Recommended Basic Borehole Geophysics for Hydrologic Investigations in a Fractured Bedrock Aquifer

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Quality GeoScience

GeoServices, Ltd.

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I have a 6-inch casing stick-up, but…

- Is there anything geophysics can do for me?
- Hydrogeologists do not always receive great exposure to borehole geophysics.
- Geophysicists do not always get a lot of exposure to hydrogeology.

Case History at Hand

- Known:
  - Well was constructed in the 1940's. Little else known…
  - With time, the well yield had slowly declined.
  - The water from the well was very high in iron and manganese.
- Plan:
  - Municipal Authority wanted to pull the well pump and rehabilitate the well.
  - Consider well reconstruction to isolate a local coal seam suspected of contributing the iron and manganese.
  - Establish a new pumping rate BUT avoid having water level to drop below the shallowest water bearing zones.

Hydrogeologist Needs, Needs, Needs, Needs…

- Well Log,
- Well Construction,
  - Depth of Casing,
- Well Depth,
- Bedrock Fracture Locations,
- Water Bearing Zones,
- Lithology,
- Well Yield

Choices, Choices, Choices, Choices, Choices…

If the Hydrogeologist did some internet surfing…

Manufacturer	Number of Sensors
Mount Sopris Instruments	29 Sonde's
Robertson Geologging	26 Sonde's

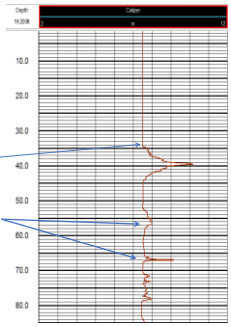
Schlumberger "Service Packages"			
Petrophysics	7	Geophysics	4
Geology	5	Reservoir Engineering	9
Geomechanics	3	**Total Packages**	**28**

How do we fill the customers needs ? ? ? ? ?

Recommended Logging

- Temperature,
- Caliper,
- Spontaneous Potential, Single Point Resistance, Normal Resistivity (8", 16", 32", and 64"), Fluid Resistivity,
- Natural Gamma Radiation,
- Heat Pulse Flow Meter, and
- Optical Televiewer

Well Construction, Depth of Casing, Well Depth, Fracture Locations



Caliper Log

What about
- Well Log,
- √ Well Construction,
  - √ Depth of Casing,
- √ Well Depth,
- √ Bedrock Fracture Locations,
- Water Bearing Zones,
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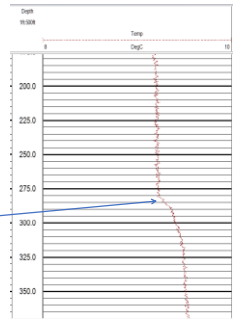
Water Bearing Zones

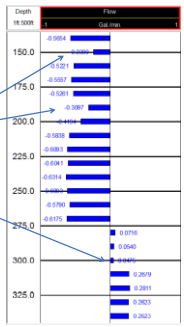
- Temperature Log



Temperature can be unreliable,
Only identifies "MAJOR" Water Bearing Zones

Water Bearing Zones

- Heat Pulse Flow Meter



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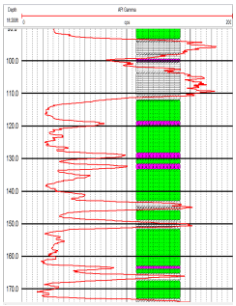
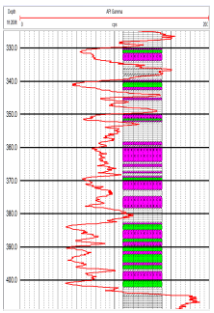
Lithology- A bit tougher…



API Natural Gamma
- Limestones, dolomites, coals, and sandstones vary from 0 to 50 API
- Shales have Gamma values in the range 80 to 200 API units
- Very high Gamma indicative of a marine beds. (Firth, 2000).

Lithology- A bit tougher…

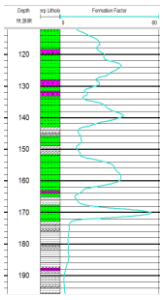


API Natural Gamma
- Thin Beds-Smoothing becomes important
  - Need to know something about the local geology…
- Selection of cut-off values may be a bit arbitrary

SP

Resistivity measurements

Calculation of Formation Factor



- Ratio of the bedrock resistivity (measured with the 32-inch resistivity) to the resistivity of water as established in Archie's law (Archie, 1942).
- The formation factor is intended to represent bedrock resistivity, independent of the electrical conductivity of the fluid in the pore spaces.
- Useful as an independent means to evaluate thick-bedded lithology.
- The formation factor is also a component in the evaluation of formation water quality.

Lithology Interpretation

Resistivity's measured are consistent with

- cemented sandstones,
- siltstone,
- shales deposited in marine environments and
- shales deposited in non-marine environments.

What about

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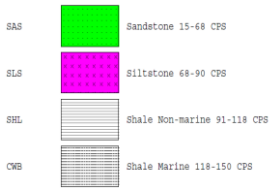
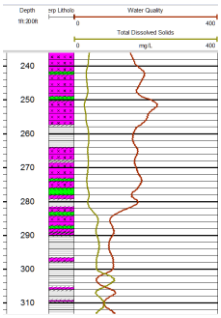


Value Added

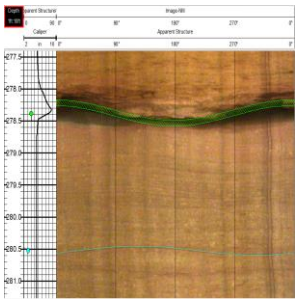
- Calculate Water Quality
- Examine fractures in detail & classify them

Formation Water Quality

- Water Quality Estimated (Jorgensen, 1996)
  - Ratio 32-inch to 8-inch normal resistivity.
- Estimated Total Dissolved Solids
  - Specific conductance (in uS/cm) =10,000/formation water resistance
  - Total dissolved solids = specific conductivity * 0.67
  - 0.67 for many fresh groundwater aquifers Fisher and Friedman (1989)



Fracture Identificaiton

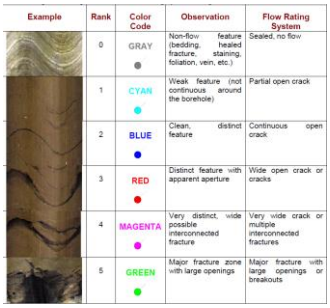


Optical Televiewer

- (A detailed look at fractures of interest)

Fracture Classification

- Followed a ranking system developed and applied by Fred Paillet (USGS, WRD, Borehole Research Project)



Example	Rank	Color Code	Observation	Flow Rating System
	0	GRAY	Non-flow feature (bedding, healed fracture, staining, foliation, vein, etc.)	Sealed, no flow
	1	CYAN	Weak feature (not continuous around the borehole)	Partial open crack
	2	BLUE	Clean, distinct feature	Continuous open crack
	3	RED	Distinct feature with apparent aperture	Wide open crack or cracks
	4	MAGENTA	Very distinct, wide possible interconnected fracture	Very wide crack or multiple interconnected fractures
	5	GREEN	Major fracture zone with large openings	Major fracture with large openings or breakouts

Value Added

- Structure by Interpreted Fracture Type
- Structure by Fracture Depth

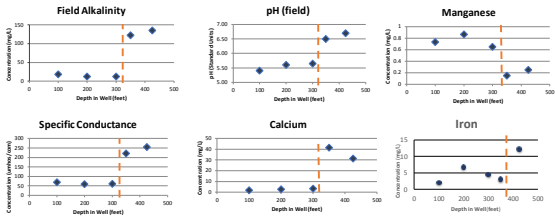
Conclusions

Hydrogeologist needed:
- ✓Well Log,
- ✓Well Construction Information,
  - ✓Depth of Casing,
- ✓Well Depth,
- ✓Bedrock Fracture Locations,
- ✓Water Bearing Zones,
- ✓Lithology,
- Well Yield,

Geophysics Delivered:
- Detailed information about the well
- Minimal number of sondes'
- Limited analysis time

Cost effective scope of services

Epilog - Field Sample Findings



Major Take-Away from the Customer

1. "This combination of geochemistry and geophysical data provided a valuable insight into the sources of iron and manganese and what corrective actions were possible."
2. "The abrupt change in resistivity along with other borehole data, clearly indicated a difference between two major geologic units, one of which was documented in the literature to be an acid producing unit and contain high concentrations of iron."
3. "A step test was performed to estimate the pumping rate to keep the water level above the shallower water producing zones

A Successful Case History

Questions?

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