THE USE OF DIGITAL ELEVATION MODELS (D.E.M.) AND GEOGRAPHIC INFORMATION SYSTEMS (G.I.S.) IN GEOLOGICAL MAPPING. A CASE STUDY IN THE SOUTHERN VERMIO MOUNTAIN (SW MACEDONIA, GREECE)

OUZOUNIS ATHANASIOS[1], **KILIAS ADAMANTIOS**[1], **MOUNTRAKIS DIMOSTHENIS**[1]

ABSTRACT

This study presents the results of the geological mapping at a scale of 1:25000 in the area of the southern Vermio Mountain. This was done in order to study the geological evolution of the Pelagonian nappe and its border with the Axios zone. In this project we used G.I.S. to develop a spatial data base and the D.E.M. of the region to obtain additional geological information.

The geological mapping showed that the Pelagonian nappe in the study area consists, from top to bottom, of: a. an upper recrystalized carbonate sequence of Triassic-Jurassic age b. a thin, upper schist-gneissic sequence of Palaeozoic age (?) c. a lower sequence of marble presumably of the same age as the upper carbonate sequence, d. a lower schist gneissic sequence of Palaeozoic age(?), which overlies a granitic-orthogneissic system of Palaeozoic age (302±5 m.y.) and e. an underlying thick locally mylonitized, schist-gneissic horizon of Palaeozoic age (?).

Concluding, the advantages and disadvantages of using D.E.M.'s and G.I.S. in geological mapping are stated.

KEY WORDS: D.E.M., G.I.S., Geological mapping, Pelagonian Zone, Southern Vermio, SW Macedonia, Greece

1.INTRODUCTION

The tectonic structure of the Pelagonian nappe (Fig.1) in the southern Vermio Mountain is still a geological problem. Until now there is poor data about the geological evolution of the study area. The first mapping of the region was effected in 1968 by the pioneering work of Godfriaux. Later Yarwood & Dixon (1977), Yarwood (1978) worked in the area stretching from the southern Vermio Mountain to the Mauroneri valley to the south. The region was also studied partly by Schmidt in 1983. Furthermore no geological map of the region at a scale of 1:50000 has been published yet by the I.G.M.E. This was the reason that pushed us to study the structure of the southern Vermio Mountain by mapping it at a 1:25000 scale.

A digital elevation model of the broader study area was built using ArcInfo™ and ArcScene™ part of the G.I.S. software package ArcView™ v.8.0.2. by E.S.R.I.™. The D.E.M. was build in order to visualize the topography derived from a 2 dimensional dataset in 3 dimensions on a computer monitor. Three dimensional displays of the terrain enhance the perception of geomorphologic features which are a result of the geologic structure and thus help the geologist to identify and to interpret structural problems (Van Driel, 1989). A Geographic Information System was used (ArcView v.8.0.2.™ by E.S.R.I.™), to assist our work in the following fields (a) data storage and management; (b) data visualization and output and (c) data manipulation and analysis. Our final goal was to present our map in a digital form.

Although there are differences of opinion about, whether digital methods are faster or more efficient for the initial production of geologic maps, nearly all agree that digital maps are much faster and more efficient to update. Digital maps can easily be re-drawn at a different scale or projection than the original, and features on the maps can be easily added, deleted or modified. In addition it is easy to combine the digital geology with other data sets (Raines, 1998).

1:School of Geology, Aristotle University of Thessaloniki, GR-54006 Thessaloniki, Greece

2. GEOLOGICAL SETTING

The Pelagonian nappe consists of various tectonic units composed of pre- and alpine protoliths showing different geodynamic evolution. They are distinguished from bottom to top in pre-alpine metamorphic and igneous basement rocks, metaclastic and volcanic rocks of Permotriassic age and platform carbonates of Triassic-Jurassic age. Ophiolitic rocks and transgrssive Cretaceous limestones alterated into a Palaeocene flysch lay on top of the Pelagonian Triassic-Jurassic carbonate rocks. The whole nappe stack overlay tectonically the high pressure metamorphic rocks of the Ampelakia unit and the neritic carbonate units of Olympos-Ossa and Rizomata-Krania, which are exposed today as tectonic windows. The Olympos Ossa and Krania-Rizomata units as well as the Ampelakia unit have suffered only one tectonometamorphic event during the Tertiary (Godfriaux, 1968, Schermer, 1993, Kilias et. al., 1993). On the contrary, the overlying Pelagonian nappe is characterized by a more complex tectonometamorphic evolution (Kilias & Mountrakis, 1989). Ductile shear zones and westward thrusting of the Pelagonian nappe accompanied its intense deformation during Cretaceous and Tertiary times. The alpine tectonometamorhic event of the Cretaceous age in the basement rocks took place under epidote-amphibole facies (Barton, 1976, Kotopoul et al., 2000, Mposkos & Peraki, 2001, Yarwood & Dixon, 1977) followed by extensional tectonics and exhumation (Kilias et. al., 1993).

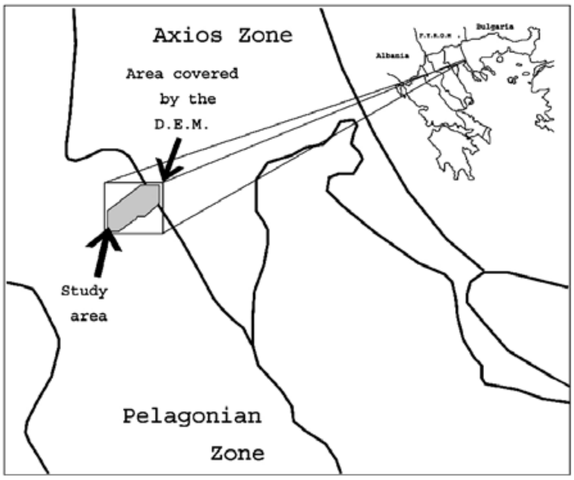


Figure 1: The study area and its position at the border of the Axios zone with the Pelagonian nappe zones and the area covered by the D.E.M. (Geotectonic zones after Mountrakis, 1983)

3. DIGITAL ELEVATION MODEL

In order to build the D.E.M. of the broader study region (fig.1, 2a and b) 100 and 20-meter contour lines from the paper documents: topographic sheet Velvendos and Kolindros, scale 1:50000 (H.M.G.S., 1970) were digitised manually. For building the D.E.M., triangulation was used rather than the grid method as lineaments in the sense of O'Leary (1976), caused by tectonic structures, could better be observed on the first. Lineaments identified on the D.E.M. were used as a guide in the field for spotting possible faults and tectonic contacts. Furthermore lineaments were also traced on the aerial photos of the area. On the D.E.M. tectonic lineaments were defined more clearly than on conventional aerial photos. The D.E.M. showed many lineaments, which could not be verified in the field or on the aerial photos. For the second occasion distortion, weather conditions (clouds) and/or vegetation were responsible in many cases. An example of a lineament marked on the D.E.M. (fig. 2a and b), which was verified as a fracture of the crust in the field can be seen on the Kastania-Zoodochou Pigi road where the mirror surface of a fault was observed (fig. 2c) on which characteristic "step" microstructures were identified (fig. 2d).

3D visualization of the terrain allowed a better perception of the available topographic information but the construction of the D.E.M. proved to be very time consuming. By the time the fieldwork finished, the D.E.M. was still uncompleted leaving many lineaments observed on it unverified in the field. In the near future high resolution D.E.M.'s should be available from the H.M.G.S. leaving the geologist more time for evaluating the D.E.M. rather than automating it.

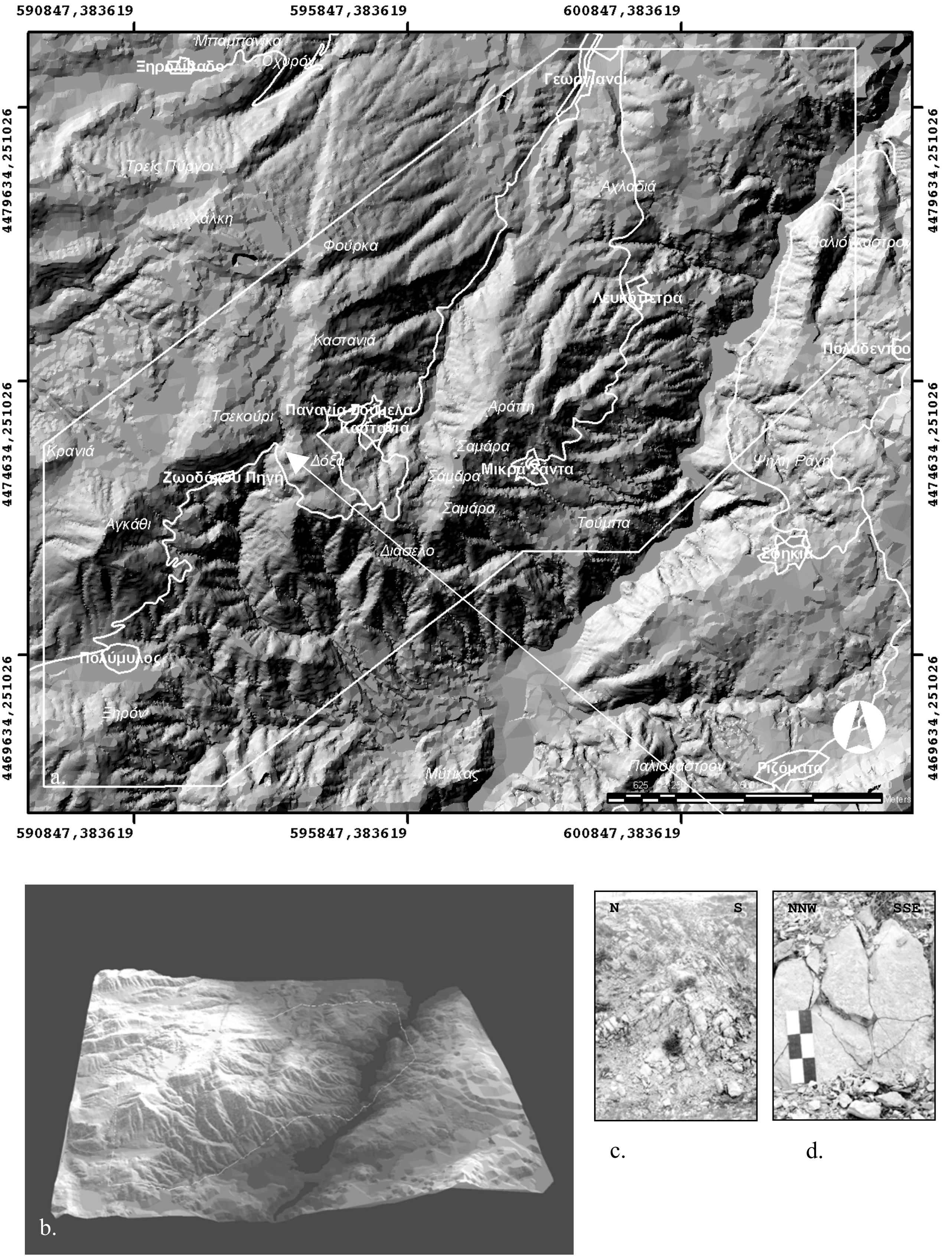


Figure 2: a. The D.E.M. of the broader study area viewed perpendicular to the surface from a virtual altitude of 20000m b. 3D visualization of the southern Vermio Mountain c. photograph of the mirror surface of a normal fault observed in the field dipping to the SW d. microstructures indicating normal movement SE 45°. The arrow points to the location of the observed mirror surface. (The white polygon on fig. 2a & b marks the area geological mapping was carried out.

4. USING G.I.S.

4.1. DATA CAPTURE

Data capture was effected by a. digitizing features directly from the topographic sheet covering the study area and b. extensive fieldwork.

4.1.1. DIGITAL TOPOGRAPHIC MAP

Before launching the actual data capture in the field a digital topographic map was built. The base map used was the paper document of the topographic sheet Velvendos (H.M.G.S., 1970), at a 1:50000 scale. The necessary geographic features of the topographic map were digitized manually from scanned images of the original document directly from the computer monitor. The territory, from which features were digitised, covers a larger surface than the actual mapping area itself as we intent to expand our study area.

The features digitized form two groups: a. Geographic features which are used as an aid in orientation in the study area and b. geomorphologic features as they can give evidence for the lithology and the geological structure of a region (Vavliakis et al, 1987). The layers listed bellows comprise the digital topographic map. Geographic data layers: 1.Main roads; 2.Cities and villages; 3.Secondary roads. Geomorphological layers 1.Drainage system; 2.Wells; 3.Contour level of 100-meter interval; 4.Contour level of 20-meter interval; 5.depressments of the terrain and 6. Marble quarries 7. Mountain peaks.

All data layers mentioned above comprise the basic spatial data base into which all geologic data collected in various ways were integrated.

4.1.2. DATA CAPTURE IN THE FIELD

Geological observations and measurements gathered during extensive fieldwork, were intergraded to the spatial database of by using an outdoor mobile G.P.S. unit that provided exact x-y co-ordinates. In order to get compatible readings for use with the topographic sheets compiled by the H.M.G.S. (scale 1:50000), the European 1950 datum was selected from the datum list of the G.P.S. unit. From tests at known locations an accuracy of 30 meter was concluded which was sufficient for the mapping in the scale of 1:25000. Using ArcInfo's™ "project" command the x-y coordinates obtained were transformed to metric units for use in our database. From document files created by this procedure we directly generated point layers that were overlain onto our digital topographic map.

The data layers compiled using this procedure, are listed below: 1. All the locations observations were made 2. The location strike and dip direction of the main schistosity was measured 3. The locations were the azimuth and the dip direction of the main stretching lineation was measured; 4. The locations the sense of shear was interpretated 5. The lithology observed at each location.

4.1.3. LITERATURE DERIVED DATA

Geological paper maps compiled by other authors (Godfriaux, 1968; 1:100000, Yarwood, 1977; scale 1:50000 and Schmidt 1983, Koroneos et al, 2000) were scanned rectified and then overlain onto our map. The geological sheet of the region was not available as it has not been published yet. In addition a polygon layer with the territory covered by 25 airborne b/w photos at a scale of 1:33000 (source H.M.G.S.) was compiled.

4.2. DATA ANALYSIS AND OUTPUT

All available data layers were used for conducting overlapping analysis, for example the geological mapping effected in this study was compared with the maps compiled by other authors (see 4.1.3.). In addition by using various spatial distributions of tectonic measurements (the dip direction and plunge for the schistosity and the stretching lineation), and using the Schmidt plotting software application StereoPlot™ a great number of Schmidt diagrams was obtained in a time consuming and accurate manner. This left more time analysing the Schmidt diagrams than constructing them. Furthermore sections of the topography were plotted with ease leaving more time to work on the geology of the sections than on drawing the topography. The digital map consists of a polygon layer with the geological formations, a line layer with possible faults observed on the D.E.M., a data layer with the faults identified in the field and one with the anticlines and synclines. All data layers described above compose our complete geologic spatial database from which the final geological map was printed. All data collected in this project can be accessed by hyperlinks from the digital map compiled using the shareware ArcExplorer™. These data sets are photographs (fig. 5a-d); geological sections (fig. 4), descriptions of the lithological formations e.t.c. The final goal is an interactive communication with the end user. This can be achieved by making hyper maps that have a user-specified data structuring. National organisations like The U.S. Geological Survey (Raines et al, 1998), the Geological Survey of Canada (Brodaric, 1998); the British Geological Survey (Nickless and Jackson, 1994, Bain and Giles, 1997) and the Geological Survey of Northrhine-Westfalia, Germany (Kuebler et al, 1999) are working towards setting standards for producing geological hyper maps. In addition overlaying capabilities of data sheets opened the possibility of compiling and printing different versions of the map at various scales conveniently and economically.

5. GEOLOGICAL OBSERVATIONS

Our fieldwork showed (that the studied area is characterized by a tectonic stacking of different lithological sequences (Fig. 4). The uppermost one forms a recrystallized carbonate sequence of Triassic-Jurassic age, underlain by an Upper Palaeozoic (?) schist-gneissic sequence of relatively small thickness ~50m (Fig.3a). They are lain through a tectonic contact on a lower carbonate sequence of marbles of a thickness ~50-100m, presumably of the same age as the upper carbonate sequence (Fig. 3b). These rocks are underlain from top to bottom by I. Palaeozoic (?) metapelitic rocks intercalated with amphibolites. Within the metapilitic rocks occurs a characteristic mica schist horizon with syntectonic growth of garnet locally up to 0.5 cm in size. In the metapelitic rocks σ-and δ-porphyroclasts of quartz, feldspars and garnet (Fig. 3c) can be observed showing a sense of shear mainly top to the SW. Also microscopic examination revealed microstructures indicating towards SW sense of shear (Fig.3d) (Paschier and Trouw, 1996, Lister & Snocke, 1984); II. an Upper Carboniferous intensively sheared granodiorite (302±5 m.y. cooling age after Yarwood and Aftalion, 1976) and III. a complicated, extremely sheared, crystalline sequence of amphibolitic, metasedimentary and igneous rocks at the NE part of the study area. Mylonitic rocks are observed within this tectonically lowermost situated sequence. Kinematic criteria indicate also a movement top to the SW. Sheath folds is a common feature within this mylonitic sequence.

In the region a penetrative schistosity is observed striking mainly NW-SE and dipping NE and SW due to folding in the megascale. On the schistosity plane a stretching lineation is visible dipping NE or SW, depending on the plane dip direction (Fig. 5). The mylonitic fabric traces parallel to the main schistosity observed in the region. According to Yarwood and Dixon (1977), radiometric dating, the main schistosity took place before 122±m.y, associated possibly with the Eo-Hellenic thrusting event.

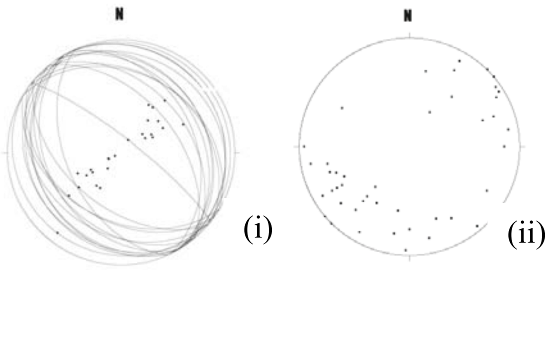
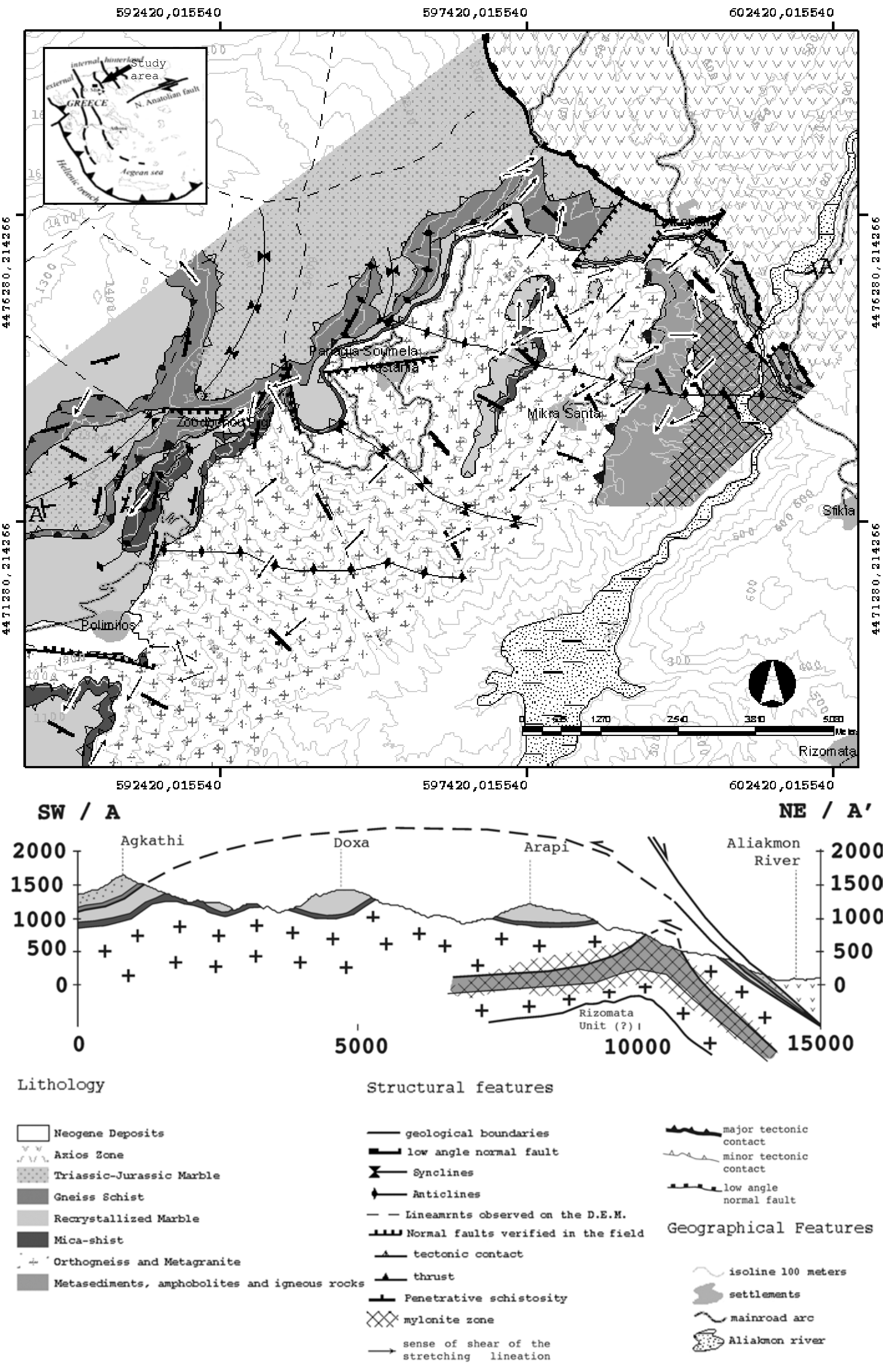


Figure 3: Lower hemisphere stereoplots showing i) the penetrative schistosity n=45 Measurements ii) the stretching lineation n=37 measurements observed in the southern Vermio Mountain.

Figure 4 (Next Page): Geological map of the study area mapped at a scale of 1:25000 and a geological section trending SW-NE.


592420,015540
597420,015540
602420,015540
4476280,214266
4471280,214266
Study area
GREECE
N. Anatolian fault
Aegean sea
Hellenic trench
Panagia Soumela
Kastania
Zoodochou Pigi
Mikra Santa
Polimilos
Sfikia
Rizomata
A
A'
0
635
1270
2540
3810
5080
Meters
SW / A
NE / A'
Agkathi
Doxa
Arapi
Aliakmon River
Rizomata Unit (?)
2000
1500
1000
500
0
5000
10000
15000
Lithology
Neogene Deposits
Axios Zone
Triassic-Jurassic Marble
Gneiss Schist
Recrystallized Marble
Mica-shist
Orthogneiss and Metagranite
Metasediments, amphobolites and igneous rocks
Structural features
geological boundaries
low angle normal fault
Synclines
Anticlines
Lineamrnts observed on the D.E.M.
Normal faults verified in the field
tectonic contact
thrust
Penetrative schistosity
mylonite zone
sense of shear of the stretching lineation
major tectonic contact
minor tectonic contact
low angle normal fault
Geographical Features
isoline 100 meters
settlements
mainroad arc
Aliakmon river

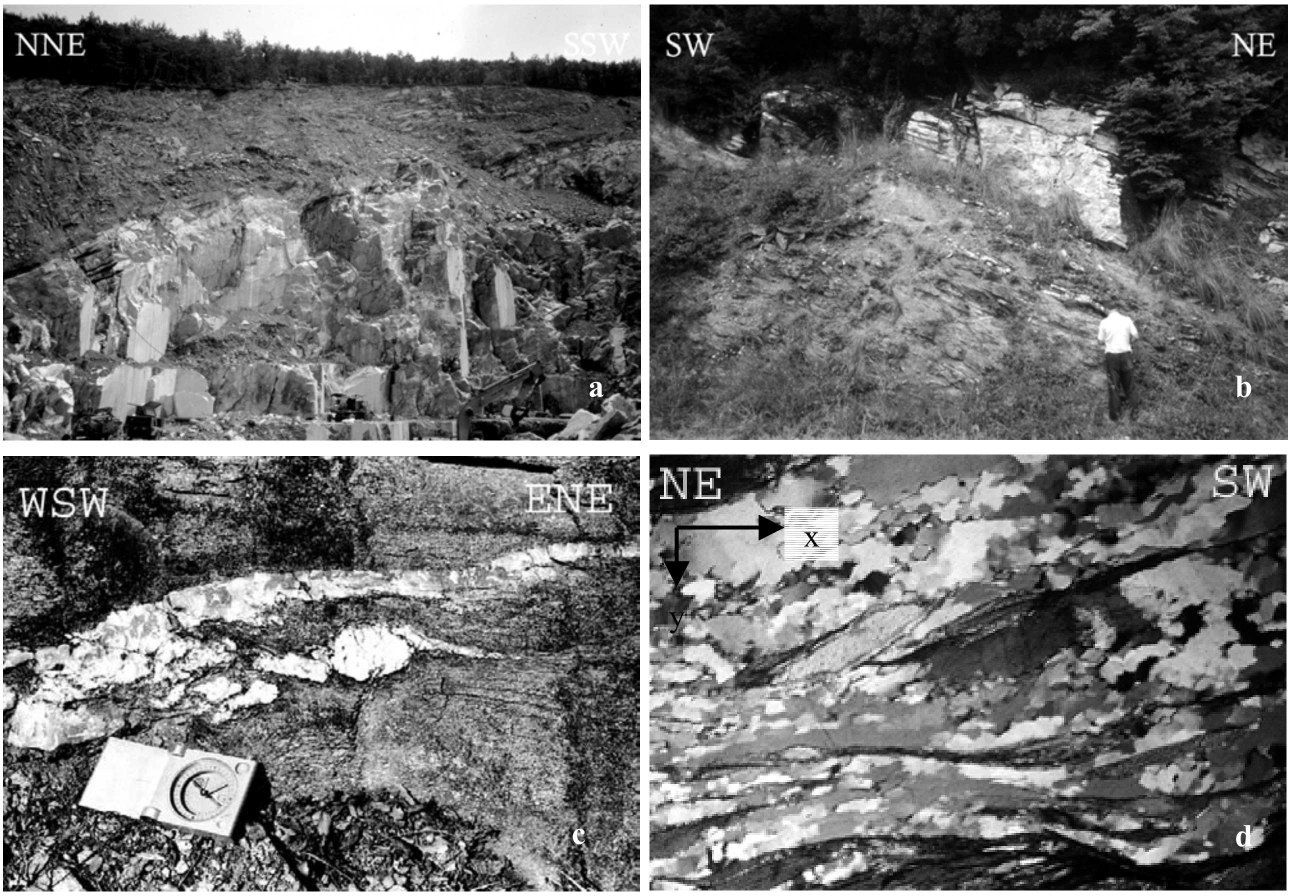


Figure 5: a. Tectonic contact between the schist gneiss (top) and the recrystallized marble (bottom); b. Tectonic contact between the recrystallized marble (top) and mica-schist (bottom); c. a quartz δ-porhyroclast in the mica-schist, sense of shear top to the SW; d. Thin section of the mica-schist with a mica fish structure, sense of shear top to the SW. length of photograph 2.5 mm.

6. DISCUSSION-CONCLUSION

A geological map at a 1:25000 scale of the southern Vermio Mountain was compiled revealing new data about the structure of the region. Although the structural relation of the upper units is more or less clear now, the role of the lower mylonite unit is still a problem. The use of the D.E.M. and the G.I.S. proved to be an aid not only for our mapping project but also for our future research in the region. Our hypermap is still under development and additional data is still added to it while fieldwork is in progress. Cost reduction is an aim when using new techniques. This cannot be achieved less some facts are taken into account. Software and hardware needed have an initial high cost and need maintenance by qualified personal. The user has to undergo time-consuming training in order to get acquired with these technologies. Unless the factor of sound maintenance and training is satisfied increase, rather than decrease, of time and cost of a project has to be expected.

ACKNOWLEDGEMENT

This paper is part of the first mentioned author's (Ouzounis A.) MSc thesis, for which an one-year scholarship was granted to him by I.K.Y.

REFERENCES

[1]BAIN, K. A., GILES, J.R.A., (1997): *A standard model for storage of geological map data*. Computers and Geosciences, **23**(6), 613-620.

[2]BRODARIC, B. (1998): *Field data capture and manipulation using GSC Fieldlog v3.0* URL: http://gis.nrcan.gc.ca/fieldlog. Accessed March 1. 2002.

[3]GODFRIAUX, I. (1968): *Etude geologique de la region de l'Olympe (Grece)*. Ann. Geol. Pays hellen., **19**, p.1-282.

[4]HELLENIC ARMY GEOGRAPHICAL SERVICE (1970): *Map Sheet Velvendos.*
[5]KILIAS, A. & MOUNTRAKIS, D. (1989): *The Pelagonian nappe. Tectonics, metamorphism and magmatism.* Bull. Geol. Soc. Greece, **23/1**, 29-46.
[6]KILIAS, A., FRISCH, W., RATSCHBACHER, L. & SFEIKOS, A. (1991): *Structural evolution and P/T metamorphic conditions of blue schists of E. Thessaly.* Bull. Geol. Soc. Greece, **25**, 81-99.
[7]KORONEOS, A., TSOUTSIKA, P. ELEFTERIADES, & E. SEIDEL (2000): *Mineralogy, Petrology and Geochemistry of the Kastania Ploutonite (Vermio).* 1st Congress of the economic geology, mineralogy & geochemistry comitee, Kozani, p. 223-242.
[8]KOTOPOULI, C., PE-PIPER G. & PIPER D. (2000): *Petrology and evolution of the Hercynian Pieria Granitoid Complex (Thessaly, Greece) paleogeographic and geodynamic implications.* Lithos, **50**, 137-152.
[9]KUEBLER, S. and VOISARD, A. (1999): *GeoHyp: an adaptive human interface for geologic maps and their databases.* Photogrammetry & remote sensing, **54**, 234-243.
[10]LISTER, G.S. & SNOCKE, A.W. (1984): *S-C Mylonites in shear zones. J. Struct. Geol.*, **6**, 617-638.
[11]MOUNTRAKIS, D. (1983): *Structural geology of the North Pelagonian zone s.l. and geotectonic evolution of the internal Hellenides*. Unpubl. "Habitation". Univ. Thessaloniki, Greece, 289 p.
[12]MPOSKOS, E. & PERAKI, M. (2001): *High Pressure Alpine Metamorhism of the Pelagonian Allochthon in the Kastania Area (Southern Vermio).* Greece. Bull. Geol. Soc. Greece, **XXXIV/3**, 939-947.
[13]NANCE, D. (1981): *Tectonic history of a segment of the Pelagonian zone, northeastern Greece*. Can. J. Earth Sci., **18**, 1111-1126.
[14]NICKLESS, E.F.P. and JACKSON, I. (1994): *Digital geological map production in the United Kingdom - more than just a cartographic exercise.* **17**, 51-56.
[15]O' LEARY, D. W., FRIEDMAN, J. D. & POHN, H. A. (1976): *Lineament, linear, lineation: Some proposed new standards for old terms.* Geol. Soc. of Am. Bull., **87**, p.1463-1469.
[16]PASSCHIER, C.W. & TROUW, R.A.J. (1996): *Micro-tectonics.* Springer-Verlag, N.York, 289p.
[17]RAINES, G.L., BRODARIC, B., JOHNSON, B.R. (1998): *Progress Report - Digital geologic database model.* URL: http://pubs.usgs.gov/openfile/of97-269/raines.html Accessed 5, March 2002.
[18]SCHERMER, E. (1993): *Geometry and kinematics of continental basement deformation during the Alpine orogeny, Mt Olympos region, Greece.* J. Struct. Geol. **15**, 571-591
[19]SCHMITT, A. (1983): *Nouvelles contributions a l'etude geologique des Pieria de l'Olymp et de l'Ossa (Grece du Nord).* These Doctorat, Univ. Mons, Belgique: 1-400; Mons.
[20]VAVLIAKIS, E. und SOTIRIADIS, L. (1987): *Beitrag der topographischen Karte zu der geologischen Forschung.* Erster Panhellenische Geographische Kongress, **1**, 198-210.
[21]VAN DRIEL, J. N. (1989): *Three dimensional display of geologic data.* Three dimensional Applications in Geographic Information Systems, Taylor and Francis, London, New York, Philadelphia.
[22]YARWOOD, A. & AFTALION, M. (1976): *Field relations and U-Pb geochronology of a granite from Pelagonian zone of the Hellenides (High Pieria, Greece).* Bull. Soc. Geol. France., (**7**), XVIII, 259-264.
[23]YARWOOD, A. & DIXON, E. (1977): Lower Cretaceous and younger thrusting in the Pelagonian rocks of the High Pieria, Greece. Colloq. Aegean Region, Athens 6th, 269-280.