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Processing of thermal parameters for the assessment of geothermal potential of sedimentary basins

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The growing interest on renewable energy sources is stimulating new efforts aimed at the assessment of geothermal potential in several countries, and new developments are expected in the near future. In this framework, a basic step forward is to focus geothermal investigations on geological environments which so far have been relatively neglected. Some intracontinental sedimentary basins could reveal important low enthalpy resources. The evaluation of the geothermal potential in such geological contexts involves the synergic use of geophysical and hydrogeological methodologies.

In sedimentary basins a large amount of thermal and hydraulic data is generally available from petroleum wells. Unfortunately, borehole temperature data are often affected by a number of perturbations which make very difficult determination of the true geothermal gradient. In this paper we addressed the importance of the acquisition of thermal parameters (temperature, geothermal gradient, thermal properties of the rock) and the technical processing which is necessary to obtain reliable geothermal characterizations. In particular, techniques for corrections of bottom-hole temperature (BHT) data were reviewed. The objective was to create a working formula usable for computing the undisturbed formation temperature for specific sedimentary basins. As test areas, we analysed the sedimentary basins of northern Italy.

Two classical techniques for processing temperature data from oil wells are customarily used: (i) the method by Horner, that requires two or more measurements of bottom-hole temperatures carried out at the same depth but at different shut-in times t_e and (ii) the technique by Cooper and Jones, in which several physical parameters of the mud and formation need to be known. We applied both methods to data from a number of petroleum explorative wells located in two areas of the Po Plain (Apenninic buried arc and South Piedmont Basin - Pedealpine homocline).

From a set of about 40 wells having two or more temperature measurements at a single depth we selected 18 wells with BHTs recorded at t_e larger than 3.5 hours; the time span between two measurements varies from 1 to 21 hours. In total 71 couples of BHT-t_e data are available; the mud circulation time is lower or equal to 4.5 hours.

Corrections require the knowledge of thermal parameters. We attempted to remedy the existing deficiency of thermal conductivity data of sedimentary rocks with a series of laboratory measurements on several core samples recovered from wells. Moreover, we developed a model for calculating the thermal conductivity of the rock matrix as a function of mineral composition based on the fabric theory and experimental thermal conductivity data. As the conductivity of clay minerals, which are present in most formations, is poorly defined, we applied an inverse approach, in which mineral conductivities are calculated one by one, on condition that the sample bulk thermal conductivity, the porosity and the amount of each mineral phase are known.

Analyses show that formation equilibrium temperatures computed with the Horner method are consistent with those obtained by means of the Cooper and Jones method, which gives on average temperatures lower than 2 °C only for shut-in times < 10 hours. The corrected temperatures compared with temperatures measured during drill-stem tests show that the proposed corrections are rather accurate. The two data sets give coherent results and the inferred average geothermal gradient is 21.5 mK/m in the Apenninic buried arc area and 25.2 mK/m in the South Piedmont Basin-Pedealpine homocline area.

The problem with the Horner method is that it implicitly assumes no physical property contrast between circulating mud and formation, and that the borehole is infinitesimally thin, i.e. it acts as a line source. This has been criticized by many authors. The accuracy of the predicted temperatures depends on the reliability and accuracy of BHT, shut-in time and mud circulation time, and the error increases with the decrease of the shut-in time. On the other hand, the method by Cooper and Jones provides more reliable results, but requires physical parameters that are not always available.

The Horner slope data as a function of depth were then fitted with a second order polynomial and depth-time correction equations were calibrated for the two test areas. The obtained depth-time correction equations allow for each area the correction for mud circulation when only one couple BHT-t_e is available. If the value of the time before circulation ceased is not included on the well log header, it is possible to formulate an empirical equation obtained from time data as a function of depth applicable to the whole investigated area.