Geothermal Regimes of the World Sedimentary Basins

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Abstract

The type of geodynamic regime is considered as the significant attribute influenced on the paleotemperature reconstruction methodology and heat flow analysis especially in basin modeling approach. That is the relevance of this study related with. A number of generalized equations were obtained by detailed studying of the temperature-depth profiles and various geothermal indicators al over the world. Three main "summarizing" groups of factors were identified. Such approach allowed to classify all equations obtained into 3 classes: the Anomalous, the Normal geothermal regimes and the regime of the Magmatic intrusions.

Introduction

The temperature field reconstruction during the sedimentary basinevolution is the emphasis of the present study. Since the temperature condition is the main factor influencing on the hydrocarbons generation processes the generalization of up-to-date studies on the sedimentary basins geothermal regime characteristics are of great interest.

Data from the temperature-depth profiles and various geothermal indicators in more than 5,000 wells and measurements were studied. 307 equations that characterize the geothermal regime of the various basins were calculated. Figure 1 shows the example of the two well termperature profiles and the equations calculated. The study was conducted for analizing different geothermal regimes all over the world sedimentary basins to find the regularities and rules for its describing in different geodynamic stages of development according to Wilson cycle (Wilson, 1966).

Several regularities of the temperature profiles and calculated equations were identified. It was allowed to classify the sedimentary basins geothermal regimes of the world. Evaluated objects are observed in the overview maps (figure 2). World sedimentary basins are delineated. Almost a half (40-50%) of the whole world sedimentary basins area (identified by drilling or prognosed by the rather geophysical data) is shown as evaluated.

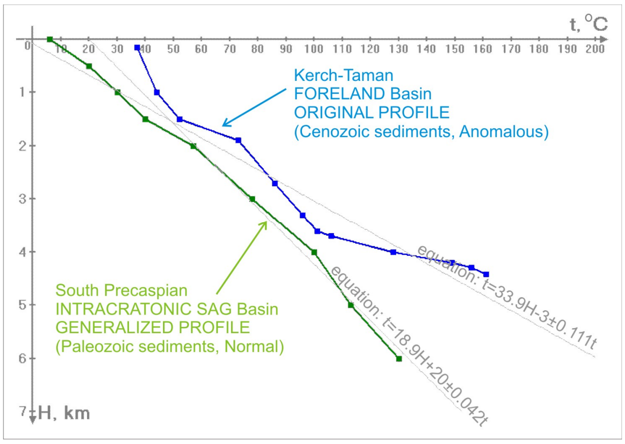

Figure 1: Different geodynamic and geothermal regimes basins example with the calculated equations

Method

Searching for the regularities in the equations behavior was the first task of the results analysis. The next step was to identify the various factors that affect the thermal regime. Three main "summarizing" groups of factors were identified: 1. Age of the sediments composing the sedimentary basin 2. The influence of so-called external geological factors; 3. Effect of geodynamic evolution and stress regime type (Basin geodynamic type; age of the recent tectonic reconstruction; overthrusting, tectonic inversions, erosions etc.). It should be noted that we used the values of temperature well logging an average depth interval from 2 km, while plotting the linear regression function. It was done to avoid hydrodynamic and paleoclimate effects.

The general form of the equation ($t = aH \pm b$) allows to differentiate equations and thereby the geothermal regimes of two parameters: the coefficient of «a», which is the geothermal gradient, and the absolute term of «b», which is the value of the external geological factors influence. The resulting set of equations is divided into three groups clearly by using magnitude of "b": 1. - With negative values of «b» (the Anomalous regime); 2. - With positive (the Normal regime); 3. - With high positive values (> 50).

The influence of "external" geological factors

The clusterization of the equations groups was primarily assumed in terms of the external factors impact on them (figure 3B). For the first group with negative "b" it was observed the match to the gas-bearing intervals of the basins evaluated (48 equations). It also was fixed the

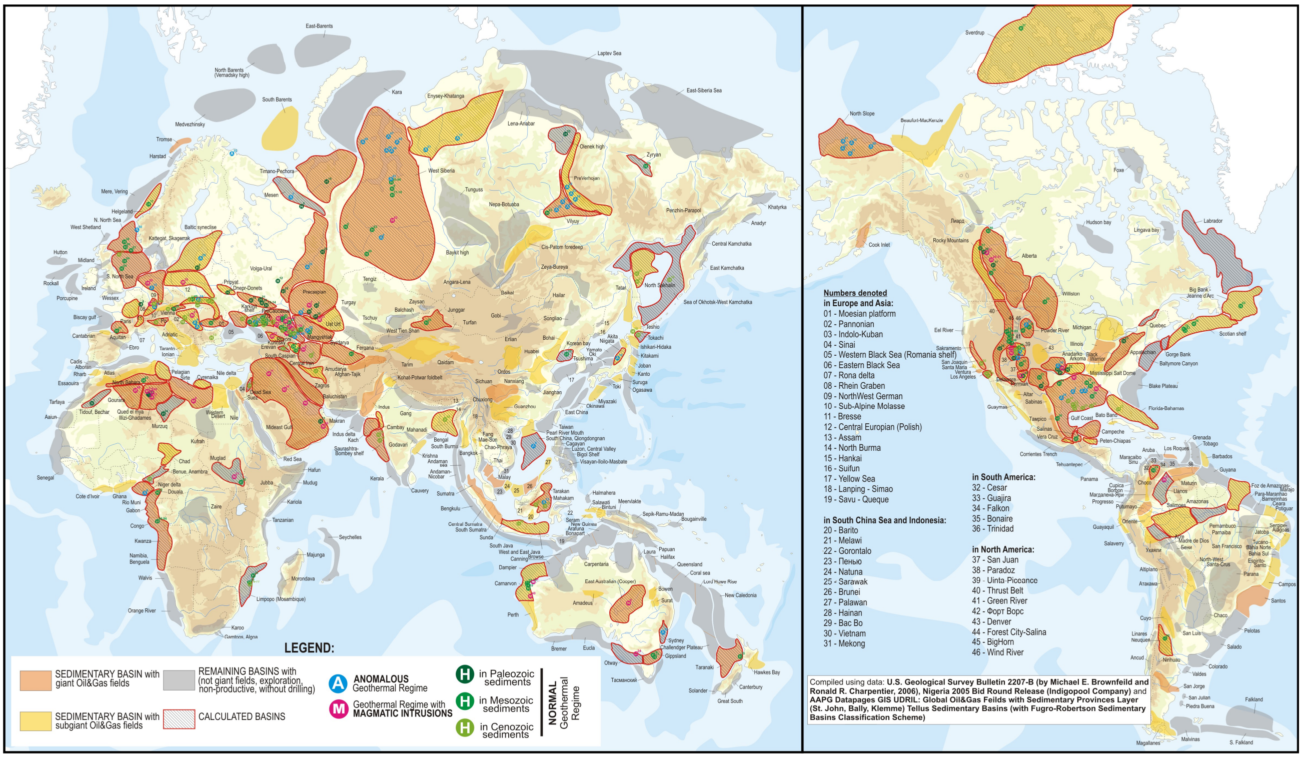

Figure 2: Map of the world sedimentary basins with the geothermal regime calculated

influence of igneous intrusions in the third group with high values of "b" (49 equations). The biggest part of the equations was classified as Normal regime. Such classification made it possible to point out 3 different geothermal regimes.

Figure 3A shows the concave shape of the temperature profile matching the negative value of "b". It means the higher gradients in deeper sections of the well (basin). Such regime was called Anomalous. It is often occures in gas-bearing intervals. For example, data for the analysis of the constructed maps of Steen River basin (USA) geothermal gradients indicate the association of areas with high geothermal gradients in gas fields and oil with a reduced (Jones et al, 1984). However, this assumption should be strictly assigned to the tectonic features of the region, in each case taking into account differences in the thermal conductivity of rocks. More "cold" terms for the upper section interval can be attributed to Joule-Thompson effect (adiabatic expansion of the gas phase with decreasing temperature).

The equations are characterized by different geothermal gradients, since they are calculated over the geological time intervals (Cenozoic, Mesozoic, Paleozoic) and absolute term "b" would characterize the effect of addition heating or cooling "from the outside" of the steady-state system.

The estimated equation is mainly localized in the individual basins, but there are individual wells within basins with the Normal regime. An additional convective effect of the deep intervals heating by the reason of dry gas saturation should be considered as a possible explanation for the stand-alone Anomalous regime wells within the Normal regime basins, as well as for the whole Normal regime basin never the less. The Normal regime equations are characterized by the convex profile shape (figure 3A).

Age of the sediments composing the sedimentary basin

The sediments age is a cummulative factor, which is a blend of many others. Nevertheless, the Cenozoic sediments are characterized by more higher values of geothermal gradient (figure 3B). The second observation is higher gradient in Anomalous regime and decreased values in Magmatic regime.

The geodynamic regime factor

As mentioned above, the shape of the temperature-depth plot can point out the different geodynamic types of the basin (Nazarkin, 1979). There are a lot of assumptions and theoretical equations for the deep heat transport from the mantle to sedimentary cover in the rift systems, active and passive margins, collision zones (Mckenzie, 1978; Sclater et al, 1980; Wernicke, 1981; Smirnov, 1988; Artyushkov, 1993). Also there are number of factors that

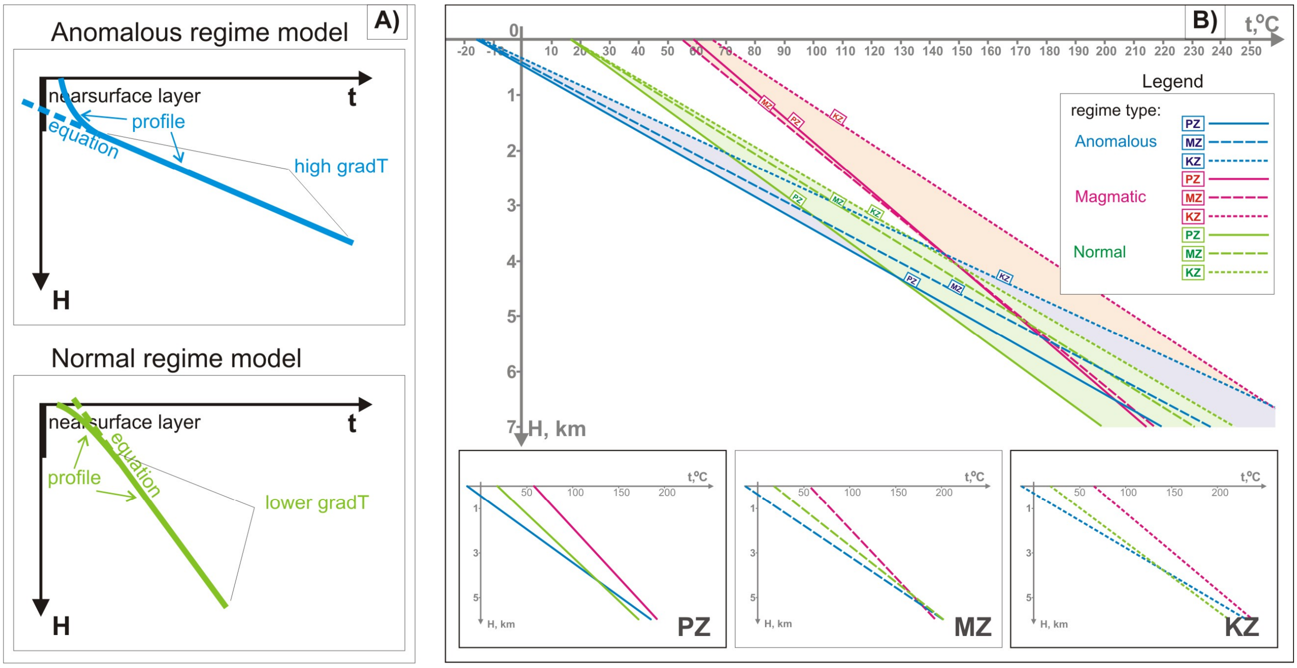

Figure 3: The generalized models of Anomalous and Normal regimes (A) and the average equations of different geothermal regimes disjunctively for the age of the sediments (B)

cause the temperature deviations in the upper parts of the Earth crust (sedimentary basins). They are summarized in this study into a 3 groups. And the most important factor seems to be geodynamic regime factor. To evaluate the influence of this factor the big investigation is now initiated. The main technique is a cluster and factor analysis of the statistical data. At the present time we collecting more temperature data (profiles) to assign some quantified parameters to each profile (tectonic basin type from different classification schemes, age of recent tectonic event, aquifers, basin sedimentary layer thickness, average sedimentation rate, the degree of igneous intrusions influence, the degree of faulting, asthenosphere depth, erosions intensity). The study is in progress. Therefore the factor of geodynamic regime is not examined at this stage.

Nevertheless, by analyzing data from various sedimentary basins in Brazil and Canada we have find out some prerequisites for systematizing geothermal regime types according to geodynamic basin type categorization (Fig. 4).

Temperature vs depth profiles of East Coast Canada (Atlantic passive margin) basins (Labrador, Jeanne d'Arc, Grand Banks, Georges Bank, Baltymore Canyon, Scotian Shelf) completely belong to the light green area of Normal regime in fugire 4. The shape of each profile is convex with the geothermal gradient decreasing below the depth of 2.5-3 km. Anomalous regime (light blue area) is observed just in the Quebec basin, which is the peripheral foreland basin. This one has a geodynamic evolution history which markedly different from others and has geothermal gradients raised below the depth of 2.5-3 km. Profiles of the Atlantic passive margin basins, located on the Brazil's East Coast (Foz de Amazonas, Barreirinhas etc) were added to plot for the comparative analysis. These depth vs temperature profiles also belong to the area of Normal regime, but have more warmed-up conditions in comparison with Canadian basins. This fact is associated with a warmer climate during the evolution history and accordingly increased temperature values of upper boundary of the sediment layer. Scotian Slope basin profiles (grey area) differ a lot from Scotian Shelf basin. These profiles belong to area with significantly colder conditions due to thick salt layer existence in the basin, causing the "refrigerator" effect for the layers below salt (Mello et al, 2002).

Thermal history paleoreconstruction mechanisms used in basin modeling software packages in standard cases even by using special equations solutions (magmatic intrusions influence, erosions, overthrusting) often have the similar results in different geodynamic type basins (close to linear temperature vs depth profiles).

The reason is the conduction heat transfer laws, which are commonly used in basin modeling packages. We propose the concave shape in cases of Anomalous regimes as the effect of convective heat transfer during some of the periods of the basin evolution. Such period will be recognized after finishing the investigation.

In frontier exploration areas basin modelers often fall back on the Global Heat Flow information (Pollack et al, 1991). It is based mostly on the shallow wells information. Unfortunately these data couldn't be successfully used for the deep section temperature prognosis since the effect mentioned above. Therefore it is possible by using our classification to conduct the "piecewise linear function" approach for the geothermal gradient accommodation trends which are sensitive for geodynamic type evolution of the basin, using the principle of actualism.

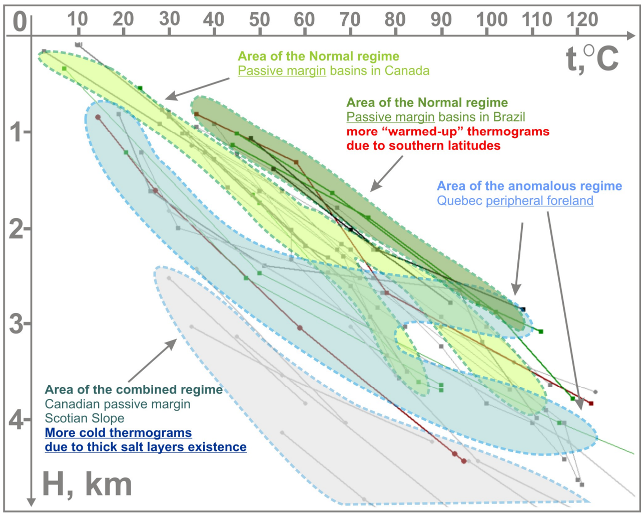

Figure 4: Temperature vs depth profiles of the Brazil and Canada sedimentary basins

Conclusions and discussion

It is allowed to make some conclusions about the specifics of the geothermal regime (without regard to the degree of geodynamic basin intensity factor):

A. The anomalous geothermal regime is characterized by the raised parameters of geothermal gradient at depths more than 2 km. Raised gradients may indirectly indicate the convective heat transfer due to the heated fluid moving from the lower layers of the sedimentary cover by high permeable zones.

B. The profile shape of the Anomalous regime is concave, and the convex shape of the profiles is defined for the Normal. In other words, at a nearsurface layer in the anomalous regime, the temperature increases more slowly, and the gradient increases with depth, while the normal regime is faster and the gradient decreases.

Further study and deeper investigation of the issues mentioned above is in progress now by the expansion of the database on the temperature logs of the world sedimentary basins and using multivariate cluster analysis based. Approach will also provide the solution of general problem to identify the "typical curves" for different types of basin accordingly to the geodynamic type and its changing history. It can be useful for paleotemperature prognosis in the frontier and exploration basins.

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