ON THE CONDITIONS OF TRANSPORT OF HYDROCARBONS TO THE EARTH'S SURFACE IN WESTERN SIBERIA

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Abstract. The gas- and oil-bearing provinces in Western Siberia are aligned nearly longitudinally their spatial distribution being quasi periodical with the wavelength ~300 km and total latitudinal range over ~10^3 km. Assuming the non-organic hydrocarbons are transported to the Earth's surface from the upper mantle by the mechanism of mantle convection aroused against the background of the mantle material motion forced due to the former subduction of the Russian platform under Western Siberia and that convection scale coincides with the spatial period of the gas- and oil-bearing provinces, the subduction velocity of the Russian platform under the Urals can be constrained with the use of certain ancillary geophysical data.

Keywords: non-organic hydrocarbons transport, mantle wedge convection, subduction angle and velocity.

Introduction

The peculiarity of localization of the gas- and oil-bearing provinces in Western Siberia is the periodicity of their disposition on the territory of Western Siberia lowland. The overall latitudinal range of the gas- and oil-bearing province in Western Siberia forms rather more than ~10^3 km, and the number of gas- and oil-bearing provinces is equal to four: Berezovskiy gas-bearing province, Shaimskiy oil-bearing, Middle Obskiy oil-bearing and Eastern gas-bearing provinces [Vasilev and others, 2006]. Being aligned in longitudinally direction, these provinces are parallel to the Ural Mountain Range and their spatial distribution is being quasi periodical with the wavelength ~300 km. The asymmetry of the distribution of Bouger gravity anomaly across Urals and a number of geological arguments in [Kogan, Kukulieva, 1988] indicate that after forming the Ural Mountain Range in Perm (300-200 million years ago) took place the subduction of the Russian platform under Western Siberia. If we assume that the gas- and oil-bearing provinces are forming above ascending convection streams in the mantle wedge, that are transporting non-organic hydrocarbons from the mantle to the daylight surface, the subduction velocity of the Russian platform in Paleozoic can be constrained.

The description of the model

As a model of thermomechanical state of mantle wedge between the bottom of the Siberian platform and the surface of the Russian platform subducting at the angle β and the velocity V, we can take the model [Gavrilov, 2014]. Within the bounds of this model the material of the mantle wedge is supposed to be a homogeneous incompressible constant-viscosity fluid with the viscosity $\overline{\eta}$ equal to its average and the temperature raise is due to the dissipative heating in the mantle wedge. Steady-state distribution of absolute temperature T was calculated in [Gavrilov, 2014] numerically in the Boussinesq approximation with the infinite Prandtl number. The results of calculation show that the temperature reaches its maximum value $T_{\max}$ near the surface of the subducting lithosphere. As applied to the subduction of the Russian platform under the Urals value $T_{\max}$ with narrow angle of subduction β can be approximated by the following analytical formulas:

$$T_{\max} = T_m + \frac{\bar{\eta} V^2}{\kappa} \frac{1}{F + GVx/\chi}, \qquad (1)$$

where $\kappa \approx 4\times10^5$ *erg/cm·s·K* is the heat conductivity, $\chi = \kappa/\rho c_p \approx 10^{-2}$ cm^2/s is thermal diffusivity, $T_m \approx 1.5\times10^3$ is subsolidus temperature, $\rho \approx 3.3$ g/cm^3 is density, $c_p \approx 1.2\times10^7$ *erg*/g·*K* is the specific heat capacity at constant pressure, x is horizontal distance from edge of the mantle wedge, and the dimensionless functions F and G at 8°<β <15° appear as:

$$F = 8.295\times\beta + 1.207,\ G = 6.933\cdot10^{-3}\times\beta - 0{,}025\cdot10^{-3}. \qquad (2)$$

Formulas (1)-(2) with the accuracy ~10% approximate the temperature in the mantle wedge that was calculated numerically.

The thermomechanical model of the mantle wedge that was constructed in [Gavrilov, 2014] was tested for thermal and convective instability. It was demonstrated, that the increment $\gamma_\perp$ of thermal and convective instability in the form of the variable thickness rolls aligned across subduction, is represented by the gradually changing function of horizontal coordinate x and is being defined by the formula

$$\gamma_\perp = 4\bar{\eta}\xi \frac{(D - Ct/2)^2}{x^2 \rho c_p T} + \frac{\alpha\rho g x^3 T' k_x^2}{\bar{\eta}(x^2 k_x^2 + \lambda^2)^2} + 16\bar{\eta} \frac{\xi U' k_x^2 \lambda^2 (D - Ct/2)}{\rho c_p T (x^2 k_x^2 + \lambda^2)^2} - \frac{x^2 k_x^2 + \lambda^2}{x^2}\chi, \qquad (3)$$

where $\xi = (E^* + pV^*)/RT$ is the index in exponential viscosity temperature dependence, E^* and V^* are activation energy and volume, R is the universal gas constant, constants $D = V(\beta\cos\beta - \sin\beta)/(\beta^2 - \sin^2\beta)$ and $C = -V\beta\sin\beta/(\beta^2 - \sin^2\beta)$ correspond to the no-slip conditions at the lithospheric plates boundaries, $t = tg\beta$, $\alpha = 3\cdot10^{-5}$ 1/*K* is the thermal expansion coefficient, g is gravitational acceleration, $T' = (T_{\max} - T_m)/t$, $\lambda = \pi/tg\beta$, $U' = (D(\sin\beta\cos\beta + \beta) - C\sin^2\beta)/tg\beta$, $T = (T_{\max} + T_m)/2$ is average temperature in vertical section of the mantle wedge, k_x is the wave number, corresponding to spatial period $2\pi/k_x$ the upwelling convection flows in the mantle wedge.

The first term in (3) is k_x – independent and describes thermal instability that occurs because of temperature dependence of viscosity, which is essential at small distances x from the trench, in which sinks the subducting lithospheric plate. The remaining terms in (3) correspond to convective instability that is caused by the vertical temperature difference $T_{\max} - T_m$ in the mantle wedge.

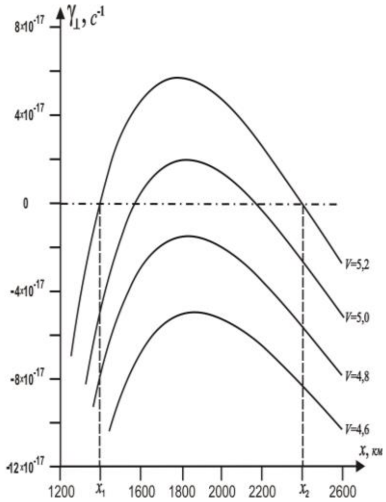
The unknown quantities that characterize the subduction of the Russian platform under Western Siberia are the subduction velocity V and the angle of subduction β. According to the results [Pavlenkova, Pavlenkova, 2014], relating to the profile “Quartz”, that crosses the Ural Mountain Range there is an inclined density anomaly in the upper mantle under Western Siberia that deepens perpendicularly to the Ural Mountain Range at an angle ~8°. If we interpret this density anomaly as the remnant fragment of the Russian platform subducted under Western Siberia in Paleozoic then we can take β ~8° for an angle of subduction.

It was noted in [Zharkov, 2012] that the viscosity of the mantle wedge material is shown to be very small because of the presence of the water – $\bar{\eta} \le 3\times10^{18}$ Pa s, and for activation energy and volume we set E^*=240 *kJ/mol* and V^*=8 *cm³/mol.* Then as average $\xi = (E^* + pV^*)/RT$ we can take $\xi \approx 20$.

Results and discussion

The Figure below shows $\gamma_\perp$ (3) at different values of subduction velocities V for the mentioned above numerical values of physical parameters and $2\pi / k_x$=300 km.

Growth rates $\gamma_\perp$ of convective instability in the mantle wedge as functions of horizontal distance x from the edge of the mantle wedge at different values of subduction velocities V in *cm/year*. In the interval $x_1 < x < x_2$ of positive $\gamma_\perp$ can be expected hydrocarbons transport from the mantle wedge to the Earth surface in Western Siberia at V ~5.2 cm/year.



Formulas (1) – (3) demonstrate that with small coefficient of viscosity ($\bar{\eta} \leq 3\times10^{18}$ Pa·s) the role of the thermal instability is insignificant and the convective instability is nearly inependent on the accepted average $\bar{\eta}$. The latter point is due to the temperature difference $T_{\max} - T_m$ that causes convection originates because of the dissipative heating and is being proportional to $\bar{\eta}$, but from the other side, the bigger is $\bar{\eta}$ the harder it is to cause convection. Weak dependence of the convective instability on average viscosity $\bar{\eta}$ is evident from (3) where in the right part in the second and third terms $\bar{\eta}$ appears both in the numerator and in the denominator. It is evident from the Figure that $\gamma_\perp$>0 (i.e. instability shows up) starting with V ~4.9 cm/year, and horizontal extent $x_2 - x_1$ of instability region reaches ~10^3 km at V ~5.2 cm/year. Herewith the period $2\pi / k_x$=300 km of the convection is assumed to coincide with the spatial period of the gas- and oil-bearing provinces. This condition is based on the assumption that gas and oil deposits are formed above the upwelling convection flows that are transporting non-organic hydrocarbons of the upper mantle to the Earth' surface.

Conclusion

The resulting estimate of the subduction velocity of the Russian platform under Western Siberia in Paleozoic, ~5.2 *cm/year,* is of the order of the observed subduction velocity of Indian continental plate under Eurasian plate that is equal to ~6.1 *cm/year* [*Schubert et.al., 2001, Fig.2.4*].

According to Fig.2.32d of the cited monograph, there is a clear correlation between the velocity of the lithospheric plate and ratio of trench length on this plate to its perimeter regardless of subduction angle and part of continental crust on the plate. In view of considerable length of the Ural Mountain Range the Russian platform seems to fit well into the noted correlation dependence.

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