PHYSICOMECHANICAL PROPERTIES OF ZEOLITIC ROCKS FROM THE NORTHEASTERN RHODOPES, BULGARIA

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ABSTRACT

Sixty two zeolitic rock samples diverse with respect to (1) origin - "autoclave" type, hydrothermal alteration products and terrigenous type; (2) zeolitic mineral present - analcime, clinoptilolite, mordenite; and (3) zeolite content of the whole rock - from 15% to 90%, were studied. Information about the effective pore volume and the quantity of the pores, large, medium, and small ones was obtained along with the saturation constant and density, etc. By measuring the velocity of longitudinal and transversal ultrasonic waves Poisson's ratio, Young's and Shear modules, and the Debye temperature were estimated. The zeolitic rocks are very porous and permeable media of low density. The balance of the elastic parameters - low enough to allow easy forming, strong enough for building purposes and very light for transportation, makes the zeolitic rocks quite suitable for numerous applications; e.g. low wave velocities and high attenuation are appropriate characteristics for excellent isolation materials.

KEY WORDS: zeolitic rocks; petrophysics; pore; density; elastic; building

1. INTRODUCTION

The zeolitic rocks in Bulgaria are of enormous reserves (Djourova and Aleksiev, 1988) represent an important mineral raw material with a progressively widening scope of applications. For their successful utilization, it is necessary to know well the physical properties of these materials as they relate to potential fields of application. The physical properties of rocks and other materials reflect every event in the history of their formation and transformation. In fact, they are the physical memory of every material and they include extremely important structure- genetic information which could be obtained by comprehensive experimental methods only.

2. EXPERIMENTAL MATERIALS

Sixty two zeolitic rocks samples were selected for study. They represented several groups based on origin, mineralogy and zeolite content of the rock as follows: (1) origin - "autoclave type" zeolitic rocks (Aleksiev and Djourova, 1975) and terrigenous genetic type (Djourova and Milakovska, 1993); (2) zeolitic mineral species - clinoptilolite, analcime and mordenite; and (3) zeolite content of the rocks ; 4)reference to the horizons of the Oligocene lithostratigraphic scheme after Goranov(1960). The samples were collected from three sections north of the Arda river (Figure 1) - profile lines 11-14 northeast of Zheljazkovtzi village; 44-45, south of Bagra village; and 46 northeast of Padartzi village. Because of the obvious genetic relationship with the zeolitic rocks several samples of marls and cherty microcrystalline rocks were investigated too. The samples are characterized using thin section, grain-size, and X-ray diffraction analysis.

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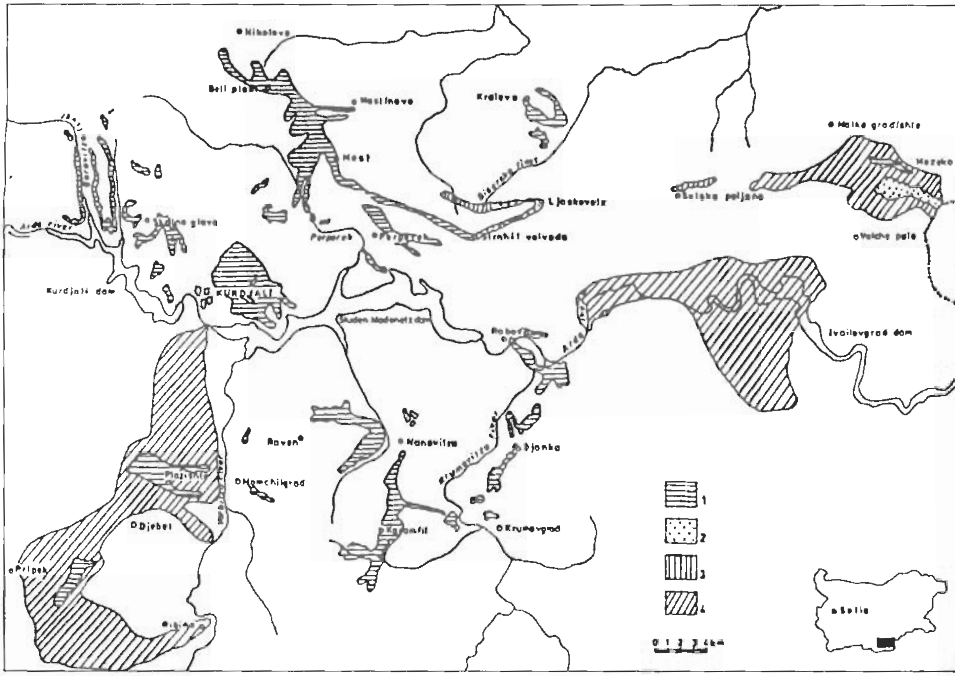

Fig.1: Scheme of the distribution of zeolitic rocks in the Northeastern Rhodopes, Bulgaria
1 - clinoptilolitic zeolitites of Ol_1 and Ol_2 ; 2- mordenite zeolites; 3 - analcime zeolites;
4 - prospective areas for zeolitic rocks

The most common lithotypes in the three sections are (1) "autoclave type" clinoptilolite zeolitites related to the 1st (Ol_1) and 3rd (Ol_3) Oligocene horizons; and (2) the terrigenous zeolitic rocks, i.e. litharenites, that are also clinoptilolite-rich and correspond to Ol in the Oligocene division scheme. Analcime zeolitites were noted in one profile line only (line 11-14). For completeness of the spectrum of the mineralogical types of zeolitic rocks, one sample of a mordenite-rich zeolitites was also included in the experiment, although mordenite rocks were not found in any of the three sections.

The "autoclave type" clinoptilolite-rich zeolitites consisted of clinoptilolite, quartz, and chlorite, which as a microcrystalline groundmass, substitutes for primary vitroclastic material. Pyroxene, amphibole, biotite (green-brown and red), sanidine, oligoclase as well as rhyolitic and pumiceous lithoclasts, were also noted. The clinoptilolite content in the rock ranged from 60% to 85% by volume.

The "autoclave type" analcime-rich zeolitites consisted of analcime (about 85%) and a microgranular mass of quartz and chlorite. The substitution of the vitric material was pseudomorphous, and the texture was relictovitroclastic, microcrystalline. Amphibole, pyroxene, plagioclase, and muscovite and metamorphic and sedimentary rock fragments were also present, but in rather small quantities.

The terrigenous zeolitic rocks were psamitic in texture and clinoptilolitic in composition and had a zeolite content of 15% to 65% by volume. This is a unrecognized genetic type of zeolitic rocks consisting of subrounded and subangular zeolitic rock fragments, i.e., zeolitic litharenites.

The marls are microcrystalline with small quantity of psamitic impurities of quartz, oligoclase, sanidine, biotite, amphibole. Mica, potassium feldspar and crystobalite were registered by X-ray analysis.

The cherty microcrystalline rocks are sandy, silty or clayey, but constantly quartz in composition(80% quartz was diffractometrically registered). Grains of plagioclase, apatite and biotite are also distinguished in thin sections. Hydromica, montmorillonite and potassium feldspar (from traces to 30%) were established by X-ray analysis.

3. METHODS

Following the approach of Starostin (1979), the petrophysical analysis consisted of: (1) free water saturation method, which consisted of seven fixed in the time specimens weighting in the process of water saturation; and (2) determination of ultrasonic waves velocities (P- and S-waves).

By computer processing, the following parameters were obtained: effective porosity (Pef, the percentage of the total volume of rock that consists of interconnecting voids); conditional momentary saturation (A, which reflects the saturation in the first few minutes i.e. 20 min) and in fact corresponds to liquid permeability; quantity of large (P1 > 10^{-2} mm), medium (P2 = 10^{-2} - 10^{-4} mm), small (P3 < 10^{-4} mm) pores, saturation constant (B, corresponds to exponential part of the saturation and it is independent of total porosity); density (ϱ); Poisson's ratio (μ, the ratio of the lateral strain to the longitudinal strain, in a body that has been stressed longitudinally within its elastic limit); Young's modulus (E, the ratio of applied stress of cross section to increase in rational length, N/m2 = Pa); Shear modulus (G, the ratio of applied tangential stress to angular deformation), Debye temperature (Θ, reflects substance structure stability, strength of connections between its separate elements, defects presence and their frequency, K) etc. (Starostin, 1979; Vladimirov, 1990, 1991).

For easier interpretation of so many physical characteristics, an integral complex petrophysical coefficient was involved (Starostin, 1979). The tape of calculation and set of properties used depended on which geologic process were to be discussed. In our study we use the following parameters: Pef, A, B, r, E, G. The complex petrophysical coefficient (Cpc) introduced in the authors interpretation, reflects the behavior of the investigated rocks in hydrothermal process. Its positive and large values define this rocks as a permeable medium and negative - as barriers for ore fluids.

4. RESULTS AND DISCUSSION

The results of the petrophysical investigations are represented on Tables 1 and 2. The effective porosity of the two genetic types of zeolitic rocks was only slightly different, the variation among samples of the "autoclave-type" was somewhat broader than that of the terrigenous type, but the average porosity was 2% lower. The large pores for the terrigenous type zeolitic rocks were about 2/3 of the total volume, whereas for the "autoclave-type", they were about half of the large pores quantity . Surprisingly the mean density (1.74 t/m3) of the "autoclave-type" zeolitic rocks was less at reduced porosity, the difference possibly being to the presence of less dense minerals and to a larger total porosity.

The elastic characteristics of the two were similar but slightly greater for the terrigenous type of zeolitic rocks. This is comformable with the higher Debye temperature values and ultrasonic velocity value.

Table 1: Physicomechanical properties of some Bulgarian zeolitic and associated rocks

No	Pef %	P1 %	P2 %	P3 %	B 1/h	Vp m/s	Vs m/s	ϱ t/m^3	μ -	E 10GPa	G 10GPa	Θ K
11	11.34	33	58	9	0.09	4385	2460	2.00	0.27	3.01	1.19	310
11a	23.43	58	3	39	0.01	3544	2103	1.88	0.23	2.00	0.81	259
11b	25.16	76	3	21	0.02	3314	2165	1.82	0.13	1.89	0.84	261
11d	24.55	67	8	25	0.02	3444	1947	1.96	0.27	1.84	0.73	244
11e	28.42	72	6	22	0.02	3716	2165	1.86	0.24	2.12	0.85	266
11f	22.27	80	5	15	0.02	3024	2053	1.90	0.07	1.69	0.79	250
11g	15.98	34	45	21	0.04	3804	1803	2.09	0.36	1.81	0.67	234
11h	12.94	29	40	31	0.04	3883	2148	2.19	0.28	2.53	0.99	280
11i	40.01	64	2	34	0.01	3016	1806	1.54	0.22	1.20	0.49	208

No	Pef %	P1 %	P2 %	P3 %	B 1/h	Vp m/s	Vs m/s	ϱ t/m^3	μ -	E 10GPa	G 10GPa	Θ K
11j	18.12	51	29	20	0.03	3409	1859	2.04	0.29	1.78	0.69	237
11k	13.69	81	6	13	0.01	4446	2582	2.17	0.25	3.53	1.42	334
11l	20.12	28	50	21	0.04	3624	2309	1.99	0.16	2.42	1.04	288
11m	15.57	66	19	15	0.03	3967	2253	2.18	0.26	2.73	1.08	292
11o	23.59	53	36	12	0.05	3021	1906	1.87	0.17	1.56	0.67	233
11p	19.99	56	31	13	0.04	3221	2111	1.91	0.12	1.88	0.84	258
12	23.56	80	6	14	0.02	2602	1703	1.81	0.13	1.16	0.52	205
13	21.70	64	22	14	0.03	2894	1802	1.87	0.18	1.41	0.59	220
14	23.02	77	2	21	0.01	3125	1916	1.86	0.20	1.60	0.67	234
19i	25.27	38	37	25	0.03	2895	1876	1.78	0.14	1.40	0.61	225
44	8.25	23	36	41	0.04	3863	2428	2.44	0.17	3.32	1.41	324
44a	20.14	29	59	13	0.06	3416	1966	1.84	0.25	1.75	0.70	241
44b	20.23	32	59	10	0.06	3531	2020	1.84	0.26	1.85	0.74	247
44c	20.45	40	52	9	0.06	3296	1869	1.82	0.26	1.58	0.63	229
44d	24.72	65	21	14	0.03	2894	1636	1.72	0.27	1.14	0.45	196
44e	27.81	66	16	17	0.02	2722	1608	1.66	0.23	1.04	0.42	190
44f	26.86	50	33	17	0.04	2907	1749	1.64	0.22	1.20	0.49	205
44g	16.19	35	53	11	0.05	3691	2043	1.89	0.28	1.98	0.78	253
44h	22.82	37	51	12	0.05	3405	2025	1.76	0.23	1.74	0.71	244
44i	24.87	61	19	21	0.02	2829	1849	1.69	0.13	1.28	0.57	217
44j	28.38	76	4	20	0.01	2845	1774	1.62	0.18	1.18	0.50	207
44k	27.18	71	9	19	0.02	2963	1901	1.64	0.15	1.33	0.58	221
44l	22.53	52	38	10	0.05	3289	1958	1.76	0.23	1.63	0.66	236
44m	29.55	69	14	17	0.03	3194	1930	1.62	0.21	1.43	0.59	225
44n	30.60	80	1	19	0.01	3478	2202	1.68	0.17	1.86	0.80	259
44o	12.78	45	35	20	0.04	3907	2504	2.04	0.15	2.89	1.25	314
44p	26.62	83	1	16	0.01	3438	1759	1.84	0.32	1.48	0.56	217
44q	31.00	81	1	18	0.01	2861	1880	1.66	0.12	1.29	0.58	219
44r	33.42	66	20	13	0.04	2745	1548	1.63	0.27	0.97	0.38	182
44s	28.43	79	1	20	0.01	3068	1916	1.79	0.18	1.52	0.65	231
44t	28.19	77	3	20	0.01	3024	1784	1.74	0.23	1.34	0.54	214
44u	28.70	79	1	21	0.01	3041	1773	1.75	0.24	1.34	0.54	213
44v	29.47	73	4	24	0.01	2552	1735	1.79	0.07	1.13	0.53	207
44w	17.43	69	5	26	0.01	4169	2604	2.08	0.18	3.27	1.39	330
45	30.54	78	3	19	0.02	2875	1812	1.70	0.17	1.28	0.55	214
45a	26.57	83	1	16	0.01	3220	1823	1.79	0.26	1.47	0.58	221
45b	16.59	78	5	18	0.01	4013	2495	2.13	0.18	3.08	1.30	319
45c	32.40	65	12	23	0.02	2678	1669	1.58	0.18	1.02	0.43	193
45d	11.63	48	35	17	0.04	4526	2861	2.15	0.17	4.03	1.73	366
45e	25.62	77	9	14	0.02	3362	2051	1.72	0.20	1.71	0.71	245
45f	22.61	58	26	16	0.03	3387	2141	1.89	0.17	1.98	0.85	262
45g	32.46	76	9	15	0.02	2648	1601	1.55	0.21	0.94	0.39	184
45h	25.41	43	44	13	0.05	3021	1875	1.70	0.19	1.39	0.59	222
45i	33.30	72	9	19	0.02	2461	1586	1.62	0.14	0.91	0.40	184
45j	24.52	54	34	12	0.05	3046	1876	1.71	0.19	1.41	0.59	223
46	31.22	79	1	20	0.01	2719	1616	1.72	0.23	1.08	0.44	193

No	Pef %	P1 %	P2 %	P3 %	B 1/h	Vp m/s	Vs m/s	ϱ t/m^3	μ -	E 10GPa	G 10GPa	Θ K
46a	1.89	15	13	72	0.02	5536	3322	2.50	0.22	6.60	2.71	450
46b	22.93	78	10	12	0.02	3504	2112	1.85	0.21	1.97	0.81	258
46c	23.42	69	17	13	0.03	3267	1969	1.78	0.21	1.65	0.68	238
46d	27.63	75	2	24	0.01	3226	1875	1.69	0.24	1.45	0.58	223
46e	23.75	64	25	12	0.04	3267	2057	1.75	0.17	1.71	0.73	246
46f	21.04	39	32	29	0.03	3244	2013	1.80	0.19	1.70	0.72	243
46g	25.09	73	3	25	0.01	3179	1924	1.88	0.21	1.65	0.68	236
59	19.49	28	34	38	0.03	3750	2051	1.78	0.29	1.89	0.74	250
59a	27.34	39	39	22	0.03	2703	1129	1.64	0.39	0.57	0.21	135
60	29.24	77	10	13	0.02	2695	1508	1.56	0.27	0.89	0.35	175
61	30.69	69	18	13	0.03	2909	1694	1.57	0.24	1.10	0.44	197
64	34.78	80	8	12	0.02	2769	1541	1.47	0.28	0.87	0.34	175
Kp	23.46	47	36	16	0.04	3217	2071	1.71	0.15	1.65	0.72	245
Lc	31.19	89	0	11	0.01	2869	1605	1.67	0.27	1.08	0.42	191
4a	24.34	65	4	31	0.01	2723	1730	1.64	0.16	1.12	0.48	202

Table 2

Rock type	Pef %	P1 %	P2 %	P3 %	Vp m/s	Vs m/s	ϱ t/m^3	μ -	E 10GPa	G 10GPa	Θ K
Autoclave zeolitites min	11.34	28	2	9	2602	1129	1.47	0.13	0.57	0.21	135
Autoclave zeolitites max	34.78	80	59	39	4385	2460	2.00	0.39	3.01	1.19	310
Autoclave zeolitites mean 19	23.62	54	28	17	3146	1821	1.74	0.24	1.46	0.59	219
Terrigenous zeolitites min	12.94	28	1	10	2461	1548	1.55	0.07	0.91	0.38	182
Terrigenous zeolitites max	33.42	83	51	31	4446	2582	2.19	0.36	3.53	1.42	334
Terrigenous zeolitites mean 32	25.26	65	17	17	3195	1923	1.80	0.20	1.62	0.67	233
Clinoptilolitic zeolitites min	11.34	28	1	9	2461	1129	1.47	0.07	0.57	0.21	135
Clinoptilolitic zeolitites max	34.78	83	59	39	4446	2582	2.19	0.39	3.53	1.42	334
Clinoptilolitic zeolitites mean 50	24.75	61	20	17	3165	1881	1.78	0.21	1.55	0.64	227
Analcime zeolitites min	19.49	28	3	21	3314	2051	1.78	0.13	1.89	0.74	250
Analcime zeolitites max	25.16	76	34	38	3750	2165	1.82	0.29	1.89	0.84	261
Analcime zeolitites mean 2	22.33	52	18	29	3532	2108	1.80	0.21	1.89	0.79	255
Mordenite zeolitite 1	31.19	89	0	11	2869	1605	1.67	0.27	1.08	0.42	191
Silicious rocks min	17.43	38	2	12	2895	1806	1.54	0.14	1.20	0.49	208
Silicious rocks max	40.01	72	37	34	4169	2604	2.08	0.24	3.27	1.39	330
Silicious rocks mean 5	26.94	59	17	23	3363	2071	1.82	0.19	1.91	0.80	252
Marls min	8.25	23	5	17	3863	2428	2.04	0.15	2.89	1.25	314
Marls max	16.59	78	36	41	4526	2861	2.44	0.18	4.03	1.73	366
Marls mean 4	12.31	48	27	24	4077	2572	2.19	0.16	3.33	1.42	330

With respect to the dominant zeolitic mineral the picture is not reliable, because fifty of the samples were clinoptilolitic, only two of them contain analcime, and one contains mordenite. Nonetheless the analcime zeolitic rocks have the lowest average effective porosity, the fewest large pores, i.e., lowest permeability, and respectively, the highest density. These values are maximized in mordenitic rocks, but the porosity is less.

Generally the values of the elastic characteristics, the Debye temperature, the ultrasonic wave velocities, and the density decrease, pointing also to a minimum reduction of the strength.

The differences in the mean values of the petrophysical parameters of the different genetic types of zeolitic rocks not significant are minimal; thus it is difficult to use them? as a differentiating criteria.

In general, the zeolitic rocks are a rather porous media of very low density and of apparent low strength. They are stable under water and do not collapse (the qualitative experimental observations give reason for this).

It is strange that the cherty microcrystalline rocks have similar characteristics. Their porosity is equal to the maximum value for the group of the zeolitic rocks. The density and the strength are also similar. It is most probable that the common condition of formation have predestinated the similar, mearly identical textures and petrophysical properties.

The marls show the lowest porosity - filtration parameters and the highest density and strength - probable proof for the different formation conditions.

5. CONCLUSIONS

The zeolitic rocks are very porous and permeable media of low density. The balance of the elastic parameters - low enough to allow easy modeling, strong enough for building purposes and very light for transportation makes the zeolitic rocks rather suitable for different applications. The low wave velocities and high attenuation are appropriate characteristics for excellent isolation materials. Some of these properties are well known as quality characteristics only, but modern industry needs their quantitative values which are rather scarc in research literature.

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