Chemical Composition, Density, Specific Gravity, Apparent Porosity, and Thermal Transport Properties of Volcanic Rocks in the Temperature Range 253 to 333 K

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The chemical composition and density related properties of the volcanic rock samples (granite and diorite) taken from the Shewa-Shahbaz Garhi volcanic complex near Mardan, Pakistan, have been measured at room temperature. ASTM standard methods have been applied in the investigation of such parameters as density, specific gravity, and porosity. Thermal properties of these samples are studied as a function of temperature, in the range (253 to 333) K, including thermal conductivity, thermal diffusivity, and heat capacity per unit volume.

Introduction

The knowledge of thermal properties and high-temperature behavior of rocks has become increasingly important with the widespread interest in thermal processes in underground fluid-bearing reservoirs. Some of these processes include thermal methods of enhanced oil recovery, management of geothermal reservoirs, underground storage of heat, and underground disposal of nuclear waste.

Rocks are divided into three major groups according to their origin.[1]

1. Igneous rocks are formed by the cooling of magma and are primary rocks (granite, dunite, gabro, basalt, diorite). They are conventionally subdivided according to their silica content, into granite (SiO_2 > 65%), diorite (SiO_2 = 65−52%), basalt (SiO_2 = 52−40%), and dunite (SiO_2 < 40%).

2. Sedimentary rocks are formed by depositing (mechanical, chemical, organic) products of weathering of igneous and metamorphic rocks by water or air (limestone, standstone, coal, sedimentary iron ore, etc).

3. Metamorphic rocks are derived from the previously formed rocks of any kind (igneous or sedimentary) through the action of high pressure and temperature and the chemical action of hot liquid and gases (quartized and marble).

In this paper the density related and thermal transport properties of granite and diorite groups are mentioned. These rocks have different uses in daily life.[2]

Experimental Procedure

All the samples were obtained from Shewa-Shahbaz Garhi volcanic complex, near Mardan, Pakistan. These samples were then cut in rectangular shapes with the cooperation of Pakistan Atomic Energy Commission, Lahore, Pakistan. The chemical composition was analyzed by using the X-ray fluorescence technique.[3,4] There were 17 samples in the granite group and 13 samples in the diorite group. The chemical compositions of these samples are given in Table 1.

Density Related Properties. Specific gravity, density, and apparent porosity are grouped as the density related properties of rocks. These parameters have in common that they have no connection with any external factor and so are not mechanical. They must, however, be considered first before any other property of the rocks can be studied. The specific gravity of the mineral depends on its chemical composition and structure: the greater the number of the heavy atoms in it, the smaller their radii, and the denser their packing in the crystal lattice of the compound, the greater is its specific gravity. The specific gravity of a rock, a_0, is wholly dependent on the specific gravity of the minerals forming it, a_i, and is calculated by the formula

$$a_0 = \sum a_i V_i / \sum V_i$$

where V_i is the volume of each mineral. Thus, the mineral composition of a rock determines unambiguously the value of its specific gravity.

Porosity. The storage capacity of porous rocks is referred to as porosity and is that fraction of the bulk volume of the rock available for the storage of fluid. The effective porosity is defined as "the amount of interconnected pore space available for fluid transmission, expressed as a percentage of the total volume".[2] The porosity of a rock depends on the shape and size of the grains it is composed of and on the degree of their sorting and packing.[1]

Density. Density is an intrinsic property of rock that denotes the relationship between its mass and unit volume. It is used as an index property or an independent variable to predict other rock properties and is difficult to characterize because density values can be affected by temperature, pressure, and the amount and type of fluid saturation. In our experimental work, the definition of the American Society of Testing and Materials Standards (ASTM) has been followed.[5]

For density related parameters, the samples were dried at (105 ± 5) °C in a furnace for 24 h. After drying, the samples were cooled at room temperature for 30 min and then weighed using a digital balance with tolerance within ±0.001 g. This gave the dry mass (*D*) in grams. After the dry mass was found, these samples were immersed in distilled water at room temperature for 48 h. At the end of this period the samples were removed from the water bath one at a time. This gave the suspended mass (*S*). This weighing was accomplished by suspending the sample by a copper wire hung from one arm of the balance. The

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Table 1. Chemical Composition of Samples in Mole Percentage

sample no.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
a. Granite Samples											
SSG-G1	65.19	0.59	17.63	1.26	1.38	0.13	0.49	0.66	6.59	5.93	0.16
SSG-G2	65.21	0.52	17.41	1.47	2.34	0.04	0.59	0.86	6.30	5.25	0.04
SSG-G3	66.04	0.65	17.07	1.15	1.26	0.14	0.46	0.76	6.53	5.79	0.14
SSG-G4	67.32	0.32	16.94	1.31	1.45	0.03	0.29	0.54	5.50	6.20	0.10
SSG-G5	67.70	0.15	16.84	1.52	1.67	0.04	0.17	0.87	5.86	5.34	0.03
SSG-G6	68.64	0.70	14.79	1.70	1.87	0.19	0.50	0.94	6.12	4.26	0.10
SSG-G7	68.86	0.64	15.00	1.72	1.90	0.16	0.41	0.59	6.49	4.14	0.10
SSG-G8	68.91	0.98	14.29	1.92	2.11	0.08	0.51	1.42	4.79	4.83	0.15
SSG-G9	69.27	0.94	14.25	1.76	1.93	0.09	0.66	1.63	4.99	4.35	0.13
SSG-G10	69.44	0.68	13.99	1.68	1.85	0.18	0.50	0.86	6.63	4.08	0.11
SSG-G11	71.31	0.54	14.08	1.30	1.43	0.13	0.30	0.41	5.39	5.05	0.05
SSG-G12	71.50	0.55	13.92	1.25	1.37	0.07	0.36	0.33	5.48	4.92	0.04
SSG-G13	72.90	0.26	14.88	0.90	0.99	0.03	0.18	0.36	4.66	4.81	0.04
SSG-G14	73.64	0.54	12.62	1.73	1.91	0.22	0.31	0.38	4.38	4.23	0.03
SSG-G15	75.75	0.42	11.26	1.55	1.71	0.13	0.21	0.08	2.52	6.34	0.03
SSG-G16	76.19	0.39	11.16	1.36	1.49	0.16	0.18	0.12	0.71	8.21	0.02
SSG-G17	77.14	0.42	12.59	0.86	0.94	0.14	0.26	0.22	3.84	3.57	0.02
b. Diorite Samples											
SSG-D1	55.25	0.08	24.28	1.13	1.02	0.41	0.01	0.74	13.83	4.71	0.02
SSG-D2	57.03	0.27	23.11	0.87	1.40	0.10	0.25	1.21	10.13	5.55	0.04
SSG-D3	58.30	0.11	21.34	0.67	1.07	0.08	0.06	0.68	11.16	6.52	0.02
SSG-D4	58.63	0.72	20.68	1.19	1.91	0.20	0.73	2.26	7.92	5.64	0.12
SSG-D5	58.77	0.94	19.08	1.82	2.91	0.21	1.21	2.86	6.88	5.16	0.25
SSG-D6	58.77	1.53	17.28	2.98	3.28	0.17	1.78	4.06	5.20	4.54	0.42
SSG-D7	58.87	0.16	21.92	1.12	1.80	0.13	0.08	0.67	10.28	4.95	0.01
SSG-D8	60.83	0.84	18.6	1.87	2.06	0.17	0.45	2.10	5.50	7.52	0.05
SSG-D9	61.63	0.58	19.47	1.03	1.64	0.16	0.28	1.25	7.99	5.93	0.04
SSG-D10	61.77	0.83	18.24	1.72	1.92	0.15	0.43	1.95	5.51	7.43	0.07
SSG-D11	61.87	0.52	19.33	1.21	1.92	0.12	0.23	1.45	7.27	6.04	0.04
SSG-D12	62.17	0.46	18.90	1.16	1.86	0.10	0.23	1.79	7.58	5.73	0.03
SSG-D13	63.93	0.46	18.63	1.38	1.52	0.11	0.35	1.23	7.09	5.38	0.12

balance was previously counter-balanced with the wire in the plane and immersed in water. After the suspended mass was determined, each sample was dried slightly with a cotton cloth to remove all drops of water from the surface, and the saturated mass (W) was determined in grams by weighing in air to the nearest ± 0.001 g. The volume (V) of each sample was also determined within 0.001 cm^3. Density related properties are tabulated in Table 2.

Thermal Transport Properties. Thermal properties of volcanic rocks (granite and diorite) are studied as a function of temperature by a transient plane source (TPS) technique. This technique has been used for the simultaneous measurement of thermal conductivity, thermal diffusivity, and heat capacity per unit volume. In this technique,[6,7] a TPS element is used both as a constant heat source and a sensor of temperature. The other advantages of the TPS technique are the simplicity of the technique and applicability to insulators, fluids, metals,[8] and superconductors.[9] This technique has also been successfully used at high temperatures[10] and pressures.[11] The thermal transport properties of both types of samples along with standard deviations are given in Table 3. It is observed that the thermal conductivity and thermal diffusivity for both types of samples decreased while heat capacity per unit volume increased with the rise in temperature.

Results

Table 1 shows the chemical compositions of the samples studied. Table 2a shows that the water absorption for all of the granite samples is below 1%. The density of these samples lies between (2.533 and 2.688) $g \cdot cm^{-3}$. These values were in agreement with the reported data.[1,2] The apparent porosity of these samples varies from 0.074% to 0.993%. This variation of porosity depends on the composition of the sample, since in this class the dominant mineral is SiO_2, which accounts for approximately 65% or above of the material in the samples.

Table 2. Density, ρ, Specific Gravity, a_0, Apparent Porosity, AP, and Water Absorption, W_{AB}, of Samples at 298 K[a]

sample no.	$\rho/g \cdot cm^{-3} \pm 0.002$	$a_0 \pm 0.003$	AP/%	W_{AB}/%
a. Granite Samples				
SSG-G1	2.642	2.646	0.182	0.069
SSG-G2	2.699	2.707	0.311	0.115
SSG-G3	2.731	2.738	0.259	0.095
SSG-G4	2.538	2.559	0.789	0.311
SSG-G5	2.666	2.675	0.334	0.125
SSG-G6	2.629	2.653	0.917	0.348
SSG-G7	2.634	2.674	0.685	0.259
SSG-G8	2.688	2.683	0.104	0.039
SSG-G9	2.682	2.684	0.074	0.027
SSG-G10	2.636	2.659	0.851	0.323
SSG-G11	2.592	2.602	0.399	0.154
SSG-G12	2.533	2.585	0.913	0.361
SSG-G13	2.549	2.575	0.993	0.389
SSG-G14	2.641	2.645	0.156	0.059
SSG-G15	2.630	2.643	0.475	0.181
SSG-G16	2.546	2.552	0.485	0.191
SSG-G17	2.641	2.653	0.432	0.163
b. Diorite Samples				
SSG-D1	2.615	2.624	0.335	0.128
SSG-D2	2.594	2.599	0.167	0.064
SSG-D3	2.599	2.603	0.162	0.062
SSG-D4	2.595	2.608	0.490	0.189
SSG-D5	2.708	2.718	0.353	0.131
SSG-D6	2.827	2.838	0.397	0.140
SSG-D7	2.583	2.589	0.234	0.090
SSG-D8	2.411	2.723	0.469	0.173
SSG-D9	2.622	2.627	0.206	0.078
SSG-D10	2.612	2.621	0.347	0.133
SSG-D11	2.613	2.624	0.424	0.162
SSG-D12	2.544	2.554	0.413	0.162
SSG-D13	2.697	2.706	0.358	0.132

[a] Following ASTM.[177408n] page: $\rho = D/V$ ($g \cdot cm^{-3}$); $a_0 = D/D - S$; AP $= W - D/V$ (This is based on the fact that 1 cm^3 of water weighs 1 g. This is true with about 3 parts in 1000 for water at room temperature.); and $W_{AB} = W - D/D$; where D = dry mass, S = suspended mass, W = saturated mass, and V = volume.

Table 3. Thermal Conductivity, λ, Thermal Diffusivity, κ, and Heat Capacity per Unit Volume, ρC_p, of Samples from 253 K to 333 K[a]

	λ/W·m^{-1}·K^{-1}		κ/mm^2·s^{-1}		ρC_p/MJ·m^{-3}·K^{-1}			λ/W·m^{-1}·K^{-1}		κ/mm^2·s^{-1}		ρC_p/MJ·m^{-3}·K^{-1}	
sample no.	mean	SD	mean	SD	mean	SD	sample no.	mean	SD	mean	SD	mean	SD
a. Granite Samples													
$T = 253$ K													
SSG-G1	3.198	0.167	1.267	0.150	2.537	0.166	SSG-G10	3.241	0.105	1.363	0.151	2.390	0.191
SSG-G2	3.215	0.101	1.203	0.104	2.679	0.148	SSG-G11	4.417	0.268	1.776	0.142	2.498	0.059
SSG-G3	3.676	0.167	1.505	0.105	2.449	0.056	SSG-G12	4.311	0.132	1.571	0.151	2.755	0.181
SSG-G4	3.576	0.141	1.310	0.094	2.710	0.096	SSG-G13	3.597	0.124	1.598	0.150	2.259	0.133
SSG-G5	3.029	0.106	1.279	0.145	2.326	0.110	SSG-G14	4.650	0.157	1.950	0.093	2.385	0.037
SSG-G6	3.195	0.150	1.316	0.126	2.463	0.096	SSG-G15	4.573	0.156	1.801	0.150	2.545	0.126
SSG-G7	3.226	0.119	1.363	0.151	2.332	0.165	SSG-G16	4.553	0.187	1.737	0.102	2.632	0.034
SSG-G8	3.124	0.090	1.619	0.083	1.904	0.065	SSG-G17	4.627	0.103	1.819	0.084	2.547	0.027
SSG-G9	3.454	0.100	1.352	0.050	2.555	0.020							
$T = 301$ K													
SSG-G1	1.627	0.064	0.783	0.101	2.077	0.199	SSG-G10	1.918	0.067	1.011	0.071	1.899	0.067
SSG-G2	2.413	0.149	0.909	0.1075	2.66	0.189	SSG-G11	2.603	0.143	1.213	0.097	2.148	0.060
SSG-G3	1.810	0.097	0.814	0.092	2.232	0.126	SSG-G12	2.251	0.094	1.123	0.085	2.276	0.081
SSG-G4	1.643	0.089	0.893	0.151	1.862	0.212	SSG-G13	1.637	0.101	0.739	0.104	2.23	0.180
SSG-G5	1.869	0.149	1.124	0.087	1.662	0.019	SSG-G14	2.920	0.085	1.205	0.114	2.432	0.163
SSG-G6	1.743	0.108	0.881	0.126	1.994	0.167	SSG-G15	2.762	0.102	1.024	0.070	2.711	0.137
SSG-G7	1.907	0.101	0.894	0.135	2.155	0.231	SSG-G16	2.789	0.161	1.193	0.111	2.342	0.087
SSG-G8	2.493	0.135	1.028	0.064	2.424	0.055	SSG-G17	2.677	0.146	0.879	0.172	3.101	0.448
SSG-G9	1.738	0.083	0.774	0.042	2.275	0.165							
$T = 311$ K													
SSG-G1	1.487	0.131	0.729	0.101	2.048	0.105	SSG-G10	1.908	0.083	0.772	0.148	2.523	0.400
SSG-G2	2.324	0.081	0.780	0.101	3.004	0.291	SSG-G11	2.564	0.120	1.075	0.117	2.395	0.150
SSG-G3	1.626	0.080	0.679	0.118	2.425	0.286	SSG-G12	2.497	0.104	1.042	0.154	2.381	0.201
SSG-G4	1.597	0.096	0.896	0.154	1.805	0.213	SSG-G13	1.583	0.135	0.730	0.098	2.178	0.128
SSG-G5	1.596	0.102	0.782	0.173	2.086	0.320	SSG-G14	2.647	0.218	1.086	0.149	2.450	0.178
SSG-G6	1.614	0.091	0.853	0.190	1.939	0.324	SSG-G15	2.705	0.166	1.013	0.111	2.680	0.133
SSG-G7	1.714	0.114	0.772	0.148	2.261	0.323	SSG-G16	2.371	0.152	1.003	0.044	2.654	0.068
SSG-G8	2.464	0.151	1.013	0.087	2.434	0.065	SSG-G17	2.563	0.149	0.773	0.090	3.333	0.246
SSG-G9	1.673	0.139	0.489	0.170	3.676	1.141							
$T = 318$ K													
SSG-G1	1.438	0.106	0.667	0.067	2.158	0.055	SSG-G10	1.810	0.036	0.913	0.086	1.991	0.143
SSG-G2	2.333	0.086	0.785	0.056	2.977	0.105	SSG-G11	2.436	0.065	1.276	0.518	2.021	0.149
SSG-G3	1.596	0.109	0.680	0.042	2.348	0.020	SSG-G12	2.352	0.070	0.833	0.066	2.871	0.116
SSG-G4	1.505	0.073	0.841	0.062	1.791	0.044	SSG-G13	1.509	0.088	0.645	0.061	2.343	0.092
SSG-G5	1.726	0.109	0.800	0.045	2.158	0.051	SSG-G14	2.567	0.087	1.055	0.082	2.533	0.114
SSG-G6	1.482	0.070	0.851	0.034	1.743	0.011	SSG-G15	2.507	0.065	0.924	0.086	2.723	0.181
SSG-G7	1.613	0.071	0.718	0.082	2.256	0.154	SSG-G16	2.410	0.052	1.125	0.071	2.206	0.148
SSG-G8	2.417	0.087	0.942	0.070	2.569	0.096	SSG-G17	2.490	0.106	0.744	0.033	3.287	0.160
SSG-G9	1.757	0.089	0.515	0.062	3.433	0.152							
$T = 323$ K													
SSG-G1	1.319	0.052	0.572	0.046	2.312	0.105	SSG-G10	1.620	0.071	0.767	0.092	2.125	0.159
SSG-G2	1.988	0.053	0.605	0.055	3.299	0.206	SSG-G11	2.091	0.073	0.831	0.065	2.522	0.109
SSG-G3	1.504	0.062	0.619	0.080	2.447	0.215	SSG-G12	2.113	0.062	0.695	0.086	3.121	0.204
SSG-G4	1.432	0.0624	0.737	0.107	1.963	0.213	SSG-G13	1.396	0.087	0.592	0.058	2.364	0.126
SSG-G5	1.507	0.089	0.744	0.069	2.028	0.067	SSG-G14	2.611	0.058	1.010	0.079	2.593	0.143
SSG-G6	1.420	0.093	0.730	0.087	1.953	0.110	SSG-G15	2.492	0.066	0.924	0.109	2.714	0.236
SSG-G7	1.545	0.090	0.625	0.084	2.489	0.191	SSG-G16	2.501	0.043	0.914	0.044	2.656	0.096
SSG-G8	2.418	0.081	0.947	0.088	2.561	0.147	SSG-G17	2.486	0.094	0.603	0.064	4.141	0.280
SSG-G9	1.611	0.066	0.422	0.089	3.791	0.146							
$T = 333$ K													
SSG-G1	1.215	0.101	0.509	0.045	2.463	0.025	SSG-G10	1.598	0.038	0.601	0.009	2.656	0.025
SSG-G2	1.905	0.064	0.488	0.059	3.929	0.375	SSG-G11	1.523	0.061	0.625	0.096	2.469	0.311
SSG-G3	1.407	0.037	0.608	0.038	2.314	0.094	SSG-G12	1.580	0.080	0.533	0.096	3.019	0.406
SSG-G4	1.256	0.109	0.534	0.055	2.353	0.083	SSG-G13	1.293	0.046	0.442	0.112	2.925	0.712
SSG-G5	1.421	0.062	0.593	0.065	2.405	0.158	SSG-G14	2.621	0.056	0.711	0.038	3.687	0.121
SSG-G6	1.407	0.068	0.618	0.049	2.278	0.073	SSG-G15	2.417	0.050	0.801	0.062	3.023	0.168
SSG-G7	1.482	0.059	0.589	0.049	2.522	0.111	SSG-G16	2.586	0.086	0.706	0.074	3.662	0.330
SSG-G8	1.624	0.042	0.450	0.074	3.662	0.525	SSG-G17	1.859	0.093	0.569	0.046	3.269	0.119
SSG-G9	1.626	0.056	0.461	0.036	3.536	0.175							
$T = 253$ K													
SSG-D1	3.151	0.154	1.379	0.137	2.260	0.195	SSG-D8	3.612	0.166	1.953	0.124	1.850	0.036
SSG-D2	3.237	0.077	1.849	0.069	1.752	0.067	SSG-D9	3.396	0.0905	1.854	0.065	1.832	0.008
SSG-D3	3.532	0.129	2.481	0.150	1.427	0.107	SSG-D10	3.502	0.186	1.994	0.148	1.777	0.013
SSG-D4	3.039	0.254	1.842	0.120	1.603	0.142	SSG-D11	3.473	0.151	1.845	0.132	1.858	0.039
SSG-D5	3.182	0.227	2.500	0.138	1.261	0.025	SSG-D12	3.888	0.117	1.891	0.105	2.053	0.041
SSG-D6	3.179	0.123	1.754	0.137	1.887	0.088	SSG-D13	3.619	0.165	2.121	0.195	1.713	0.120
SSG-D7	3.066	0.152	1.871	0.131	1.662	0.059							

Table 3 (Continued)

	λ/W·m^{-1}·K^{-1}		κ/mm^2·s^{-1}		ρC_p/MJ·m^{-3}·K^{-1}			λ/W·m^{-1}·K^{-1}		κ/mm^2·s^{-1}		ρC_p/MJ·m^{-3}·K^{-1}	
sample no.	mean	SD	mean	SD	mean	SD	sample no.	mean	SD	mean	SD	mean	SD
b. Diorite Samples													
T = 301 K													
SSG-D1	1.512	0.108	0.758	0.149	1.963	0.156	SSG-D8	1.618	0.140	0.821	0.156	1.934	0.119
SSG-D2	1.488	0.153	0.856	0.235	1.782	0.18	SSG-D9	1.677	0.140	1.010	0.101	1.0.650	0.197
SSG-D3	1.525	0.189	0.857	0.135	1.743	0.027	SSG-D10	1.654	0.192	0.883	0.146	1.827	0.199
SSG-D4	1.462	0.095	0.665	0.105	2.147	0.011	SSG-D11	1.645	0.212	0.811	0.170	2.274	0.155
SSG-D5	1.422	0.138	0.895	0.147	1.559	0.069	SSG-D12	1.867	0.212	0.877	0.134	2.105	0.177
SSG-D6	1.590	0.154	0.735	0.102	2.157	0.140	SSG-D13	1.688	0.130	0.879	0.161	1.901	0.182
SSG-D7	1.529	0.198	0.767	0.134	1.911	0.164							
T = 311 K													
SSG-D1	1.407	0.158	0.696	0.145	2.033	0.194	SSG-D8	1.552	0.108	0.815	0.159	1.948	0.133
SSG-D2	1.539	0.117	0.848	0.165	1.956	0.168	SSG-D9	1.626	0.150	0.928	0.071	1.762	0.089
SSG-D3	1.441	0.085	0.802	0.146	1.840	0.123	SSG-D10	1.612	0.155	0.857	0.110	1.960	0.067
SSG-D4	1.375	0.167	0.646	0.097	2.223	0.076	SSG-D11	1.636	0.196	0.802	0.152	2.051	0.169
SSG-D5	1.238	0.088	0.820	0.091	1.518	0.087	SSG-D12	1.737	0.099	0.851	0.071	2.076	0.099
SSG-D6	1.437	0.120	0.745	0.092	1.998	0.075	SSG-D13	1.654	0.111	0.893	0.115	1.911	0.131
SSG-D7	1.445	0.187	0.745	0.100	1.941	0.010							
T = 318 K													
SSG-D1	1.447	0.072	0.692	0.176	2.071	0.072	SSG-D8	1.409	0.105	0.527	0.162	2.652	0.131
SSG-D2	1.483	0.124	0.890	0.122	1.574	0.153	SSG-D9	1.528	0.089	0.904	0.135	1.637	0.106
SSG-D3	1.306	0.100	0.704	0.102	1.840	0.181	SSG-D10	1.486	0.135	0.777	0.052	1.937	0.159
SSG-D4	1.331	0.100	0.636	0.134	2.121	0.121	SSG-D11	1.534	0.084	0.679	0.168	2.231	0.116
SSG-D5	1.085	0.118	0.505	0.083	2.010	0.074	SSG-D12	1.613	0.099	0.743	0.242	2.111	0.192
SSG-D6	1.312	0.101	0.643	0.098	2.017	0.106	SSG-D13	1.583	0.130	0.796	0.166	1.874	0.163
SSG-D7	1.284	0.107	0.577	0.134	2.271	0.076							
T = 323 K													
SSG-D1	1.341	0.066	0.495	0.132	2.332	0.108	SSG-D8	1.331	0.106	0.641	0.162	2.038	0.164
SSG-D2	1.429	0.076	0.903	0.101	1.588	0.102	SSG-D9	1.409	0.098	0.564	0.127	2.464	0.153
SSG-D3	1.301	0.123	0.644	0.081	2.025	0.090	SSG-D10	1.442	0.058	0.667	0.130	2.107	0.156
SSG-D4	1.216	0.035	0.511	0.095	2.321	0.164	SSG-D11	1.381	0.160	0.622	0.104	2.232	0.116
SSG-D5	1.022	0.059	0.502	0.143	2.024	0.192	SSG-D12	1.509	0.109	0.699	0.151	2.153	0.154
SSG-D6	1.315	0.102	0.607	0.102	2.185	0.192	SSG-D13	1.482	0.163	0.677	0.129	2.111	0.174
SSG-D7	1.296	0.106	0.492	0.164	2.604	0.198							
T = 333 K													
SSG-D1	1.280	0.144	0.589	0.123	2.197	0.111	SSG-D8	1.214	0.099	0.431	0.183	2.843	0.163
SSG-D2	1.311	0.100	0.900	0.132	1.564	0.101	SSG-D9	1.292	0.071	0.576	0.170	2.197	0.152
SSG-D3	1.220	0.073	0.567	0.152	2.425	0.107	SSG-D10	1.324	0.141	0.596	0.150	2.283	0.164
SSG-D4	0.976	0.133	0.406	0.053	2.441	0.073	SSG-D11	1.410	0.107	0.515	0.136	2.741	0.184
SSG-D5	0.994	0.051	0.430	0.119	2.381	0.147	SSG-D12	1.478	0.129	0.520	0.100	2.842	0.189
SSG-D6	1.241	0.097	0.403	0.136	3.016	0.122	SSG-D13	1.419	0.140	0.417	0.106	3.378	0.131
SSG-D7	1.217	0.128	0.507	0.175	2.431	0.110							

[a] All the experiments were repeated five times under identical conditions. The mean and standard deviation (SD).

The specific gravity of all these samples lies between 2.552 and 2.728. This is explained by the fact that the specific gravity of slightly porous rocks depends on the extent of their mineral composition. In these samples SiO_2 is over 65% and the specific gravity of SiO_2 is 2.65. Also, the specific gravity of igneous rocks ranges from 2.17 to 3.74.[1]

Table 2b again shows all the parameters, like water absorption, bulk density, specific gravity, and apparent porosity, of diorite samples. All depending factors vary slightly due to a difference in the chemical composition of SiO_2. The density of these samples lies between (2.411 and 2.827) g·cm^{-3}. These values are in agreement with the reported data.[1,2] The apparent porosity of these samples varies from 0.162% to 0.490%. The specific gravity of all these samples lies between 2.554 and 2.838.

The thermal conductivity of rocks depends on the ability of their constituent minerals to conduct heat. All of the samples are multimineral with apparent porosity ranging from 0.074% to 0.993%, and the thermal conductivities ranged from 1.422 W·m^{-1}·K^{-1} to 2.920 W·m^{-1}·K^{-1} at 301 K for both types of rocks. The decrease in the thermal conductivity with increasing porosity within experimental errors is in complete agreement with the reported results of Woodside and Messmer,[12] Sugawara and Yoshizawa,[13] and Shabbir et al.[14]

In summary, the density related properties of the samples have been measured by using the (ASTM) standards.[5] The TPS technique is used for the determination of thermal transport properties of volcanic rocks under a wide variety of test conditions. All the experiments were performed at atmospheric pressure and with air as the fluid in the pore spaces.

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