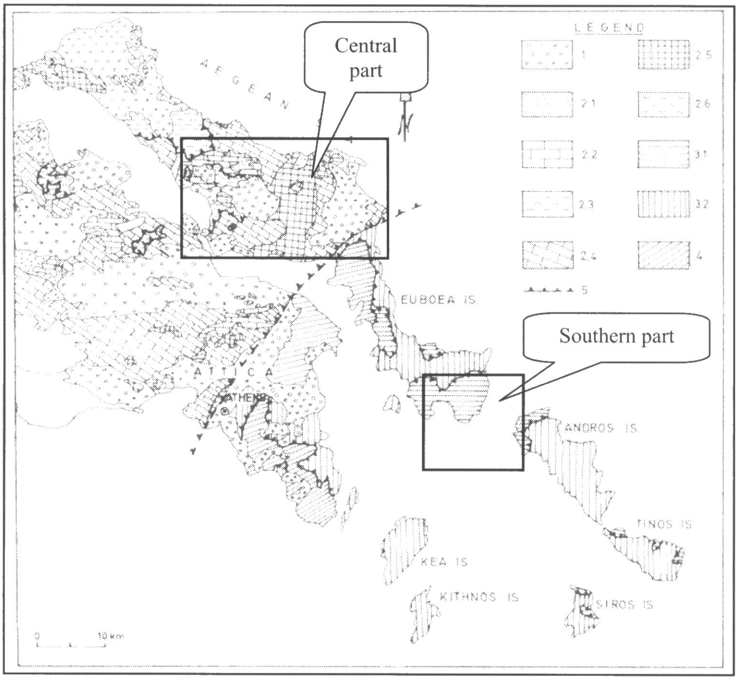

Figure 19. Geotectonic map of Euboea-Attica and N. Cyclades (Katsikatsos et al., 1986): 1.Neogene and Quaternary formations; 2. Pelagonian zone; 2.1. Flysch; 2.2. Upper Cretaceous Limestones; 2.3. Eohellenic nappe formations; 2.4. Middle Upper Triassic-Upper Jurassic limestones and dolomites; 2.5. Neopaleozoic-Middle Triassic formations; 2.6. Crystalline basement; 3. Neohellenic nappe; 3.1 Ochi unit; 3.2. Styra unit; 4. Autochthonous system; 5 Overthrust.

The crystalline basement presents a thickness over 800 m of gneiss and gneissic schist. The upper part is composed by mica and amphibolitic schist, while the carbonate rocks are entirely absent.

The Neopaleozoic sequence is consisted by sandstones, sandstones-schists, arkoses, graywackes and clay schists.

The Lower-Middle Triassic sequence presents clayey-sandstone phases, basic volcanic rocks and tuffs.

The ophiolitic tectonic nappe, composed by volcano-sedimentary formations, ultra basic bodies (serpentinized peridotites), gabbros, amphibolites, and basalts.

The main fracture aquifer seems to be the ophiolitic cover, presenting an intense differentiation related to the lithology, the geological structure and the tectonic regime. Figure 20 depicts the lineaments in the ophiolitic cover as they were derived by a Landsat - 7 ETM+ image, showing a NE-SW preferential orientation.

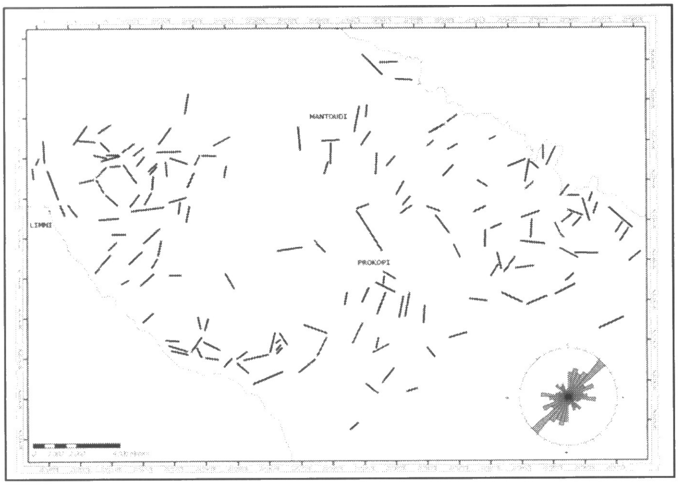

Figure 20. Lineament map of ophiolitic cover.

Southern part of Euboea Island

The Southern part of the island (Figure 21) constitutes a tectonic window equivalent to the the Olympus-Ossa one. Ochi and Styra units, tectonically overlay, corresponds to the Ampelakia unit and are composed of marbles, cipolines, schists and quartzites. These rocks compile a complex of intercalations and alterations.

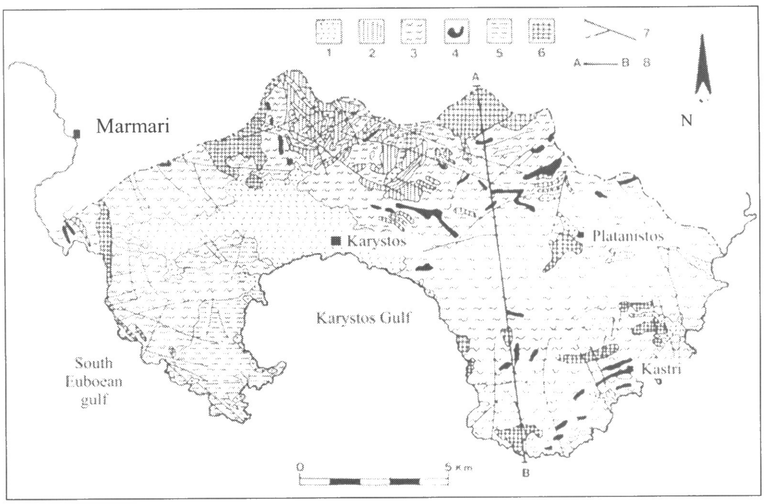

Figure 21. Geology of the study area 2: 1. Alluvium, 2. Marbles and Sipolines, 3. Schists 4. Quartz schists 5. Orthogneisses and 6. Metamorphic basic rocks, 7. Faults.

The hydrogeological conditions of the southern part (Figure 22), shows that the spring's location is related to fracture pattern of the area, and to the drainage network. Some hydrochemical data are given in Table 17.

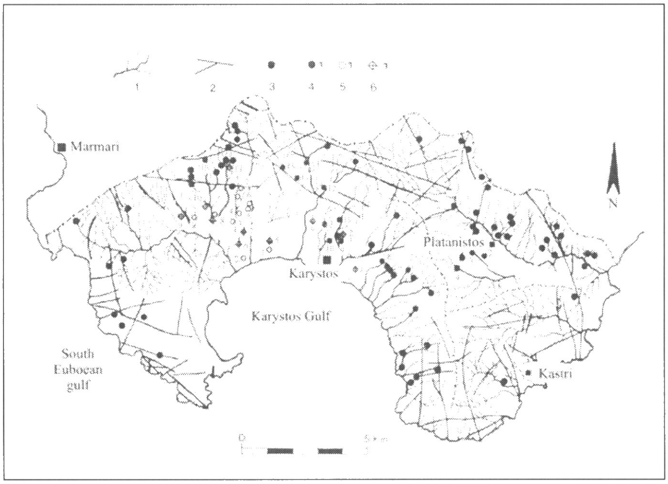

Figure 22. Drainage network and sampling points of the study area (1: drainage network, 2: faults, 3: spring locations, 4: sampling springs, 5: sampling wells and 7: sampling boreholes).

Table 17. Hydrochemical data of Southern Evoia.

Parameters	Springs									Wells		
	Marbles and Cipolines			Schists			Metabasites					
	min	max	aver	min	max	aver.	min	max	aver	min	max	aver
T^0C	14.8	16.8	15.4	12.8	18.5	16.3	18.2	18.5	18.4	17.5	20.9	18.9
Q (m^3/h)	4.8	35.0	17.9	1.7	60.0	28.1	0.1	2.0	1.1			
pH	7.7	8.1	7.9	7.6	8.2	7.9	7.5	7.6	7.6	7.2	8.4	7.9
EC (μS/cm)	413	489	451	289	617	386	830	848	839	587	1794	969
Ca^{2+} (mg/l)	48.1	64.1	54.1	27.3	40.1	36.4	56.1	72.1	64.1	32.1	120.0	80.8
Mg^{2+} (mg/l)	8.8	16.5	13.5	2.9	19.9	9.4	30.2	39.4	34.8	11.7	68.1	30.5
Na^+ (mg/l)	20.7	34.5	25.3	12.0	66.7	29.2	48.3	57.5	52.9	34.5	179.0	76.9
K^+ (mg/l)	0.8	2.3	1.4	0.4	0.8	0.7	0.8	0.8	0.8	0.8	5.9	2.5
HCO_3^- (mg/l)	207.0	234.0	217.0	73.0	167.0	125.0	266.0	293.0	279.5	95.0	397.0	266.7
Cl^- (mg/l)	28.4	53.2	36.4	21.3	141.8	50.5	88.6	117.0	102.8	53.2	195.0	99.3
SO_4^{2-} (mg/l)	13.4	21.6	17.6	8.2	36.5	18.1	38.4	48.0	43.2	21.6	205.0	78.2
NO_3^- (mg/l)	0.0	6.2	4.7	0.0	6.2	2.6	0.0	9.3	4.7	0.0	74.4	18.3
SiO_2 (mg/l)	7.6	14.9	10.2	10.1	14.6	12.8	20.3	20.3	20.3	12.2	34.5	20.9
TDS (mg/l)	347.6	418.2	380.1	207.7	366.0	278.2	581.0	604.8	592.9	436.7	814.8	674.2
Total Hard.	178.0	208.0	190.5	112.0	150.0	129.2	302.0	304.0	303.0	194.0	520.0	327.1
Temp. Hard.	170.0	192.0	178.0	60.0	137.0	102.5	218.0	240.0	229.0	78.0	325.0	219.2
Perm. Hard.	8.0	16.0	12.5	8.0	90.0	26.7	64.0	84.0	74.0	16.0	316.0	107.9

5) Cyclades Island Complex

The islands of Cyclades are located in the central Aegean and constitute the Cycladic plateau. The biggest islands of Cyclades (Naxos, Andros and Tinos) are located at the eastern part of the plateau and have the highest elevation points. There are four islands, much smaller in size, located at the western edge of it (Kea, Kythnos, Serifos, Sifnos). The islands of Syros, Paros, Ios and Mykonos are located between these two groups of islands. The islands of Milos, Santorini and Amorgos are situated around the southern edge of the plateau and are considered as peripheral expansions of the plateau (Botsialas et al. 2005, Leonidopoulou et al. 2005, Louis et al. 2005, Melidonis 1980, Melidonis & Triantaphyllis 2003, Stournaras et al. 2002, Stournaras et al. 2003).

Geology

The islands of Cyclades are generally characterized by metamorphic rocks such as mica-schists, marbles, gneisses, amphibolites, glaucophane schists and plutonian rocks (Figure 23). According to the results of radiometric studies the principal metamorphic events have taken place during the Tertiary period (Eocene, Lower Miocene). The structures of metamorphic rocks are dominated by isoclinic folding, thrusts and re-folding during Eocene - Oligocene.

Figure 23. Geographical distribution of the main lithological units at Cyclades area.

Tectonics

The islands of Cyclades belong to the internal metamorphic zone of central Aegean which is part of the internal crystallic zone of the Hellenides. The recent tectonic history of Cyclades islands starts with the Alpine orogeny during Eocene, a period with dominant tectonic compression. A group of rocks, the blueschists, was metamorphosed under high pressure and low temperature conditions. This compression gave way to a tensile phase during Oligocene or Miocene; the result of this phase was the development of shallow normal faults. During Miocene the sea depths at central Aegean were too shallow with extensive emerging regions and small elongated basins, resulting from the exceedingly intense compression. The compression resulted in the generation of a graben, which, shortly, gave rise to the blueschists. During that period, low pressures transformed a mass of rocks into the greenschists. After the ending of the faulting processes, the phase of low pressures was followed by the infiltration of plutonian rocks (granites). The infiltration took place through the older faults of the area which reached the surface of the Cycladic mass. Volcanic activity in the area of Cyclades took place mainly to the islands of Milos and Thira.

The study of the fracture orientation is fundamental, for the study of ground water flow. In most of the cases, the orientation of fractures is identical with the orientation of the preferential flow path. At figure 24 we may see the principal faulting zones at a part of Cyclades and more precisely in the islands of Naxos, Tinos and Santorini. In order to describe the relationship between faults and fractures and lithological units, rose plots have been created for each lithological unit (Figures 25-28). It is obvious from these plots, that the dominant orientation for the faults of all lithological entities is NW-SE. Furthermore, the carbonate rocks appear a second most dominant orientation of NEE –WSW, and soft rocks appear to have an important number of faulting zones which are oriented vertically to the dominant faulting zones. The fissured rocks cover the biggest extent of the Cycladic area and that explains the fact that the dominant faulting orientations are almost the same with those for the whole area.

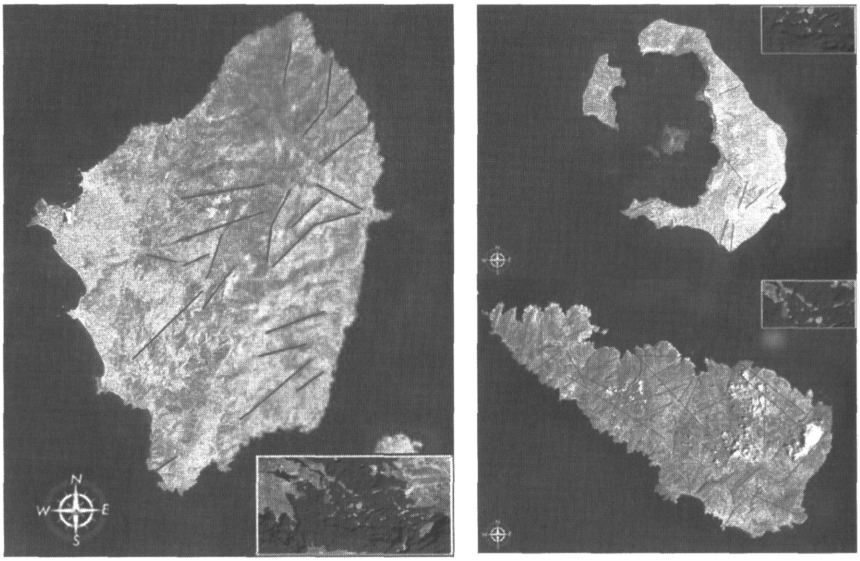

Figure 24. The faults at Naxos (left), Santorini (up and right) and Tinos (low and right) islands.

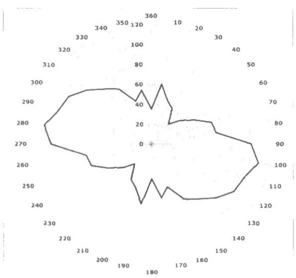

Figure 25. Faults Rose Plot in Cyclades area.

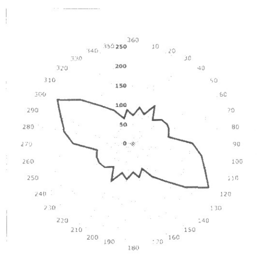

Figure 26. Faults Rose Plot in fissured rocks.

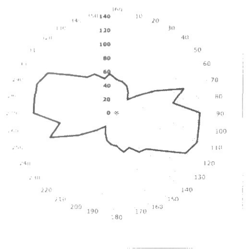

Figure 27. Faults Rose Plot in Carbonate rocks.

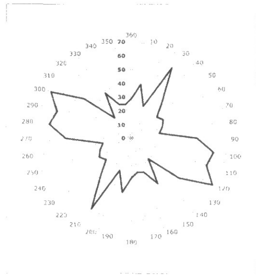

Figure 28. Faults Rose Plot in soft rocks.

Hydrogeology

Cyclades islands are small in extent and are characterized by low annual rainfall, high medium annual temperatures and high sunlight and thus the developed aquifers are of low capacity. Simultaneously most aquifers are open towards the sea resulting to loss and qualitative revalorisation of the water that they hold.

The main water-bearing rocks of the region, apart from carbonate rocks, are the hard, fissured rocks (granites, schists, gneisses, etc.).

6) *Tinos Island*

One of the Hellas pilot areas, in which the hydrogeology environment of hard rocks is been studied, is Tinos Island which (Figure 29) belongs to the Attic-Cycladic Complex. Metamorphic rocks are classified, by their mineral composition, metamorphic phase and the age of metamorphosis, into three tectonic units: (1) the Upper Unit composed of serpentinites, metagabbros, metabassalts, phylittes and stratified amfibolites. Its thickness is 500m approximately; (2) the unit of Cycladic Blueschists, which thickness is more than 2.000 meters and covers the greatest part of the island. Meta-volcanic, clastic rocks and marbles are being met into that unit; (3) the Lower unit, derived from Mesozoic Limestones, marls, shales, cherts, tuffs, basaltic volcanites and acidic rocks of probable volcanic origin. Magmatic rocks of the island are being classified into two main categories: (1) a complex of granite and granodiorite intrusion, which took place at early Miocene; (2) small outcrops of rocks of volcanic origin, with rhyolitic and andesitic composition.

A study area was selected in Tinos, in order to investigate, the hydrogeological environment of the hard rocks aquifers. The study area (Figure 30) lies on the 2/3 of Tinos Island. From July to August of 2003, a spring inventory was conducted in the study area. Topographic maps at the 1/5.000 scale were used to plot 150 spring locations.

Their spatial distribution shows that 95.3% of the springs, are located, into the hard rock formations of the island (gneisses, gneisschists, glaucophane schists, greenschists, ophiolites, prasinites). Their discharge, varies from $0.5m^3/sec$ to $3.5m^3/sec$ in the humid periods of the year. The majority of the springs (69.34%) are located on or near the streams of the drainage network, which is heavily influenced by the tectonic regime of the island. It is also interesting the fact that 82% of the springs are located very close, to faults or fractures, or to the intersection of two or more fractures. This is a strong evidence of the influence of the hard rock environment on the groundwater flow in the study area.

In order to obtain a reliable picture of the groundwater flow, it was necessary to depict the fractures systems of the study area. For that purpose GIS and remote sensing techniques were integrated along with results from field study. A map of fractures (Figure 31) was obtained which demonstrates 3178 features which correspond to map-scale faults and lineaments from aerial photographs and satellite images. Most of these lineaments are easily identified in the field as steeply dipping to vertical large scale fractures, and as meso-scale faults. The criteria of interpreting image lineaments and identify them as indicators of fractured zones of hydrogeological interest are: i) their length, ii) their directional distribution, iii) the detection of anomalous directions, iv) their intersection, v) the existence of a constant distance between lineaments of a directional group and vi) relation between fracture density and the density of lineament intersections.

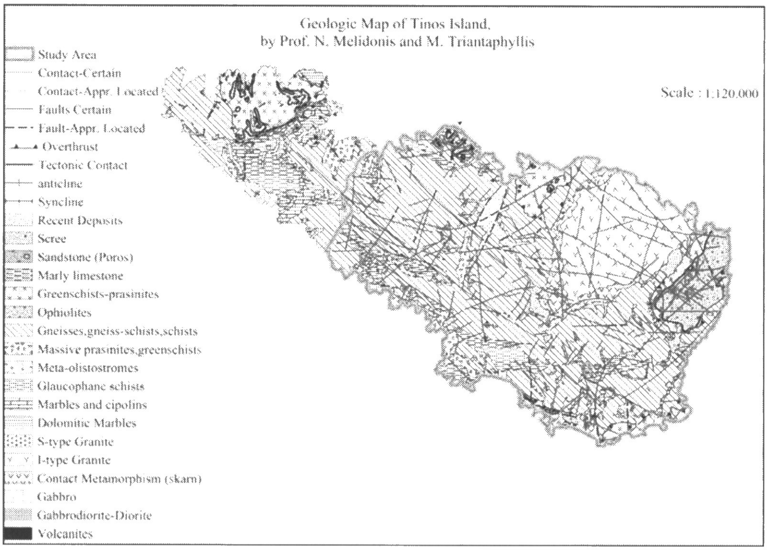

Figure 29. Geological map of Tinos Island.

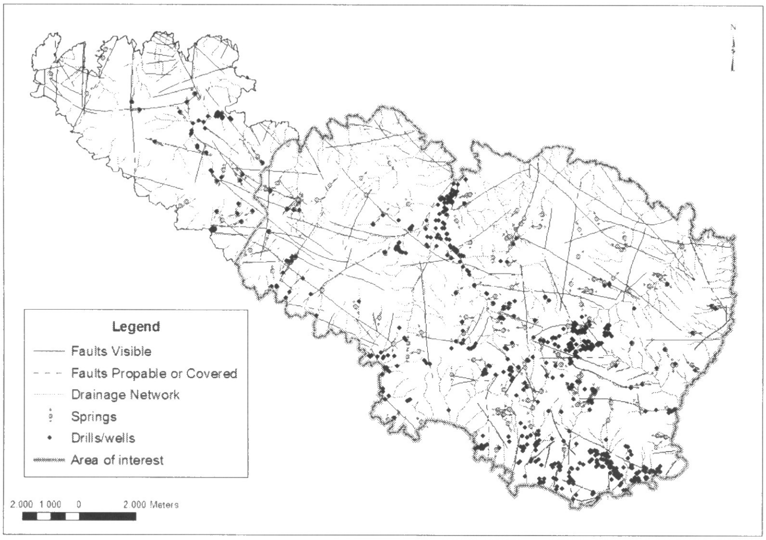

Figure 30. Location of springs and drills/wells in Tinos Island.

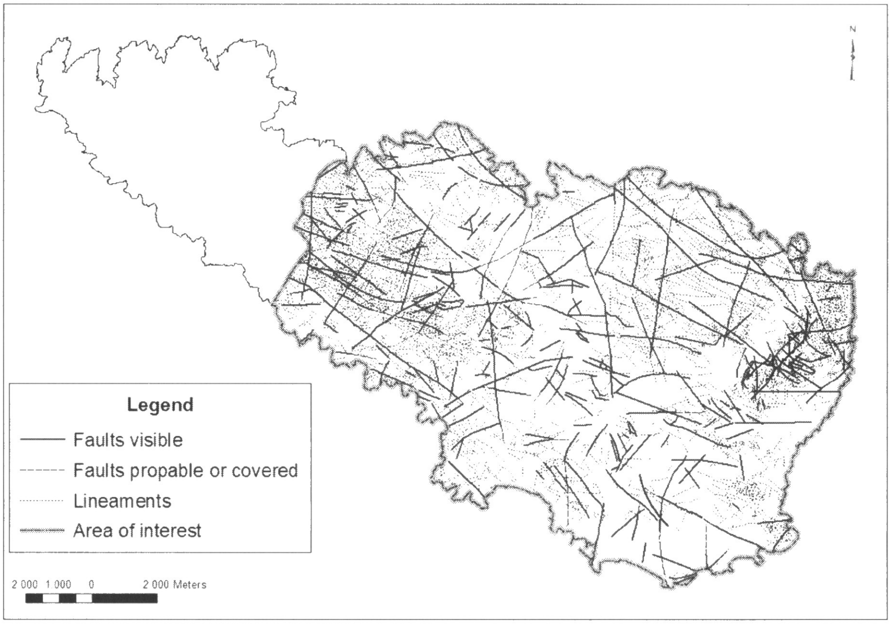

Figure 31. Faults and lineaments of the study area.

The study of the fracture orientation is fundamental, for the study of ground water flow. In most of the cases, the orientation of fractures is identical with the orientation of the preferential flow path. In Figure 33 the fractures rose plot shows that there are two sets of orientation classes. The main one has a NW-SE strike while the secondary one has NE-SW strike. The faults rose plot (Figure 32) reveals four orientation classes. The two main classes have NW-SE and NE-SW strike, while the secondary ones are of N-S and E-W strike. On the other hand the lineaments rose plot (Figure 34), indicates that two main orientation classes exist (NW-SE and NE-SW). In order to describe the relationship, between faults and lineaments, rose plots of each of those features for each lithological unit were created (Figure 35 to Figure 40). It can be seen from these plots, that the dominant orientations are the NW-SE and the NE-SW strike on both faults and lineaments, suggesting the link between them. Exception occurs in the case of the Upper Unit of Greenschists and Prasinites. Faults in the Upper Unit are classified in two main orientation sets (N-S and NE-SW respectively) and in two secondary ones (NW-SE and E-W), while the majority of the lineaments seem to be oriented along NW-SE. This fact is due to the effect of the ductile tectonics, as two parallel fold axes, of NW-SE trend (a syncline and an anticline) are located in the area of the Upper Unit.

The conclusions that were obtained from the study of map above are the following:

a) Four orientation classes of faults are located in the study area. The two main classes have NW-SE and NE-SW strike, while the secondary ones are of N-S and E-W strike.
b) Lineaments are trending at the same strike with the main fault systems (NW-SE and NE-SW). Exceptions occur, where ductile tectonics affect the development of fractures.
c) The occurrence of fractures is strongly linked with the proximity to the map scale faults. The majority of lineaments/fractures are located in the distance of 250m to faults.
d) The fractures density and degree of interconnection is depended on the combination of brittle and ductile tectonics, on the thickness of the weathered mantle, and on the lithology.

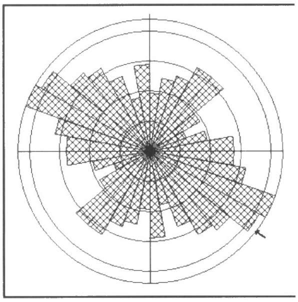

Figure 32. Faults Rose Plot.

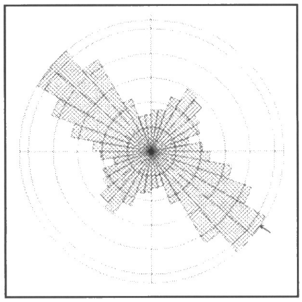

Figure 33. Fractures Rose Plot.

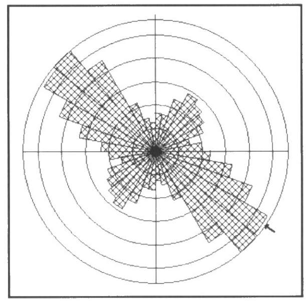

Figure 34. Lineaments Rose Plot.

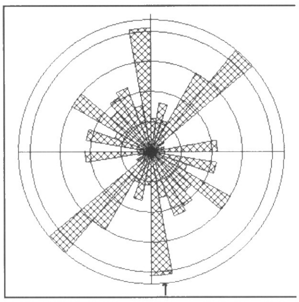

Figure 35. Faults Rose Plot in Upper Unit.

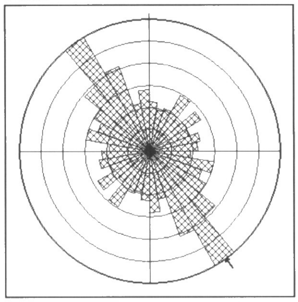

Figure 36. Lineaments Rose Plots in Upper Unit.

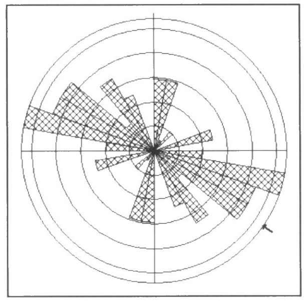

Figure 37. Faults Rose Plot in Granites.

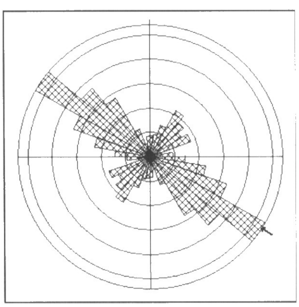

Figure 38. Lineaments Rose Plot in Granites.

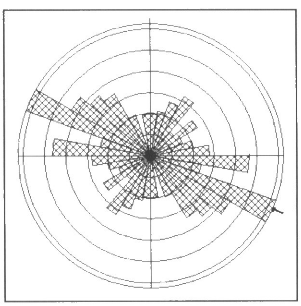

Figure 39. Faults Rose Plot in Lower Unit.

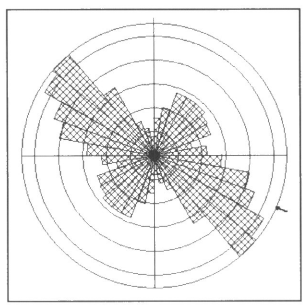

Figure 40. Lineaments Rose Plot Lower Unit.

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