THERMOGRADIENT MODEL OF FORMATION OF OIL AND GAS TRAPS AT SALT DIAPIRISM

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Summary This research covers outcomes of numerical modeling of a stressed-deformed state of a sedimentary complex and subsalt bed, formation of oil and gas traps. It has demonstrated that areas of oil and gas traps are associated with higher temperature gradients. The small-scale thermal convection in the top horizons of earth crust makes essential impact on distribution and formation salt diapirs in a sedimentary cover.

Introduction

In Kazakhstan, a lot of tasks of salt-dome tectonic geology were set by academician Zh.S.Erzhanov. Several numerical methods which make possible correctly trace evolution of interfacial areas of layers to the extent of formation of salt lenses have been developed and substantiated. Reference [1] sums up outcomes of these longstanding researches.
References [2], [3] show a possibility of existence of small-scale heat convection in upper levels of Earth's crust. The latter demonstrates significant influence on distribution and formation of salt diapirs in a sedimentary cover.

Mathematical model and its implementation

System of equations which describes movements of viscous incompressible fluid in gravity field and heat conduction is as follows:

$$\rho \frac{\partial V_i}{\partial t} + \rho V_k \frac{\partial V_i}{\partial x_i} = -\frac{\partial p}{\partial x_i} + \frac{\partial \sigma_{ik}}{\partial x_k} + \rho g_i, \tag{1}$$

$$\frac{\partial V_k}{\partial x_k} = 0, \tag{2}$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_k}\left(\rho V_k\right) = 0, \tag{3}$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + V_k \frac{\partial T}{\partial x_k} \right) = \frac{\partial}{\partial x_k}\left(k \frac{\partial T}{\partial x_k} \right) + \sigma_{ik}\dot{\varepsilon}_{ik}, \quad \left(i, k = 1{,}2\right) \tag{4}$$

where σ_{ik} is a deviator stress, $\dot{\varepsilon}_{ik}$ is a strain velocity tensor, P is pressure, V_k is velocity components, g_i is components of gravity acceleration, ρ is density, C_p is specific heat capacity at constant pressure k is a coefficient of heat conductivity, T is an absolute temperature.
Linear relation is adopted as an equation of condition for density:

$$\rho = \rho^* (1 - \alpha (T - T_*)), \tag{5}$$

where ρ^* is undisturbed density dependent on a chemical condition of a material or density at temperature T_0. Moreover, dynamic viscosity of local fluid particle is preserved:

$$\frac{\partial \mu}{\partial t} + \frac{\partial}{\partial x_k}(\mu V_k) = 0 \cdot \tag{6}$$

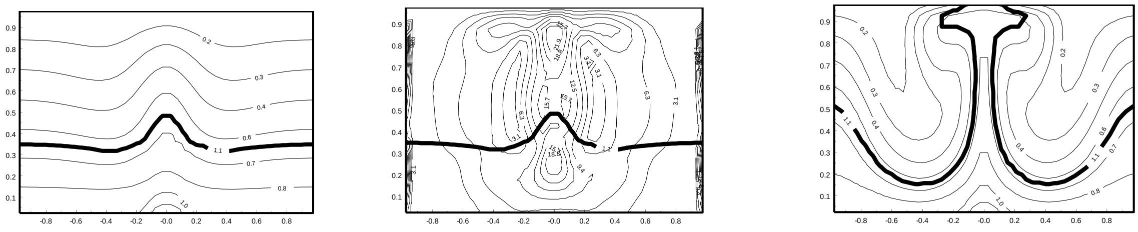
Further we use Boussinesq approximation: dependence of density on temperature is taken into consideration only in an expression of buoyant force in (1).
In order to calculate a purely dynamical problem of formation of salt structures the authors have developed and implemented numerical method [1]. In thermal task a member proportional to temperature and expresses an energy balance with relevant boundary and initial conditions are added in impulse equations. Therefore, a computation algorithm of a dynamic part remains the same (buoyant force linked to temperature which is determined in a center of a cell is added in discrete impulse equations). Energy equation is approximated by implicit absolutely stable figure of alternate directions which is realized by a lateral-cross nonmonotonic pass.

Calculation of stress and strain state

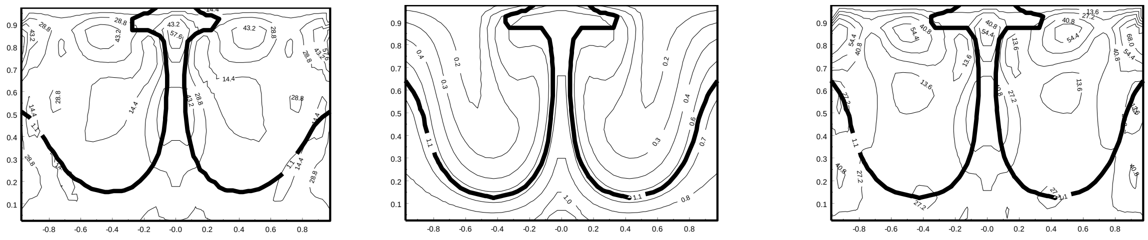
Numerical modeling determines a field of pressures, velocities and temperature. Then stress fields σ_{11}, σ_{22}, σ_{22} and τ were constructed by using numerical differentiation (through central differences on spaced grids). Zones of elevated concentrations of a deviator of shear stresses were earmarked and they were used to determine most probable areas of oil and gas traps. For isotropic elastic (viscous) body stress tensors and deformation tensors (sensors of strain rates) are coaxial. Therefore, it is enough to earmark areas of stress concentration. Pattern of calculation of a spatial model is similar to a plane model (with a relevant recalculation of a deviator of shear stresses for a 3-D case). Authors of this research have limited themselves to study a plane model with exposure of oil and gas traps based on evaluation of areas where deviator of shear stresses is maximum.

Outcomes of numerical modeling

Figures 1a – 1f show formation of a main salt diapir and secondary diapirs in various moments of non-dimensional time.



t=0.3 (a) (b) t=0.8 (c)



(d) t=1.0 (e) (f)

Dynamic viscosity of strata: $\mu_1 = 10^{18} P,\ \ \mu_2 = 5 \cdot 10^{17} P$

Fig. 1. Formation of diapirs through time (two-layer model) and distribution of isotherms and insulators of a deviator of shear stresses.

Original temperature distribution throughout the space was set by a linear function of vertical coordinate. Zero temperature was maintained on a top wall and $250^0 C$ on a bottom wall. Temperature in two points of an analysis grid which imitate a local heat source was set at temperature which is higher by $50^0 C$. Original boundary line is a straight line. Moreover, figures 1a, 1c, 1e show isotherms T=const, while 1b, 1d, 1f show insulators of a deviator of shear stresses $\tau = const$.

Calculations have shown that a value of stress component for an advanced phase is approximately 2-2.5 times higher than a less developed phase. Upper part of a dome space and space itself is represented by horizontal stresses and contraction vertical stresses. Bottom part of a dome is represented by contraction stresses. Bottom central part of a dome is featured by approximately equal intensity of vertical stresses and maximum difference in intensity is typical for its peripheral part. Value of shear stresses varies by 1-1.5 times which is attributed to formation of an eddy zone. We emphasize that stress distribution through time corresponds to a mechanism and formation of a salt dome. Similar picture is reported in the area of formation of peripheral domes.

We would like to indicate that the numerical method is applied to axisymmetric and three-dimensional problem with slight changes and to tasks of calculation of asthenospheric diapirism with slight modifications [4-8].

Conclusion

Outcomes of numerical modeling of formation of salt diapirs in a temperature field quantitatively confirm that hydrocarbon reserves are associated with areas of increased temperature gradients. The research has demonstrated that they exert significant influence on formation of oil and gas traps.

References

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