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Advanced approaches to determination of rock thermal properties for estimation of vertical variations in heat flow

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Estimation of vertical variations in a conductive component of heat flow and their interpretation requires detailed information on spatial variations in rock thermal conductivity, thermal anisotropy and thermal diffusivity/volumetric heat capacity. The recently developed approaches and corresponding equipment provide the experimental data for the problem solution using (1) continuous non-destructive thermal core logging, (2) numerous measurements on hard synthetic samples with rock cuttings, (3) transformation of standard well logging data in rock thermal conductivity, and (4) experimental determination of the thermal properties of rock matrix with following application of mixing lows for estimation of the formation thermal properties. In case (1) the fast continuous thermal core logging on all core samples provides the detailed data on distribution of the rock thermal properties along the wells drilled with core recovery. The following measurements of the thermal properties at formation conditions are performed on the core sample collections for the principal rock types along the well which are well-grounded selected from the continuous thermal property profiles accounting for rock heterogeneity, anisotropy and other geological peculiarities of the formation. The dependencies of the rock thermal properties on the formation conditions established from corresponding experiments allow us to correct the continuous profiles of the thermal properties along the well for corresponding temperature and pressure. For case (2) the special technique and equipment was developed to perform the numerous measurements of the rock thermal conductivity and thermal diffusivity/volumetric heat capacity on rock cuttings. The rock cuttings are mixed with a special wax and form hard synthetic samples under pressure. The effective thermal properties of the numerous synthetic samples are measured with the special optical scanning instrument. The rock thermal properties are determined from the measurement data and inverse problem solution using special theoretical models of effective thermal properties of two-phase medium. In case (3) the correlations and analytical dependencies between thermal conductivity and other properties of sedimentary rocks (porosity, sonic velocities, acoustic anisotropy, density, natural radioactivity, total organic carbon) which were established in 2014-2017 from our experimental investigations of more than 23 000 cores from 35 wells drilled in 24 conventional and unconventional hydrocarbon fields are being used. Approach (4) to the sedimentary rock thermal property determination consists of determination of rock matrix thermal properties from integration of thermal core analysis and standard petrophysical logging data. The rock matrix thermal properties are used with the Lichtenecker-Asaad's theoretical model to determine the thermal conductivity of porous rocks using the rock porosity values taken from the standard well logging data. A similar approach is being used when representative collections of core plugs with various porosity values are studied with the laser version of the optical scanner to establish regression equations of "thermal conductivities vs porosity" for different rock types with following determination of rock matrix properties from the regression equations. The information on the formation thermal properties obtained with the approaches described is necessary also to be integrated into the simulators used for interpretation of the experimental data on vertical variations in heat flow.