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PETROPHYSICAL CHARACTERISTICS OF ZVEZDEL-PCHELOJAD ORE FIELD (EASTERN RHODOPE)

V.VLADIMIROV, Z.ILIEV

ABSTRACT

The Zvezdel- Pchelojad ore field is situated at the southern margin of the Momchilgrad graben - syncline, a part of the East Rhodopean paleogene sink, Bulgaria. The ore field is hydrothermal, polymetal and vein type. The conducted investigation aimed at acquiring of information about the petrophysical properties of rocks and their influence upon ore formation. By means of free water-saturation was obtained information about effective pore space including quantity of large, medium and small pores as well as the conditional momentary saturation, constant of saturation, density, etc. By measuring the velocities of longitudinal and transverse ultrasonic waves different elastic moduli and ratios (Young's modulus, Poisson's ratio, Shear modulus, etc.), were computed as well as the Debye temperature etc. 20 different petrographic types of rocks were investigated and described in terms of their ability to percolate through them or not ore bearing hydrothermal solutions. The rhyolites, tuffs, tuffobreccias, polygenetic breccias and tuff's sandstones, have been most favorable for hydrothermal circulation. The amphibolites are typical shields only. Most of the rocks played a dual role - e.g. one petrographic type includes varieties with different petrophysical nature. Some of them have played predominantly shield role and some conduit role, e.g. latites, marbles, breccias, gneisses, limestones, monzonites, syenites and basalts. The shields predominate in another big group of rocks including trachybasalts and gabbros, and also andesitobasalts, skarns, andesites, monzogabbros. Thus, a petrographic type canembrace rocks with quite different physical properties which could form in their inner parts petrophysical structures favorable for ore deposition. Consequently, in the Zvezdel- Pchelojad ore field, the lithological control is only an isolated case for the ore bearing structure formation. In fact the mineralization could be controlled by petrophysical barriers which should be studied by means of special volumetric investigations.

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INTRODUCTION

The physical properties of rocks and ores play an extremely important role in the processes of formation and transformation of ore deposits especially for the hydrothermal ones. The conducted investigation aimed at acquiring of information about the petrophysical properties of rocks and their influence upon formation of structure favorable for ore localization in Zvezdel-Pchelojad ore field. It is located in the East- Rhodopean metallogenic region about 30 km SE of the town of Kurdjali and 30 km N of the Bulgarian - Greek boundary. The ore field is related to the intermediate volcanism of Late Eocene - Early Oligocene age, following the evolution of the Tethyan sea and Alpine orogen (Dabovski et al., 1991). The mining activity has a long history in the region and can be recognized from the Roman times. Currently the prospecting in the region is being undertaken mainly for establishing and exploitation of gold ore.

GEOLOGICAL SETTING

The Zvezdel- Pchelojad ore field is situated at the southern margin of the Momchilgrad graben - syncline, a part of the Eastern Rhodopean paleogene sink. The development of the ore field is quite advanced and most of its reserves are already depleted. There is much information about its geological, mineralogical, geochemical and structural features (Atanasov 1965, Gergelchev 1971, Nedjalkov 1986, Mladenova 1989, etc.) but the knowledge about the influence of the wall rocks on the ore generation is still insufficient. This was the reason for the authors to conduct the present investigation of the physico - mechanical properties of occurring rocks.

Spatially and genetically the Zvezdel- Pchelojad ore field is connected with the Zvezdel volcano - plutonic paleogene central type morphostructure. In most of its features it is analogous to other ore fields, known in the Eastern Rhodopean megablock as Madgarovo, Lozen, Spachievo, Kirky - Esimy etc.

There are two principal structures in the region: Prepaleogene crystalline basis and Paleogene volcano - sediment covering superstructure. The crystalline rocks are block fractured by a network of deep long living faults. They consist of biotite, two-micas, amphibolite and garnet- disten - biotite gneisses, marbles and amfibolites. The Paleogene rocks are widely varying in composition: conglomerates, breccias, sandstones, limestones, tuffs, tuffobreccias, tuffoconglomerites, andesites, andesitobasalts, monzonitoides, latites, dacites, rhyolites. Magmatic rocks are strongly predominating.

The ore field is hydrothermal, polymettal and vein type. It is probably formed at a medium to low temperature, at a depth down to 1500 m. The veins are younger, hypogenic formations and intersect all other rocks. They fill mainly E-W or NW (280-300°)

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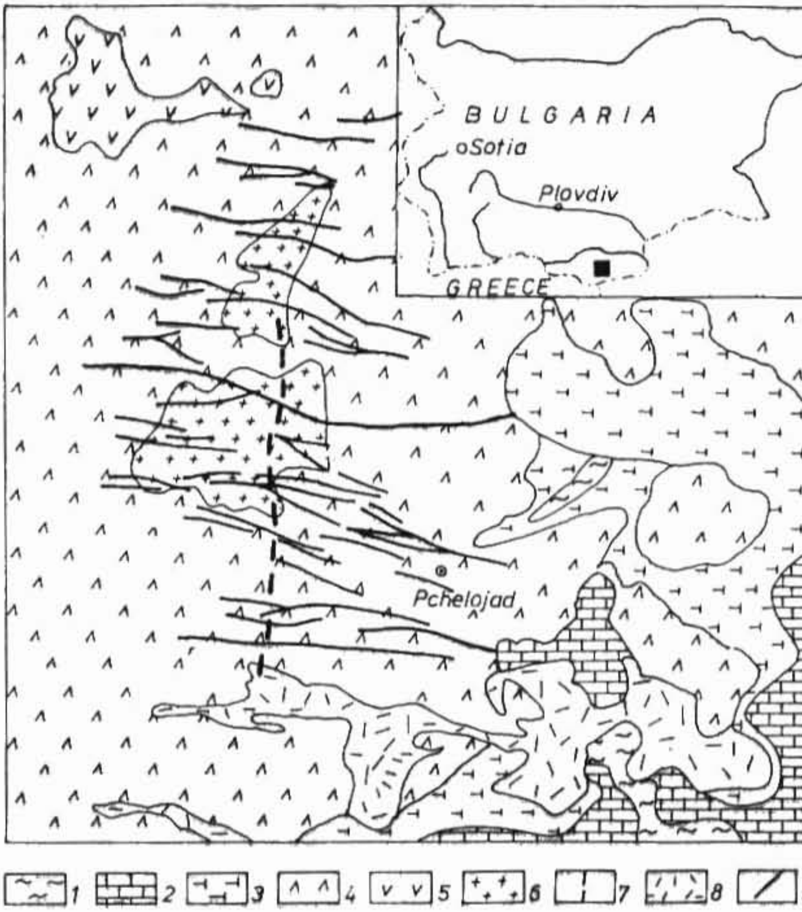

Fig. 1 Schematic Geological Map of Zvezdel- Pchelojad Ore Field

1) Gneisses, Marbles, Amphibolites.
2) Limestones.
3) Tuffs, Tuffobreccias, Tuff's sandstones.
4) Basalts, Andesitobasalts.
5) Andesites.
6) Monzonites, Syenites, Gabbros etc.
7) Latites.
8) Rhyolites.
9) Ore Veins and Zones.

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oblique - normal slip faults (Gergelchev 1971).

There are two main ore bearing structures in the ore field - Zvezdel- Galenit fault and zone 2 in Pchelojad ore deposit. Both of them plunge steeply to the North and the first one is mineralized along several kilometers. The ore field is divided into a Northern and Southern part by the Zvezdel- Galenit fault zone. There is a number of small veins that converge in depth.

The borders of the ore field are distinctly marked to the North, East and South by the periclinal of the volcano - plutonic structure, dikes, faults and low temperature mineralization. The West border is not clearly defined because of the step-like dipping of the crystalline basis and thick volcanic rocks covering the area of Varbitza river. There are several asymmetrically localized monzonite bodies occurring in the ore field that are probably genetically related to the ore formation.

The rocks in ore field are altered in different facies depending on their composition. The most common alteration of the magmatic rocks is widespread propilitization (Atanasov 1965). A typical alteration mineral assemblage consist of pyrite, chlorite, epidote, sericite, albite, quartz, calcite, dolomite.

METHOD

The presented results are obtained from the petrophysical investigation (Structure Petrophysical Analysis - Starostin 1979, 1984, Vladimirov 1990) of samples from Pchelojad, Galenit and Esseler deposits where most of the ore veins and bodies are concentrated.

By means of free water-saturation we obtained information about effective pore space (Peff) including quantity of large (P1 $>10^{-2}$mm), medium (P2 = 10^{-2}- 10^{4}mm), small (P3 $<10^{-4}$mm) pores as well as the conditional momentary saturation (A), constant of saturation (B), density (ρ), etc.

By measuring the velocities of longitudinal and transverse ultrasonic waves we computed different elastic moduli and ratios (Young's modulus(E), Poisson's ratio(μ), Shear modulus(G), etc.), as well as the Debye temperature (Θ) etc.

The total number of the studied samples was 247. They were praparated in the form of 1 sm thick plates with parallel walls and area about 20-25 square sm.

The Complex petrophysical coefficient (Cpc) was computed. Its positive or negative values show the role the corresponding rocks play in the process of ore deposition.

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RESULTS AND DISCUSSION

20 different petrographic types of rocks were investigated and described in terms of their ability to percolate through them or not of ore bearing hydrothermal solutions.

The rhyolites, tuffs, tuffobreccias, polygenetic breccias and tuff's sandstones, have been most favorable for hydrothermal circulation. Their average effective porosity is higher then 10% (11.1%, 13.97, 13.62, 12.09 and 16.71 % respectively) and ranges between 11.11 % for rhyolites and 16.71 % for tuff's sandstones. Nevertheless the share of the large pores (>10-2 mm) is not so big (between 23-39 % of effective porosity) their relative weight is considerable and ranges between 3.11 and 4.47 % of the volume of the rocks. The large effective porosity, which is saturated first is a premise for a large saturation volume. It is equal to the conditional momentary saturation (A) and defines a significant ability of the rocks for comparatively intensive filtration. The fact that the average values of saturation constant are too high (between 0.09 and 0.13 h^{-1}) presents additional evidence in this respect. This kind of structure of the pore space is most favorable for the hydrothermal circulation (see Fig. 2).

The high effective porosity values result in abnormally low density, that varying from 2.04 t/m3 for sandy tuffs (with highest Peff) to 2.39 t/m3 for tuffobreccias. The Poisson's ratio values are low too showing that rock deformations in a particular direction correspond to quite small deformations in a perpendicular direction. Probably this effect is predestinated by the large pore space. These rocks show the lowest average values for Young's modulus (from 2.12 to 3.42 x 10^4 MPa) that defines them as frailest ones. The low Debay temperature values show the significant presence of defects in their crystal structure and loosening the links between the separate elements of the substance.

All the described properties define these rocks as favorable for solutions filtration and show that the hydrothermal processes could be intensive in them. This fact is reflected by the value of Cpc - between +1.61 and +2.32. The zones and areas built up of those permeable rocks served as both conduits and accommodative media during the ore formation.

For ore localization it is very important that rocks with shield properties are present which leads to changes in hydrodynamic conditions and thus in thermodynamics of processes of the ore formation.

All the sampled rocks of the amphibolite group, are typical shields only. They are characterized by low values of Peff (from 0.17 to 1.08 %, with average 0.51 %), A (from 0.06 to 0.48 %, average 0.18 %) and B (average 0.07) and predominating of small pores (39 %). The density of amphibolites is high - average 2.93 t/m3 varying from 2.77 to 3.12 t/m3. The elastic and strength properties of amphibolites are several times higher then those of

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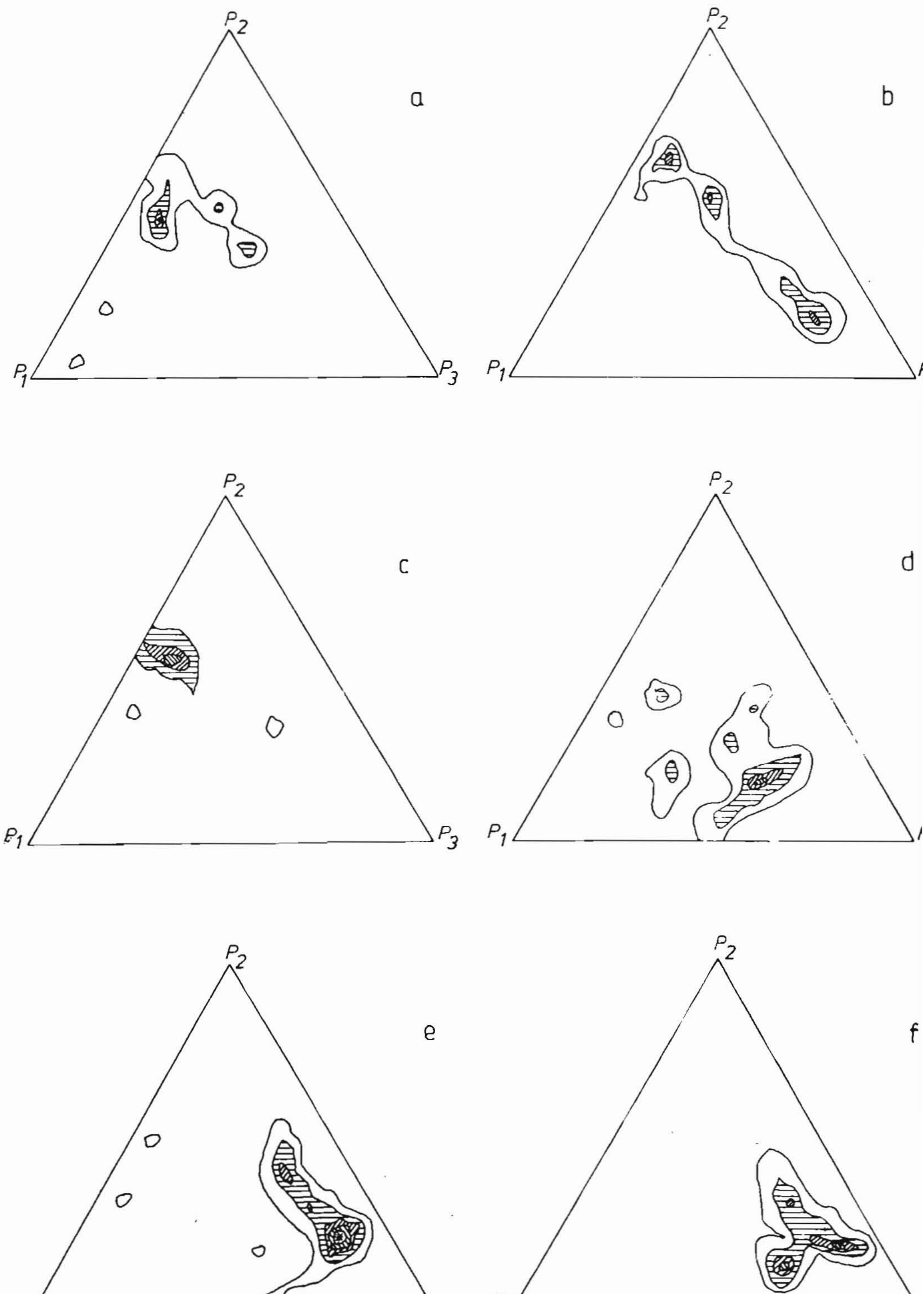

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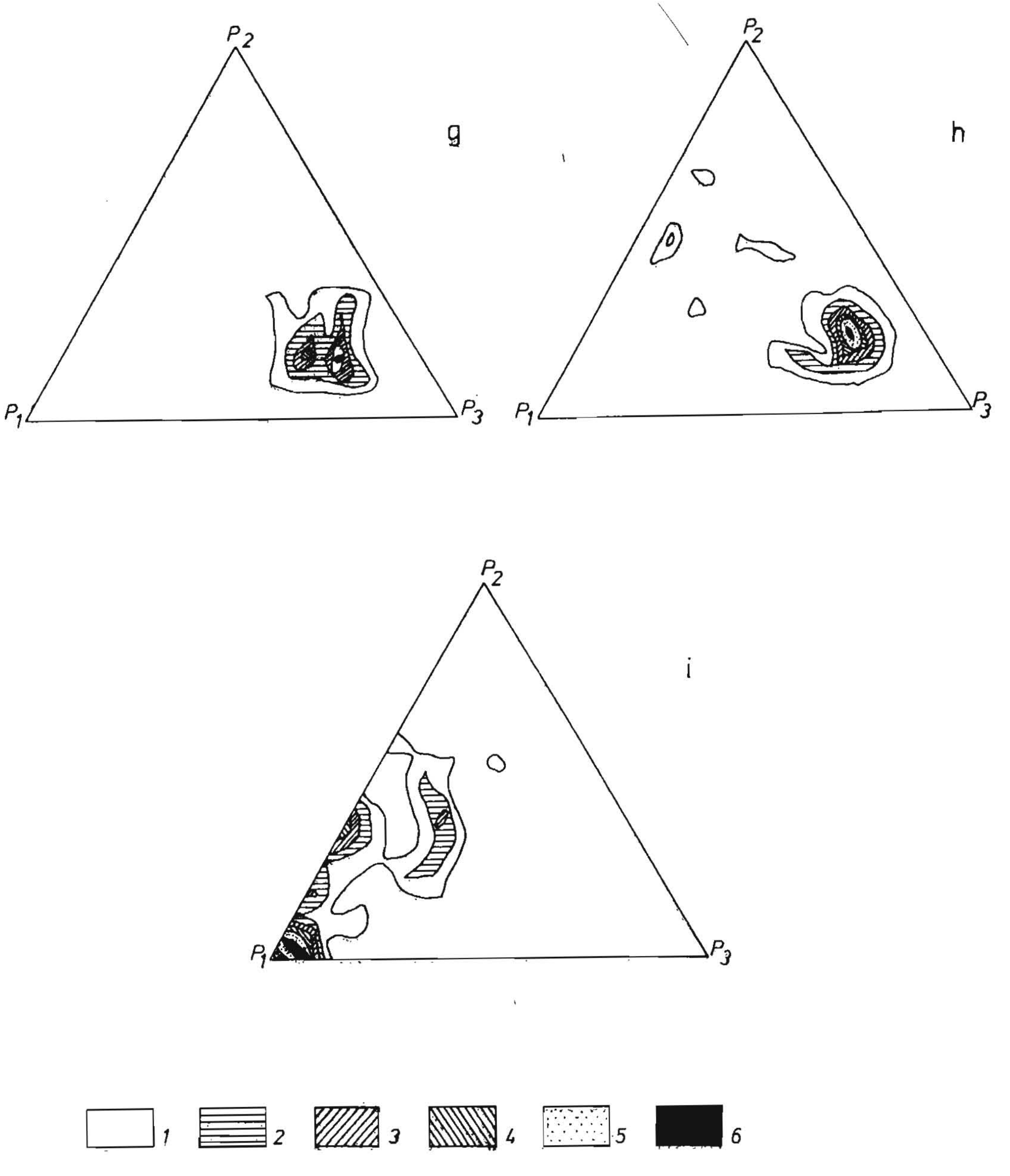
Fig 2



Fig, 2 Diagrams of Space Pore Distribution by Their Dimension for:

a) rhyolites and rhyolitic breccias;
b) tuffs and tuffobreccias;
c) poligenic breccias;
d) amphibolites;
e) latites;
f) monzonites, gabbros and monzogabbros
g) trachybasalts and andesitobasalts;
h) andesites and andesitobasalts;
i) limestones, marbles and marble breccias.

Frequency: 1) =1; 2) =2; 3) =3; 4) =4; 5) =5; 6) =>6.

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the previous group of rocks - from 2 times for the Poisson's ratio (0.21) to 2.5 - 4 times for Young's modulus. The Debay temperature for these rocks reaches its extreme values too (up to 545°K, average 472°K). All this result in a low average Cpc - 0.98 (ranging from -1.88 to -0.14). The joint localization of amphibolites with the rocks of the previous group form the structures favorable for ore deposition. The SE part of the ore field, where the amphibolites and rhyolites. are in an immediate contact, is of great interest in this concern.

According to the petrophysical data analysis only 6 of a total of 20 petrographic types of rocks are uniform in respect to their role in the ore formation - i.e. they play the role either as conduits only or shields only.

Most of the rocks played a dual role - i.e. one petrographical type includes varieties with different petrophysical nature. Some of them have played predominantly shield role and some conduit role. The latites as well as marbles, breccias and gneisses played mainly the role of conduits. Even some samples of limestones, monzonites, syenites and basalts show definitely high filtration properties. Nevertheless, the predominant part of the samples of these rocks show shield properties.

The shields predominated in another big group of rocks including trachybasalts and gabbros, and also andesitobasalts, skarns, andesites, monzogabbros. Their physical properties vary widely. For example Peff for latites rang from ..32 % to 16.18 %, and for andesites from 0.15 to 11.81 %. The Cp in those types of rocks varies respectively from 9.09 to 2.4 and from -1.26 to 1.55. Thus, in the one and the same petrographic kind fall rocks with quite differentdiferent physical properties which could form in their inner parts petrophysical structures favorable for ore deposition. Similar structure are observed in the marbles where is discovered presence of embedded mineralization.

CONCLUSIONS

Consequently, in the Zvezdel- Pchelojad ore field, the lithological control is only an isolated case for the ore bearing structure forming. In fact they could be controlled by petrophysical barriers which should be studied by means of special volumetric investigations(e.g. Structure Petrophysical Analysis). This will help a deeper understanding of ore formation processes to be acquired and the exploration effectiveness to be increased.

Petrophysical properties of rocks and ores obtained for the Zvezdel- Pchelojad ore field, can have also unestimable signifficance for environment protection, mining activity and for the insitu leach technology in the future.

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Table # 1

Type rock	Min Max Av.	Num. sam.	Peff %	A %	P1 %%	P2 %%	P3 %%	B h^{-1}	ρ t/m3	μ –	E $\times10^4$	G MPa	θ TK°	Cpc —
Rhyolite		15	4.93	1.29	21	5	5	0.04	1.93	0.01	1.62	0.68	232	0.75
			20.47	11.61	81	60	45	0.16	2.44	0.28	5.2	2.17	406	2.51
			11.11	4.57	39	43	18	0.11	2.26	0.15	3.33	1.46	328	1.77
Tuff		18	5.81	0.74	5	25	5	0.08	1.77	0.01	1.22	0.56	206	0.57
			22.94	8.66	44	80	60	0.15	2.62	0.25	5.73	2.32	416	3.19
			13.97	3.86	26	50	24	0.12	2.23	0.15	2.91	1.26	299	1.88
Tuffo-breccia		5	10.95	2.59	18	38	22	0.1	2.32	0.01	2.32	1.14	291	1.45
			15.79	4.14	26	53	44	0.13	2.46	0.26	3.34	1.61	342	2.23
			13.62	3.11	23	45	32	0.11	2.39	0.11	2.92	1.32	311	1.77
Polygenic breccia		8	1.88	0.39	21	35	5	0.09	1.96	0.03	1.49	0.63	220	0.28
			26.27	10.91	58	55	44	0.17	2.69	0.32	5.61	2.39	416	2.97
			12.09	4.54	37	47	16	0.13	2.39	0.13	3.42	1.5	324	1.61
Tuff's sandstone		2	16.12	3.71	21	34	27	0.09	2.0	0.04	1.48	0.71	235	2.06
			17.3	4.68	29	44	44	0.09	2.08	0.19	2.77	1.17	303	2.59
			16.71	4.19	25	39	36	0.09	2.04	0.11	2.12	0.94	269	2.32
Amphibolite		23	0.17	0.06	18	5	9	0.01	2.77	0.08	5.52	2.35	408	-1.88
			1.08	0.48	59	42	61	0.14	3.12	0.33	11.12	4.74	548	-0.14
			0.51	0.18	38	23	39	0.07	2.93	0.21	8.05	3.33	472	-0.98
Andesite		30	0.15	0.08	7	2	8	0.01	2.36	0.07	3.23	1.43	328	-1.26
			11.81	5.9	80	61	75	0.13	2.76	0.32	8.25	3.27	486	1.55
			3.52	0.87	26	23	51	0.07	2.64	0.24	6.18	2.48	423	-0.03
Andesito-basalt		10	0.43	0.12	9	10	44	0.04	2.55	0.18	4.06	1.53	341	-0.98
			6.69	0.82	29	29	67	0.12	2.77	0.33	8.17	3.21	480	0.85
			2.31	0.39	22	19	59	0.06	2.67	0.26	6.55	2.6	433	-0.24
Trahy-basalt		6	0.34	0.08	14	10	50	0.03	2.48	0.27	3.9	1.49	338	-1.3
			4.94	0.69	36	24	69	0.08	2.77	0.35	8.43	3.3	487	0.64
			1.45	0.27	24	16	60	0.05	2.68	0.3	6.79	2.61	435	-0.61
Latite		36	1.32	0.3	8	4	8	0.02	2.09	0.01	2.5	1.16	295	-0.09
			16.08	7.88	59	49	73	0.12	2.57	0.26	6.58	2.98	465	2.4
			5.19	1.22	21	25	54	0.06	2.46	0.16	5.17	2.23	404	0.71
Basalt		8	1.23	0.38	20	4	23	0.03	2.66	0.16	5.35	2.17	400	-0.43
			3.98	1.01	38	57	66	0.15	2.75	0.26	7.06	3.03	463	0.51
			2.65	0.66	27	25	48	0.09	2.69	0.22	6.09	2.5	425	0.13
Gabbro		10	0.54	0.15	9	10	19	0.03	2.61	0.16	5.57	2.13	396	-1.32
			4.36	0.73	62	29	70	0.12	3.03	0.31	10.38	4.45	545	0.32
			1.51	0.39	32	18	50	0.06	2.79	0.23	7.85	3.2	471	-0.53
Monzo-gabbro		5	0.64	0.18	18	1	41	0.03	2.65	0.05	6.18	2.6	435	-0.74
			3.59	0.64	58	36	61	0.11	2.79	0.22	8.06	3.48	494	0.27
			1.62	0.4	29	20	51	0.08	2.75	0.15	6.94	3.04	462	-0.1

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continuation of Table # 1

Type rock	Min Max Av.	Num. sam.	Peff %	A %	P1 %%	P2 %%	P3 %%	B h^{-1}	ρ t/m3	μ –	E $\times 10^4$MPa	G	θ TK°	Cpc –
Monzonite		15	0.74	0.27	16	6	1	0.03	2.47	0.01	3.03	1.32	312	-0.52
			12.74	8.28	72	40	64	0.24	2.74	0.29	7.24	3.09	466	1.92
			2.75	1.08	33	23	44	0.08	2.67	0.2	5.91	2.5	421	0.18
Syenite		4	2.0	0.26	8	16	65	0.03	2.5	0.17	4.81	2.05	389	-0.12
			3.92	0.57	15	20	75	0.05	2.64	0.2	6.88	2.95	463	0.59
			3.0	0.38	13	18	69	0.04	2.58	0.18	5.9	2.49	426	0.16
Gneiss		2	2.27	0.96	37	16	22	0.05	2.61	0.12	4.19	1.88	367	0.15
			2.62	1.4	62	17	47	0.07	2.64	0.18	7.21	3.06	472	0.72
			2.44	1.18	49	17	34	0.06	2.62	0.15	5.7	2.47	420	0.43
Skarn		2	2.67	0.89	32	14	36	0.04	2.76	0.21	6.93	2.81	448	-0.43
			3.35	1.07	33	21	54	0.11	2.85	0.23	9.34	3.86	517	0.07
			3.01	0.98	33	17	50	0.07	2.8	0.22	8.13	3.34	482	-0.18
Marble		26	0.38	0.35	49	1	1	0.03	1.98	0.02	1.59	0.66	218	-0.39
			2.05	1.48	97	36	24	0.17	2.72	0.32	7.01	2.88	458	1.03
			1.06	0.8	78	12	10	0.08	2.66	0.17	4.13	1.76	354	0.32
Marble breccia		7	0.64	0.39	40	10	3	0.07	2.66	0.02	2.18	0.91	256	-0.12
			2.18	1.08	83	45	23	[illegible]	2.75	0.29	7.14	3.05	[illegible]	0.55
			1.24	0.68	59	29	12	0.13	2.7	0.16	5.65	2.46	414	0.26
Limestone		13	0.88	0.37	22	14	12	0.04	2.56	0.07	3.87	1.81	[illegible]	-0.27
			3.39	0.93	73	56	62	0.18	2.7	0.33	7.98	3.51	500	0.76
			1.51	0.63	47	35	18	0.13	2.66	0.22	6.6	2.7	443	0.1

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