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MAGNETIC CHARACTERISTICS OF THE RHYOLITES IN THE RHODOPE MASSIF

Stefan Dimovski, Radi Raditchev

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria
E-mail: dimovski@mgu.bg; radirad@mgu.bg

ABSTRACT

The rhyolite formation in the Rhodope massif is presented by Tertiary extrusive and effusive lava in the Western and Central Rhodopes.
Data from measurements performed by the Department of Applied Geophysics, University of Mining and Geology, Sofia and other organizations are summarized. Magnetic characteristics – the magnetic susceptibility and the value of the remanent magnetization vector, are studied on samples from different areas of the Rodope massif – the Bratsigovo-Dospat depression, the Dospat anticline, the Southern Rhodope syncline, the Northern Rhodope syncline, the Smolyan depression and other more local structures as the Kovachevo syncline, the Batak syncline, the Vacha uplift, the Lyaskovo uplift and the Hvoina graben-syncline.
Statistical analysis is applied for estimating the characteristics of sample packs from one and the same region, as well as for estimating the characteristics of the total set of available data. The surface distribution of the magnetic susceptibility is studied for several local outcrops, using the available data from detailed parametric measurements.
The compound analysis of the magnetic susceptibility and the remanent magnetization of the rhyolites in the Western and Central Rhodopes is proving that the detailed mapping according to magnetic characteristics can efficiently enrich the information obtained by the traditional geological mapping.

INTRODUCTION

The rhyolite formation in the Rhodope massif is presented by Tertiary extrusive and effusive lava in the Western and Central Rhodopes and is most completely studied in the Bratsigovo-Dospat structure (Bahneva *et al.* 1978 ; Bojkov *et al.* 1978). It is composed by biotite and amphibole-containing rhyolites up to rhyodacites. In the northern part of the Bratsigovo-Dospat volcanogenic structure they form one elongated in subequatorial direction zone (Bahneva *et al.* 1978). In the rhyolite zone can be isolated several elementary volcano-structures. The authors state that each of these structures is built by several close in age, in structural-morphologic peculiarities and in magnetic characteristics extrusives, as well as by the connected to them effusive lava flows. For the extrusives is established the presence of remanent magnetization.

I.Bojkov *et al.* (1978) confirm that in the Bratsigovo-Dospat depression the rhyolite covers have frequent occurrence and are characterized by a well-expressed almost horizontal surface parallelism – angle of dip of about 12°. Extrusive rhyolite bodies intersecting the rhyolite covers are located in the western part of the depression. These extrusive bodies are normally determining the contrast in the relief.

The presented study is based upon data from measurements performed by the Department of Applied Geophysics, University of Mining and Geology, Sofia and other organizations. Magnetic characteristics – the magnetic susceptibility and the value of the remanent magnetization vector, are studied on samples from different areas of the Rodope massif – the Bratsigovo-Dospat depression, the Dospat anticline, the Southern Rhodope syncline, the Northern Rhodope syncline, the Smolyan depression and other more local structures as the Kovachevo syncline, the Batak syncline, the Vacha uplift, the Lyaskovo uplift and the Hvoina graben-syncline.

The magnetic susceptibility is studied according to data from laboratory measurements on rock samples of outcrop and drill core (973 samples) and according to parametric measurements on outcrop surface. The value of the remanent magnetization vector is determined on 536 rock samples of outcrop and drill core.

Statistical analysis is applied for estimating the characteristics of sample packs from one and the same region, as well as for estimating the characteristics of the total set of available data. The surface distribution of the magnetic susceptibility is studied for several local outcrops, using the available data from detailed parametric measurements.

MAGNETIC SUSCEPTIBILITY OF THE RHYOLITES IN THE RHODOPE MASSIF

In a regional plan, the rhyolites in the Rhodope massif have low to middle magnetic characteristics. The magnetic susceptibility measured on 973 rock samples of outcrop or drill core varies in a wide range - from 0 up to 1800.10^{-5} SI, and for some samples it goes even higher. In many cases the values of the studied parameter are quite different in the boundaries of one and the same relatively small area. For example, in the area of Dospat, the pink-coloured rhyolites have magnetic susceptibility of $600\text{-}900.10^{-5}$ SI, and the gray rhyolites, intruded on separate places among the pink-coloured, are characterized by a magnetic susceptibility of $1400\text{-}2000.10^{-5}$ SI. For part of the samples the magnetic susceptibility is relatively low (æ< 500.10^{-5} SI). Obviously in such cases there is a presence of secondary hydrothermal-metasomatic and hypergenic processes leading to destruction or oxidation of the primary ferromagnetic minerals and to formation of non-magnetic or low-magnetic varieties. It can be summarized that the well-expressed local variations of the rhyolites magnetic susceptibility are due to the effect of two major factors – the

differentiation according to the studied parameter of the types of distinct phases and the influence of secondary hydrothermal-metasomatic and hypergenic processes.

In Table 1 are systematized the main statistical characteristics of the values distribution for the magnetic susceptibility and in Fig.1 is shown a histogram of the parameter distribution for the main group of rhyolites – only about 4% of the samples having relatively high values (æ>1800.10^{-5} SI) are excluded.

Table 1. Main statistical characteristics of the magnetic susceptibility of the rhyolites in the Rhodope massif (the magnetic susceptibility values are in SI)

Region	Count	$æ^{min}.10^5$ / $æ^{max}.10^5$	Average æ.10^5 SI	Standard deviation	Skewness	Kurtosis
Western Rhodope Block	174	0 / 3634	821	652	6	10
Bratsigovo-Dospat Depression	416	0 / 5940	967	704	17	51
Dospat Anticline	92	0 / 3189	734	595	5	9
Southern Rhodope Syncline	106	0 / 2384	520	624	3	2
Northern Rhodope Syncline	48	183 / 1629	1012	378	0	0
Smolyan Structural Depression	79	0 / 1448	393	421	2	0
Total	973	0 / 5940	834	666	19	51

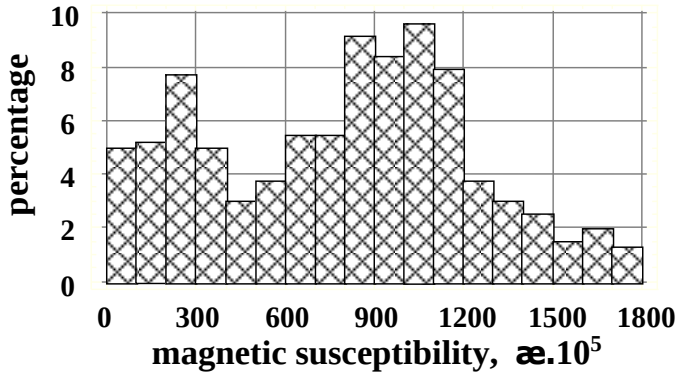

Figure 1. Histogram of the magnetic susceptibility distribution of the main group of rhyolites in the Rhodope massif.

The compound analysis of the illustrated histogram and the histograms elaborated for the different regions is showing that two main groups are well pronounced in the magnetic susceptibility distribution. The first group is including samples having magnetic susceptibility within the limits of 0-500.10^{-5}SI, and the second one is containing samples having magnetic susceptibility within the limits of 500-1800.10^{-5}SI. A limited number of samples (about 5%) has a zero magnetic susceptibility and almost the same number of samples (about 4%) has high parameter values (æ>1800.10^{-5} SI) reaching up to 6000.10^{-5} SI.

The Bratsigovo-Dospat depression is represented by the greatest number of samples and the magnetic susceptibility distribution for this region has predominant influence on the illustrated histogram of the parameter distribution for the main group of rhyolites samples (about 96% of the total set). Almost identical is the distribution for the Dospat anticline and the Western Rhodope block. Insignificant differences are observed for the rest of the studied regions.

It should be accepted, that the group having æ<500.10^{-5}SI is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having magnetic susceptibility 500.10^{-5} < æ < 1500.10^{-5} SI are included samples from the predominating rhyolite zone, and the samples having relatively high values (æ > 1500.10^{-5} SI) are related to extrusive formations.

The surface distribution of the magnetic susceptibility is presented in Fig.2. The Bratsigovo-Dospat depression is generally characterized by increased values for the magnetic susceptibility. For the entire territory, on the background of the rhyolite zone having magnetic susceptibility of about up to 1500.10^{-5} SI, can be separated areas having increased parameter values that are mapping the presence of extrusive formations.

The data from laboratory measurements of the magnetic susceptibility on rock samples of Rhodope massif rhyolites are enriched substantially by the performed parametric measurements on outcrop surfaces. These measurements are confirming the very wide range of parameter variation and are proving that this fact is valid within the boundaries of relatively small areas. Special studies are carried to determine the

regulations in the local zonal distribution of the rhyolites magnetic susceptibility in the boundaries of separate outcrops.

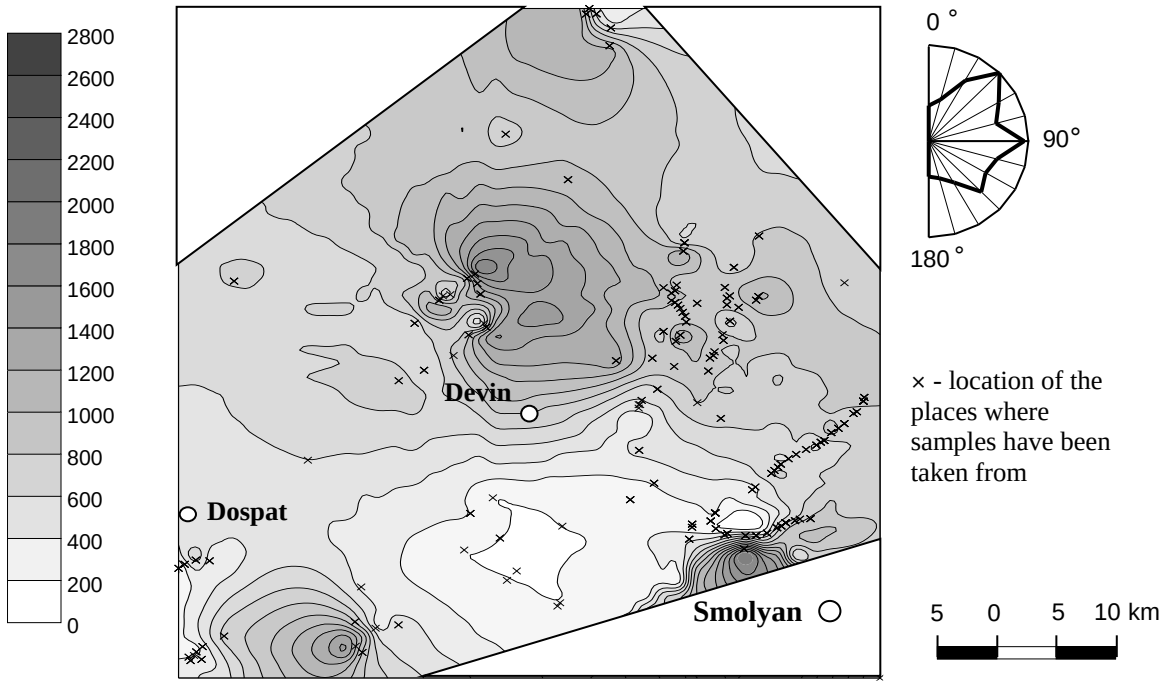

Figure 2. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the Western and Central Rhodopes region and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10^5 SI.

Parametrical measurements of the magnetic susceptibility are performed by a field kappa-meter and along a regular net of 10x10m. Four outcrops of rhyolites in the Smolyan area are studied – "Orlov kamak", "Chervenata skala", "Torlouka" and "Perelik".

In order to avoid the influence of the microstructure non-uniformity, five measurements are done around each station on an area of 1m^2. The differences between the measured values are in the limits of 3-10%. Samples for a laboratory analysis are taken from about 30% of the stations studied during the parametrical measurements. The magnetic susceptibility data of the laboratory analysis and the field measurements are comparable with a precision of 5-15%, so the differences are in the limits of the variations during the parametrical measurements in each station.

In Fig.3, Fig.4 and Fig.5 are illustrated the parameter surface distributions for three of the studied outcrops.

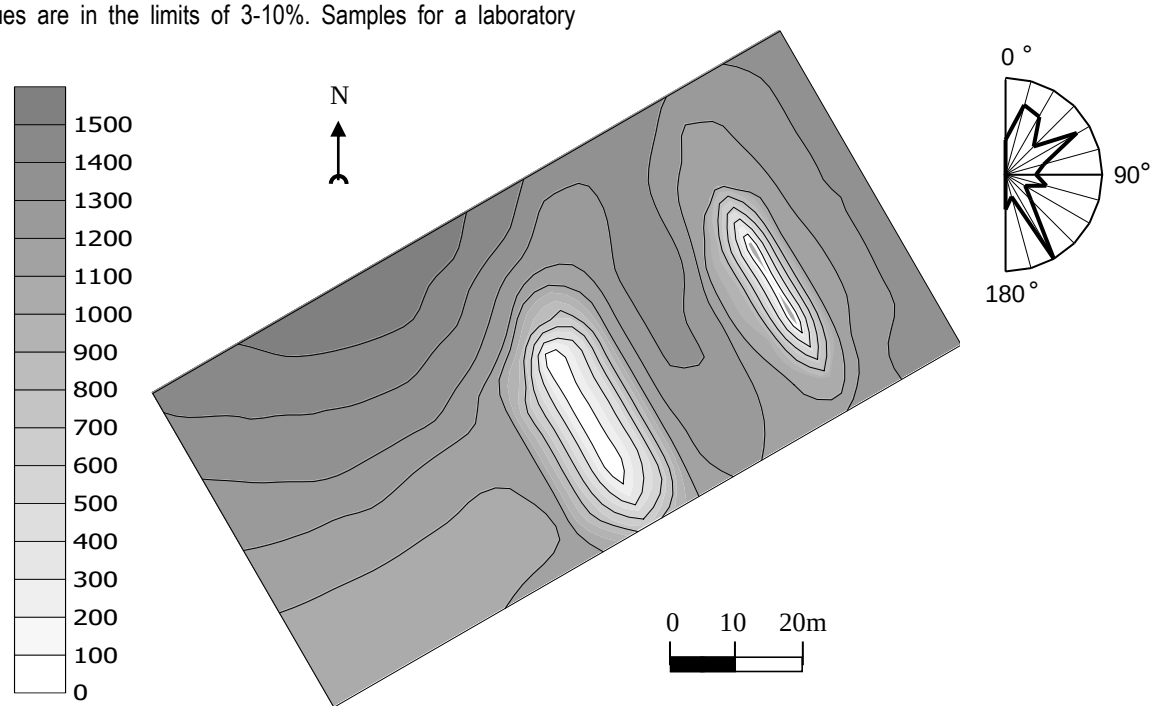

Figure 3. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the outcrop "Torlouka" nearby the village of Smolyan and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10^5 SI.

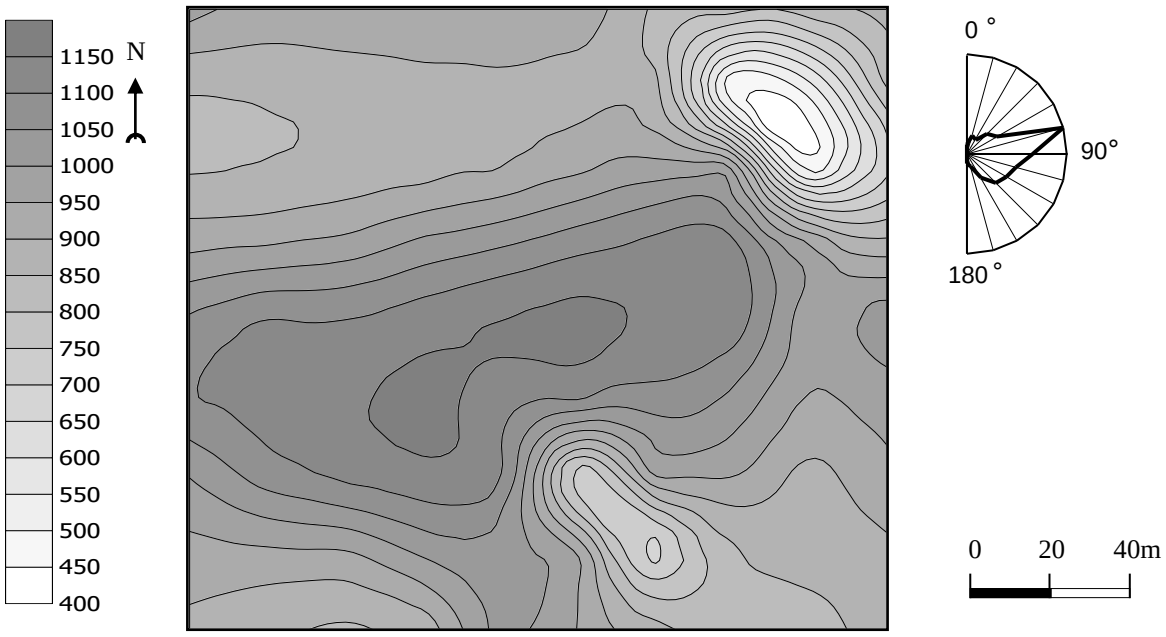

Figure 4. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the outcrop "Orlov Kamak" nearby the village of Smolyan and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10^5 SI.

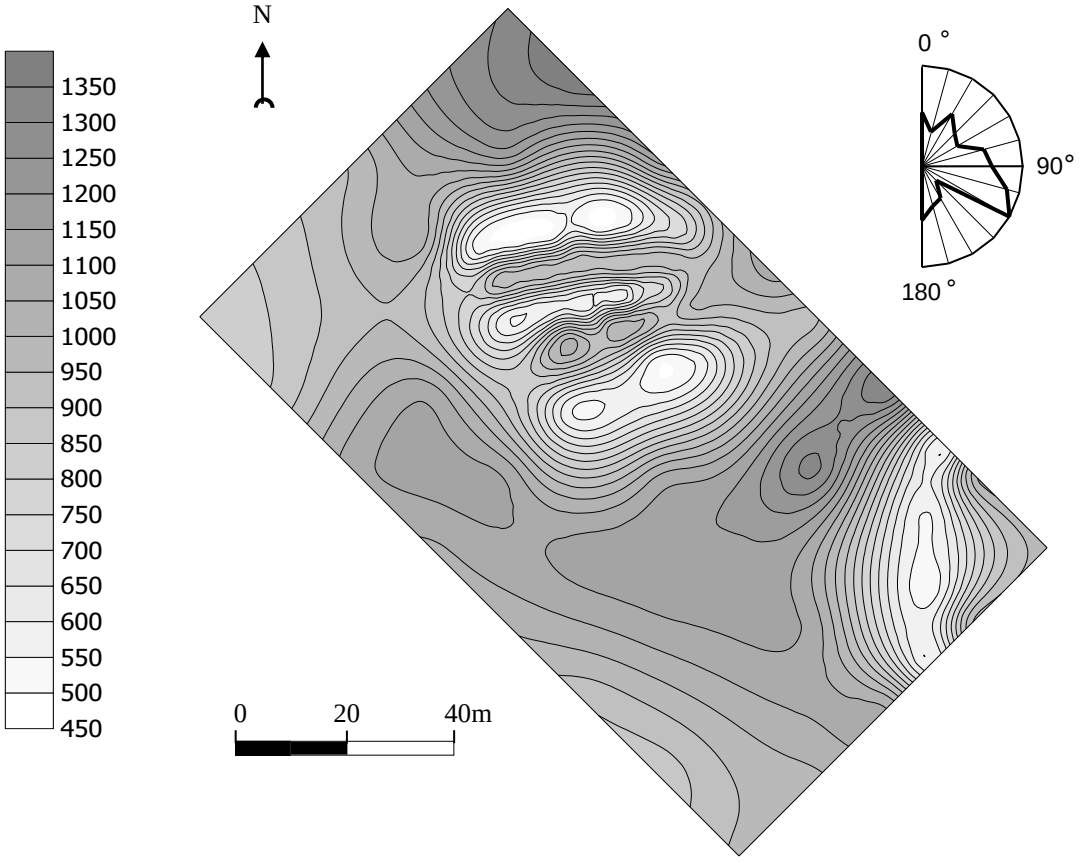

Figure 5. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the outcrop "Chervenata skala" nearby the village of Smolyan and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10^5 SI.

The compound analysis is showing that in all outcrops subject to detailed study on the background of magnetic susceptibility values in the range of 900-1700.10^{-5} SI, one can easily detect peculiar stations having relatively very low magnetic susceptibility (down to 50.10^{-5} SI).

Rose-diagrams are composed using the developed method for quantity estimation of the isolines surface distribution of the geophysical fields isolines (Dimovski 1999). They are tracing very well the microtectonic destructions. The main directions of these destructions in all studied outcrops are comparable. The predominant trends appear to fall into two groups, striking NE-SW and NW-SE with bearings 75-80^o and 150-165^o respectively.

REMANENT MAGNETIZATION OF THE RHYOLITES IN THE RHODOPE MASSIF

The absolute value of the remanent magnetization vector is determined on 536 rock samples of outcrop and drill core of the rhyolites in the Rhodope massif. It is established that the parameter varies in a very wide range – from 0 up to about 3000.10^{-3} A/m, with some samples reaching even higher values. In Table 2 are systematized the main statistical characteristics of the values distribution for the remanent magnetization and in Fig.6 is shown a histogram of the parameter distribution for the main group of rhyolites – only about 6% of the samples having relatively high values (Jn >700.10^{-3} A/m) are excluded.

Table 2. Main statistical characteristics of the remanent magnetization of the rhyolites in the Rhodope massif (the remanent magnetization values are in A/m)

Region	Count	$Jn^{min}.10^3$ / $Jn^{max}.10^3$	Average $Jn.10^3$	Standard deviation	Skewness	Kurtosis
Western Rhodope Block	78	0 / 988	304	218	5	6
Bratsigovo-Dospat Depression	184	0 / 6786	354	662	35	14
Dospat Anticline	43	0 / 901	158	214	6	7
Southern Rhodope Syncline	46	0 / 3694	439	935	8	9
Northern Rhodope Syncline	48	29 / 1587	426	405	4	3
Smolyan Structural Depression	79	0 / 290	52	72	6	7
Total	536	0 / 6768	319	603	34	12

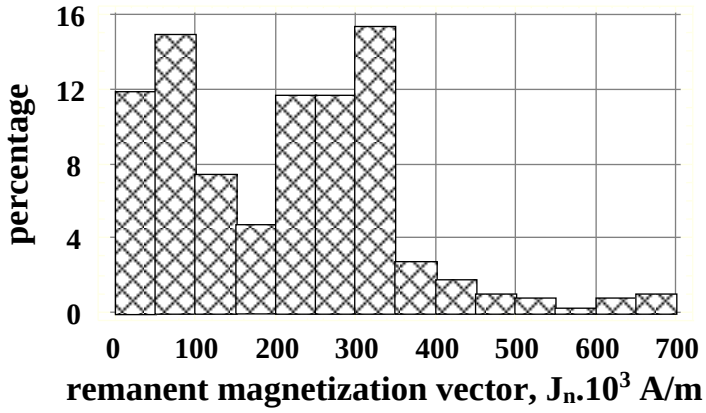

Figure 6. Histogram of the remanent magnetization vector distribution of the main group of rhyolites in the Rhodope massif

The compound analysis of the illustrated histogram and the histograms elaborated for the different regions is showing that we have the same picture as in the case of the magnetic susceptibility - two main groups are well pronounced in the remanent magnetization distribution. The first group is including samples having remanent magnetization within the limits of 0-200. 10^{-3} A/m, and the second one is containing samples having remanent magnetization within the limits of 200-500.10^{-3} A/m. A limited number of samples (about 5%) has a zero remanent magnetization and almost the same number of samples (about 6%) has high parameter values (Jn > 700.10^{-3} A/m) reaching up to 6500.10^{-3} A/m.

In the case of the remanent magnetization it should be accepted once again, that the group having Jn < 200.10^{-3} A/m is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having 200.10^{-3} < Jn < 500.10^{-3} A/m are included samples from the predominating rhyolite zone, and the samples having relatively high parameter values (Jn > 500.10^{-3} A/m) are related to extrusive formations.

The surface distribution of the remanent magnetization in the Western and Central Rhodopes is presented in Fig.7. For the entire territory, on the background of the rhyolite zone having

remanent magnetization of about up to 400.10^{-3} A/m, can be separated areas having increased parameter values that are mapping the presence of extrusive formations.

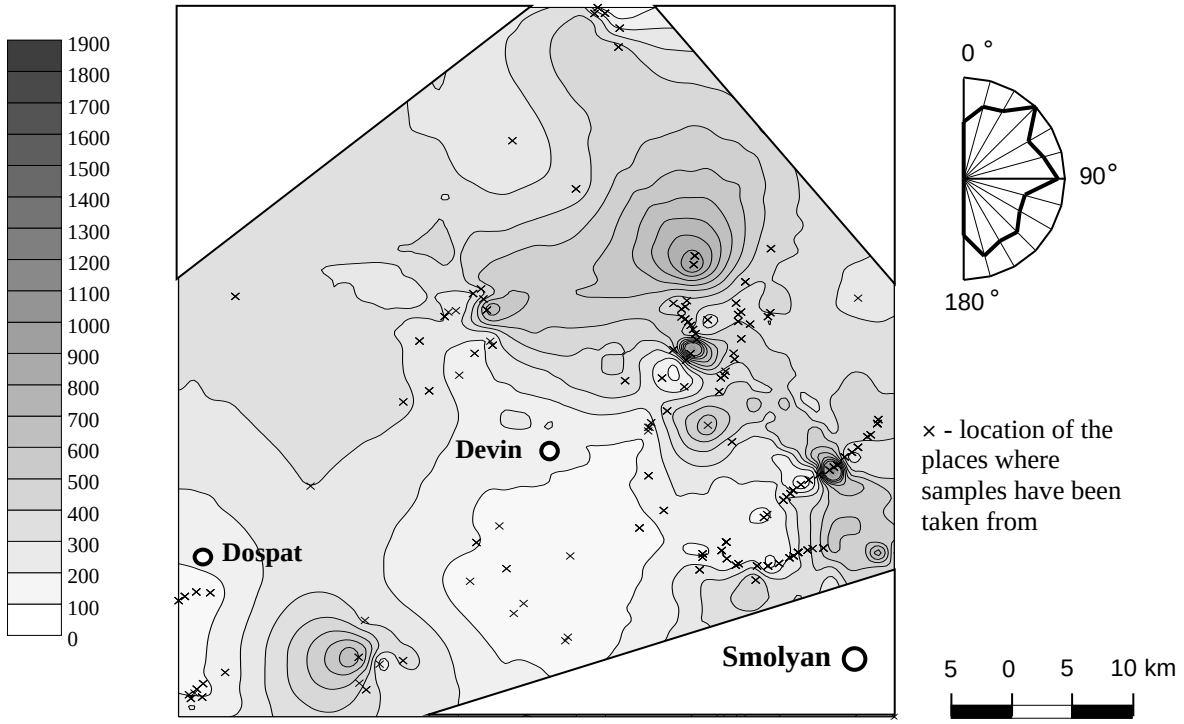

Figure 7. Scheme of the remanent magnetization surface distribution of the rhyolites in the Western and Central Rhodopes region and a rose-diagram of the isolines orientation.
The zoning is performed in Jn.10^{3} A/m.

DISTRIBUTION OF THE RHYOLITES IN THE RHODOPE MASSSIF ACCORDING TO THEIR MAGNETIC PARAMETERS

The correlation analysis between the magnetic susceptibility data and the remanent magnetization of all rock samples of rhyolites in the Rhodope massif (536 samples) shows the absence of a well-expressed correlation tie. The only regularity is that all samples (24 by number) having æ=0, have also Jn=0. These are the samples where secondary hydrothermal-metasomatic and hypergenic processes have lead to destruction or oxidation of the primary ferromagnetic minerals and to formation of non-magnetic or low-magnetic varieties. The summarized trend towards plane correlation can be observed in the visual comparison between the magnetic susceptibility surface distribution scheme (Fig.2) and the remanent magnetization one (Fig.7).

Different cluster analysis methods have been tried. The best results were obtained using the Ward's method, City-Block distance metric and classifying the data into 4 clusters. In Table 3 are presented the centroids values for the magnetic susceptibility and the remanent magnetization of the separated clusters and In Fig.8 are illustrated the 2-D cluster scatterplot (a) and the dendrogram (b) of the performed grouping.

Table 3. Centroids values for the magnetic susceptibility and the remanent magnetization of the separated 4 groups after applying cluster analysis using the Ward's method, City-Block distance metric

Cluster number	Samples		Centroids values for the magnetic susceptibility æ	Centroids values for the remanent magnetization Jn
	Count	%		
1	128	31	170.10^{-5} SI	71.10^{-3} A/m
2	214	52	899.10^{-5} SI	233.10^{-3} A/m
3	149	12	1692.10^{-5} SI	317.10^{-3} A/m
4	21	5	1357.10^{-5} SI	1798.10^{-3} A/m

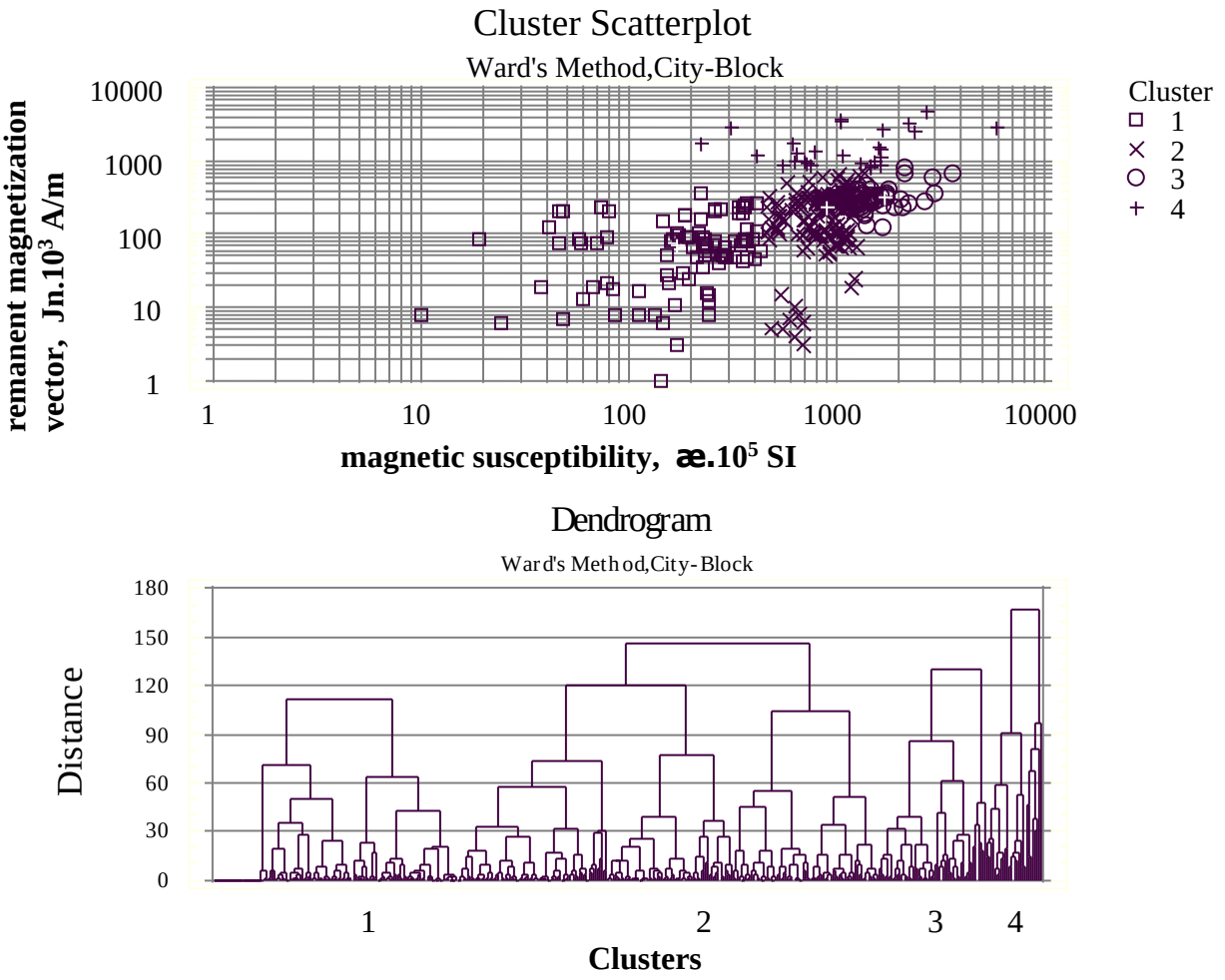

Figure 8. Results from the performed cluster analysis : 2-D cluster scatterplot (a) and dendrogram (b) of the performed grouping

The first three groups are including the major volume of samples – 95%. They are representing the main riolite zone and the centroids values for the magnetic susceptibility and the remanent magnetization of these three clusters have a coefficient of correlation 0,98. The last fourth group is representing the rhyolite samples from the extrusive formations. They are characterized by relatively high average magnetic susceptibility and by very high average remanent magnetization.

CONCLUSIONS

- The magnetic susceptibility of the rhyolites in the Rhodope massif varies in a wide range - from 0 up to 1800.10^{-5} SI, and for some samples it goes even higher. Two main groups are well pronounced in the magnetic susceptibility distribution. The first group is including samples having magnetic susceptibility within the limits of 0-500.10^{-5}SI, and the second one is containing samples having magnetic susceptibility within the limits of 500-1800.10^{-5}SI. The group having æ<500.10^{-5}SI is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having magnetic susceptibility 500.10^{-5} < æ < 1500.10^{-5} SI are included samples from the predominating rhyolite zone, and the samples having relatively high parameter values (æ > 1500.10^{-5} SI) are related to extrusive formations.
- The detailed parametrical measurements of the magnetic susceptibility are showing that on the background of magnetic susceptibility values in the range of 900-1700.10^{-5} SI, one can easily detect peculiar stations having relatively very low magnetic susceptibility (down to 50.10^{-5} SI). They are tracing very well the microtectonic destructions. The main directions of these destructions in all studied outcrops are comparable. The predominant trends appear to fall into two groups, striking NE-SW and NW-SE with bearings 75-80^{o} and 150-165^{o} respectively.
- The rhyolites remanent magnetization varies in a very wide range – from 0 up to about 3000.10^{-3} A/m, with some samples reaching even higher values. We have the same picture as in the case of the magnetic susceptibility - two main groups are well pronounced in the remanent magnetization distribution. It should be accepted once again, that the group having Jn < 200.10^{-3} A/m is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having 200.10^{-3} < Jn < 500.10^{-3} A/m are included samples from the predominating rhyolite zone, and the samples having relatively high parameter values (Jn > 500.10^{-3} A/m) are related to extrusive formations.

- The surface distributions of the magnetic susceptibility and the remanent magnetization in the Western and Central Rhodopes are generally comparable. For the entire territory, on the background of the rhyolite zone having relatively low values for the magnetic parameters can be separated areas having increased values that are mapping the presence of the extrusive formations.
- After applying a cluster analysis the rhyolite samples were classified into four groups. The first three groups are including the major volume of samples – 95%. They are representing the main riolite zone and the centroids values for the magnetic susceptibility and the remanent magnetization of these three clusters have a coefficient of correlation 0,98. The last fourth group is representing the rhyolite samples from the extrusive formations. They are characterized by relatively high average magnetic susceptibility and by very high average remanent magnetization.
- The compound analysis of the magnetic susceptibility and the remanent magnetization of the rhyolites in the Western and Central Rhodopes is proving that the detailed mapping according to magnetic characteristics can efficiently enrich the information obtained by the traditional geological mapping.

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