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Distribution of the pore sizes in the continental crust: inferences from experimental data about permeability

V. M. Vitovtova[1], V. M. Shmonov[1], A. V. Zharikov[2]
[1] Institute of Experimental Mineralogy RAS, Chernogolovka
[2] Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry RAS, Moscow
vitovt@iem.ac.ru; shmonov@iem.ac.ru

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Structural characteristics of rocks define dynamics of movement transcrust fluids, and also the contribution of surface energy to thermodynamic properties nanofluid. It defines necessity of the information about distribution of porosity, permeability, a specific surface and the sizes of a pore of rocks in an earth crust. By us are experimentally studied permeability of rocks at high pressures and temperatures. Data on permeability of samples granites, granodiorites, diorites, serpentinites, gneisses, amphibolites, marble, limestones and sandstones are presented in our monography [*Shmonov et al.,* 2002,a]. On the basis of our experimental data we have constructed a trend of permeability of continental earth crust [*Shmonov et al.,* 2002,b; *Shmonov et al.,* 2003]. Paleopermeability established on an isotope exchange [*Ingebritsen and Manning,* 1999] or to flow in metasomatic and metamorphic processes [*Manning and Ingebritsen,* 1999] it will well be coordinated with our trend. Our experimental data about permeability of rocks have allowed to receive representation about distribution of a pore in the sizes within earth crust.

Permeability measurements are executed by a steady-state method gas (argon) of a filtration [*Shmonov et al.,* 2002,a]. At a gas filtration through porous media its speed depends on a parity of mean free path length of molecules of gas and the pore size. Klinkenberg [*Klinkenberg*, 1941] has found that

$$k_g = k_w (1 + b/p), \qquad (1)$$

where k_g – gas permeability, k_w – water permeability, p – average pressure of filtered gas, and b – a constant for given pair «gas – porous media». Thus the method allows to define on a gas stream simultaneously a) values of permeability of the sample for the condensed fluid, k_w, b) permeability of the sample for gas, k_g, at various pressure of a filtration and c) constant, b, characterizing structure of pore spaces of rocks. The equation (1) transformed to a kind $k_g = k_w + B/p$ gives value of parameter of Klinkenberg in the form of $B = k_w b$ allowing to calculate
effective radius of capillaries of the cylindrical form on the equation from [*Scott and Dullien,*1962] in a kind

$$r = 4/3\ \pi\tilde{\upsilon}\mu\ (k_w/B) \qquad (2)$$

where $\tilde{\upsilon}$ – average thermal speed of movement of molecules, μ – dynamic viscosity of argon, k_w – permeability, and B – parameter of Klinkenberg. As a result of processing of a primary material values of parameter of Klinkenberg, B, for various temperatures have been defined. Their values depending on permeability are presented on fig. 1. On the equation (2) effective radiuses of a pore for model of rocks with a series of parallel cylindrical capillaries of identical radius have been calculated. Results of calculations are resulted in tabl. 1.

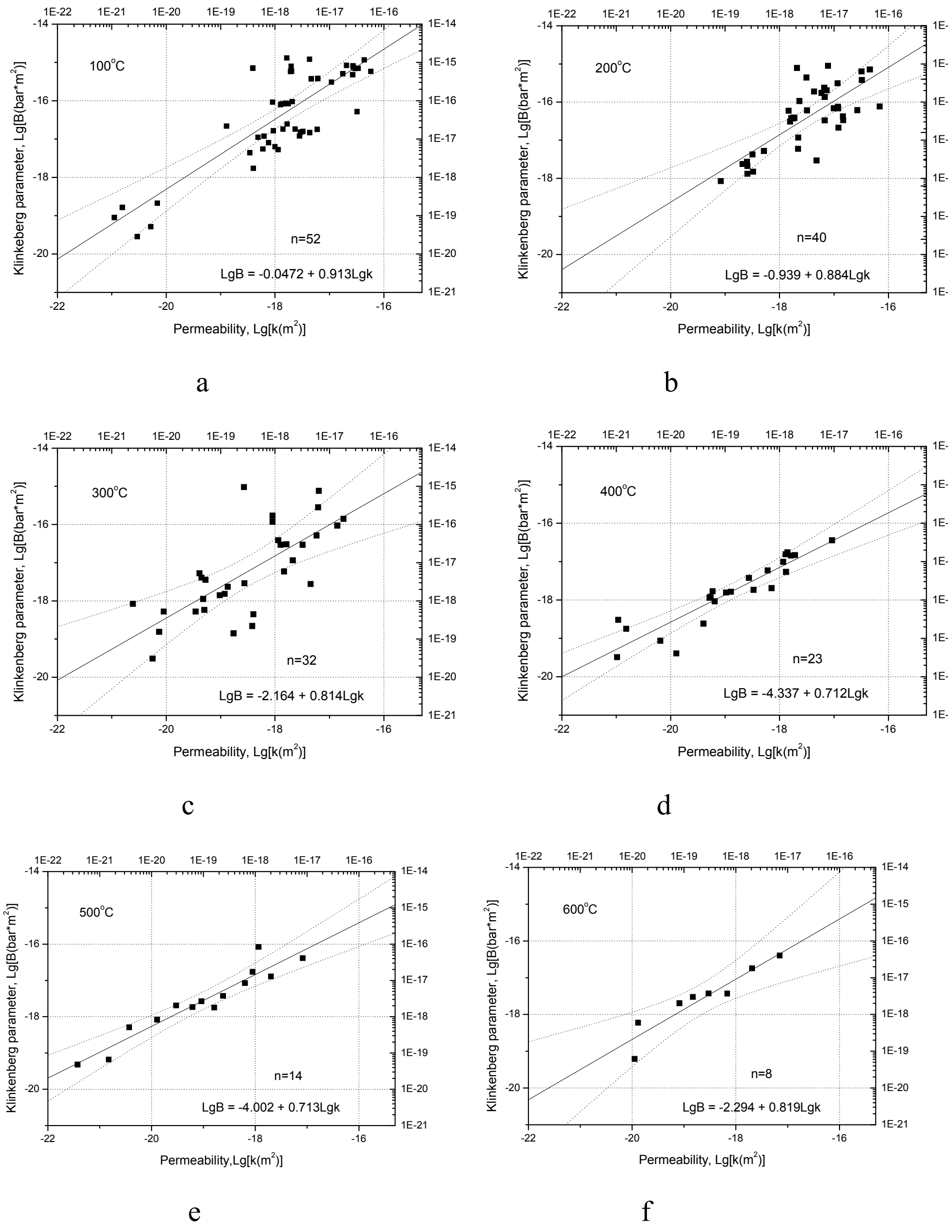


Fig.1 Dependence of parameter of Klinkenberg on permeability at various temperatures. On each schedule a) n designates quantity of experimental points, b) the equation of linear regress for a continuous line is resulted and c) the dotted line gives the top and bottom borders of 99 % of a confidential interval.

Table 1. Values of effective pore radius, r (nanometer), in rocks with various permeability, k, at temperatures 100–600°C.

k, m^2	100°C	200°C	300°C	400°C	500°C	600°C
1×10^{-16}	38	130	205	854	482	543
1×10^{-17}	31	100	133	440	249	358
1×10^{-18}	25	76	87	227	129	236
1×10^{-19}	21	58	57	117	66	156
1×10^{-20}	17	45	37	60	34	103
1×10^{-21}	14	34	24	31	18	68
1×10^{-22}	11	26	16	16	9	45

Permeability, k, is defined by structure of a porous material. Dimension of permeability – a square of length, [L^2] that is «a rough measure root-mean-square pore diameter» [*Collins*, 1964]. As one would expect on an isotherm to permeability reduction there corresponds reduction of radius of a pores. Among constant values of permeability to higher value temperatures there correspond the big sizes of a pore. But at the same value of permeability «openancy» [*Dmitriev*, 1995] should remain a constant. In this case it is possible to believe that the same permeability at higher temperatures is provided with a pores more the size, but their quantity should be less.

In the conditions of earth crust permeability decreases from a surface of the earth to border M-discontinuity under the power law [*Shmonov et al.,* 2002b] (fig. 2). Our experimental data about permeability of rocks in works [*Vitovtova and Shmonov*, 1982; *Zharikov et al*., 1990; *Shmonov*, 2000; *Zharikov et al*., 2003] are presented for multiple values of temperatures: 100, 200, 300, 400, 500 and 600°C. Therefore at trend construction at first on equation H = T/gradT, where H - depth in km, it has been defined to what depths in earth crust corresponds aforementioned a number of multiple temperatures for gradients 9, 15 and 26°C/km. At gradT=9oC/km experimental data can be used for depths 11.1, 22.2, 33.3 and 44.4

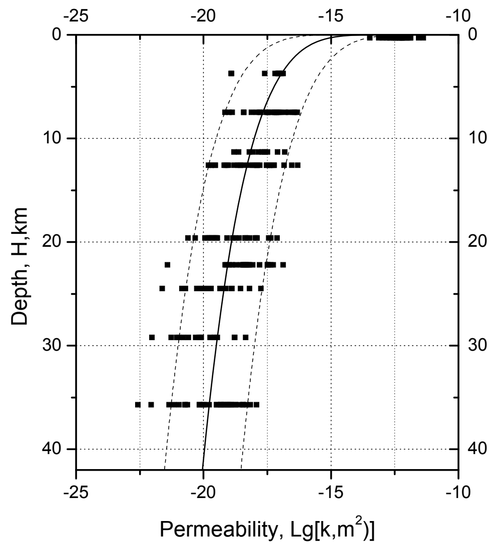


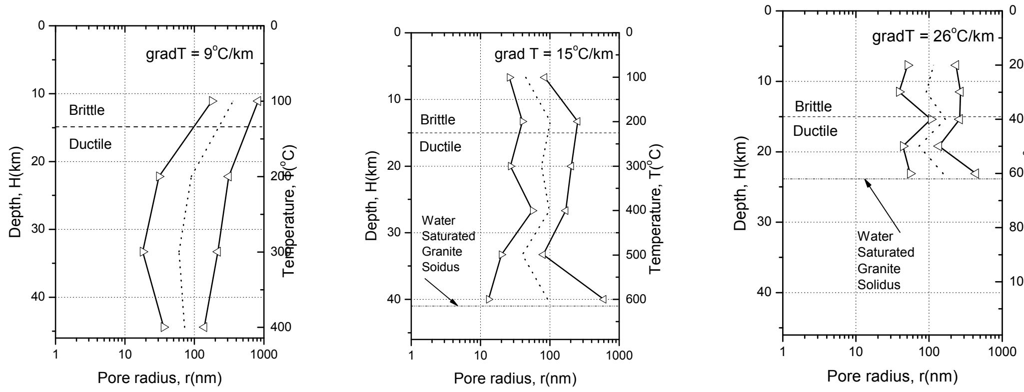
Fig.2. A permeability trend of continental earth crust constructed on our experimental data.

km; at gradT=15°C/km - a number of depths will be values 6.7, 13.3, 20.0, 26.7, 33.3, and 40.0 km and for gradT=26°C/км - 3.8, 7.7, 11.5, 15.4, 19.2 and 23.1 km.

Earlier by us [*Shmonov et al.,* 2002,b] it has been shown that dependence k=f (H) can be presented the sedate equation log k = a + bH^c. For k-H at low heat flow the equation looks like a curve log k =-12.56 – 2.703H0.2682; at average heat flow log k =-12.55 – 3.124H0.2447 and log k =-12.45 – 4.330H0.1360 - at high heat flow. On these equations for the above-stated depths values permeability have been calculated.

At a following stage according to the equations on schedules fig. 1 for values of permeability parameters of Klinkenberg, B. And on the equation (2) radiuses of a pore have been defined.

The result of data processing is shown on fig. 3 a, b and c. On schedules are shown limiting values of radiuses of a pore calculated according to a range of 99 % of a confidential interval of values of parameter of Klinkenberg and permeability (fig. 1). At low heat flow reduction of radius of a pore with depth from 179÷827 nanometer at level of 11.1 km to 36÷139 nanometer at level of 44.4 km is observed. At average and high heat flow there is no obviously expressed dependence of the sizes of a pore on depth. It is probably connected by that with increase in heat flow decompaction more plastic rocks interferes compressing pressure. Within an error of calculations on experimental data about permeability average values of radiuses of a pore is about 100 nanometers (~ 0.1 microns) though the disorder on occasion can reach one and a half decimal order.



a b c

Fig.3 Trend of effective radius of a time of breeds for a cut continental crust at various thermogradients.

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