Some problem to produce of non conventional or tight gas formation in Hungary

Society of Petroleum Engineers

SPE HUN Gas Exploration and FD in the Pannonian Basin

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Questions

- How we characterize this type of rocks?
- Are we need any special measurement, or special treatments of these kind rock?
- The wettability properties may cause problem?
- Compressibility may cause problem?
- Is there any chance to produce this kind of formation?

Characterization of non-conventional or tight gas formation

- **Why we need reservoir characterization?**
  - ✓ Determination of the rock parameters requested to build up geological model of tight gas formation or BCGA resource
  - ✓ Determination of the parameters need to estimate the reserves of tight gas formation or BCGA resource
  - ✓ We need some petrophysical properties of tested formation to estimate of production capacity of drilled and fractured wells.

Characterization of non-conventional or tight gas formation

- **What kind measurements necessary to good formation characterization?**
  - ✓ **Routinely performed petrohysical**

    Porosity measurement (with Helium pycnometry, with brine re- saturation method and with mercury injection)

    Gas and water permeability measurement (with Nitrogen and brine)

  - ✓ **Special measurements (1)**

    Determination of initial water saturation or connate water saturation (i.e. Dean-Stark method) or probable connate water saturation (i.e. re-saturation and displacement method)

Characterization of non-conventional or tight gas formation

- **What kind measurements necessary to good formation characterization?**
  - ✓ **Special measurements (2)**

    Pore throat distribution, subsurface area of the tested rocks,

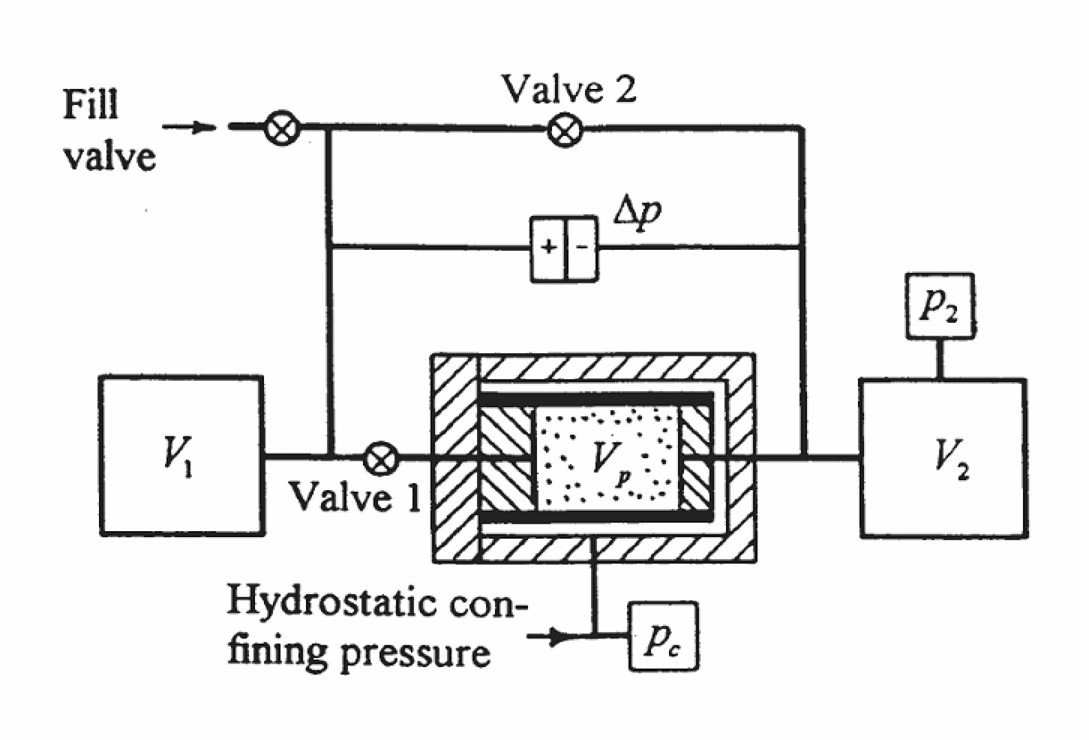
    Capillary pressure curve and connate water saturation from mercury injection data

    Wettability and spontaneous imbibiton measurement

Equipments and measurement methods

Permeability measurement

Pulse Dacay permeability measurement



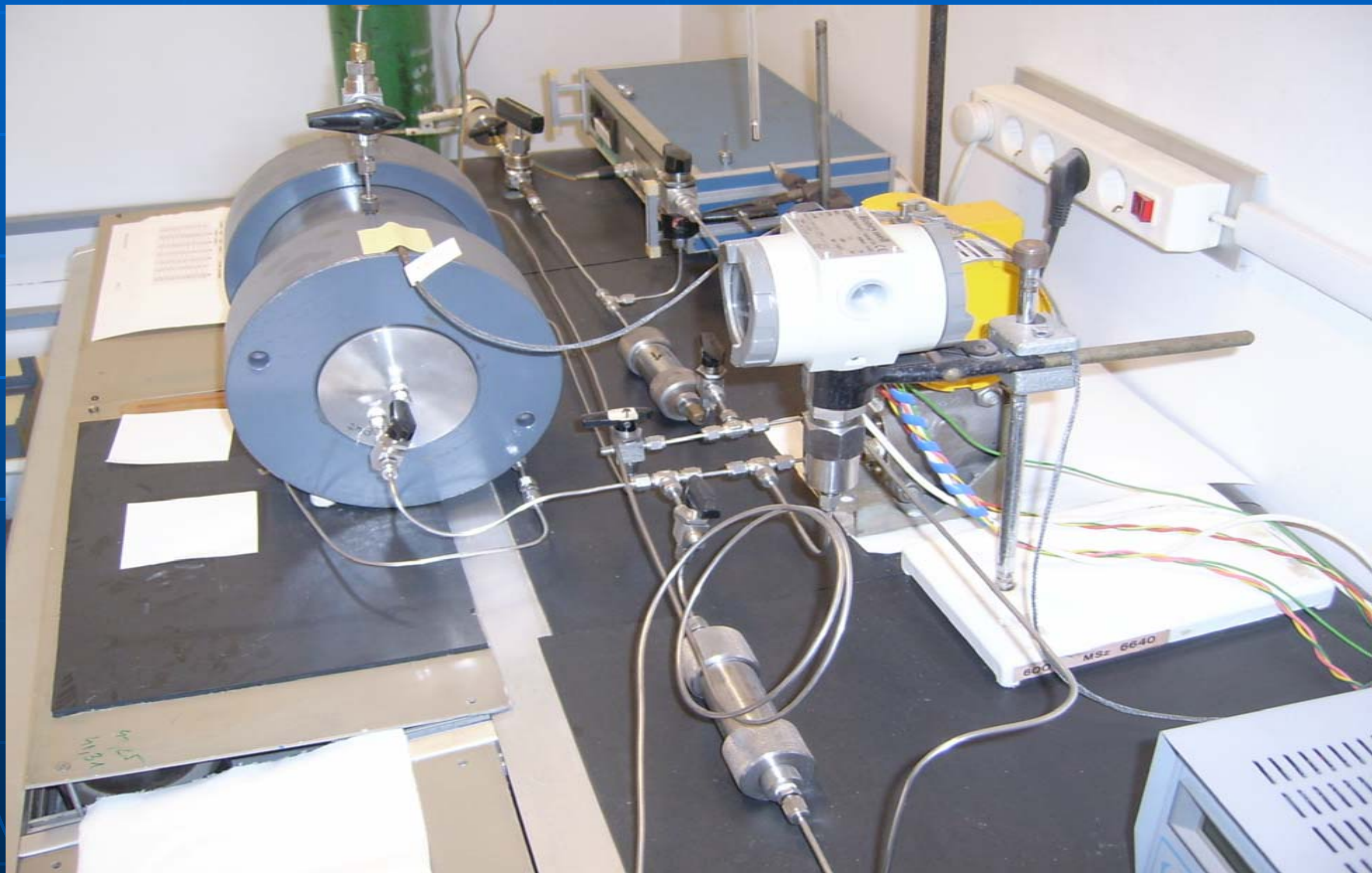
S. C. Jones

$$\ln\left(\frac{\Delta p}{\Delta p_0}\right) = b + m_1 \cdot t$$

$$k_w = \frac{-m_1 \mu_w l (c_w + c_{v1})}{A\left(\frac{1}{V_1} + \frac{1}{V_2}\right)}$$

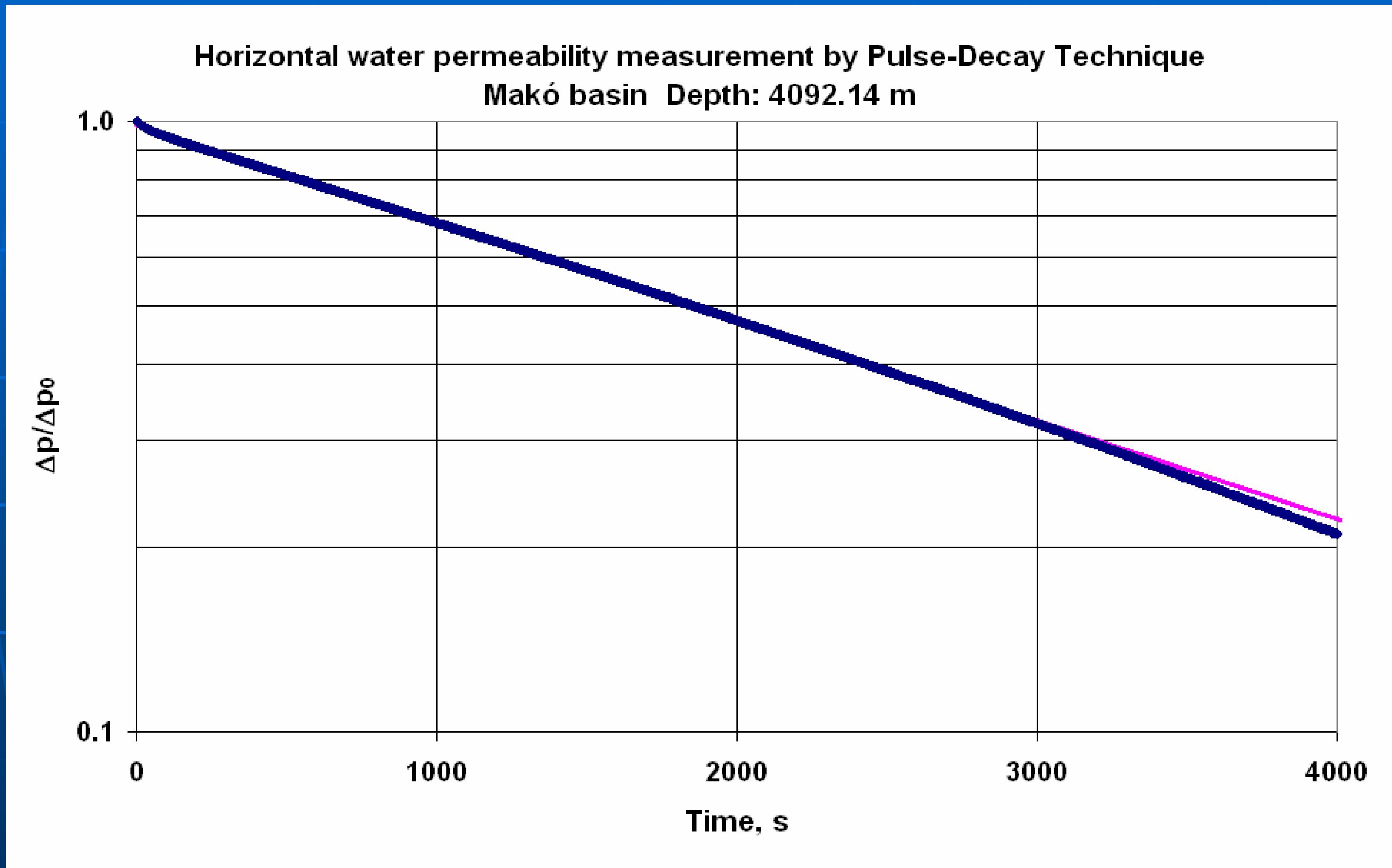
Equipments and measurement methods
Permeability measurement

Pulse Dacay permeability measurement linear or radial system



Equipments and measurement methods

Permeability measurement



$$k_w = \frac{-m_1 \mu_w l (c_w + c_{v1})}{A\left(\frac{1}{V_1} + \frac{1}{V_2}\right)} = 3.34157 \cdot 10^{-7}\,\mu m^2$$

Equipments and measurement methods

Measurement of threshold pressure and connate water

$$V_p = \frac{m_{\text{wet sample}} - m_{\text{dry sample}}}{\rho_{\text{brine}}}$$

$$V_{\text{w out}} = \frac{m_{\text{wet sample}} - m_{\text{disp sample}}}{\rho_{\text{brine}}}$$

$$S_{\text{wirr}} = S_{\text{wc}} = \frac{V_p - V_{\text{w out}}}{V_p}$$

Equipments and measurement methods

Determination of capillary pressure curve and connate water saturation

$$p_{c\,w/g} = \frac{\sigma_{w/g}\cos\theta_{w/g}}{\sigma_{Hg/Air}\cos\theta_{Hg/air}} \cdot p_{c\,Hg/Air}$$

Purcell usinig the Poiseuille and Darcy's laws derived

$$k = \frac{(\sigma\cos\theta)^2\phi}{2}\sum_{i=1}^{N}\frac{S_i}{P_{ci}^2}$$

Lithology factor F

$$k = \frac{(\sigma\cos\theta)^2\phi F}{2}\sum_{i=1}^{N}\frac{S_i}{P_{ci}^2}$$

$$\sum_{i=1}^{n_i}\frac{S_i}{(p_{ci})^2} \cong \left[\frac{\Delta S}{(p_c)_{av}^2}\right]_j$$

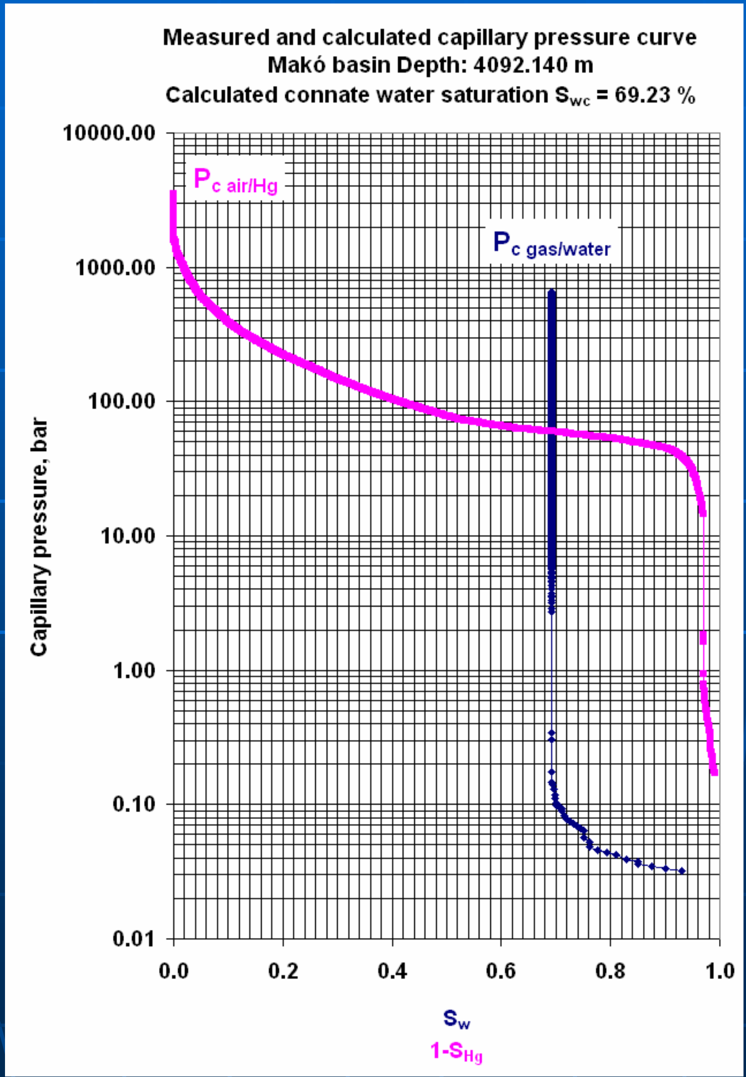
$$\sum_{i=1}^{N}\frac{S_i}{(p_{ci})^2} = \sum_{j=1}^{r}\sum_{i=1}^{n_j}\frac{S_i}{P_{ci}^2} = \sum_{j=1}^{r}\left[\frac{\Delta S}{(p_c)_{av}^2}\right]_j$$

$$\lim_{\substack{\Delta S\to 0\\ r\to\infty}}\sum_{j=1}^{r}\left[\frac{\Delta S}{(p_c)_{av}^2}\right]_j = \int_{S=0}^{1}\frac{dS}{p_c^2} = \sum_{i=1}^{N}\frac{S_i}{P_{ci}^2}$$

$$\sum_{i=1}^{n_i}\frac{S_i}{(p_{ci})^2} = \int_{S=0}^{1}\frac{S_i}{(p_{ci})^2}$$

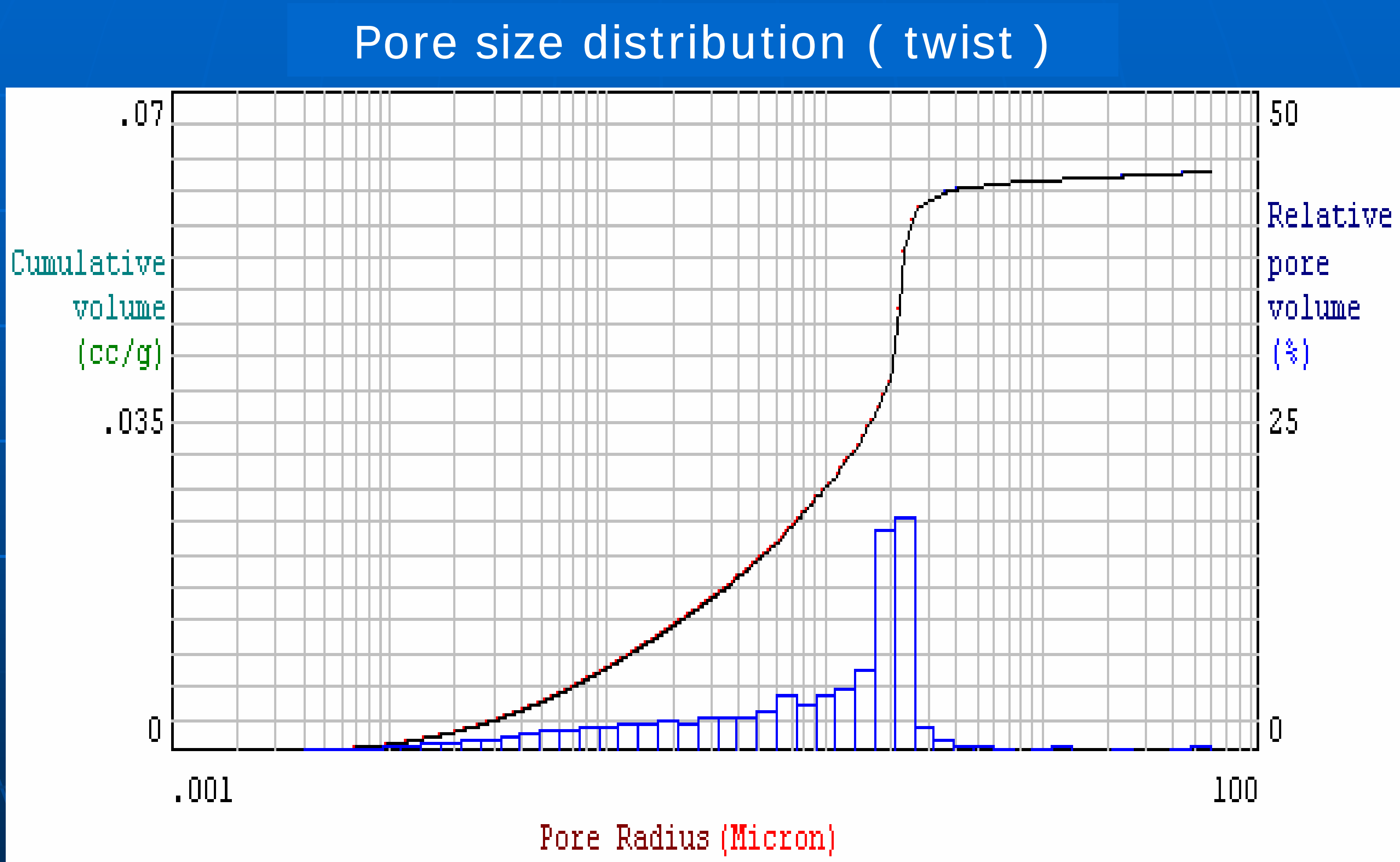
Equipments and measurement methods

Determination of capillary pressure curve and connate water saturation



Equipments and measurement methods

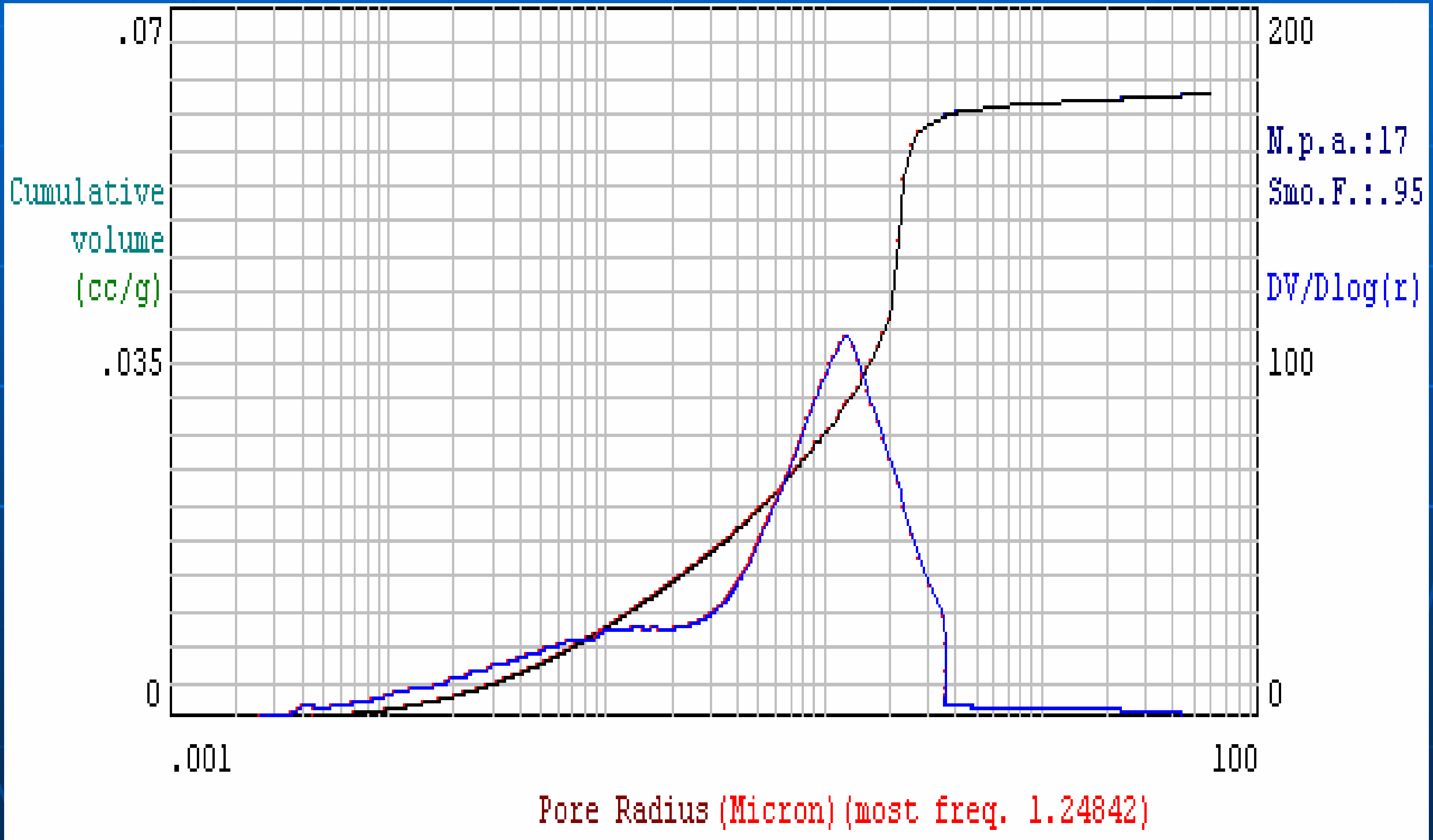
Determination of capillary pore throat distribution



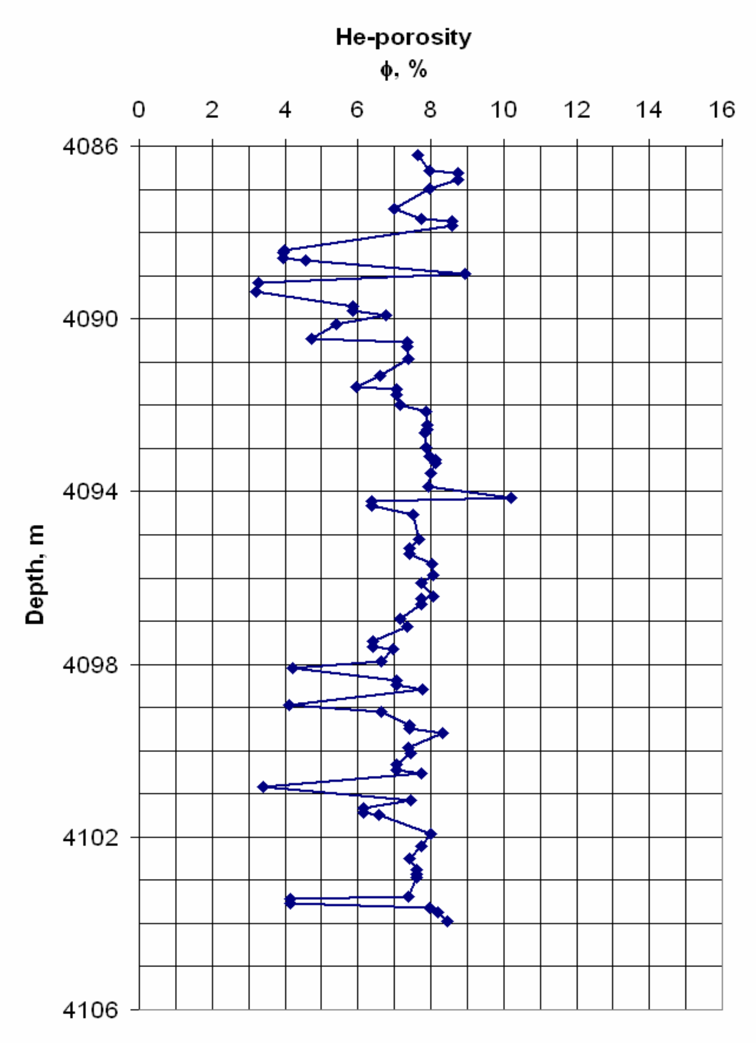
Equipments and measurement methods

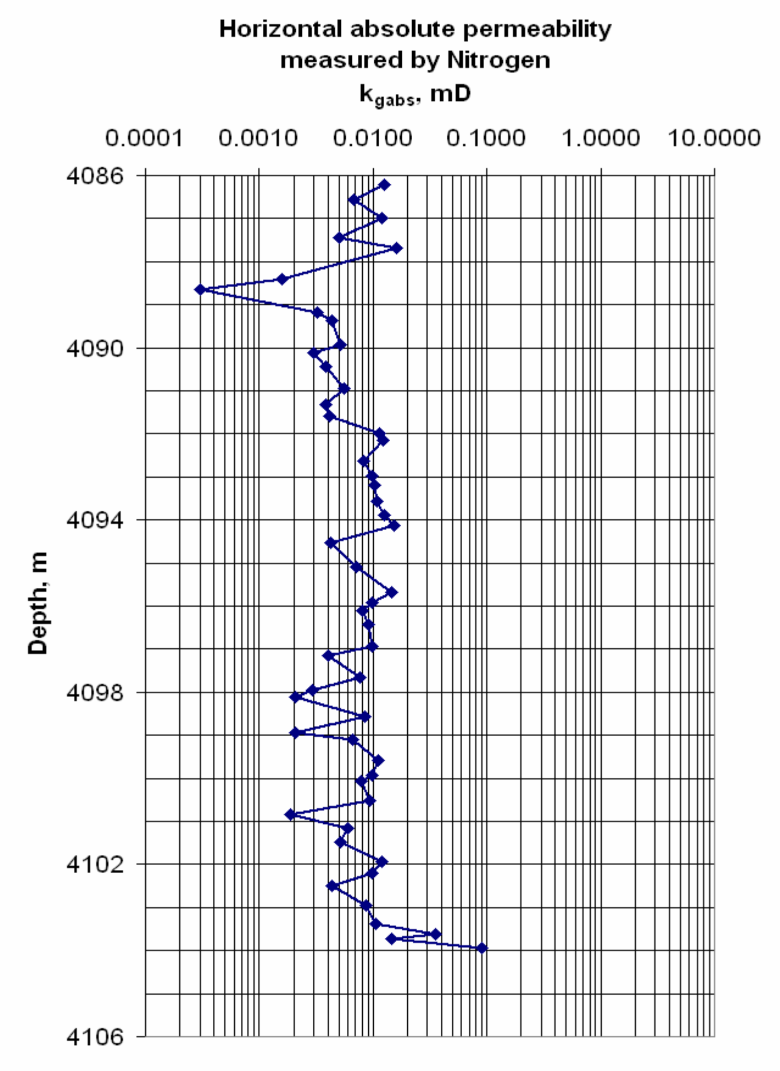
Determination of capillary pore throat distribution

Pore size distribution (twist)



Measurement results of deep zone of Makó basin





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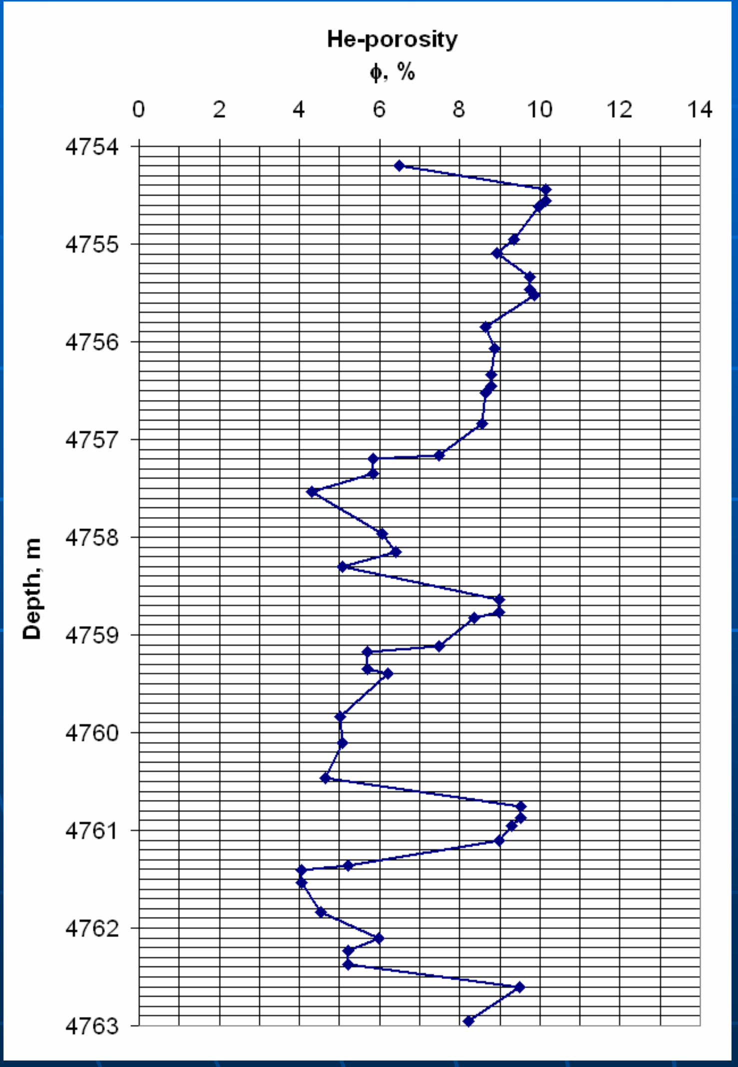

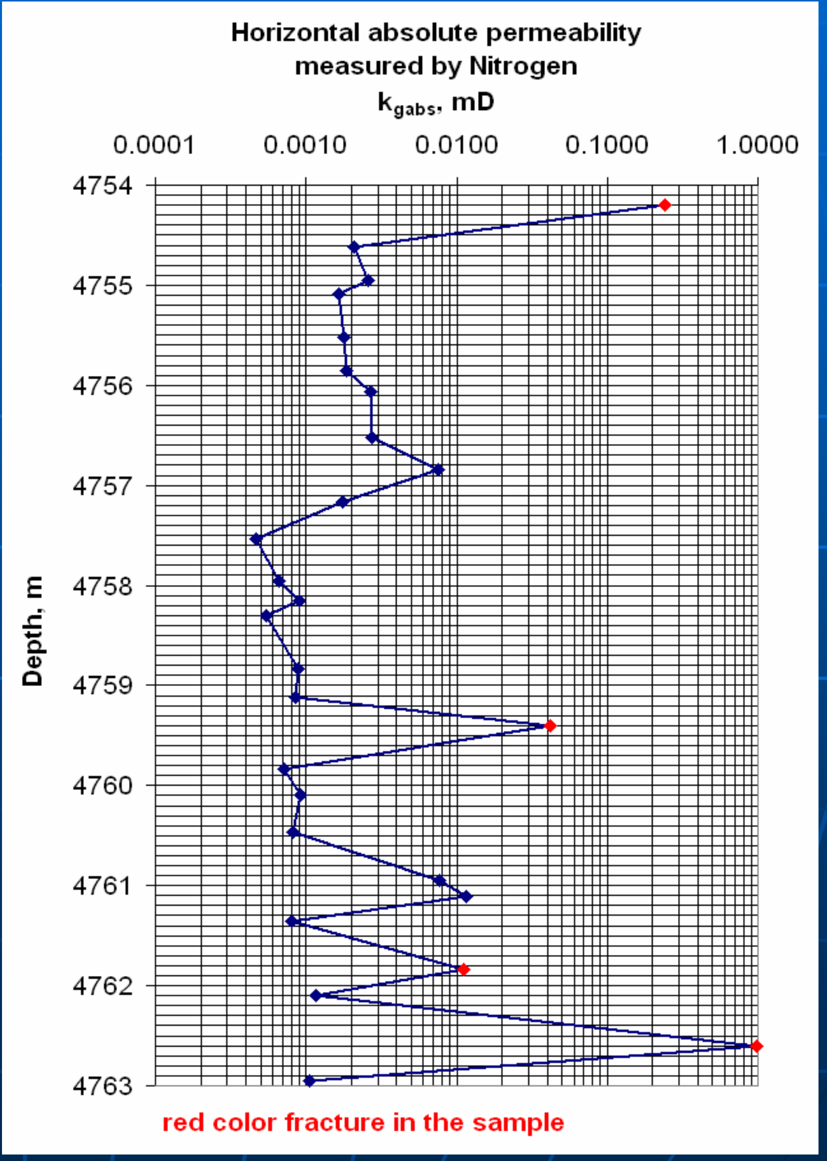

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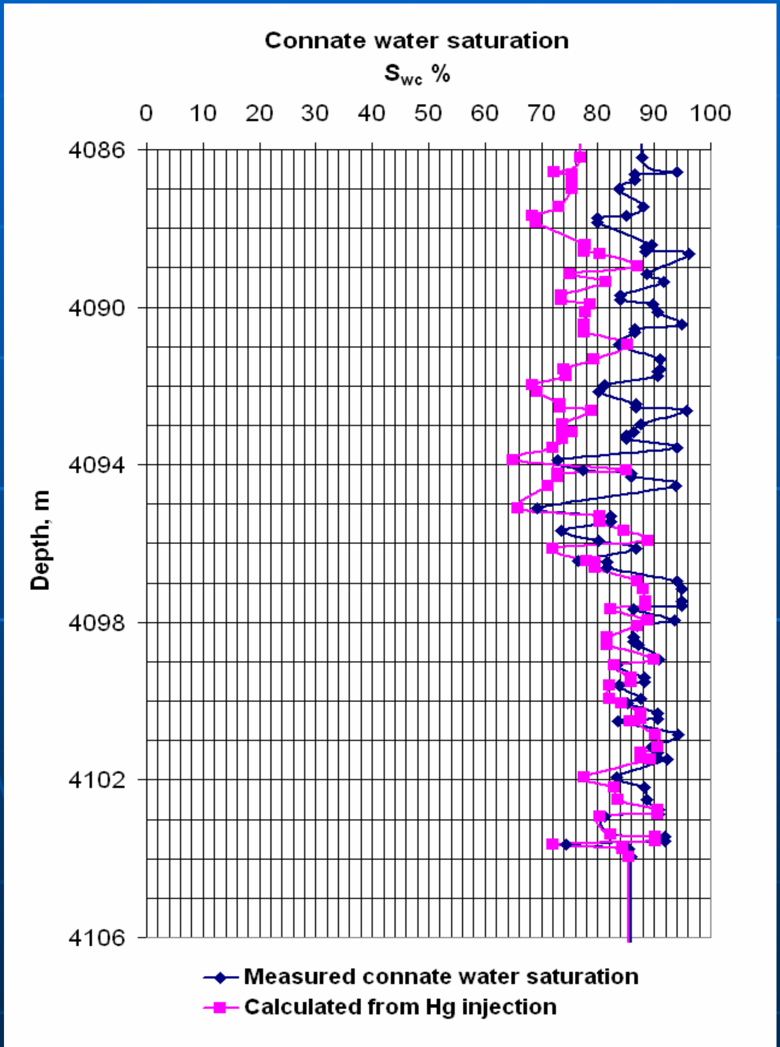

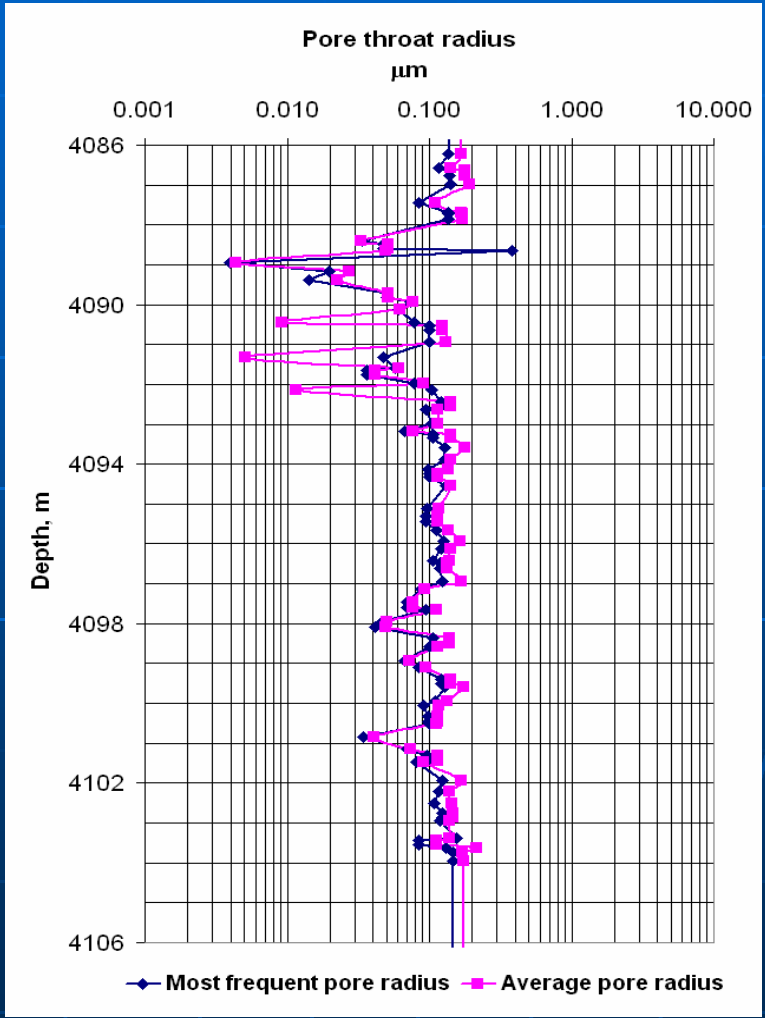

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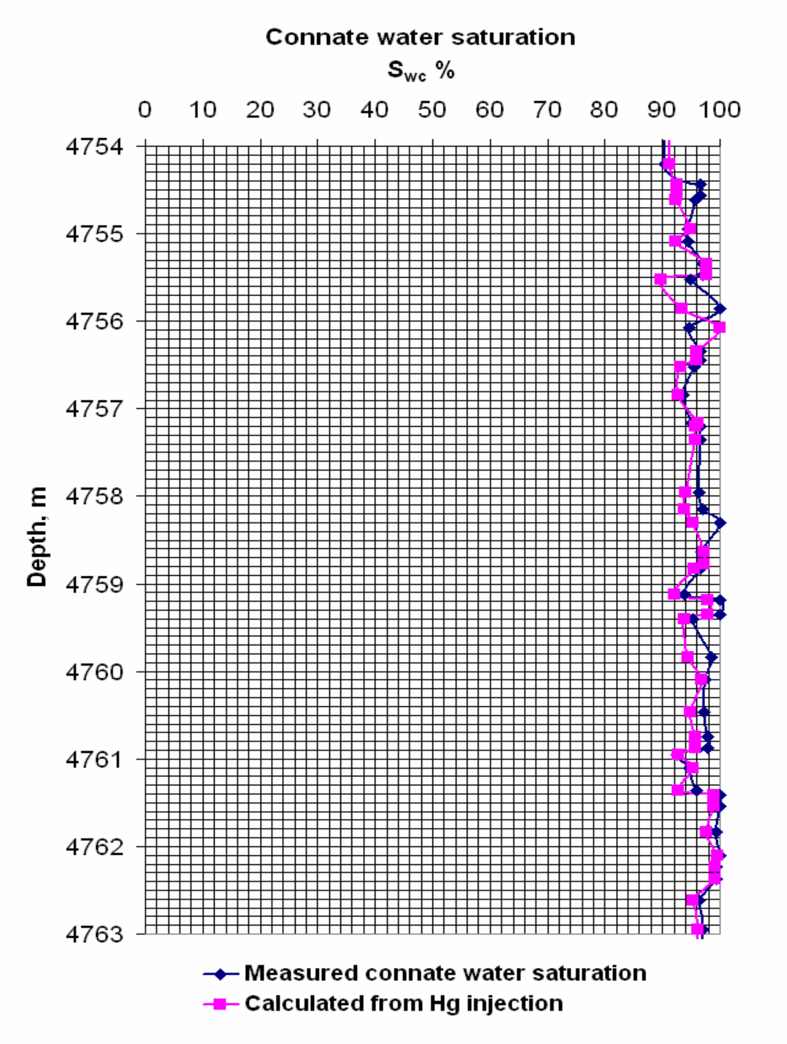

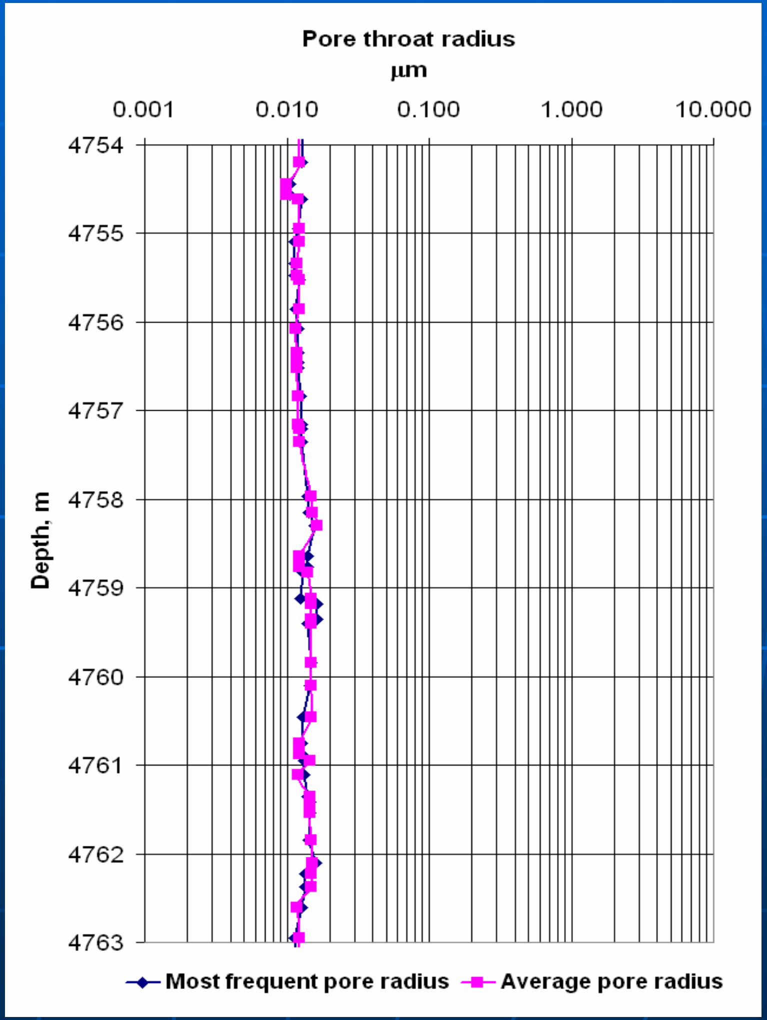

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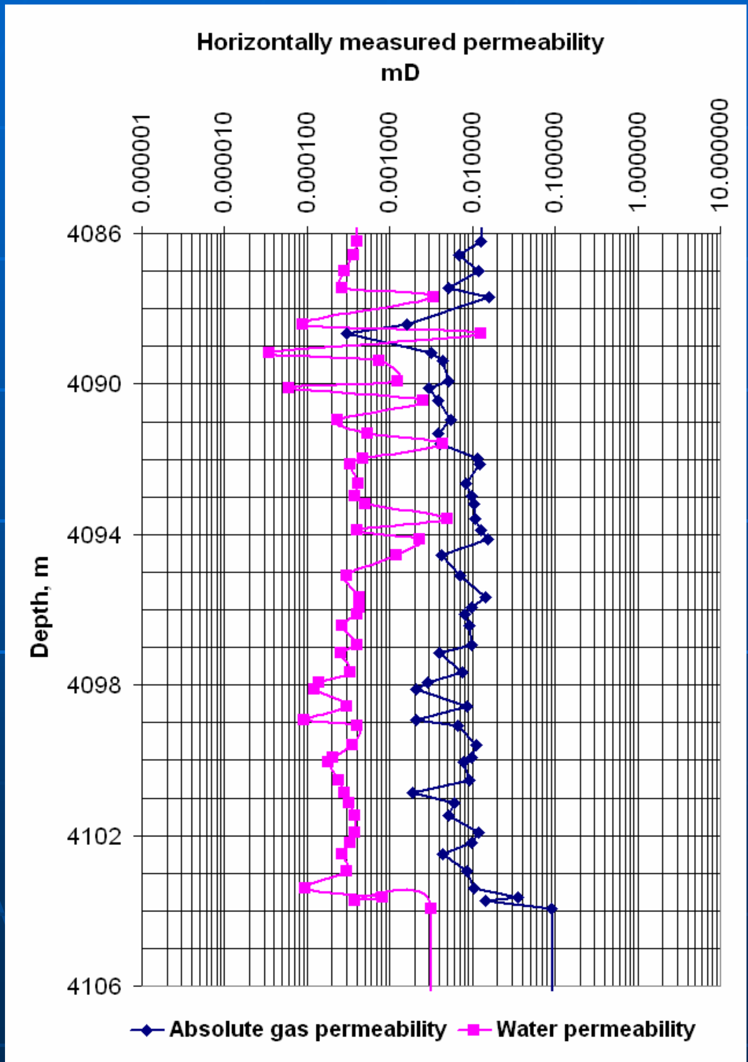

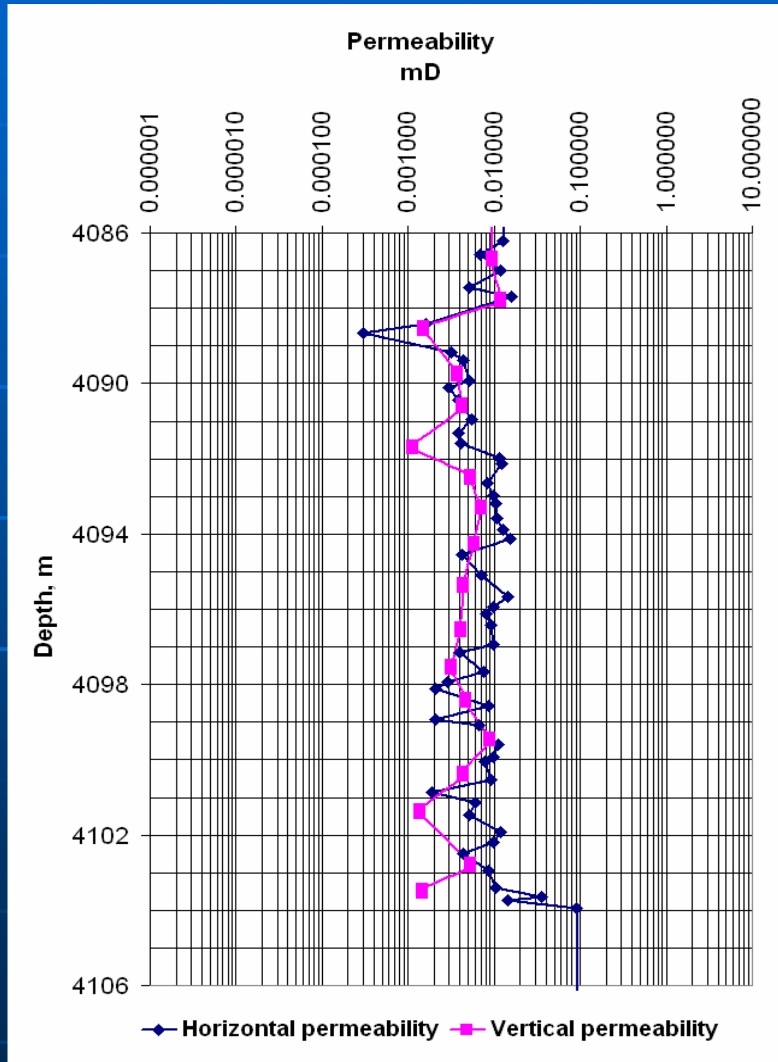

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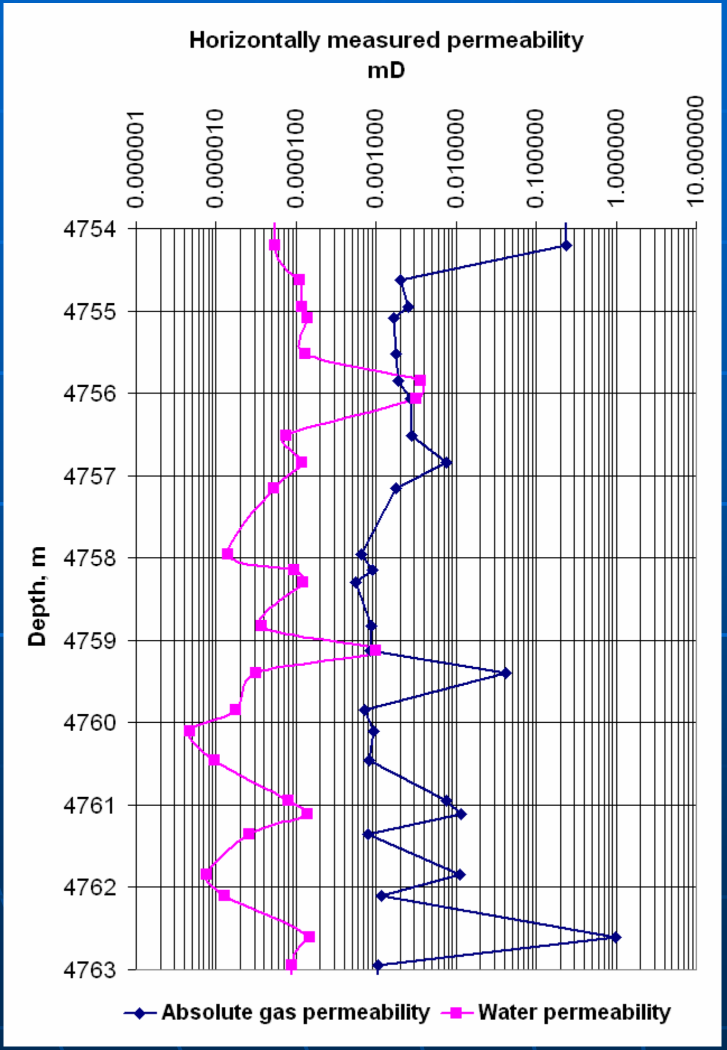

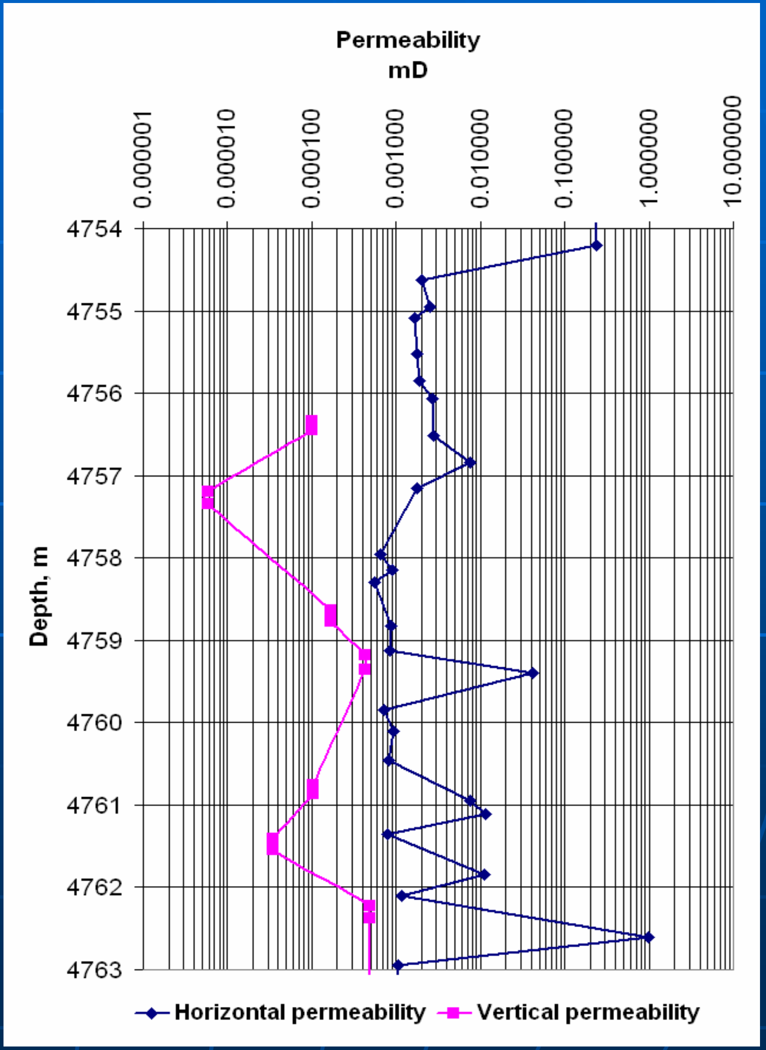

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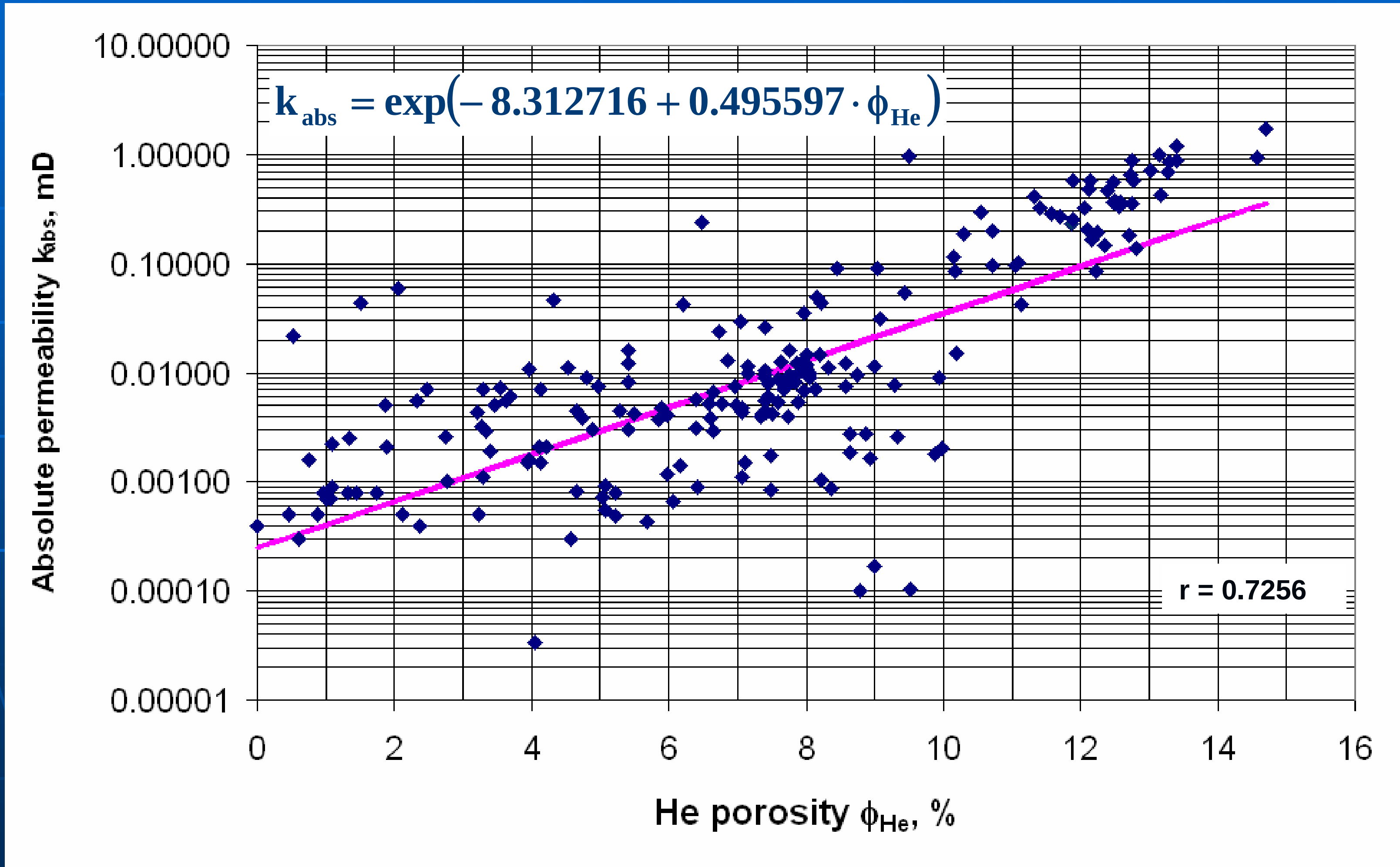

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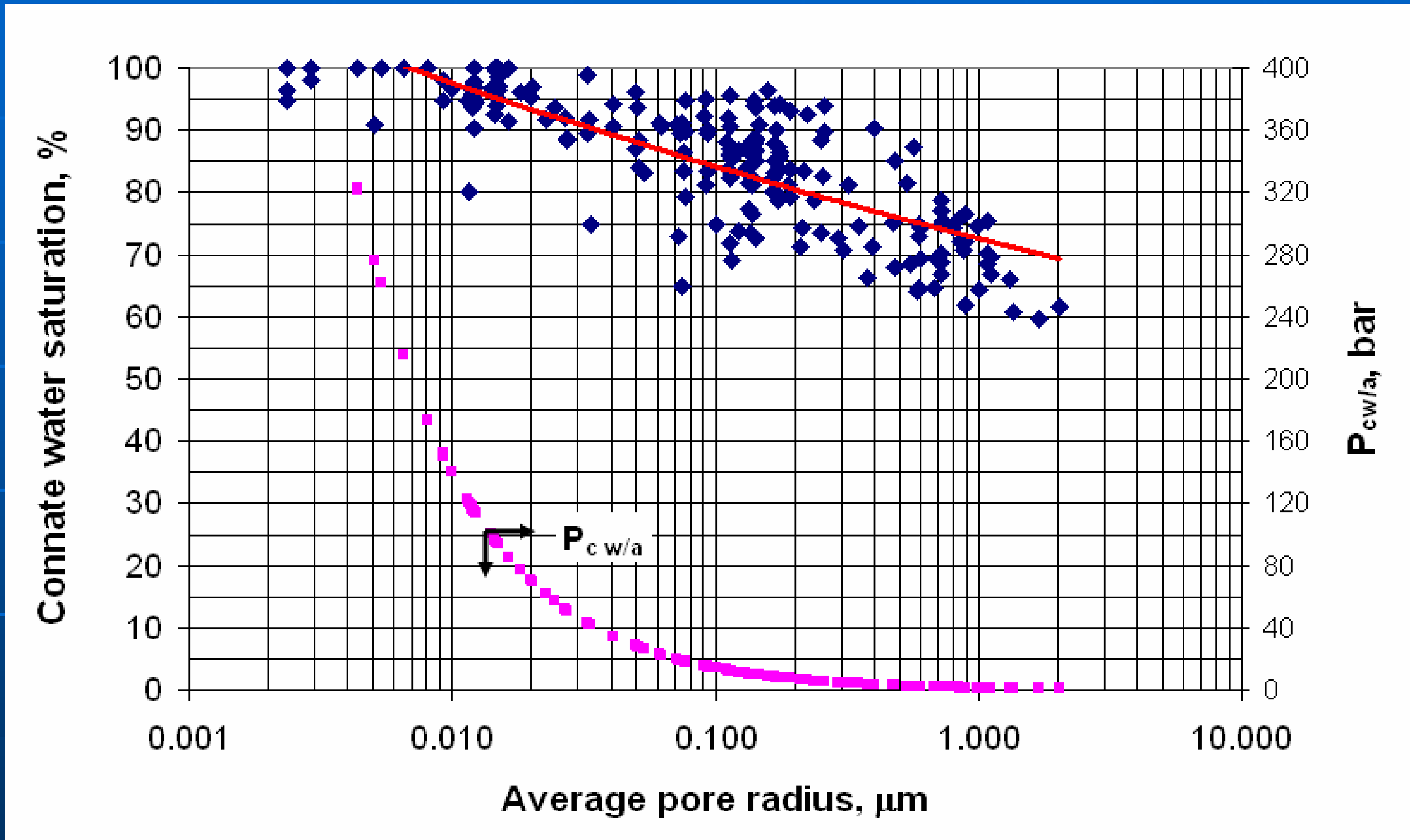


$$p_{c\,w/a} = \frac{2\sigma_{w/a}\cos\theta_{w/a}}{r_a}$$

$$S_{wi} = 72.589264 - 5.356965\ln(r_a)$$

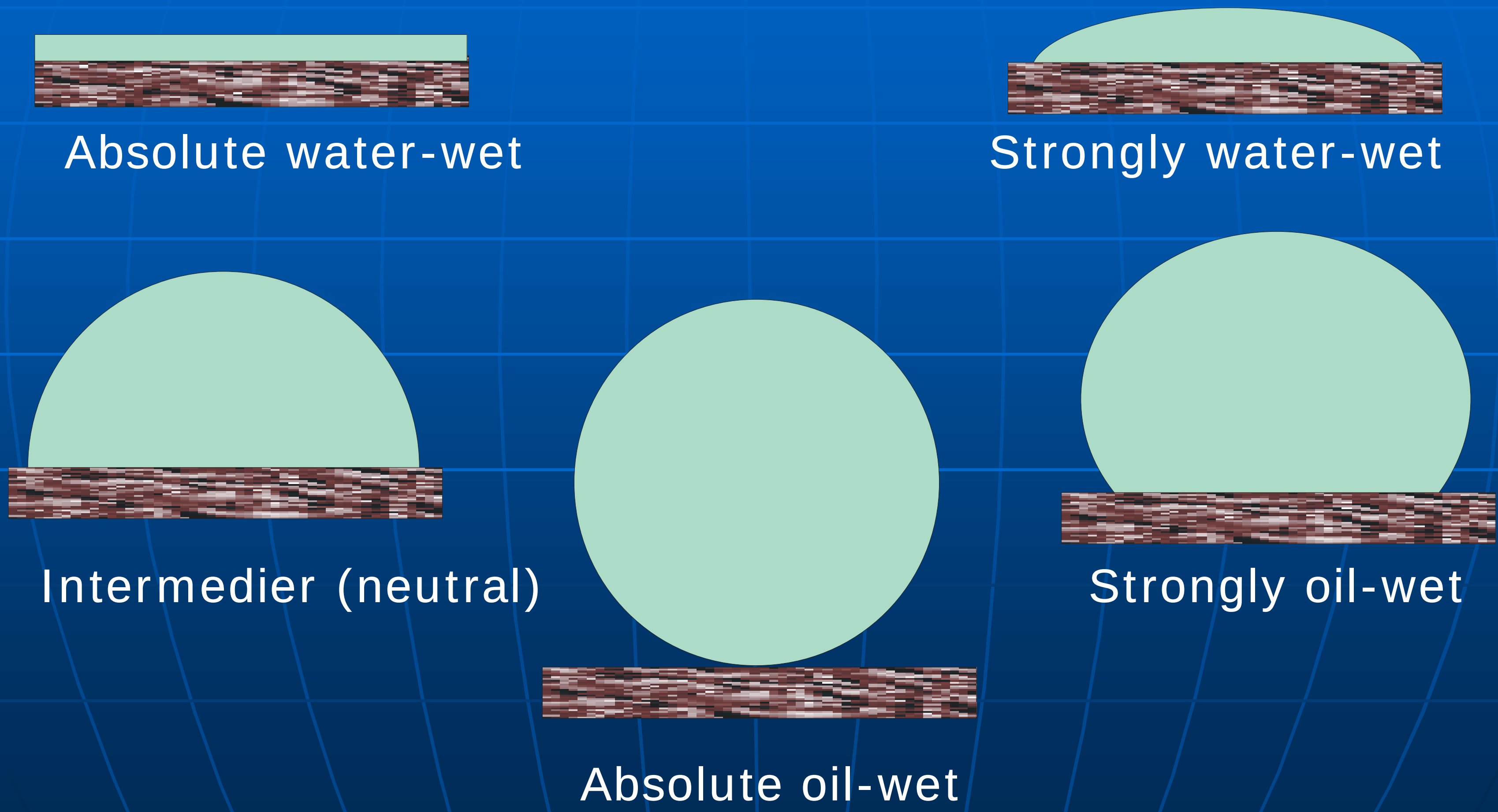
$$r = 0.8117$$

The wettability properties may cause problem?

First of all, it should be emphasized that the results of the wettability measurements didn’t give any answer for the fundamental question whether the formation rocks in the reservoir were ever contacted with water or not.

Therefore, the conclusions can only be used to predict the effects when the tested core samples get into the contact with water and what will be its consequences.

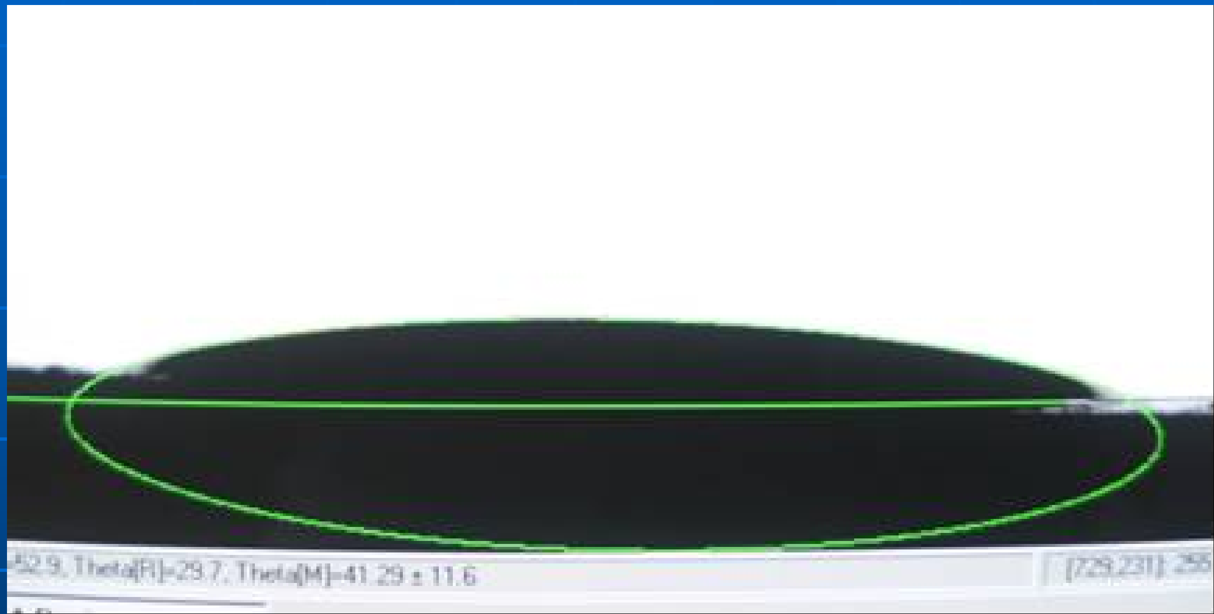
Wettability and spontaneous imbibiton character of rocks



Wettability and spontaneous imbibiton character of rocks

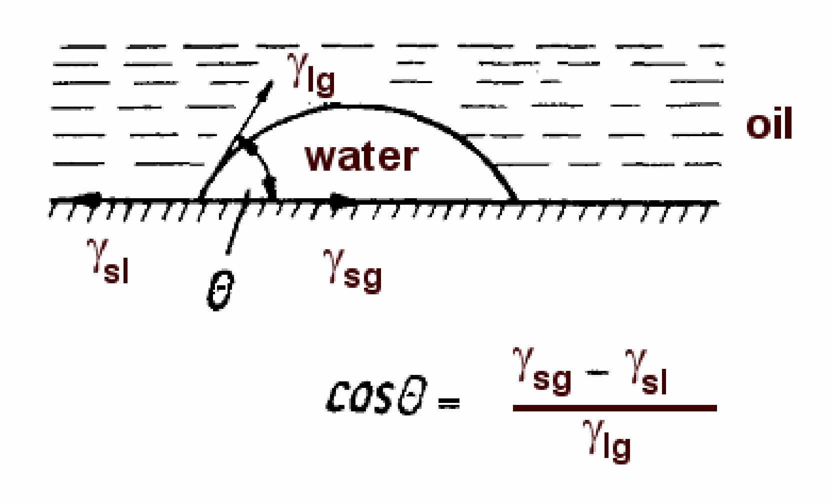
Krüss G10 computer controlled contact angle measuring device

Wettability and spontaneous imbibiton character of rocks



Young-Laplace (drop fitting) method: the drop contour can be mathematically described by adapting the Young-Laplace equation for curved boundary areas. The contact angle is determined as the slope of the contour line at the three-phase contact point.

Wettability and spontaneous imbibiton character of rocks



$$\gamma_{sg} - \gamma_{sl} = \gamma_{lg} \cdot \cos\Theta$$

$$\cos\Theta = \frac{\gamma_{sg} - \gamma_{sl}}{\gamma_{lg}}$$

Wettability and spontaneous imbibiton character of rocks

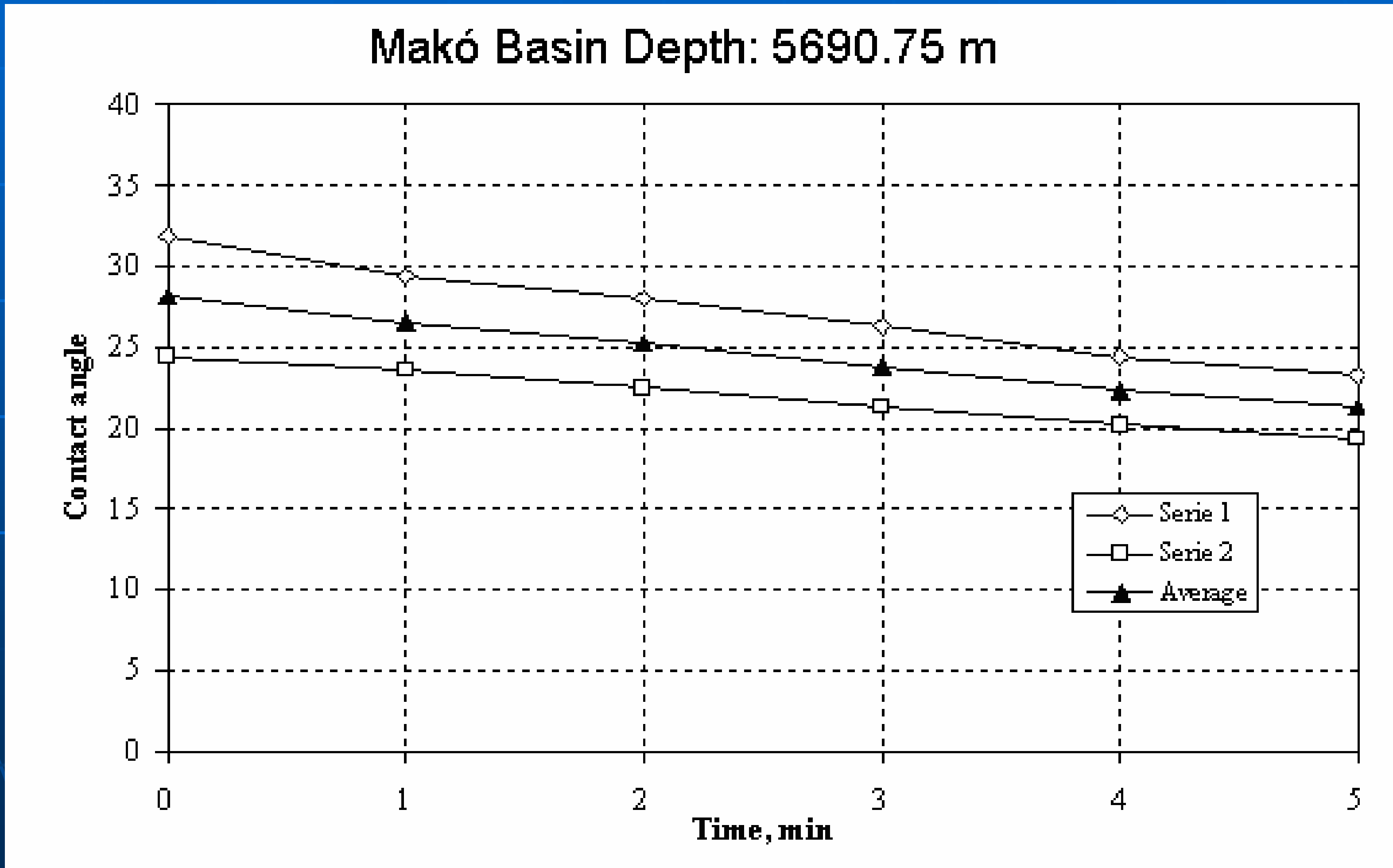
Time, min	Θ_1	Θ_2
0	31.88	24.42
1	29.41	23.62
2	28.01	22.48
3	26.27	21.34
4	24.40	20.20
5	23.22	19.32
Average Θ (t=5 min)		21.27
W, mN/m		67.51

Dupré introduced a new concept of reversible work of adhesion of liquid and solid, W_A, and defined it as

$$W_A = \gamma_{sg} + \gamma_{lg} - \gamma_{sl}$$

This equation is simply the thermodynamic expression of the fact that the reversible work of separating the liquid and solid phases must be equal to the change in free energy of the system.

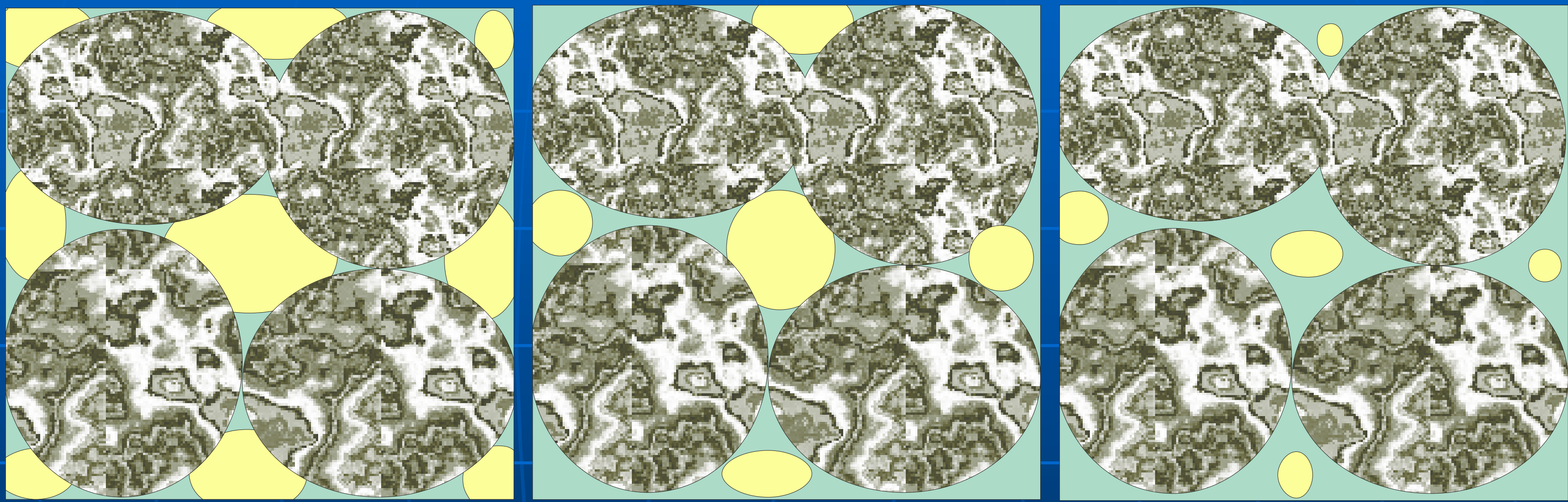
Wettability and spontaneous imbibiton character of rocks



Wettability and spontaneous imbibiton character of rocks

1. Based on the experimental finding we may definitely conclude that all rock samples are strongly water-wet. The measured contact angles were in range of 12° - 29°, and their time dependency was negligible.
2. The lifetime of the droplets on the surface was short (less that 10 min) and in certain cases, the spreading rate was so rapid that the time dependency could not be measure. That phenomenon can be explained by the high reversible work (energy) of adhesion that is usually above 65 mN/m.
3. The fast decease of the drop volume implies that not only the spreading and the high adhesion force between the water and the rock surface is responsible for the small contact angles, but the enhanced spontaneous water imbibition by microfractures and micropores (capillaries) detected by the Hg porosimetry in the same rock samples.

Wettability and spontaneous imbibiton character of rocks



Low water saturation Medium water saturation High water saturation

Wettability and spontaneous imbibiton character of rocks

$$2 \cdot \pi \cdot r \cdot \gamma \cdot \cos\Theta = \pi \cdot r^2 \cdot \rho \cdot h \cdot g$$

$$P_c = \frac{2 \cdot \gamma \cdot \cos\Theta}{r}$$

$$P_c = P_l - P_g = \gamma \cdot \left(\frac{1}{r_1} + \frac{1}{r_2} \right)$$

$$v \equiv \frac{dh}{dt} = \frac{1}{8 \cdot \eta \cdot h} \left[\frac{2 \cdot \gamma \cdot \cos\Theta}{r} - \rho \cdot g \cdot h \right] \cdot r^2$$

the independent parameters determining the rate are

the viscosity of water,
surface tension,
radius of the capillary
wettability

Wettability and spontaneous imbibiton character of rocks

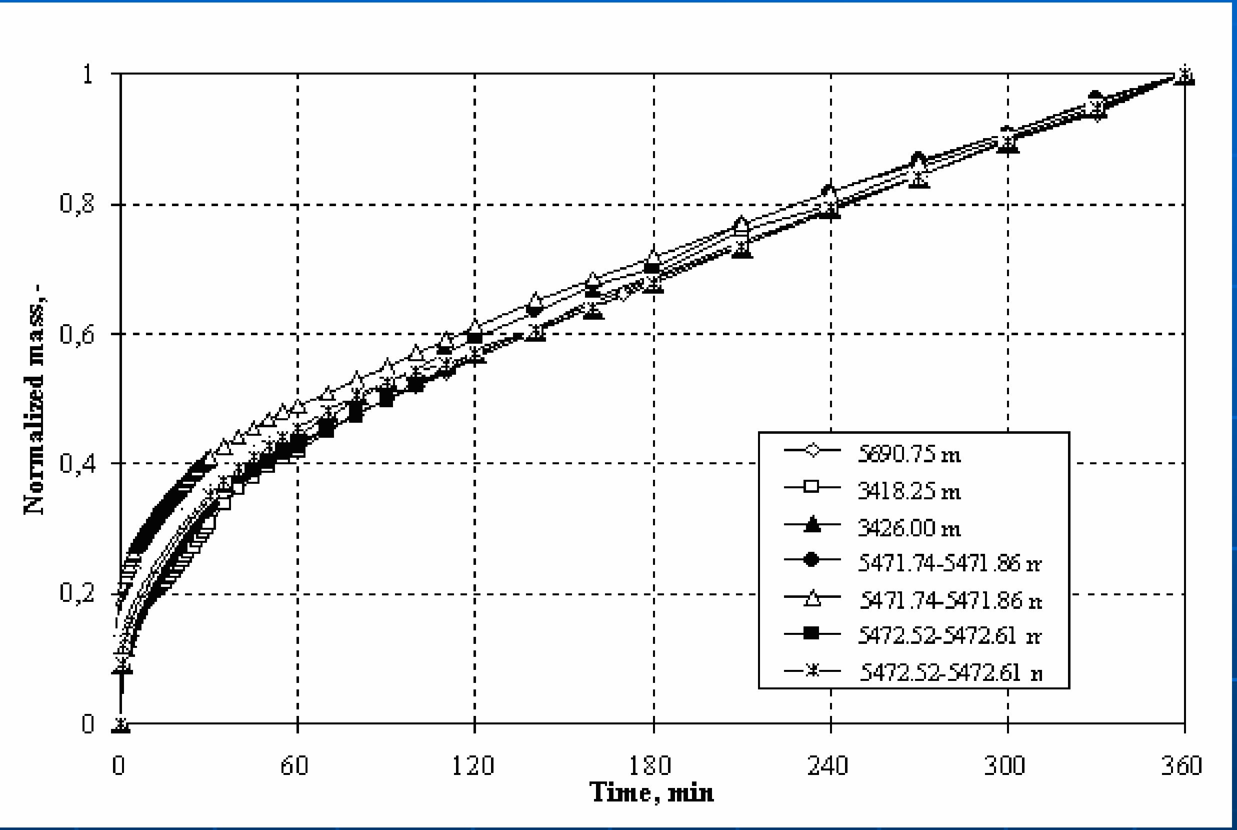
Semiautomatic apparatus for imbibition tests

Wettability and spontaneous imbibiton character of rocks

Trends of the imbibition tests met the expectation. In the first period, the imbibition of water is very rapid, and then it is gradually slowing down. It can be observed, however, that the change of absolute weight is approaching a constant value though, but never reaches it (plateau region) as the *Washburn* equation suggests

The only conclusion what we may draw is that the imbibition rate is high in all instances, the 60-80% of the pore space is saturated with water within 50-60 min.

Wettability and spontaneous imbibiton character of rocks



The difference among the curves in negligible and that fact definitely indicates similarity in capillary behavior and independence of location (depth) where the samples were taken from.

The wettability properties may cause problem?

1. Two fundamental consequences must be take into account, when we assume that the formation is normal reservoir
   - First, the probable gas content (OGIP, resource) might be very low because of the high irreducible water saturation.
   - Second, potential of gas production from these pore spaces might be much less than expected because of the extremely high critical capillary pressure, which can be as high as some hundreds bars.

2. If the formations tested in the present laboratory project have never been in contact with water, and the gas displacement mechanism is not a water drive, it is strongly recommended to avoid any well operation and technology, which is based on extensive application of water-base fluids. Using water-containing drilling muds, well completion, hydraulic fracturing, acidization, conformance treatment, bottom cleaning fluids and scale and corrosion inhibition, etc., not only the well, but even the productive pay zone can be killed.

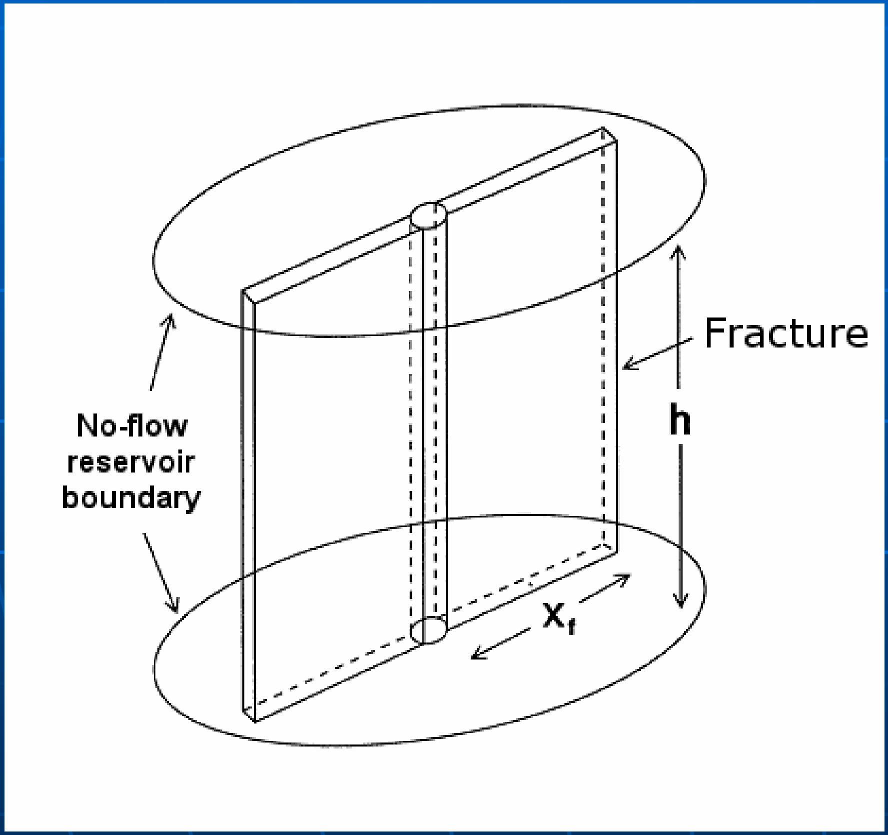
Compressibility may cause problem?

Presently we have no any information about the compressibility of the rock derived from Makó basin.

It is possible that the measured low porosity properties of the tested rocks not as much as we expected.

It may happen that the porosity at reservoir condition much more less as we measured at laboratory condition

Is there any chance to produce this kind of formation?



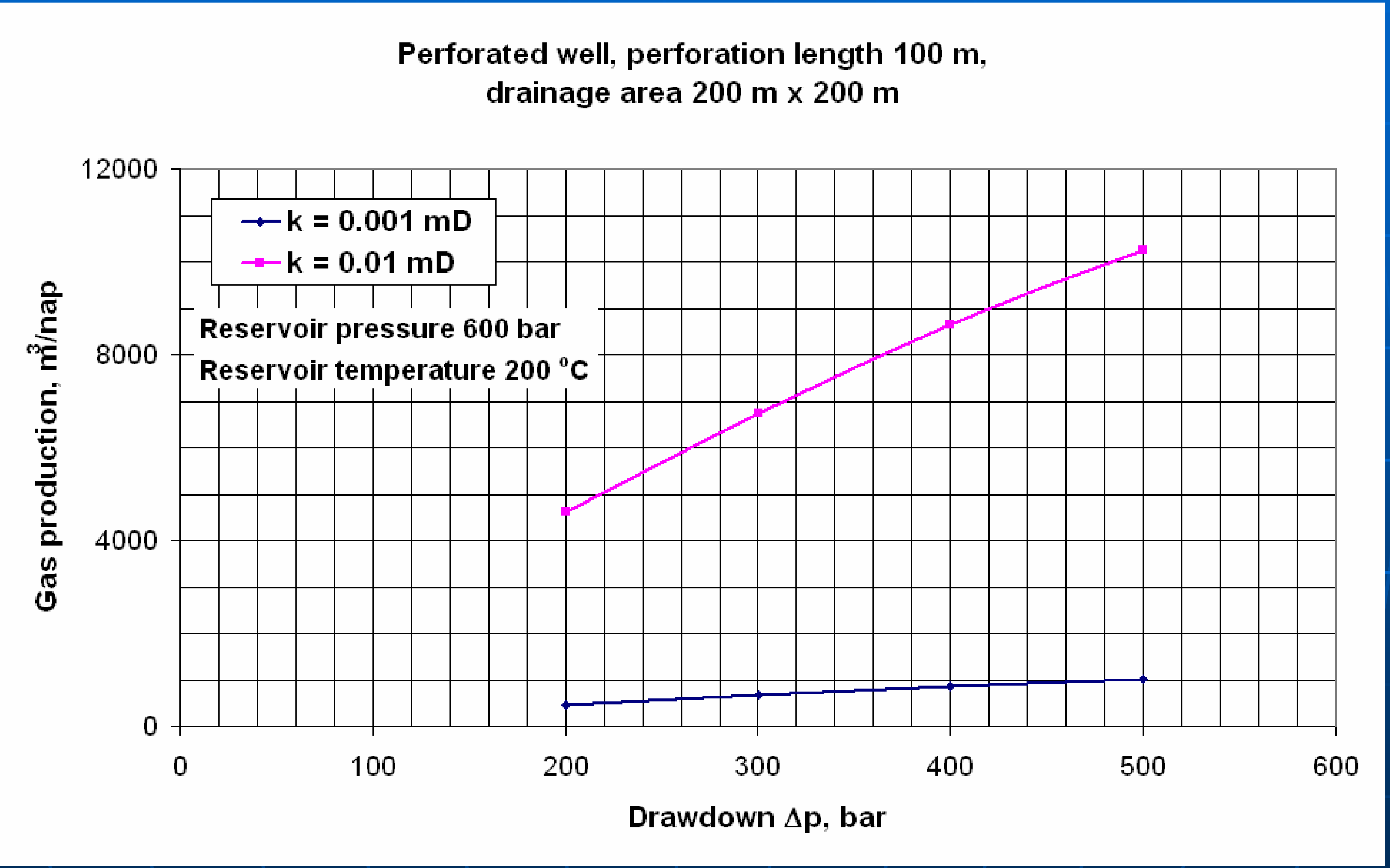
Finite conductivity factures

$$F_{cD} = \frac{k_f w_f}{k\, x_f} > 300$$

Infinite conductivity factures

Uniform flux factures

Is there any chance to produce this kind of formation?



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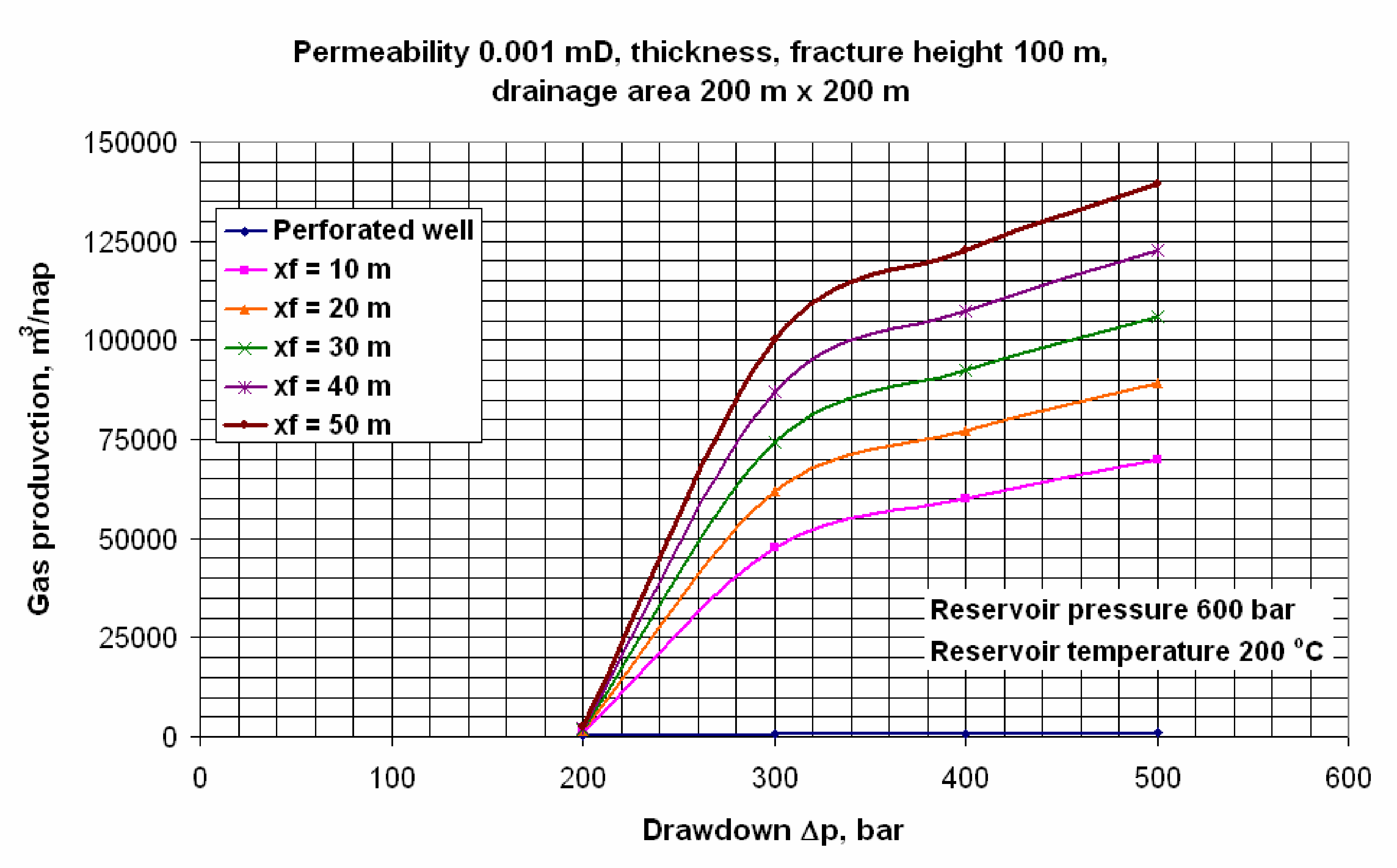

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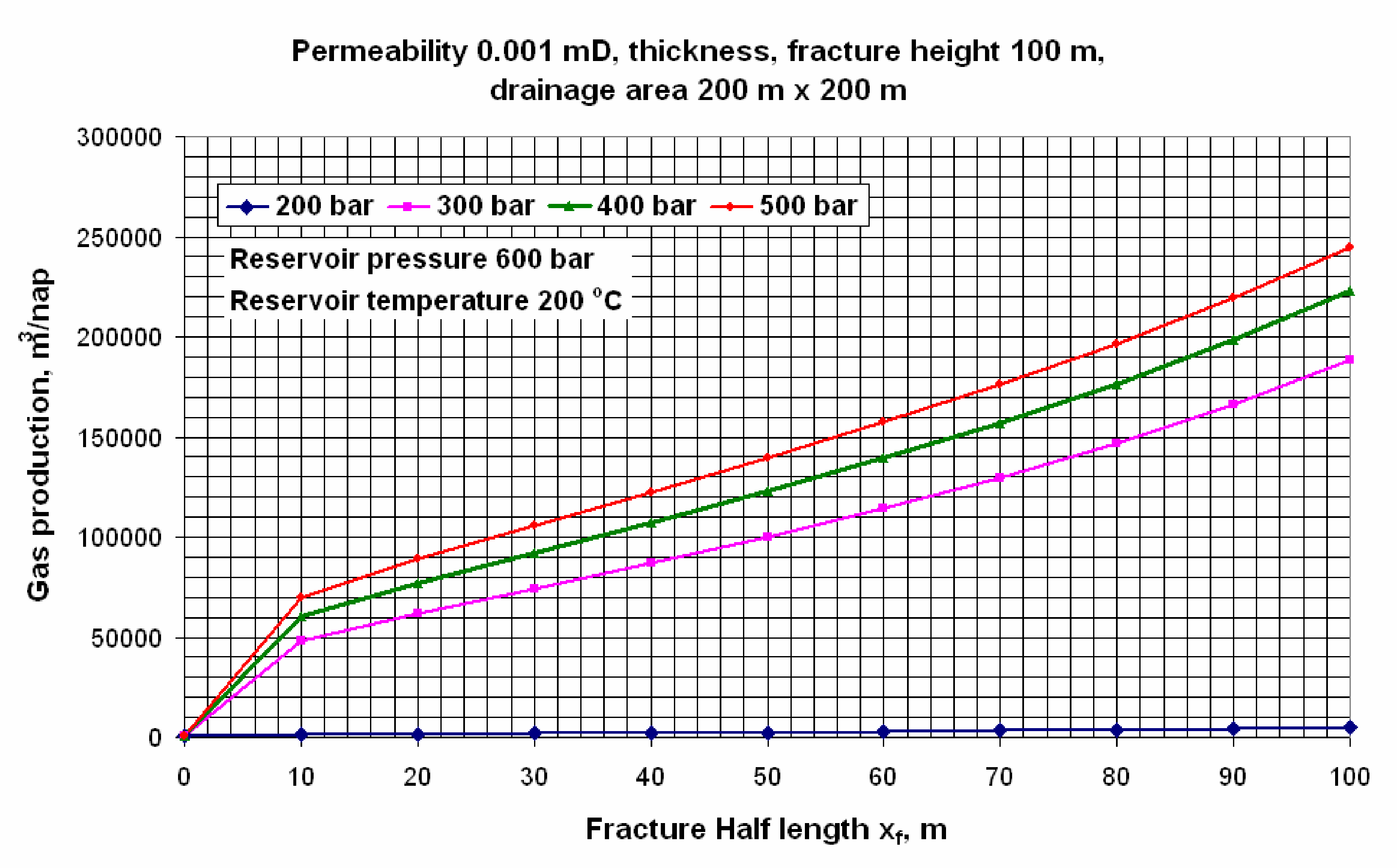

Tank you for attention and patience!