

Hydrology

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Outline

- Background
- Flowmeter Logging – Fluid Movement Logging
- Fluid Logging (temperature, fluid resistivity)
- Borehole Televiwer Logging – Television camera
- Case Study LDEO Testwells

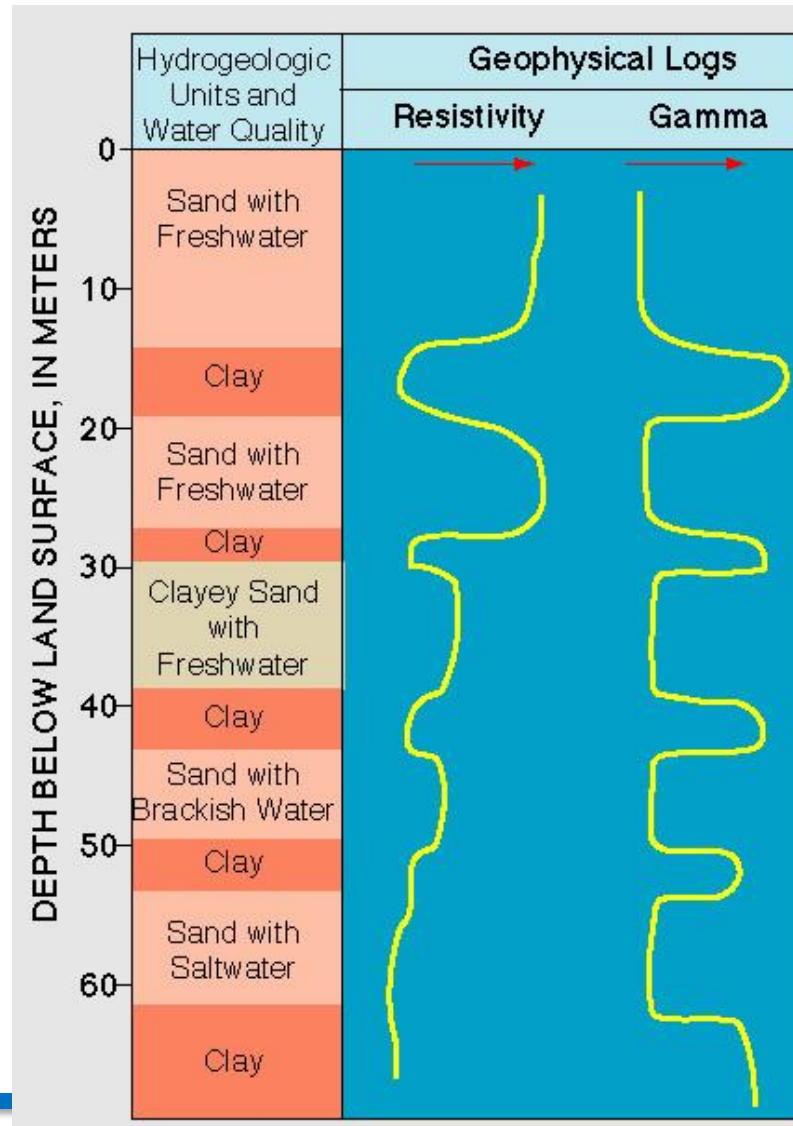
Borehole Geophysics in Groundwater Studies

- 1890's first geophysical well logs plotted from temperature measurements made by W. B. Hallock (1897)
- C. E. Van Orstrand (1918) USGS, described downhole-temperature equipment with a sensitivity of 0.01°C
- Orstrand thought that temperature curves could be used to determine relative water content of rocks in situ
- Well logs can be used to determine lithology, porosity, density, moisture content, clay content, direction and velocity of flow, water level, water conductive fractures
- **No direct determination of permeability by logging**

Equipment

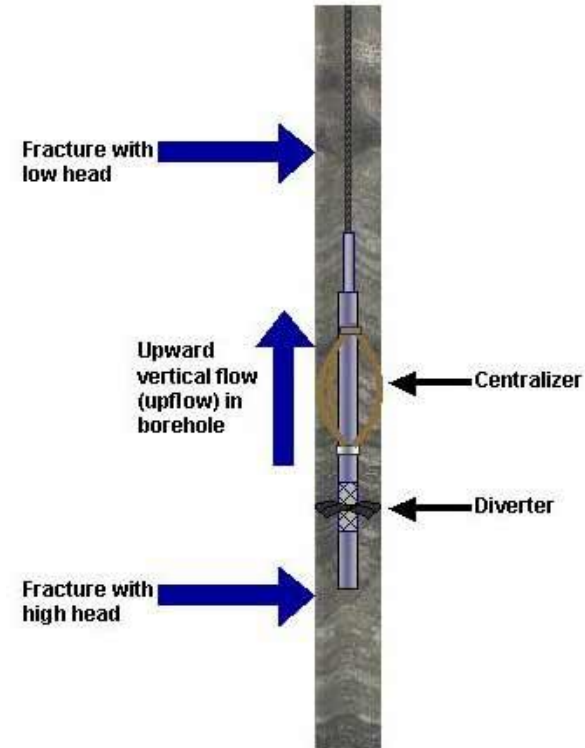


Hydrostratigraphy



Flowmeter Logging

- conventional single hole flowmeter logging – ambient, pumping or injection conditions
- vertical or horizontal flow logging
- cross-hole flowmeter logging – pumping or injection conditions
- discrete interval hydraulic testing – pumping or injection conditions
- discrete interval sampling



<http://water.usgs.gov/ogw/bgas/flowmeter/>

Flowmeter Tools

1. Heat-pulse Flowmeter

- Measurement at stationary position
- Activation of heat grid to heat packet of water
- Movement of heated water packet if flow in well
- Monitoring difference in T between sensors
- Measurement of time difference between activation and greatest T measurement
- Calculation of rate of flow and direction
- resolution 0.01 to 1.5 gallons/min



<http://water.usgs.gov/ogw/bgas/flowmeter/>

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2. Electromagnetic Flowmeter

- based on Faraday's law of induction
- electromagnet generates a magnetic field in hollow cylinder within the tool
- flow of water (conductor) thorough magnetic field at 90° to the field induces a voltage
- voltage measured by electrodes within the tool and used to calculate velocity of water through fixed-diameter chamber
- flow velocity used to calculate volumetric flow
- measurement while moving or stationary
- resolution 0.5 – 10 gallons/min



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2. Spinner or Impeller Flowmeter

- impeller revolves in response to fluid flow
- recording of number of impeller revolutions per second and used to calculate fluid velocity
- measurement while moving or while stationary
- minimum velocity is ~5 feet/min
- generally poor resolution



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Vertical Flowmeter Logging

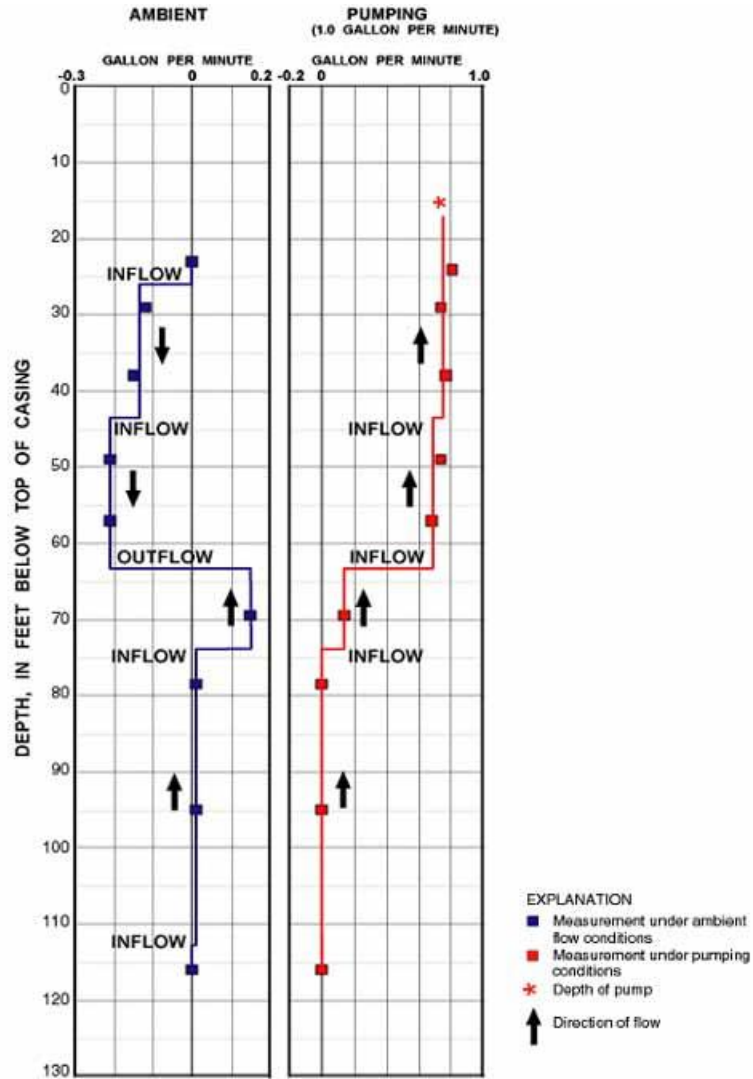
Single hole

- measurement of vertical movement of fluid in a borehole, produced by difference in hydraulic head between two permeable units
- measurement of rate and direction of vertical flow
- relative hydraulic gradients
- identify permeable units or fractures

Cross-hole

- identify cross-hole connections
- transmissivity
- hydraulic heads
- storage coefficient of permeable unit or fracture between borehole

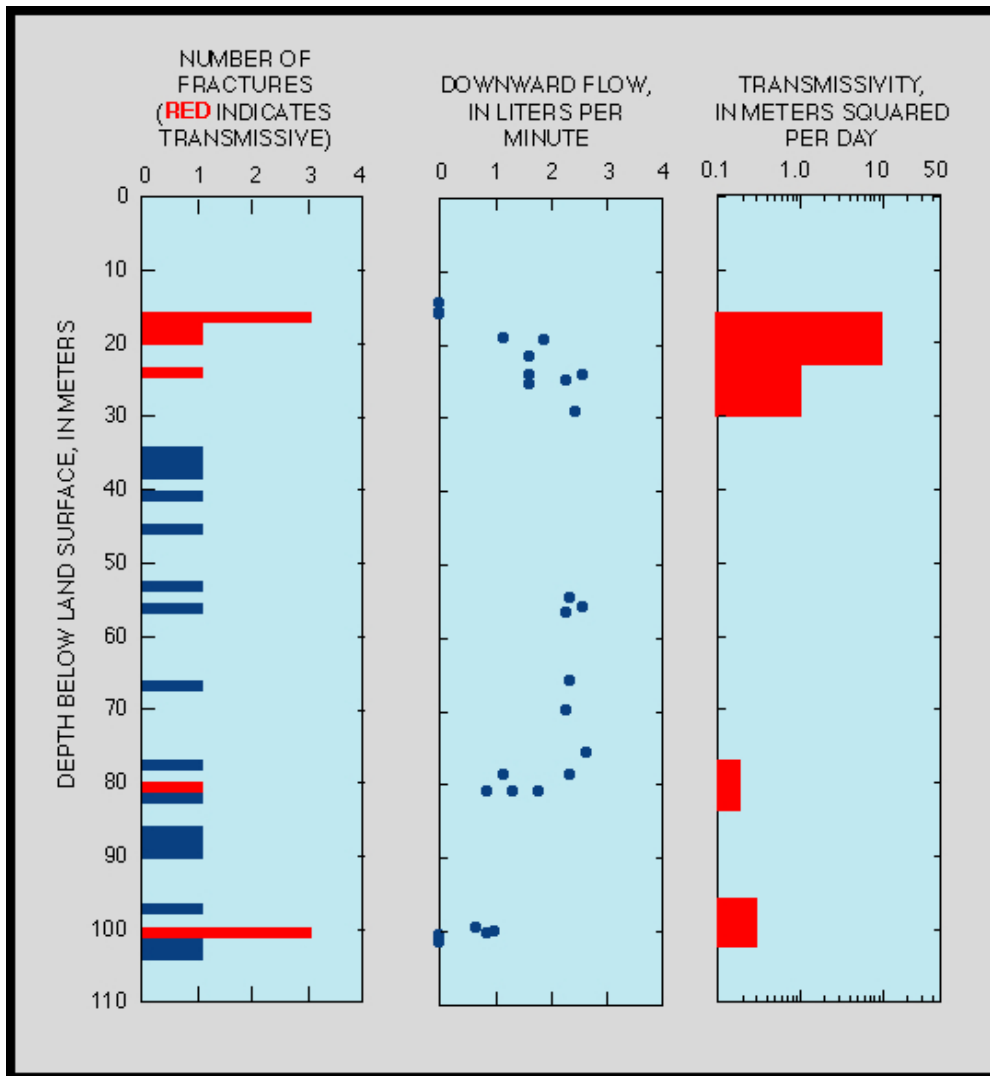
Single Hole Flowmeter Log



➤ fluid moves from higher head to lower head!

<http://water.usgs.gov/ogw/bgas/flowmeter/>

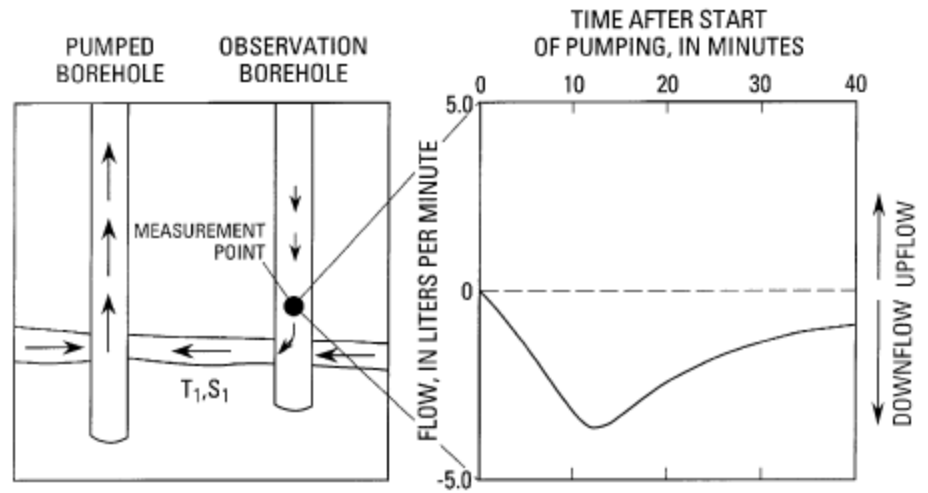
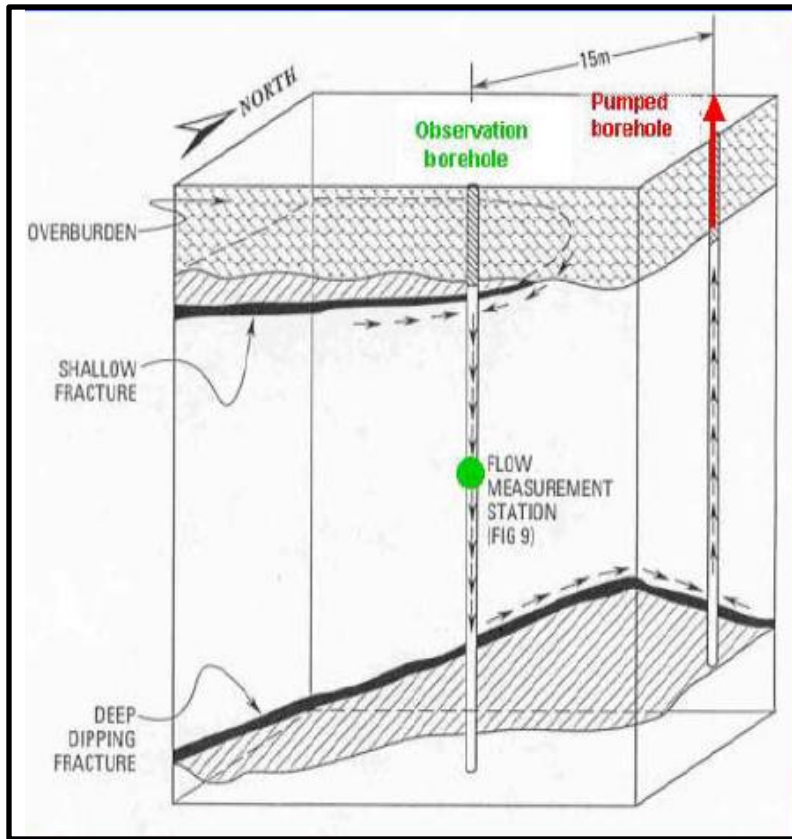
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- detection of transmissive zones
- fracture distribution determined by acoustic televiewer
- Transmissivity estimated from pumping tests using straddle packer

Williams and Conger (1990)

Cross-Hole Flowmeter Log

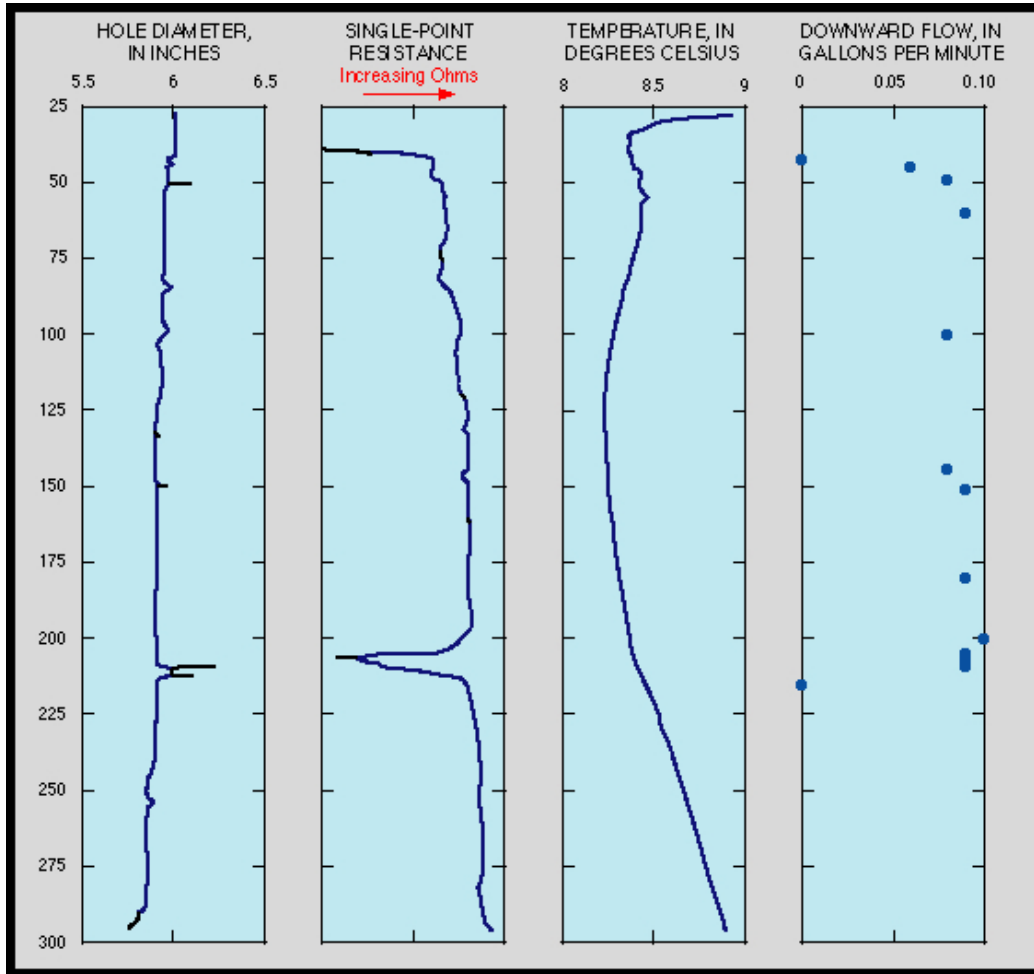


Williams and Paillet (1998)

Horizontal Flowmeter Logging

- **KVA Heat-Pulse Flowmeter**
- **Scanning Colloidal Borescope Flowmeter (LLNL)**
 - evaluates horizontal groundwater flow direction and velocity
 - employs a charge couple device, magnetometer, light source and remotely controlled focal lens mechanism to track colloid-sized particle
- **Acoustic Doppler Velocimeter (USGS)**
 - position of colloids is measured by acoustic reflections
 - as colloids move with groundwater, software tracks the particle paths and calculated transport rate and direction
 - Built-in magnetometer

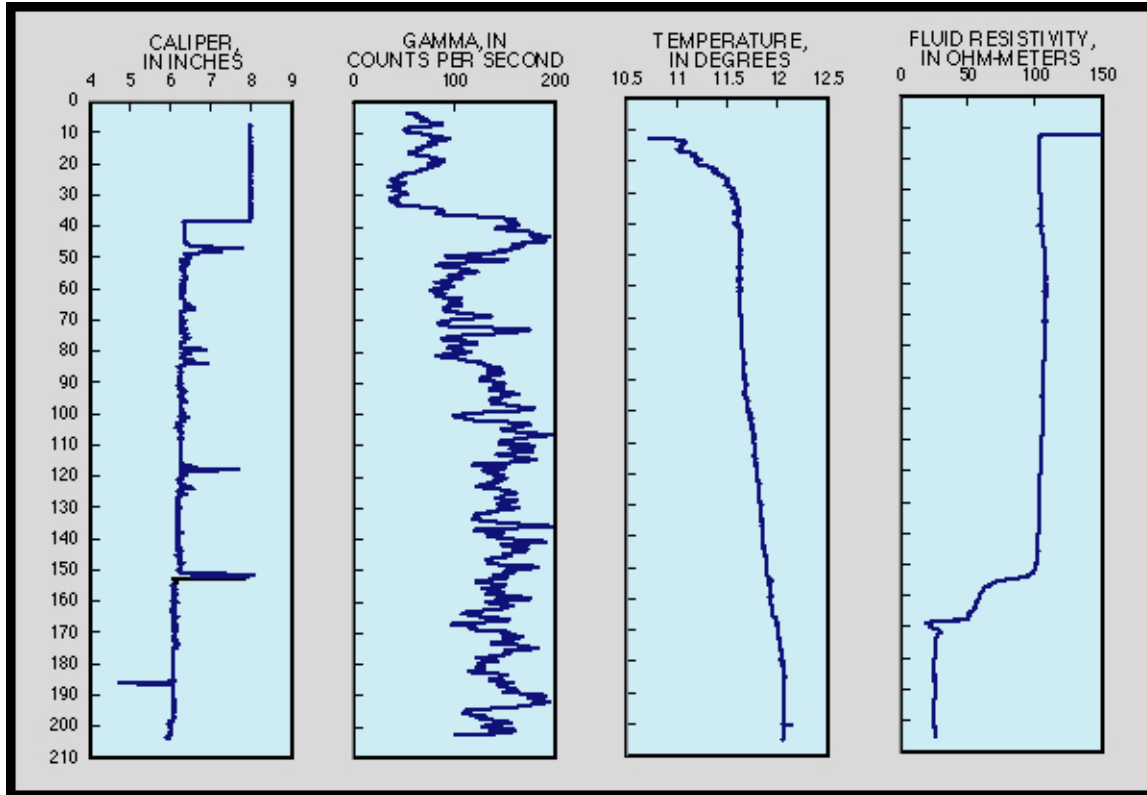
Fluid Logging - Temperature



- used to delineate water-bearing zones
- identify vertical flow between zones of different hydraulic head
- flow is indicated by T-grad < regional geothermal gradient
- used to identify recharge water and liquid waste discharges to the ground
- convection in well can disturb thermal gradient (deep and large wells)

<http://ny.water.usgs.gov>

Fluid Logging – Fluid Resistivity (ohm-m)

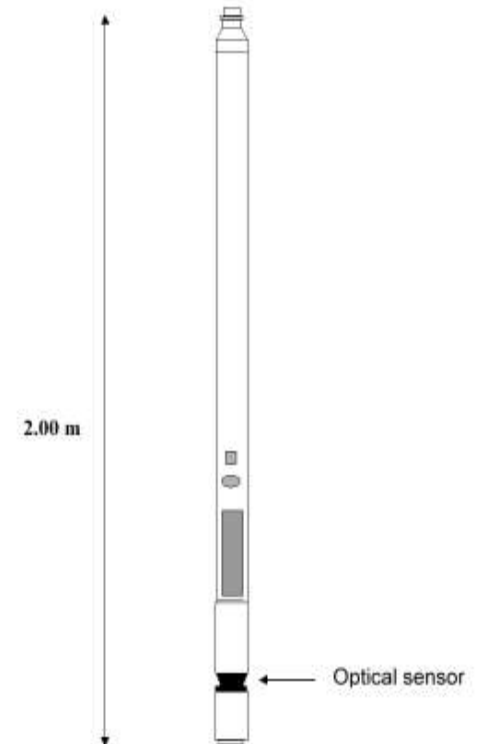


- used to identify water-bearing zones, vertical flow, contaminants
- probe measures AC-voltage drop across two closely spaced electrodes -> function of fluid resistivity
- fluid conductivity (mhos/cm) is reciprocal of resistivity (10,000 / resistivity)

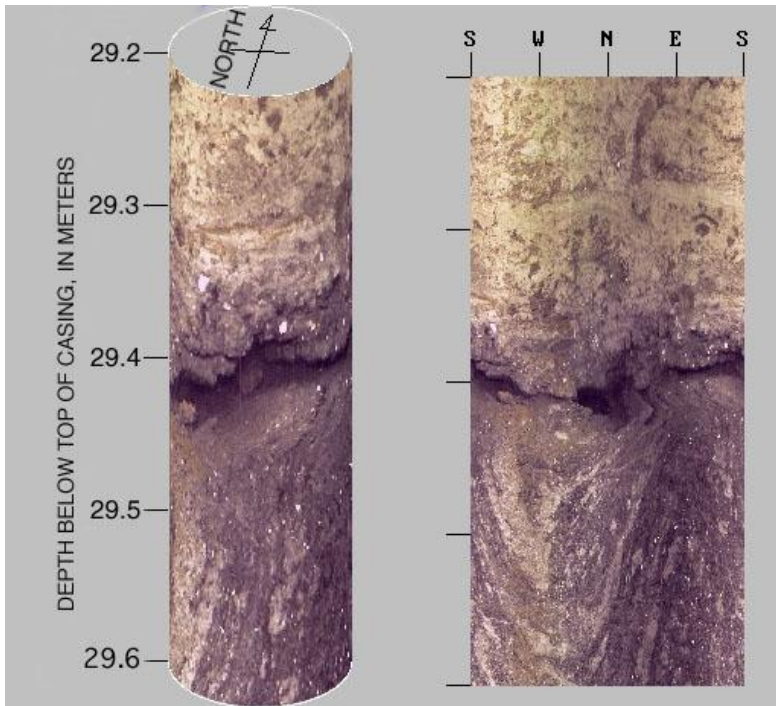
<http://ny.water.usgs.gov>

Borehole Televiewer Logging

- used to obtain oriented images from borehole wall
- two different technologies are available: acoustic televiewer, optical televiewer
- acoustic televiewer uses an acoustic signal from a rotating sonar transducer
- optical televiewer uses a high resolution digital color camera with a light source
- both have a built-in magnetometer to orient the image with respect to magnetic north
- identify fractures, breakouts and other borehole features



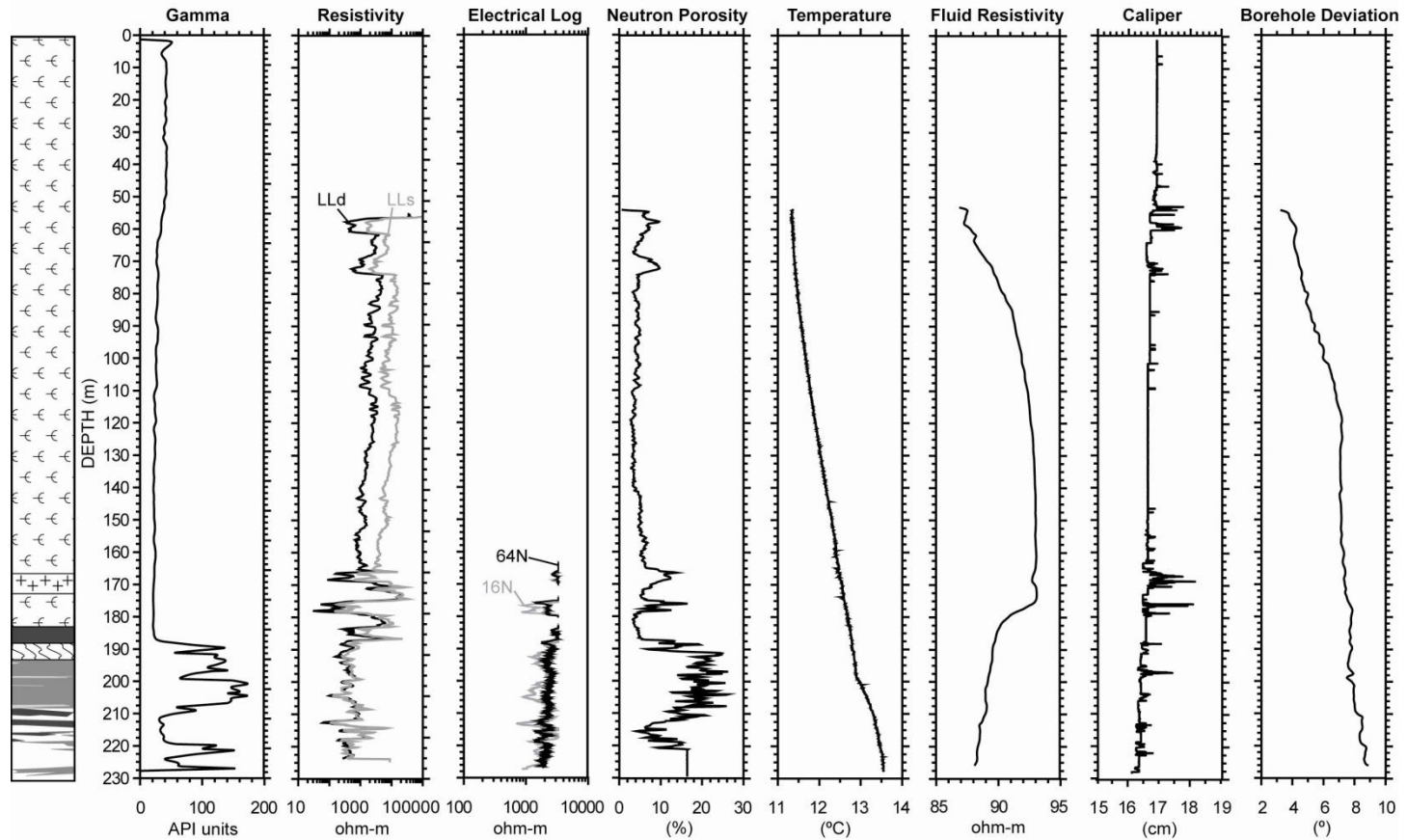
Digital Borehole Television Camera



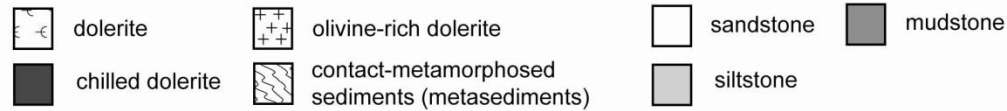
- commonly used to inspect well casing conditions and screens
- also used to view: lithologic texture, grain size, color, water levels, fractures
- applicable in clear water above and below water level
- built-in magnetometer for oriented 360° digital images of borehole wall

Case Study – Lamont Test Wells

LDEO-2

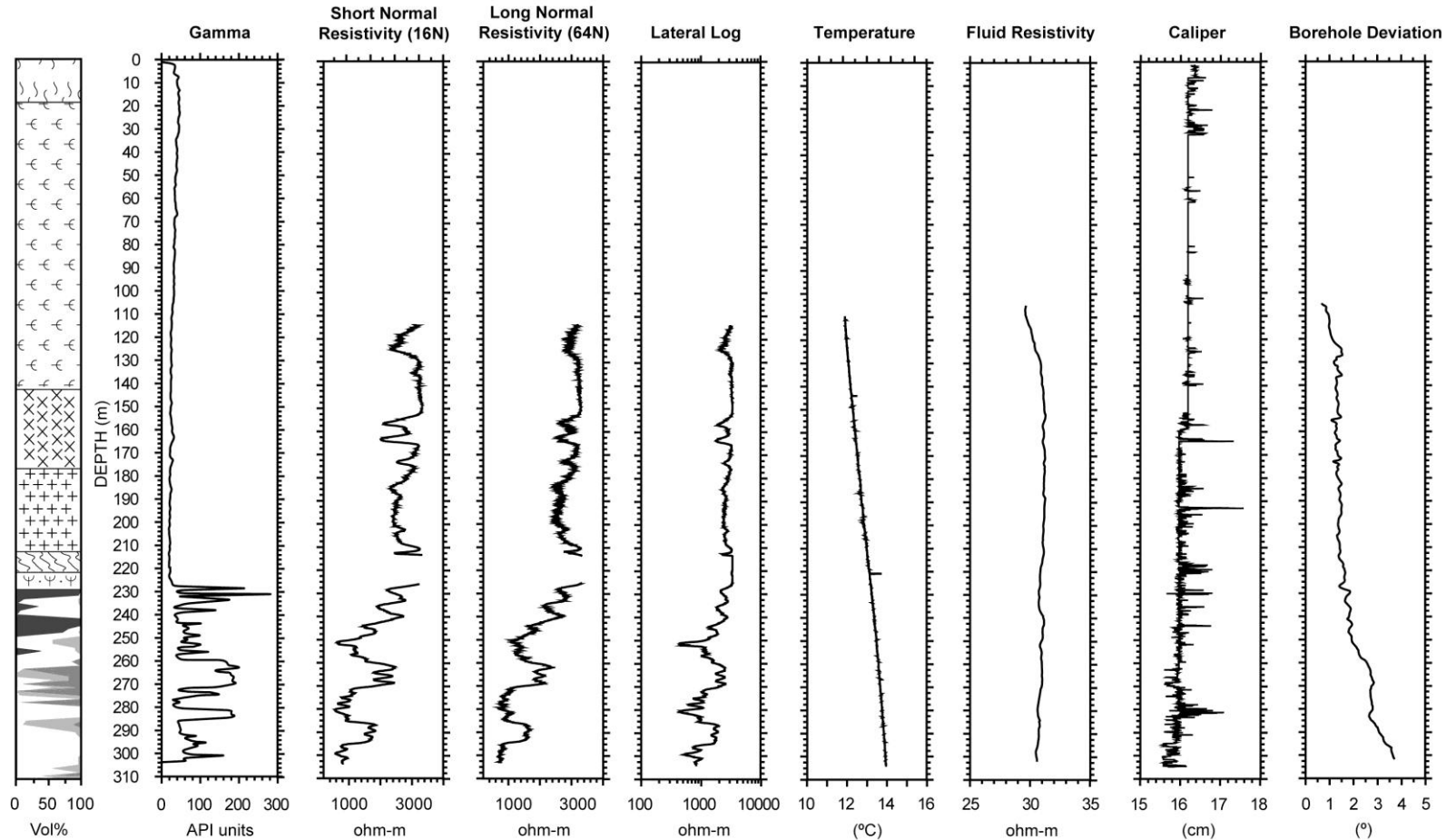


Lithology

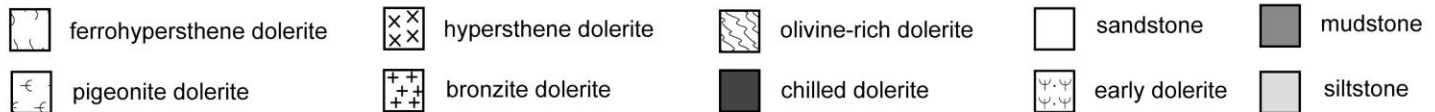


Matter et al. (2006)

LDEO-3



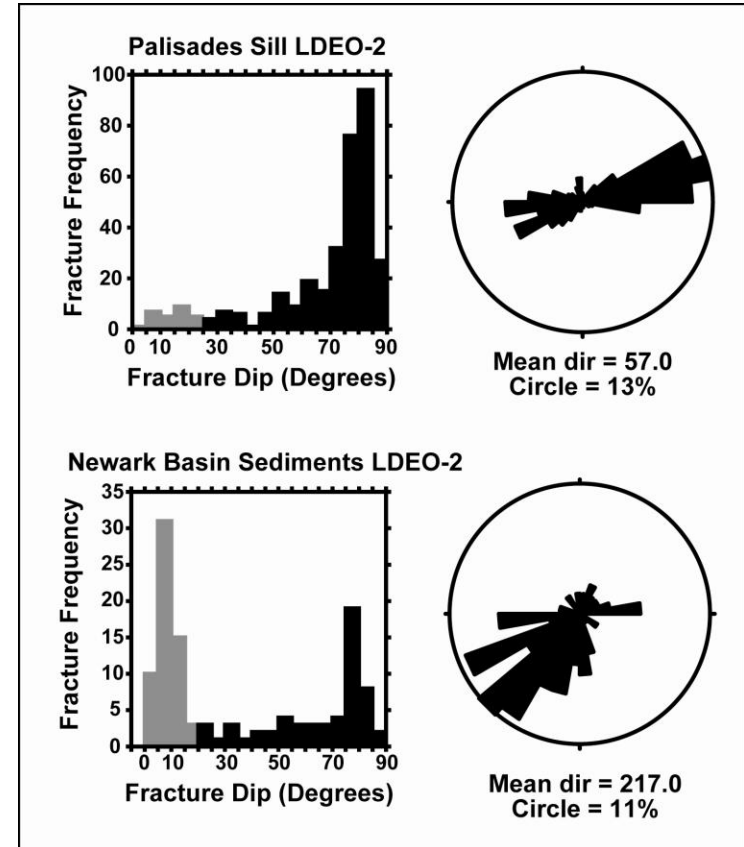
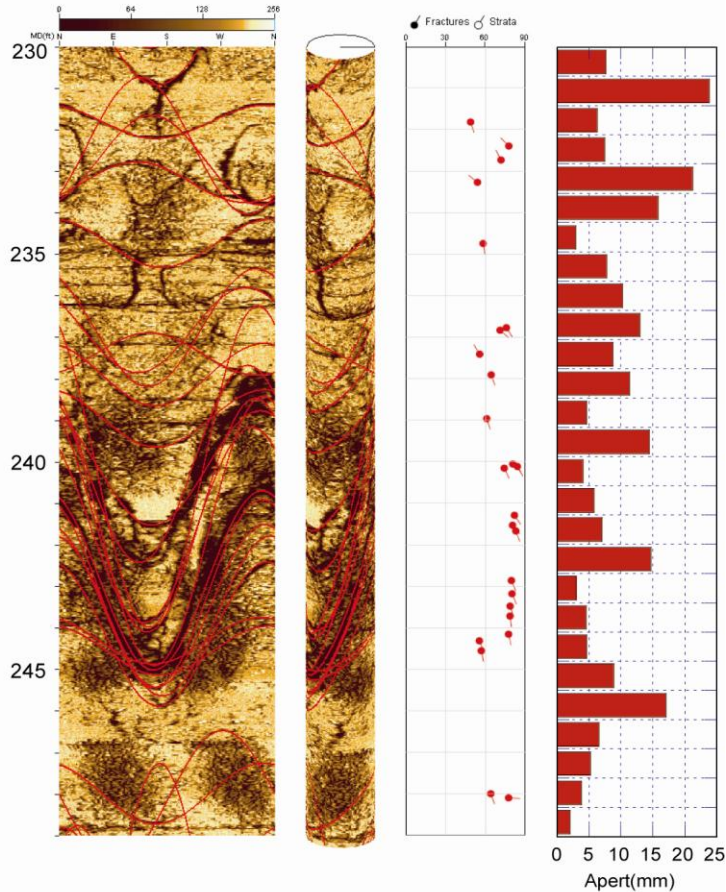
Lithology



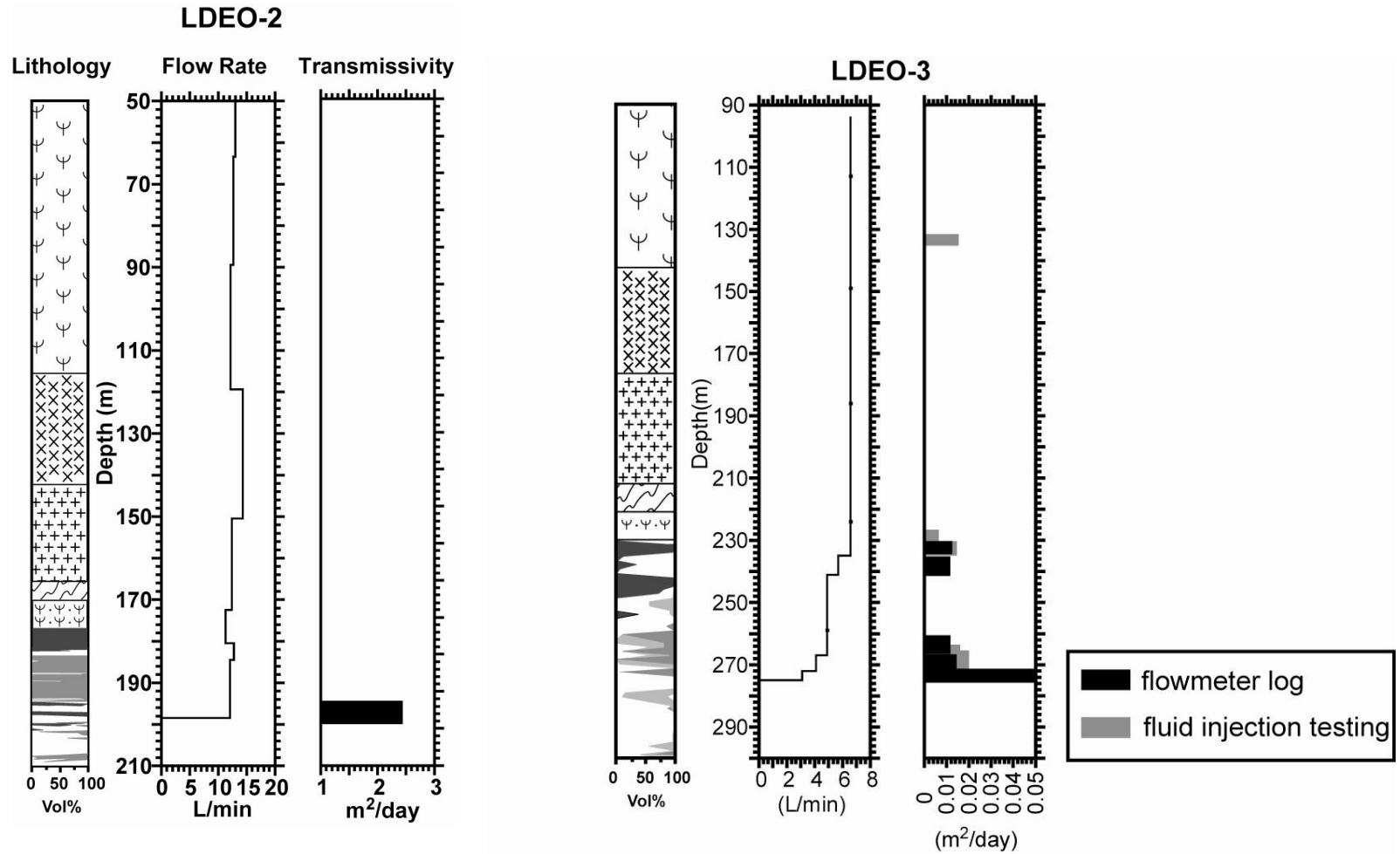
Matter et al. (2006)

Borehole Televiewer – Lamont Test Wells

Well Name: TW-2 Log Date: 6/22/02
 Well Location: Palisades NY Depth Range: 230.0 - 250.0 ft



Flowmeter Logging – Lamont Test Wells



Matter et al. (2006)

Flowmeter Log Analysis

- Transmissivity (T) – horizontal flow rate per unit width of aquifer under unit head gradient
- $T = K_h \cdot b$, where b is aquifer thickness
- K_h = horizontal hydraulic conductivity (m/s)
- Cooper and Jacob method (1946)

$$K_1 = \frac{\Delta Q}{2\pi H(\Delta p)} \cdot \ln \left[\frac{2.25 K_2 H t}{R^2 S} \right]^{1/2}$$

Q: horizontal volumetric flow

H: thickness of interval

Δp : change in hydraulic head from static conditions

t: time since onset of pumping or injection

R: borehole radius

S: Storativity (5.5E-05)

Permeability Testing

- Short duration fluid injection tests
- Flowmeter measurements with electromagnetic flowmeter
- 48-hour constant discharge pump test

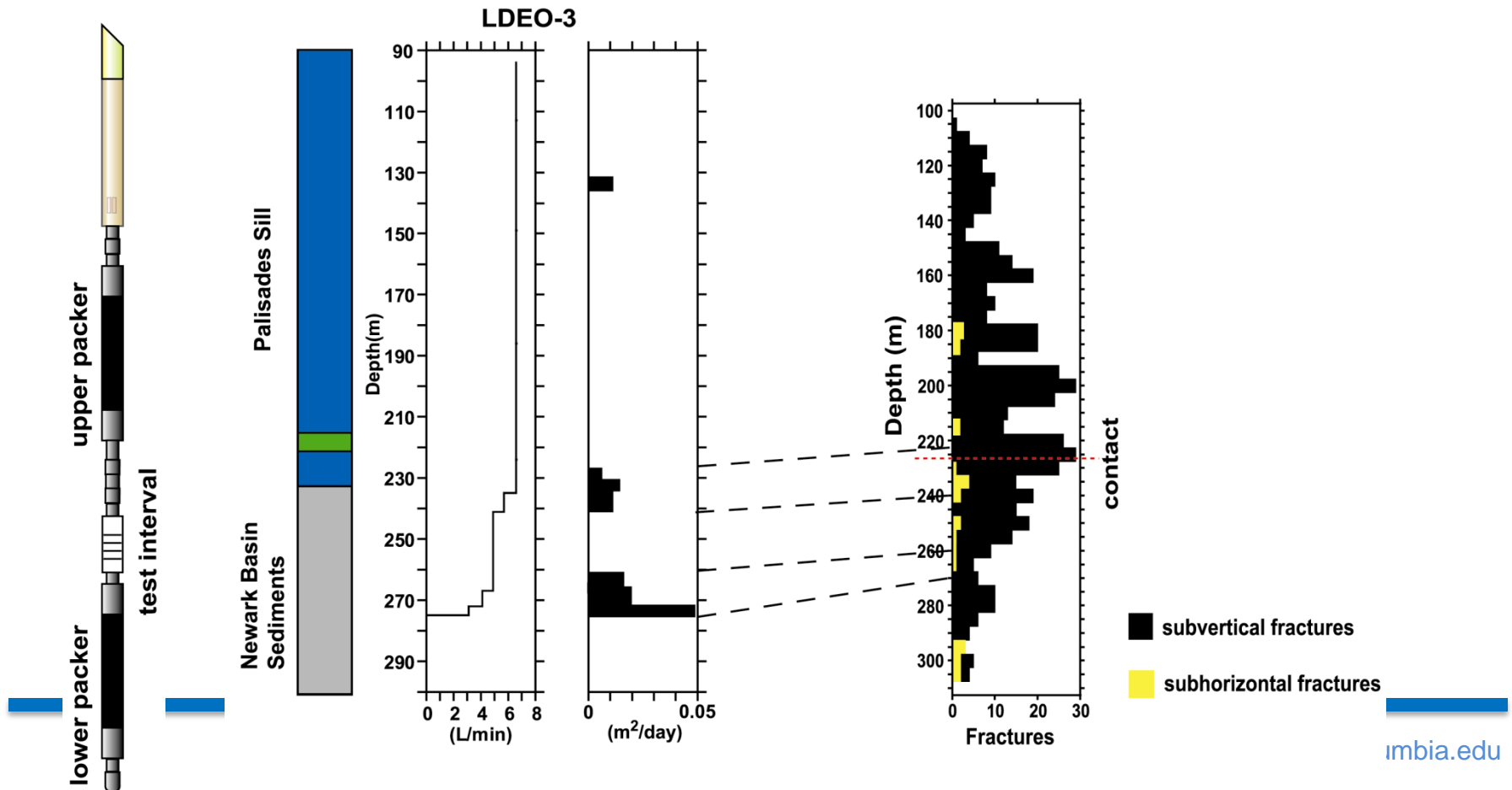
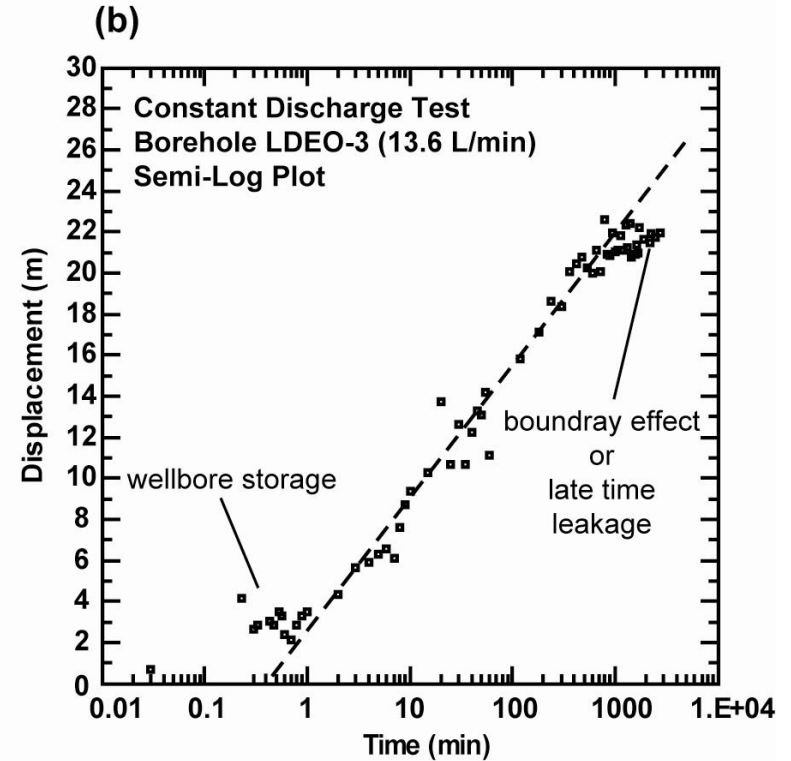
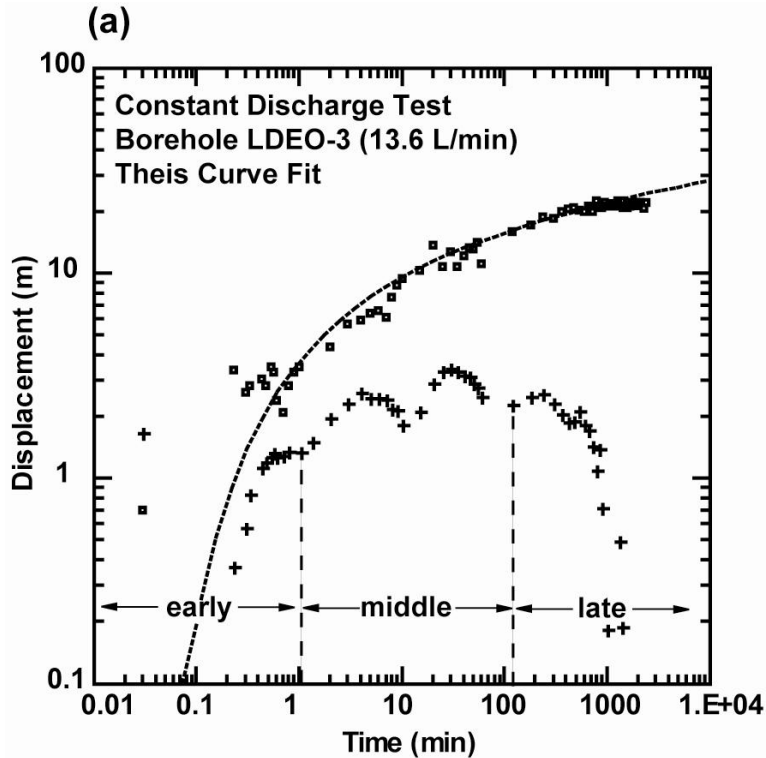


Table 1 Calculated transmissivity values for LDEO-3 based on flowmeter logs, straddle-packer injection, and aquifer tests

	Depth interval (m)	Transmissivity (m ² /s)
Fluid injection	121–124	*
	132.5–135.5	3.04E-07
	146–149	*
	161.5–164.5	*
	170.5–173.5	*
	180–183	*
	190.5–193.5	*
	209.5–212.5	*
	214.5–215.5	*
	218.5–221.5	*
	224.5–234.5	*
	227–230	8.10E-08
	231.5–234.5	1.62E-07
	260.5–263.5	*
	264–274	2.17E-07
271–274	*	
Flowmeter	228–300	9.95E-06
	115–230	*
	231–234	1.39E-07
	235–241	1.27E-07
	242–260	*
	261–266	1.27E-07
	265–269	1.62E-07
Discharge test	269–275	5.67E-07
	110–227	*
	228–300	6.28E-06

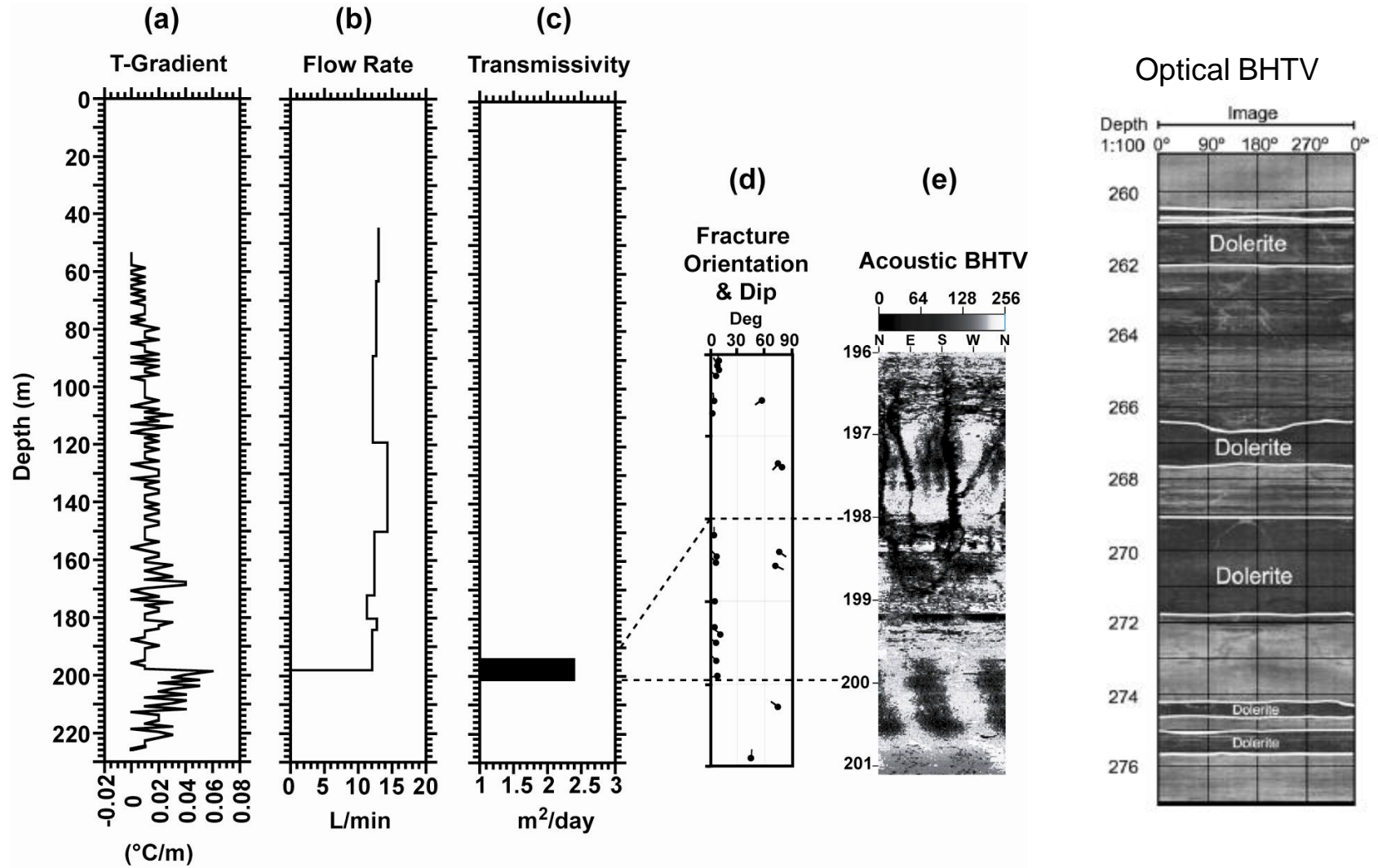
*Data below detection limit of applied methods

Pump Test Analysis



	T (m²/day)	K (m/day)
Sill	0.01	0.0034
Contact Zone	0.02	0.006
N.B. Sediments	0.57*	0.0075*

Correlation



Literature

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