The Measurement of Permeability and Other Ground Fluid Parameters

Drilling for Geology II

26-27 July 2017

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The reasons for measuring ground fluids

GROUNDWATER

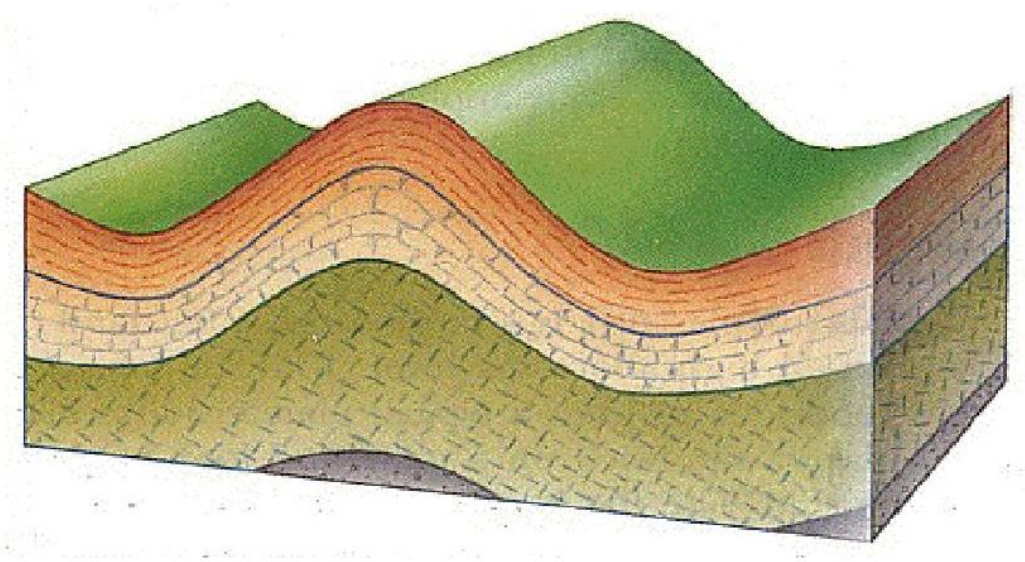
- Slope groundwater behaviour -for stability
- Dewatering needs -flow rate
- Magnitude and extent of drawdown -settlement, reserves
- Containment and removal of contaminants
- Water supply -quantity and flow rate

PETROLEUM

- To delineate a reserve and deduce a production scheme

The Need to Understand the Geology

- It is not possible to interpret any ground fluid measurement without having some understanding of the geological context



Ground Fluid Terms

Flow terms

- Permeability (length^2)
- Hydraulic conductivity (length/time)

Storage terms

- Compressibility (pressure^{-1})
- Porosity (fraction)
- Storativity and specific yield

  dimensionless (vol/(area*length))

Potential

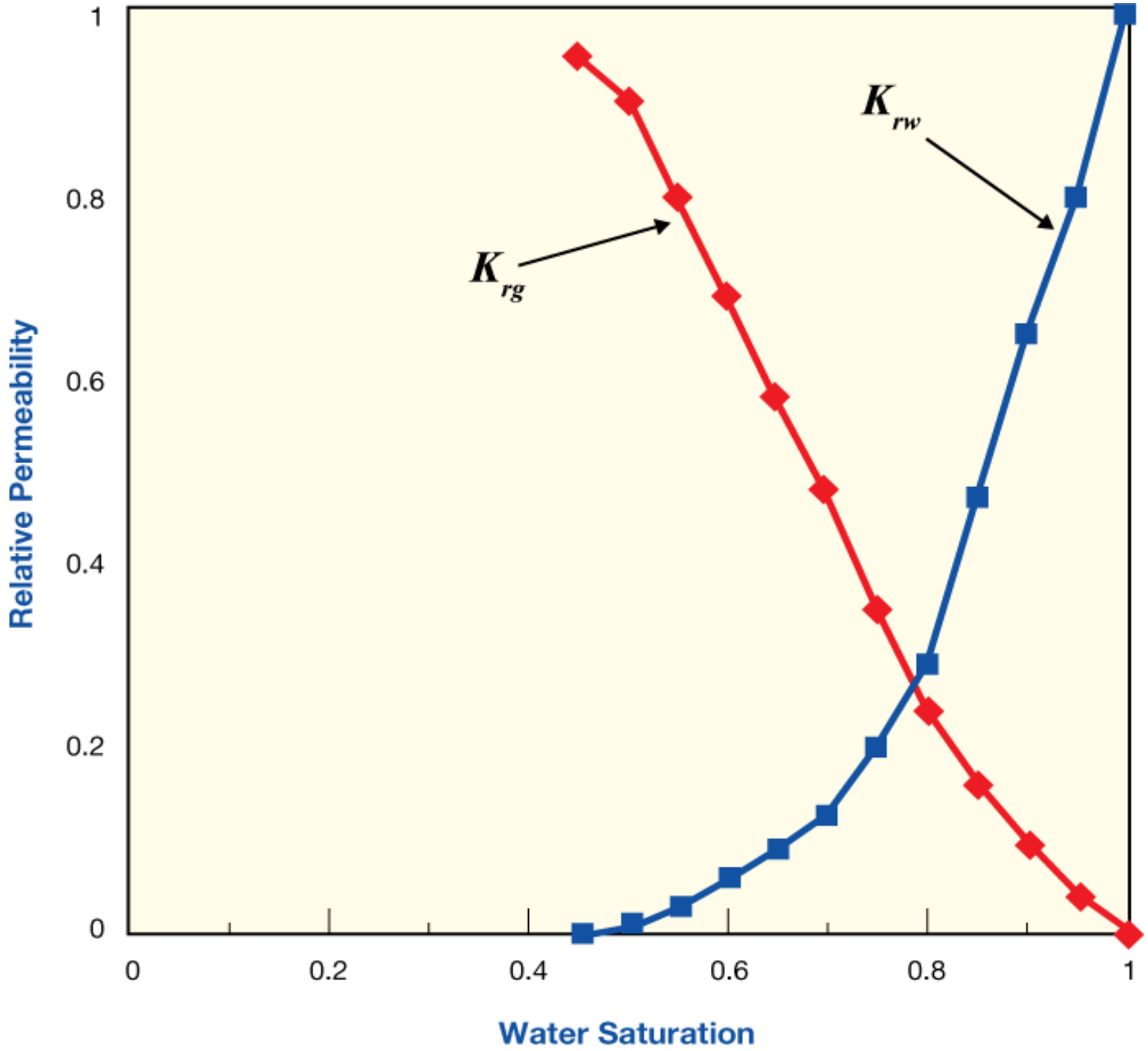
- Pressure
- Head

Darcy flow

$$V = -\frac{k}{\mu} \cdot \frac{d\phi}{dx}$$

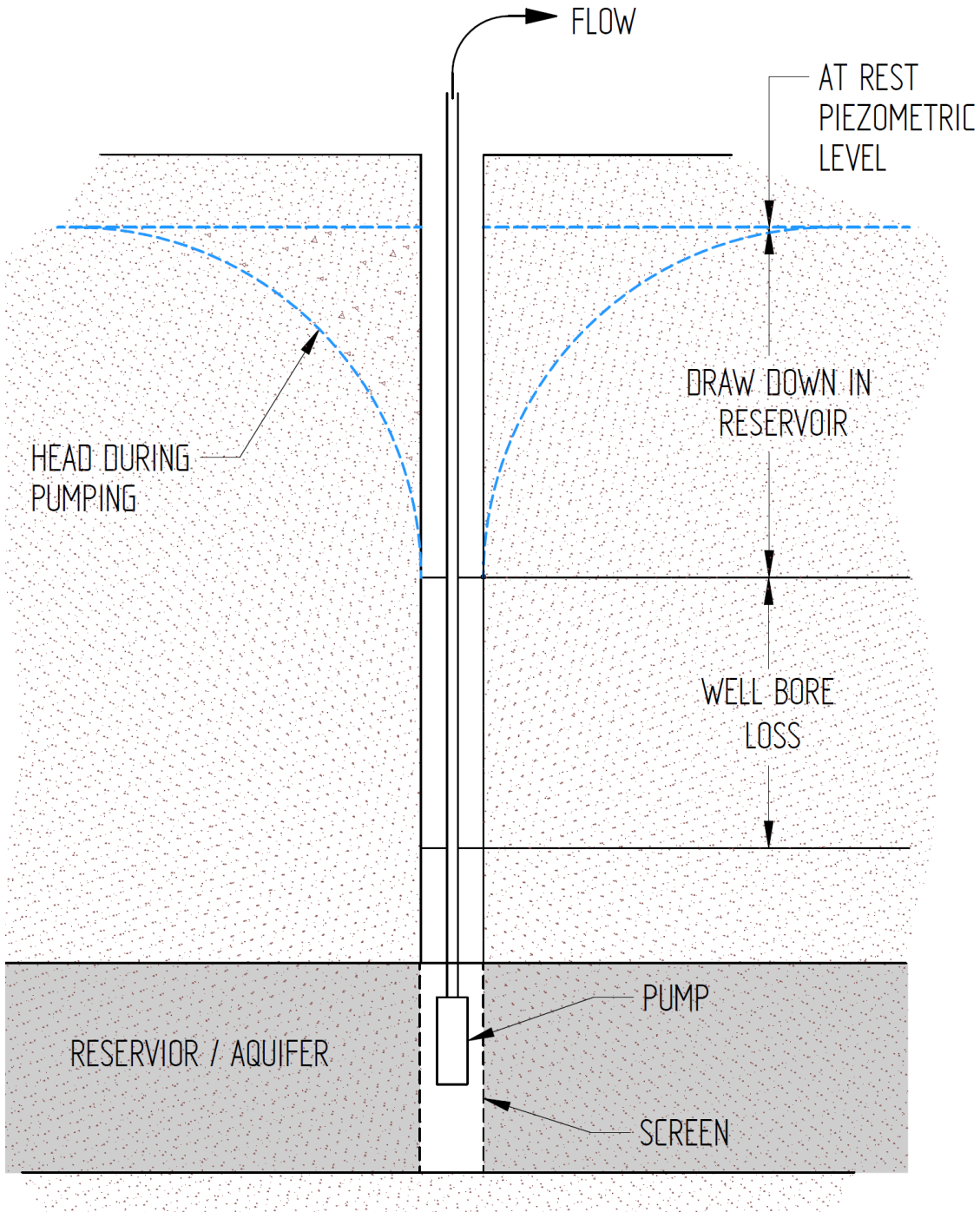
Relative permeability curves for gas and water

gas gets in the way of water
and
water gets in the way of gas



THE INTERESTED GROUPS

- **The Hydrogeologist – probably interested in water supply relies on geology, geophysics and major pumping tests**
- **The Petroleum Reservoir Engineer – needs as much information down a deep hole as quickly as possible because of cost constraints**
- **The Civil and Mining Engineer – generally pretty ignorant of what is really required**
- **The Geologist – frequently left in the middle trying to get the job done**



What happens around a well?

Single hole tests
Can give information on permeability
but not storage terms
nor directional permeability

- Pumping tests without piezometers – constant rate tests good
- Injection tests – but what are you injecting? Clog up the well bore
- Slug tests – variable rate injection, virtually impossible to analyse due to lack of separability of well bore loss – pretty bad!
- Packer tests – even worse! No attention to original fluid pressure (head). Assume steady state situation
- Drill stem tests – very useful. Important measurement during no flow.

Interference tests to give information on storage and directional permeability

- Pumping tests with piezometers (pressure monitoring)

  Good practice but often expensive to set up

  – need prior knowledge of reservoir/aquifer to be able to design

- Pulse tests between wells – based on amplitude and lag of signal – need existing well field

- Pulsed DST tests – ideal for exploration

Mathematical basis of solving any well test
Transient analysis – nothing is steady state

- Well equation

  Pressure (head) is a complex function of time and flow

  governed by the exponential integral

- Log-linearisation of well equation – suitable for large times,

  small radii and small storage

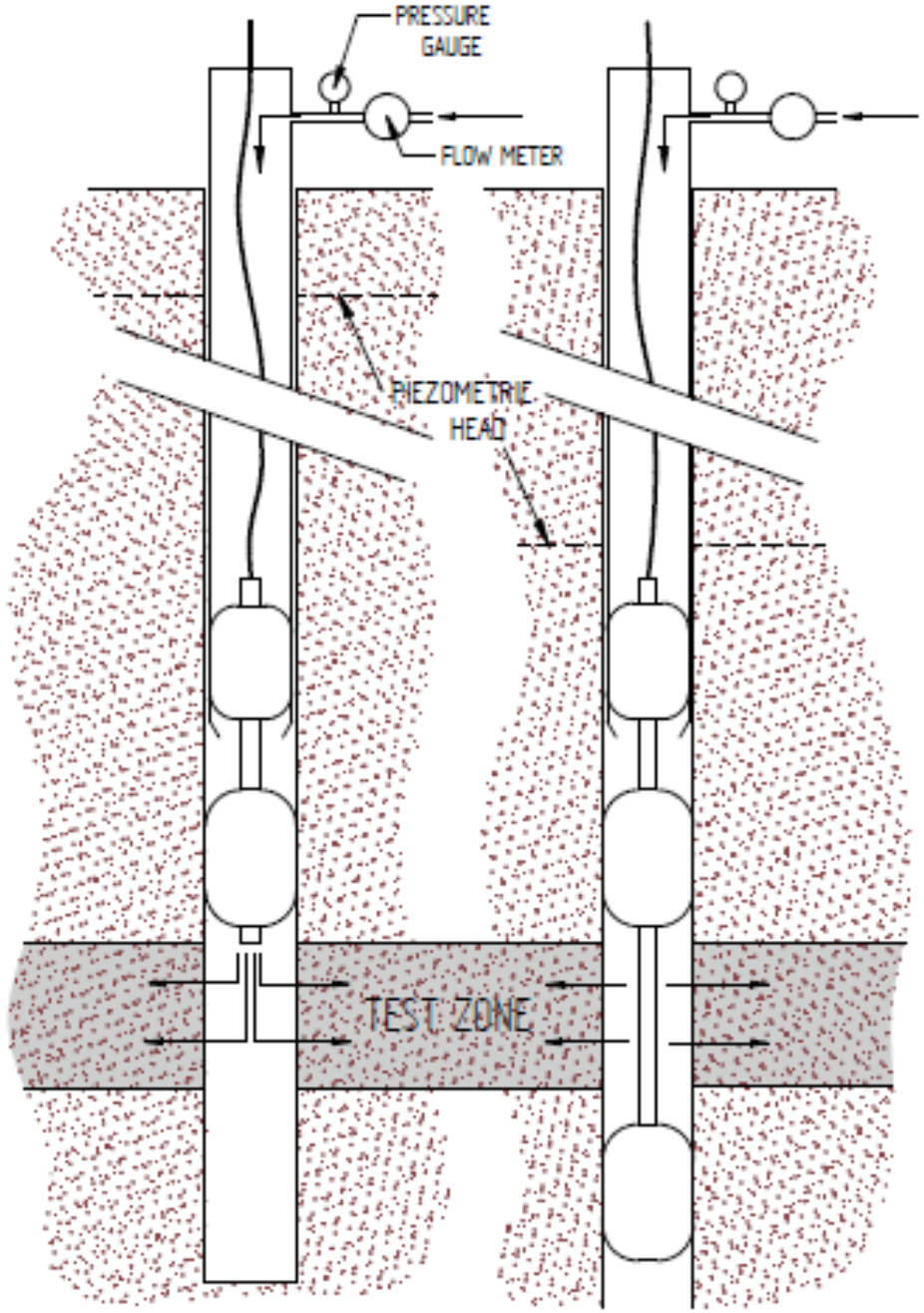
  Generally used for analysis in a single well – small radius

  Gives straight line drawdown vs log time for constant flow

Typical civil and mining permeability test practices

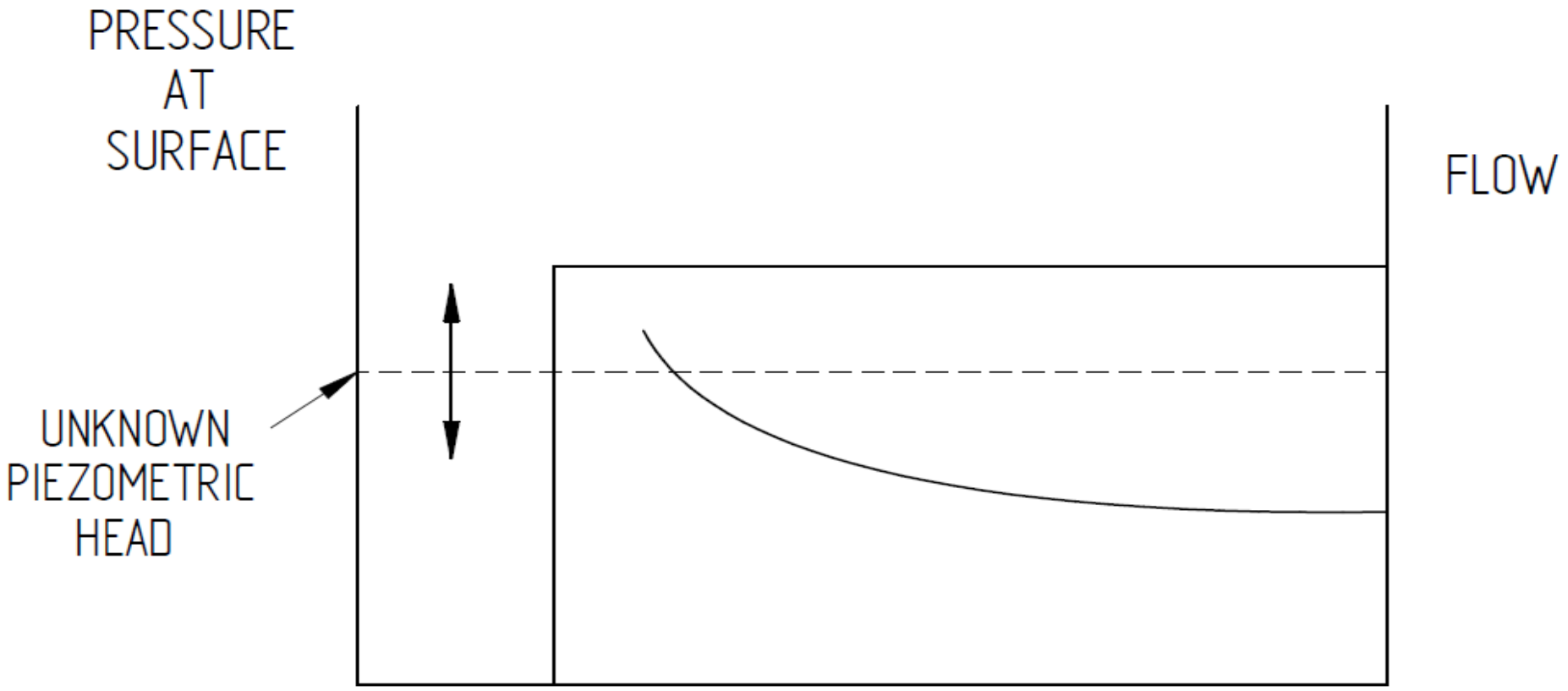
- Packer tests – analysed in terms of lugeons – a flow rate/metre of hole at constant pressure of 10 atm at surface (has no relation to permeability)
  - Designed to determine grout take in dam foundations
  - No account of initial head
  - Assumes steady state conditions
  - Most pressure drop is at the wellbore

- Falling head tests in boreholes
  - Mostly analysed by steady state solutions
  - Can theoretically be analysed in non steady manner for constant skin (well bore loss) behaviour. Well bore loss changes with pressure and time.

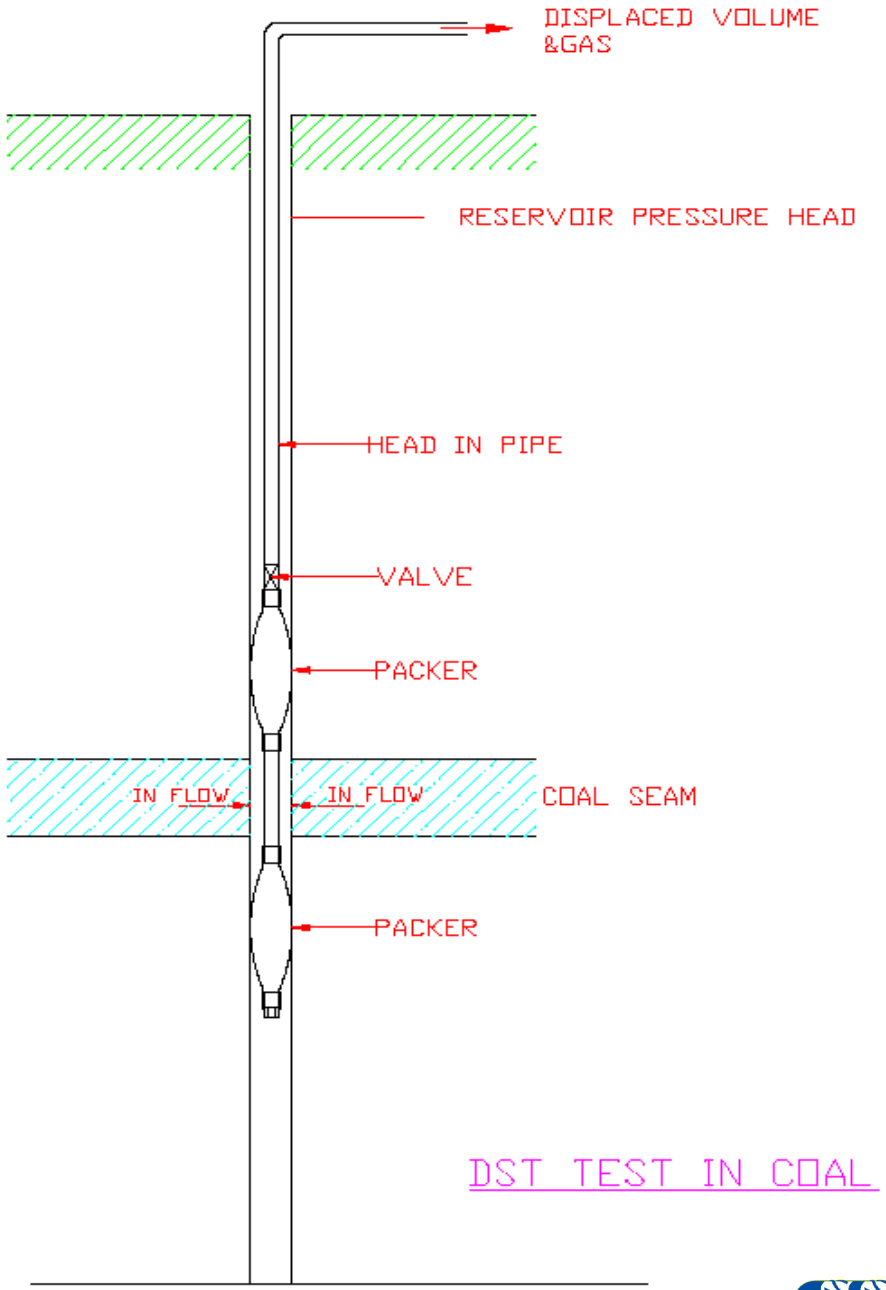


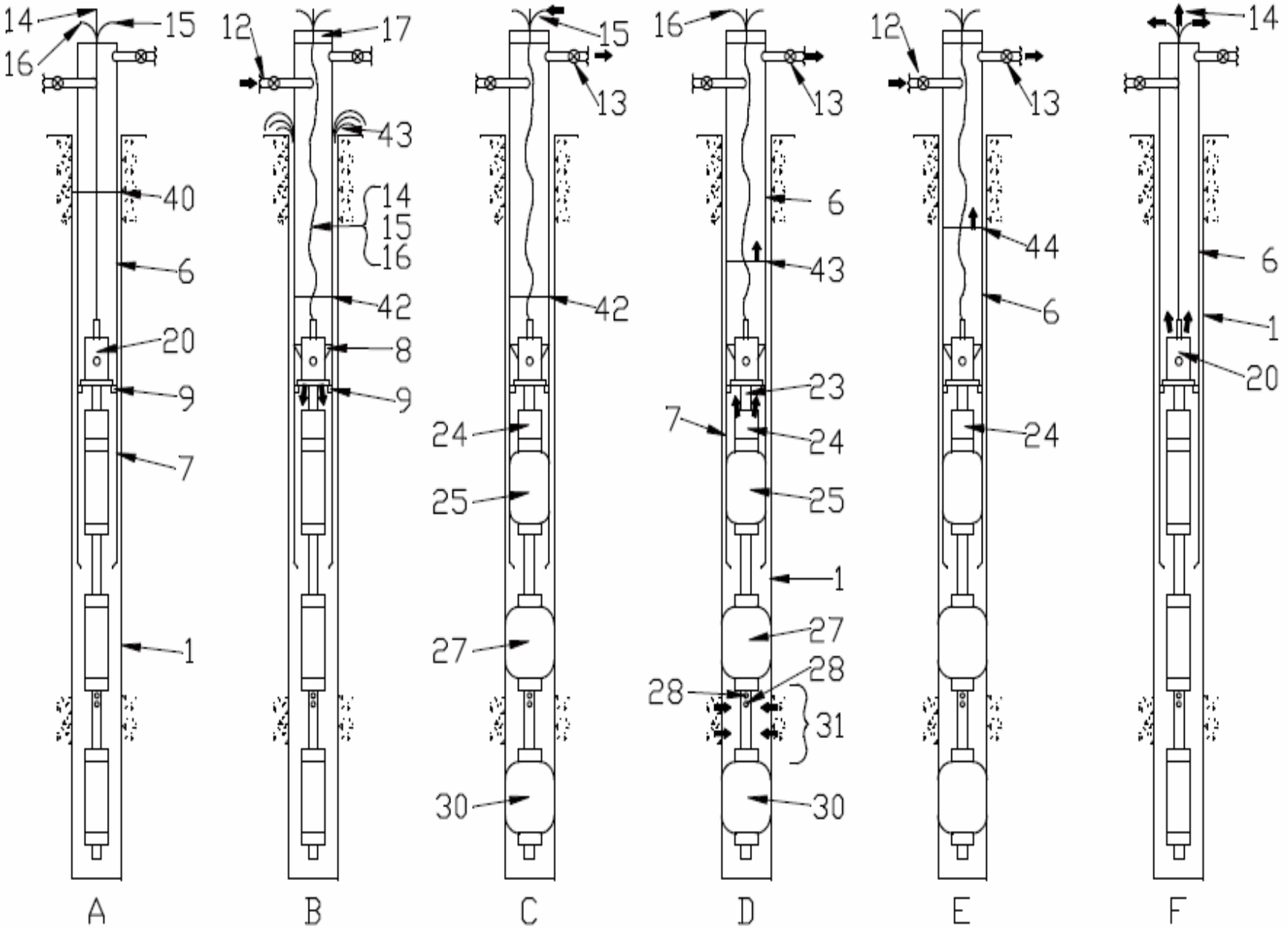
Packer test

What is happening in a packer test?



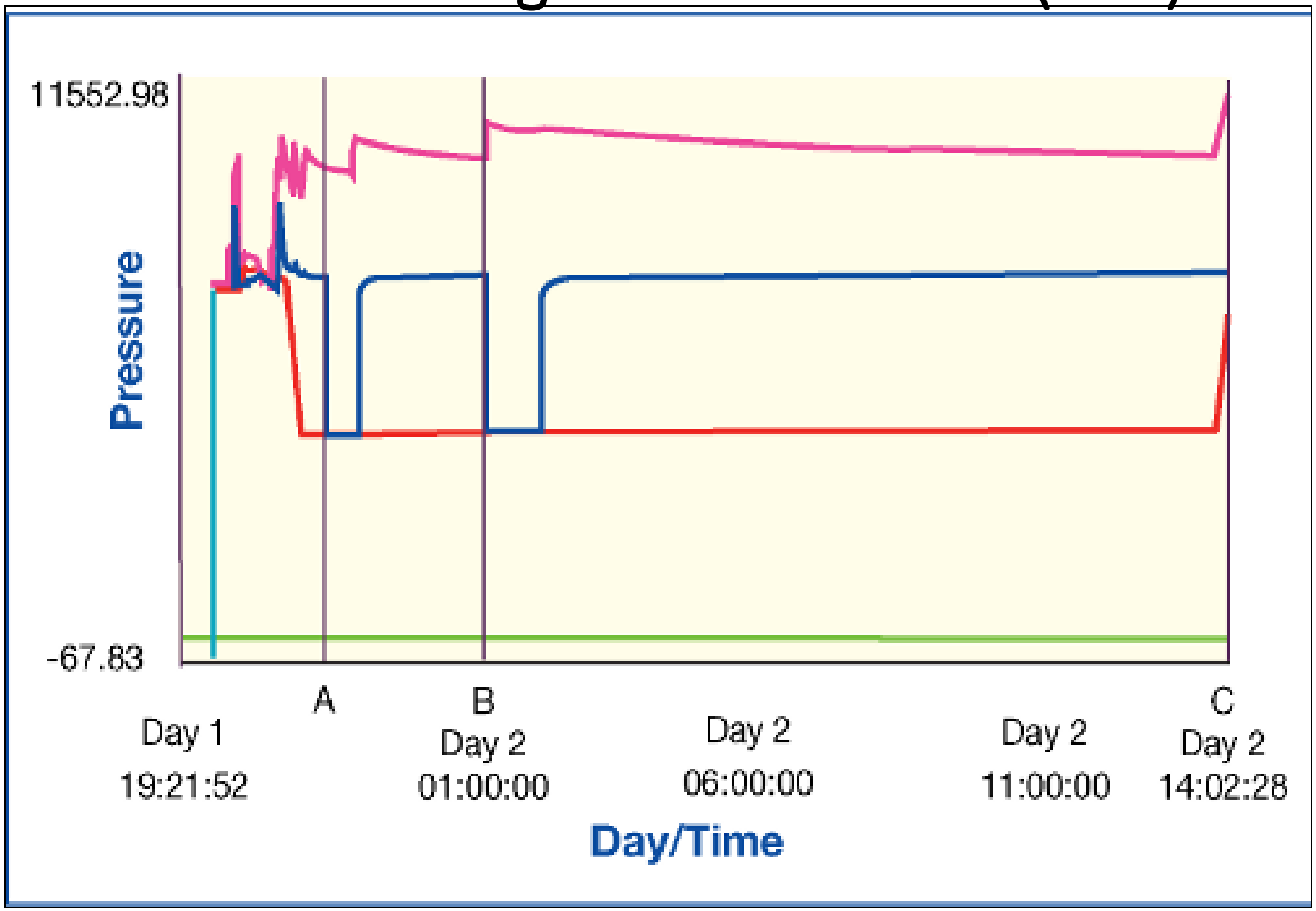
DST TEST SETUP





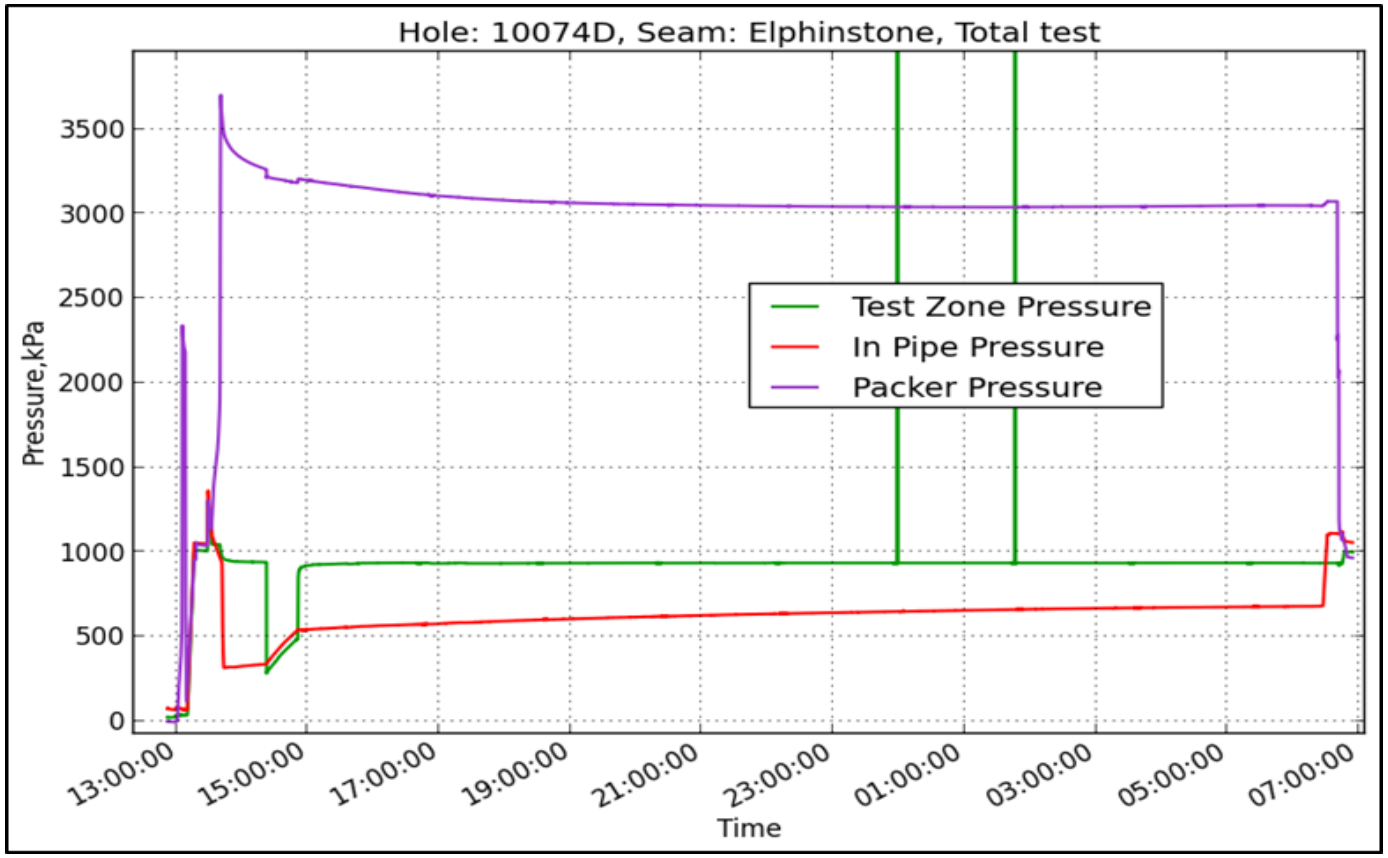
SIGRA WIRELINE DST

Total Plot of Sigra Drill Stem Test (DST)



High Permeability Total Test

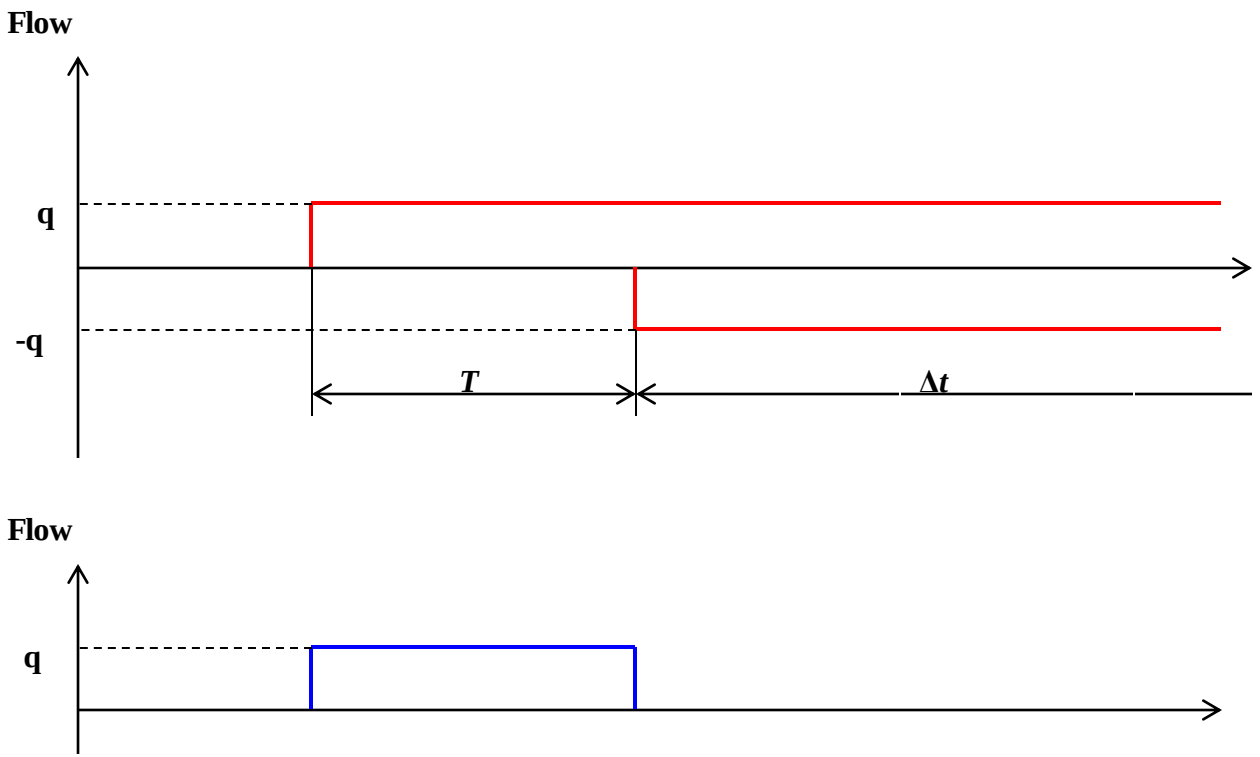
With drill string leakage



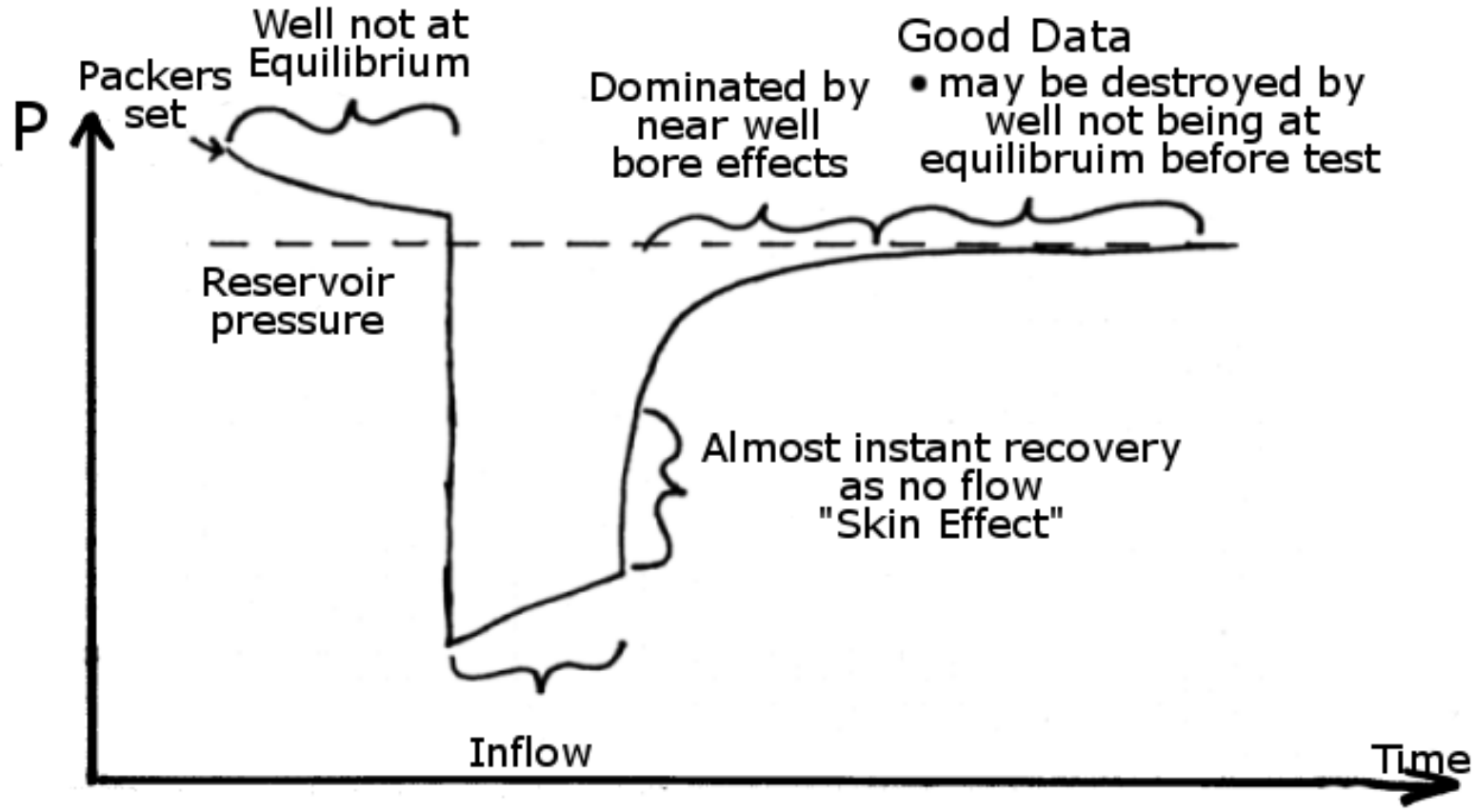
Analysis of DST

- Based on the recovery period rather than the flow period
- Removes problems with near well bore loss or skin
- Removes problems with uneven flow

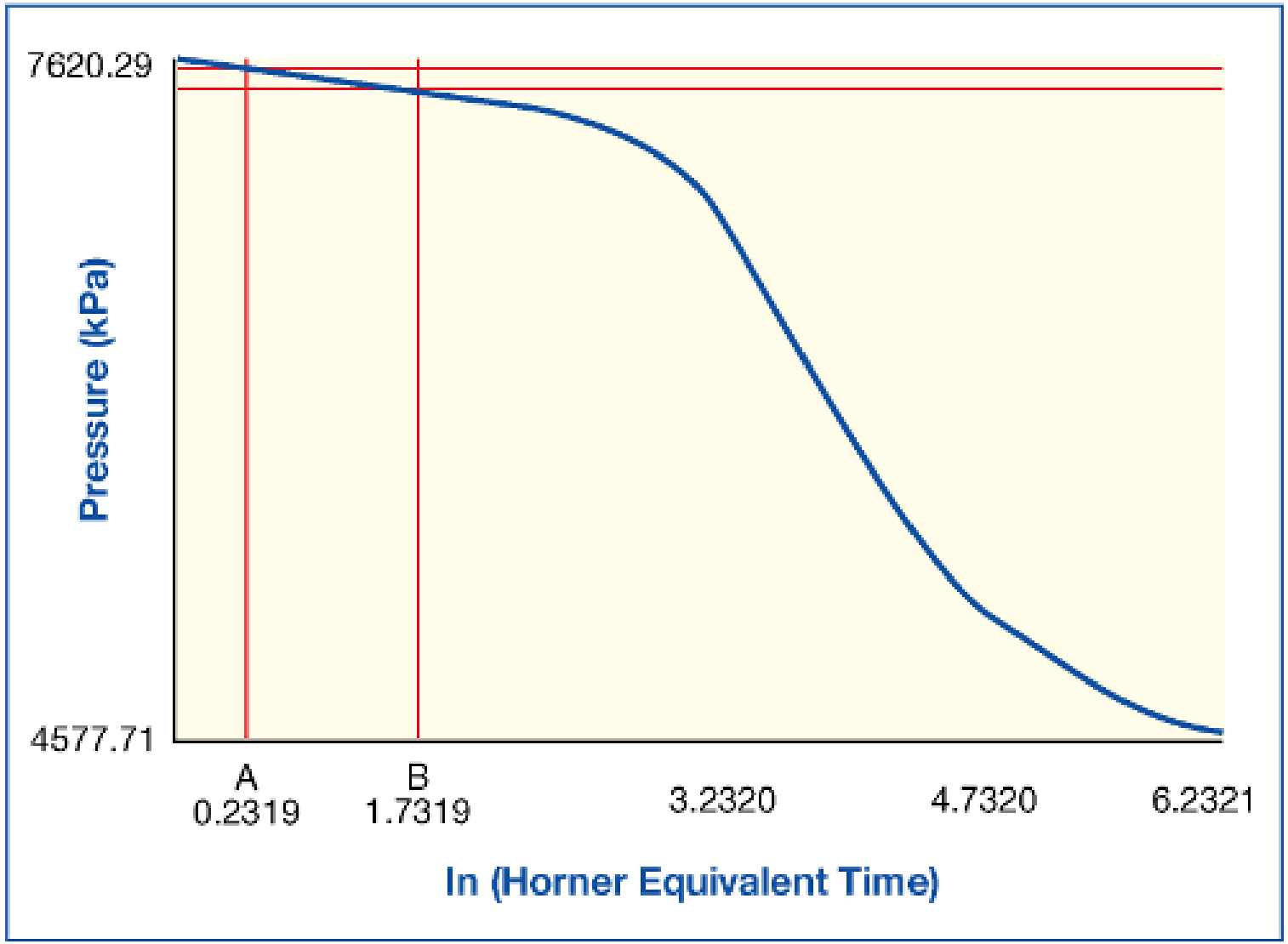
Concept of Superposition for DST



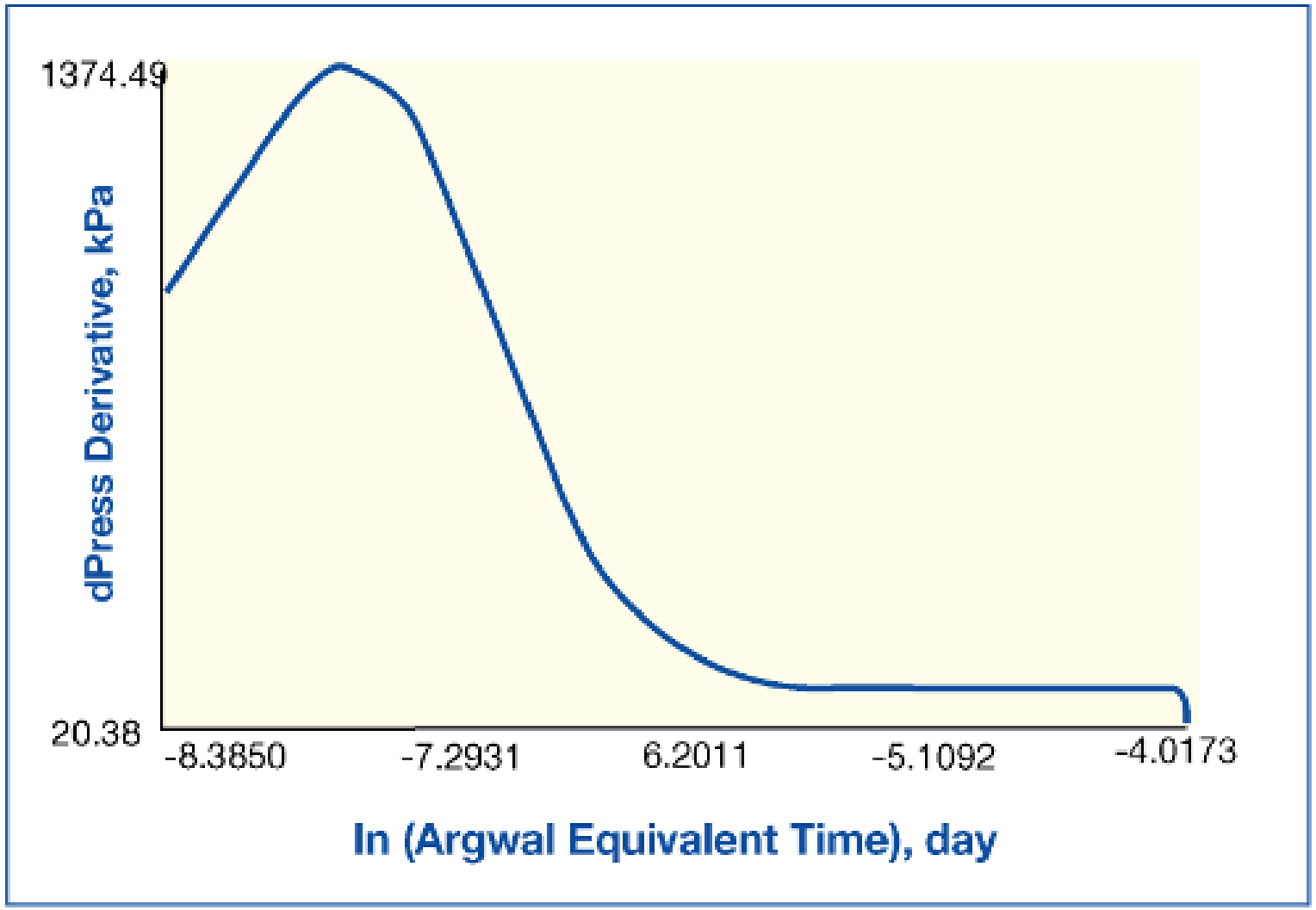
Real DST


Well not at Equilibrium
Packers set
P
Good Data
• may be destroyed by well not being at equilibruim before test
Dominated by near well bore effects
Reservoir pressure
Almost instant recovery as no flow "Skin Effect"
Inflow
Time

Horner Build-Up Plot



Plot of Derivative with Respect to Agarwal Time



Well Test Trailer

Set up for testing with through the HRQ string DST tools or end of drill string tools

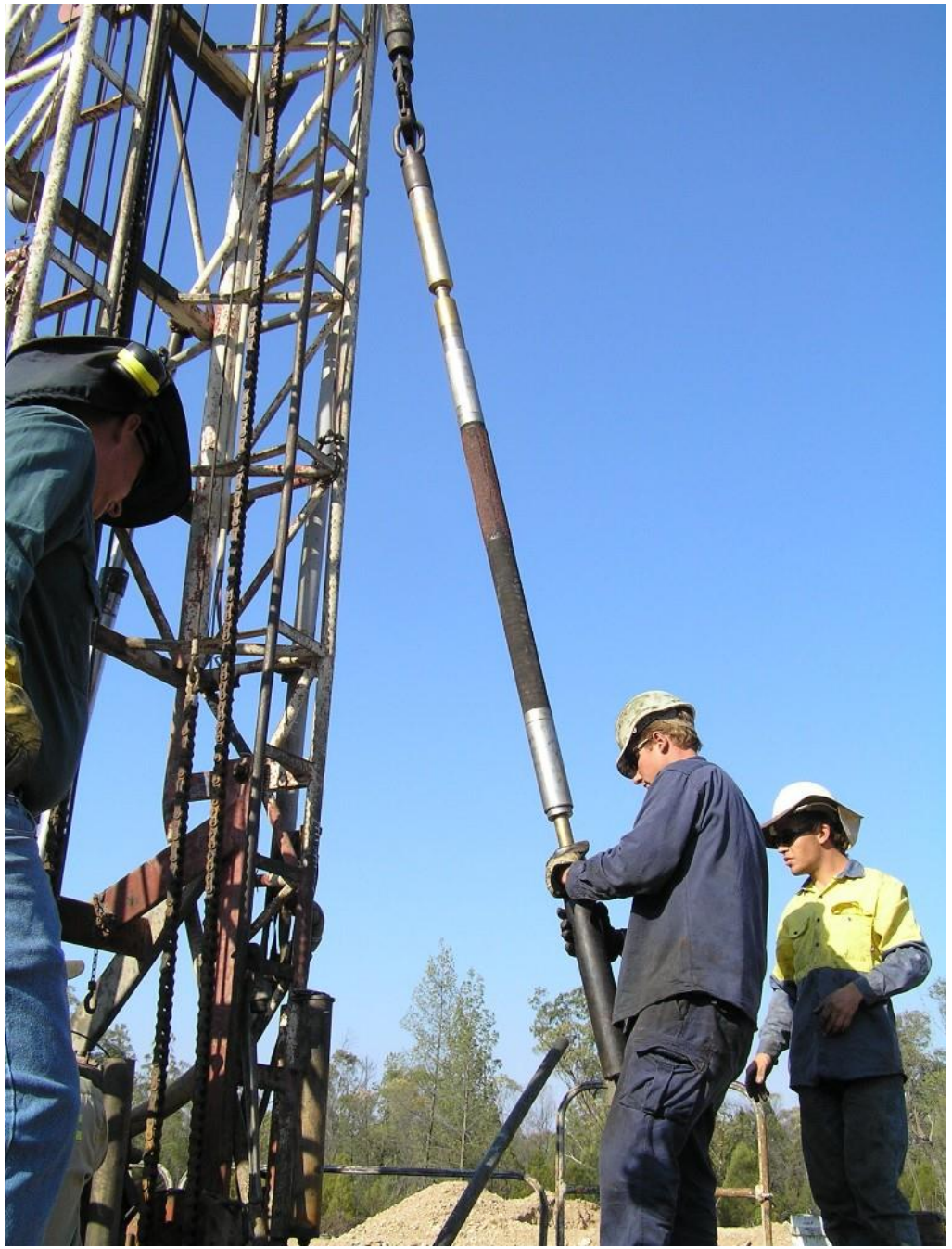
Can be used for injection

Real Time display of test results

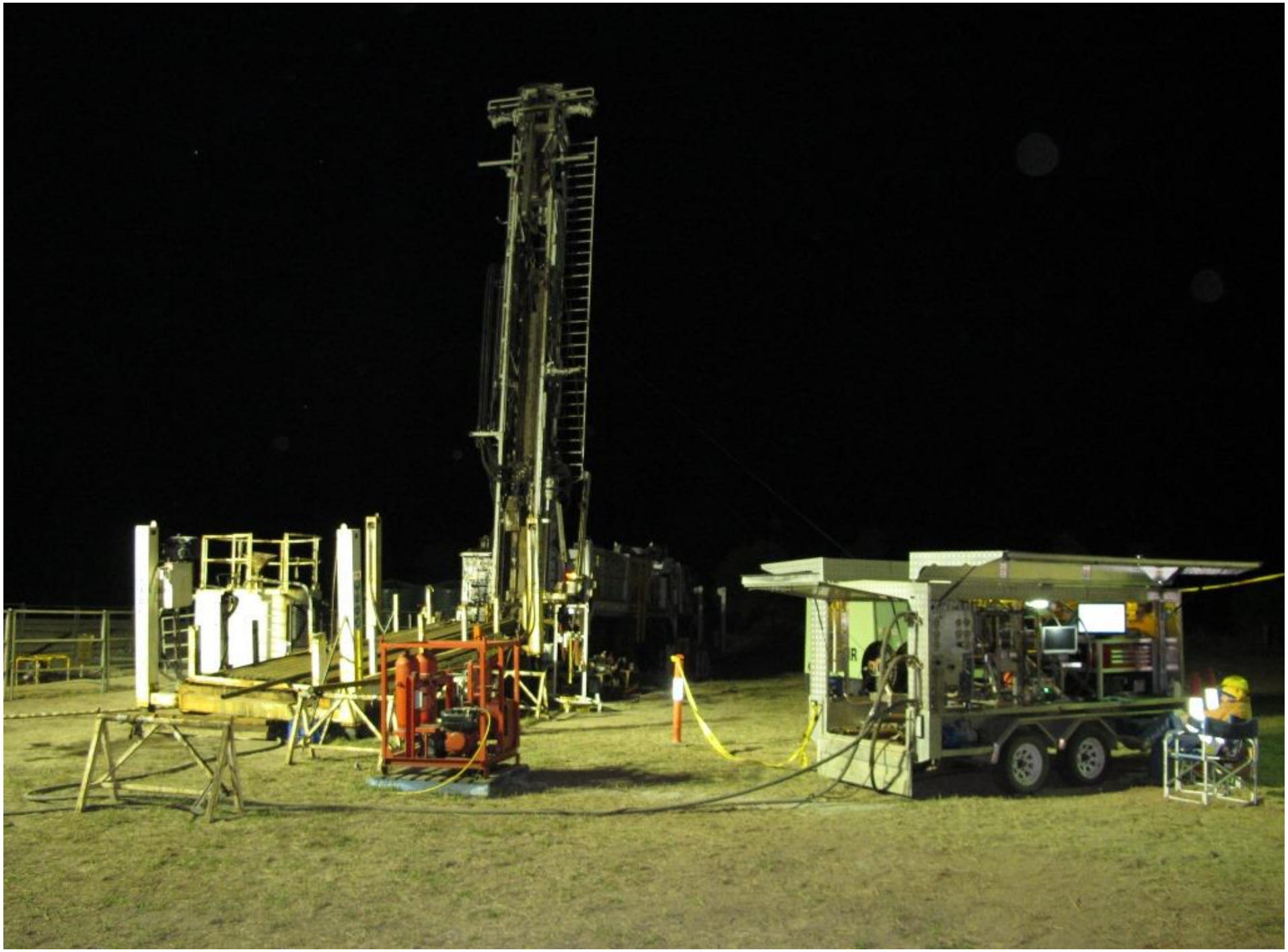
Total Test, Derivative Plot, Horner Plot


CRATES
TRIPLE M
TOYO A/T
OPEN COUNTRY

DST Tool and Trailer



Lowering the DST Tool

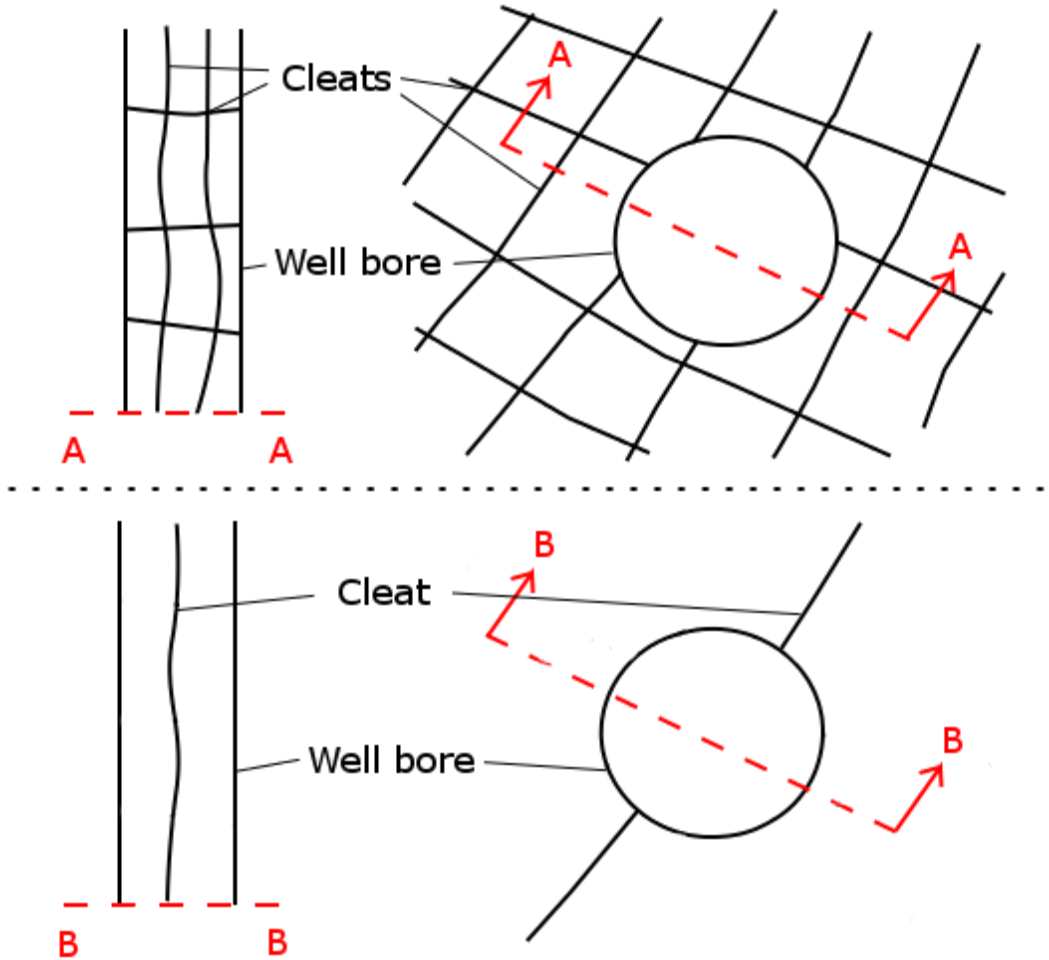


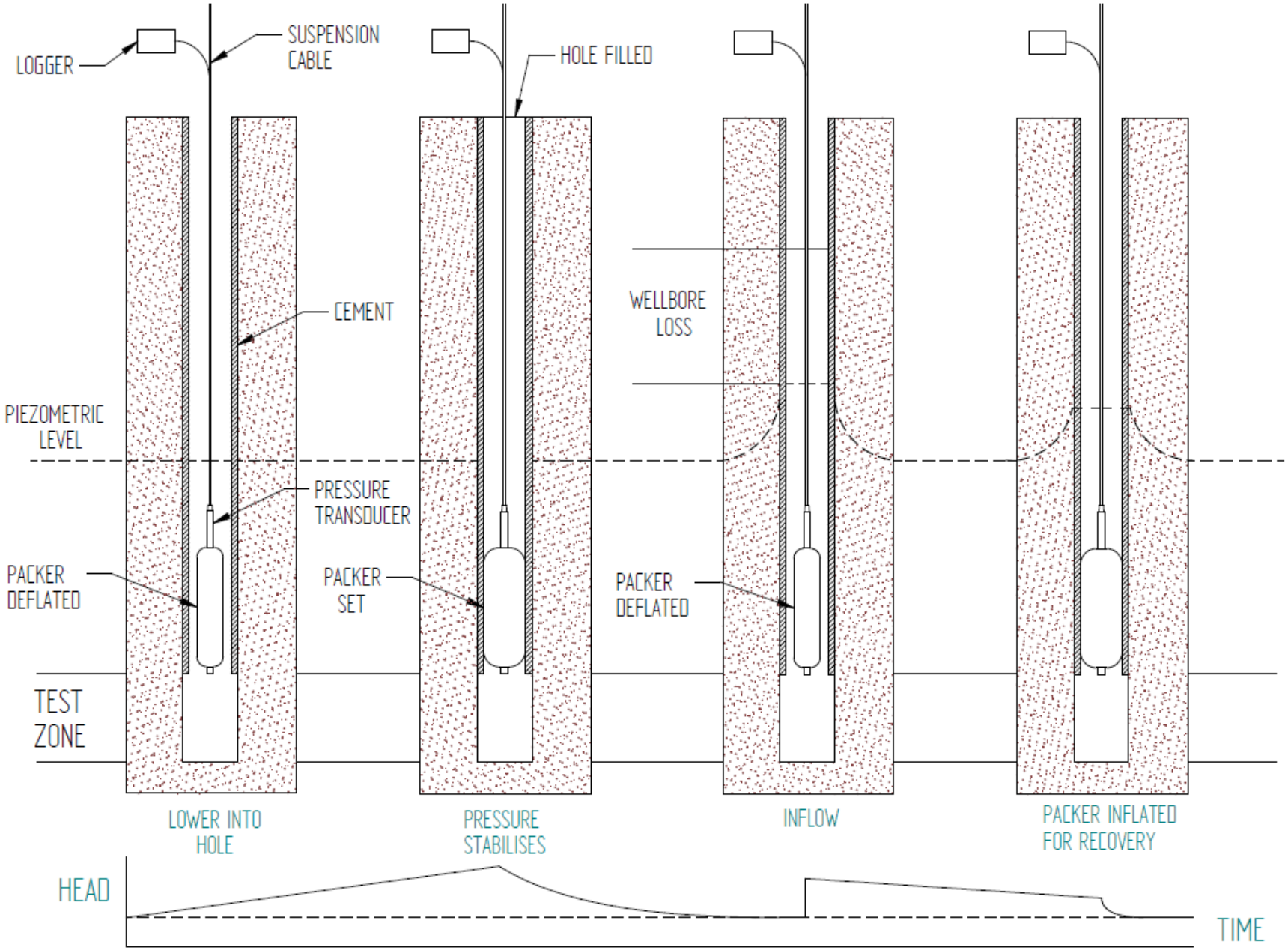
DST Site Setup

Sigra

Portable DST Equipment – 1.5 m cube

How Well are You Connected?





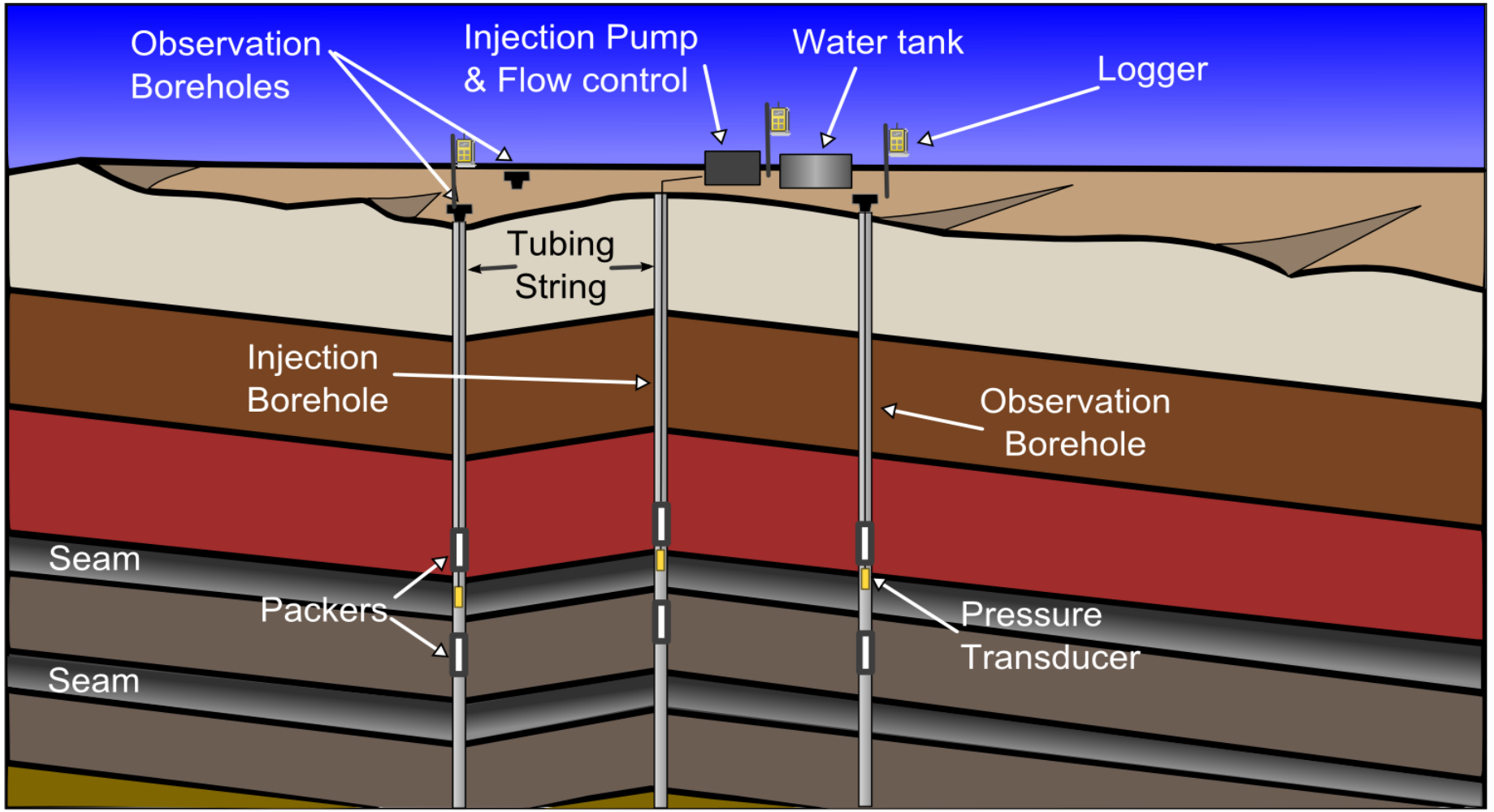
DST FOR SOILS

Field Measurement of Permeability

- DST preferred if permeability adequate
- Injection tests tend to block up
- Interference testing works best but is expensive

  Need to know permeability range to design an interference test
- Can use pulsed DST with pressure measurement in adjacent hole

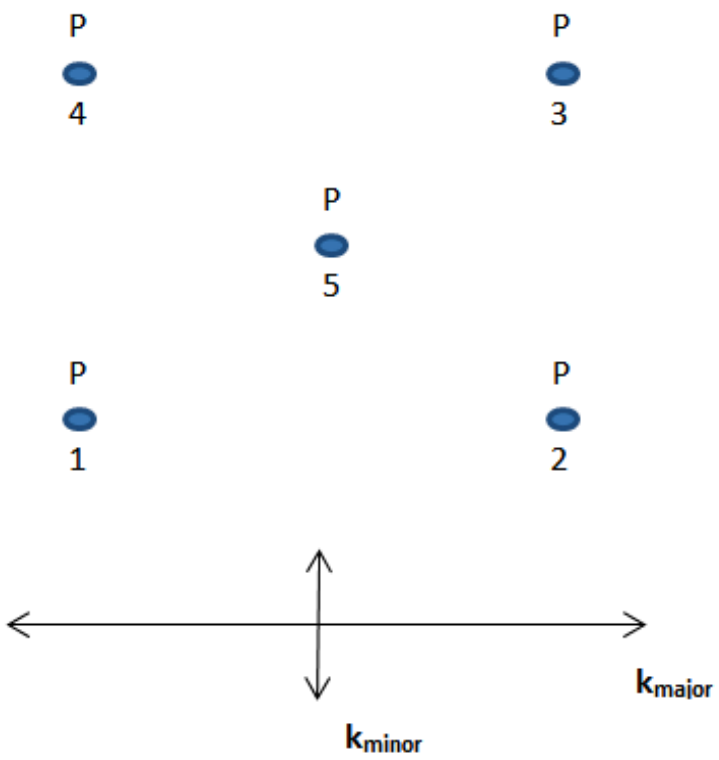
Interference Testing



Progressive Pulsed Tests

- Measure fractures and stress
- Guess direction of major permeability
- Undertake test in single hole to get a mean permeability
- Drill second hole along line of expected major permeability
- Undertake pulsed test from second to first well and get mean and directional permeability
- Continue with more holes

Progressive development with pulse testing



- 1 $k_{average}$
- 2 $k_{average}$

  k_{1-2}
- 3 $k_{average}$

  k_{1-3}

  k_{2-3}
- 4 $k_{average}$

  k_{1-4}

  k_{2-4}

  k_{3-4}
- 5 $k_{average}$

  k_{1-5}

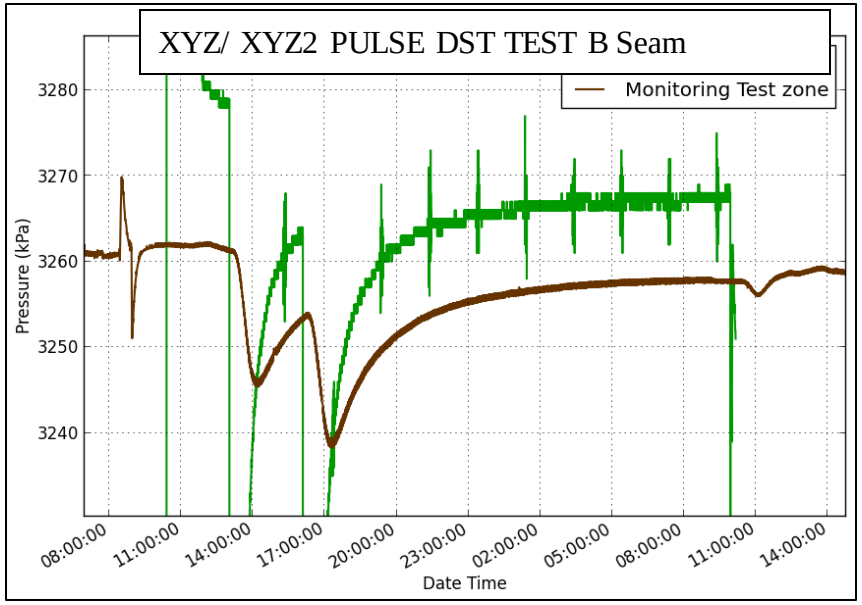
  k_{2-5}

  k_{3-5}

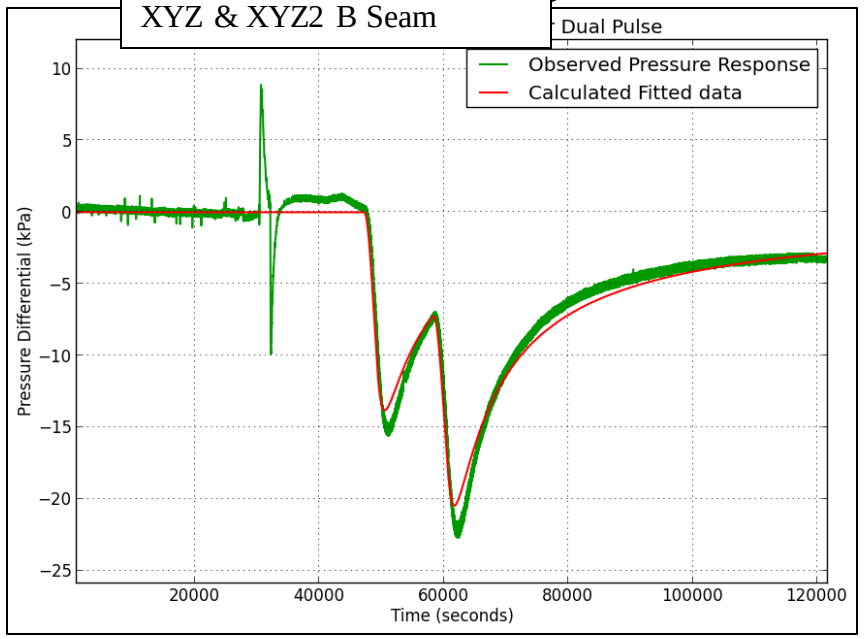
  k_{4-5}

Results of Pulsed DST to Measure Directional Perm

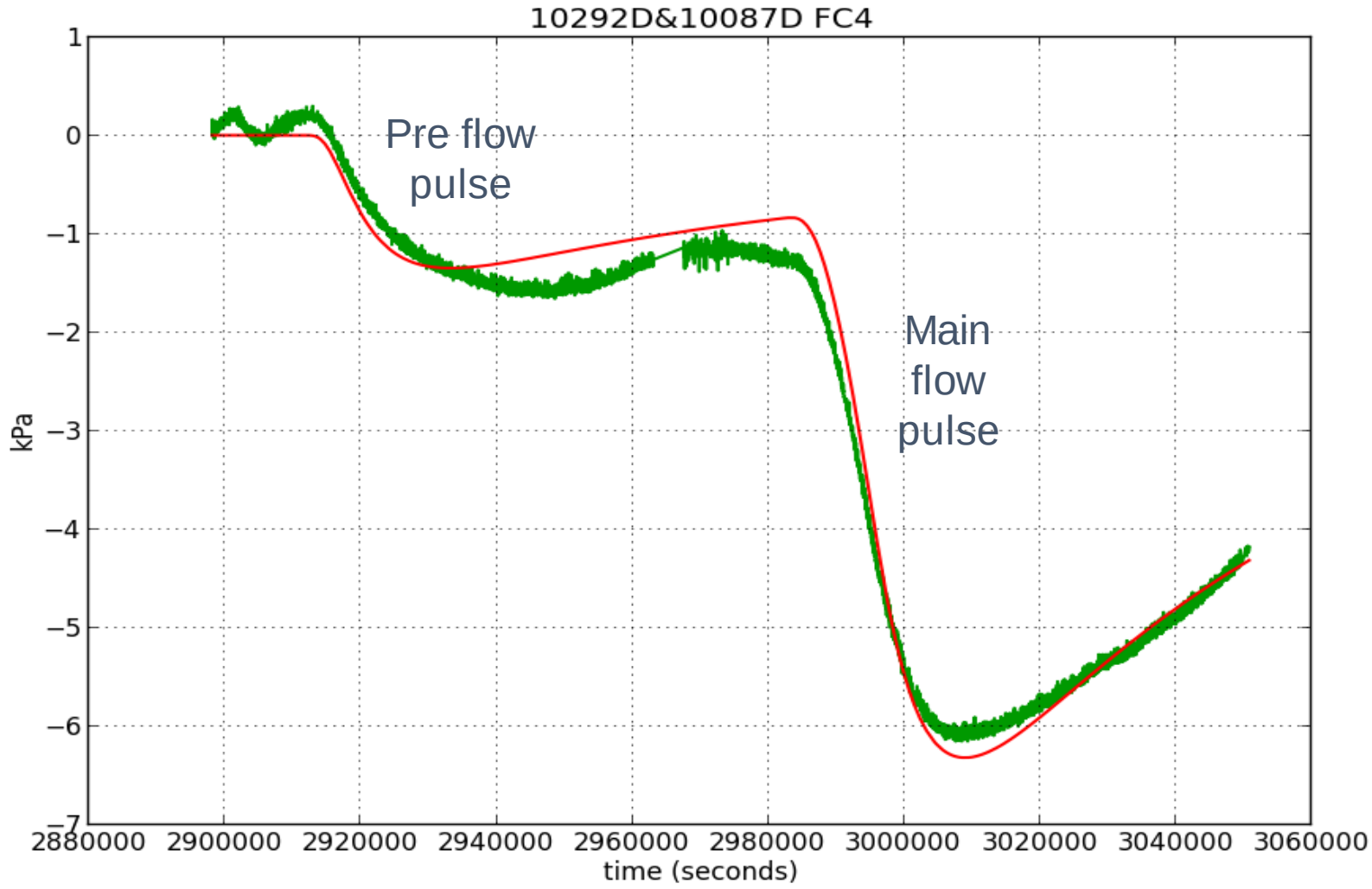
Pulse DST Test



Curve Matching of DST Pulse Test



2 stage DST pulse match



Permeability Varies Spatially and With Time

- Geological factors give spatial and directional variability
- Effective stress changes influence permeability greatly (stiffness dependent)
- Withdrawing fluid increases effective stress
- Relative permeability effects important
  - Air and water get in each others way

Long Term Monitoring is an Important Key to Understanding Ground Fluids Behaviour

Monitoring tool - Piezometers

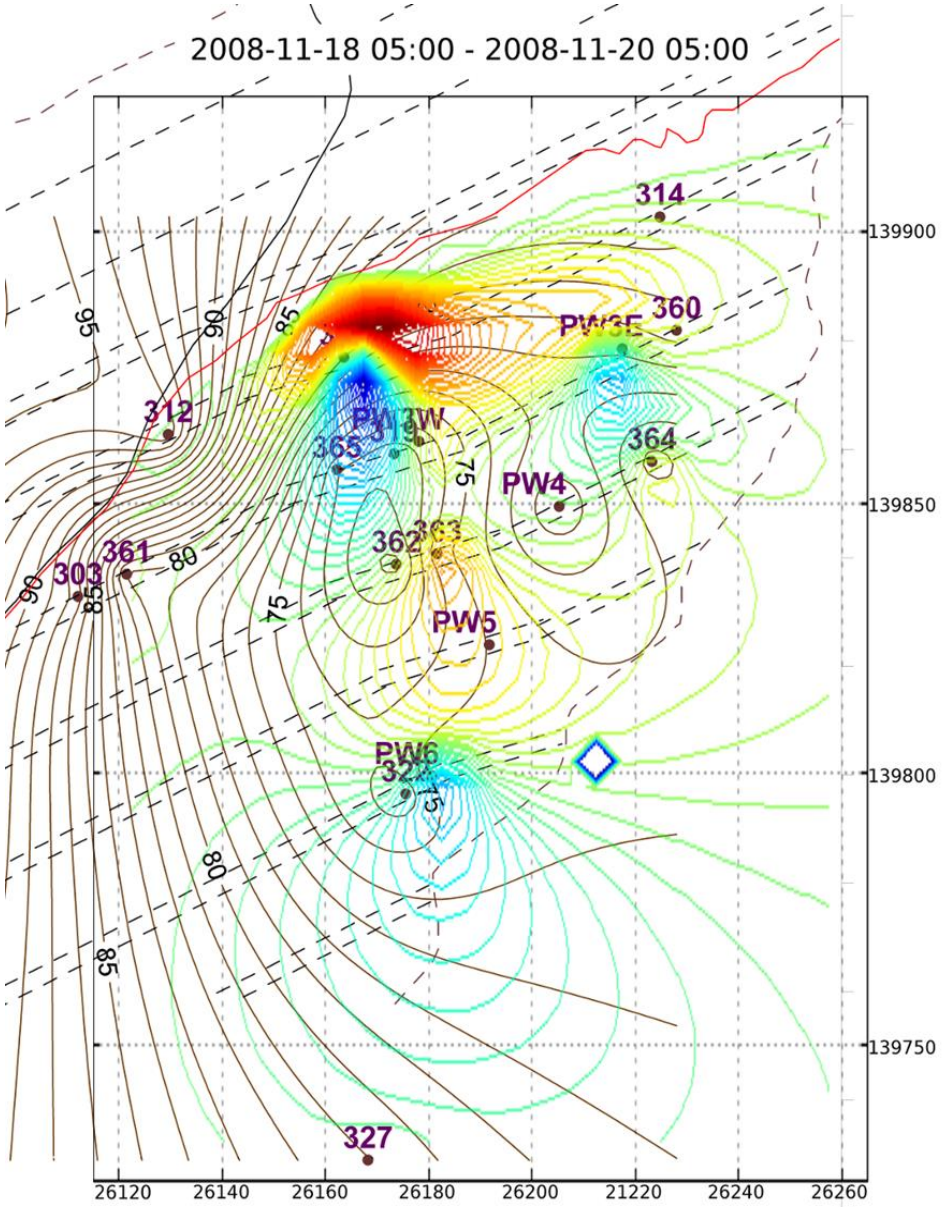
- Sigra have developed a new installation method for piezometers.
  - Requres less labour
  - Is very suitable for multi-level installation
  - Is testable
- We call it Cement Displacement
- Swell packers
- Combined settlement and piezo monitors

Eight transducers to 600 m

The cementing system

Cut Slope Hydro-geology

Net infiltration model of cut slope



Thank You

For listening to

a small part of what we do

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