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Influence of Hydrothermal Transformations on Changes of Volcanic Rocks (Data of Physical Modeling)

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ABSTRACT

The purpose of this work is to study the character and dynamics of volcanic rock changes by simulating hydrothermal transformation conditions. Tasks performed include carrying out a series of autoclave experiments changing temperature, pressure and solution compositions. Methods include preparing rock samples; studying chemical and mineral composition, structure and properties of rocks and solutions before and after experiments.

The following properties of rocks were investigated: density (bulk, specific), porosity (total, effective), hygroscopy, velocity of longitudinal and cross-section waves, effect hygroscopy, geomechanical characteristics (compressive and tensile strength), softening factor, magnetic susceptibility. The first similar experiments were conducted in 2006 (Nuzhdaev and Shanina, 2006).

In this work 28 experiments are considieried that were carried out while altering the following parameters: temperature 200, 300 and 450 ºC; pressure 16, 86 and 1000 bars; four solutions (1 alkaline and 3 acid); duration (15, 23, 30 and 60 days). Study specimens include basalts, hyaloclasites and obsidian from Iceland and tuffs from Kamchatka. Each of these four groups of rocks react under hydrothermal influence. The changes observed include sample colours, microstructure, and new mineral phases creation. This changes were especially active in acid solutions. The folowing new minerals were established: 94.2 % smectite, 3.5 % kaolinite, 1.2 % crisrobalite, 1.1 % a mineral which appears similar to diopside; others pores were filled by chlorite. Amorphous silica was established in alkaline solution. The most appreciable changes in measured properties were observed in velocity of longitudinal waves and magnetic susceptibility. It should be noted that for tuffs are observed the same mentiond above changes plus changes in density and porosity.

1. INTRODUCTION

The majority of the volcanic rocks are exposed to secondary transformations; this especially occurs in fields with active volcanic and hydrothermal activity. Today, with the growing popularity of renewable energy sources, the "human factor" is increasing. Within the limits of run hydrothermal systems it is often occurs dumping of used thermal waters in superficial water flows or putting them back in the reservoir with the help of reinjection wells. Sometimes an accident happens on these wells. It can lead to the floods of waters with high temperature and mineralization. All of this is related to the mountain rock's structure and properties changes.

Due to active geothermal power development, a number of articles were published regarding experiments that study mineral and rock transformations under the influence of hydrothermal processes (Steiner, 1953; Ellis, 1960; Gramenitskiy etc., 2000; Karpov, 1969). But practically, nobody has researched the changes in the petrophysical properties of rocks and minerals. Only A. J. Karpov (1976) carried out volumetric weight researches of rocks samples for studying changes in it porosity. With a combined effort from the two departments of Geological faculty Lomonosov Moscow State University authors created conditions for experimental study of influence of temperature, pressure and composition of solutions on change of structure and properties of basalts, obsidian, hyaloclastites and tuffs.

2. EXPERIMENTS TECHNIQUE AND MATERIALS

In this work, basalts, hyaloclasites and obsidian from Iceland and tuffs from Kamchatka were utilized. Locations were chosen based on connections with active geothermal power stations in these regions, and as a consequence availability of core material. This provides an opportunity to compare experimental results of transformed rocks with natural analogues. Experimental results have practical importance because it simulates rocks changes when spent thermal waters are pumped back in the reservoir.

The experiments were carryed out at the department of geochemistry in the geological faculty of Lomonosov Moscow State University. Autoclaves used in experiments (fig. 1) consist of of titanium alloy VT-8, volume 116-119 ml. Each autoclave held 2 to 6 sampels with for investigation of structure and properties. The heating was made in OVEN TPM-10 with accuracy ± 1 ºC, temperature constancy was supervised by thermocouples.

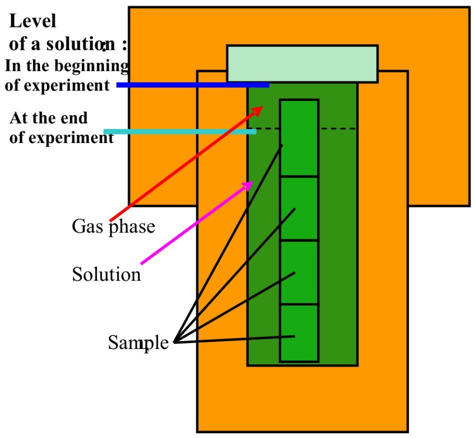

Figure 1: The circuit autoclav during experiment

Petrophysical properties of rocks samples they were studied after cutting and grinding samples. Investigated properties include: ground density, solid phase, total and effective porosity, water absorption and hydroscopic moisture, velocity of passage of elastic waves (longitudinal and cross-section waves in dry conditions and longitudinal in water saturated), magnetic susceptibility, durability on uniaxial compression and tension. All work was carrried out at the department of engineering and ecological geology according to standard techniques and practices described in various methodical works (Laboratory works on..., 2008; the methodical manual …, 1984; Kalachev, 1997) and normative documents (GOST 5180-84).

In parallel with the above-mentioned work, petrographic microdescription of the samples was conducted under a polarized light microscope (Olymmpus BX 41). Photos of the initial and changed rocks were recorded for better illustration changes that occurred. Also, microphotos were taken of thin sections. In addition, secondary transformations were researched, including pore space morphology, using Scanning Electron Microscope LEO 1450 as well as mineral point-counter chemical analyses. Also, the "Jeol JSM-6480LV" miscroscope was used at the department of petrology (laboratory of the local methods of substance research). At the laboratory of x-ray diffractometry quantitative x-ray analyses of new mineral phases was carried out (analysts – conducting engineer L. A. Levitskaya, senior researcher V. V. Krupskaya).

This work is based on the results of 28 experiments, all parameters are listed in Table 1. The first autoclaves were put in oven on October 31, 2007, and the last one was taken out on April 20 2009. The minimum experiment duration was 15 days, maximum – 60 days, and for several samples it took 90 days (stage by stage). During experiments, 114 samples of volcanic and volcanic-sedimentary rocks were investigated. Basalts from the volcano Krafla are subjected the highest temperatures and pressures (450 C and 1000 bars), and tuffs from Kamchatka are subjected the lowest temperatures and pressures – (200 C and 16 bars accordingly). Temperatures at which experiments were conducted were chosen based on knowledge about the natural conditions of the hydrothermal systems of the volcano Krafla (Iceland) and Pauzhetskaya (Kamchatka). The pressure in autoclaves during experiments was calculated based on information about sample volume and chosen fill factor.

During the first year, experiments were conducted on samples from Iceland, therefore based on literary data of concentration of substance (Ellis, 1982) was re-established characteristic hydrothermal weak solution, which was called the «alkaline» (initial pH 8,2). During eruption per 1975-84 years the factor CO_2/H_2S in some of wells on Krafla reached the increased meanings, and in one of wells pH of a solution has fallen with 9 up to 2. Therefore for study of influence of the contents CO_2 in a solution on change of properties of rocks was created the solution «acid-1» (contents of CO_2 10 mol /%). During the second year were used tuffs samples, that were selected at 2008 during field work at Pauzhetska (S. Kamchatka). S. I. Naboko (1963) on the deposit Pauzhetskaya had identified three types of hydrothermal solutions. The initial are chlorid-sodium interstitial waters with mineralization 2.6-3.4 g/l ("acid-2" (initial pH 4,1)), they are most fully studied, collected from the installed wells. Pore solutions in a surface area of steam condensation are sulfate, with complex cationic composition and mineralization up to 13 g/l. The solution "acid-3" (pH 1) (Table 2) was created for study of fast changes in aggressive conditions

Table 1. Parameters of Experiments.

Experi-ment	Conditions					Hardening solution	
	Rocks	T, C	P, bar	Solution	Dura-tion, days	pH	pS
1-1	Basalts	300	86	Alkaline	15		
1-2		300	86	Alkaline	30	5,9	4,2
1-3		300	86	Acid-1	15	6,6	
1-4		450	1000	Alkaline	15	5,4	2,2
1-5		450	1000	Acid-1	15	5,4	3,7
2-1	Obsidian (volcanic glass)	300	86	Alkaline	15	6,7	
2-2		300	86	Alkaline	30	7,1	
3-1	Hyalo-clastites	300	86	Alkaline	30	7,8	
3-2		300	86	Acid-1	30	7,1	
4-1	Tuffs	200	16	Acid-2	15	5,5	
4-2		200	16	Acid-2	60		
4-3		200	16	Acid-3	15		
4-4		200	16	Acid-3	30		
4-5		300	86	Alkaline	30		
4-6		300	86	Acid-2	30		

Table 2. Composition of Solutions.

Solu-tion	Concentration of substance, gr/l				CO_2 m/kg
	NaCl	$NaHCO_3$	K_2SO_4	H_2SO_4	
Alka-line	0,499	0,142	0,068	-	-
Acid-1	0,499	0,142	0,068	-	5,5
Acid-2	1	0,1	-	-	1,5
Acid-3	-	-	-	9,8	-

3. THE INVESTIGATED ROCKS

3.1 Basalts

The greatest number of experiments were carried out with samples from Iceland with quaternary basalts representing porous constant rocks (Table 3). Samples 6-2a and 6-2б belong to a lava flow 1727-1729 years from Krafla, and samples 6-1 and K-1 were selected from a flow from 1984. The most part of used samples was given J.

Table 3. Properties of Quaternary Basalts of Iceland .

Sample	ρ, g/cm³	ρ_s, g/cm³	n, %	Wg, %	W, %	V_p km/s	V_pw. km/s	Vs, km/s	Rc MPa	χ* 10^{-3} SI
6-1	1,44	3,09	52,0	0,0	18,0	2,55	3,10	1,60	14	8,2
6-2a	1,78	3,08	42,3	0,0	5,8	2,85	4,05	1,70	34	6,7
6-2б	2,08	3,06	32,1	0,0	3,3	2,20	3,55	1,40		11,1
6-3/2	2,05	3,06	32,9	0,0	4,8	3,30	4,10	1,85	18	8,4
К-1	1,51	2,95	48,7			2,45		1,10		1,9

The note: ρ -density, g/cm³; ρs –specific density, g/cm³; n - porosity, %; Wg – hygroscopy, %; W – water absorption, %; Vp (Vpw.) – velocity of longitudinal waves (in dry and water-saturated conditions), km/sec; Vs – velocity of cross waves, km/sec; Rc - durability on compression, Mpa; æ –magnetic susceptibility, $*10^{-3}$ SI

V. Frolova, and the sample К-1 is selected in 2007. It is possible to note, that the high porosity of basalts (32.1-52.0%) relates to low values of density, velocity of longitudinal waves and durability; and the absence of hygroscopy specifies the volcanic glass, not changed by secondary minerals, that is basalts maximum fresh, not transformed (fig. 2). Besides, in OOO "Podzemgazprom" the permeability of К-1 ($1,4*10^{-5}$ mD) was determined.

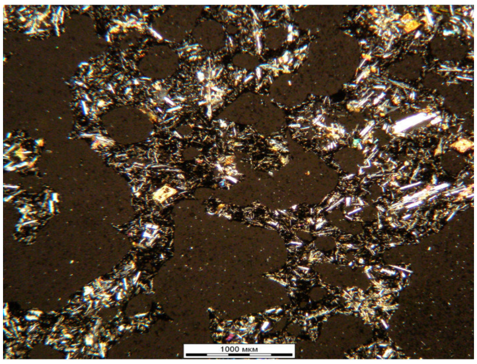

Figure 2a: Fresh basalt (sample 6-1) (nicols X)

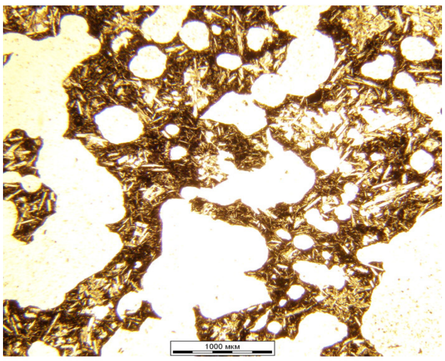

Figure 2b: The same site at 1 nicol (1)

On table 4 the properties of basalts after experiments and also change of a magnetic susceptibility and velocity of longitudinal waves, as these two properties have changed maximum. So in alkaline environment at temperature 300 C in 15 days velocity has increased on 0.95-1.90 km/sec (35-85%), and magnetic susceptibility (æ) on 0.8-5.1*10-3 SI (41-60%). After the same duration of experiment but already at 450 C the changes are following: velocity 1.15-1.55 km/sec (42-70%) and æ 8.7-11,6*10-3 SI (118-133%) accordingly. At increase of duration up to 30 days under the first conditions velocity increases up to 1.25 km/sec (46%) and æ on 0.9-35.7*10-3 SI (72-455%).

Table 4. Properties of Basalts after Experiments.

Sample	Groups (solu-tion)	r, g/cm³	Vp km/s	Vpw. km/s	Chan Vp km/s	Ch Vp %	æ.*10^{-3} SI	Chan æ*10^{-3} SI	Ch. æ%
6-1	Alk. 15/1	1,38	3,70		0,95	35	13,4	5,0	60
	Alk. 30/1	1,52	3,40	4,55	1,05	46	43,5	35,7	455
	Acid 15/1	1,36	3,15	3,20	0,60	23	7,3	-1,1	-14
	Acid 15/2	1,53	3,45	3,40	0,95	38	4,0	-4,2	-51
6-2a	Alk. 15/1	1,63	4,75		1,90	68	9,5	3,5	58
	Alk. 30/1	1,90	4,15	5,15	1,25	44	19,6	12,8	188
	Alk. 15/2	1,79	3,90	4,05	1,15	42	16,0	8,7	118
6-2б	Alk. 15/1	2,20	4,00		1,85	85	14,8	5,1	52
	Alk. 15/2	2,06	3,80	4,00	1,55	70	20,8	11,6	126
	Acid 15/1	2,06	2,65	2,80	0,45	21	6,6	-4,8	-42
	Acid 15/2	1,97	3,30	3,70	1,15	54	14,6	0,4	3
6-3/2	Alk. 30/1	2,04	4,40	5,20	1,25	39	24,1	16,0	200
	Alk. 15/2	2,03	4,50	4,40	1,45	48	18,9	10,8	133
	Acid 15/1	2,15	4,20	3,70	0,65	18	8,8	0,0	1
	Acid 15/2	1,96	4,30	4,40	0,85	25	5,1	-3,6	-41
К-1	Alk. 15/1	1,67	4,15		1,60	63	2,6	0,8	41
	Alk. 30/1	1,55	2,60	2,80	0,00	3	2,2	0,9	72
	Acid 15/1	1,31	2,70	2,90	0,55	33	2,1	0,2	10

The note: fraction in which the numerator is - duration of experiment (day) and the denominator is - condition (1-at 300 C, 2-at 450 C).

In acidic environments the velocity of longitudinal waves increased as well, but less than in alkaline. In 15 days at 300 C on 0.45-0.65 km/sec (18-33 %), and at four hundred fifty on 0.85-1.15 km/sec (25-54 %). The magnetic susceptibility in acid environment decreased to $1.1\text{-}4.8*10^{-3}$ SI (14-42 %) and $3.6\text{-}4.2*10^{-3}$ of system unit (41-51 %). It is possible to see in the table 4, that within one subgroup some samples have lower properties than another. The reason is that they were in top of autoclaves and by the end of experiment they already partially or even completely, were in a gas phase.

In photo 3 you can see basalts before experiments. Visually, after alkaline environment they practically have not changed. And after the acidic environment basalts get light grey color. On the surface we observed white new growths.

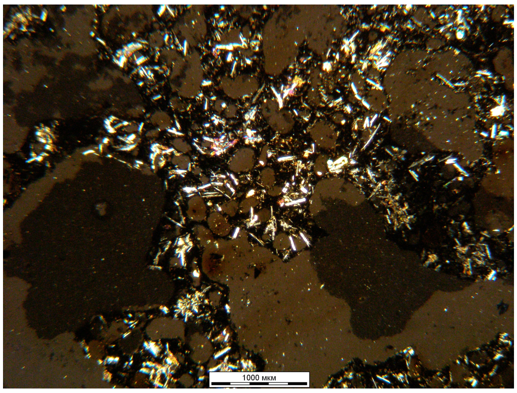

Figure 3a: Filling pores by secondary minerals (test 6-1-1, acid solution) (nicols X)

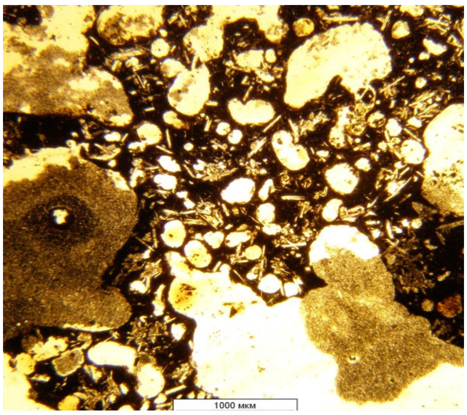

Figure 3b: The same site at 1 nicol (1)

For an explanation of the occurrence of strong changes in properties of basalts as a result of experiments, we the study the microstructure via scanning electronic microscope. That has allowed us to define, that the increase of velocity of longitudinal waves is connected to change of pores space of rocks and occurrence of new mineral phases (chlorite in acid solution, amorphous silica in alkalinesolution) and additional contacts.

At the expense of such microscopic, but very important changes there is a transformation of rocks attracting essential change of their properties and if density of basalts after experiences is reduced rather insignificantly, and porosity only slightly varies, the occurrence hygroscopy speaks (up to 0.4 %) about going transformation of rocks, which is accompanied by occurrence of clay minerals healing pores, that essentially increases of velocity of longitudinal waves.

Was are made not only photo (fig. 4, 5), but also the analyses are carried out which have shown, that after an alkaline solution of a wall pores SiO_2 (fig. 5), and after acid in them a new mineral (fig. 4), which on the spectrum corresponds chlorite.

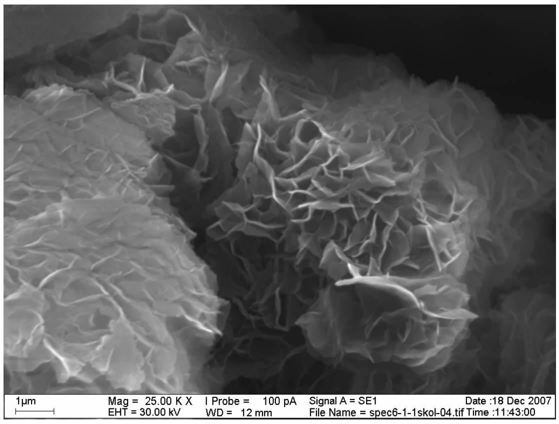

Figure 4: New mineral (300 C, 15 days, acid solution)

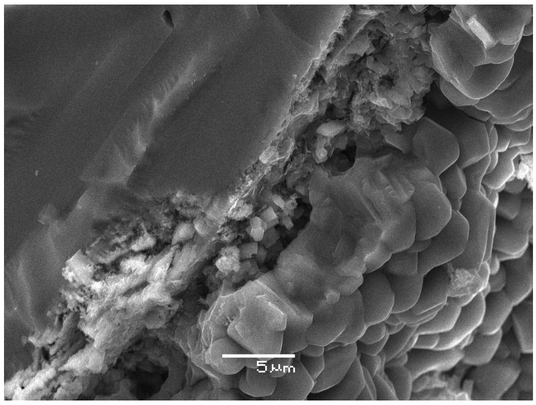

Figure 5: Wall pore (450 C, 15 days, alkaline solution)

3.2 Hyaloclasites

The following rocks for experiments became hyaloclasites (tuffs, formed as a result of eruptions under ice) as in Pliocene-Pleistocene sedimentary of Iceland main a water zone most often are located on borders of lavas and hyaloclasites. The investigated of initial rocks - vitroclastic tuffs (fig. 6) with massive texture, meet rare crystals plagioclases and pyroxenes (basically hypersthene).

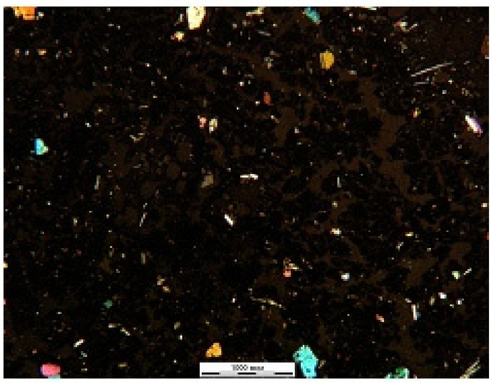

Figure 6: Initial hyaloclasites (nicols X)

With hyaloclasite two experiments (in everyone were carried out only participated till three samples), identical on duration (30 days), temperature (300 C) and pressure (86 bars), but with different solutions, and it was very brightly showed in their changes. After opening autoclav, facing with a acid solution (fig. 7), on its walls and especially it is a lot of on the top side top in autoclav of a sample the congestions similar to friable white snow, greasy to the touch were are found. Quantitative x-ray analysis of the new mineral phases (fig. 7) has allowed us to identify the minerals as: smectite 94.2%, kaolinite 3.5%, cristobalite 1.2%, diopside 1.1% (analysis has executed V. V. Krupskaya, apparatuses - DRON– UM1). The researches thin section have shown, that having added CO_2 to the first solution we have achieved the following stage alteration, when in pores begins of new minerals.

Figure 7: New minerals (basically clay)

The standard complex of research of properties was carried out. It is necessary to note, that it is heavy to reveal any tendencies in hyaloclasite, which structures and origins initially differ by the increased heterogeneity because of features of the structure,, and also samples which, used in experiments, - cylinders, that at once reduces amount of definitions of some parameters, such as velocity of elastic waves up to one for a sample, instead of three, as for tuffs, basalts and obsidian, which are submitted cube. But it is precisely visible, that on the initial ambassador of stay of an alkaline solution density of rocks is increased by size from 0.6 up to 0.24 g/cm³, and after stay in acid is reduced (up to 0.6 g/cm³) because of replacement of a part of a glass by easier new minerals (fig. 8) (Frolova, Ladygin, 2003).

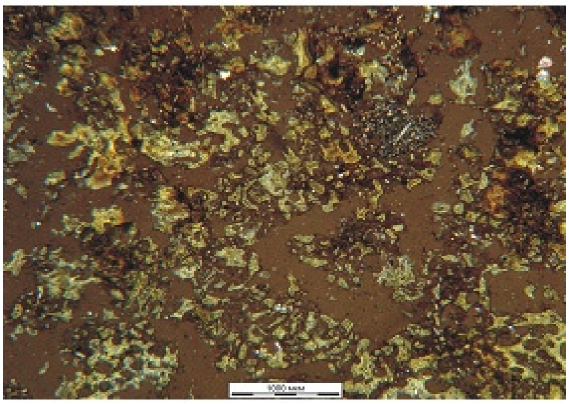

Figure 8: Hyaloclasites after alkaline solution (nicols X)

3.3 Obsidian

Volcanic glass is in all investigated rocks, which at hydrothermal conditions often is the first alterred componenet (crystallization of a glass of basic weight). Was decided to carry out experiments with monolithic obsidian, from which have made four samples for two parallel experiments, the experiences passed at temperature 300 C, pressure 86 bars, in an alkaline solution, only on duration they differed twice (15 and 30 day). Samples naturally changed visually (fig. 9). But these changes took place only from the surface. In shorter experiments a rind with a thickness of 1-2 mm was formed. After longer durations rind thickness increased up to 2-3 mm. In thin section, the altered mineral composition could not be determined. But, under scanning electron microscope the nature is simply hydrated glass (fig. 10, tab. 5).

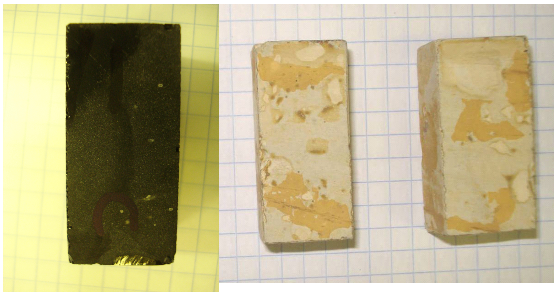

Figure 9: Initial obidian and after 30 day (alkaline)

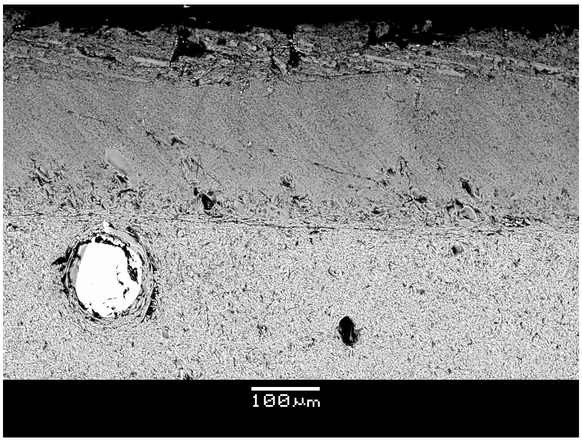

Figure 10: Front diffusion, parallel to an external side of a sample obsidian

The strict scientific explanation of the occurrence rind and its correct borders was found in the book of G. A. Vagner "Scientific methods dating in geology, archeology and history" (2006). The glass (obsidian) slowly adsorbed water from the environment and thus accumulated up to 3-4% water in its structure. Such absorption of water (hydration reaction) occurs in the form it diffusion in directly at superficial a zone flown down. Rind hydration arises on a background of the not changed internal parts of a glass as the sharply outlined front diffusion, parallel to a surface. But the process hydration reaction consists not only of molecules of water, but also is connected to a material exchange. In 1978 it was revealed (Tsong et al., 1978), that along structures in rind hydration besides increase of the contents of water the reduction of the contents of alkaline elements is observed. Obviously, there are reactions to replacement of hydrogen by alkaline elements:

Na^+(glass) + $2H_2O$ - > H_3O^+(glass) + NaOH, and in a course of this process the silicate skeleton of rock remains practically not mentioned. The conformity of processes hydration obsidian in natural and laboratory conditions allows to spend dating (Vagner, 2006), first in 1960.

The research carried out studying the changed properties of obsidian have convinced us of the above explanation, as in samples with apparent hygroscopy (in 15 day – 0.1 %, and 30 day- 0.5 %), which was absent earlier. The velocity of elastic waves after influence of an alkaline solution is reduced, that is connected to processing of a volcanic glass from a surface and rind of a hydration glass, which on the properties strongly differs from initial. Therefore greatest decrease of velocity of waves occurs on the party "c" (smallest at sample), where a layer of a hydration glass greatest concerning length of a sample. If for 30 day fall of speeds of longitudinal waves (Vp) on the party "a" practically no, on "c" - 0,95 km/sec (18 %), and cross (Vs) accordingly 0,55 km/sec (18 %) and 1,25 km/sec (45 %). Changes of magnetic susceptibility in obsidian is practically impossible, as the changes are on the order of $*10^{-3}$ SI units.

3.4 Tuffs

On a peripheral site of a Pauzhetsky geothermal deposit are located a three wells: 146; 142 (the depth 720 m, is entered into operation in October, 1983, since 1994 - absorbing), 143 (the depth 595.2 m is maintained since October, 1983, since 1988 - absorbing). In 2006, the monitoring of parameters of thermal waters in well 142 showed temperatures of 119-123 C.

In August, 2008 in the right to a board of stream, on some tens meters the hydroterm is higher on stream of a Nizhne-Pauzhetsky geothermal field, outside of a zone of influence hydrotherm, was investigated tuffs (N_2-Q_1 pau_3) and 7 tests are selected which in a consequence (in Moscow) have resulted in 81 samples. Opening side stream column represents pereslaivayuschihsya tufaceous of tonkooblomochnyh (pelitic and alevritovyh) to krupnooblomochnyh (psefitovyh), at varying degrees of cementation. A chemical analysis of tuffs allowed us to evaluate their composition with respect to andesite-dacite (table 6).

Tuffs very non-uniform rocks, therefore we shall consider in detail some tests and their properties.

Test НП-08-2 psammitovy tuff, shows laminated, alternating white (enriched with fragments of pumice) and yellowish-gray layers of the thickness of 1-3 mm. Crystal structure, has massive partly laminated texture. Debris present was mostly crystallin plagioclase, quartz, temnotsvetnyh minerals (fig. 11). There are some isolated fragments litoklastov (0.3 mm) (mostly pumice). Ore minerals initial interest rate. Properties studied psammitovyh tuffs: density of 1.23 to 1.47 g/cm^3 (the gravelisty) (average 1.33 g/cm^3), firm phase 2.71 g/cm^3, porosity from 45.6% (a very dense sample) to 54.5% (in the sample with the lowest density) (average 50.9%), open porosity of 38.0% (from 36.7 to 38.9%), hygroscopy 3.6%, water absorption 28.7% (26.9-30.6%), velocity of longitudinal waves 1.55 km/s (1.40-2.00 km/s) at water slightly decreases, the magnetic susceptibility of $7.3*10^{-3}$ SI (from $6.2*10^{-3}$ SI to $8.3*10^{-3}$ SI (near the gravelistogo)), uniaxial compression strength of 21 kg/cm^2.

Test НП-08-3 alevro-psammitovy tuff, is non-uniform light gray-beige in color. Debris (20-30%; size from 0.1-1 mm)), is distributed unevenly on the rocks - there are concentrations of them in some lenticular, elongated plots cracking. The structure of mixed texture of massive, heterogeneous, fragments are not evenly distributed. Presented by rare crystals of: a lot of plagioclase (0.05-0.1 mm), quartz (0.1 mm), temnotsvetnye minerals (0.03-0.05 mm) (mainly pyroxene). Ore minerals comprise the first interest. Cement glass wool. Is found chalcedony.

Properties studied alevro-psamitovyh tuffs: density of 1,43 to 1,58 g/cm^3 (average 1,50 g/cm^3), firm phase 2,64 g/cm^3 (the lowest among the studied tufaceous because of the high content of tonkooblomochnogo-glass wool material), porosity of 40,1% (at the most dense samples) to 45,8% (in the sample with the lowest density) (average 43,3%), open porosity 33,9 % (from 31,3 to 35,6%), hygroscopy of 6,9% (maximum for tufaceous of this section, it indirectly suggests a high content of clay minerals in the sample), water absorption 22,5% (19,8-24,1 %), velocity of longitudinal waves 2,10 km/s (1,90-2,30 km/s), if water is not changed, the magnetic susceptibility of $6,2*10^{-3}$ SI (3, 4-$9,5*10^{-3}$ SI).

Test НП-08-4 differ from the lowest density of the studied species (from 0,98 to 1,35 g/cm^3 (sample НП-08-4-6 (gravelisty)) (an average of 1,14 g/cm^3), and the greatest porosity (from 49,8% (from the above sample) to 63,5% (average 57,4%)), is related to the content of light, porous pumice rubble (fig. 12).

Table 5. Composition of Obsidian and it of a Hydration Part (Rind) (Analyst V. O. Yapaskurt).

	Na_2O	Al_2O_3	SiO_2	SO_3	Cl_2O	K_2O	CaO	TiO_2	FeO	Sum
Rind	3,8	11,4	63,5	0,1	0,3	4,6	0,6	0,1	1,7	85,8
Obsidian	5,0	12,9	71,5	0,0	0,2	4,6	0,5	0,0	2,1	96,6

Table 6. Chemical Analysis Tuffs Verhnepauzhetskoy Podsvity Weight.%

N	SiO_2	Al_2O_3	FeO	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	MnO	Na_2O	K_2O	H_2O	n.n.n	sum
НП-08-5	61,54	15,58	1,08	4,99	0,65	0,13	4,55	2,14	0,11	1,75	1,14	2,40	3,28	99,34
НП-08-7	62,40	15,38	1,01	4,40	0,53	0,14	3,50	1,76	0,07	1,68	1,45	3,00	4,31	99,63

Melkopsefitovye tufy (НП-08-6) with the content of debris up to 80% most dense (from 1,59 to 1,80 g/cm^3 (average 1,70 g/cm^3)) and the least porosity (from 33,8% to 41,6% (average 37,6%)) in the entire section, associated with a high content of dense lavas litoklastov and ancient tuffs.

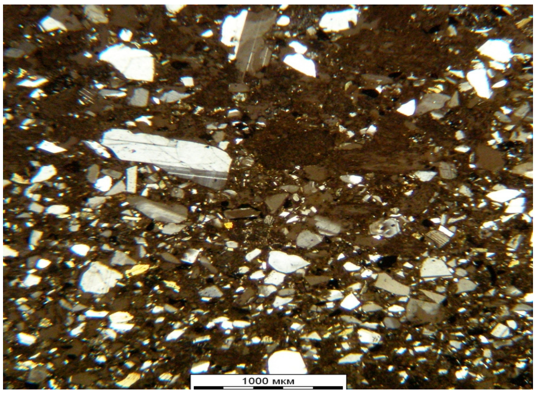

Figure 11: Psammitovy tuff (nicols X) (sample НП-08-2)

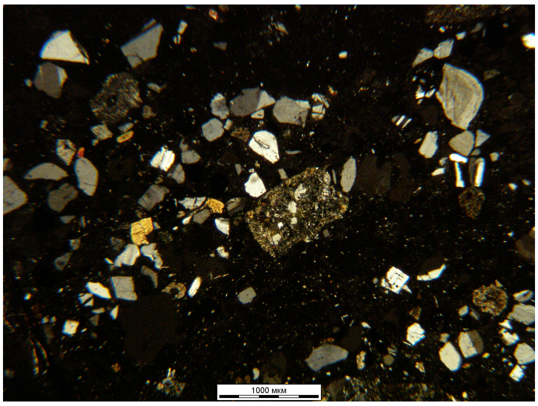

Figure 12: Pemzovy tuff (nicols X) (sample НП-08-4-1)

Sample tuffs verhnepauzhetskoy podsvity conducted 18 experiments during the academic year 2008-2009, the maximum stop time vystaivaniya autoclave 60 days, the majority of experiments conducted at a temperature of 200 C, typical of Pauzhetsky hydrothermal systems, and five at 300 C to evaluate the impact of temperature on transformation of the composition and properties tuffs and the possibility of comparison of changes with in the first year of teaching experience with the basalts, hyaloclasites and obsidian. Changes occurring in the composition were studied via microsection of modified samples and X-ray diffraction analysis. Also at the Department of Geochemistry of the thermodynamic calculations were conducted using high-performance computing program «HCh», to calculate the equilibrium in the systems of arbitrary complexity. Data is enterred about the composition of the artificial hydrothermal fluids used in the experiments (Table 2), and chemical composition of tuffs (Table 6). According to calculations for tuffs in the first case (the solution «acid-2») are formed: quartz, hematite, calcite, K-montmorillonite, kaolinite, chlorite, and pH of solution hardening gradually increased and after 50 steps (proportional to the square root from the time of interaction) should reach 5.6. Using the solution «acid-3», to be formed: quartz, hematite, alunite, anhydrite, K-montmorillonite, kaolinite, chlorite and pH increased significantly more (up to 3,3).

Study of microsections showed that the first change tuffs start of ozhelezneniya for cracks and around the crystals and fragments of rocks (fig. 13), with increasing duration of exposure occurs dissolving and leaching pyroxenes and plagioclases (fig. 14, 15), quartz crystals in the experiments remained unchanged.

Past experiments have revealed the general trends of changes in the properties of andesite-dacite tuffs verhnepauzhetskoy podsvity influenced by temperature (200 and 300 C) and pressure (16 and 86 bar) and the composition of different solutions («acid-2 and -3», «alkaline»).

1) reducing the density, particularly the sharply reduced of specific density (Fig. 16) (due to the emergence of newly lighter minerals ((smektity and smeshanosloynye number smektit or chlorite-illite-smektit) (from 20 to 50%)) are distinct structure, the density and size of aggregates);

Observed in Fig. 16 rebound (higher density of solid components tuffs), associated with ozhelezneniem and gematizatsiey samples (fig. 17), which at the time of experimentation to be the top in autoclave.

2) reducing the total porosity, while increasing open and water absorption;

3) decreasing the content water (as indicated by hygroscopy);

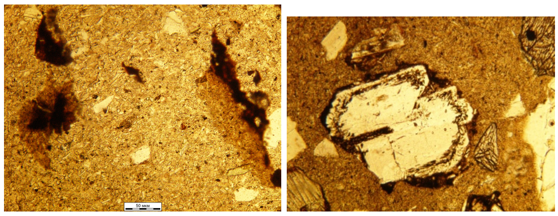

Figure 13: Ozheleznenie for cracks and around the plagioclase crystal (1 nicol) (sample НП-08-3-11)

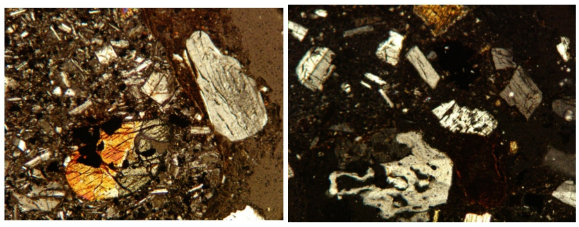

Figure 14: Changes in crystal pyroxenes and plagioclases (nicols X) (sample НП-08-5-15)

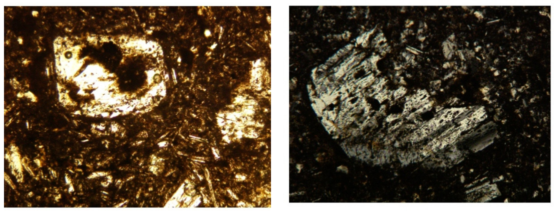

Figure 15: Crystal plagioclases (1 nicol and nicols X) (sample НП-08-6-6)

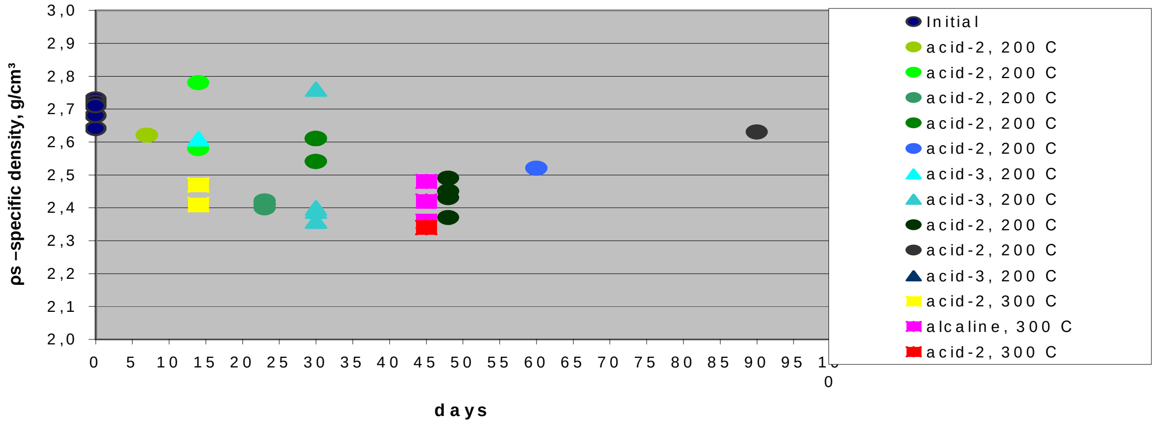

Figure 16: Reduction of specific density of tuffs with increased of duration of experiments

4) reduced velocity of longitudinal waves (Fig. 18), which is primarily due to fracturing and no water resistance data tuffs;

5) changing the magnetic susceptibility of rocks (after a stay in a solution of «acid-3» it is reduced, and the remaining increase more significantly, because of the gematizatsiey and leaching).

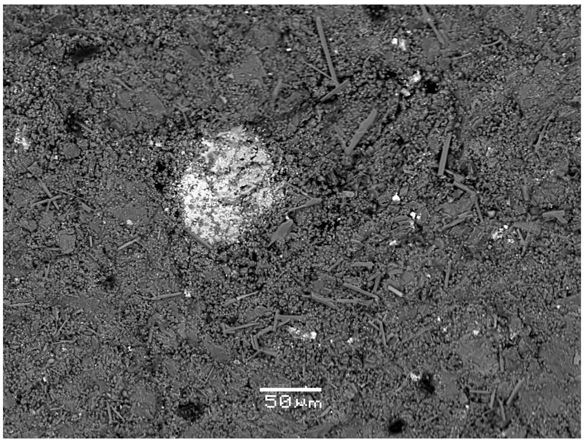

Figure 17: SEM-image of a site with ozhelezneniem

CONCLUSIONS

Experiments have shown the influence of temperature, pressure, solution composition and experiment duration on changes in the composition and properties of basalt, obsidian and hyaloclasites from Iceland and tuffs from Kamchatka. Changes in these conditions lead to the hydrothermal transformation of rocks, but there are also changes in features specific to each rock type:

For basalts:

- To change the pore space - the emergence of new mineral phases (chlorite in acidic solution, amorphous silica in alkaline);

- Increase in velocity of longitudinal waves at 0.45-1.90 km/s (85%);

- Increase in magnetic susceptibility in an alkaline solution, and reducing it in acid.

For hyaloclasites:

- The initial alterations after stay in alkaline solution at 300 C and a pressure of 86 bar - Increase the density of rocks;

- The next phase palagonizatsii under similar circumstances, but in acidic solution - lowering the density of rocks.

For obsidian:

- The appearance of the surface crust hydrated glass (in alkaline solution);

- In the part of the samples a strong drop in velocity of longitudinal waves.

For tuffs:

- A sharp decline in the density of the solid phase (due to the emergence of newly formed minerals ((smectite and smeshanosloynye) (from 20 to 50%));

- Reducing the velocity of longitudinal waves (by increasing the fracture due to pressure of crystallization of new minerals and is not waterproof tuffs).

In general, neither the composition nor the properties of any of the studied rocks remain unchanged after temperature and pressure effects in geological time.

This is very important, because similar changes are observed in the modern hydrothermal systems, where waste hot water is injected, because then the problem is recycling of hot water. These experiments can be used to reproduce the return of used injection of thermal waters, the assessment of changes of composition and properties of rocks of hydrothermal reservoir (as a result of formation of secondary minerals in the reinzhektsii), evaluation and prediction of changes in acceleration reinzhektsionnyh well.

The studies for three of the four groups of species showed conformity changes in the properties and composition of rocks in the hydrothermal transformation of nature and with the physical modeling of similar conditions in the laboratory (temperature, pressure and composition of, different solutions). It should be noted that for obsidian was

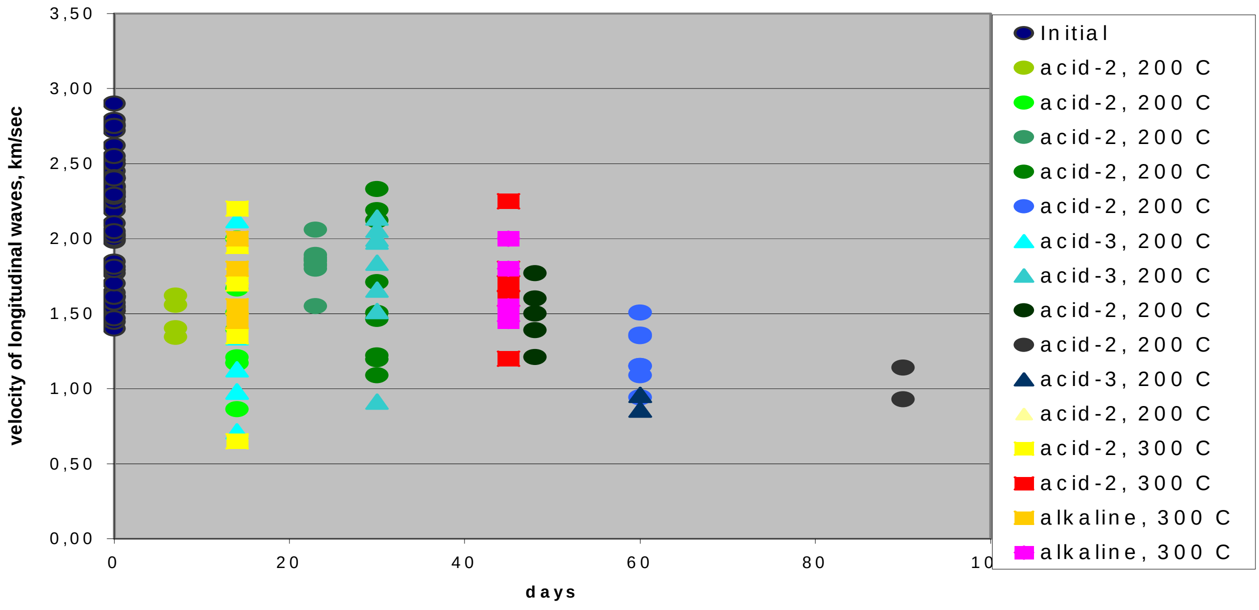

Figure 18: Reduction of velocity of longitudinal waves at increase of duration of experiments

known already long. The thickness of a newly formed crust on a hydrated glass has been used for dating since 1960 (Vagner 2006). Only a significant increase in the velocity of longitudinal waves in basalts can not be compared with the natural, as yet not been found completely unmodified counterparts porous rock, but in the pores of which have already appeared the first secondary minerals.

It should be noted that the use of autoclave creates closed systems, but in the nature the hydrothermal systems are open, but with a long experience it is not played a big role. What can be seen by comparing the results described above, the transformation of rocks with the observed GA Karpov (1976), with multi-experiments conducted by them in the geothermal wells («natural autoclaves»), including the Pauzhetskaya geothermal fields. Also known for a number of experiments on the regeneration of the effusive rocks in an environment of hot springs and fumaroles, the results of which coincide with the natural change of species that come into contact with the natural fluids in similar conditions. GA Karpov concludes, «that found in the cores of geothermal wells albite, quartz, mordenit and other minerals crystallized under the influence of modern solutions». The last allegations, I personally still can not accept because of insufficient knowledge of the subject.

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