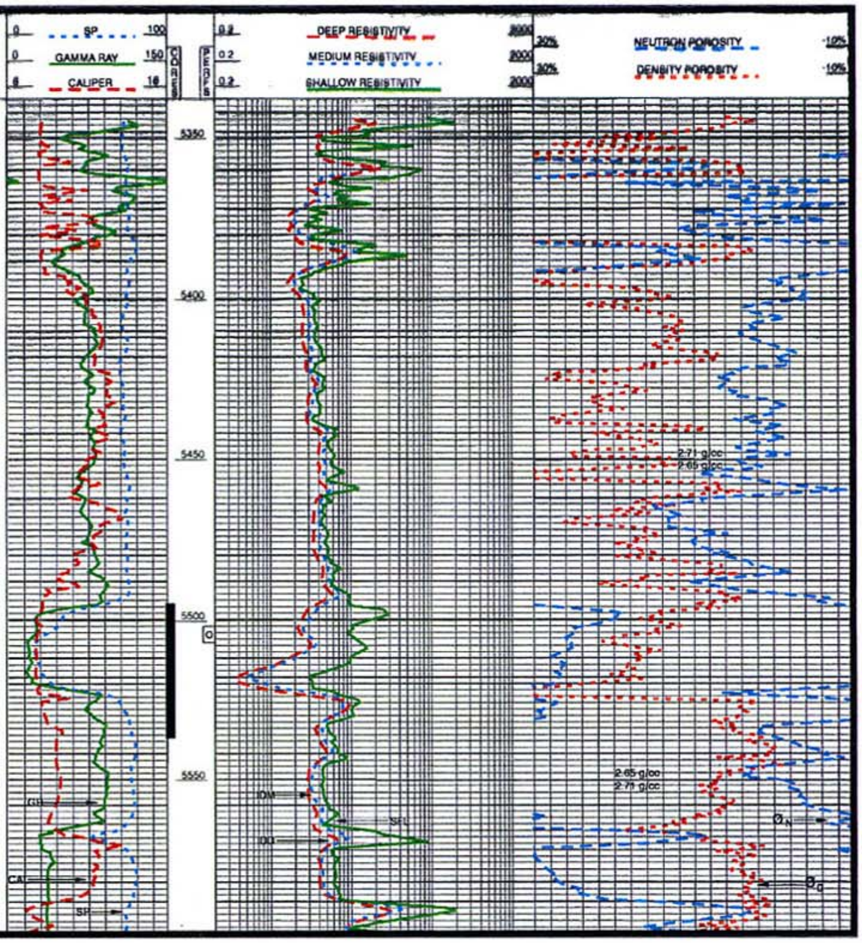
Rocky Mountain Association of Geologists
1996

LABORATORY CORE LAB WIRELINE CO. SCHLUMB.

CORE ANALYSIS						
DEPTH	PERM MD (HORIZ)	PERM MD (VERT)	POR %	OIL SAT % POR	WTR SAT % POR	CORE DESCRIPTION LITHOLOGIES AND/OR SAMPLE DATA
5495-5496	3.1	3.2	15.9	0.0	70.1	SD GRAY F-M GRN
5496-5497	13	8.5	15.8	4.1	47.9	SD GRAY F-M GRN
5497-5498	9.3	9.3	13.8	4.7	32.3	SD GRAY F-M GRN
5498-5499	32	27	17.8	4.5	46.4	SD GRAY F-M GRN
5499-5500	53	45	15.7	6.9	40.5	SD GRAY F-M GRN
5500-5501	4.6	4.5	12.9	0.7	72.7	SD GRAY F-M GRN
5501-5502	76	5.1	15.7	0.0	73.2	SD GRAY F-M GRN
5502-5503	23	2.1	13.1	0.0	71.2	SD GRAY F-M GRN
5503-5504	2.5	2.1	10.3	0.0	56.3	SD GRAY F-M GRN
5504-5505	68	8.7	18.6	2.4	45.9	SD GRAY F-M GRN
5505-5506	313	197	19.9	3.1	52.7	SD GRAY VF-CSE CONG
5506-5507	270	129	20.2	3.1	57.6	SD GRAY VF-CSE CONG
5507-5508	603	183	19.2	3.2	55.5	SD GRAY VF-CSE CONG
5508-5509	534	216	16.0	4.1	64.1	SD GRAY VF-CSE CONG
5509-5510	335	82	15.1	3.1	55.6	SD GRAY VF-CSE CONG
5510-5511	60	404	16.1	2.9	67.6	SD GRAY VF-CSE CONG
5511-5512	332	408	18.5	2.5	68.3	SD GRAY VF-CSE CONG
5512-5513	230	20	19.5	2.3	60.1	SD GRAY VF-CSE CONG
5513-5514	424	69	18.8	2.4	63.8	SD GRAY VF-CSE CONG
5514-5515	451	445	13.9	3.5	67.9	SD GRAY VF-CSE CONG
5515-5516	3735	2145	17.6	0.5	79.2	SD GRAY VF-CSE CONG
5516-5517	1436	443	20.6	0.4	72.1	SD GRAY VF-CSE CONG
5517-5518	1466	558	16.0	0.0	74.8	SD GRAY VF-CSE CONG
5518-5519	1682	29	14.6	0.0	84.7	SD GRAY VF-CSE CONG
5519-5520	3909	326	18.5	0.0	87.7	SD GRAY VF-CSE CONG
5520-5521	9219	2405	16.9	0.0	86.1	SD GRAY VF-CSE CONG
5521-5522	15420	2478	16.0	0.0	89.1	SD GRAY VF-CSE CONG
5522-5523	2339	537	15.1	0.0	71.3	SD GRAY VF-CSE CONG
5523-5537	–	–	–	–	–	NO ANALYSIS-SHALE

No. 7 McCormick



HYDROCARBON PRODUCTION FROM LOW CONTRAST, LOW RESISTIVITY RESERVOIRS ROCKY MOUNTAIN AND MID-CONTINENT REGIONS LOG EXAMPLES OF SUBTLE PAYS

Editors

Edward D. Dolly and James C. Mullarkey

Calculate a More Accurate Water Saturation by Visually Estimating Archie "m"

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Water saturation calculations derived from wireline log responses have historically used an "m" = 2 when "m" (the cementation exponent) is unknown. This practice can lead to erroneously high values for water saturation and possibly by-passed pay, since there are many instances where "m" is less than 2 (Fig. 1).

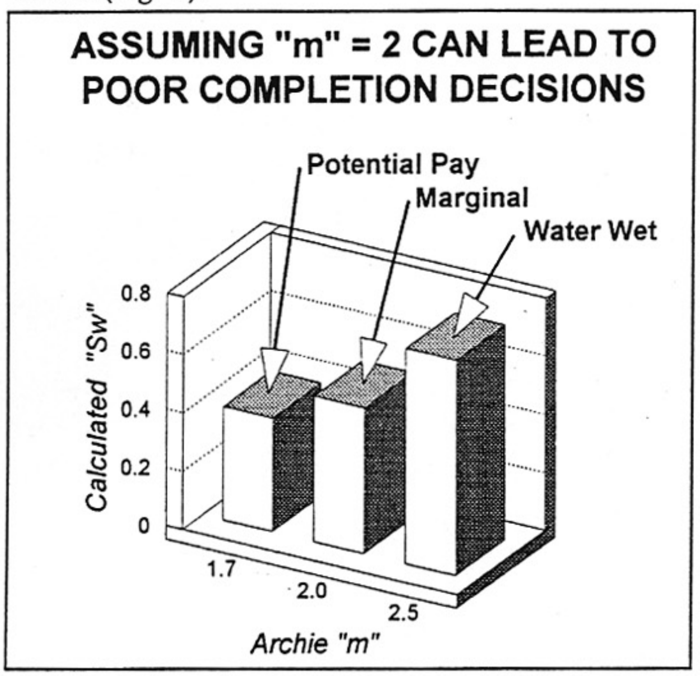

Figure 1 This graph shows how varying the values of "m" effects calculated water saturation when all else remains constant. A more accurate "m" is quickly and inexpensively estimated from visual rock analysis. This greatly increases your chances for success. (after Stolper, 1994)

From Archie's equation, $F = a/Ø^m$; F will increase with a decrease in porosity. Likewise, "m" will increase with a decrease in porosity. A cross plot of F vs. porosity vs. "m" by Martin clearly demonstrates this point (Fig. 1). Porosity is visually comparable from one rock with measured values to one without known values.

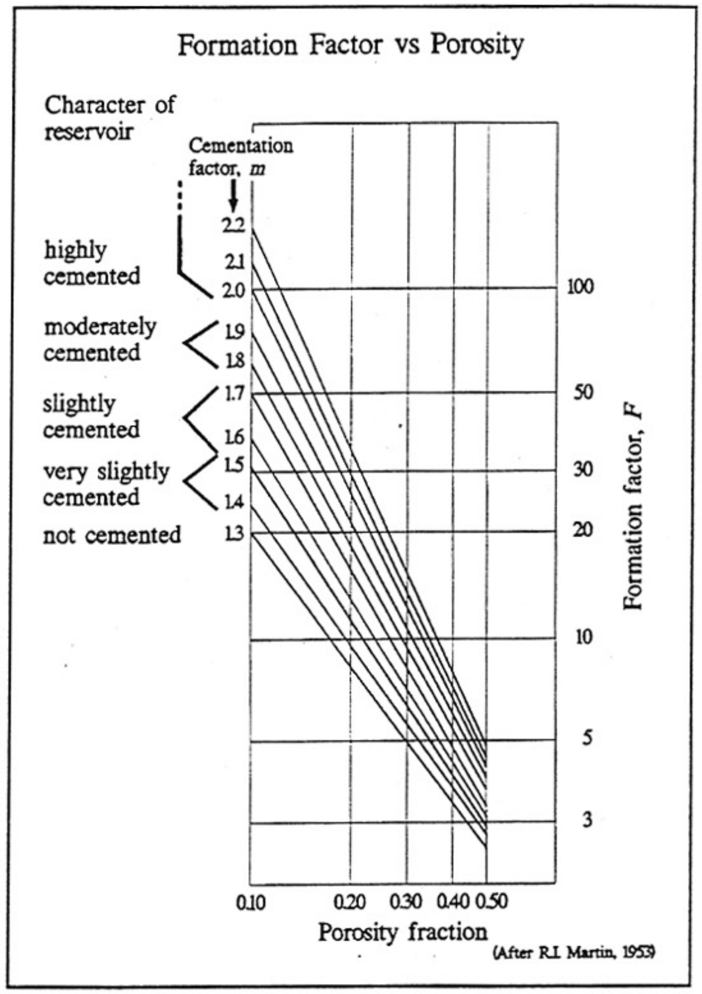

Figure 2

The Archie "m" can be measured in the laboratory, but this is an expensive ($300-$500 per sample) and time-consuming process. Also, rotary core plugs are required for the analysis—a measurement cannot be obtained with cuttings or sidewall core samples. A quicker and less expensive alternative (and the only alternative if rotary core plugs are unavailable) is to estimate "m" by comparing your samples to rocks with known "m" values. Rather than assuming "m" = 2, a more accurate estimate can be made to better calculate water saturation.

Other methods of estimating Archie "m" include:

- Archie's "m" based on degree of cementation (Fig. 3).

Archie generalized a range of "m" values for various degrees of cementation in sandstone as follows:

Unconsolidated	1.2-1.3
Very Slightly Cemented	1.3-1.5
Slightly Cemented	1.5-1.7
Moderately Cemented	1.8-1.9
Highly Cemented	1.9-2.2

Figure 3

- Calculations using wireline log responses and the equations of $F = R_O/R_W$ and $F = a/(\varnothing^m$.
- Graphical methods using cross plots, for instance:
  Visually determine carbonate porosity and the Archie rock type then enter the cross plot by Archie (Fig. 4).
  Visually determine separate vuggy porosity and total porosity then enter the cross plot by Lucia (Fig. 5).
  Visually determine clastic porosity, estimate F, then enter cross plot by Archie and Schlumberger (Fig. 6).

Visual evaluations and use of comparators with known values are the most reliable. Visual evaluation of cuttings, sidewall core, and/or whole core using a binocular microscope at 20X to 50X magnification will allow you to describe the many features of a rock which affect Archie "m". Once these features have been described, an accurate estimate of "m" can be made.

Pattern recognition skills are useful for visually estimating Archie "m" since it is based on the familiarization of rock comparators which have measured "m" values. The comparators referred to here can be the ones supplied to members of the Shell Rock Catalog, or similar ones which companies make for their private use.

Once a frame of reference has been established for rocks with measured "m", estimates can be made for rocks with unknown "m". To accurately make a visual estimate of Archie "m" requires practice and patience. The best way to acquire this skill is through the use of rock comparators.

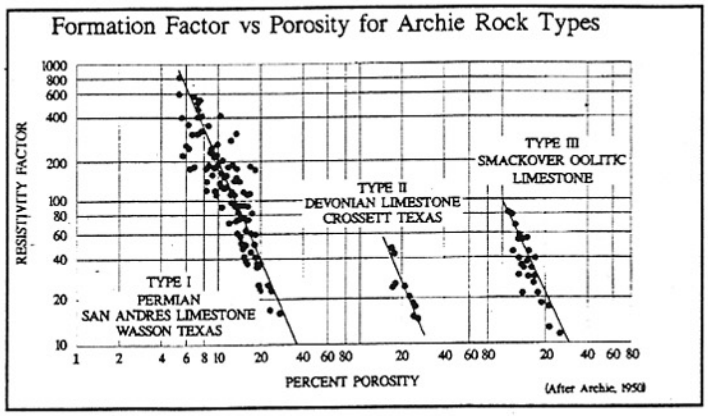

Figure 4

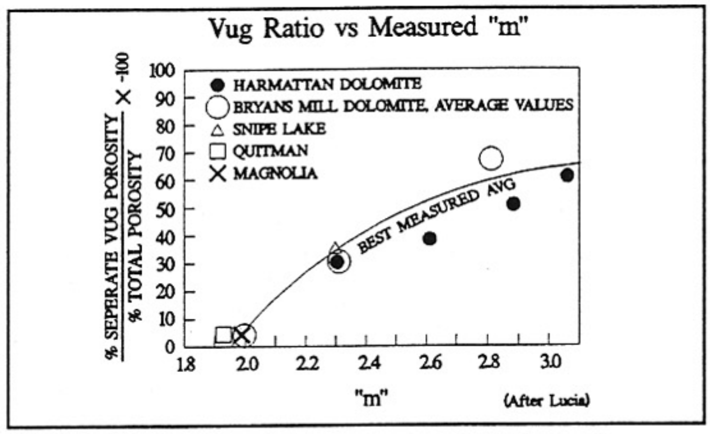

Figure 5

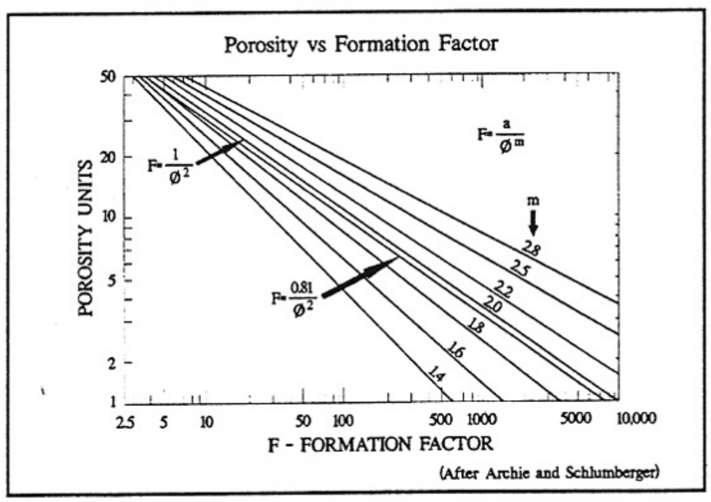

Figure 6

In examining the cuttings, or other rock material, you will need a quality binocular microscope with 20X to 50X magnification capabilities.

The cementation exponent, "m", is related to the pore geometry of the rock; therefore, it is extremely important that you view a dry, freshly broken surface for this examination.

In visually estimating “m”, it is important to realize that “m” is relative. Relative to what? Relative to a rock of similar grain size, sorting, sphericity, and mineralogy. For instance, there are three samples which have similar properties with the exception that:

1 is clean
2 has “x” amount smectite
3 has “x” amount kaolinite

Then, “m” will be high for sample 2 relative to sample 1, but low relative to sample 3!

The effects on “m” can be said to be associated with the concept of order versus disorder. That is, the more orderly the pore geometry of a rock, the lower the value of “m”; conversely, the more disorderly the pore geometry, the higher the “m” value.

The cementation exponent can vary from 1.2 to 2.2 for sandstones, and can be as high as 3.1 for carbonates. The following is a list of factors which can influence “m” (if the porosity remains unchanged) along with the reasons for their impact on “m”.

1. An increase in grain sorting decreases “m” since the pore geometry becomes more orderly.
2. An increase in cement increases “m” because the pore geometry becomes more disorderly.
3. An increase in compaction increases “m” because pore throats are cut off, thus isolating pores.
4. An increase in “patchy” cement increases “m” due to the breaks in net electrical continuity.
5. A decrease in grain size increases “m” because the surface area to grain volume increases.
6. Bimodality increases “m” because the pore geometry becomes more disorderly.
7. An increase in the amount of inter-connected vugs increases “m” because the pore geometry becomes more disorderly.
8. An increase in the amount of clay increases “m” because the surface area to grain volume increases. Some clay types will have more of an effect than others because of the variation in cation exchange capacity (CEC). The greater the CEC, the greater the conductivity, and the lesser the effect on the “m” value. The commonly encountered clay minerals in order of increasing CEC and decreasing effect on the value of “m” are: kaolinite with CEC of 3 to 15; chlorite and illite with CEC of 10 to 40; and smectite with CEC of 80 to 150.
   To illustrate this, two Chinook samples from a Canadian Hunter Exploration field are compared. Recall that highly conductive clays result in “m” being low relative to a non-conductive rock of the same surface area. Here sample 1 has a measured “m” of 2.06 and sample 2 has a measured “m” of 1.87. These calculations were made measuring F without taking into account the electrical effects of the clay. Now, using the Waxman-Smits-Thomas equation ($FF^* = F(1+R_w[B][Q_v])$ where $Q_v = CEC([1-\varnothing][\text{matrix density}])/100(\varnothing)$ which uses CEC values to factor out the electrical effects of clay, “m*” for sample 1 becomes 2.2 and “m*” for sample 2 becomes 1.95!
9. For carbonates, “m” is affected by particle size, interparticle porosity, and vuggy porosity (isolated and interconnected).

All of these contributing factors are visible features of the rock and can be used to visually estimate Archie “m”. Cuttings are a readily available source from which an accurate and inexpensive estimate of “m” can be made. The more accurate the “m”, the more accurate the water saturation calculation, which ultimately leads to a reduced danger of by-passed completions.