

MULTI-PHASE FLOW: THE PROCESS THAT PRODUCES LARGE ORE BODIES? Bruce Hobbs, CSIRO, Perth.

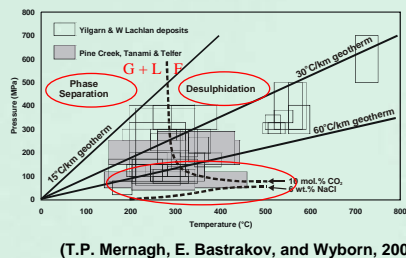


pmd*^{CRC}

SUMMARY.

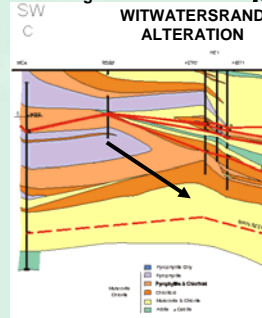
Many mineralising systems imply that more than one fluid was involved in the mineralising process. However, it is commonly difficult to identify the various fluid supply plumbing systems that were responsible for bringing the various fluids together. A multi-phase fluid only needs one supply system. Moreover it supplies an intimate mixture of immiscible fluids in the pore spaces ready to do the job. This mixture varies in its composition with respect to whether the fluid system is proximal or distal within the flow system.

1. MULTI-PHASE SITUATIONS MUST BE COMMON IN ORE ENVIRONMENTS

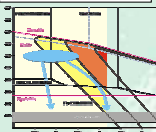


(T.P. Mernagh, E. Bastrakov, and Wyborn, 2005)

2. Many ore environments show evidence of fluid mixing with little field evidence of the plumbing system that enables the fluid mixing.



Note zonal alteration pattern:
Pyrophyllite only
is surrounded by
pyrophyllite + chloritoid
which is surrounded by
chloritoid only
Passing outwards to
Muscovite + chlorite



3. THE PHYSICS OF TWO-PHASE FLOW

Transport Laws

Wetting and non-wetting fluid transport is described by Darcy's law:

$$q_i^w = -k_{ij}^w \frac{\partial}{\partial x_j} (P_w - \rho_w g x_j) \quad (2.1)$$

$$q_i^g = -k_{ij}^g \frac{\partial}{\partial x_j} (P_g - \rho_g g x_j) \quad (2.2)$$

where k_{ij} is saturated mobility coefficient, which is a tensor, k_r is relative permeability for the fluid, which is a function of saturation S_w , μ is dynamic viscosity, P is pore pressure, ρ is fluid density, and g is gravity. **THIS MEANS THAT FOR TWO PHASE FLOW, AS IS TRUE FOR MULTI-PHASE FLOW, THE VARIOUS PHASES MOVE AT DIFFERENT FLOW VELOCITIES AND HENCE SEPARATE.**

Capillary Pressure Law

The capillary pressure law relates the difference in fluid pore pressures to saturation:

$$P_g - P_w = P_c(S_w) \quad (2.6)$$

In FLAC, this empirical law is of the van Genuchten form (see Figure 2.2):

$$P_c(S_w) = P_0 \left[S_r^{1/n} - 1 \right]^{1-a} \quad (2.7)$$

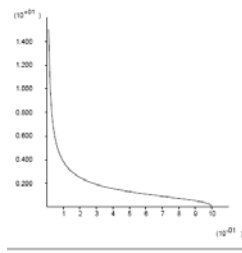


Figure 2.2 Capillary pressure, P_c , vs effective saturation, S_e

Relative Permeability Laws

Relative permeabilities are related to saturation S_w by empirical laws of the van Genuchten form (van Genuchten 1980):

$$k_r^w = S_e^2 \left[1 - \left(1 - S_e^{1/a} \right)^2 \right]^2 \quad (2.3)$$

$$k_r^g = (1 - S_e) \left[1 - S_e^{1/a} \right]^{2a} \quad (2.4)$$

In those laws, a , b and c are constant parameters and S_e is the effective saturation.

The effective saturation is defined as:

$$S_e = \frac{S_w - S_w^r}{1 - S_w^r} \quad (2.5)$$

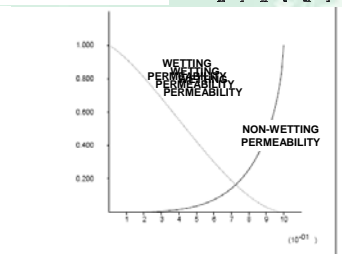
where S_w^r is residual wetting fluid saturation (the residual saturation, which remains in spite of high capillary pressures, is referred to as "connate" in the case of water).

The parameter P_0 is larger for finer material, and its dependency on material properties may be assessed using the Leverett scaling law (see, e.g., Nikolaevskij 1990, p. 414). This law, derived using dimensional analysis, has the form:

$$P_0 = \frac{\sigma}{\sqrt{k/n}} \quad (2.8)$$

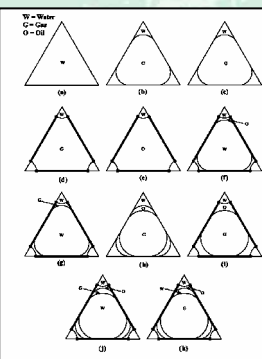
where σ is surface tension, a property of the matrix, k is intrinsic permeability, and n is porosity.

This means that the pore space has a structured distribution of fluids depending upon the wetting angle of each fluid. Depending upon how far down the flow path one is, the pore space may be filled with one end member of the multi-phase assemblage or another. In a system such as CO_2 - CH_4 - H_2O for instance, at early parts of the flow path the pores will be rich in CO_2 . At more distal parts the pores will be rich in CH_4 .

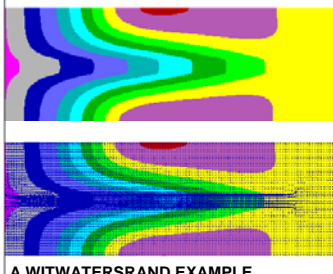


Relative permeabilities, k_r^w , k_r^g , vs effective saturation, S_e

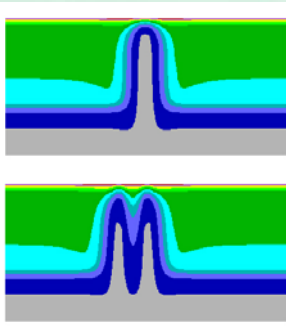
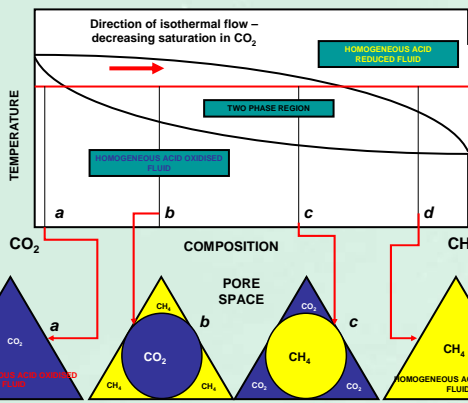
PORE FLUID DISTRIBUTIONS IN 3-PHASE SYSTEM



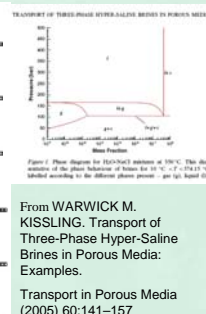
SATURATION DISTRIBUTION. THIS EQUATES TO pH-EH DISTRIBUTION



A WITWATERSRAND EXAMPLE



A YILGARN EXAMPLE



Transport in Porous Media (2005) 60:141-157

Multi-phase flow provides a mechanism for supplying fluid to a site with a range of fluids with pH's and Eh's intimately structured within the pore space. Thus, different fluid conduits for different fluids are not required to supply contrasting fluid chemistries to a mineralising site. The complete range of chemistry is delivered in each pore ready for reaction with the country rock.

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