Permeability in coal

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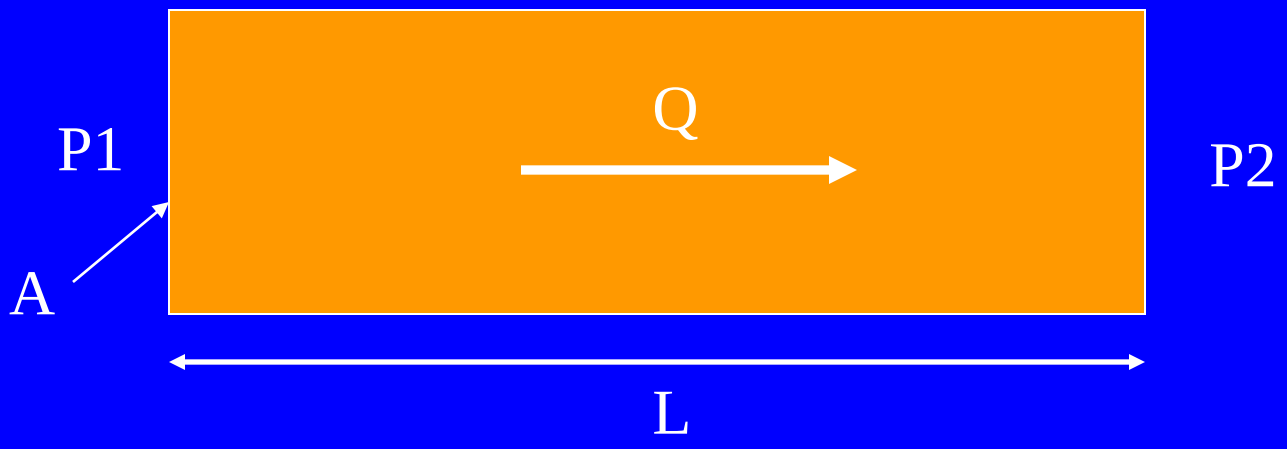
- What is permeability
  - Permeability and diffusivity
  - Absolute and effective
- How is it measured, lab and field
  - How are these tests analysed
- What effects permeability and drainage
  - Saturation
  - Effective stress
  - Borehole damage (skin)
  - Size of sample or volume of coal tested

Darcy's law

$$k = \frac{Q\mu}{A}\frac{L}{P_1 - P_2}$$

Example: 1D steady state flow through core.



Units of permeability

K is used in ground water hydrology and has units of velocity (L/T)

k (intrinsic permeability) has units of area, L^2

$$K = \frac{k\gamma}{\mu}$$

k is a property of the rock only while K depends also on fluid properties.

1 Darcy = 9.87 x 10^{-13} metres squared

Hydraulic Diffusivity

Darcy's law + continuity equation = diffusion equation

The diffusion equation governs fluid flow and pressure diffusion in a porous medium and holds for small pressure gradients, small fluid compressibility, and porosity and permeability that do not depend on pressure.

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} = \frac{\phi \mu c}{k} \frac{\partial p}{\partial t}$$

Hydraulic diffusivity

Relative permeability

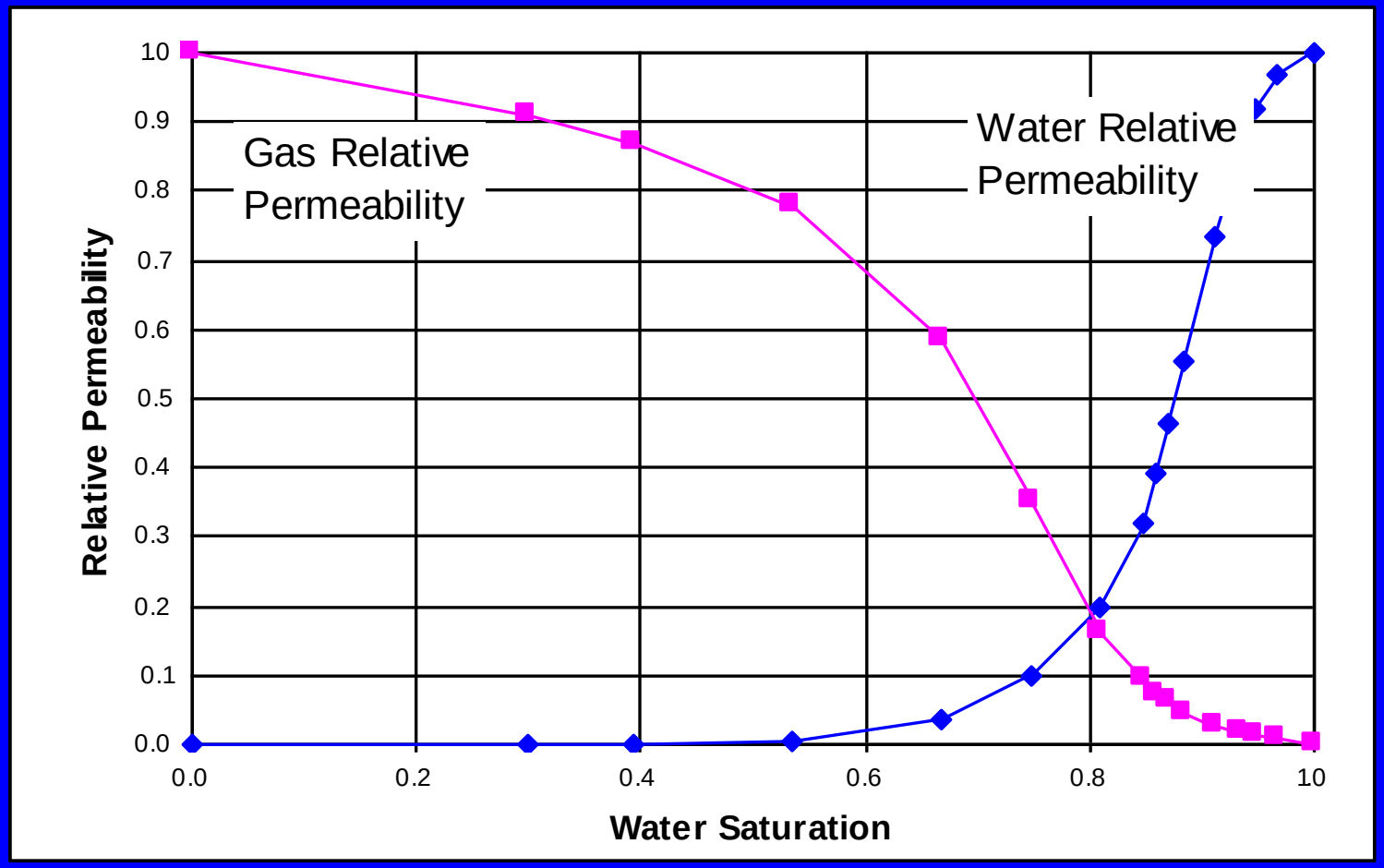
When more than one fluid (phase) is present in the reservoir, the permeability to each phase is reduced relative to single phase permeability (absolute permeability).

For example, the permeability of the rock to water when water and gas are present depends on the water and gas saturation.

$$k_{rw} = \frac{k_w(Sw, Sg)}{k}$$

krw is the relative permeability to water, kw is the permeability to water, and k is the absolute or single phase permeability.

Relative permeability curves

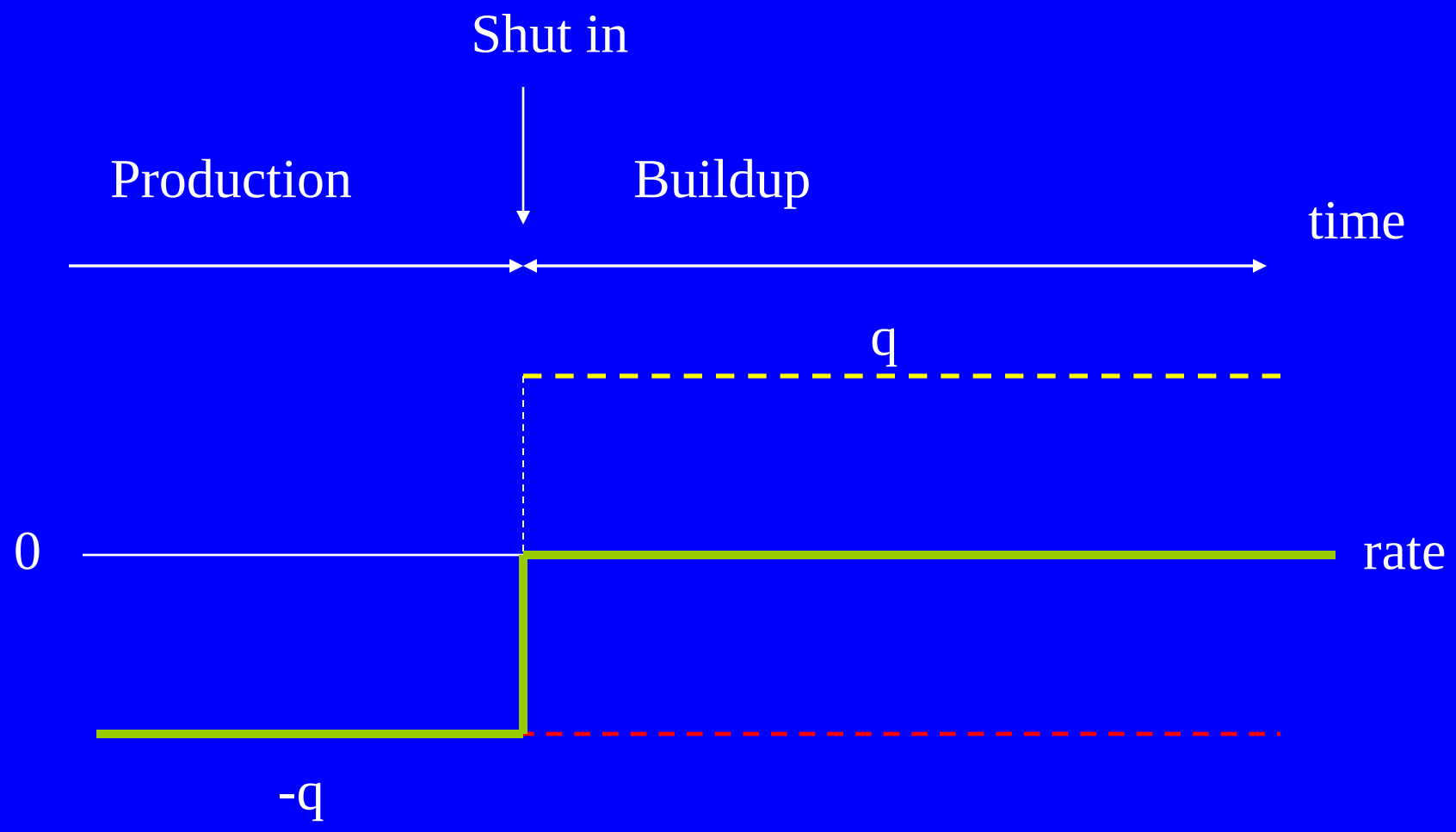


Field Permeability Testing

Common Test Methods

- Injection / falloff testing – average permeability, skin, and reservoir pressure.
- Production / buildup testing – average perm, skin, and reservoir pressure.
- Interference testing – average and directional permeability, skin, reservoir pressure, and porosity-compressibility product.

Analysis of a production/buildup test



For production / buildup test, a production rate q occurs for time t and is followed by a shut-in / buildup period for time delta t.

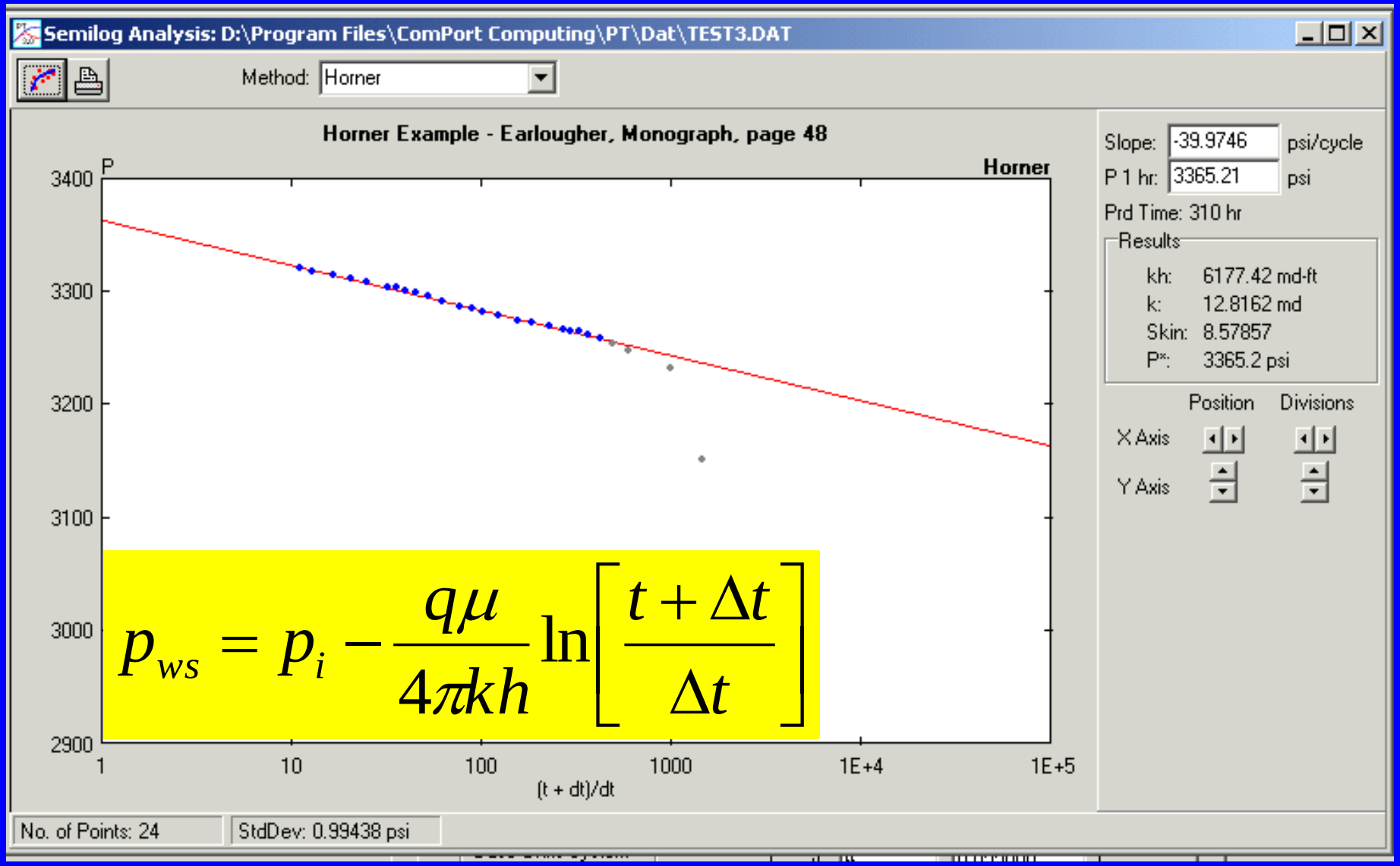
$$p_i - p_{ws} = \frac{-q\mu}{4\pi kh}\ln\left[\frac{\gamma\phi\mu c r_w^2}{4k(t+\Delta t)}\right] + \frac{q\mu}{4\pi kh}\ln\left[\frac{\gamma\phi\mu c r_w^2}{4k(\Delta t)}\right]$$

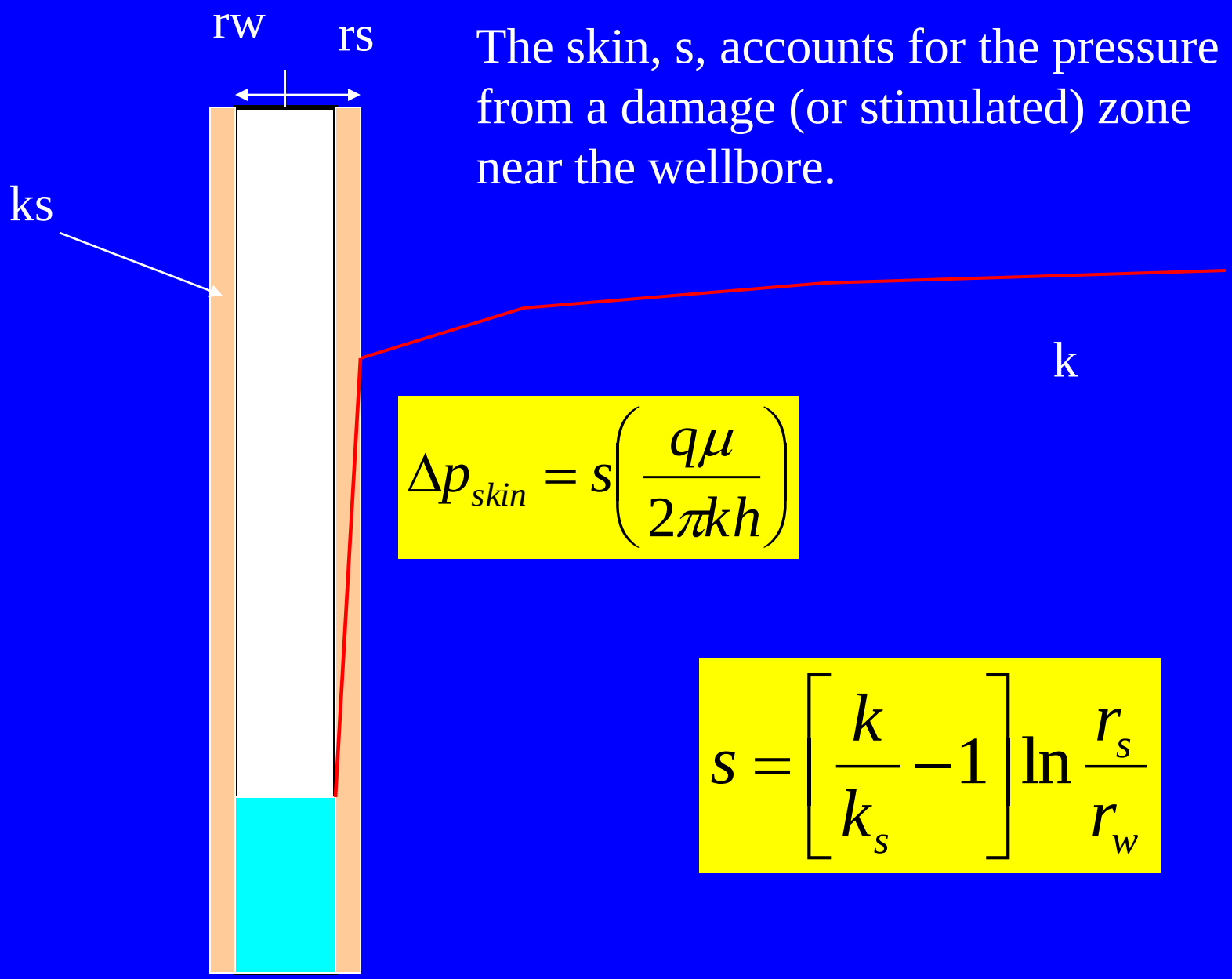
or

$$p_{ws} = p_i - \frac{q\mu}{4\pi kh}\ln\left[\frac{t+\Delta t}{\Delta t}\right]$$

This is the motivation for the Horner plot method of analysis.

Horner analysis of example data.





The skin, s, accounts for the pressure drop from a damage (or stimulated) zone near the wellbore.

$$\Delta p_{skin} = s\left(\frac{q\mu}{2\pi kh}\right)$$

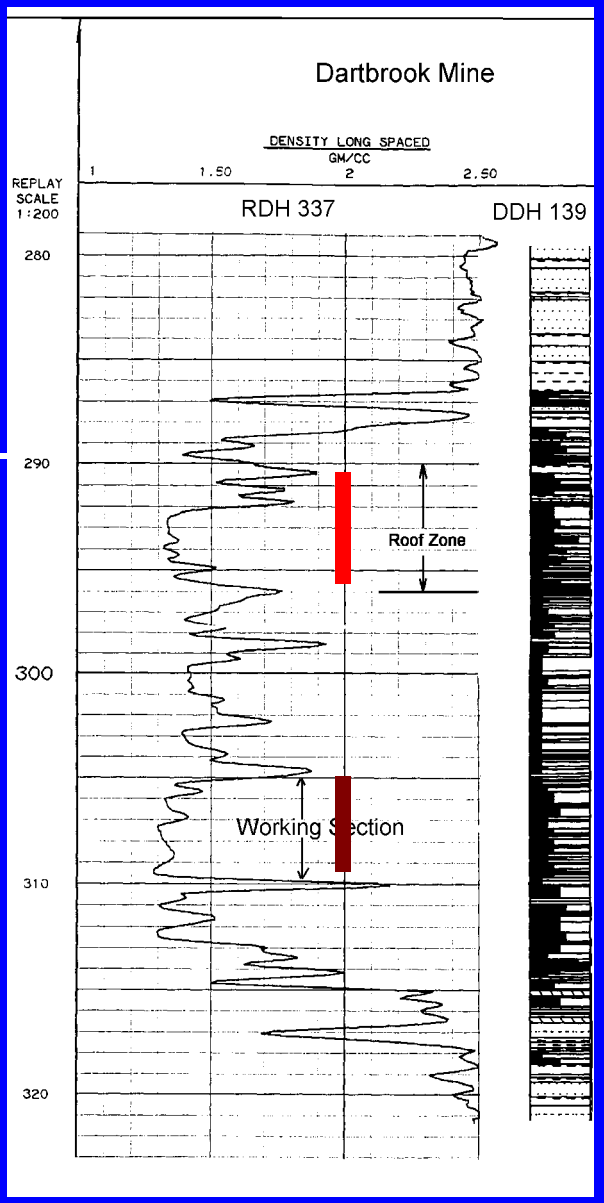
$$s = \left[\frac{k}{k_s} - 1\right] \ln \frac{r_s}{r_w}$$

Density and core logs across the mega seam at Dartbrook.

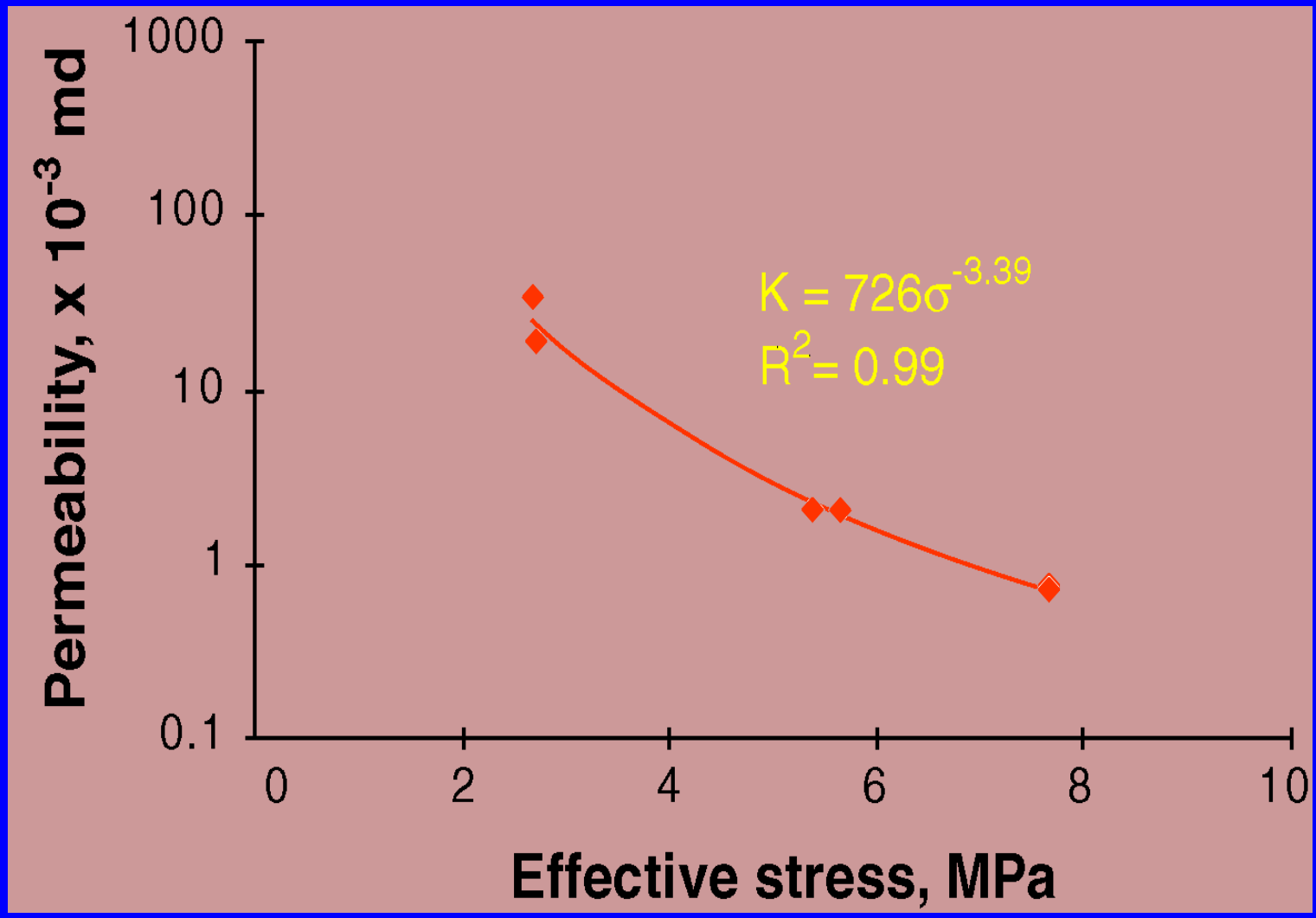
290 m

300 m

310 m



Laboratory permeability vs. effective stress for all test samples from horizontal hole oriented at 240 degrees.



Permeability measurement relies on:

- Analytical solutions for particular flow conditions.
  - Linear flow, most core lab tests
  - Radial flow, constant injection or production, well tests
  - Radial flow, constant pressure, well tests
  - Spherical flow, constant injection or production, well tests
- Numerical model analysis for cases that fall outside of analytical solutions.
  - Multiphase flow, pressure sensitive permeability …
- Porosity and compressibility values are also needed (diffusivity coefficient).

The End

Thank you