

HARD ROCK AQUIFERS OF CENTRAL AND EASTERN CHALKIDIKI, REGION OF CENTRAL MACEDONIA, NORTHERN GREECE

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Abstract

The study area is located in the central and eastern Chalkidiki peninsula and covers an area of 2338 km². In the study area the fractured aquifers are mainly located in fractured metamorphic, igneous rocks and rarely in carbonate rocks. They were classified as minor aquifers as they are not of highly productive. The springs located in the fractured rocks have supplies ranging from 0,5 to 5,0 m³/h and rarely from 10 to 25 m³/h, while for those located in the carbonate rocks the supply ranges from 5 to 60 m³/h and mean value is 10 m³/h. In the boreholes the average yield is 25 m³/h and varies from 5 to 80 m³/h, but the greatest part of the study area is characterized by low aquifer potential or even is waterless. The groundwater total consumption for drinking, irrigation and other purposes is 19*10⁶ m³/yr, while the pumped and treated mine waters are 5,5*10⁶ m³/yr. Common natural contaminants are Fe, Mn and occasionally F, As, SO₄.

1. INTRODUCTION

The study area covers 2.338 km² and includes the central and eastern Chalkidiki peninsula. The previous hydrogeological studies include only certain parts of Chalkidiki (Manakos et al., 1998, Veranis and Meladiotis, 2005, Veranis et al. 2010a,b). In this study the focus will be on the hydrogeological characteristics of the fractured aquifers hosted within the metamorphic and igneous rocks of the central and eastern Chalkidiki peninsula, but we are also referring to the carbonate rocks aquifers which are occurred as intercalations in the metamorphic rocks.

We assessed several types of data such as registrations of boreholes and springs, well-logs, pumping tests, water pressure tests, water discharge measurements from the springs and borehole yields, static water level data and groundwater chemical analyses from previous unpublished studies carried out by the Institute of Geology and Mineral Exploration (IGME) in the period 2004-2010. Well-logs information, water table level measurements and pumping test data also obtained from the Water Resources Department of Chalkidiki Prefecture.

The landscape varies from coastal, hilly, semi- mountainous to mountainous with a sharp relief and a dense network of deep valleys and shears. The elevations range from 0 to 2027 m and the average altitude is 332 m. The streams are discharged occasionally and more often during the wet season of the hydrologic year and after intensive rainfalls in the dry season. For the longest time of the year runoff occurs in Chavrias and Olynthios rivers, as wells as in the streams Asprolakkas, Mavrolakkas, Cholonon rema, Megalo rema (Veranis et al. 2010b).

According to CORINE, from the total area of 2.338 km², the cultivated and fallow lands cover 540,44 km² (23,12 %). The forest, semi-forest and pastures areas are 1.766,9km² (75,57%), 30,01 km² (1,28%) are covered by the settlements and 0,65 km² (0,03 %) are water surfaces.

2. GEOLOGICAL STRUCTURE AND TECTONIC

Geologically the study area, as referred to the geological maps of IGME (Kockel and Mollat, 1977), is built up of a variety of metamorphic and igneous rocks which belong to the Servomacedonian massif (Paleozoic or older age) and the Circum Rhodope belt (Mesozoic age), (Fig. 1). The most common rocks of Paleozoic age (>250 m.y.) are the two-mica gneisses, quartz-microcline gneisses, biotite gneisses, mica schists and amphibolites which are located in the central as well as in the eastern part of the area. Biotite gneisses with intercalations of marble horizons are also located in the eastern part. Metamorphic rocks of Mesozoic age (250-65

m.y.) are mainly located in the central part of the Chalkidiki peninsula and consist of acid meta-volcanosedimentary rocks, quartzites, phyllites, greenschists, marbles, re-crystallised limestones, diabbases, quartz diorites, gabbros and epi-gneisses. Ophiolites are located in Vavdo, Gerakini, Metamorphosis, Gomati, Nea Roda and Porto Koufo (Sithonia) areas. In the metamorphic rocks granites and granodiorites of Mesozoic age are intruded in Arnaea, Ierissos, Ouranopolis and Sithonia peninsula. In the eastern part of the study area (Stratoni, Tsikara, Skouries, Fisoka) granodiorites and acid to intermediate sub-volcanic rocks of Oligocene to Miocene age (25-16 m.y.) were intruded into the gneisses but they cover small areas.

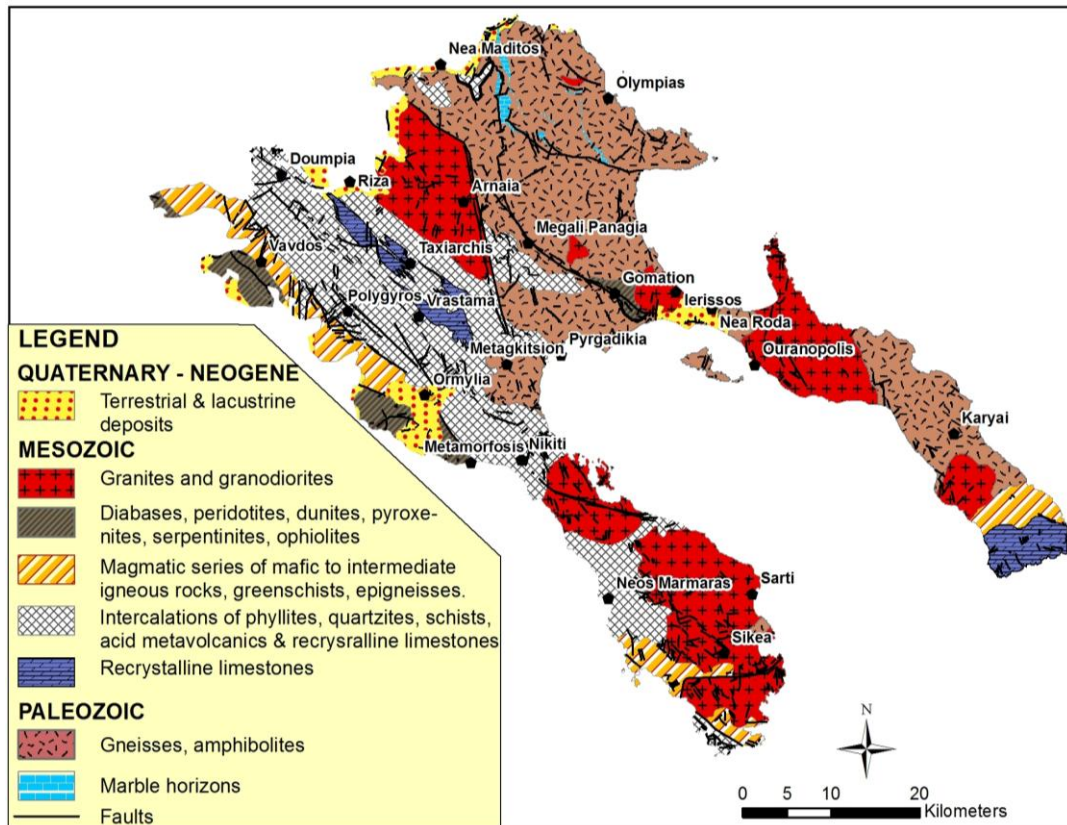


Figure 1. Simplified geological map of central and eastern Chalkidiki peninsula.

The metamorphic and igneous rocks are often overlapped in some places by loose sediments of Holocene to Pleistocene age and cover an area of 135 km² (5,77 %). They are located in the coastal areas of Olympias, Stratoni, Asprolakkia, Ierissos and Nea Roda, as well as in the coastal areas of Sarti, Marmara, Nikiti and Agios Nikolaos villages. Also, unconsolidated sediments are located along the small elongated valleys in the areas of Xironeri-Plana-Smixi, Megali Panaghia, Neochori-Paleochori, Gomati-Develiki, Agios Prodomos and in the upper part of Anthemounta basin. The thickness of these sediments ranges from few meters to 120 m in some coastal basins and are divided in erosion mantle, eluvial deposits, alluvial deposits, terraces, old and new scree, cone scree, coastal deposits. They mostly consist of red clays, loose or compact conglomerates, pebbles, sands, as well as mixes of them.

Neocene (Up. Miocene to L. Pliocene) sediments are located in the areas of Agios Nikolaos, Nikiti and Nea Roda and have superimposed the igneous and metamorphic rocks. They cover an area of 50 km² (2,14%) and composed of lacustrine limestones, red clays series with lenses of sandstones, marls, marly limestones and cemented conglomerates. The hydrogeological characteristics of the granular aquifer systems of Chalkidiki peninsula are referred in detail in previous studies of IGME (Veranis et al., 2010b).

Due to the intense shear tectonics of the last stages of the Alpine age deformations and the neotectonic activity, different system of fractures and faults were formed in the metamorphic and igneous rocks. The analysis of aerial and satellite images shows that the metamorphic and igneous rocks are intersected by normal faults trending in NW-SE, NE-SW, N-S and E-W directions. Regarding the hydrogeological investigation the fractures follow N-S or NE-SW directions are related to the extension movements and are an important point of interest. The faults trending in NW-SE direction usually coincide with the lithological contacts and they are related to the compressive movements during the last stages of the Alpine folds. In many cases the faults accompanied by lateral displacement. In some places faults accompanied by fine-graded mylonite zones with low hydraulic conductivity and they act as a negative hydraulic border preventing the groundwater flow. Typical fracture zones with impermeable mylonite are located along the Stratoni-Varvara and Gomati- Megali Panaghia faults as well as in the granodiorite of Sithonia. Besides the major faults, from the processing of aerial and satellite images, systems of tectonic lineations were obtained that constitute the expressions of the topography and potentially related to the fracture zones of the underlying metamorphic or igneous rocks. These fracture systems act as conduits for the infiltration of the precipitation or for the filtration of surface waters along the beds of the streams. The most favorable conditions are formed when a vertical or sub-vertical system of discontinuities for the water movement into deeper levels coexists with a horizontal or sub-horizontal system for the lateral transfer respectively (Ahmed et al. 2008).

3. HYDROLITHOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS

3.1. *Aquifers of metamorphic and igneous rocks*

The metamorphic (no carbonate) and igneous rocks occupy an area of 2.063 km² corresponding to an 88,24% of the total study area and are generally characterized as semi-permeable or impermeable. In the vertical profile three hydrostratigraphic units are distinguished (Fig. 2).

(i) *The higher hydrostratigraphic unit (number 1, Fig. 2)*, where the aquifer is located in the contact between the lower part of the weathered fractured rock and the underlying un-weathered which is usually a fractured rock. The crystalline metamorphic and igneous rocks until a depth from 2-15 m in many places are eroded, weathered with increased clay minerals content and have low hydraulic conductivity. The thickness of the weathered zone is also associated with the rock type and the slope of the topography. In some areas with smooth gradients of the slopes, the thickness of the weathered mantle ranges from 15 to 20 m or more in the flat areas. The weathered rocks and the overlying loose sediments regulate the rate of recharge and when saturated constitute the reservoir for the fractured aquifers. The hydraulic conductivity of the eroded, weathered rock varies not only from place to place, but also in the vertical profile. From water pressure tests made in boreholes that completed in the gneisses of Asprolakkos catchment (northeastern Chalkidiki area), the hydraulic conductivity (K) of the weathered rocks has been estimated to vary from 10⁻⁴ m/s to 10⁻⁹ m/s with mean value of 10⁻⁷ m/s. The smaller values of the hydraulic conductivity are identified in the weathered zone of the phyllites, mica schists, amphibolites and serpentinites, where the surface procedures have formed clay minerals and also ferrous or manganese oxides deposits that have filled the fissures of the weathered rock.

The active porosity of the weathered rocks ranges from 2 to 20%. The higher values are 10-20% and have been identified in the weathered granitic rocks of Sithonia peninsula and Arnaia area. The porosity of the weathered rock generally decreases with depth, along with clay content until fresh rock is reached. Weathered rocks are recharged from the infiltration of the precipitation and the filtration of surface waters along the stream beds. The rate of infiltration varies depending on the composition, thickness of the soil mantle, the degree of the rock fragmentation, the slope of the relief, the intensity of the rainfall, the vegetation and the climate changes (Earon, 2014). The mean precipitation is about 600 mm/yr and the infiltration in this hydrostratigraphic unit varies from 3 to 12% with mean value about 8%, corresponding to 48 mm/yr and ranges from 20 to 70 mm), (Manakos et al.1998, Veranis et al. 2010a,b).

The hydrostratigraphic unit of the weathered rocks has small water potential, but since it covers a large area, it has significant storage capacity and acts as the rain water deposit, that releases

slowly through percolation to the deeper fractured aquifers or discharges through springs and small outflows in the lower topographic areas contributing to the runoff maintenance (Fig. 2).

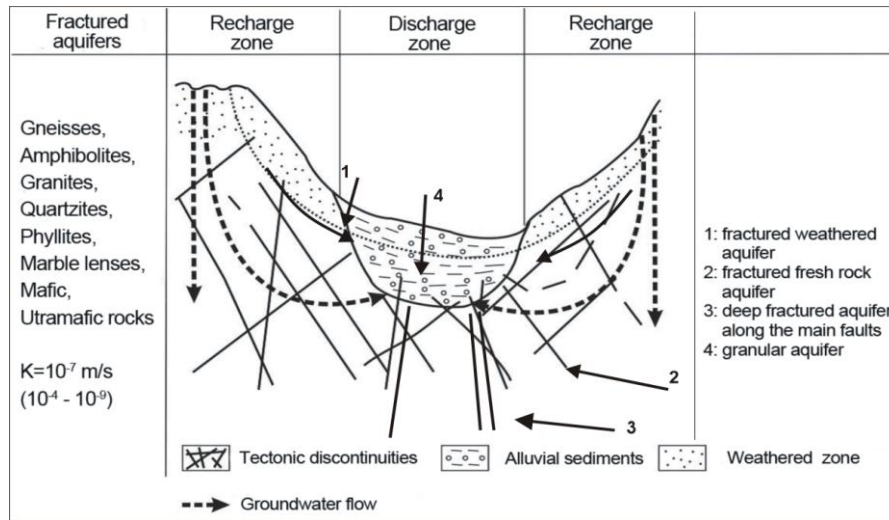


Figure 2. Simplified figure of the groundwater flow in the weathered and fresh fractured rocks.

The greatest part of the *upper hydrostratigraphic unit* is expected to be unsaturated in water. The aquifer of the weathered rocks is unconfined and it belongs to the perched aquifers and roughly follows the contact between the overlying weathered and the un-weathered underlying fractured rock. The horizon of fracturing between the regolith and the fresh rock has a higher permeability depending on a number of factors including the nature of the fracturing and the presence of clay in the fractures and imparting inter-granular secondary porosity behaving like a granular material. Where the un-weathered rock has been intersected by discontinuities, the perched aquifer has a variable thickness, depending on the surface variation between the weathered and un-weathered rock. This aquifer is often interrupted by waterless parts and the water age being recent. During the wet season the aquifer is being recharged and then it maintains the supply of the springs and partially the runoff. Most of the groundwater flow occurring through a thin permeable weathered zone close to the contact between the weathered and fresh rock.

The springs are located in the beds of the stream or are associated with an abrupt change in the slope of the relief, probably because of tectonic reasons and are attributed to the discharge of the weathered rock. In some places the axes of the major streams are associated with faults, where the hydraulic conductivity is higher a fact that explains the coexistence of the beds of the main streams and the discharge zone of the fractured-weathered aquifer.

In the study area forty (40) main springs were recorded and many of which are used for drinking water purposes. In most cases, the springs are located in the contact between the weathered and un-weathered fractured gneisses, amphibolites or schists, have small yields ranging from 0,5 to 5,0 m³/h, with a continuous flow during the year and seasonal fluctuations. In some places larger springs with yields of 10 to 60 m³/h are located discharging the thick (20-30 m) weathered granodiorite of Sithonia or they are associated with the carbonate rocks (Veranis et al. 2010b). During the dry season (June to September) or in cases of drought, the perched aquifer can be completely drained and the supply of the springs is minimized or even dry up.

(ii) The *intermediate hydrostratigraphic unit* (number 2, Fig. 2) is located where the un-weathered metamorphic and igneous rocks are intersected by fracture systems as well as in strongly faulted positions. Most of the groundwater flows through the joints, fractures, shear zones and faults (Fig. 2). In the strongly foliated rocks such as phyllites, chlorite or mica schists and in serpentinites the secondary porosity have not been developed sufficiently in relation to the dark color coarse grade ones, the fissures are filled by clay minerals and therefore the aquifer conditions in these rocks are bad. The leucocratic felsic rocks as the microcline gneisses or pigmatites or dark color coarse grain rocks such as gabbros and amphibolites are more favorable

for developing secondary porosity compared to the dark color fine-grade ones (Singhal and Gupta, 1999).

The pumping data interpretation has resulted in a great heterogeneity in the hydraulic parameters of the fractured aquifers. This can be attributed to the petrogenetic differences that affect the primary porosity, however this effect usually has a small impact. The heterogeneity in the hydrogeological behaviour mainly attributed to the secondary porosity, which is mostly associated with the different degree of fracturing. By observing boreholes construction as wells as of underground works data at Madem Lakkos, Mavres Petres mines we concluded that fracture zones in the gneisses of few centimetres in thickness yield 5 to 20 m³/h, while the neighbouring gneisses are waterless. The effective porosity is created of the discontinuities which intersect the very low permeability ($K=10^{-7}$ to 10^{-8} m/s) rock matrix and the conductive network of these discontinuities contribute to only 10% of the active porous. In general, most of the water has been stored in the matrix and most of the flow occurs in the fractures (Maréchal et al. 2006). This double porosity model has also been validated in many pumping tests conducted in the boreholes drilled the gneisses and amphibolites (Veranis et al. 2010b).

(iii) *The lower hydrostratigraphic unit* (number 3, Fig. 2) consists of the fractured metamorphic and igneous rocks defined along the main faulted zones. It is generally accepted that the fracture density decreases with depth and it can be related to the tectonic activity or lithostatic decomposition processes or to cooling stresses in the magma (Holland, 2011). From observations in the underground works of the Madem Lakkos and Mavres Petres mines at a depth of 200 to 400 m, the drilling cores inspection and the results of water pressure tests until a depth of 400 m, has noted that with increasing depth there is a slight reduction in the frequency and aperture of the discontinuities, resulting to the relative decline of the rocks permeability. The permeability reducing with depth depends on the individual circumstances of the fault tectonics of the region. From observations in the underground mine works and tunnels it concluded that in greater depths the groundwater flow is localized along the fault zones only (Singhal and Gupta, 1999).

-Boreholes: For the needs of domestic, irrigation and other uses water about five-hundred (500) boreholes and ranging in depth from 70 to 330 m were constructed. We have studied the data of one hundred fifty (150) productive boreholes. Their yield varies from 3 to 80 m³/h with geometric mean value 25 m³/h. Moreover there are many sites where the boreholes were absolutely barren. In the past, the site selection for drill has been mostly decided without hydrogeological study and was mainly determined from the existing infrastructure and the land ownership.

The maximum yields (40-80 m³/h) are usually associated with the fault zones, carbonate rock intercalations, extended drainage basin upwards, high density hydrographical network, smooth gradient of the slopes, thick cover of the saturated weathered rock or in place where the overburden sediments have considerable (>20 m) thickness and high storage capacity (low clay content). Higher yields often have the boreholes completed in the carbonate rocks intercalations or drilled pegmatites and quartz veins of significant thickness and of course in sites where the fracture aquifer is recharged from the runoff filtration along the stream beds. The geological criteria are not always enough to predict the aquifer potential in the fractured rocks. Since, more water resources potential zones generally produce low resistivity anomalies; the geophysical prospecting (resistivity, VLF, Radar, SP, Hydraulic Tomography) contributes toward the proper site selection. The forecasting process is complex, depends on many factors (Eaton, 2014) and therefore the success of locating a potential aquifer in the fractured rocks is sometimes also a matter of luck (Ahmed et al. 2008).

Boreholes completed in phyllites, greenschists, sericite calcschists, epi-gneisses, not fractured igneous rocks as quartz diorites, norites, granites, mafics and ultramafics generally either had low yield ranging from 2 to 10 m³/h or in many sites they did not succeed in identifying aquifer. Unsuccessful boreholes are often located in the granites of Ierissos and Ouranoupolis areas, in the granodiorite of Sithonia peninsula, in the basic to ultrabasic rocks of Metamorphosis and Gerakini areas, in the phyllites all over the study area and in the epi-gneisses of Vavdos area.

The intensively pumped boreholes demonstrated a reduction in their yield over time, so replacement is required in 5 to 10 years or in less. During pumping the permanent groundwater reserves were also involved in many sites and this is attributed to the small storage capacity of the fractured aquifers. The average value of the active porosity in such rocks is estimated 2% with a range from 0,2 to 5% (Maréchal et al. 2006).

Pumping tests were conducted in fifteen (15) boreholes of the Asprolakkas catchment (95 km²) located in the eastern part of the study area. The boreholes drilled the gneisses and amphibolites until a depth of 170-250 m. From the data processing it concluded that the yield ranges from 16 to 60 m³/h and the specific capacity (Sc) ranges from 0,3 to 14,5 m²/h. Transmissivity (T) was calculated by analytical solutions that better represent the complex boundary conditions inherent to fractures aquifers (Tonder et al. 2001) and ranges from 2,5 to 350 m²/day. Hydraulic conductivity (K) varies from $3,5 \cdot 10^{-7}$ to $3,5 \cdot 10^{-5}$ m/s and the storage coefficient was estimated in few boreholes ranging from 10^{-3} to 10^{-5} that is within those commonly found for confined to semi-confined aquifers in fractured rocks (Veranis et al. 2010).

In Varvara, Stanos, Stavros, Olympias and Athos Peninsula areas potable water boreholes (n=15) were completed in fractured gneisses with marble lenses in places and their yield ranges from 20 to 40 m³/h. Hydraulic parameters obtained from the pumping test: Sc=0,5-3,0 m²/h, T=8-50 m²/day, K= $4,6 \cdot 10^{-7}$ - $3,6 \cdot 10^{-6}$ m/s. In the Olympias mine the hydraulic parameters of the marble-gneiss aquifer are: Q=300-350 m³/h, b= 450 m, T=12-14 m²/day, K= $2,26 \cdot 10^{-7}$ m/s, ranging from $1,1 \cdot 10^{-8}$ to $9,5 \cdot 10^{-7}$ m/s. Drinking water boreholes (n=10) drilled the granite of Arnaia area and their yield ranges from 8 to 25 m³/h. The boreholes located in Gompelos area and in the Forest Service installations of Arnaia, drilled the gneisses and their yield ranges from 18 to 45 m³/h. Boreholes completed in the granites of the Ierissos and Ouranoupolis areas haven't identified potential aquifer. In the east of Ouranoupolis village area were recorded four (4) boreholes drilled gneisses with granite dykes and their yields range from 10 to 20 m³/h.

Irrigation and drinking water boreholes (n=70) were recorded in the areas of Palaiochori, Megali Panaghia, Gomati, Pyrgadikia and Metaghitsi villages. They were completed in amphibolites or gneisses and their yields usually range from 10 to 30 m³/h. Maximum yields are 40-60 m³/h and are associated with fault zones or recharging from the runoff filtration in the stream bed. Boreholes (n=5) were drilled the phyllites of Plana area but their yields are low (3-7 m³/h).

In the area of Taxiarchis, Palaiokastro, Geroplatanos and Riza villages, eighteen (18) drinking water boreholes were recorded. Alternations of phyllites, re-crystallised limestones, quartzites, calcschists were drilled and their yields range from 10 to 35 m³/h. Productive boreholes (n=4) are located east of Agios Prodromos village area, they drilled an elongated re-crystallised limestone bed, 200 - 400 m in thickness, fixed between the phyllites. Their yields are 40-80 m³/h and supply drinking water to the Polygyros town (6.300 permanent inhabitants).

The drinking water boreholes (n=4) located around Vavdos village, have drilled until a depth of 250-330 m the greenschists, phyllites, calcschists, gabbros and epi-gneisses but their yields are low (3-15 m³/h). Boreholes (n=3) that were completed in the fault zones of greenschists and gabbros of the Galarinos village area were successful and their yields are 30-40 m³/h.

At Vrastama village area eighty (80) boreholes with 160-330 m depth were recorded. They drilled the re-crystallised limestones intercalated with quartzites and phyllites and their yields range from 20 to 80 m³/h. In the ultramafic to mafic rocks (10 km²) located in Metamorphosis village area an excessive number (6/km²) of boreholes was completed (30-220 m drilling depth). They have low yields (1-15 m³/h), several boreholes are waterless or their water reserves have been extinguished shortly. Also in the Metamorphosis village area thirty-five (35) boreholes were recorded with 80 to 230 m drilling depth. They have drilled alterations of calcschists, phyllites and quartzites but have low yields (1 -20 m³/h). Also, several boreholes were waterless and in many sites the groundwater reserves have been depleted soon.

In Nikiki town area seventy (70) boreholes were recorded. They drilled Quaternary, Neogene sediments, quartzites, calcschists, phyllites and the granodiorite of Sithonia until 230 m depth. The potential aquifers are mainly located in the faulted zones of the quartzites. The yields range from 5 to 80 m³/h, but there are several waterless boreholes especially where they have been

drilled phyllites or unfractured granodiorite. In Marmara area boreholes drilled in the phyllites, greenschists and granodiorite were waterless or their yields were low (2-12 m³/h). The productive boreholes (20-80 m³/h) are associated with the granular aquifers located in the overlying loose sediments and are recharged by the runoff filtration along the Tripotamos and Myli streams.

At Sykia-Sarti-Toroni area fifty (50) low yielding (2-7 m³/h) boreholes were recorded. They drilled the granodiorite and the overlying loose sediments and the drilling depth varies from 40 to 300 m. The productive boreholes with yields 20-50 m³/h are associated with extended and thick cover (20-30 m) of the overlying loose sediments or weathered granodiorite located upstream. In some places, the intensive fracturing along the main faults located in the granodiorite created fine grade materials consisting of clay minerals and they formed a barrier preventing the groundwater flow. Conversely, where the mylonite zone is transverse to the direction of the groundwater flow it works positively. Boreholes completed upwards of the mylonite zone have yields ranging from 20 to 30 m³/h. The over-exploitation of fractured aquifers of the coastal areas of Sithonia peninsula and Metamorphosis, Agios Nikolaos, Pyrgadikia areas resulted to rapid decline of groundwater levels, drastic reduction of the well yield and subsequent salinization of the aquifers (Manakos et al. 1998, Veranis et al. 2010b).

-Correlation between specific capacity and transmissivity: From the processing of the reliable pumping test data for forty (40) boreholes located in Chalkidiki peninsula and Krousia mountains (Veranis and Christidis, 2013) resulted that the values of the Sc and T follow a lognormal distribution, as shown in Fig. 3, and their correlation equation is:

$$T = 0,7434(Sc)^{0,96} \quad (1)$$

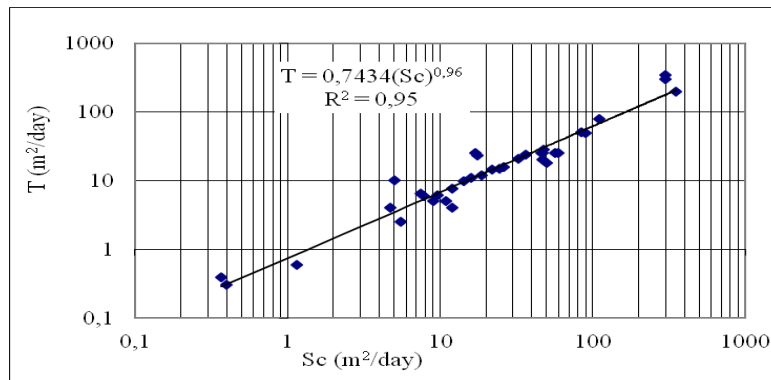


Figure 3. Correlation between specific capacity and transmissivity of the boreholes drilled in the fractured aquifers of Chalkidiki and Kerdyllia-Krousia areas.

Based on the equation (1) and the values of the specific capacity resulting from the well-logs data of one hundred-twenty (120) boreholes that drilled gneisses, amphibolites, granites, quartzites and schists was calculated the transmissivity. Finally for one-hundred-fifty (150) boreholes studied the value of the transmissivity ranges from 0,3 to 350 m²/day, the arithmetic mean is 25 m²/day (±51) and the geometric mean is 13,0 m²/day. About 46% of the boreholes belongs to the class values: T = 0,3-10 m²/day and 50 % in the category: T=10-100 m²/day respectively. Is noted that values: T=1-10 m²/day is characterize fractured aquifers of low potential appropriate for personal use boreholes only and values: T=10-100 m²/day declare intermediate potential suitable for public water supply wells in villages or farms and factories (Krazny, 1993).

-Groundwater table level/piezometric surface data: At the stage of the boreholes inventory carried out by IGME, the water static level (WSL) was recorded, but systematic measurements were made in thirty-six (36) boreholes of the Asprolakkas basin during the period 1996-2013 and in fifteen (15) boreholes located in the granodiorite of Sithonia peninsula during the period 2005-08 (Veranis et al. 2010a,b, Veranis and Devilekas, 2010, unpublished data from the Hellenic Gold Company) respectively. The WSL values in fractured aquifers ranges from +0,1 m to 160 m depth. The greater depths were recorded in the recharge zone located in the uplands and

the lower in the discharged area in the low lands respectively. In the recharge zone the aquifer is unconfined and became gradually sub-confined to confined, in the lower topographic areas. The water table level/piezometric surface roughly follows the topographic slope. The values of the hydraulic gradient is relatively high with mean value: $i=0,076\%$ and ranges from 0,09 to 0,04%.

The interannual fluctuations of the WSL vary, depending on the location of the borehole to the topography of the basin, the thickness of the soil cover and the weathered rock and the degree of the fracturing. Low fluctuation values (0,1-0,5 m/yr) are recorded in the boreholes located in the lower parts of the basin or where the soil cover/weathered rock mantle have great thickness. On the contrary, sudden variations of the WSL ranging from 5 to 40m were observed in the recharge zone of the aquifer or where the soil cover and the weathered rocks are lacking or are very thin and wherein the rocks are intensely fractured. In the Asprolakkia basin boreholes ($n=36$) the mean of the annual fluctuations is 1,68 m (0,01-9,74), while in the fracture aquifers of Sithonia peninsula granodiorite the mean is 1,15 m (0,6-28) respectively.

3.2. Carbonate rocks aquifers

The carbonate rocks that are considered important for the hydrogeology are occupied a total area of 90 km² (3,85%). They distinguished into marbles and re-crystallised limestones, forming horizons with thickness ranging from 50 to 200 m. The carbonate rock beds were often structurally juxtaposed during the Alpine folds in the gneisses and phyllites, are separated among them and therefore do not hydraulically connected to form potential aquifers. The re-crystallised limestones laterally transform to quartzites, calcareous schists and phyllites. In many places the re-crystallised limestones have small thickness, occur as elongated zones alternating with the phyllites and have little hydrogeological interest. Special importance has the carbonate aquifers that are recharged from surface waters filtration along the streams beds.

The carbonate rocks are mostly located in the central part (Vrastama, Metaghitsi, Chavria, Taxiarchis, Agios Prodomos, Galatista) where the re-crystallised limestones are located and in the eastern part where two marble horizons are intercalated into the gneisses (Fig. 1). In places, the carbonate rocks are intensely karstified but there are also microcrystalline limestones with minimal karstification. Due to the small thickness of the carbonate rocks only the epikarst zone was formed. Their hydraulic conductivity is estimated to range from 10^{-3} to 10^{-6} m/s in the upper levels and decreases in 10^{-7} m/s at greater depths. The infiltration rate of the precipitation varies and depends on the degree of the karstification, the slope of the relief, the thickness of the soil cover and the vegetation. It estimated that the infiltration is about 20-50% of the precipitation and ranges from 150 to 280 mm/yr.

The springs located in the contact between the overlaying marbles and the underlying gneisses of the Varvara and Neochori areas have yields of 5-20 m³/h. The spring Pente Bryses in the Kipouristas stream outflows from the faulted marble lenses and weathered biotite gneiss yielding 40 to 60 m³/h. The marbles in the Modi-Retina area are discharged to Rentina valley with a total flow of 160.000 m³/yr. Boreholes were drilled in the marble of Esphigmenou Monastery at Athos Peninsula and yield 35 m³/h (Veranis et al. 2010b).

In the Olympias, Madem Lakkos and Mavres Petres mines through the marble horizons significant quantities of waters are infiltrating creating severe problems to the mining operations. In the marbles outcrops lying above the mines, ditches are constructed to collect surface waters and preventing them to enter in the mine works (Veranis & Meladiotis, 2005 & 2002).

In the re-crystallised limestones located in the central Chalkidiki area, are hosted high potential aquifers but there are also sites where the boreholes drilled the carbonates and were waterless. A large number of boreholes were constructed to exploit the groundwater reserves of the re-crystallised limestones of the Vrastama-Chavrias area and also at Agios Prodomos and Galatista areas. Their drilling depth ranges from 150 to 300 m and the yields are 20-80 m³/h. The springs located in the contact between the carbonates and the underlying schists have supplies of 5-15 m³/h, while in Chortiatia Mountain near to Peristera village the spring yields 40-60 m³/h.

4. HYDROLOGIC BALANCE AND GROUNDWATER USES

Inputs: From previous water balance calculation studies it resulted that the average annual precipitation over the period 1974-2009 is 600 mm (550-750) and the mean annual real evapotranspiration is 450 mm (75,0%), (Veranis et al. 2010b). The average percolation, based on data reported previously and of the rocks distribution in the geological map, is estimated about 50 mm/yr (8,3%). Mean runoff calculated from the equation of water balance is 100 mm/yr. Based on the above, the water quantities infiltrating are about $116 \cdot 10^6$ m³/yr and the total runoff is $234 \cdot 10^6$ m³/yr. The water quantities from the infiltration and runoff mostly are discharged towards the coastal areas and sedimentary basins surrounding the fractured rocks.

From runoff measurements in the main streams and rivers it concluded that the amounts of surface water quantities could assist the communities in the solution of the demanding water supply problems. Up to date, technical and feasibility studies carried out for the dams of Chavrias and Olynthios rivers as well as for the Petrenia stream in the Gomati area. There are also suitable sites for smaller dams construction in the streams of Myli, Tripotamos, Smixi of Sithonia peninsula (Manakos et al. 1998).

Outlets: The groundwater consumption for the drinking water purposes for 50.000 permanent inhabitants, plus seasonal residents derived from the springs and the boreholes are estimated to $9 \cdot 10^6$ m³/yr. The irrigated lands are 22.000 acres and irrigation mainly concerns olive trees. The pumped groundwater quantities for irrigation are $9,0 \cdot 10^6$ m³/yr. About 10-15% of the irrigation water returns back to the aquifer system. The greater pressure to the aquifers happens during the summer season because in this period coincides the low or no recharge of the aquifer, the piezometric low and the higher consumption. In the Olympias, Madem Lakkos and Mavres Petres mines the total pumped and treated groundwater quantities are $5,5 \cdot 10^6$ m³/yr (Veranis et al. 2010a,b, Veranis and Meladiotis, 2005).

5. NATURAL AND MAN-MADE CONTAMINATION OF GROUNDWATERS

In order to assess the groundwater quality IGME has carried out chemical analyses of the springs and boreholes water during the period 2004-2010 and in previous studies. The spring's water meets the drinking water standards but in many boreholes that drilled the fractured aquifers high values of Fe (200-1300 µgr/l) and Mn (50-500 µgr/l) are determined exceeding the upper permissible standards for the drinking water. High values in F (1,5- 4,0 mg/l) are found in boreholes located in the Arnaia type granite (Veranis et al. 2010b).

Relatively higher values in As (10 - 80 µgr/l) and SO₄ (200 - 400 mg/l) are occasional defined in fractured aquifers of the north-eastern Chalkidiki metallogenic area and are attributed to the mineralization process. The mining activities in this area have started from the ancient times and continuous until present, so high values of heavy metals, toxic elements (Fe, Mn, Zn, Pb, Al, As, Sb, Ni, Cd) and SO₄ are determined in the acid waters located in old adits and waste sites deposition. Mine waters after treatment discharged to the sea (Veranis and Meladiotis, 2002).

The carbonate aquifers usually contain good quality water. The predominant water types are Ca-Mg-HCO₃±Cl±SO₄ and Ca-Na±Mg-HCO₃±Cl±SO₄. Borehole over-pumping in the coastal areas of Sithonia peninsula and Metamorphosis, Nikiti, Agios Nikolaos, Pyrgadikia areas caused the intrusion of seawater into fractured aquifers in the mainland (Veranis et al. 2010b).

6. CONCLUSIONS

In the central and eastern Chalkidiki peninsula low potential fractured aquifers are located in the contact between the weathered and the un-weathered rock, and low to moderate potential aquifers in the fractured un-weathered metamorphic or igneous rocks and occasionally in the carbonate rock intercalations as well as granular aquifers in the overlying the hard rocks of small thickness (30-60 m) loose sediments.

The yield of the springs in fractured crystalline (no carbonates) rocks ranges from 0,5 to 5,0 m³/h, while the carbonate rocks the yield varies from 5 – 60 m³/h and the mean value is 10 m³/h. Average yield of the boreholes (n=150) is 25 m³/h and the maximum values are 40-80 m³/h. The mean of the specific capacity is 0,80 m²/h ranging from 0,10 to 15,0 m²/h. In many places

the metamorphic and igneous rocks have very low potential or are waterless. Although the fractured aquifers are of low to moderate potential, are important for the needs of the local society. Long-term boreholes productivities rely on the presence of saturated weathered material overlying the fractured rock or an alternative source of the aquifer recharge such as the runoff of a stream or associated loose sediments. Where there is a lack of surface water filtration and the weathered overburden is very thin, the predominant factors for the location of a potential aquifer are the faults and fractures developed in the un-weathered rocks.

The groundwater consumption for drinking, irrigation and other uses are $19 \cdot 10^6$ m³/yr. The pumped and treated mine-waters quantities in north-eastern Chalkidiki are $5,5 \cdot 10^6$ m³/yr. The common natural contaminants in fractured aquifers are Fe, Mn and occasionally F, As, SO₄.

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