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Stratigraphic Cross-Section of Ratcliffe Interval through the Foreman Butte Field Using Neutron-Density Logs with the Distribution of Moveable Hydrocarbons and Water Saturation

by
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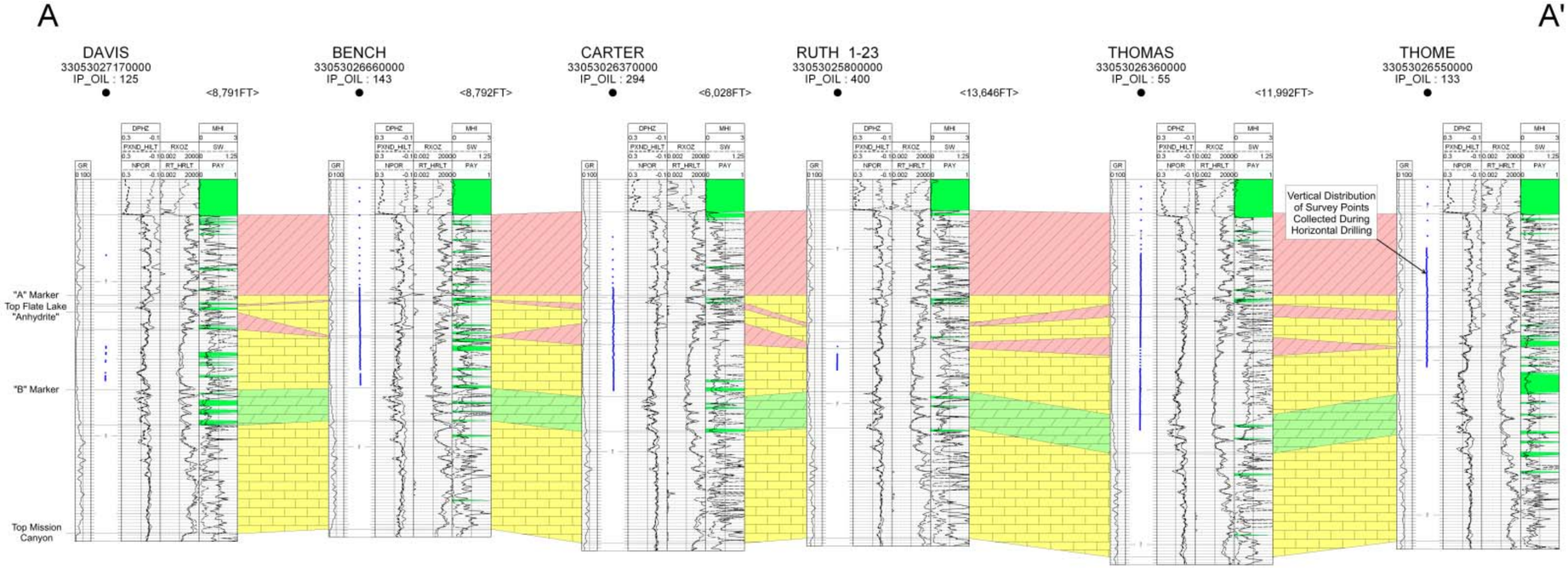
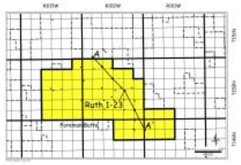
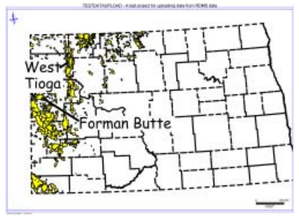
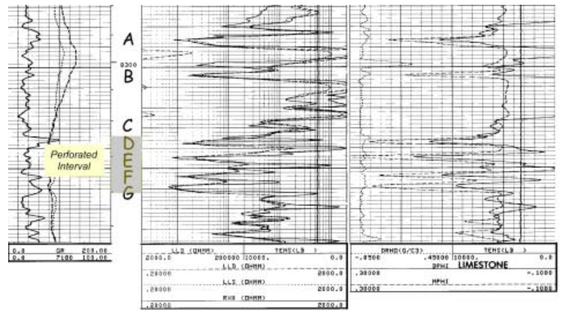






West Tioga Field - Borstadt 3-3
NDIC #: 12024

Gamma Ray-Caliper, Dual Induction – Microspherically Focused Log and Compensated Neutron – Density Porosity logs from the Borstad 3-3 well. The interval depicted is in the Ratcliffe interval. The perforated zone (8334-8362) consists of four porosity zones (D, E, F and G) separated by thin anhydritic beds. More than 25,000 bbls of oil and 3100 bbls of water have been produced from the perforated interval in this vertical well.



Raw log data from the Ratcliffe interval in the Borstad 3-3 well located in the West Tioga field. The shaded zones correspond to oil saturated intervals that could be expected to produce oil. The logs used are a dual laterolog – microspherically focused log and neutron-density porosity log.

Zone	R_{LLD}	R_{LLS}	R_{MSFL}	$\%\Phi_{N}$	$\%\Phi_{den}$	Top	Bottom
A	2.20	1.63	0.95	22.33	12.20	8284	8291
B	3.05	2.16	1.89	18.90	2.00	8303	8306
C	58.00	58.35	43.25	0.08	2.49	8325	8330
D	2.37	2.04	1.36	26.00	14.00	8336	8339
E	2.30	2.10	0.79	29.48	17.00	8343	8347
F	1.83	1.51	1.14	24.00	11.40	8352	8355
G	0.89	0.79	0.67	25.50	9.10	8358	8363

The resistivity of the mud filtrate in the Borstad 3-3 well was 0.048 ohm-m at 76 °F. The resistivity of the formation water (Rw) in the West Tioga Field is, from the water catalogue, 0.46 ohm-m at 75 °F. The raw resistivity data is corrected for the influence of the flushed zone. The Movable Hydrocarbon Index (MHI < 0.6) and water saturations (S_w < 0.6) of zone E obtained from the corrected formation and flushed zone resistivities (R_T and R_{xo}) are consistent with the oil production obtained from this interval.

Zone	R_{LLD}/R_{MSFL}	R_{LLD}/R_{LLS}	R_T/R_{LLD}	d_i	R_T/R_{XO}	R_T	R_{XO}	MHI	Cross Plot %Φ	S_w
A	2.32	1.35	1.35	35.00	3.00	2.97	0.99	0.56	17.99	0.64
B	1.61	1.41	1.80	100.00	2.30	5.49	2.39	0.63	13.44	0.64
C	1.34	0.99	1.20	0.00	1.40	69.60	49.71	0.81	1.76	1.36
D	1.74	1.16	1.20	22.00	1.30	2.84	2.19	0.84	20.88	0.57
E	2.91	1.10	1.20	20.00	3.30	2.76	0.84	0.53	24.06	0.50
F	1.61	1.21	1.30	50.00	2.00	2.38	1.19	0.68	18.79	0.69
G	1.33	1.13	1.20	40.00	1.50	1.07	0.71	0.79	19.14	1.01

Wireline analysis of the Ratcliffe subinterval in the Foreman Butte field

The Archie equation (Archie, 1952) is used to estimate the amount of water and thus the amount of hydrocarbons that are present in a formation (S_w) based on the ease with which electrical current passes through the water saturated rock (R_t). The complexity of the current path through the fluid filled pore space within rock is described by the tortuosity factor "a" and the cementation factor "m" and the fraction of the rock occupied by pore space (ϕ). An additional term (n) is used to describe the flow of electrical current through the pore space when it is filled with a combination of conductive water and insulating hydrocarbons.

The Archie equation is effective in evaluating the in place reserves within a formation. However this evaluation cannot, by itself, determine whether or not the hyrdorcarbons within the reservoir are capable of being produced. Asquith (1982) shows that the Archie equation can be used to indicate the presence of producible hydrocarbons through the calculation of the so called Moveable Hydrocarbon Index or MHI. This is accomplished by making use of the fact that during drilling, fluids from the drilling mud infiltrate the formation near the well bore. If the fluid displaces a significant portion of the original formation fluid then the resistivity of the invaded zone changes relative to the resistivity of the formation that is beyond the invaded zone. Resistivity measurements of these two zones can be used in conjunction with the Archie equation to provide an indication of hydrocarbon migration during the drilling process. This is done by comparing the water saturation of the invaded zone to the water saturation in the uninvaded formation. The calculation involves two sets of Archie equations in which the water saturation in the flushed zone (S_{xo}) is determined by the resistivity of the mud filtrate (R_{mf}) and the water saturation in the uninvaded formation (S_w) is controlled by the resistivity of the formation water (R_w). The MHI is the ratio between the water saturations in the invaded and univaded zones that provides the comparison that indicates whether hydrocarbons have moved. Taking the ratio of these two sets of Archie equations forces all of the unknown variables (a, m and ϕ) to cancel one another. The MHI can therefore be found from resistivity measurements alone.

Archie equation

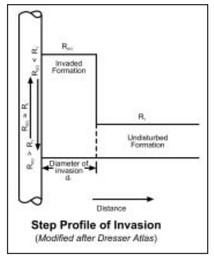
Water saturation in formation

$$S_w = (a/\phi^m \times R_w/R_t)^{1/n}$$

Water saturation in flushed zone

$$S_{xo} = (a/\phi^m \times R_{mf}/R_{xo})^{1/n}$$

Where:
S_w = Water saturation of the uninvaded zone
S_{xo} = Water saturation of the flushed zone
a = tortuosity factor (assumed to be 1)
ϕ = porosity
m = cementation factor (assumed to be 2)
n = saturation exponent (assumed to be 2)
R_w = Resistivity of the formation fluid at formation temperature
R_{mf} = Resistivity of the mud filtrate at formation temperature
R_t = True resistivity of formation (ILD or LLD log corrected for invasion)
R_{xo} = Resistivity of the flushed zone (LL8 or MFL or MLL logs)



Moveable Hydrocarbon Index: (S_w/S_{xo})

$$MHI = S_w/S_{xo} = [(R_{xo}/R_t)/(R_{mf}/R_w)]^{1/2}$$

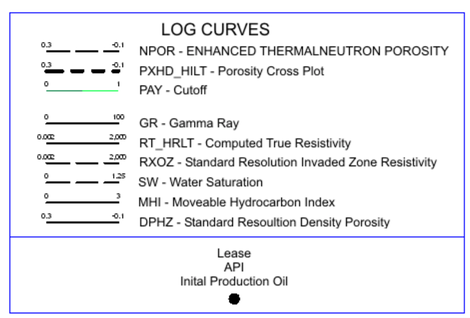
LAS Data Used:
R_{xo} = RXOZ - Standard Resolution Invaded Zone Resistivity
R_t = RT_HRLT - Computed True Resistivity
R_{mf} = Log Header corrected for temperature using Arp's equation
R_w = Water catalogue corrected for temperature using Arp's equation
ϕ = PXND_HILT - Corrected Total Porosity

When (S_w/S_{xo}) is:

greater than or equal to 1 then no hydrocarbons were moved during invasion.

< 0.7 (sandstone) moveable hydrocarbons indicated.

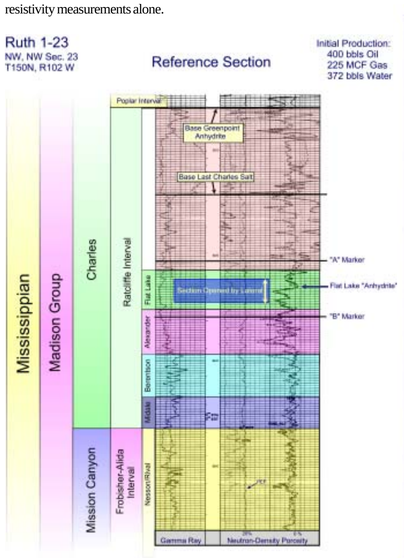
< 0.6 (carbonates) moveable hydrocarbons indicated.

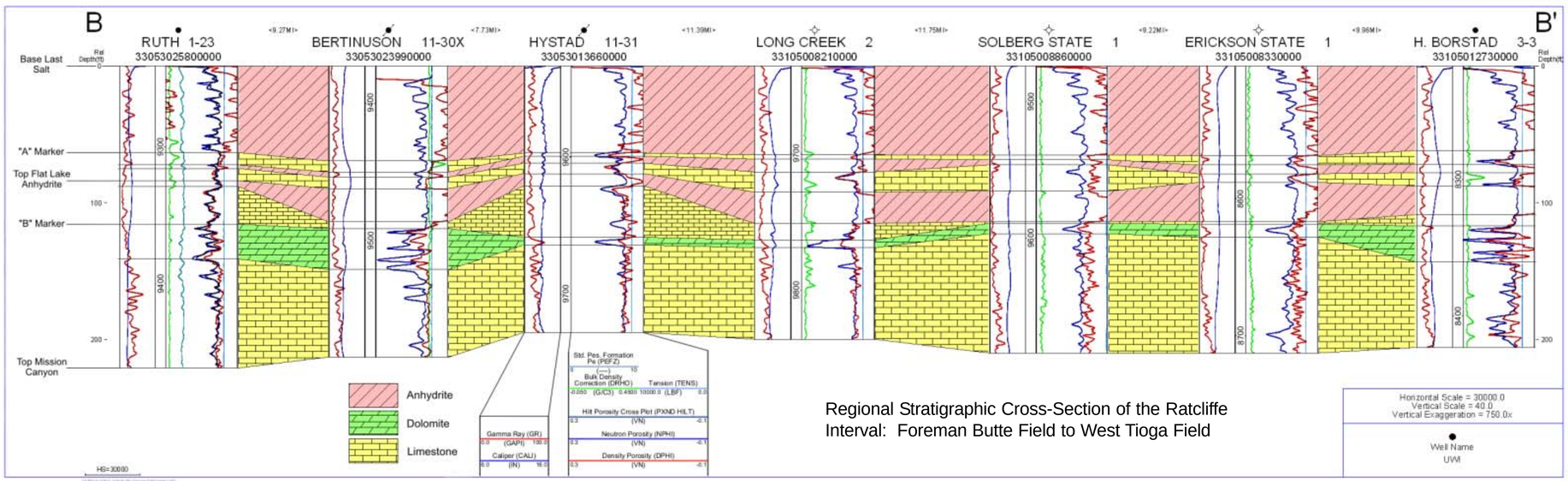


References:

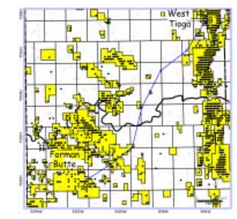
Asquith, G.A. (1982) *Basic Well Log Analysis for Geologists*, American Association of Petroleum Geologists, Tulsa, Oklahoma, 216 pgs.

Archie, G.E., 1952, Classification of reservoir rocks and petrophysical considerations: AAPG Bull., v. 36, no. 2, p. 278-298.





Regional Stratigraphic Cross-Section of the Ratcliffe Interval: Foreman Butte Field to West Tioga Field



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