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Development of technology of petrophysical knowledge synthesis and its application to formation evaluation.

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Summary

We propose two approaches to be used as basic ones in solving petrophysical inversion problem – automation of cluster analysis and visualization by using polygons. We also propose organizational structure which allows integrating petrophysical and log interpretation expertise into a single complex.

Petrophysical inversion

Petrophysical knowledge synthesis and particularly petrophysical basis of interpretation of current object is usually regarded beyond 'knowledge management' approach, which includes estimating of petrophysical interrelations and their implementation in up-to-date formation evaluation. A probable reason for that is a complicity of practical usage of petrophysical knowledge and interpretation expertise, as this approach requires taking into account statistical irregularity, limitations and shift of training material, difficulties in formalizing of a priori information and integration of various ways of data management.

Meanwhile ubiquitous and excessively simplified semi-graphical methods provide hardly correct basis for huge economical risks, as these approaches have been developed for a less number of dimensions, and thus they are poorly accepted by the customers.

Hypothesis concerning a nature of physical interrelations provides a basis for a systematization of petrophysical knowledge which allows forming dedicated cause-and-effect relations that are applicable both in 'pure' petrophysics and in formation evaluation.

Previously [3] it has been proposed by the author that formalization of petrophysical knowledge is added up to 2 basic types of stochastic interrelations.

First type interrelations demonstrate a possibility to estimate vector X (unknown properties) having vector Y (log measurements with errors), if equation (1) is known:

$$y_j = F_j^1(x_1, x_2, \dots, A_{j1}^1, A_{j2}^1, \dots) + (1 - P_{jj}^1)E1_{jj}^1(0, S_{1jj}) + P_{jj}^1 E2_{jj}^1(0, S_{2jj}) \quad (1)$$

Where $E_j(0, S_j)$ represent random errors with zero mathematical expectation and root-mean-square error S_j .

This approach was first proposed in USSR by L.A. Halfin [1]. Similar approaches to solving the inverse problem in well logging are now widely used by many companies worldwide, however the simplest forms are mostly used that don't distinguish between lithotypes and assume normal distribution of measurement errors.

Second type of equations may be used as a supplementary to (1). These are so-called 'bundle equations' that define interrelations between unknown variables (2):

$$G_j^1(x_1, x_2, \dots, B_{j1}^1, B_{j2}^1, \dots) = (1 - P_{jg}^1)E1_{jg}^1(0, S_{1gj}) + P_{jg}^1 E2_{jg}^1(0, S_{2gj}) \quad (2)$$

It's worth mentioning that both (1) and (2) have already taken into account such factors as desirableness of choice from a system of alternative interrelations in various discrete cases (lithology, saturation, dependence structure – introduce 'L' index in (1)) and robustness (low probability P_j^L of gross or hurricane errors).

Optimization inversion using criterion $S(X)$ and taking into account necessity of regularizing summands has become the most popular approach to solving the inversion problem (3):

$$S(X) = \sum \|y - F(X, z, A)\| + \sum \|G(X, z, B)\| + \sum \|A - [A_{\min}, A_{\max}]\| + \sum \|B - [B_{\min}, B_{\max}]\| \quad (3)$$



When petrophysics is formalized in such a way, the associated interpretation task may be conditionally divided into 3 stages:

1. Choose unknown properties X, choose or adjust A and B ratios by using training material;
2. Narrowing uncertainties of the inversion problem by refinement of (1) and (2) depending on a set of logging measurements, ways of differentiation between types of 'L' and estimation of errors' (both routine and hurricane) probability;
3. Deriving a solution from minimization of (3).

It's easily seen that different results may be obtained by alteration of (1) and (2) structure and a number of contained parameters. Structure of (1) is usually pre-defined by existing tradition approaches, which is not true in case

of (2). Meanwhile, introduction of (2) for various types of 'L' is difficult, as any way of petrophysical data management has its constrictions and is usually replaced by functional equations.

Usage of various approaches to petrophysical data management

To choose the optimal way of petrophysical data management and establishment of petrophysical interrelations it's necessary to jointly analyze their limitations and advantages and possibly to come to a conclusion that new technologies need to be created that allow realizing of chosen method at up-to-date level. Authors have analyzed vast volume of petrophysical literature in order to find out usage of various known approaches (Fig.1):

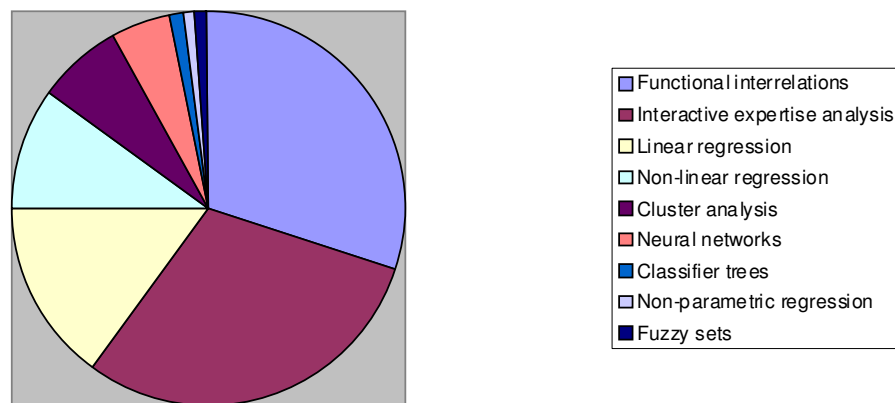


Fig.1. Analysis of usage of petrophysical data management approaches (by literature sources)



Table 1 contains advantages and limitations distinctive for the approaches listed above:

Nº	Formalization approach	Advantages	Limitations
1	Functional interrelations	Uniformity, simplicity of interrelations, absence of errors	Strong influence of clay and carbonate content, secondary porosity etc.
2	Interactive expertise analysis	Heuristic approach, high dependence on log analyst's level of proficiency	Problems occur if variables are highly correlated
3	Linear regression	Uniform training material and adequacy of equations	Narrow range of factors that provide linearization
4	Non-linear regression	Adequacy of interrelations plays an important role	Loses efficiency in case of vast volume of non-shifted training material
5	Cluster analysis	Division into segregated areas of uniformity	Strict bounds between lithotypes and low variability within them
6	Neural networks	Large volume of data and uniformly compact training material	Problems occur in low density area
7	Classifier trees	Division into segregated areas of uniformity	Strict bounds between lithotypes and low variability within them
8	Non-parametric regression	Large volume of data and uniformly compact training material	Problems occur in low density area
9	Fuzzy sets	Heuristic approach, high dependence on log analyst's level of proficiency and level of tools	Problems occur in highly non-linear area

Table 1. Advantages and limitations of existing approaches to petrophysical data analysis

Methods of automated cluster analysis and polygons in optimization inversion

Recently [3] the author has proposed representing of (2) as a Kohonen's neural network for making out optimization inversion. This article proposes using the following approaches as basic ones for introducing of (2) into optimization inversion algorithms:

1. Automation of cluster analysis for approximation of (2);
2. Usage of polygons for approximation of (2).

Fig. 2 illustrates examples of application of stated above approaches to formalization of petrophysical data:

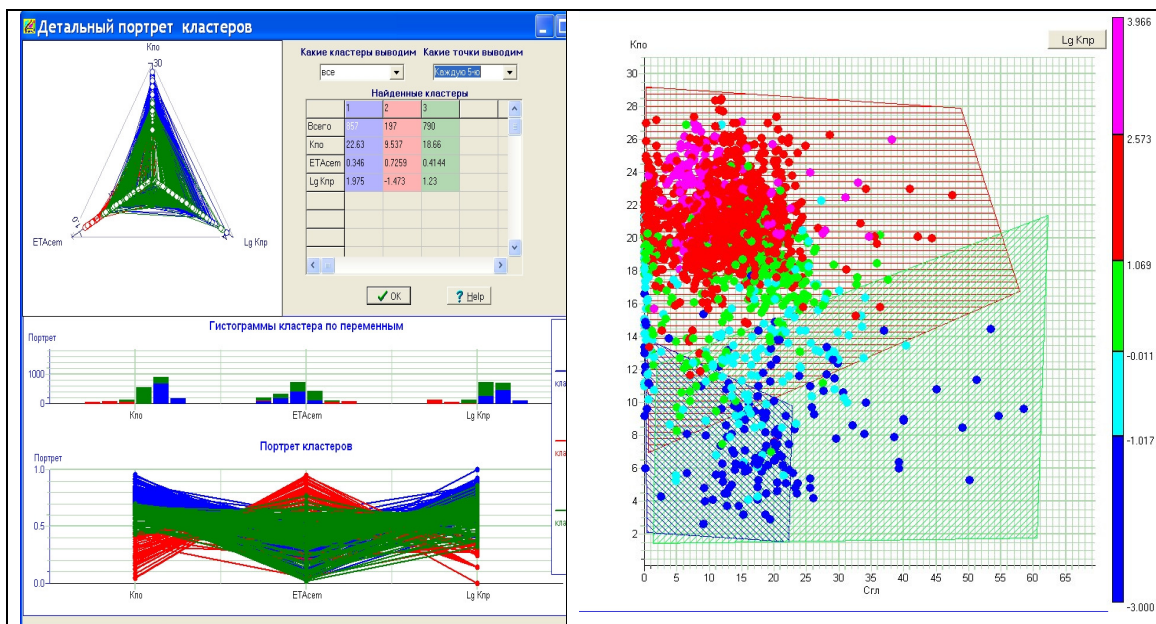


Fig. 2. Interrelations of type (2) presented as clusters (left) and polygons (right) – screenshots of MODERn™ software developed by PANGEA Inc.

Use of both these approaches representing bundle-equations allows visual comparing between them. Structure and parameters of a penalty function should be equivalent to the diffusivity of interrelations in (2).

Petrophysicist and log analyst interaction

Introduction of petrophysical expertise into formation evaluation tasks means adjustment and application by log analyst in optimization inversion of core-based lithological-petrophysical interrelations derived by a petrophysicist. This implies reviewing their interaction in a wider context, which is illustrated in Fig.3:

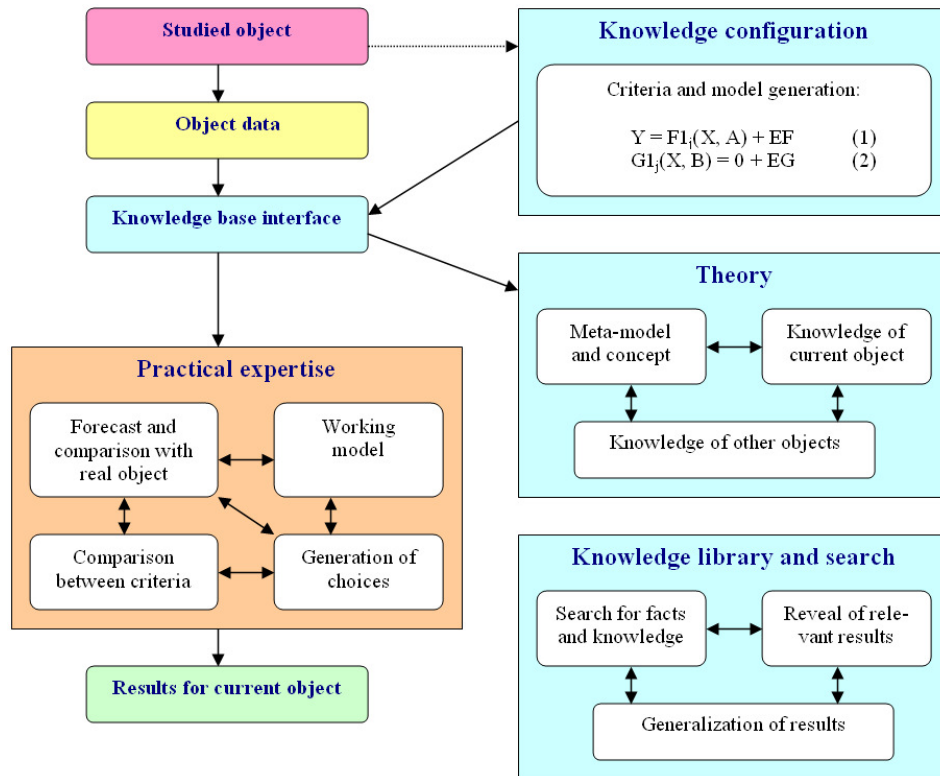


Fig. 3. Proposed integrated scheme of interaction between petrophysicist and log analyst

This scheme looks awkward however it allows representing a number of various information roles and interrelations. Their existence allows using proposed algorithmic approach in full. It's no doubt that in most of the successful practical cases this scheme is realized similarly; however the following obstacles may occur:

1. System approaches may not have technological support available;
2. Contractual works usually don't estimate work content and correctness of derived results (moreover, poorly scientifically-grounded results are multiplied due to refusal of responsibility declared by some contractors).

Conclusion

Described above approaches of petrophysical data management used for representing of petrophysical interrelations similarly to (1) and (2) or representing of inverse

problems (where X directly depends on Y) may be regarded as alternative for conventional approaches.

Advantages of approaches based on optimization inversion of direct problem may be considered as follows: confirmation of developed petrophysical model on the similar object and statistically regularized stability of result. Each of the described approaches may be applied to petrophysical study and interpretation, while its efficiency depends on correctness of derived solution for a direct problem.

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