P028 Prediction of stresses in gently sloping structures using P and S waves.

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Abstract

Anew method of fluid-stress modeling on the basic of 3D seismic and drilling data provided new information on the stress conditions and the hydrodynamics of the U_1 Upper Jurassic sand reservoir in the Arigol field (West Siberia, Russia). It is suggested to detect and online oil fields and divide them into isolated traps each marked by low overburden pressure and fluid-trapping properties on the basic of correlation between structural pattern and mapped stress. In the model, counter lines of constant anomalous overburden pressure are used as outer hydrodynamics barriers for hydrocarbon migration and the geometry of fluid flow lines (horizontal pressure gradients) corresponds in barriers between traps. The areas of the detected fluid-stress traps depend on the choice of the boundary values of overburden pressure and its horizontal gradients. Unlike the traditional methods of hydrodynamic modeling, this method is based on 3D multi component seismic exploration data (V_P, V_S, ρ).

Key words; ***stress, shear waves, porosity, specific surface, pressure.***

Introduction.

3D geodynamic modeling of buried oil and gas traps has received much recent attention. This modeling is based primarily on down hole logging followed by the estimation of porosity and permeability with implications for the inter well space. In this approach, seismic data are used as supplementary information to specify the structural framework and to find relationship between the seismic image and the geodynamic parameters of hydrocarbon reservoir.

A different systematic approach implies the use of seismic data (V_P and V_S velocities and density ρ) for stress modeling of reservoirs to detect regions of low overburden pressure and orientation of fractures caused by the non hydrostatic behavior of stresses. Even in simplest situation of horizontal structures the pressure in solid has jumps on the horizontal boundaries. Really this jump is

$$\Delta P = \frac{4}{3} P_0 (\gamma_1^2 - \gamma_2^2), \tag{1}$$

where P_0 is the weight of rocks, and $\gamma_i = V_S^i / V_P^i$. Hence if there are different values of γ in two layers, there is a jump of pressure between them. This jump may be negative and positive. The first case very interesting because arrived a zone of small pressure. These zones of small pressure tend fluid to them, if there is some transport system for it. In common case the problem of stress-strain calculation may be solved using Kupragze method [1]. For two dimensional structures this method was used by Sibiriakov and Zaikin [2]. Nevertheless there are some simplifications for gently sloping structures both calculations and physical interpretation.

Calculation of stress tensor for gentle folds.

It may be shown that the sum of horizontal strains $e_{xx} + e_{yy} << e_{zz}$, for gently sloping structures, and there is an estimation $(e_{xx} + e_{yy}) / e_{zz} \approx O(h^2 / L^2)$, where h is the amplitude of structure, L is a horizontal range of it. Hence, in vicinity of such structures there is so-called the plane incompressibility situation. The field of displacements (or stresses) is satisfying to equilibrium equation in the form:

$$\frac{\partial \sigma_{ik}}{\partial x_k} = \rho g_i, \tag{2}$$

where ρ -is the density of layer, and g_i is the gravity vector. Using Hook's law (2) state as closed equation. The displacement field as a solution of (2) represents as a sum $u=u_1+u_2$,

$$u_{1_i}(x) = \rho g \int_V \Gamma_{iz}(x,y) dV_y, \tag{3}$$

V is a volume of structure, $\Gamma_{ik}(x,y)$ is the Green tensor of elastic equilibrium equation. It means that u_1 is a special solution, as to u_2, this term is satisfying to equation $\partial \sigma_{ik} / \partial x_k = 0$. Analogously the plane deformation is a sum $e^1_{xx} + e^1_{yy} + e_{xx} + e_{yy} = 0$, because there is the incompressibility on the plane. Here $e^1_{xx} + e^1_{yy}$ is a special part of solution, which will make from (3). The field of displacements is given by expressions:

$$u_i = u_{1_i} + \varphi_i [1 - \frac{z}{z_0(x,y)}] + [z - z_0(x,y)] \frac{\partial \phi}{\partial x_i}, \tag{4}$$

where $\varphi_1, \varphi_2, \varphi_3, \phi$ are harmonic functions, and $z = z_0(x,y)$ is a surface of structure, and u_{1i} is given by (3). Using relations, kind of $z'_{0,x} << 1$, $z'_{0,y} << 1$, for gently sloping structures, may be obtained more or less simple algorithm for calculation of mentioned harmonic functions and stresses. In order to illustrate this method of stresses calculation it was used the productive Jurassic layer in Arigol deposit in West Siberia (Russia). The system of equation includes six unknown stresses and only three equilibrium equations. Thus is not closed in general case but can be made closed using an elastic model of stress-strain relationship. this is justified by relative simplicity of the model, and by possibility to measure elastic constants using *P, S,* and *PS* waves. the closed system of partial derivative equations ca be transform into a system of integral singular equations.

However, direct extrapolation of the method into 3-D problems complicates the computation. It can be simplified in view of the fact that many geological structures in West Siberia are quite shallow dipping, i.e. one tangential stress component is small relative to the two others. Sibiriakov and Zaikin [2] used a particular solution to inhomogeneous equilibrium equations as Poisson type integrals where the integration is made over the structure volume.

The effect of 3D structures on stress is more local, that 2D ones, as it decreases in inverse proportion to square distance from the structure. Author suggests a new method to calculate Poisson cubature integral in which these integrals are reduced to a succession of 2D quadratures followed by common 1D integration. Stress is defined by velocity jumps and the effect of structure geometry. The latter contribution is, for instance, 20% of the total effect in the Arigol local high (Vakh pattern holes). Therefore, the overburden pressure in the producing bed and layers below and above is controlled mainly by velocity ratios. The distribution of layer velocities of *P* waves was modeled on the basic of *SMP* stacks and *VSP* data from three wells. The greatest difficulty was in the estimation of velocity ratios as no direct *P* or *S* velocity measurements were made. Nevertheless, petrophysical measurements allowed us to find that the γ ratio for the producing bed ranges between *0.577* and *0.550.* Velocity ratios for other layers were inferred from density-velocity relationship. It is obviously expected that if the γ ratio is higher in the producing bed, its overburden pressure is lower, than in the overlying. Indeed, the pressure deficit in the producing bed is about 5 *MPA* in the average.

Pressure break in rock skeleton and fluid.

Consider a fluid-filled reservoir. Let u_n the radial displacement of a skeleton grain. Applying the Gauss theorem, obtain

$$\iint_S u_n ds = \iiint_V div[u_n]dv = fV \frac{P_0}{\rho_0 C^2}, \qquad (5)$$

where S is the grain surface, f –porosity, P_0 is the fluid pressure, and ρC^2 is the inverse fluid compressibility. At the same time, $\iint_S u_n ds = < u_n > S,$ where $< u_n >$ is the mean displacement. Therefore,

$$\frac{p_0}{\rho C^2} = \frac{1}{f} \frac{< u_n >}{r_0} \sigma_0 r_0, \qquad (6)$$

where $\sigma_0 = S / V$ is the specific surface, and r_0 is a mean grain radius.

a rigorous relationship, where Δ is a Laplace operator, and e is the dilatation of grain.

In the Fig 1 is shown the contours of equal pressure in productive Jurassic layer. First of all this pressure is sufficiently less, then the weight of rocks about 30 percent. The second thing that the pressure in solid in productive layer is decreasing compared to upper layer about *5 Mpa* . The jump between pressures in solid and in liquid depends on structure of pore space and it not be predict by using seismic waves only. Nevertheless, if the pore space structure is constant in layer, the orthogonal trajectories to pressure lines are probabilistic streamlines of fluid. This streamlines are shown by dashed lines on the Fig. 1.

In the Fig.2 is shown the map of cracks probabilistic orientation. In the center of structure the plane of crack reach to 45^0 with horizontal plane. It may be caused the chaotic orientation, or orthorhombic anisotropy. But near boundary of structure this orientation is changing. The cracks state as sub vertical ones (light color). . Such tectonophysical prediction may be verified by multi component *VSP* investigations.

Conclusions.

1. The relationship between overburden pressure, which is a scalar function *P(x,y,z)* and rock stresses is a fairly complex function in a general case. However, it is obvious that fluids accumulate in closed sites of porous reservoirs where the overburden pressure is minimum.
2. Thus detected regions are a sort of "fluid-stress" traps in which hydrocarbons may accumulate under the control of stress rather than structural factors.
3. Maps of horizontal gradients of overburden pressure are especially informative for the detection and outlining of these traps as these maps reveal

- convergent (inflow) and divergent (outflow) pressure gradients:
- isolated inflow regions in the detected trap separated by the geometry of outflow lines (fluid-stress barriers)
- all possible fluid-stress traps in structural and nonstructural conditions.
- **References.**

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2. B.P. Sibiriakov. (1996) " Prediction of stresses in hydrocarbon bearing structures using seismics." *EAGE 58th Conference , Amsterdam 1996, P148.*

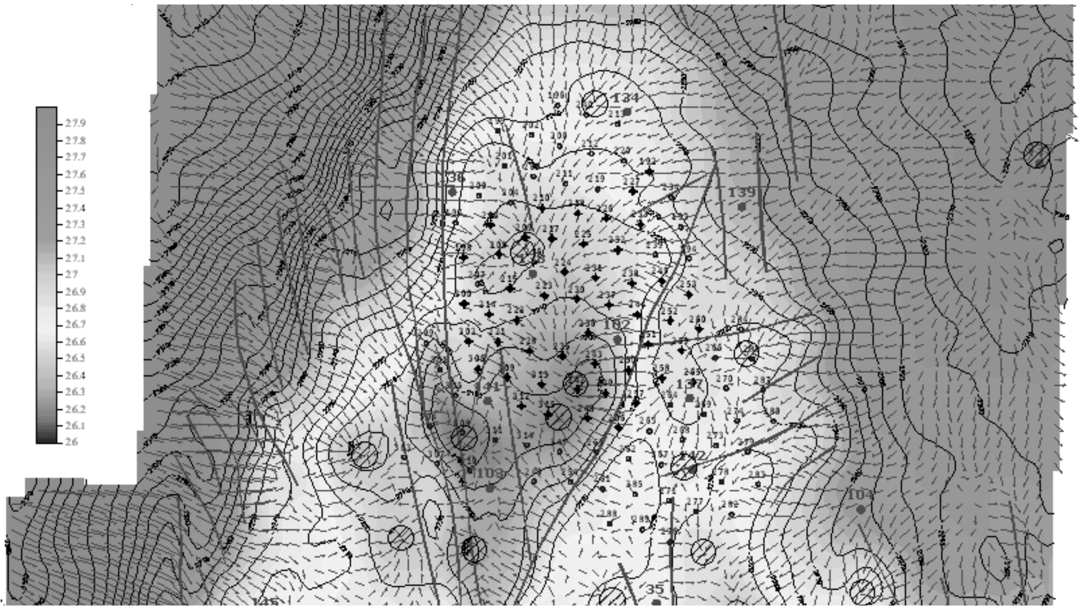

Fig.1.

Isolines of pressure and probabilistic streamlines in productive layer. Dark area in center is the area of small pressure.

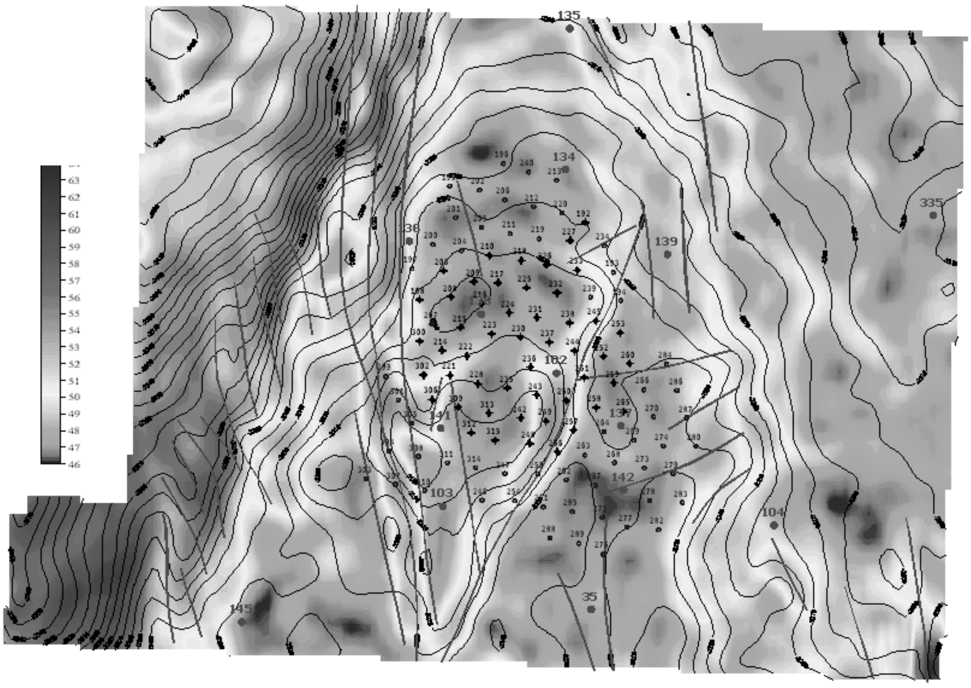

Fig.2.

Orientation of cracks. The dark area corresponds to chaotic orientation. The light area corresponds to subvertical crack orientation.