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Recent evolution in experimental thermal petrophysics

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Achievements in development of new methods and instruments for measurements of rock's thermal properties in 1980-2000th have provided a sharp increase in quality of experimental data on thermal conductivity (TC) and thermal diffusivity (TD) from experiments on rock samples. Development of optical scanning technology (theoretical background and instruments) has allowed one to begin numerous high-precision non-destructive non-contact measurements of thermal properties directly on full cores, standard core plugs and single crystals of minerals with determination of TC/TD tensor components and recording thermal property variations along every core studied. The instruments for simultaneous determination of TC and TD at formation conditions accounting for high temperature and 3-component pressure (pore, confining axial and lateral pressures) have been developed. Methods have been developed for thermal conductivity and thermal diffusivity measurements on core cuttings. The direct metrological comparisons of equipment (on representative standards and core collections) from more than 30 laboratories with participation of four National Standard Bureaus in 1982-2007 have provided estimation of a real quality of the measurement data and discovered serious problems in measurements of thermal properties often (especially for high porous sedimentary rocks). New theoretical models of effective thermal properties have been developed and previous models have been improved.

The new methods and equipment have been used for non-destructive TC/TD measurements on more than 200 rock forming minerals (single crystals and aggregates) to correct and extend the data on thermal properties of minerals and their anisotropy. The new technologies have provided the measurements on cores from wells with core sampling interval of 1-3 m. Our results on more than 90 000 cores from 15 superdeep and deep scientific wells in Russia, Germany, Mexico, USA (1.7... 12.2 km) and wells in

ore deposits, oil-gas fields and different geological structures (1982-2007) have shown that essential thermal anisotropy and significant TC variations even within every core and few meter depth intervals along wells (often by $\pm$50%) are typical. Numerous measurements of TC on cores have provided information on vertical distribution of heat flow density (HFD) values along the wells with HFD calculation intervals of 10-20 m. It helped to discover significant vertical variations and regular trends in HFD values along the wells (up to 100-200%), that changes essentially the information on terrestrial HFD values for corresponding crustal blocks. Influence of *in-situ* conditions has been taken into account due to TC and TD measurements on cores at elevated pressure and temperature.

Vast new information about correlations between thermal and other physical properties (porosity, permeability, sonic velocity, electric resistivity) have been obtained from the measurements on core plugs. Approaches have been developed to characterize pore space geometry on thermal conductivity variations at fluid saturation of rock samples. The high precision measurements of TC and TD tensor components on more than 4000 sedimentary rock samples (consequently dry and fluid-saturated) have allowed to develop the representative database on sedimentary rock's thermal properties and their correlations with other physical properties. Theoretical geometric mean model, popular for TC prediction in petrophysics, has been improved due to introduction of correction factors found experimentally for different types of sedimentary rocks.

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