FRACTURE PATTERN DESCRIPTION AND ANALYSIS OF THE HARD ROCK HYDROGEOLOGICAL ENVIRONMENT, IN A SELECTED STUDY AREA IN TINOS ISLAND, HELLAS

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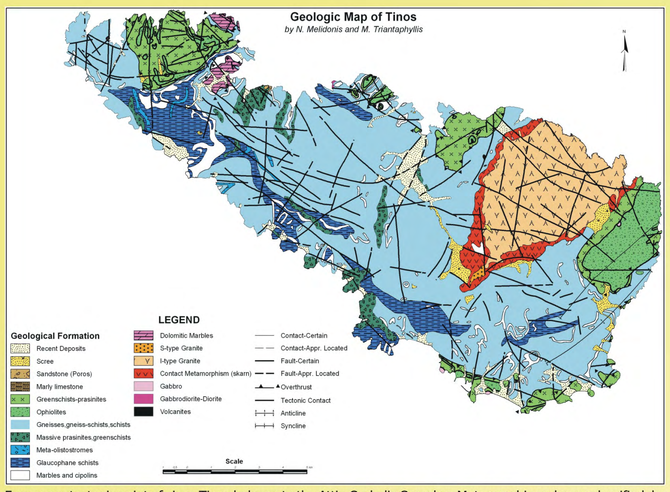


From a geotectonic point of view, Tinos belongs to the Attic-Cycladic Complex. Metamorphic rocks are classified, by their mineral composition, metamorphic phase and the age of metamorphosis, into three tectonic units: (1) the Upper Unit composed of serpentinites, metagabbros, metabassalts, phylittes 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.

ABSTRACT

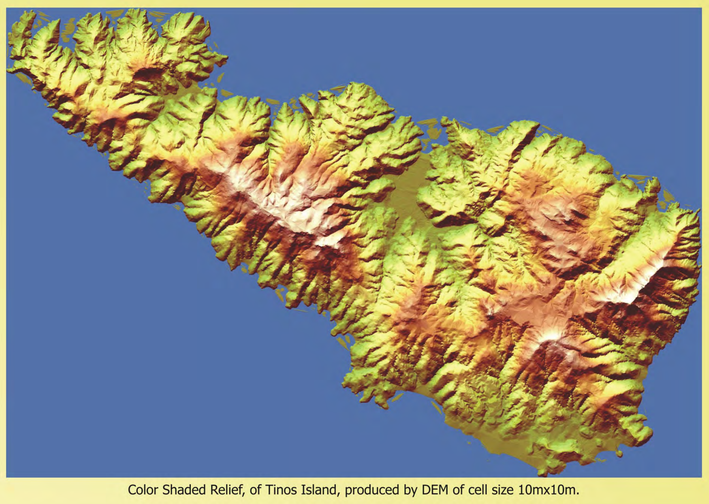
The description of the main parameters that control the groundwater flow regime, are of critical matter, in a hydrogeological/hydraulical or in a geotechnical study. This paper, aims to describe and analyze the fracture pattern in the hard rock hydrogeological environment in Tinos Island. Remote Sensing and GIS techniques were integrated along with results from field work. The parameters that were analyzed are: a) the frequency and spatial location of fractures, b) fractures orientation, c) fractures dimensions, d) fractures density and e) the degree of fractures intersection, along with their relation to lineament structure that was extracted after remote sensing image interpretation.

The increasing need of groundwater for water supply during the last decades, led to a continuous interest for groundwater in hard rocks. This interest was focused on a better knowledge about the hydrogeological environment of hard rocks and the recharge, flow and composition of groundwater as well. The groundwater flow regime in hard rocks depends on several factors, including the climate (precipitation and evapotranspiration), geomorphology, tectonic regime and with no doubt on the dimensions, nature, density, orientation and interconnection of fractures. As a result the description of the fracture pattern is a crucial matter for a hydrogeological investigation in this type of environments.

The purposes of this study were the depiction and analysis of the fracture pattern of a selected study area in Tinos Island and its relationship with the major structures like faults and folds, by emphasizing on the following parameters:

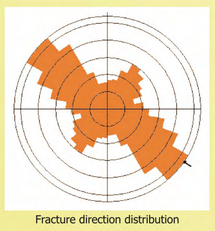
a) Fracture frequency and distribution
b) Orientation of fractures
c) Fracture dimensions
d) Fracture density
e) Degree of intersection between fractures

Images collected by late generation satellites are characterized by improved spatial and spectral resolution. The spatial resolution could be improved more by using higher resolution images like air photographs, resulting images ready for lineament interpretation in larger scales. An image lineament, which is a linear object of a priori geological origin, is a structural expression detected by remote sensing.

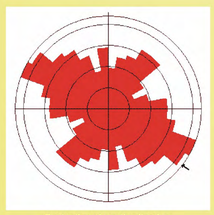


Color Shaded Relief, of Tinos Island, produced by DEM of cell size 10mx10m.

A dataset of Landsat 7 – ETM+ was subset and a combined satellite image of Tinos Island was produced with a resolution of 15m per pixel and 8 available spectral bands to combine. In order to reach the best possible accuracy, the georeferenced images were orthorectified using a digital elevation model with a cell size of 10m and finally projected on the Hellenic Geodetic Reference System (HGRS'87). The orthorectified image was used in order to identify lineaments that could correspond to tectonic structures which might be supplementary to previous researchers' mapping work. Consequently a set of air photographs (1/30.000 scale) was also orthorectified at the same projection and an orthophoto mosaic was produced reaching a high resolution of 5 meters per pixel. Following, the high and relatively low resolution images were merged using the principal component method, in order to produce a higher resolution digital set of 8 bands. This image has the same spectral characteristics of Landsat 7, but also better resolution. The figure above shows the extracted detail of the interpreted image. This new image was used for lineament interpretation (at larger scales) as these could be related to zones of deformation and fracturing, which implies zones of higher secondary porosity.



Fracture direction distribution



Fault direction distribution

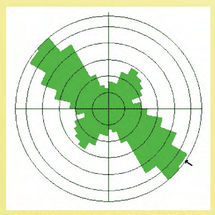
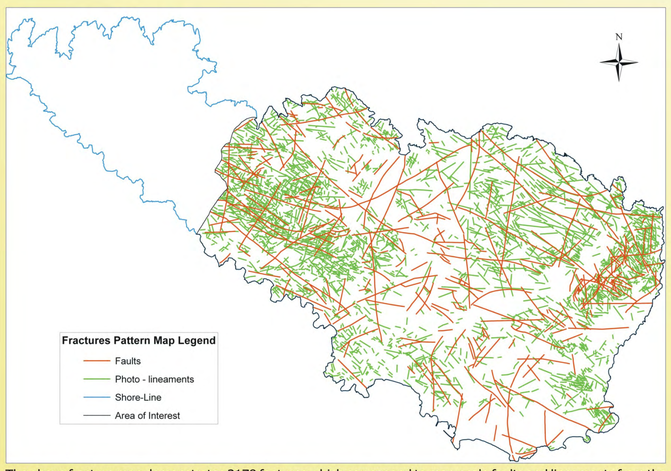
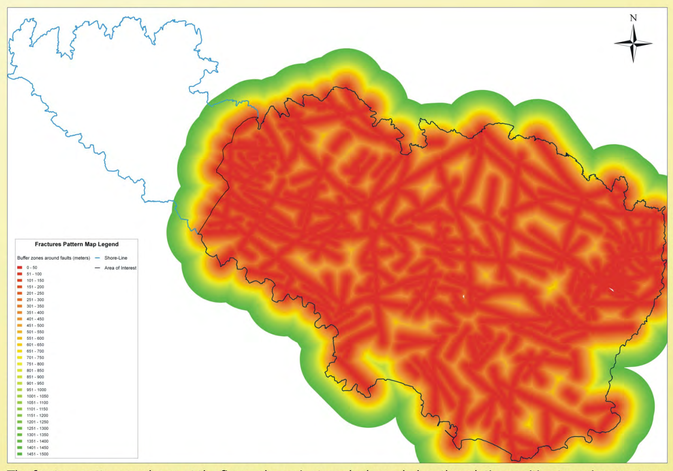


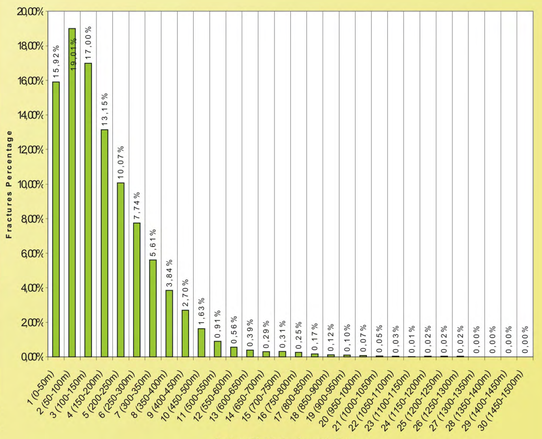
Photo-Lineament direction distribution

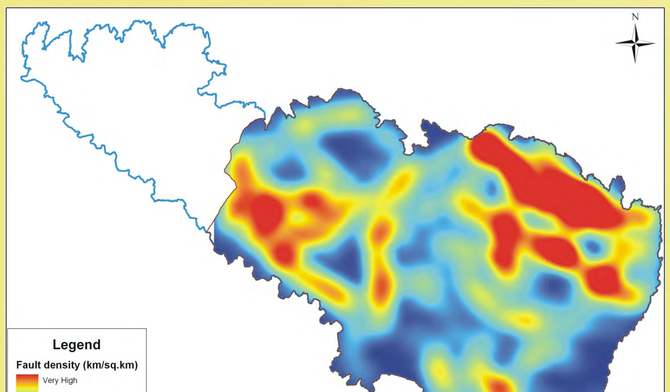


The above fracture map demonstrates 3178 features which correspond to map-scale faults and lineaments from the ortho image products which became after the aerial photographs and satellite image interpretation. Most of these lineaments are easily identified in the field as steeply dipping to vertical 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.



The fracture pattern as shown at the figure above, is strongly depended on the relative position to major structures like faults. In order to show this relation, a buffer zone of 1500m, was created around each fault. This buffer zone was divided into 30 sub zones of 50 meters each and the total number of lineaments in each zone was computed. The distribution of lineaments shows that 51.93% of the lineaments are located within a distance of 150m from the faults (right figure). After this distance the lineaments frequency, follows roughly a lognormal curve, as is common in many geological populations.





Fracture density is an important parameter for the delineation of the groundwater flow in hard rocks. Fracture density maps were constructed in order to interpret the frequency and distribution of fractures. The above density map represents the total length (in km) of lineaments per square kilometer of area.

CONCLUSIONS

The general idea of increasing the spatial resolution of multispectral satellite images using other types of remote sensing data seems to be the key of using them at a variety of scales, depending on the aim of the work to be done.

The study of the fracture pattern, extracted from such products, reveals that:

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 is located within the distance of 250m to faults.
d) The fracture density and degree of interconnection is depended on the combination of brittle and ductile tectonics, on the thickness of the weathered mantle and the lithology.
e) The combination of Remote Sensing, GIS and field work, leads to an accurate and reliable description of the fracture pattern in hard rocks hydrogeological environments.

ACKNOWLEDGEMENTS

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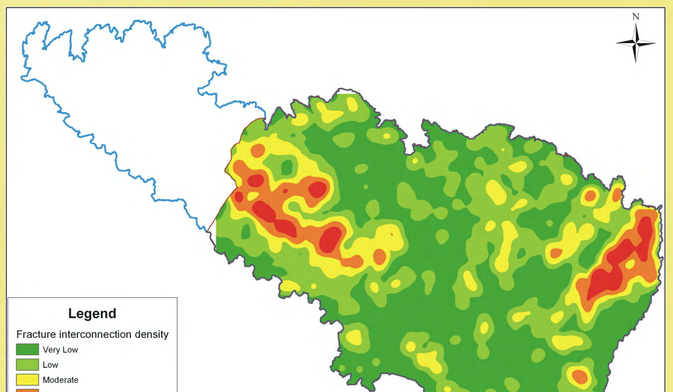

The degree of fracture intersection along with fracture density, depicts completely the fracture network in terms of spatial analysis. These two parameters determine the degree of anisotropy of the groundwater flow in the fracture network. It is unquestionable the fact, that in environments with high degree of interconnection (red areas in the figure above), the groundwater flow is smoother and more uniform.