Method for improving the spatial resolution of resistivity logging

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The main aim of resistivity logging is to determine geometric and electrical parameters of a model of borehole environment. Subsequent problems of geophysical investigations of well, such as determinations of fluid saturation, daily flow of fluid production and others will be solved the more precisely, the more precisely these parameter are determined. Sounds in the complex differ each from other as to the depth of investigation and the vertical resolution (along the axe of well). Naturally, the vertical resolving power is worse for sounds with larger depth of investigation. In this connection, the necessity to build sounding system for logging with the maximum high vertical resolution of all sounds including the most subsurface ones.

A creation of such equipment based on traditional principles is complicated by the necessity to use frequency, spatial or time separation, what complicates considerably the design (a creation of effective equipment with more than two sounds was found practically impossible). A creation of such equipment for induction logging are also complicated because of fundamental design limitations.

A factorization is believed an affective approach to create sounding system for logging with the maximum high vertical resolution of all sounds including the most subsurface ones. The factorization permits to solve separately the inverse problem along the axe of well and along a normal to it. It means that in each point of sound's position we can believe that the bed has infinite thickness (is free of shoulder effect). In this case, the conductivity values will change only along the normal to the axe of well.

The following methodical approach was used for induction logging: to determine the resistivity according to the apparent resistivity measured within the frame of the linear Doll theory using a solution of the first kind Fredholm equation of convolution type. The present method was tested on model material from various complexes (4IK, 7IK, AIT Schlumberger). The example of application of such method to data of 4IK equipment is shown in Fig. 1 (sounds: I0.5; I0.85; I1.25; I2.05. The numbers corresponds to the length of each sounds). It is evident that using the proposed approach permits to factorize the problem with high degree of accuracy. In the work, it is also shown that after such factorization the vertical resolution of each sound is limited only by the error of measurement and the value of recording step along the axe of well.

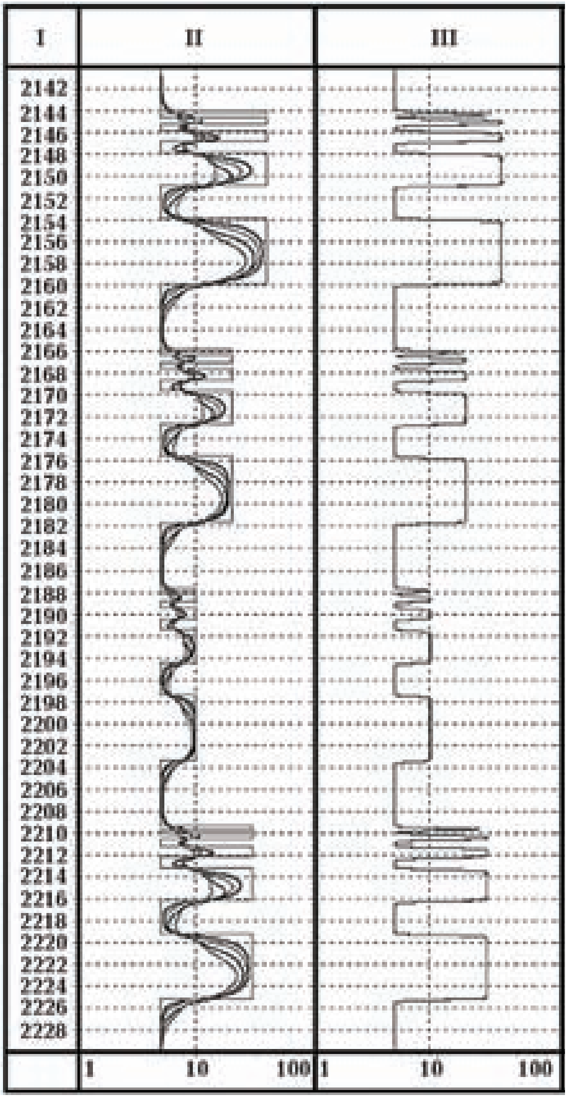

Fig. 1. The example of factorization of 2D inverse problem of inductive logging: I — depth, II — measured apparent conductivity and specified conductivity of beds, III — reconstructed conductivity.

The assumption on absence of current interaction in medium also is a restriction of this method. This restriction is not critical since the linear Doll approach describes many cases being topical for practice with high degree of accuracy. Besides, a lot of authors linearize the problem using a correction for skin effect. In the course of investigation, it was shown that use of correction for skin effect is only some approximation, which introduces its own error being, in essence, unavoidable, but it permits to find some, undoubtedly approximate, solution. The modelling has shown that solution based on using a correction for skin effect can lead to qualitatively incorrect results. One of obvious advantages of described method consists in its applicability to already existing equipment of inductivity logging.

In contrast to inductivity logging problems, the problems of electric logging are nonlinear in essence. So, the variant of algorithmic solution is inapplicable for electric logging. In this work, the new type of multisound electric logging equipment (MEK) is proposed. The principle of lateral logging, but without a necessity of frequency, spatial and time separation, is used as principle of its action.

The idea of the method consists in the possibility to realize a simultaneous measurement of currents, every of which penetrates down to strictly defined depth. In this case, high vertical resolution is reached by means of use of the principle of lateral logging.

The example of MEK borehole logs for invaded profile is shown in Fig. 2. It is evident that proposed method also factorizes the problem with high degree of accuracy. It is demonstrated that the vertical resolution of each sound is limited mainly by the error of measurement and the value of step recording along the axe of well as well as the sound's size.

The MEK design and the principle of measurement proposed in the work have a number of advantages: the possibility to be used in horizontal wells; the insusceptibility to the Groningen effect; the constructive ease of realization and small overall dimensions.

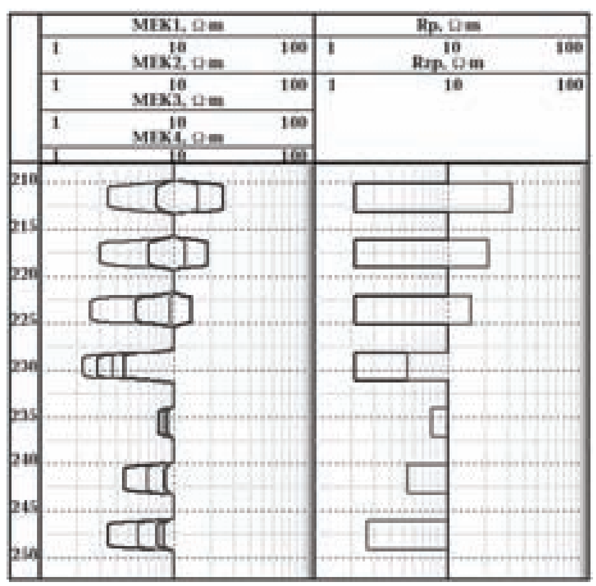

Fig. 2. The example of factorization of 2D inverse problem of electric logging: MEK1, MEK2, MEK3, MEK4 are resistivities obtained by different depth sounds; Rp is the resistance of virgin part of bed; Rzp is the resistance of invaded zone.

The efficiency of proposed methods of electric and inductivity logging was analyzed under the conditions of Western Siberia and the Dnieper-Donetsk depression. On the grounds of performed analysis, the conclusion that MEK and 7IK have much better characteristics in comparison with commonly used BKZ-BK-IK complex and some of other multisound complexes used on the territories of Ukraine, Russia, Kazakhstan and other countries was made. They also are not inferior to similar complexes developed by leading geophysical corporations as to their characteristics.