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A model for generating near-lithostatic pore pressures at seismogenic depths.

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Introduction:

The influence of fluids in crustal rocks has been considered and evaluated in several works regarding fracturing processes (Secor (1965), Engelder and Lacazette (1990), Segall e Rice (1995) e Olson (2003)).

In this work we analyze the effects of fluids trapped within deep rocks, which come suddenly into contact with shallower fractured regions, modifying their temperature, pressure, permeability and stress conditions. In particular we examine the solutions of a set of two coupled equations for heat and pressure transfer in compressible thermo-poro-elastic fluid-saturated media, which become suddenly connected with an hot and pressurized fluid reservoir.

The model employed is 1D and the fluid and materials parameters are considered to be constant, except the viscosity, which has been assumed temperature dependent, and the permeability, which has been considered pressure dependent. The solutions obtained are compared with those calculated keeping these physical quantities constant.

Model and governing equations:

The set of equations considered is the following:

$$\left\{ \begin{array}{l} \rho c \frac{\partial T}{\partial t} - k_T \frac{\partial^2 T}{\partial z^2} = \frac{\rho_f c_f K}{\mu} \frac{\partial T}{\partial z} \frac{\partial P}{\partial z} \\ \frac{\partial P}{\partial t} - \frac{\partial}{\partial z} \left(\kappa_f \frac{\partial P}{\partial z} \right) = \frac{S}{T_0} \frac{\partial T}{\partial t} \end{array} \right. \quad \text{with} \left\{ \begin{array}{ll} z = 0,\ t = 0^+ & T = T_0,\ P = P_0 \\ z = b,\ t = 0^+ & T = 0,\ P = 0 \\ 0 < z < b,\ t = 0 & T = 0,\ P = 0 \end{array} \right.$$

The model is constituted by a layer 0<z<b, which, before the connection, is at refer-

ence pressure (hydrostatic value) P_{ref} and temperature T_{ref} and by a reservoir, which occupies the half space z<0, characterized by a pressure P_0 and a temperature T_0 higher than the reference values. At the time t=0 the reservoir is connected with the medium and the fluid migrates upward in response to the overpressure and temperature excess at the boundary.

The solutions have been calculated through a numerical procedure for different values of the boundary conditions. We have in particular considered two cases: in the first we have assumed for the reservoir a depth equal to 5 Km, at which the environmental conditions determines a marked viscosity dependence on the temperature; in the second case the depth is equal to 10 Km with higher pressure and temperature boundary values.

First of all we have compared the solutions calculated assuming a viscosity dependent on temperature $\mu = \mu(T)$ and a constant viscosity $\mu = \mu(T=T_{ref})$. This dependence has been obtained starting from experimental data published by Haar, Gallagher and Kell (1984) for water at high temperature and pressure.

The permeability has at first been assumed constant and the solutions have been obtained considering three different values ($K=10^{-15}$, 10^{-17} e 10^{-20} m^2) found in literature for basaltic rocks.

The temperature field show a conductive behaviour for the low permeability rock ($K=10^{-20}$ m^2), while it is possible to observe a marked influence of the advective term for the highest permeability ($K=10^{-15}$ m^2). The trend of the pressure field is also influenced by the permeability value of the rock: the viscosity dependence on temperature generates a pressure front visible especially for $K=10^{-15}$ m^2, while for $K=10^{-20}$ m^2 we can notice effects caused by temperature changes due to a different thermal expansion for the fluid and the rock matrix.

Furthermore, while the solutions for a variable viscosity are well distinct from those for a constant viscosity at a depth of 5 Km, they are practically superimposed for higher temperature and pressure boundary values. Here in fact the viscosity dependence on temperature is substantially negligible.

The permeability dependence on pressure has been obtained starting from a model constituted by layers of intact porous rock with a constant characteristic permeability K_r, alternated with layers characterized by a distribution of equidistant interacting fractures represented by Volterra dislocations, whose opening depends linearly on the pressure within.

The effective permeability of the whole system results to depend on the pressure and on three geometrical parameters of the model: the horizontal and vertical distances between the centers of two near dislocations D, and d and their length l.

Even in this case a comparison has been done between the solutions calculated taking into account this new dependence and the previous ones, obtained keeping the permeability constant.

The new solutions show often marked differences with respect to those for a constant permeability, especially for the pressure field in rocks with low characteristic permeability. In the region where the permeability increases with respect to its initial value, the pressure gradient decreases and the layer is characterized by higher pressure values with respect to those seen for a constant permeability.

Conclusions:

Among these solutions we are particularly interested on the pressure ones, because significant variations of pressure can have an important role on the stability of a fracture system. The results show how the viscosity dependence on temperature can affect the pressure field and then contribute to increase the pressure within the rock, but only in regions at shallow depth or relatively cold.

The permeability dependence on pressure can instead influence the trend of the pressure field even in case of higher temperature and pressure conditions. If the layer $0<z<b$ is identified as the brittle-ductile transition layer, these solutions show that episodes of fluid migration can increase the pore pressure up to lithostatic values and then decrease substantially the instability threshold of a fault region, with obvious seismogenic implications.

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