Determining Suitable Water Zones from Log Analysis

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Abstract

A suitable water zone for geothermal power would be a sandstone or limestone with high permeability, porosity, and temperature. The depth and temperature of a water zone can vary based on the required heat for the geothermal application. Generally, favorable temperature conditions are (110-160°C), while depth can vary based on tectonic setting. Well logs provide an effective method of qualitatively and quantitatively identifying characteristics of the subsurface (including locating a water zone). A triple combo log is used in an open hole (borehole with no casing) and contains a high-definition Induction Log, Spontaneous Potential, Compensated Z-Densilog, Compensated Neutron Log, and Gamma Ray Log. Log readings can be used to calculate temperature, water saturation (S_w), porosity (ϕ), and shale volume (V_{sh}) of a water zone. Permeability is determined qualitatively from the log. Water zones will have a low(salt water) or high(fresh water) true resistivity (R_t) on the Induction Log, high permeability on the S.P. (Spontaneous Potential), high porosity from the Neutron and Density Porosity Logs, and a negative kick on the Gamma Ray depending how clean the zone is. The temperature is either recorded on the log or can be extrapolated by calculated a temperature gradient based on bottom hole temperature and surface temperature.

Well Logs

- Open hole logs (OHL) are ran in the uncased borehole
- Cased hole logs (CHL) are ran after casing has been set

OHL

- High definition Induction Log, Spontaneous Potential, Compensated Z-Densilog, Compensated Neutron Log, and Gamma Ray Log (*Note this is a common modern log combo; several other combos exist whether modern or outdated)
- Logs ran simultaneously in suite called "Triple Combo"
- Provides formation resistivities, permeability, porosity, and temperature
- Used to evaluate formation (calculating temperature, salinity, S_w, R_w, ϕ, and V_{sh}) and subsurface mapping

CHL

- Cement Bond Log, Variable Density Log, Neutron Density Log, Gamma Ray Log, and Collar Log
- Determination of cement bond to casing, density of cement, and casing collar location
- Used to select perforation points and evaluate effectiveness of workover operation
- This log will not be covered in the presentation

Log Header

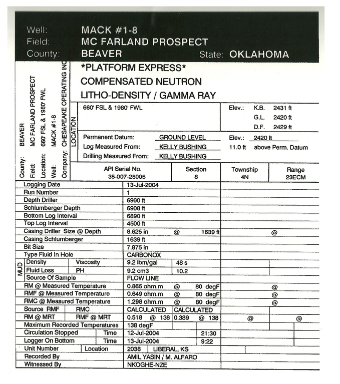


Figure 1. A well log header containing TD, Rm, Rmf, Rmc, driller data etc. (Schlumberger Oilfield Services: Basic Open Hole Log Interpretation and Advanced Technology Applications)

Basic Relationships

$$R_o = F \times R_w$$

$$F = \frac{a}{\phi^m}$$

Archie's Equation

$$S_w = \left(\frac{R_o}{R_t}\right)^{\frac{1}{n}} = \left(\frac{F \times R_w}{R_t}\right)^{\frac{1}{n}} = \left(\frac{a \times R_w}{R_t \times \phi^m}\right)^{\frac{1}{n}}$$

- S_w = Water Saturation
- F = Formation Resistivity Factor (Porosity ϕ , Tortuousity factor (a) 0.62- 2.45, Cementation factor (m) 1.0-2.15
- R_w = Water resistivity
- R_t = True resistivity
- R_o = Resistivity of 100 % water saturated zone

Temperature

Geothermal Gradient:

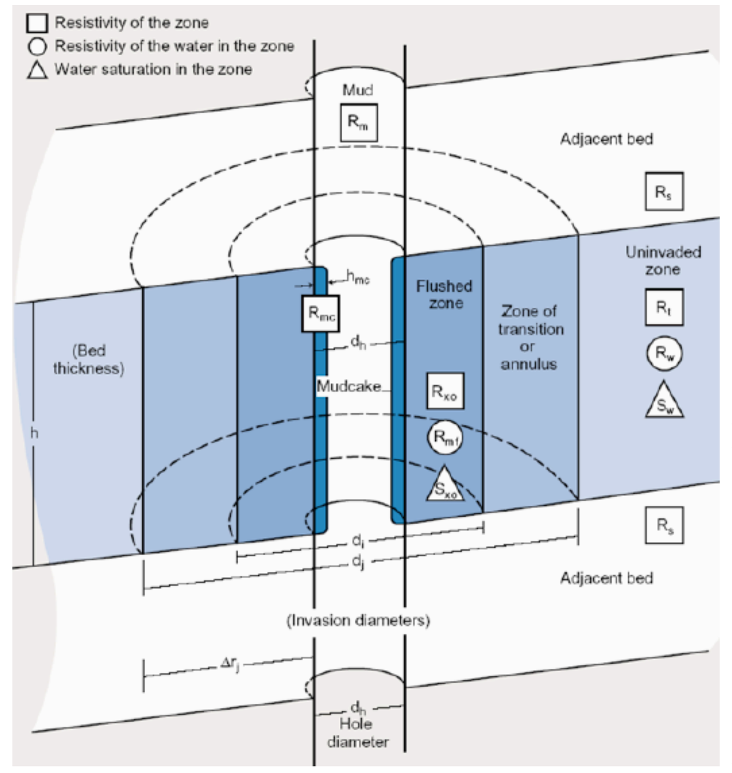
$$= \frac{(formation\ temp) - (mean\ annual\ surface\ temp)}{(formation\ depth)}$$

Formation Temperature:

$$= \frac{(formation\ depth)}{(70°F/\ 1ft)} + mean\ annual\ surface\ temp$$

* Standard Geothermal Gradient = (70°F/ 1ft) or (25°C/1km)

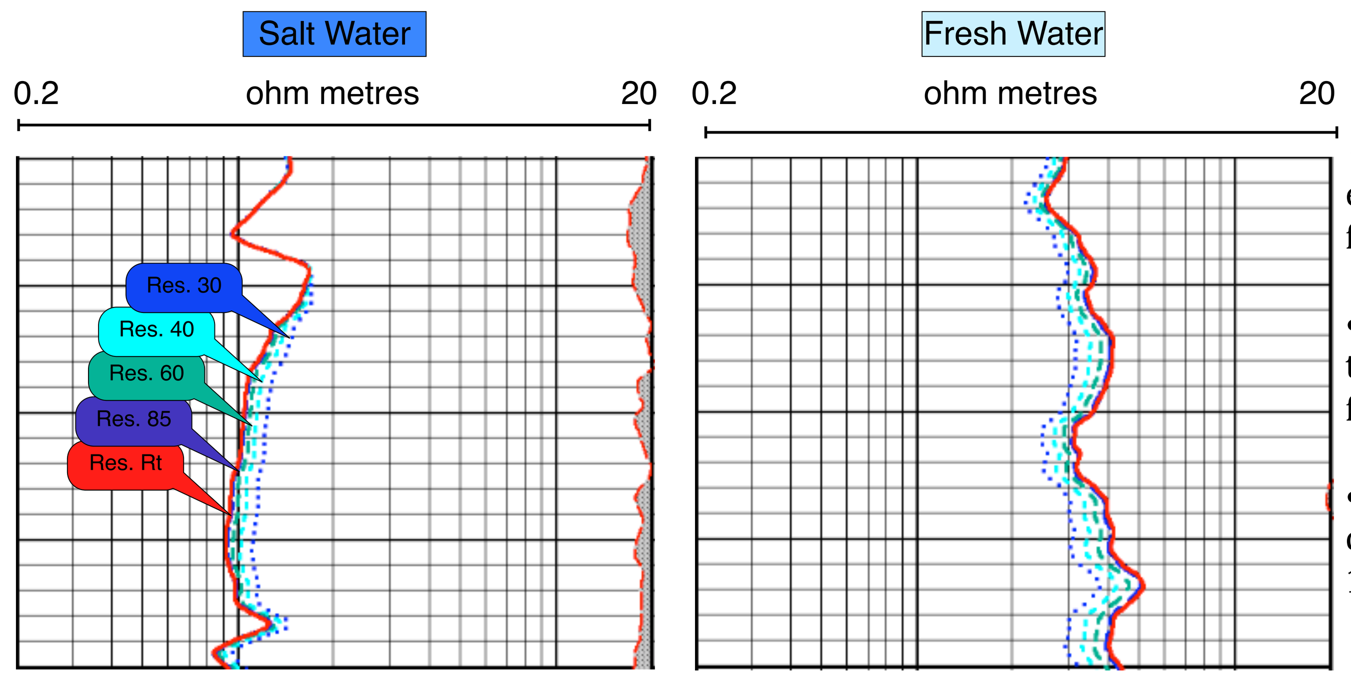
Borehole Environment



- Flushed zone has been completely flushed of original formation fluid by mud filtrate
- Transition zone or annulus contains a mix of formation fluid and mud filtrate
- Univaded zone contains formation fluid uncontaminated by drilling mud
- Mud cake: forms due to drilling mud accumulating on the borehole adjacent to porous and permeable formation
- Mud filtrate: the liquid component of the drilling mud, can be fresh, salt, or oil based

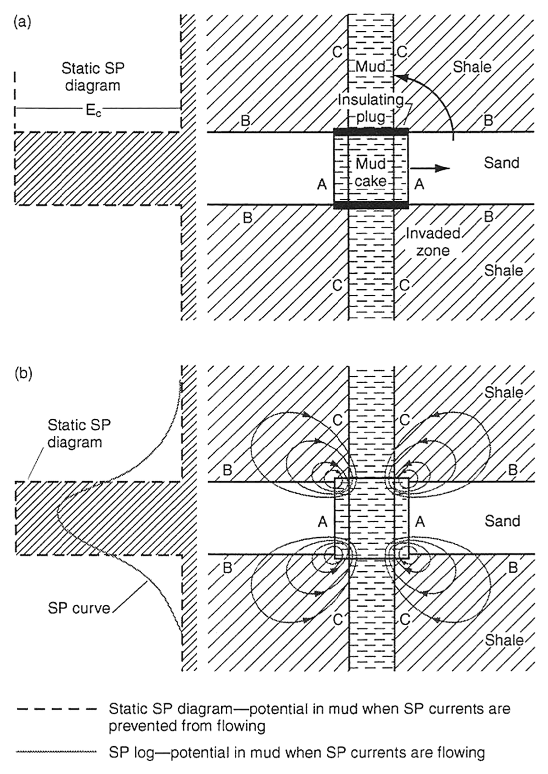
Figure 2. Borehole schematic (Schlumberger Oilfield Services: Basic Open Hole Log Interpretation and Advanced Technology Applications)

Induction Logs



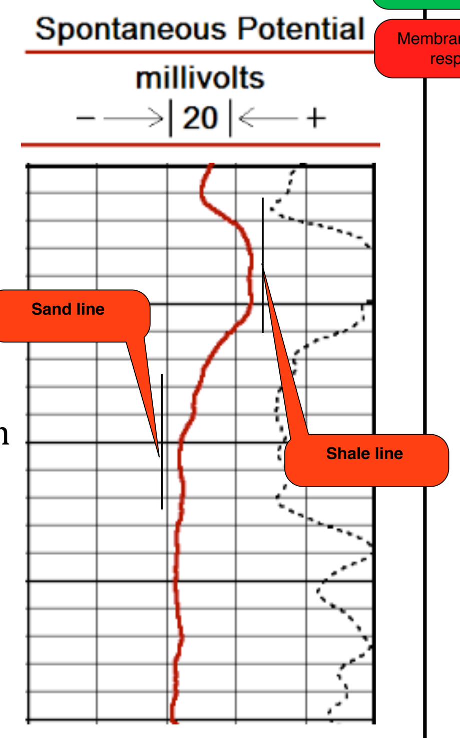
- Tool measures the resistance of an electrical current induced on a formation
- Salt water is a conductor of electricity thus low R_t ; Hydrocarbons, rock, and fresh water are insulators thus high R_t
- Multiple arrays (Multi-array) for different depths of investigation e.g., 10in, 20in, 30in, 60in, 90in, 120in array
- Water zone (salt water): resistivity will decrease from shallow to deep investigation; (fresh water): resistivity will increase from shallow to deep investigation

Spontaneous Potential (S.P.)



- Measures electrochemical potential resulting from salinity differences between mud filtrate and formation water
- Membrane Potential: between drilling mud and shales, shale has selective permeability, negative electric charges on surface, only permeable to positive charged ion (catatonic membrane) (Shale has positive S.P. response)
- Liquid-Junction Potential: between drilling mud and formation fluid, Na^+ and Cl^- move freely from more to less concentrated, Cl^- has better mobility (Sand has negative S.P. response)
- Determine permeable formation, calculate volume of shale (V_{sh}), and calculate formation (R_w)

Figure 3. Electrochemical Potential Schematic (Schlumberger Oilfield Services: Basic Open Hole Log Interpretation and Advanced Technology Applications)

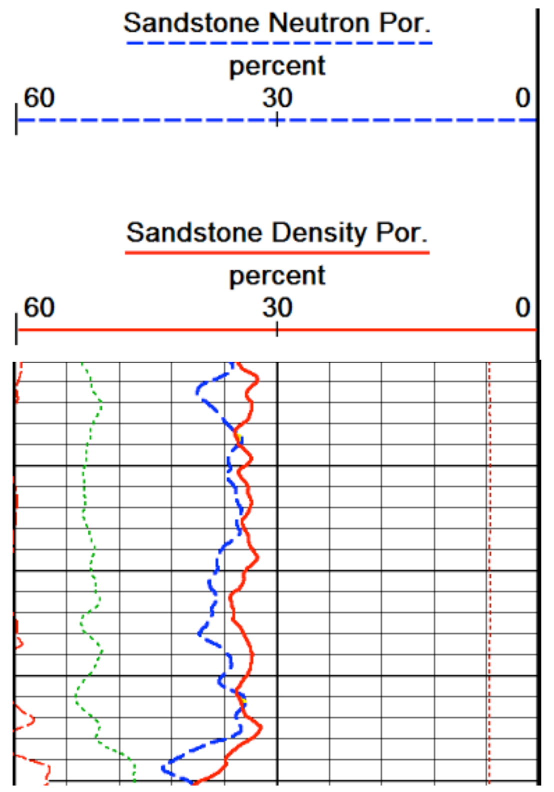


Density Log

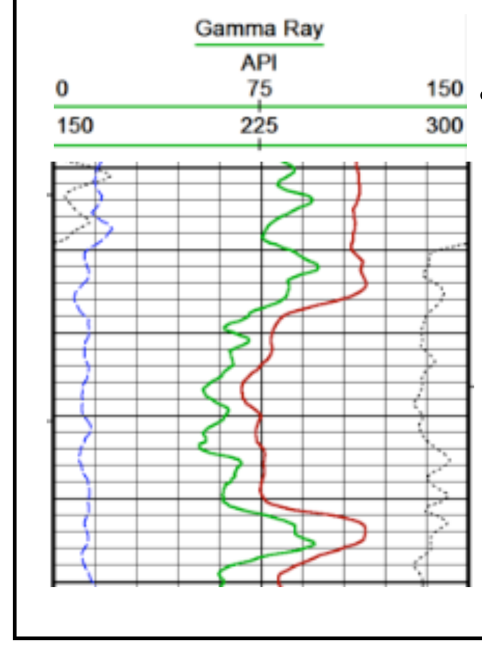
- Emits a gamma rays into formation, gamma rays collide with electrons in formation losing energy, amount of scattered gamma rays returned to detector indicate formation density
- Determine formation porosity, bulk density, detect gas-bearing zone, and evaluate complex lithology

Neutron Log

- Emits neutrons from radioactive source (americium beryllium), which collide with hydrogen atoms causing energy loss, hydrogen is concentrated in formation's pores (fresh water, salt water, or hydrocarbons) thus energy loss is related to formation porosity
- Gas-bearing zones have lower porosity because gas has lower concentrations of hydrogen then oil or water
- Determine formation porosity and detect gas-bearing zones

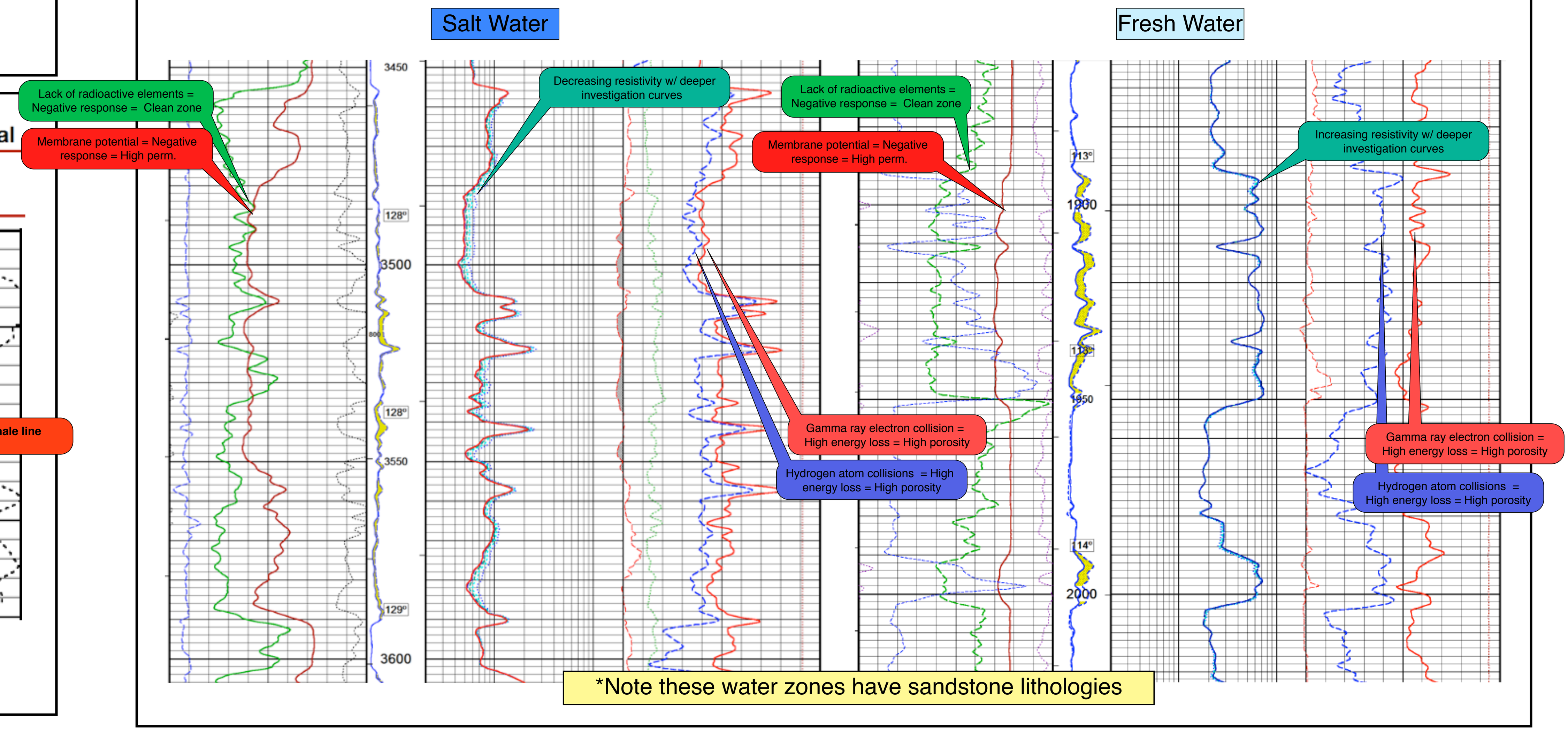


Gamma Ray Log



- Measures formation's naturally occurring radioactivity; common radioactive elements are potassium, thorium, and uranium.
- Shale typically has high concentrations of radioactive elements thus increases the gamma ray log response
- Sand and limestone generally have low concentrations of radioactive elements thus decreased gamma ray response (clean sandstones with potassium feldspars, micas, gluconite, or uranium waters can increase gamma ray)
- Determine lithology of formation, calculating volume of shale, and log correlation

Water Zones on Open Hole Log



Conclusion

- The use of drilling mud creates a Flush Zone, Transition Zone, and Univaded Zone in the borehole thus creating differences in the resistivity of formation immediately surrounding the borehole
- OHL's combine an Induction Log, Spontaneous Potential, Compensated Z-Densilog, Compensated Neutron Log, and Gamma Ray Log providing an intigrated platform of data to evaluate a formation.
- A salt water zone's character will have low R_t on Induction Log, strong negative kick on S.P., high porosity on both Density and Neutron Logs(favorable porosity varies based on formation lithology), and a strong negative kick on the Gamma Ray Log.
- A fresh water zone's character will have high R_t on Induction Log, weak negative kick on S.P.(effects of fresher water), high porosity on both Density and Neutron Logs (favorable porosity varies based on formation lithology), and a strong negative kick on the Gamma Ray Log.

References

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Selley, R. (1985). Elements of petroleum geology. New York: W.H. Freeman and.
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