

New Approaches for Transient Testing and Long-Term Pressure Monitoring of Low-Permeability Caprocks

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Background

- Geological sequestration involves injecting supercritical CO₂ into subsurface reservoirs
- Injected supercritical CO₂ displaces pore fluids and is trapped below caprock or seal
- Necessary to determine sealing potential and hydrologic characteristics of caprock at potential CO₂ sequestration sites

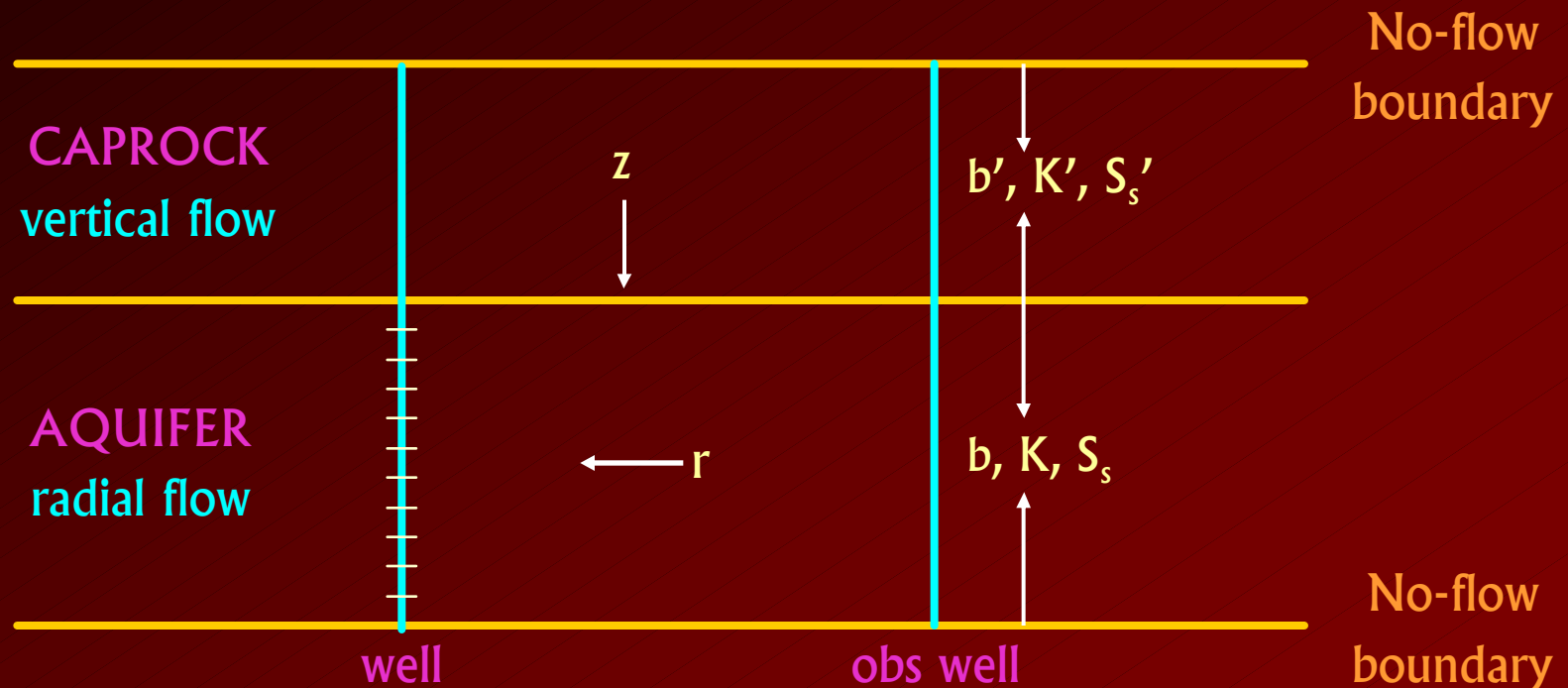
Well Hydraulics of Coupled Formations

Hantush (1964)	Leakage from low-permeability aquitard to permeable aquifer
Streltsova (1988)	Leakage from low-permeability adjoining formations to permeable oil-producing reservoir
Moench (1985)	Leakage from low-permeability semi-confining formations for aquifers with large diameter wells
Witherspoon et al. (1967)	Caprock characterization for large/small leakage in aquifer gas storage problems

Objectives

- Explore solutions for constant pressure inner boundary condition (constant-drawdown well)
- Restrict solution space to caprocks with permeability significantly lower than aquifer
- Investigate use of wireless telemetry based pressure monitoring devices for low-K formations

Aquifer–Caprock Schematic



Analytical Model

$$\bar{s}(r, p) = s_w \left\{ \frac{K_0(Ir)}{pK_o(Ir_w)} \right\} \quad \text{aquifer drawdown}$$

$$I^2 = \frac{p}{h} + \left(\frac{K'}{Kbb'} \right) \left\{ b' \sqrt{\frac{p}{h'}} \tanh \left(b' \sqrt{\frac{p}{h'}} \right) \right\} \quad \text{aquifer-caprock interaction}$$

$$\text{well flow rate} \quad \bar{q}(r_w, p) = -2pKb \left(r \frac{\partial \bar{s}}{\partial r} \right)_{r_w} = 2pKbs_w \left\{ \frac{I r_w K_1(Ir_w)}{pK_o(Ir_w)} \right\}$$

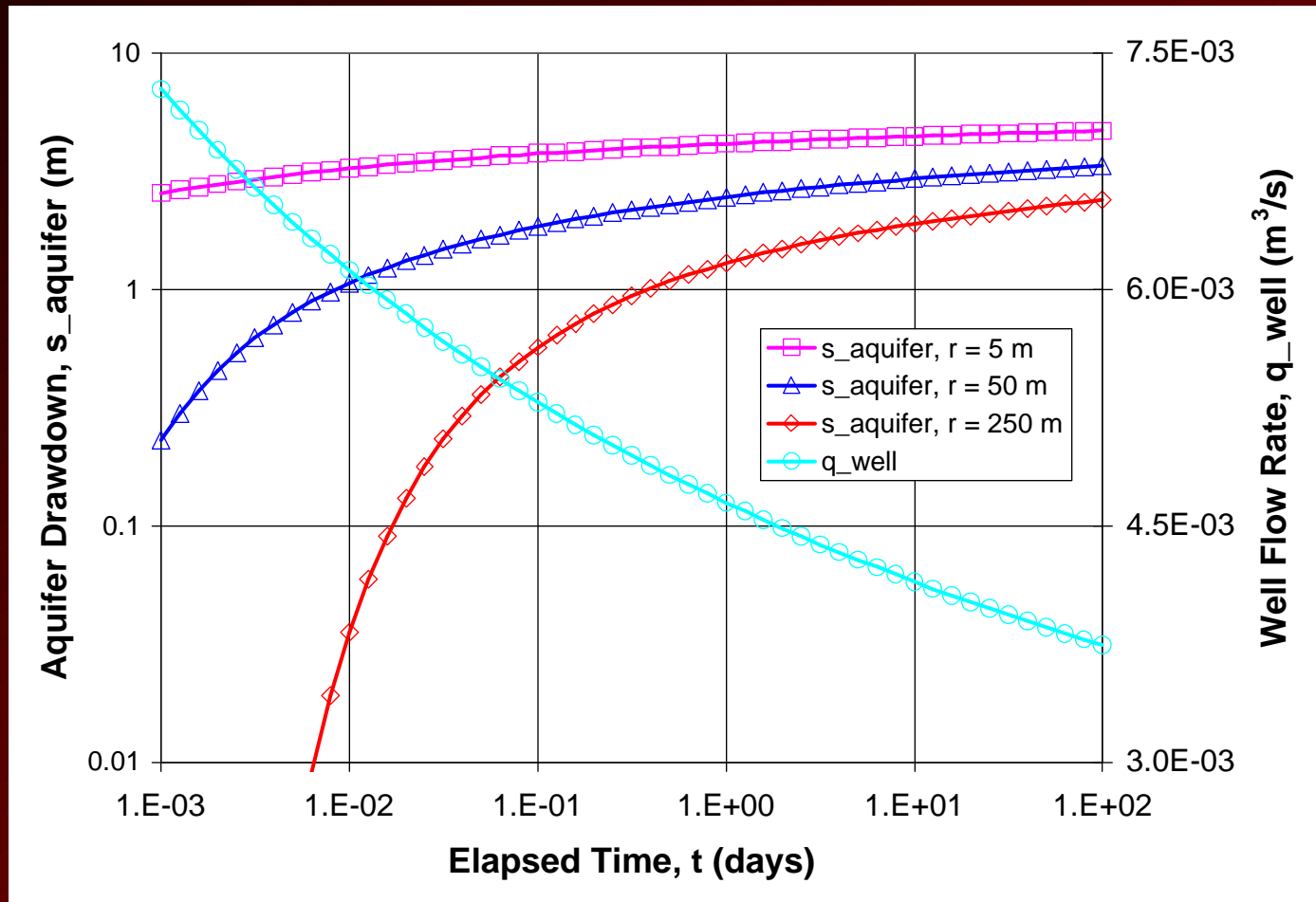
caprock drawdown

$$\bar{s}_1(z, r, p) = \bar{s}(r, p) \left\{ \text{Sinh} \left((b' - z) \sqrt{\frac{p}{h'}} \right) \right\} / \left\{ \text{Sinh} \left(b' \sqrt{\frac{p}{h'}} \right) \right\}$$

Evaluation of Solution

- Inversion of Laplace-domain solutions via Stehfest algorithm
- Conductivity $\Rightarrow K = 1\text{E-}5 \text{ m/s}; \quad K' = 1\text{E-}10 \text{ m/s}$
- Sp. storage $\Rightarrow S_s = 1\text{E-}6 \text{ 1/m}; \quad S_s' = 1\text{E-}7 \text{ 1/m}$
- Thickness $\Rightarrow b = 100 \text{ m}; \quad b' = 10 \text{ m}$
- @ Wellbore $\Rightarrow s_w = 7 \text{ m}; \quad r_w = 0.1 \text{ m}$
- Radial distance $\Rightarrow r = 5, 50, 250 \text{ m}$
- Elapsed time $\Rightarrow t = 0.1, 1, 10, 100 \text{ d}$

Aquifer Drawdown and Rate Response



$$q(r_w) \left(\frac{dr}{r} \right) = -2\pi kh_s \left(\frac{D_w k_r(D_w)}{\rho k_r(r)} \right)$$

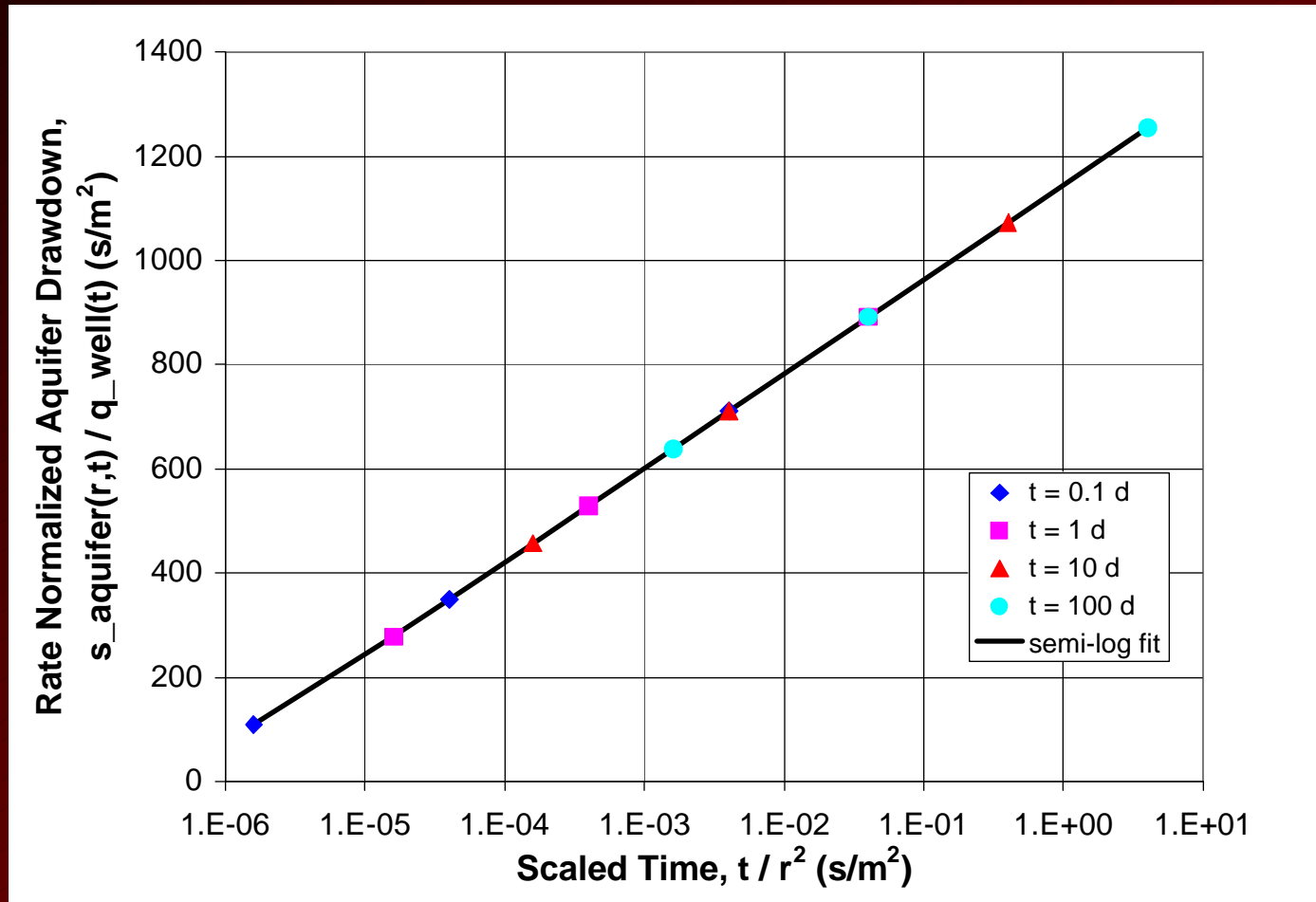
Rate-Normalized Drawdown

- Mishra & Guyonnet (1992) developed a rate-normalized method for analyzing observation well response during constant drawdown testing in confined aquifers

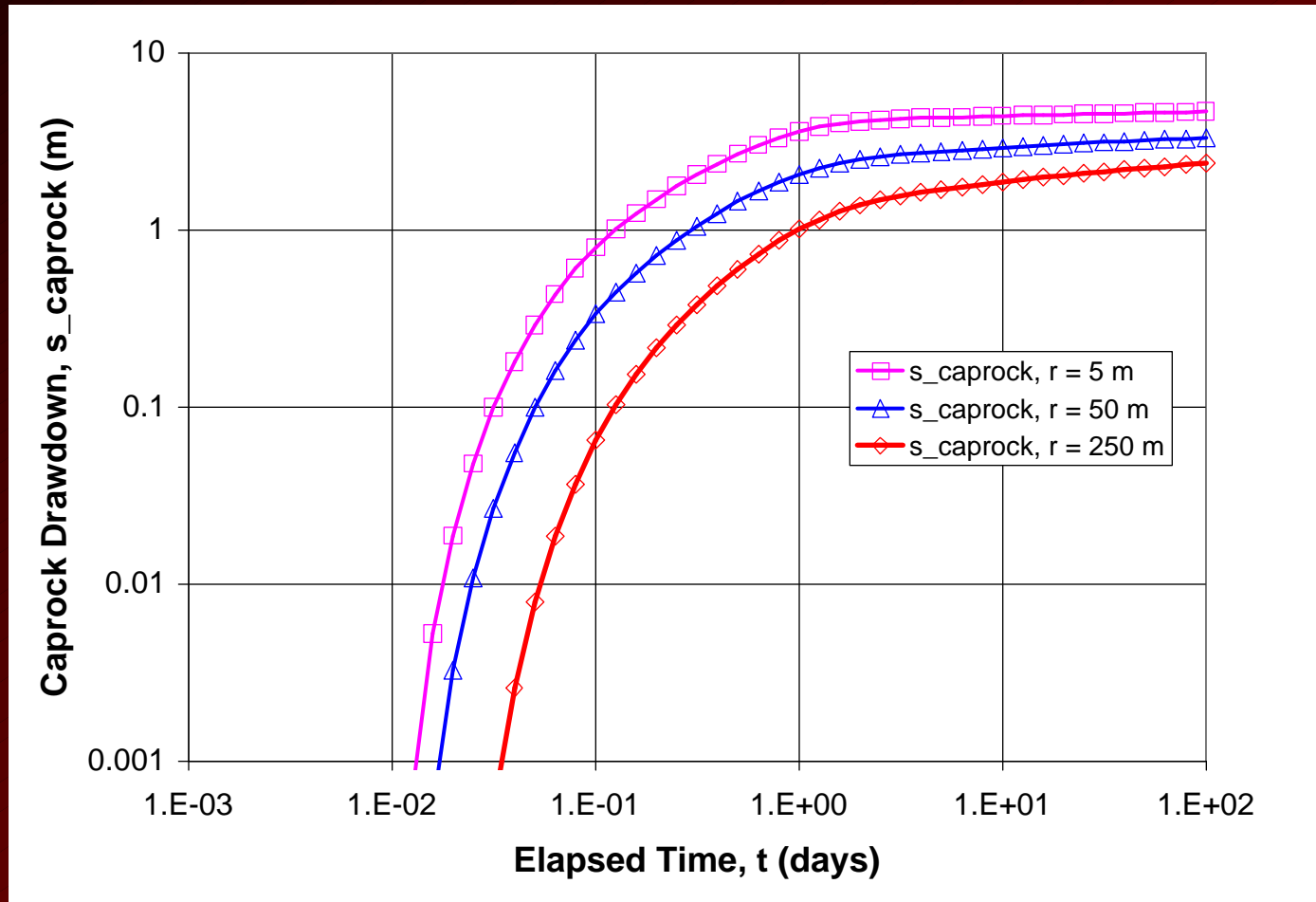
$$\frac{s(r,t)}{q(r_w,t)} \cong \frac{1}{4pT} Ei \left(-\frac{Sr^2}{4Tt} \right) \cong \frac{1}{4pT} \ln \left(\frac{2.25Tt}{Sr^2} \right)$$

- Method successfully applied to present problem

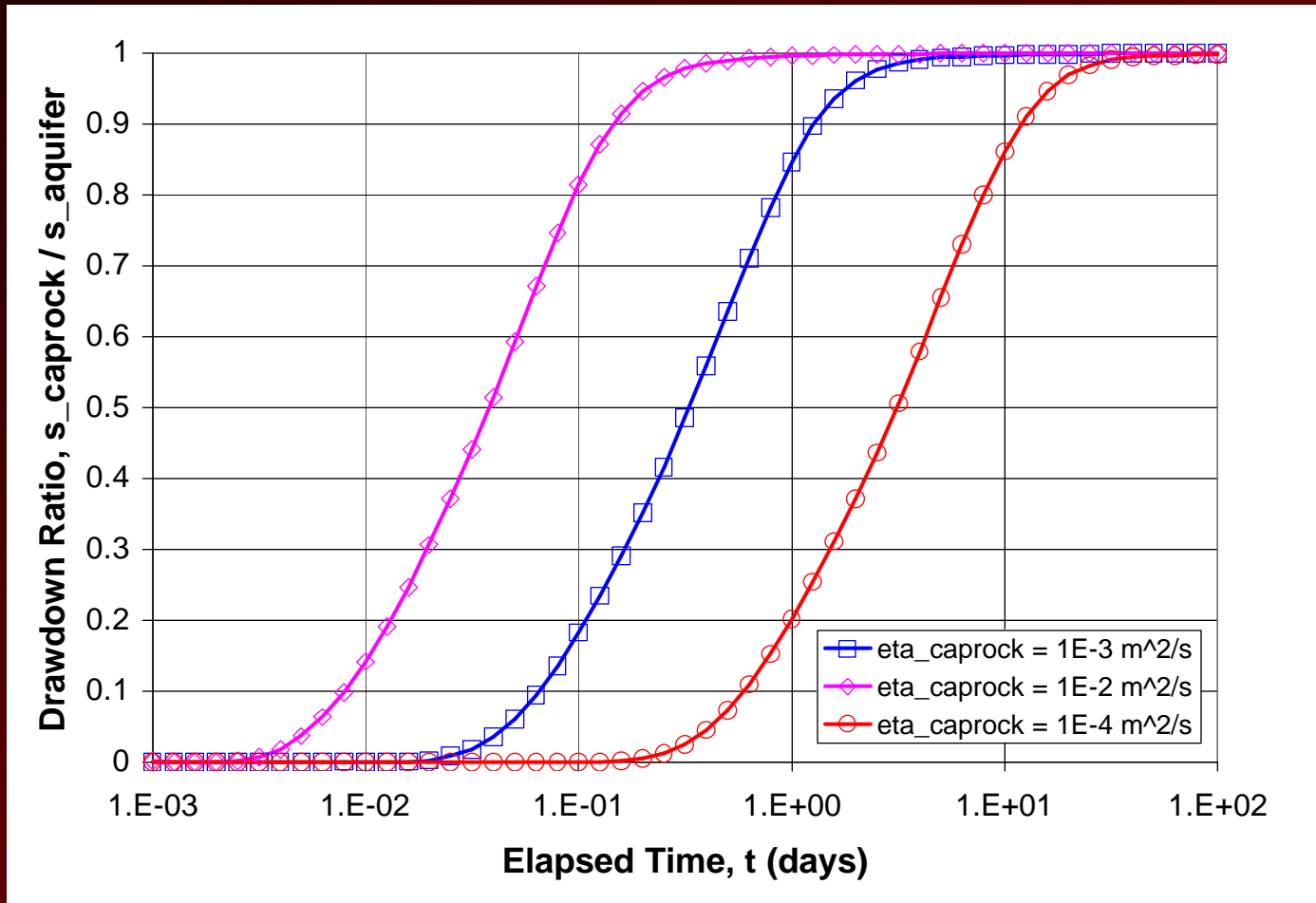
Rate-Normalized Drawdown Analysis



Caprock Drawdown Response



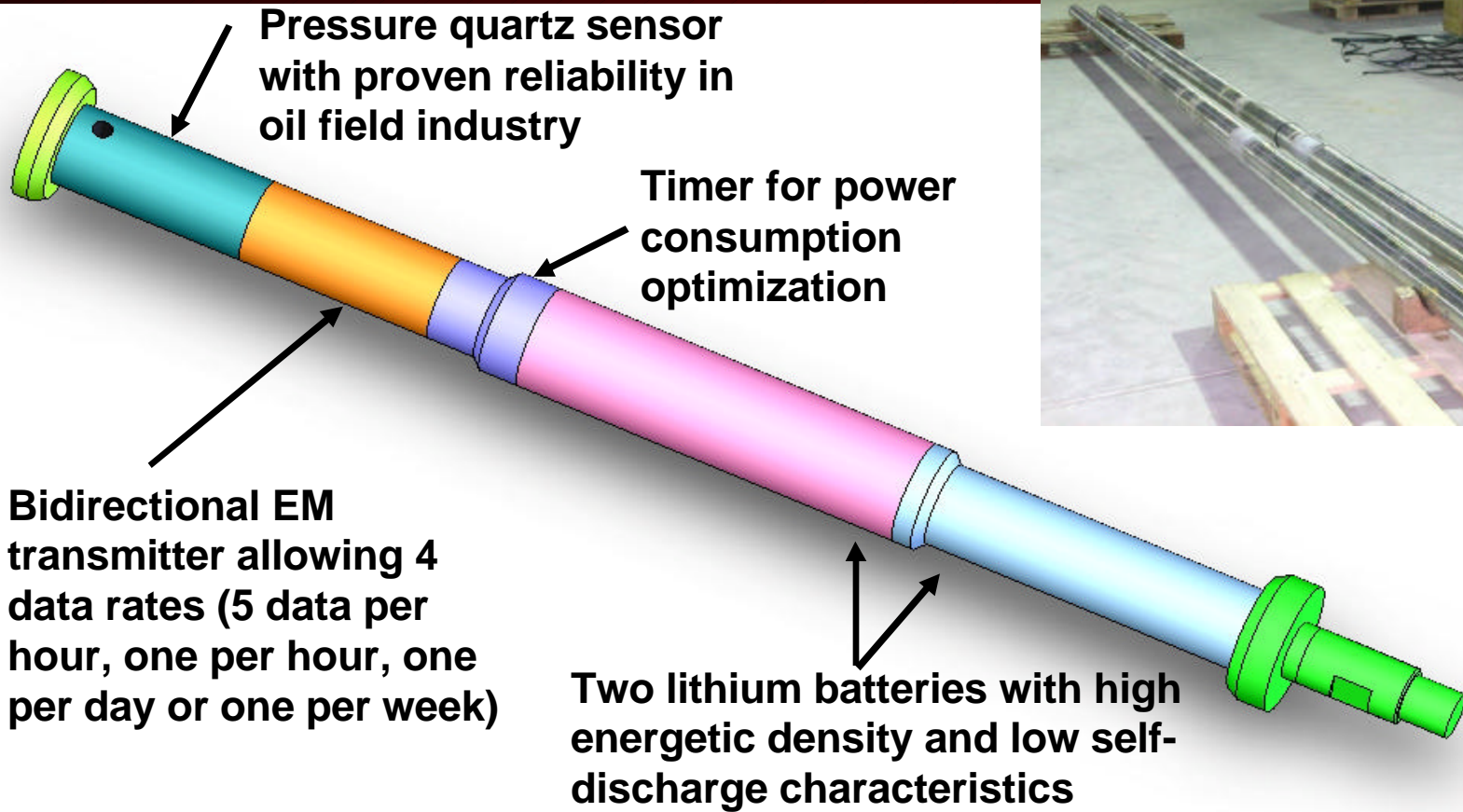
Drawdown Ratio Analysis



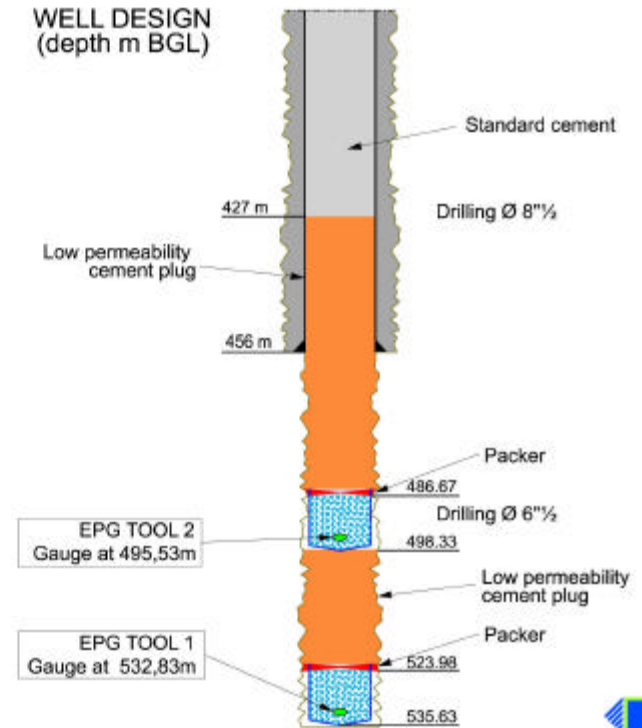
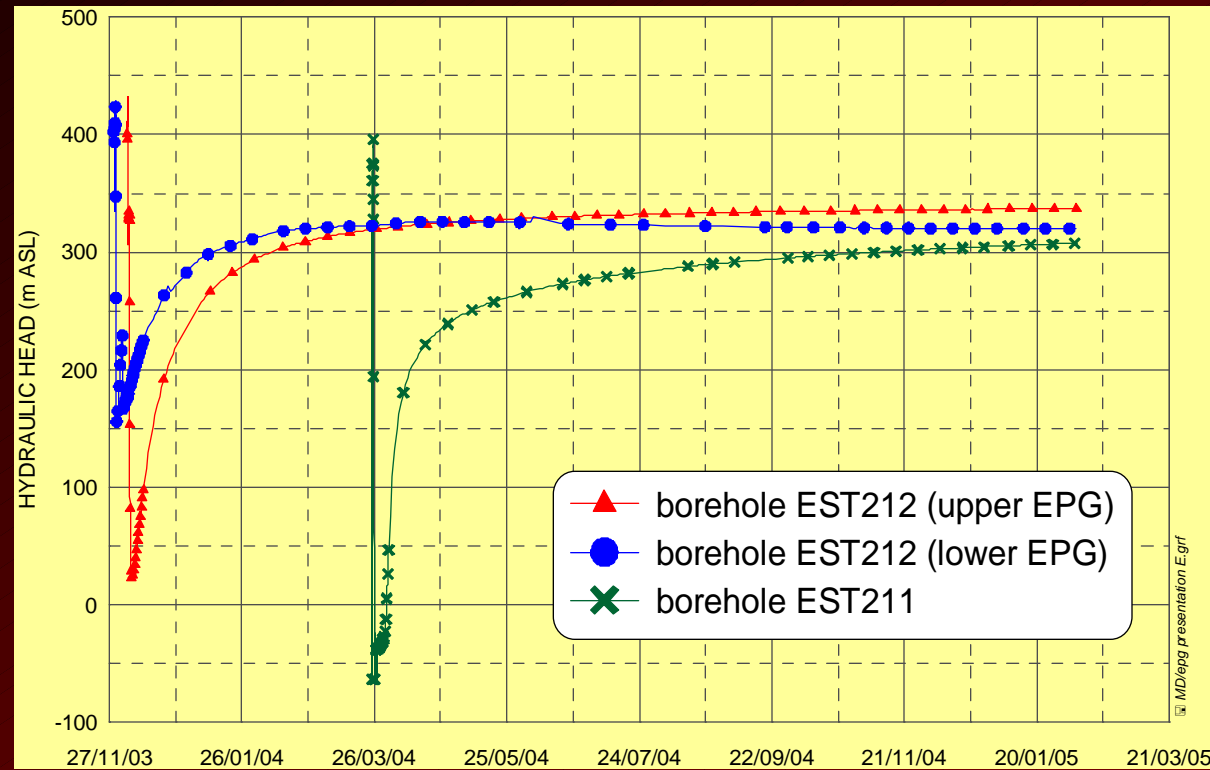
Long-Term Pressure Monitoring

- Requires accurate pressure measurement minimally compromised by borehole and equipment
- EPG concept adapted from oil industry by ANDRA
 - Permanent installation of pressure gauge
 - Low-K cement plug isolation
 - Wireless EM data transmission to surface (no electric or hydraulic lines)

EPG – The Gauge



Dual EPG System in Practice



Concluding Remarks

- Constant drawdown testing is a useful strategy for simultaneously characterizing aquifers and caprocks
- Rate-normalized drawdown analysis can be utilized for graphical determination of aquifer transmissivity
- Nonlinear regression analysis on caprock drawdown data can be used for determining caprock diffusivity
- Wireless telemetry based EPG is a promising tool for pressure monitoring of low-permeability caprocks