KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 2002-66

THE CRASH COURSE IN LOG ANALYSIS:
AN EXCEL SPREADSHEET WORKSHOP
presented at the
Kansas Geological Survey
Lawrence, Kansas

by

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October 17, 2002

THE LOG ANALYSIS YELLOW PAGES

CORE-M	Core measurements of porosity and formation factor
SENSITIVITY	Archie equation water saturation sensitivity analysis
ARPS	Arps' equation (temperature conversion of Rw1 to Rw2)
CHEMRW	Water resistivity estimation from brine composition
ARCHIE	Archie equation estimation of water saturation
RWA	Reconaissance water resistivity (Rwa) method
PICKETT	Resistivity-porosity Pickett plot
SPRW	SP log estimation of formation water resistivity
SONIC	Archie equation used with sonic log
DENSITY	Archie equation used with density log
DENS-NEUT	Archie equation used with density and neutron logs
NDXPLT	Neutron - density crossplot for lithology and porosity
RHOmaa-Umaa	RHOmaa - Umaa crossplot for mineralogy
NUGENT	Nugent equation estimation of variable m

CONTENTS

Fundamental Physics and Equations

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

CWLS LAS FILE FORMAT:

The LAS file consists of two parts:

- Header information
- Log data

The **header** consists of records that give well and logging information. There are three kinds of record:

- The first non-space symbol is a pound sign, # :
  These are comment records which are useful to the user, but can be ignored by LAS reading software.
- The first non-space symbol is a tilde, ~ :
  These records start a new section in the header and the next letter signifies what the section is, so the section types are:
  - ~V contains version and wrap mode information
    VERS. There are now three versions: 1, 2, or 3, which are all in ASCII format and so readable by word processing or spreadsheet software.
    WRAP. **YES** means there are multiple lines per depth step;
    NO means there is one line per depth step.
  - ~W contains information about the **well**
  - ~C contains information about the log **curves**
  - ~P contains information about the **parameters** from the well.

  Other tilde records that may occur include **~D** (**downhole** information, such as tops, drill-stem test data, core information etc.), **~O** (**other** information),etc.
- The third kind of record is the information that is listed in the header sections.

Each of these records is generally divided into three parts, with a period (.) between the first and second, and a colon (:) between the second and third.

The **log data** section starts with a record that begins with **~A** gives the mnemonics for the log curves in the order that they appear. The mnemonics are tabulated in the header **~C**. The **~A** record is followed by the **ASCII** log data.

LOG ANALYSIS OF A CHESTER SANDSTONE SECTION FROM LOGS RECORDED ON AN LAS FILE

The Hugoton MLP Koenig #1-28 well was drilled in 1997 in the South Eubank field, Haskell County, Kansas, with oil production from the sandstones of the Mississippian Chesterian Series. The sandstones are fine-grained, generally well-sorted, and occupy a north-south oriented incised paleovalley that was delineated by 3-D seismic data (Montgomery and Morrison, 1999). The Chesterian section contains two sandstones that will be referred to here informally as the "Upper sandstone" and the "Lower sandstone".

The gamma-ray log indicates the sandstones to be relatively free of shale, so that the Archie equation can be applied to volumetric estimations of water- and oil-saturation in most of the zones.. The Archie equation constants for these sandstones are:

$$a = 1 \qquad m = 1.8 \qquad n = 2$$

and the formation water resistivity at formation temperature, Rw = 0.05 ohm-m.

A selection of the logs run on this well are recorded on the LAS (Log Ascii Standard) file **koen.las** for the interval between 5400 and 5600 feet below KB. They are the caliper (CAL), gamma ray (GR), spontaneous potential (SP), bulk density (RHOZ), density porosity (PHID), and deep induction resistivity (ILD). We will use the density porosity and deep induction resistivity log measurements in the Archie equation and the Archie equation parameters listed above to calculate water saturations for the section (5400 -5600) containing the two sandstone reservoirs, where the depth range of the "Upper Sandstone" is 5426 - 5471 feet and that of the "Lower Sandstone" is 5522 - 5557 feet.

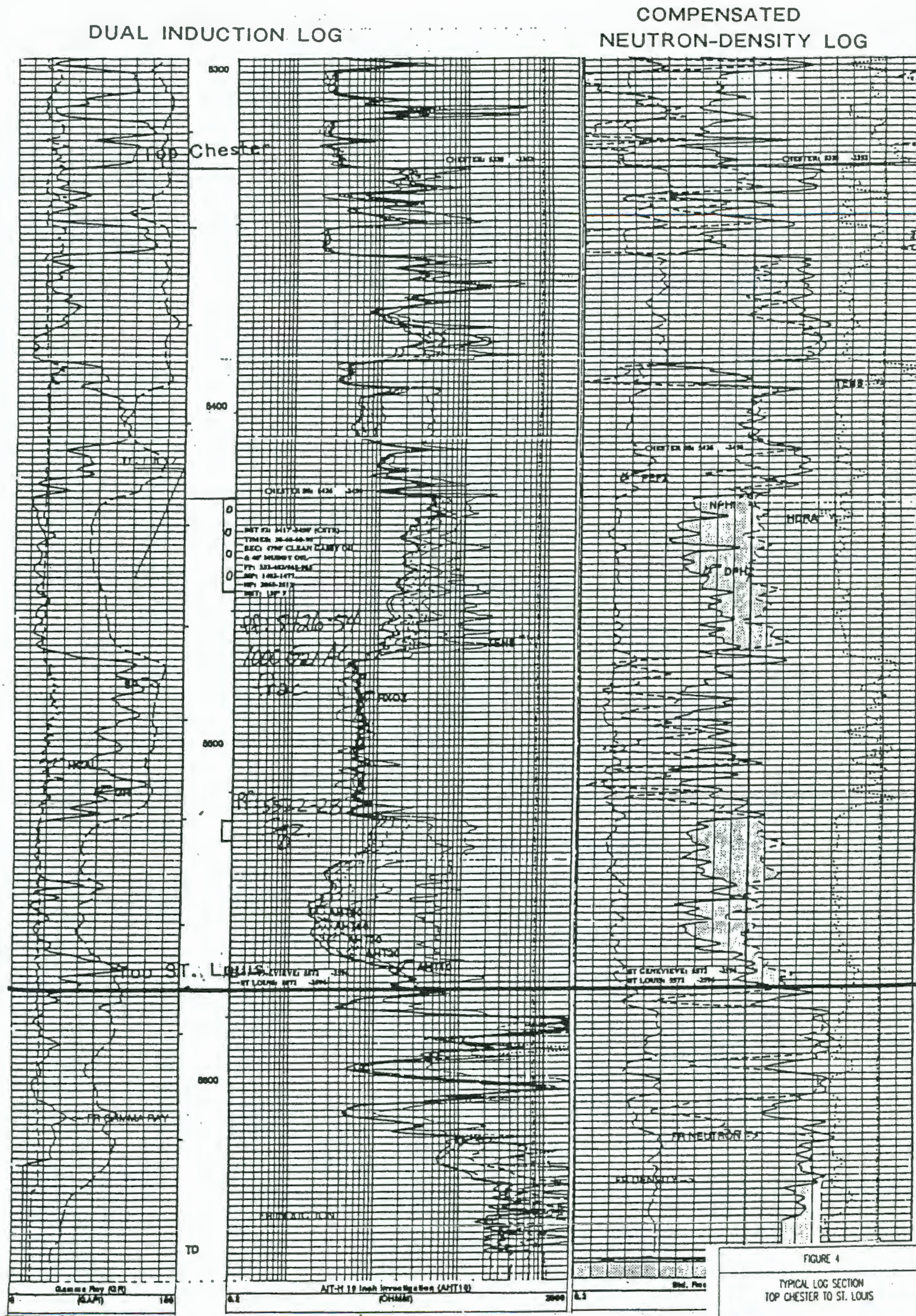


FIGURE 4
TYPICAL LOG SECTION
TOP CHESTER TO ST. LOUIS

EXCEL PROCEDURE FOR ESTIMATION OF WATER SATURATION FROM LOG ANALYSIS OF RESISTIVITY AND POROSITY USING LOGS DOWNLOADED FROM AN LAS FILE

---

(1) **Open** koen.las using EXCEL.
In EXCEL 5 the steps are:
Choose **Delimited** for **Original Data Type.**
In the **Start import at Row** box, use the row number of the title record of the log data (the record that follows the ~**A** record).

In the **Delimiters** box, check the **Space** box and check the **Treat multiple delimiters as one** box.
Save the imported log file as an Excel workbook.

(2) Insert multiple colums to the left of the logs so that you can insert a copy of the **ARCHIE** template that was used for the Oasis Deutsch #1 well.

(3) Within the **PARAMETERS** box use:

- **A** = Archie equation a (=1)
- **M** = Cementation exponent (=1.8)
- **N** = Saturation exponent (=2)
- **RW** = Formation water resistivity at formation temperature (= 0.05)

(4) Copy the log depth values (DEPT) into the **Depth** column.
Copy the deep induction (ILD) into the resistivity (**Rt**) column.
Copy the density porosity (PHID) log into the **Phi** column

ARCHIE EQUATION ESTIMATION OF WATER SATURATION

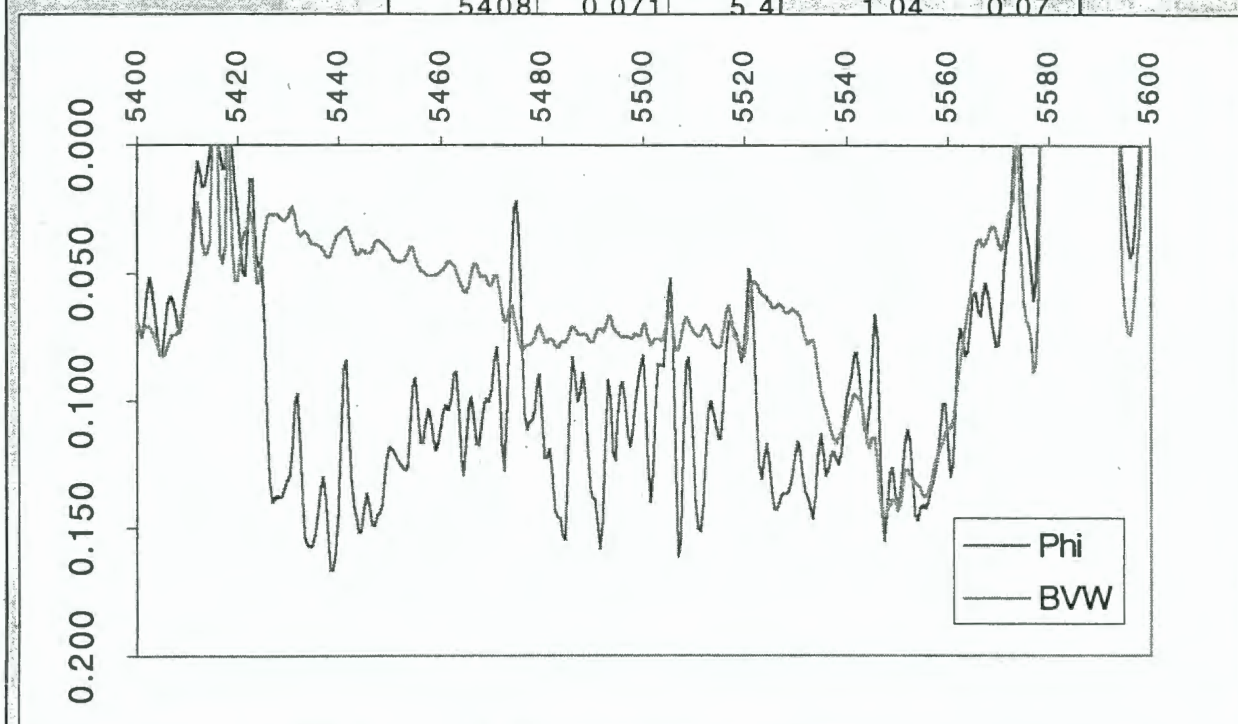
Well: Hugoton MLP Koenig #1-28 28-29S-34W

Formation: Chester Sandstone

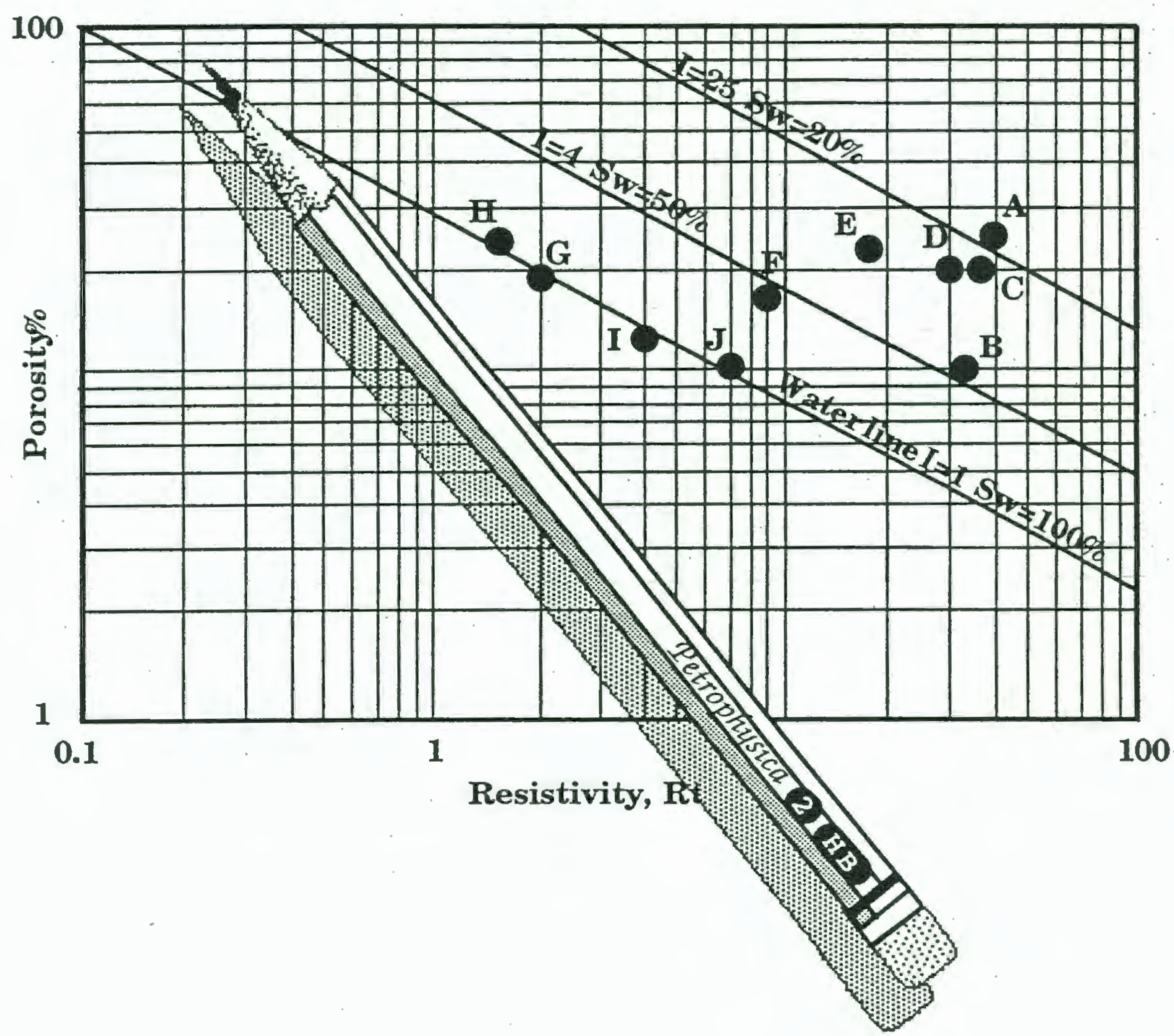
Parameters

a	1
m	1.8
n	2
Rw	0.05

Depth	Phi	Rt	Sw	BVW
5400	0.068	5.8	1.04	0.07
5400.5	0.072	5.6	1.01	0.07
5401	0.075	5.5	0.98	0.07
5401.5	0.068	5.7	1.06	0.07
5402	0.057	5.6	1.24	0.07
5402.5	0.052	5.4	1.38	0.07
5403	0.056	5.3	1.31	0.07
5403.5	0.064	5.1	1.17	0.08
5404	0.074	4.9	1.05	0.08
5404.5	0.082	4.6	0.99	0.08
5405	0.082	4.4	1.01	0.08
5405.5	0.072	4.4	1.14	0.08
5406	0.062	4.6	1.27	0.08
5406.5	0.059	4.9	1.28	0.08
5407	0.060	5.2	1.23	0.07
5407.5	0.065	5.2	1.15	0.07
5408	0.071	5.4	1.04	0.07



Basic log analysis techniques



HISTORICAL ORIGINS

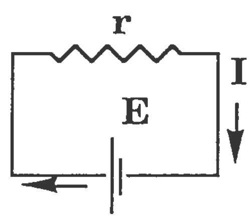
Conrad and Marcel Schlumberger were French geophysicists from Alsace, who originally worked with surface electrical prospecting techniques in the search for ore bodies and petroleum. In 1927, as a result of a conversation with the manager of a Franco-Belgian drilling company, Conrad arranged for his son-in-law, Henri Doll to attempt the first experimental resistivity survey in a well. In the Pechelbronn oilfield in Alsace, the top of the Hydrobiae marls was used as a stratigraphic marker, but was sometimes missed or misidentified in drilling. Consequently, the problem the resistivity survey would attempt to solve was whether the technique could be an effective means to recognize subsurface formations for use in correlation and mapping.

Doll put together a four-electrode (lateral) resistivity device and drove out to the well Diefenbach 2905, Tower 7, together with Scheibli and Jost on September 5, 1927. There, they linked the sonde weighted with lead to three conductive cables spliced together with insulating tape, loaded it onto a hand-operated winch, and attached it to batteries and a potentiometer. The first run was to 140 meters and took 15 hours largely because of interruptions caused by breaks in the cable . A new and longer cable was brought in by taxi to allow them to reach the full well depth of 600 meters. Resistivity readings were taken at one-meter intervals in a slow process that gradually speeded up as they became more practiced.

On returning to Paris, Doll plotted the resistivities as a function of depth and, by joining the points, drew the first electric log. Because the well had been cored, the geology was known, so that useful comparisons could be made with the resistivity curve. The Hydrobiae marls were recognized as a zone of uniformly low resistivity which was succeeded by a mixed sequence of conglomerates, sandstones and hard marls. which were distinguished by more resistive peaks and troughs. Logging runs in neighboring wells showed that many of these resistivity features could be recognized and correlated laterally. The new method was called "electrical coring"; the term "electrical logging" did not replace it until 1933. It is interesting to notice that this first log was run for a specific **geological** purpose -- to see if borehole resistivity measurements could be used to recognize lithologies to aid in stratigraphic correlation.

BASICS OF RESISTIVITY

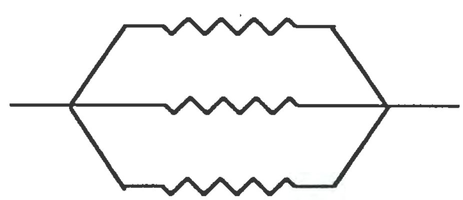
In 1827, Ohm published a pamphlet in Berlin, in which he proposed that the current in a metallic wire is proportional to the potential difference between its ends. This idea was widely ridiculed as being too simple, and Ohm was forced to resign his professorship. After some years in obscure poverty, Ohm was finally vindicated. "Ohm's law" is expressed by the equation: $E = Ir$ where the potential difference (E) is related to the current (I) by a constant called resistance (measured in ohms), which is a characteristic of the medium.



In keeping with the simplicity of Ohm's law, the algebra which governs combinations of resistances is extremely straightforward. The total resistance of a sequence of resistances in *series* is given by:

$$r = r_1 + r_2 + \cdots r_n$$

but differs from that of a set arranged in *parallel*, when it is:

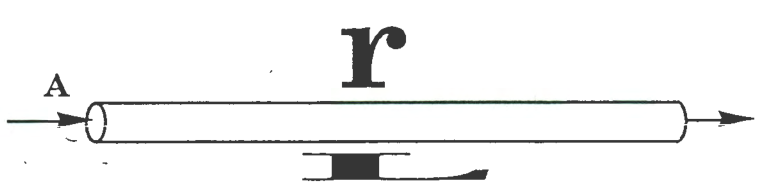


$$1/r = 1/r_1 + 1/r_2 + \cdots 1/r_n$$

The resistance of any material will vary with both its size and shape. In order to have some common basis for comparison of electrical measurements in rocks we need a parameter that characterizes each specific component, in a similar sense to the way that density, rather than weight, functions as a diagnostic property. This parameter is resistivity, given by:

$$R = \frac{r \times A}{L}$$

where A is the cross-sectional area of the resistor and L is its length. The relationship matches intuition: long, narrow resistors are shown to have higher resistances...........



The sensitivity of a resistivity tool run through a borehole is generally restricted to a range below 2000 ohm-m, and it is clear from the figures above that any measurable fluctuations are controlled by:

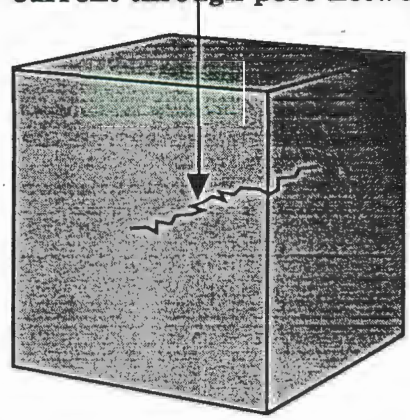
(1) the conductivity of formation waters within the pore space of reservoir rocks, and
(2) the cation-exchange conductivity of clay minerals,

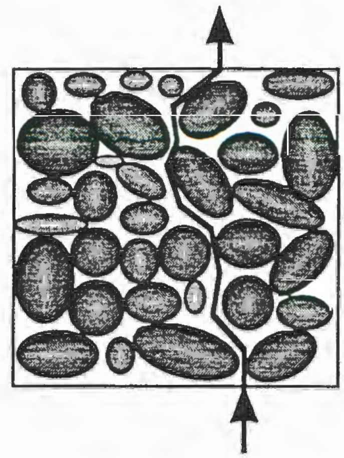
barring freak events such as concentrations of magnetite or pyrite.

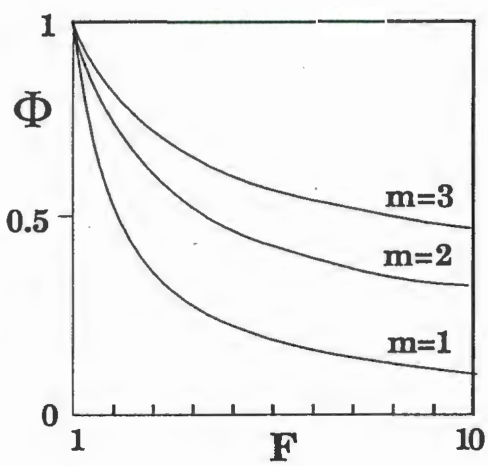
Even today, the conductivity behavior of clay minerals is a complex and poorly understood concept in log analysis and its treatment will be considered in a later section of this manual. In the initial section, the theory and practice of resistivity variations in clean (effectively shale-free) reservoir rocks will be considered. The equations developed have been applied successfully for over fifty years all over the world in the search for oil and gas reservoirs and their quantitative evaluation.

In 1942, G.E. Archie of Shell published several papers in which he explored the theoretical resistivity relationships of hypothetical rocks and confirmed his general conclusions from measurements made on core samples.
His basic ideas are retraced in the following development.

Consider a meter cube of a hypothetical sandstone (or limestone or dolomite). At one extreme, the lowest limiting case is a sandstone with zero porosity, which is a quartz cube with both resistance and resistivity effectively infinite for any simple measuring device. At the other extreme is a totally hypothetical sandstone with 100% porosity, which is a tank of brine whose resistivity is denoted as R_w. As an intermediate case, we could construct an artificial sandstone by sketching a 10 x 10 square grid on the face of a quartz meter cube, drilling a number of channels through the cube at selected grid cells and filling these with brine whose resistivity is R_w. The resistance of this "sandstone" cube is r_o and its resistivity is R_o. (The meter cube is a convenient model, since both its cross-sectional area (A) and its length (L) are equal to one.) In log analysis, R_o is the standard designation for the resistivity of a rock which is completely saturated with a brine, whose resistivity is designated R_w. The resistance of the "sandstone" block is easily calculated, since the block can be considered as a stack of quartz prisms and brine channels which are arranged as resistances in parallel. The number of brine channels is equal to the "porosity" of the "sandstone" times 100 or $n = 100\phi$. The simple mathematics of the resistivities of this simple model are shown on the next two pages.







First Archie equation:

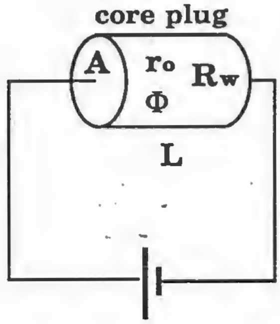
$$F = \frac{1}{\Phi^m}$$

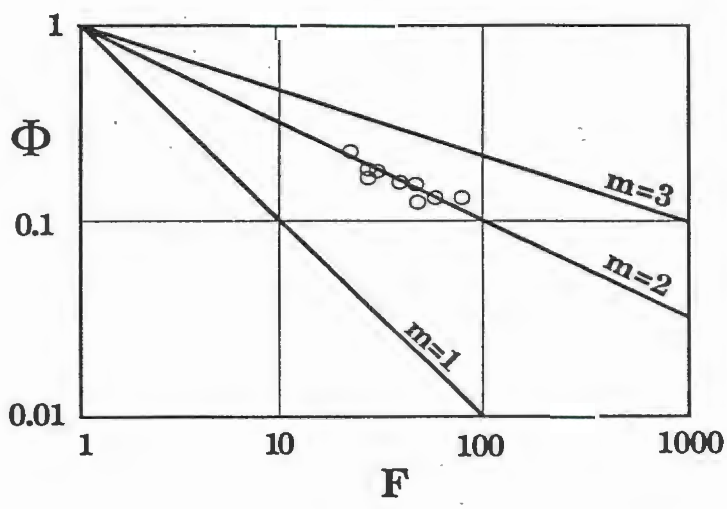
m **is termed the "cementation exponent" and is determined by the pore network geometry.**

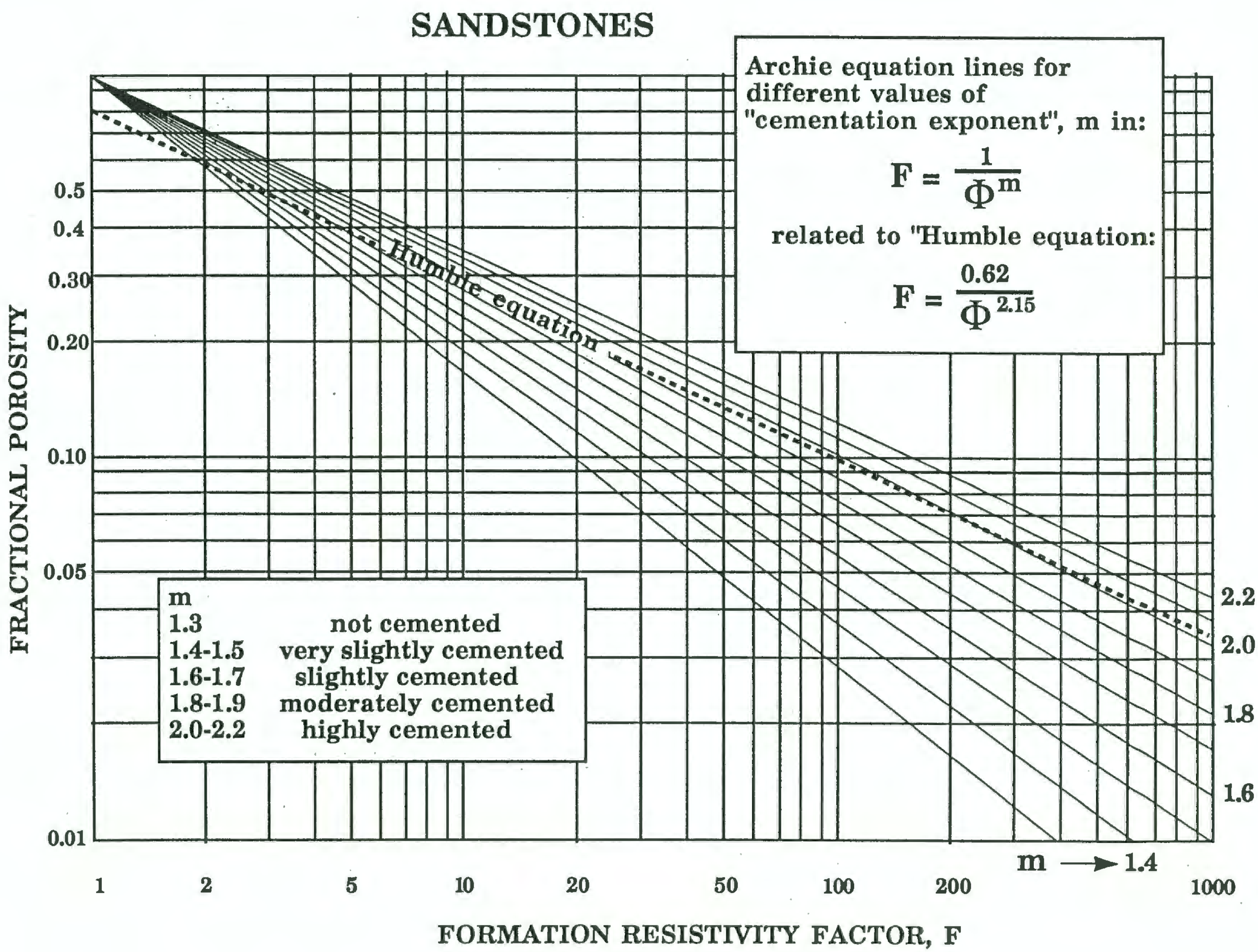
The equation is linearized by:

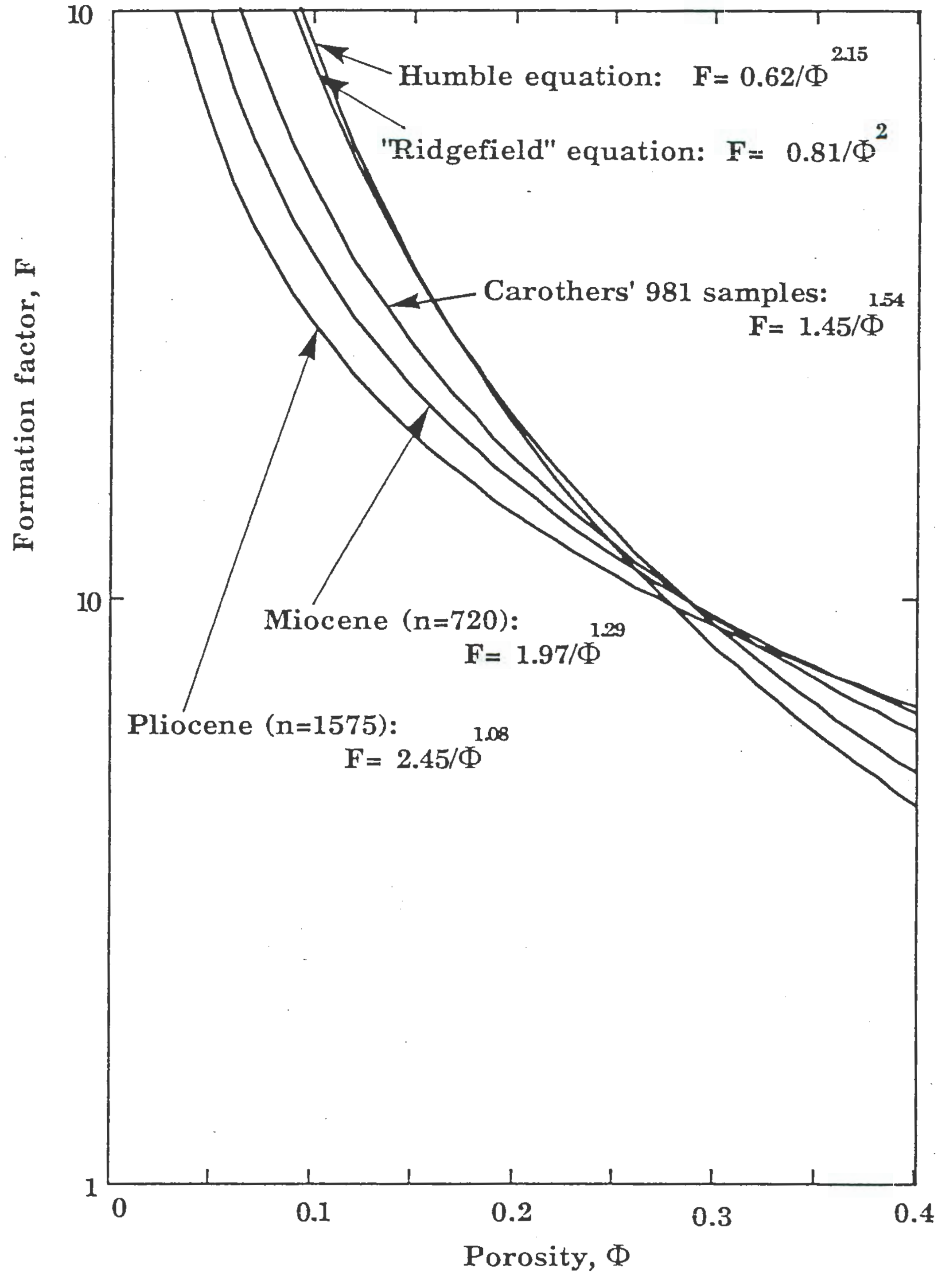
$$\log F = -m \log\Phi$$

so that laboratory measurements can be plotted on logarithmic graphs and trends fitted by straight lines






SANDSTONES
Archie equation lines for different values of "cementation exponent", m in:
$F = \frac{1}{\Phi^m}$
related to "Humble equation:
$F = \frac{0.62}{\Phi^{2.15}}$
Humble equation
m
1.3 not cemented
1.4-1.5 very slightly cemented
1.6-1.7 slightly cemented
1.8-1.9 moderately cemented
2.0-2.2 highly cemented
FRACTIONAL POROSITY
0.5
0.4
0.30
0.20
0.10
0.05
0.01
2.2
2.0
1.8
1.6
m → 1.4
1
2
5
10
20
50
100
200
1000
FORMATION RESISTIVITY FACTOR, F



Graphic comparisons of Archie equations for sandstones: the Humble equation (Winsauer and others, 1952), the Ridgefield equation (Schlumberger publications), Carothers (1968), and Miocene and Pliocene sandstone relationships (Porter and Carothers, 1970)

ESTIMATION OF THE ARCHIE EQUATION CEMENTATION EXPONENT, m FROM CORE MEASUREMENTS OF POROSITY AND FORMATION FACTOR

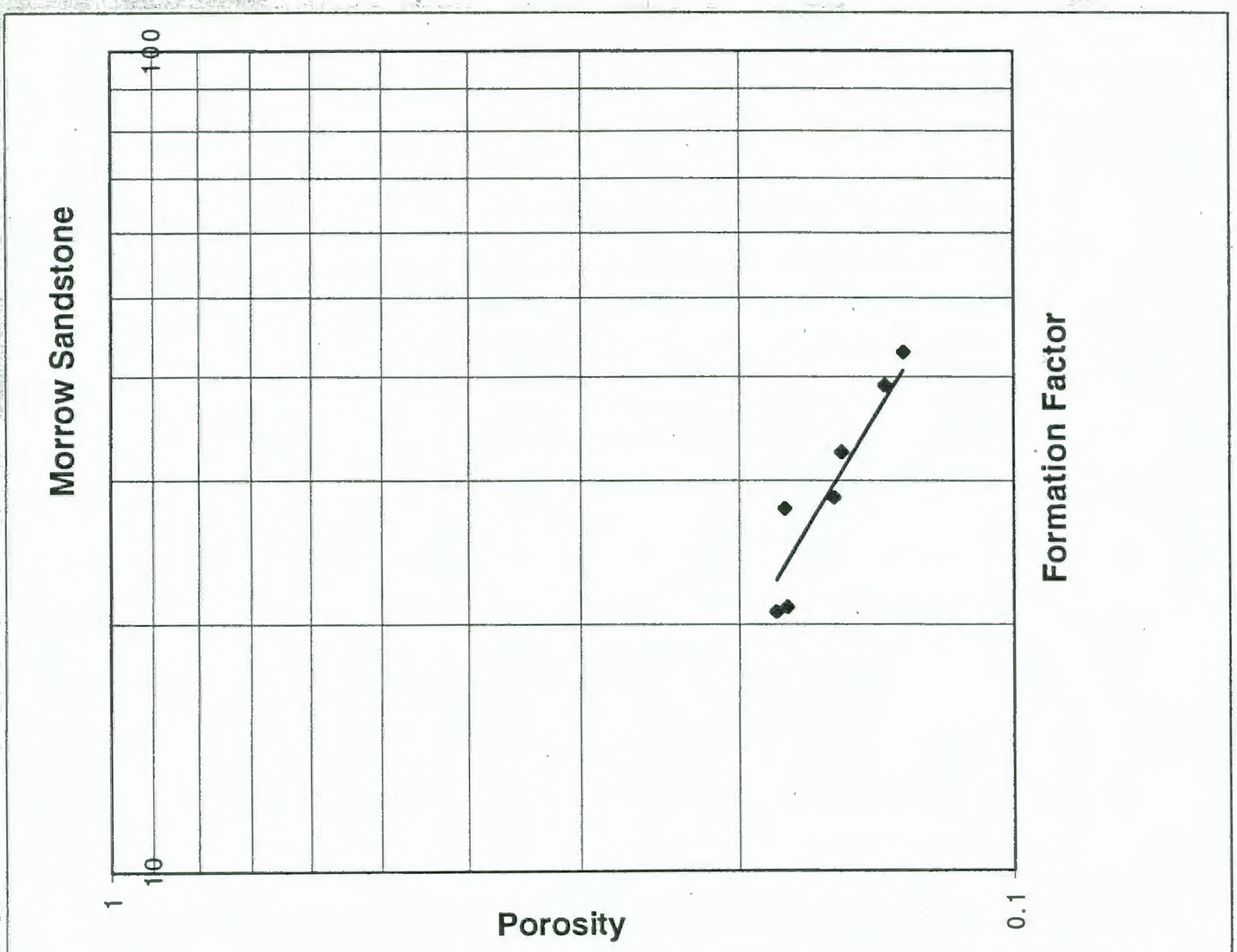
Well:	Murfin Patton #1-3 3-30S-25W
Formation:	Morrow Sandstone

Parameters

a	1
m	1.83

Depth	Phi	F	Fa	Ma
5318.1	0.138	39	37.5	1.85
5318.9	0.154	32.4	30.7	1.86
5320.1	0.178	27.7	23.5	1.92
5325.7	0.182	20.7	22.6	1.78
5326.3	0.177	21	23.8	1.76
5327.3	0.157	28.6	29.6	1.81
5328.1	0.132	42.8	40.7	1.86

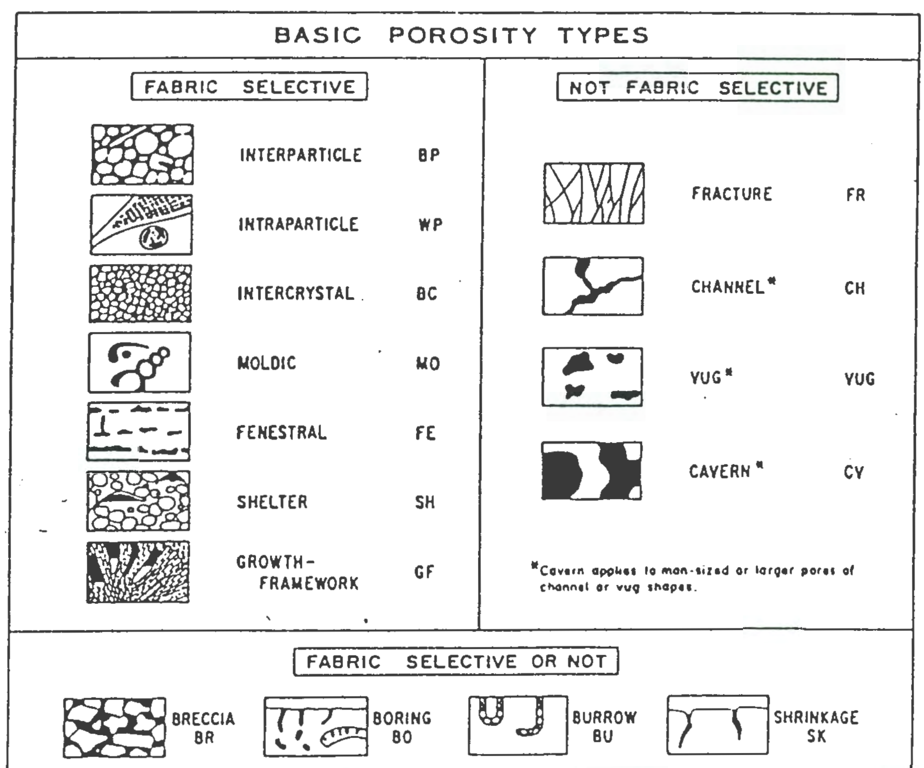
MEAN m: 1.83



FORMATION FACTOR - POROSITY RELATIONSHIPS FOR CARBONATES

Porosity in sandstones generally takes the form of *intergranular* pores: the pore space between the grains of quartz and other detrital minerals. In some cases there may be *intercrystalline* porosity caused most commonly by calcite or quartz cement introduced by diagenesis in the lithification of the sandstone. Porosity in carbonate rocks (limestones and dolomites) can take a wide variety of forms as shown in the illustration from Choquette and Pray (1970). The geological classification of carbonate pore types is based on *genesis;* geologists are interested in the history of pore formation. The petrophysicist should pay attention to the geological description and interpretation of carbonate pore types in a reservoir. However, there will be times when such detailed information is limited or non-existent and the petrophysicist should focus on the *morphology* of the pores, because it is this aspect that affects the wireline log measurement.

Petrophysicists subdivide pore types between:
(1) **interparticle**: intergranular and intercrystalline porosity;
(2) **fracture**
(3) **vug**: either moldic porosity from the dissolution of grains or vugs that are larger than the grains.
Notice that all the genetic forms in the carbonate classification of Choquette and Pray can be assigned to these broad petrophysical categories.



from Choquette and Pray, 1970

DETERMINING THE CEMENTATION EXPONENT (M) IN KANSAS

From: Dan DeBoer, 1990, "The Log Header" (KWLS Newletter), v. 5, no. 1

ESTIMATION OF THE ARCHIE EQUATION CEMENTATION EXPONENT, m FROM CORE MEASUREMENTS OF POROSITY AND FORMATION FACTOR

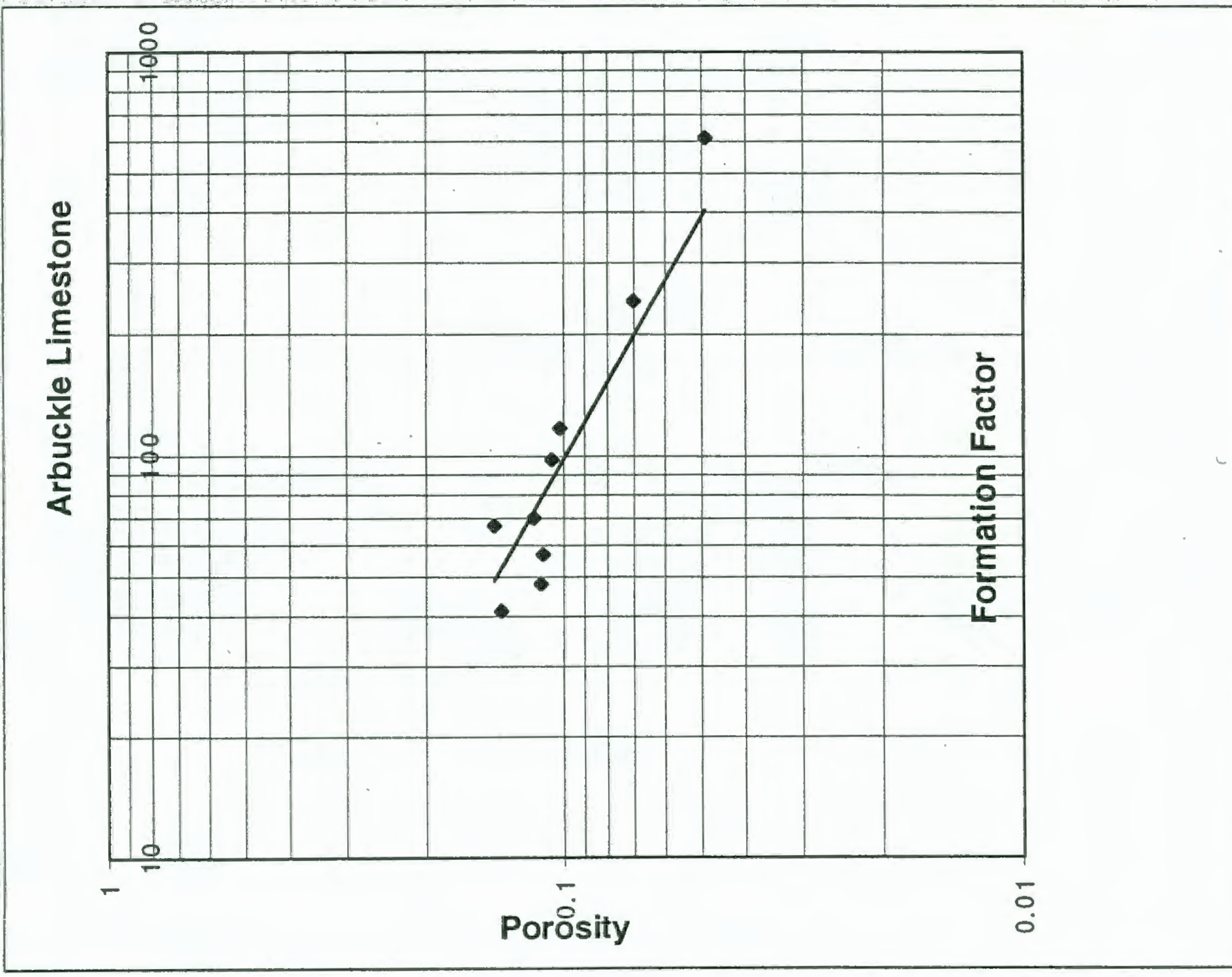
Well: USGS-KGS Big Springs #1 13-12S-17E, Douglas Co., Ks
Formation: Arbuckle Limestone (Cambro-Ordovician)

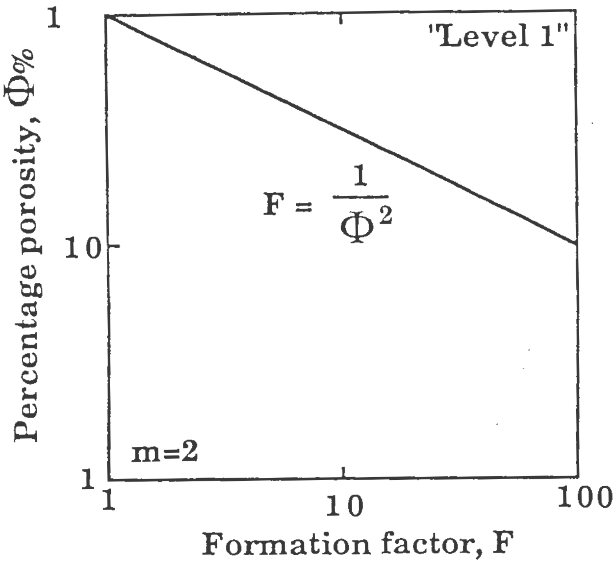
Parameters

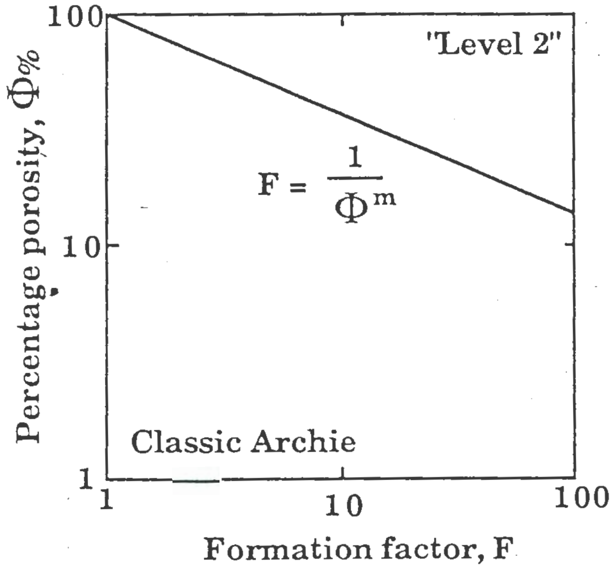
a	1
m	1.99

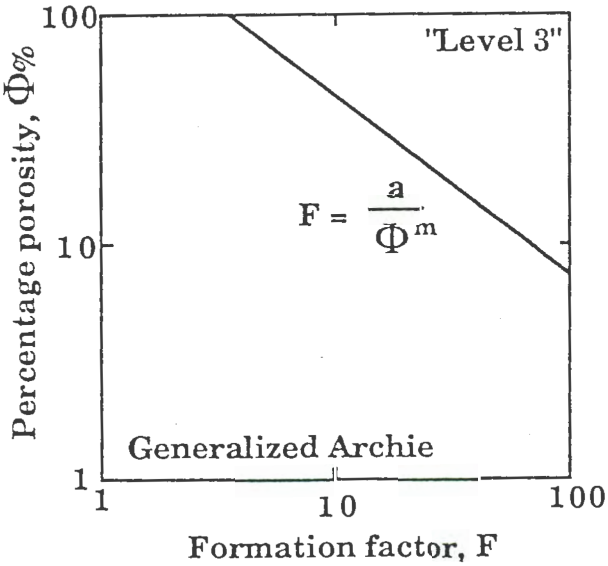
Depth	Phi	F	Fa	Ma
2421	0.102	117	93.9	2.09
2422	0.049	611	404.1	2.13
2424	0.142	66.9	48.6	2.15
2429	0.07	241	198.7	2.06
2430	0.116	70	72.7	1.97
2438	0.106	98	87.0	2.04
2440	0.137	41.1	52.2	1.87
2442	0.112	48	78.0	1.77
2444	0.111	56.7	79.4	1.84

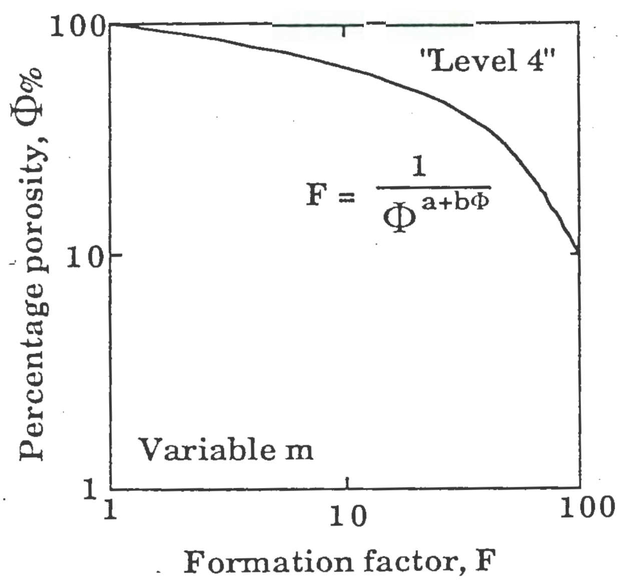
MEAN m 1.99

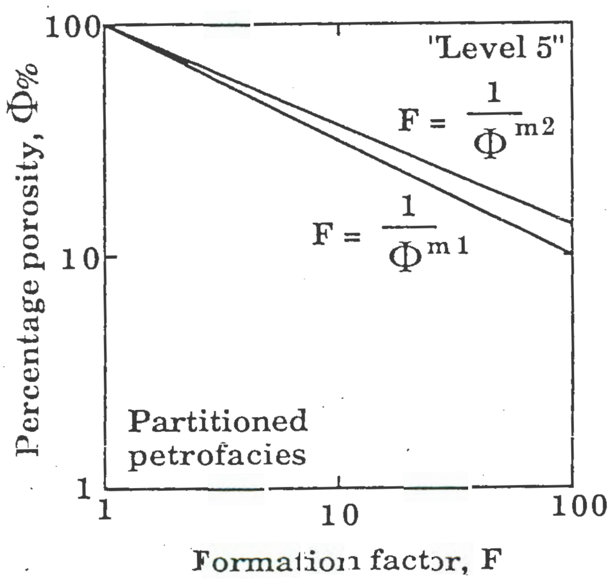


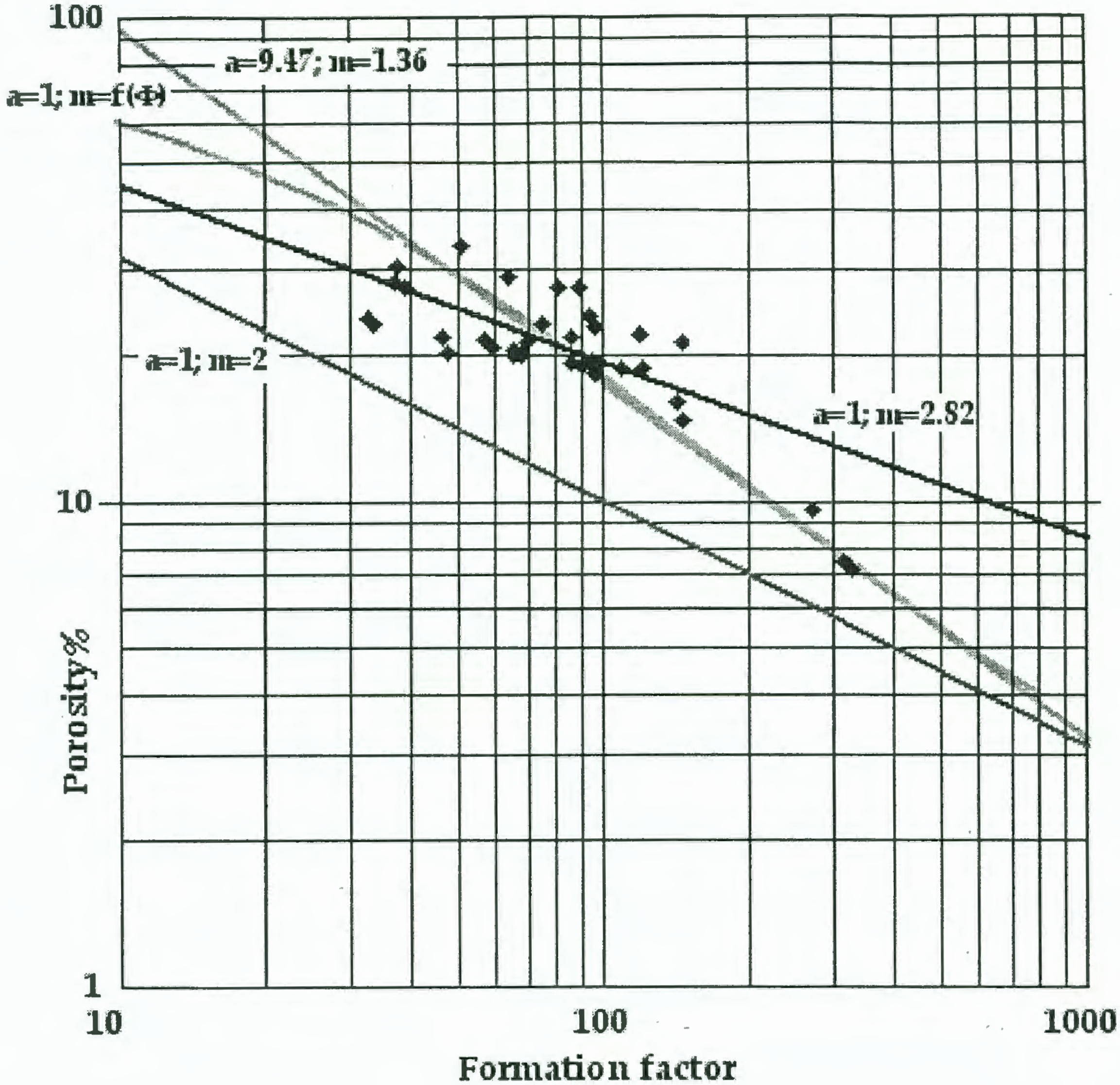

"Level 1"
$F = \frac{1}{\Phi^2}$
m=2
Percentage porosity, Φ%
1
10
1
1
10
100
Formation factor, F


"Level 2"
$F = \frac{1}{\Phi^m}$
Classic Archie
Percentage porosity, Φ%
100
10
1
1
10
100
Formation factor, F


"Level 3"
$F = \frac{a}{\Phi^m}$
Generalized Archie
Percentage porosity, Φ%
100
10
1
1
10
100
Formation factor, F


"Level 4"
$F = \frac{1}{\Phi^{a+b\Phi}}$
Variable m
Percentage porosity, Φ%
100
10
1
1
10
100
Formation factor, F


"Level 5"
$F = \frac{1}{\Phi^{m2}}$
$F = \frac{1}{\Phi^{m1}}$
Partitioned petrofacies
Percentage porosity, Φ%
100
10
1
1
10
100
Formation factor, F



Formation factor - porosity plot of core measurements from the Carter -Colliver #1 well matched with four models of Archie equation predictions:

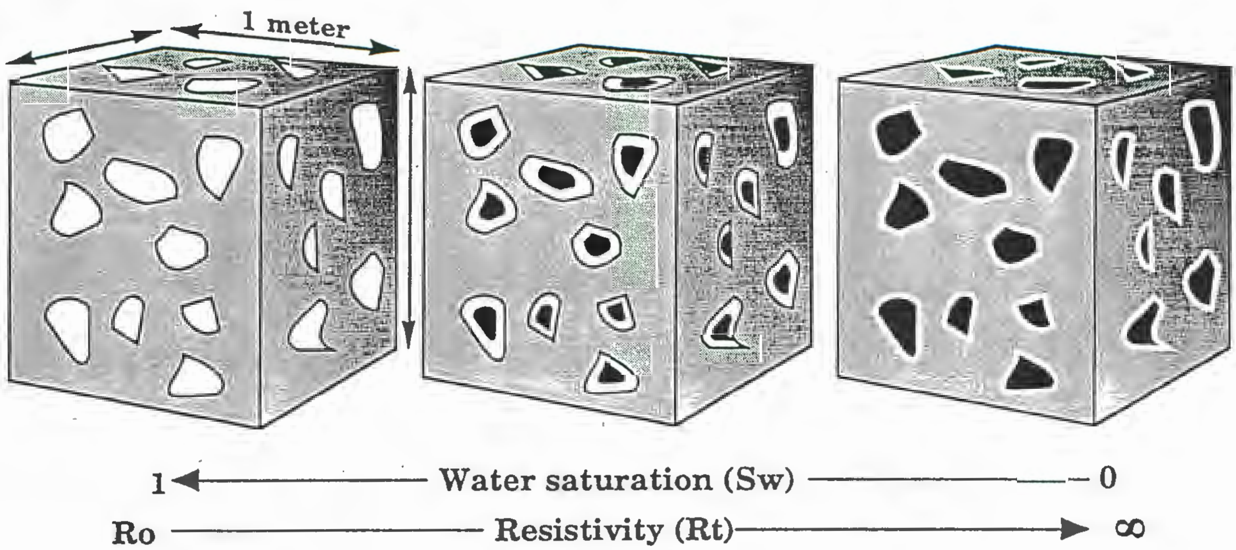
$a = 1$, $m = 2$

$a = 1$, $m = 2.82$

$a = 9.47$, $m = 1.36$

$a = 1$, $m = 1.9 + 4.35\,\Phi$

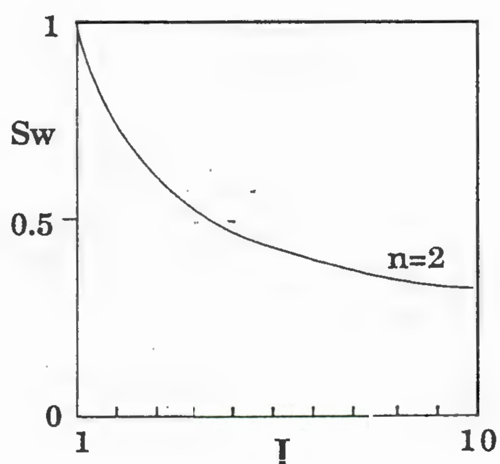
THE RESISTIVITY OF HYDROCARBON-BEARING ROCKS



Symbols: Sw is the water saturation, used in calculations as a FRACTION, but often reported in equivalent percent.

Rt is the actual resistivity of a rock – it is to be determined whether the rock is completely saturated with formation water (Sw=1), in which case Rt=Ro, or whether Rt>Ro, in which case Sw<1 and the pore space is suggested to be partially filled with hydrocarbon (oil or gas).

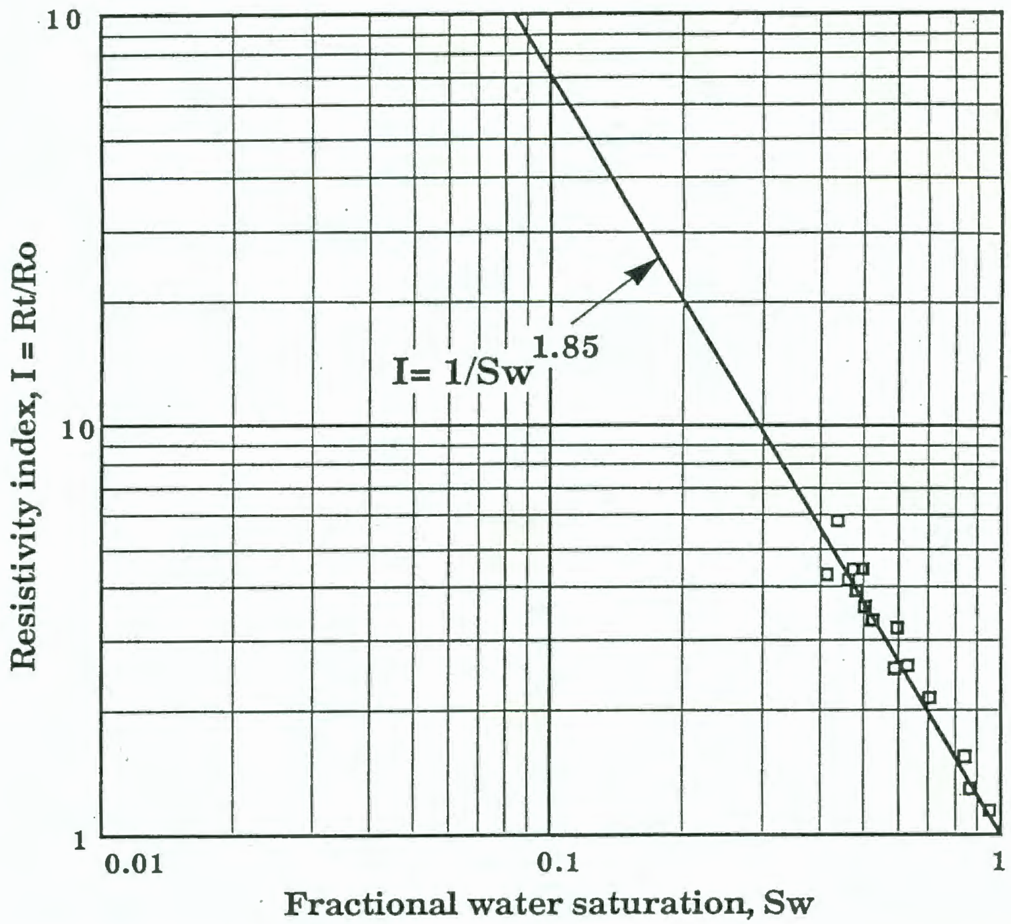
I is defined as the "resistivity index"=Rt/Ro and functions as a comparison test between the actual resistivity of the formation, Rt, and the value that it should have if its pore space is completely filled with formation water, Ro.



Second Archie equation:

$$I = \frac{1}{Sw^{n}}$$

n **is termed the "saturation exponent" and is generally taken to be equal to 2 for log analysis purposes.**



Finding the value for the saturation exponent, n (=1.85) from measurements of resistivity and water saturation in Arbuckle Limestone core samples

The graph above shows the results of crossplotting resistivity indices and water saturations from five of the core samples from the Arbuckle formation used in Exercise 2. The laboratory procedure was as follows: First, the resistivities of the samples were measured when completely saturated with brine. These values are *Ro*. Then, the samples were placed in a porous-plate capillary pressure cell for desaturation. The sample resistivities were re-measured at a sequence of reduced brine saturations to give estimates of Rt. The resistivity index, *I*, at any brine saturation level, *Sw*, is then:

$$I = Rt/Ro$$

From the second Archie equation: $I = 1/Sw^n$

which can be rewritten as: $\log I = -n \log Sw$

and will be a straight line on a crossplot of the resistivity index and brine saturation on log-log paper. The slope of the line is determined by the saturation exponent, which for this Arbuckle sample is closely approximated by a value of 1.85.

From: "The Log Analyst", March - April, 1997

To the Editor:
Dear Sir,

Not wishing to let a good argument stagnate (or perhaps to flog a horse until it is really dead), I feel obliged to add another 10 pennies worth.

Whilst my co-contributers have now expounded on the advantages of borehole, invasion corrections and tool modelling (hopefully to the benefit of your readers), I have to regrettably point out that even if we can calculate R_t to within a hairs' breadth of the true formation R_t, this should not by any remote chance lull us into the incorrect assumption that we have produced an accurate value for HCPV.

In order to calculate saturation, and thus HCPV, we must invoke Archie's equation, which requires the use of exponents for porosity *(m)* and saturation *(n)* as well as accurate measurements of porosity and R_t.

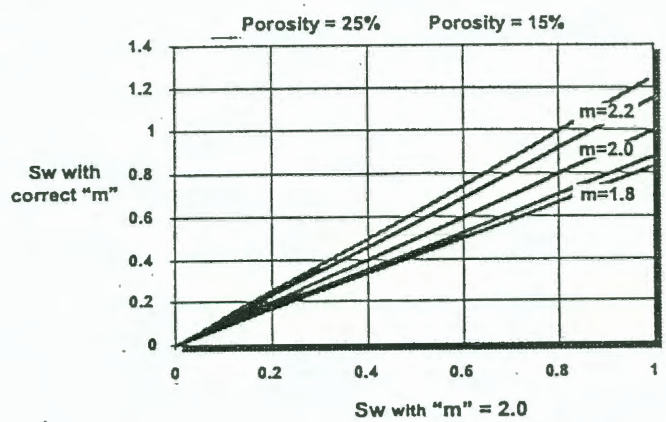
It is my experience that these exponents are frequently poorly characterised and can have a significant effect on the "real" value of HCPV (on one recent large field of several hundred wells I came across only a couple of core measurements of *n* had ever been made!). The two plots show how errors in the measurement of *m* and *n* translate into errors in the saturation calculation. To use, enter the horizontal axis with S_w assuming *n* or *m* is 2.0 and then see the effect of a different value on the vertical axis.

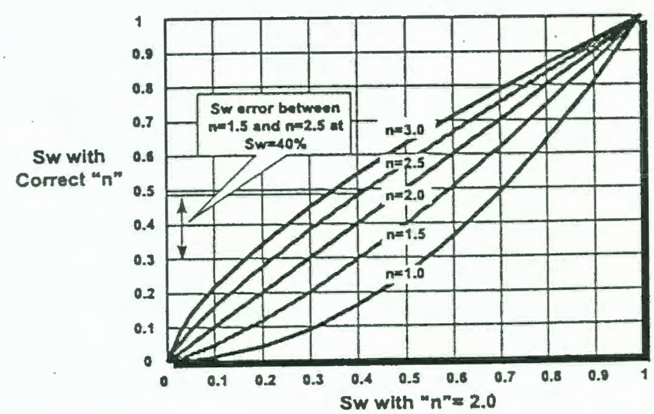
In summary, errors in *n* have most effect at intermediate saturations and errors in *m* have most effect in low porosities and high saturations.

Getting R_t right is only part of the story.

Sincerely,

- G.A. Brown



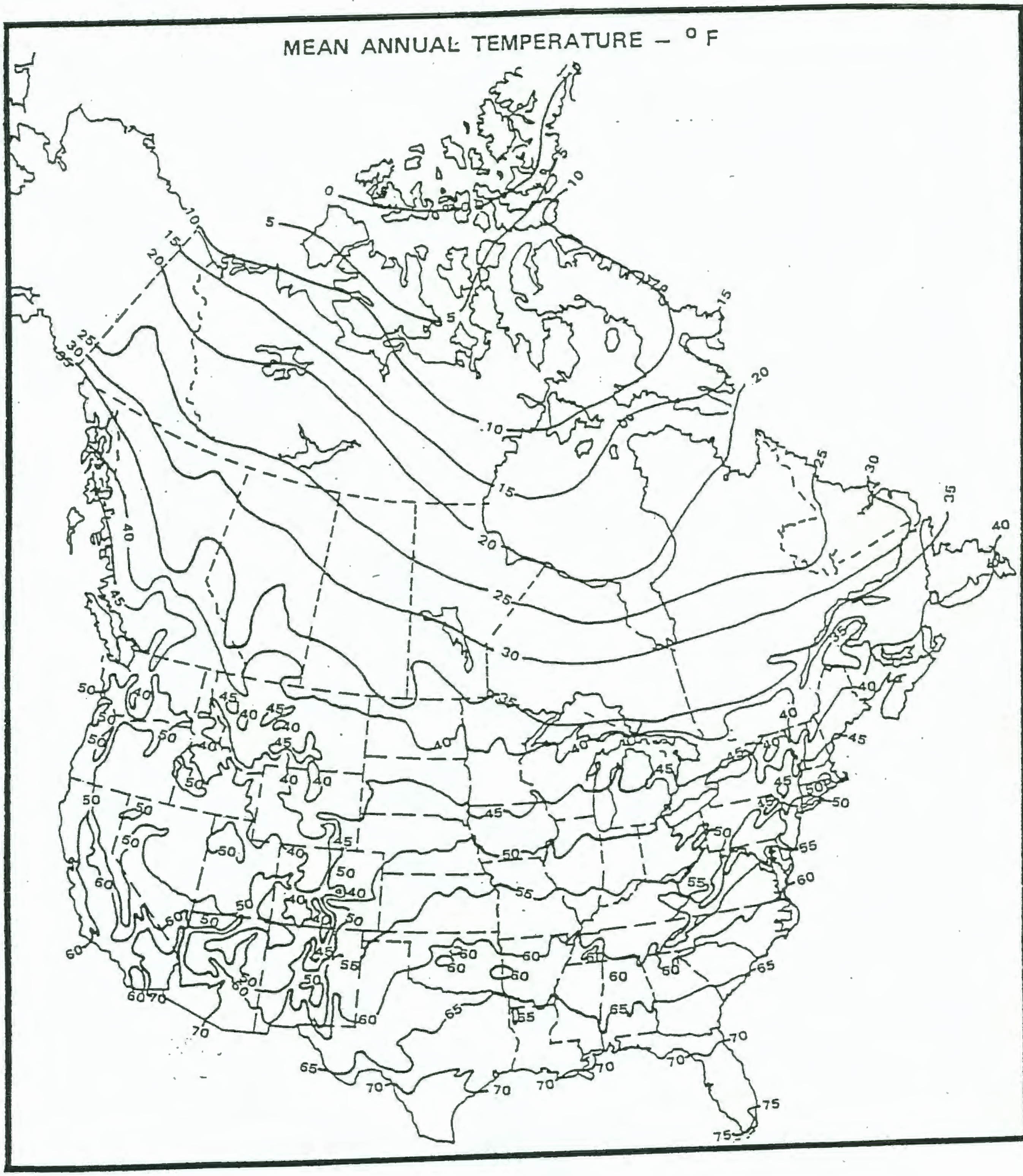


TEMPERATURE AND WATER RESISTIVITY

For shale-free formations, the conduction of electrical current is almost entirely carried by ions in the formation water. Quantitative calculations of oil or gas saturation are therefore predicated on a knowledge of the formation water resistivity. For any given brine, this value is not constant, but decreases with increasing temperature. A common source of formation water resistivity data is a catalog of laboratory measurements made of samples from drill-stem tests, etc.

For example, if you had drilled a well in Stafford County, Kansas and one of your target formations was the Viola Limestone, this is the information that you would see in the KGS Brine Catalog (along with chemical composition of the dissolved solids). Water resistivity catalogs are available in a number of areas that have oil and gas development. Data for samples that are obviously contaminated by acid treatment, excessive mud invasion, etc. are screened out of the catalog, but there is usually some variability left, and the catalog reader should look for a "typical" value. Some of the log analysis techniques described later (the Rwa method, the Pickett plot, and estimation from the SP log) provide additional checks on these values. Once a representative value of Rw has been chosen, its value must be corrected from that of its laboratory measurement to that at the temperature of the formation in the well.

FORMATION WATER RESISTIVITIES		
laboratory measurements of produced samples		
Stafford County, Kansas		
VIOLA		
Location	**Rw**	**RwT**
Sec-T-R	**ohm-m**	**deg F**
27-21-13W	0.127	100
9-21-14W	0.210	70
10-24-11W	0.048	100
12-24-11W	0.082	100
22-24-11W	0.055	100
2-24-12W	0.077	100
10-24-12W	0.062	100
11-24-12W	0.072	100
15-25-11W	0.088	100
2-25-14W	0.075	60
2-25-14W	0.070	60
		kgs



Mean annual surface temperatures in North America
(after Connolly and U.S. Dept. of Agiculture)

CONVERSION OF FORMATION WATER RESISTIVITIES FROM A MEASUREMENT TEMPERATURE TO A FORMATION TEMPERATURE COMPUTED USING ARPS' EQUATION (FAHRENHEIT VERSION)

Well:	Shell Robbins #1-32 (Glick)
Formation:	Mississippi "Chat"

Formation temperature calculation:

	DEPTH		TEMPERATURE	
Surface		0	ST	57
Formation	FD	4838	**FT**	111.7
Bottom hole	TD	5398	BHT	118

KEY:
- ST = Mean annual surface temperature
- TD = Total depth
- BHT = Bottom-hole temperature
- FD = Formation depth
- FT = Formation temperature

Arps' equation:

Rw1	0.05	T1	75
RwFT	0.035	FT	111.7

Rw1 = Formation water resistivity at temperature T1

RwFT = Formation water resistivity corrected to Ft

WATER RESISTIVITY ESTIMATION FROM BRINE COMPOSITION

Well:	Oasis Deutsch #1 C-NE-SE 33-21S-24W Hodgeman Co, Ks
Formation:	Warsaw Formation (Mississippian)

Well Parameters

ST	57
TD	4723
BHT	117
FormD	4650

Formation Estimates

FormT	116
Measured Rw @ FormT =	0.116
Estimated Rw @ FormT =	0.1043

Measured Rw @ T deg F =	0.17
T =	77
Measured Rw @75 DEG F=	0.1741

Water data:

Density (gm/cc)=	1.032
pH =	6.7

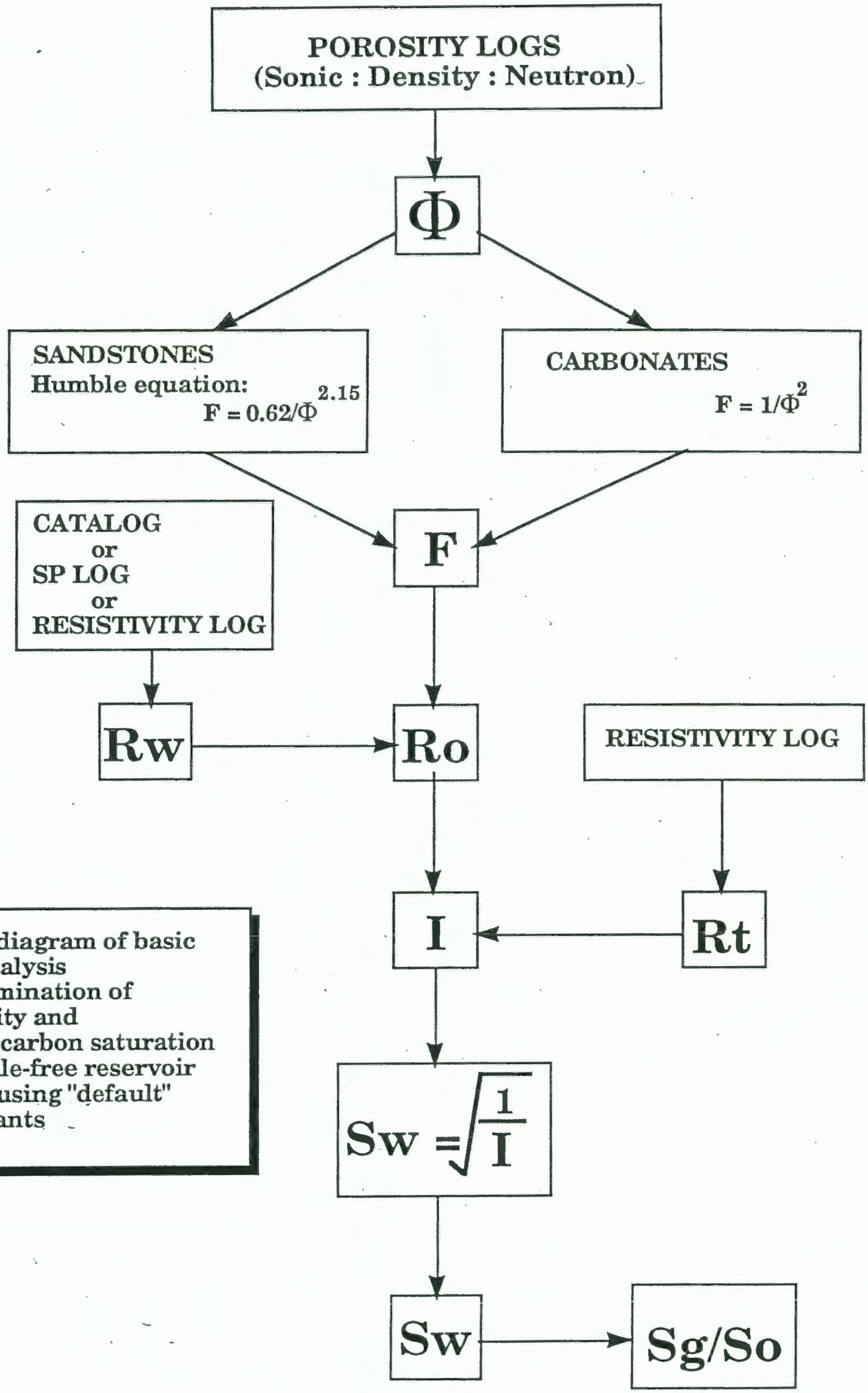
CATIONS	**mg/l**	**meq/l**
Sodium	12990	564.8
Potassium		0.0
Calcium	2010	100.5
Magnesium	660	54.3
	Sum equiv. cations =	719.6

ANIONS	**mg/l**	**meq/l**
Chloride	23520	663.3
Bicarbonate	350	5.7
Sulfate	2440	50.8
Carbonate		0.0
	Sum equiv. anions =	719.9

Anion/cation imbalance% = 0.0

TDS (mg/l)	41970
TDS Equiv.NaCl (mg/l)	42077
TDS Equiv.NaCl (ppm)	40772

Estimated Rw @75 DEG F= 0.157



Flow diagram of basic log analysis determination of porosity and hydrocarbon saturation in shale-free reservoir rock, using "default" constants

BACKGROUND ON NORTH AMERICAN FORMATIONS USED IN ARCHIE EQUATION SOLUTION SPREADSHEET

MORROW SANDSTONE (Lower Pennsylvanian) Colorado
Hartmann, D.J., and Coalson, E.B., 1990, Evaluation of the Morrow Sandstone in Sorrento Field, Cheyenne County, Colorado: in Morrow Sandstones of Southeast Colorado and Adjacent Area: RMAG, Denver, Colorado, p. 91-100.
Lithology: Fluvial point-bar sandstone - very coarse to fine-grained, poorly sorted.
Production: Oil

MISSISSIPPI "CHAT" (Mississippian) Kansas
Duren, J.D., 1960, Some petrophysical aspects of the Mississippian "Chat" Glick Field, Kiowa County, Kansas: The Shale Shaker, September, p. 316-321.
Lithology: Tripolitic chert
Production: Gas

MINNELUSA SANDSTONE (Permian-Wolfcampian) Wyoming
James, S.W., 1989, Diagenetic history and reservoir characteristics of a deep Minnelusa reservoir, Hawk Point Field, Powder River Basin, Wyoming: in Sandstone Reservoirs: RMAG, Denver, Colorado, p. 81-96.
Lithology: Eolian sandstone - fine-grained, well-rounded, well-sorted, with anhydrite and dolomite cement.
Production: Oil

HUNTON DOLOMITE (Upper Ordovician - Lower Devonian) Oklahoma
King, E.E., 1975, Rapid Sw determination using Rw Index Sliding Overlay technique: The Log Analyst, v. XVI, no.6, p.33-39.
Lithology: Dolomitic limestone
Production: Gas

WABISCAW SAND (Lower Cretaceous) Alberta
McCoy, J.T., and Burge, E.J., 1976, Petrophysical mapping of the Wabiscaw Sand, Marten Hills area, Alberta: CWLS Jour., v.9, no.1, p.55-68.
Lithology: Marine blanket sandstone
Production: Gas

SMACKOVER FORMATION (Jurassic) Arkansas
Mitchell-Tapping, H.J., 1983, Petrophysical evaluation of the Smackover oomoldic porosity of East Texas and Southern Arkansas: The Log Analyst, v.XXIV, no.4, p.3-13.
Lithology: Oomoldic limestone
Production: Water

ESTIMATION OF HYDROCARBON SATURATION IN ZONES FROM NORTH AMERICAN FORMATIONS

Formation/Location	Morrow Sandstone, Colorado	Mississippi "Chat", Kansas	Minnelusa Sandstone, Wyoming	Hunton Group, Oklahoma	Wabiscaw Sandstone, Alberta	Smackover Formation, Arkansas	Red River Formation, North Dakota	Austin Chalk, Texas	Bluell Formation, North Dakota	Olmos Sandstone, Texas	Niagaran Reef, Michigan
Depth, ft	5600	4838	11420	13610	1915	5595	9100	7038	5800	6880	4032
Lithology	Ss	Chat	Ss	Dol.ls	Ss	Ls	Dol.	Chalk	Ls	Ss	Dol.
Archie: a	1	1	1	1	0.62	1	1	1	1	0.62	1
m	1.8	2.36	1.83	2	2.15	2	2	2	2	2.15	2.5
n	2	1.8	1.5	2	2	2	2	2	2	2	2
Rw @F.t.	0.04	0.0345	0.017	0.03	0.4	0.026	0.02	0.04	0.025	0.068	0.04
Φ%	19	37	13	12	30	32	16	12	5	16	5
F	19.87	10.45	41.83	69.44	8.25	9.77	39.06	69.44	400	31.88	1789
Ro	0.8	0.4	0.7	2.1	3.3	0.3	0.8	2.8	10.0	2.2	71.6
Rt	9	1.7	16	100	80	6	16	63	28	8	1790
I	11.3	4.7	22.5	48.0	24.2	23.6	20.5	22.7	2.8	3.7	25.0
Sw%	29.7	42.2	12.5	14.4	20.3	20.6	22.1	21.0	59.8	52.1	20.0
Sh%	70.3	57.8	87.5	85.6	79.7	79.4	77.9	79.0	40.2	47.9	80.0

Logs: Blue-lines and digits

Schlumberger — CEMENT BOND LOG VARIABLE DENSITY

COUNTY BARBER
Field or LOCATION 14-32S-15W
WELL RIDING INTO HELL AND BACK AGAIN #1
COMPANY WILD BOYS

COMPANY WILD BOYS LAND, CATTLE & OIL CO. & THE SILVER BULLET OIL CO.

WELL RIDING INTO HELL AND BACK AGAIN #1

FIELD WILDCAT

COUNTY BARBER STATE KANSAS

LOCATION 150' SOUTH OF C NE SW — API Serial No. 15-007-21220 — Other Services:

Sec 14 Twp 32S Rge 15W

Permanent Datum: GROUND LEVEL, Elev 1993
Log Measured From KB, 15 Ft. Above Perm. Datum
Drilling Measured From KB

Elev.: K.B 2008, D.F ----, G.L 1993

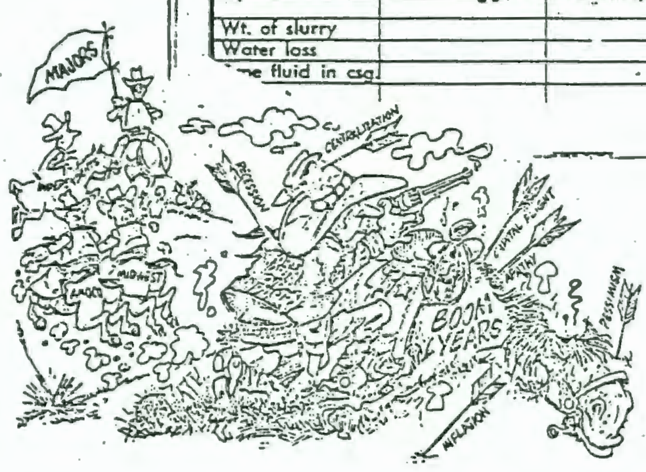
Date	7-27-81	Casing Fluid	WATER
Run No.	ONE	Fluid Level	FULL
Depth — Driller	5105	Max. Rec. Temp.	NA °F
Depth — Logger	5102	Est. Cement Top	3760
Btm. Log Interval	5094	Unit / District	7704 / WICHITA
Top Log Interval	3540	Recorded By	KRUCKEBERG
Open Hole Size	7 7/8	Witnessed By	CHRISTENSEN

CASING REC.	Size	Wt/Ft	Grade	Type Joint	Top	Bottom
Surface String	8 5/8				SURF	337
Prot. String						
Prod. String	5 1/2	14.0			SURF	TD
Liner						

PRIMARY CEMENTING DATA

STRING	Surface	Protection	Production	Liner
Vol. of cement				
Type of cement				
Additive				
Retarder				
Wt. of slurry				
Water loss				
Type fluid in csg.				

The well name, location and borehole reference data were furnished by the customer.

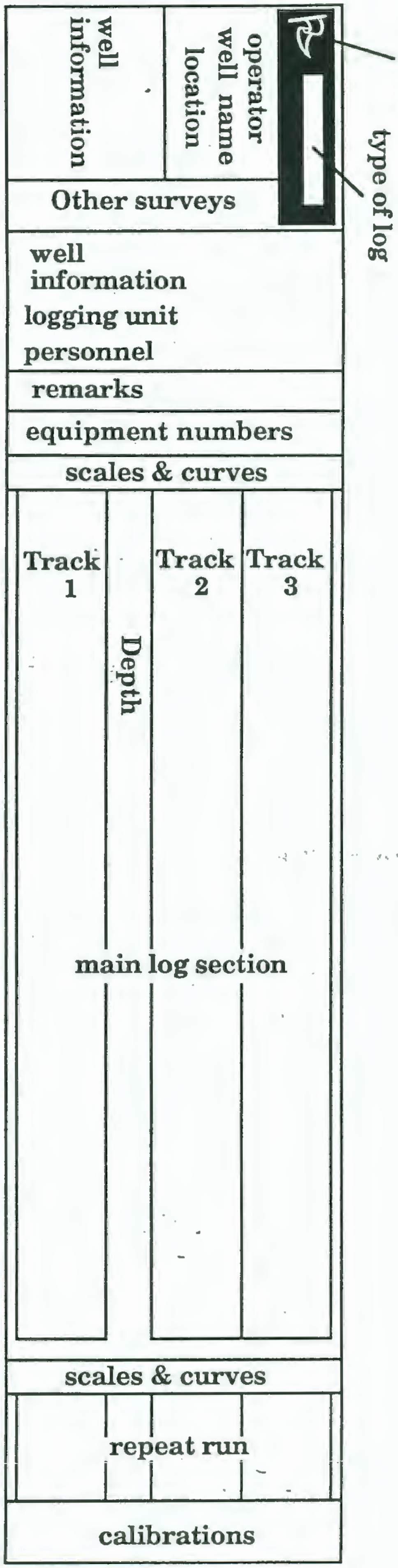


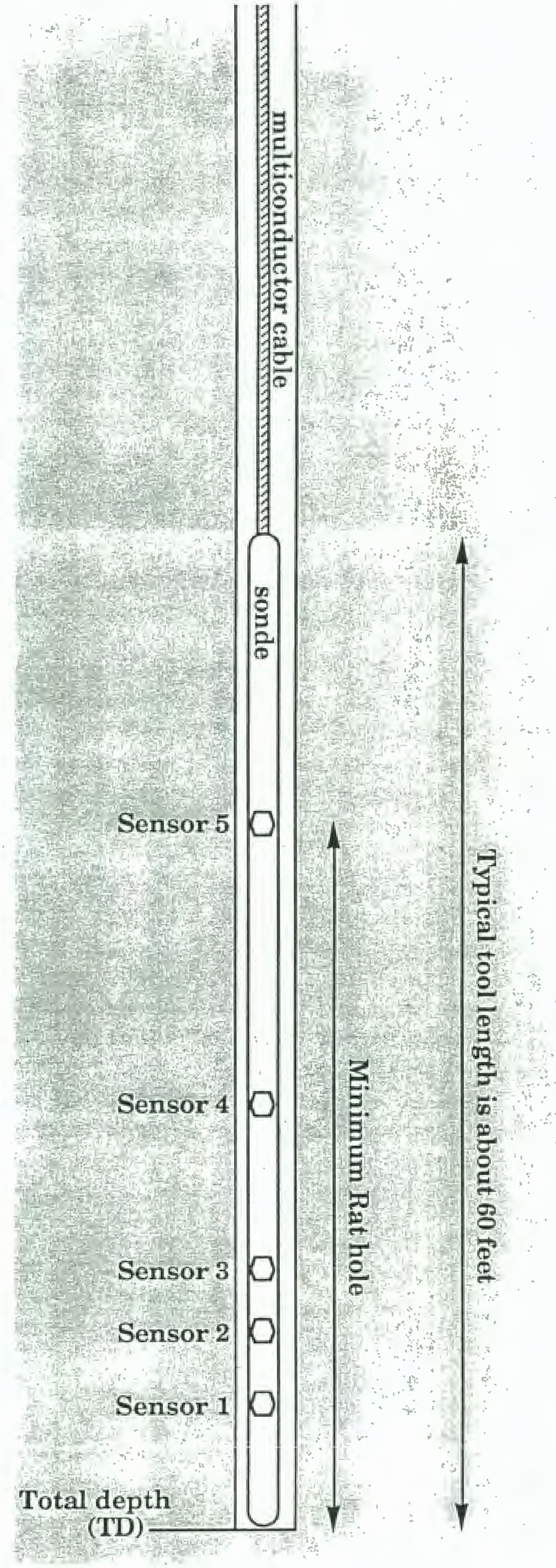
THE LOGGING JOB

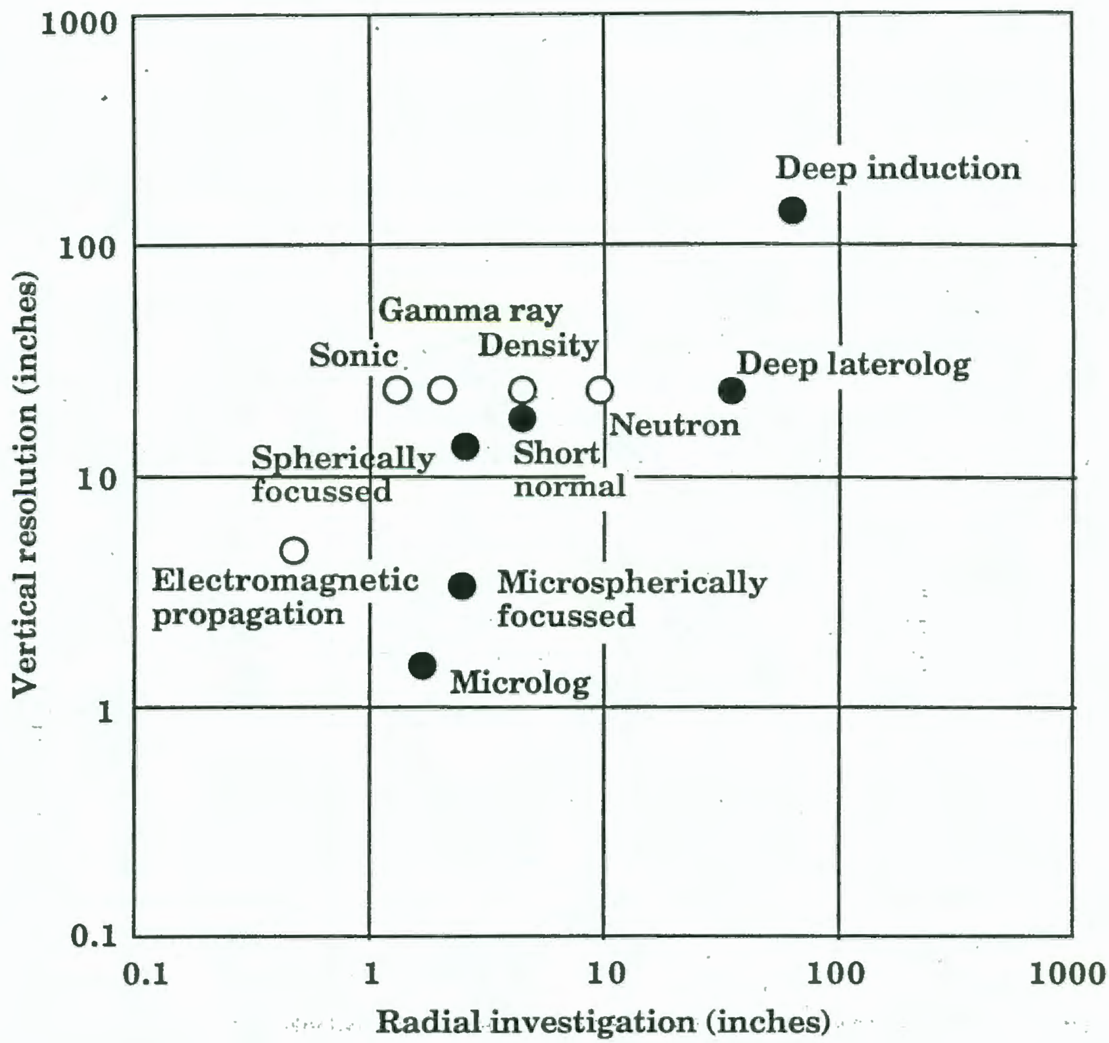
Prior to drilling a well, a logging program is chosen with a suite of tools to be run that is suitable for the target formation petrophysical properties, the engineering characteristics of the hole (mud type, hole diameter, etc.), and the problems to be resolved by the tool measurements. The logging company is chosen for the job. When the hole approaches total depth, the logging company is contacted and a logging truck is sent to the location of the drilling rig. The wireline logging crew typically has a field engineer, who directs the logging, and two equipment operators. The crew prepares for logging as the drill-pipe is tripped out of the hole. They lay the tool parts out on the catwalk, calibrate them, and assemble them into a tool. When the drill-pipe has been removed from the hole, the tool is attached to a cable and lowered down the hole. The length of the tool is variable, but can be anything between 20 and 100 feet (or more). In the plan for the drilling, some allowance will have been made for the anticipated tool length by drilling an extra depth of "rat-hole", beyond the desired total depth.

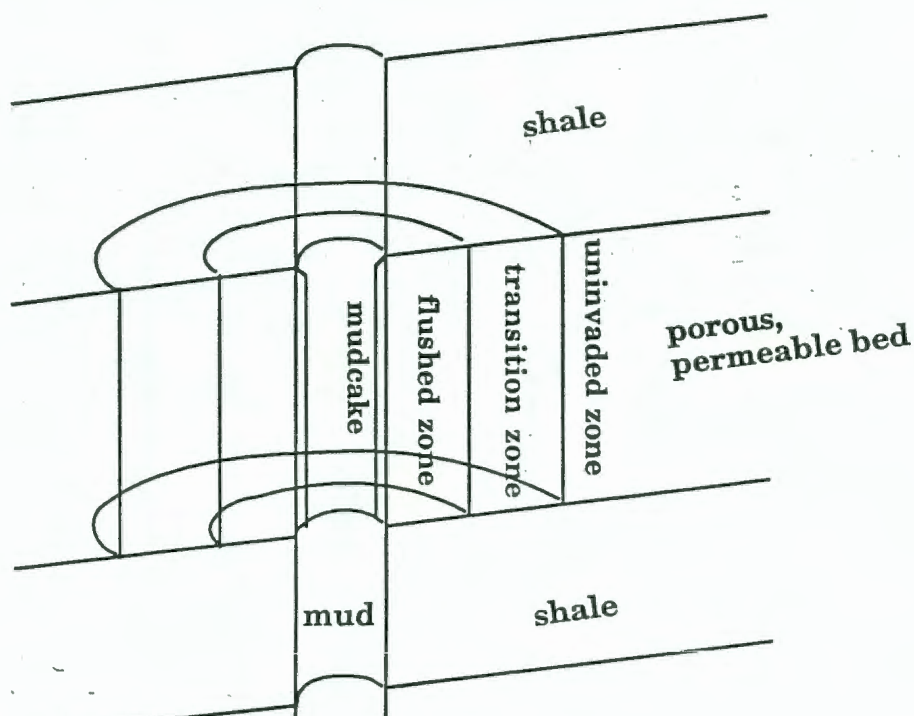
On reaching bottom , the depth is measured either from the ground or the Kelly Bushing (KB) of the drilling platform, and compared with the drill crew's estimate. The logging crew is now ready to record logs. First, the tool is raised through 100 to 200 feet in an initial recording pass, that creates the "repeat section". The tool is lowered back to the bottom and the main run initiated as the tool is pulled through the entire hole. Comparison between the main run and repeat section are made for a quality assurance of repeatability (precision). The field engineer checks this, as does a company representative (the well-site geologist or engineer), who also does other quality checks on the final log. The company person will sign off as the witness if he or she is satisfied; if not satisfied, another run will have to be made.

The logging tools are pulled up at a uniform speed so as to maintain a fairly constant tension in the steel cable. Sometimes, the tool may get caught in the hole and then (hopefully) spring free, and these problem intervals will show on the tension log and warn that log depths there will have some error. The logging speed varies with the type of physical measurement, but is usually between 1800 to 3600 feet per hour. The logging crew will also take a sample of the drilling mud and measure the resistivity of the mud and the mud filtrate in a conductivity cell in the logging truck. The old logging trucks recorded logs in analog form as "blue-lines" that were photographically developed in the truck. Modern logging equipment is computerized, with logs recorded digitally. Both hard-copy blue-lines and digital files can be supplied to the company representative at the well-site. In the case of major company wells in remote locations, the logging information can be bounced off a satellite and analyzed immediately by a petrophysicist in a company office.

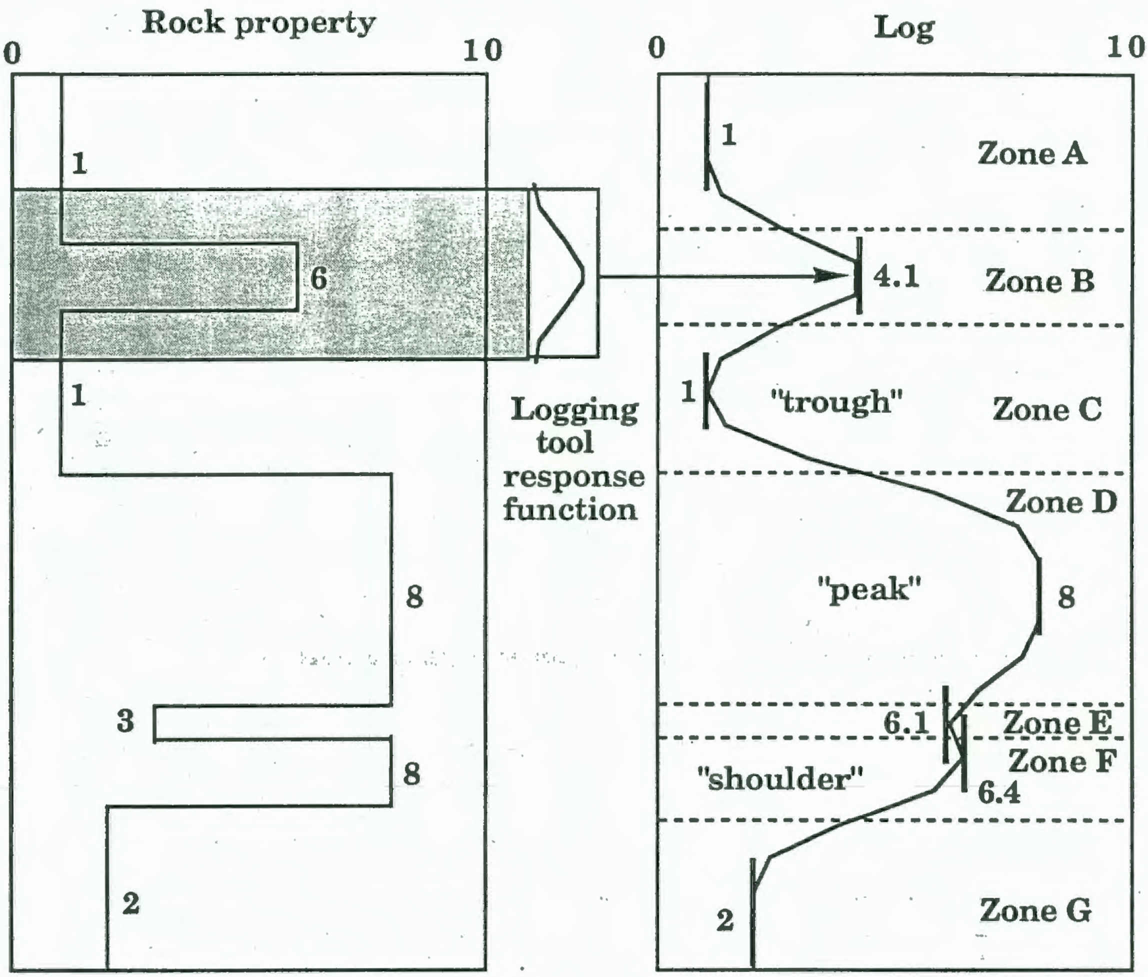

logging company
type of log
operator
well name
location
well information
Other surveys
well information
logging unit
personnel
remarks
equipment numbers
scales & curves
Track 1
Depth
Track 2
Track 3
main log section
scales & curves
repeat run
calibrations


multiconductor cable
sonde
Sensor 5
Sensor 4
Sensor 3
Sensor 2
Sensor 1
Total depth (TD)
Minimum Rat hole
Typical tool length is about 60 feet

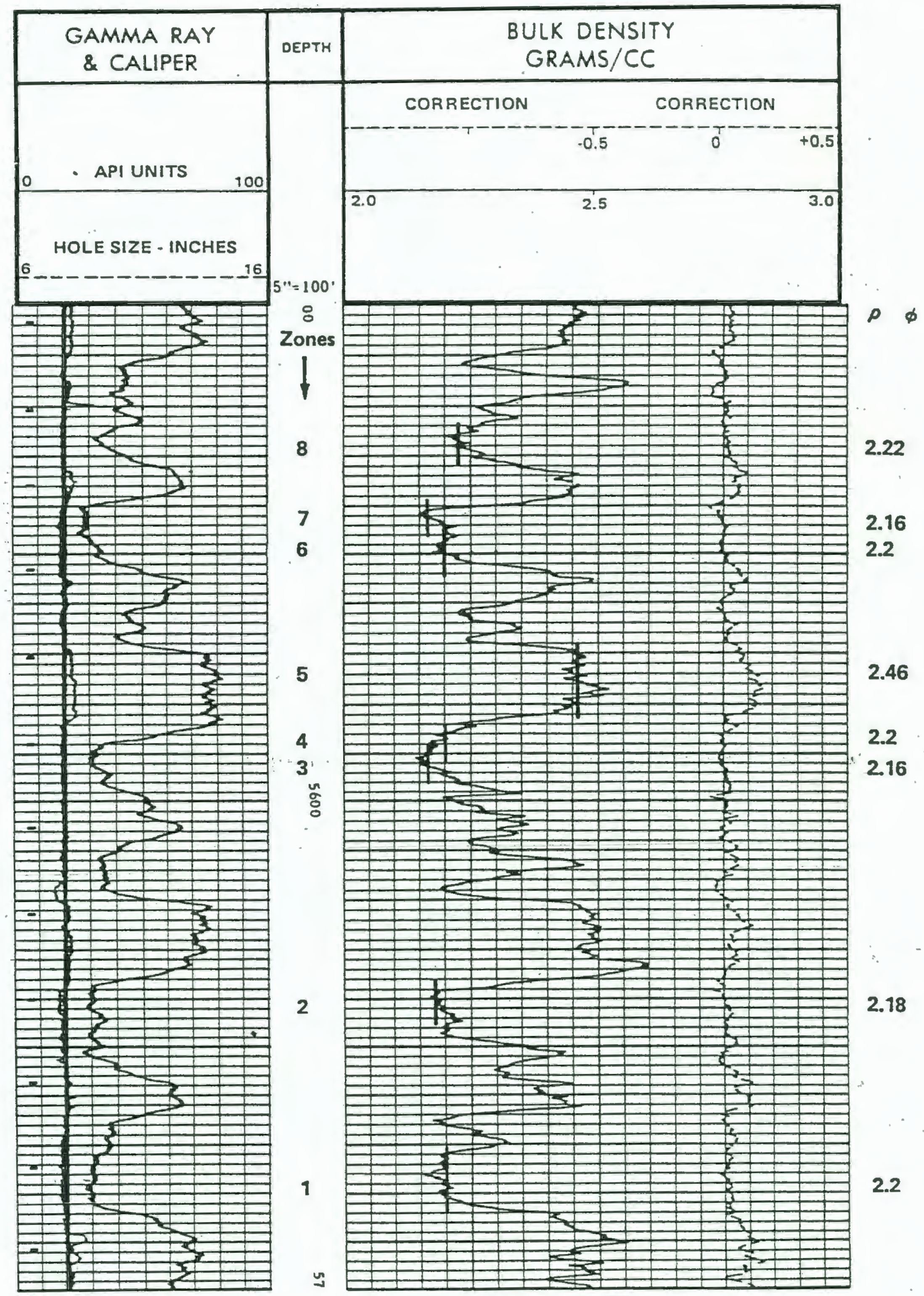

1000
100
10
1
0.1
Vertical resolution (inches)
Deep induction
Gamma ray
Sonic
Density
Deep laterolog
Neutron
Spherically focussed
Short normal
Electromagnetic propagation
Microspherically focussed
Microlog
0.1
1
10
100
1000
Radial investigation (inches)


shale
mudcake
flushed zone
transition zone
uninvaded zone
porous, permeable bed
mud
shale

Zonation

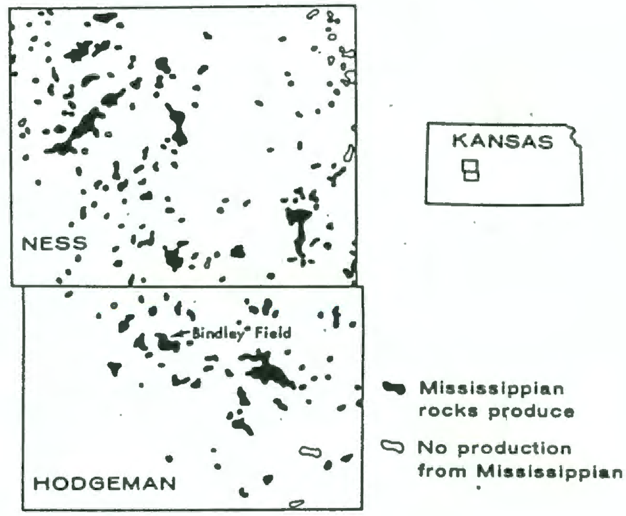


Rock property
0
10
1
6
1
8
3
8
2
Logging tool response function
Log
0
10
1
Zone A
4.1
Zone B
1
"trough"
Zone C
Zone D
"peak"
8
6.1
Zone E
Zone F
"shoulder"
6.4
2
Zone G

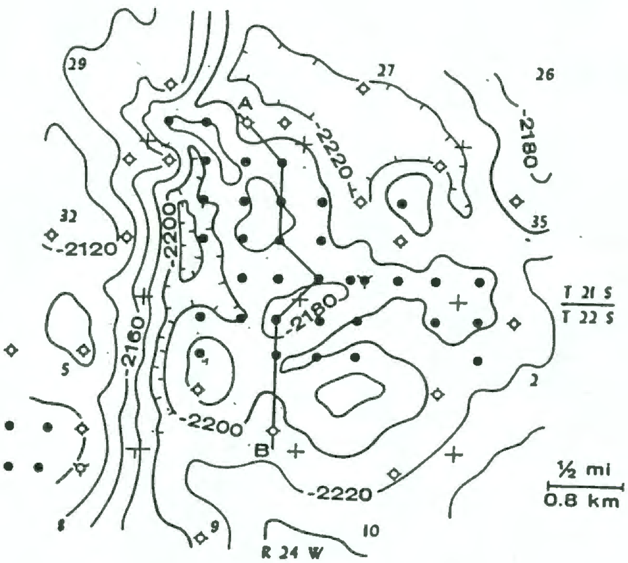


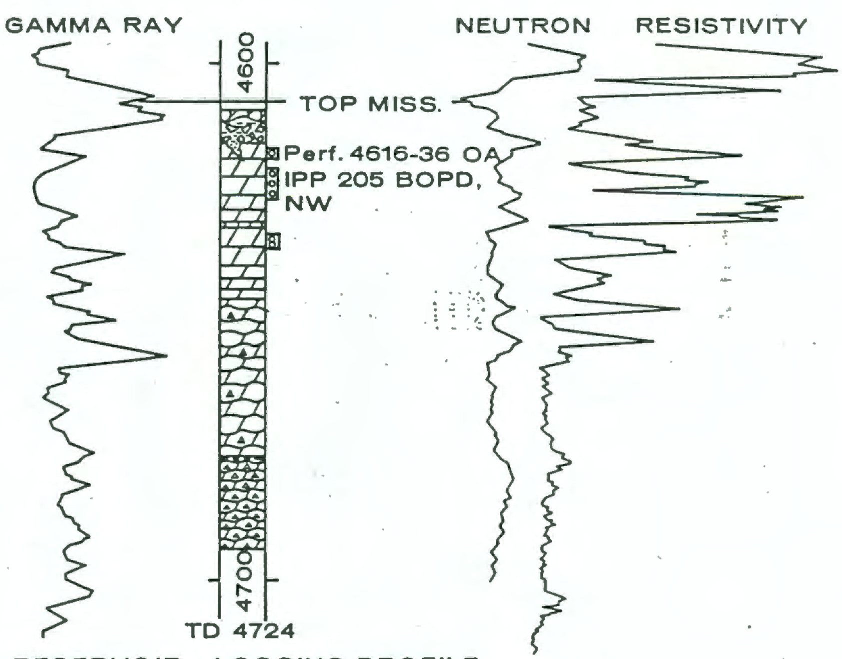
L. Cretaceous Sand. in Mississippi

(from Dresser Atlas manual)



Bindley Field





RESERVOIR - LOGGING PROFILE

Oasis Deutsch #1 C-NE-SE 33-21S-24W Hodgeman County, Kansas

	FORMATION WATER RESISTIVITIES			
	laboratory measurements of produced samples			
	MISSISSIPPIAN			
	Hodgeman County, Kansas			
	Location	Rw	RwT	
	Sec-T-R	ohm-m	deg F	
	24-22-24W	0.136	100	
	24-22-24W	0.180	77	
	25-22-24W	0.170	77	
	25-22-24W	0.168	77	
	25-22-24W	0.170	77	
	25-22-24W	0.166	77	
	3-24-24W	0.094	100	
				kgs

A KGS Water Resistivity Catalog of laboratory measurements of Hodgeman County Mississippian formation brines.

Rw = 0.17 ohm-m @ 77°F.

Well location:

Mean annual surface temperature (ST) of Hodgeman County (south-central Kansas) from the North American temperature map:
ST = 57 degrees Fahrenheit

From Header:

Total depth (TD) = 4723 feet
Bottom-Hole Temperature (BHT) = 117 degrees F

Formation :

Formation depth (FormD) = 4650 feet
Formation temperature of the Mississippian section (FormT) = 116 degrees F
Expected value of Rw in the Mississippian, using Arps' Formula: Rw = 0.116

ARCHIE EQUATION ESTIMATION OF WATER SATURATION

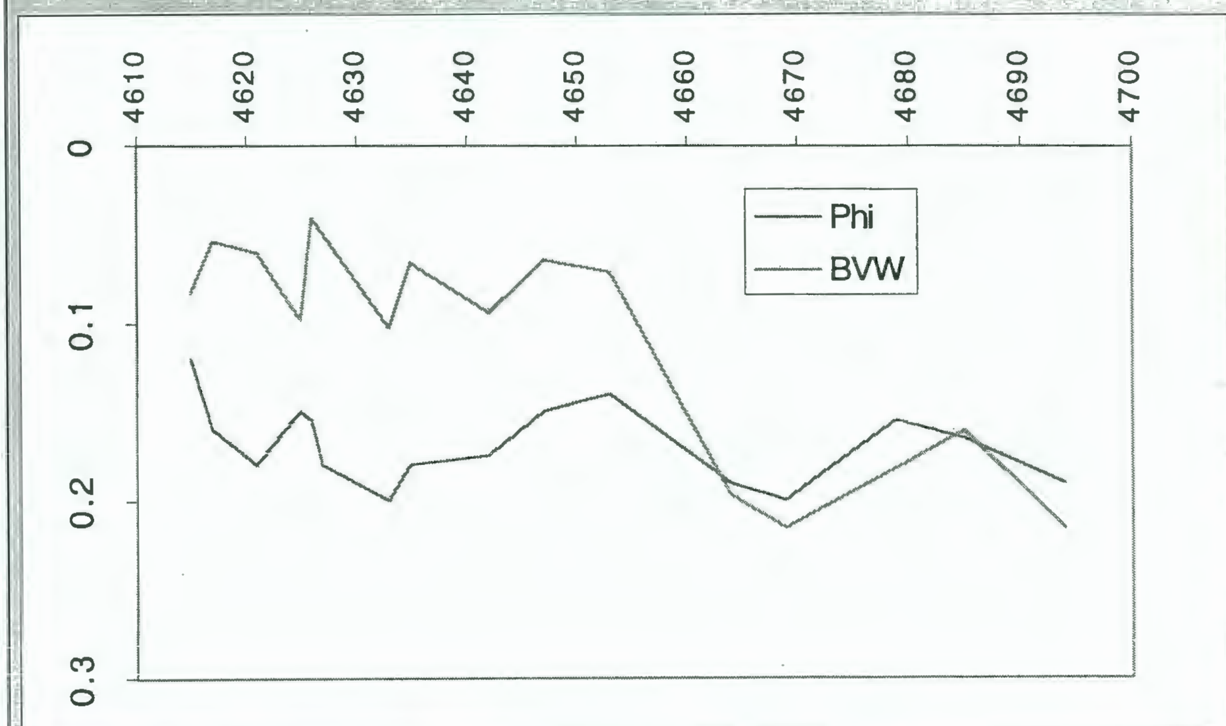
Well: Oasis Deutsch #1 C-NE-SE 33-21S-24W

Formation: Warsaw Formation (Mississippian)

Parameters

a	1
m	2
n	2
Rw	0.116

Depth	Phi	Rt	Sw	BVW
4615	0.12	17	0.69	0.08
4617	0.16	40	0.34	0.05
4621	0.18	32	0.33	0.06
4625	0.15	12	0.66	0.10
4626	0.155	70	0.26	0.04
4627	0.18	48	0.27	0.05
4633	0.2	11	0.51	0.10
4635	0.18	27	0.36	0.07
4642	0.175	13	0.54	0.09
4647	0.15	28	0.43	0.06
4653	0.14	23	0.51	0.07
4664	0.19	3	1.03	0.20
4669	0.2	2.5	1.08	0.22
4679	0.155	3.5	1.17	0.18
4685	0.165	4.5	0.97	0.16
4694	0.19	2.5	1.13	0.22

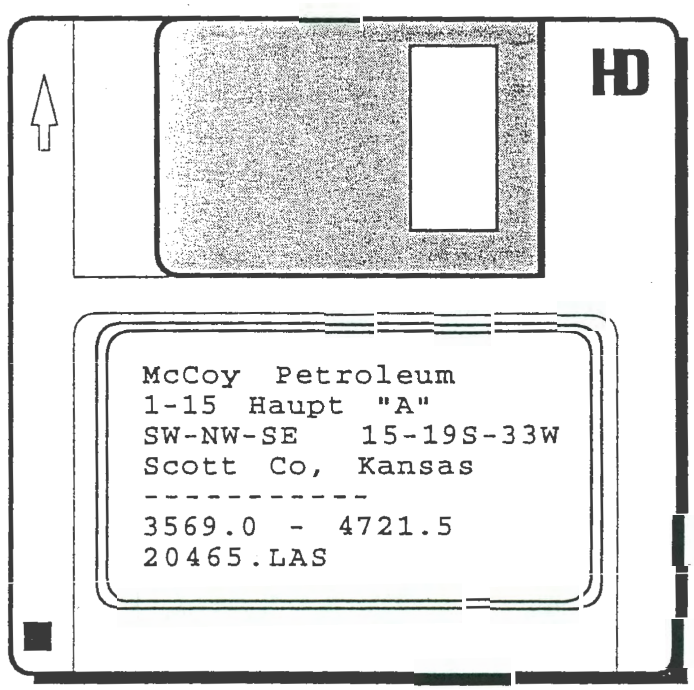


DIGITAL LOG DATA

Log analysis calculations used to be done mostly with slide-rules and charts (pre-1972), then with calculators, and now increasingly with computers. The digital data for computations are recorded by the logging truck and are made available either directly or from the logging company computer processing center. The data are stored either in binary format (LIS) on tapes, or in ASCII format (LAS) usually on floppy discs. LAS (**L**og **A**scii **S**tandard) is the more recent standard and was introduced by the Canadian Well Logging Society in the late 1980's. LIS (**L**og **I**nformation **S**tandard) tapes are often difficult to read, not only because of their binary code, but the variability in formatting styles. LAS files on floppy discs can be read by standard word-processing programs and LAS is ideal for PCs. Both forms conventionally list data at a rate of two readings per foot of hole for common log combinations which have vertical resolutions of 2 to 3 feet or greater. This frequency is fine enough to pick up the systematic features of the log curves without wasteful oversampling, but not so coarse as to cause "aliassing" problems.

Blue-line logs can also be digitized using relatively inexpensive hardware and software, or through the service of a digitizing company. Digitized logs for some areas are available for purchase over the Internet. In all cases, the most popular data format is LAS.

The header information and initial curve data are shown overleaf for a an extension well in the Hugoton North field of Scott County , Kansas. The data were read from an LAS file on the floppy disc pictured below, by a standard word processing program on a PC.



EVALUATION OF WATER SATURATION WHEN EITHER OR BOTH THE FORMATION WATER RESISTIVITY AND CONSTANTS OF THE ARCHIE EQUATION ARE KNOWN OR UNKNOWN

The procedure outlined by the preceding flow diagram and examples are predicated on a knowledge of both the formation water resistivity and the constants of the Archie equation. There are many occasions when either or both of these quantities are unknown. There will also be situations where, for example, the Humble form of the equation will not be deemed a satisfactory approximation for evaluation of relatively tight sandstones, or the "limestone" form of the equation adequate for certain carbonates. However, both water resistivity and an appropriate form of the Archie equation may be deduced from logs provided that some zones with 100% water saturation occur in the unit of interest. This is not usually a difficult stipulation to meet since many productive units will have a hydrocarbon/water contact separating the reservoir from a lower, water-saturated section. Failing this, an adjacent water-saturated unit of similar lithology and (hopefully) with similar water resistivity may be used as a surrogate for the critical zones. These critical water zones do not have to be recognized initially, but will manifest their presence (or absence) in the methods of analysis described in the following pages.

The log characteristics of a hypothetical "Oz Sandstone" (very loosely modeled after a generalized Rotliegendes Sandstone from the North Sea) are shown on the preceding page and procedures used for solving the unknowns together with water saturation are outlined using this as an example under the following conditions:

A. Both water resistivity and Archie equation constants are known.

B. Water resistivity is unknown, but Archie equation constants are known.

C. Water resistivity is known, but Archie equation constants are unknown.

or

Neither water resistivity nor Archie equation constants are known.

Note that an independent method for estimating the formation water resistivity using the SP log will be described in the SP section.

A. BOTH WATER RESISTIVITY AND ARCHIE EQUATION CONSTANTS ARE KNOWN

Laboratory measurements of Archie equation constants in Oz Sandstone samples determined a=1 and m=1.8

Then,

$$F = \frac{1}{\Phi^{1.8}}$$

The formation water resistivity, R_w was found to be 0.10 ohm-m at formation temperature.

Now, $F = Ro/Rw$

$I = Rt/Ro$

and $I = Sw^{-2}$

then, $$S_w = \sqrt{\frac{R_w}{R_t \Phi^{1.8}}}$$

ZONE	R_t	Φ%	S_w	S_h
A	39	24	0.18	0.82
B	31	10	0.45	0.55
C	36	20	0.22	0.78
D	30	20	0.25	0.75
E	19	22	0.28	0.72
F	9	18	0.49	0.51
G	2	19	1.00	0.00
H	1.5	23	0.97	0.03
I	4.0	12	1.07	-0.07
J	7	10	0.95	0.05

ZONE	R_t	Φ%	R_{wa}	S_w	Sh
A	39	24	2.988	0.18	0.82
B	31	10	0.491	0.45	0.55
C	36	20	1.987	0.22	0.78
D	30	20	1.656	0.25	0.75
E	19	22	1.245	0.28	0.72
F	9	18	0.411	0.49	0.51
G	2	19	0.101	1.00	0.00
H	1.5	23	0.106	0.97	0.03
I	4	12	0.088	1.07	-0.07
J	7	10	0.111	0.95	0.05

It is fairly obvious that the water zones are G, H, I and J. A representative value can be picked out by eye. Alternatively, a best estimate can be calculated following the work of Porter et al (1969) who pointed out that the square roots of Rw estimates should be normally distributed. The square root Rwa values of the four Oz Sandstone water zones are: 0.318, 0.326, 0.297, and 0.33. Their mean value is 0.318, from which it follows that the best estimate of Rw is 0.318^2, which is 0.10 ohm-m.

If a core- or log-based estimate of Archie m was not available, then the Humble equation could have been used as an estimator, since the Oz is a sandstone. In this case, the Rwa equation would be:

$$R_{wa} = R_t \Phi^{2.15} / 0.62$$

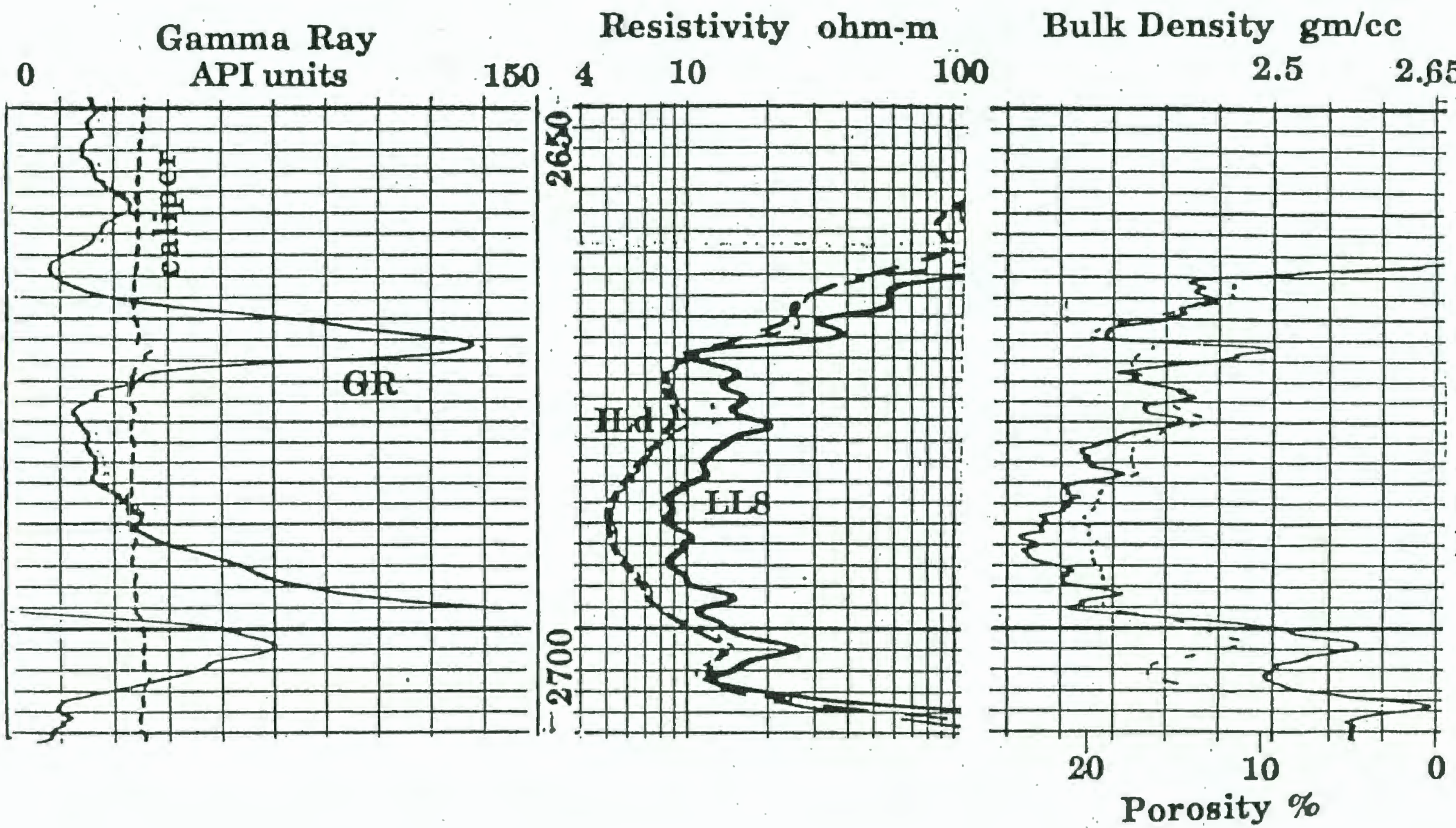
Calculations could be simplified by substituting the "Ridgefield equation", when:

$$R_{wa} = R_t \Phi^2 / 0.81$$

If the generic carbonate equation, $F=1/\Phi^2$ is used, then the Rwa formula is simply:

$$R_{wa} = R_t \Phi^2$$

Cities Service Beck #A-1 SW-SW-SE 14-5S-12E Nemaha Co., Kansas
St. Peter Sandstone (Middle Ordovician)



C. WATER RESISTIVITY AND/OR ARCHIE EQUATION CONSTANTS ARE KNOWN OR UNKNOWN

The most commonly used technique for this situation is a graphical procedure which is another type of resistivity/porosity crossplot, generally known as the "Pickett Plot" (named after Dick Pickett of the Colorado School of Mines). Either the specific form of the Archie equation ($F = 1/\Phi^m$) or the general form ($F = a/\Phi^m$) may be assumed The equations underlying the crossplot are then very simple to derive.

Now,

$$F = R_o/R_w = a/\Phi^m$$

Therefore,

$$\log R_o = \log aR_w - m \log \Phi$$

Since R_w, a and m are effectively constant within any one unit, this equation defines a straight line relationship between the variables log Ro and log Φ The slope of the line is -m and its intercept is log aRw at log $\Phi = 0$ (corresponding to a porosity of 100%). If a is considered to be equal to unity, then this intercept corresponds to the formation water resistivity The sloping line is the water line. If the vertical axis is the logarithm of the porosity and the horizontal axis is the logarithm of resistivity, the water line will slope from north-west to south-east. Hydrocarbon zones will be scattered as points to the north-east of this line.

These general properties allow the use of a "pattern recognition" approach to be applied to the crossplot of resistivities and porosities on conventional log-log graph paper. Water zones should tend to impinge on a linear "barrier" to the south-west with the remainder of zones in the north-east. A sketch of this water line allows the definition of m and R_w (or aRw) Lines which correspond to different hydrocarbon saturations may be added very easily and will be parallel to the water line since:

$$I = S_w^{-2}$$

and $$I = R_t/R_o$$

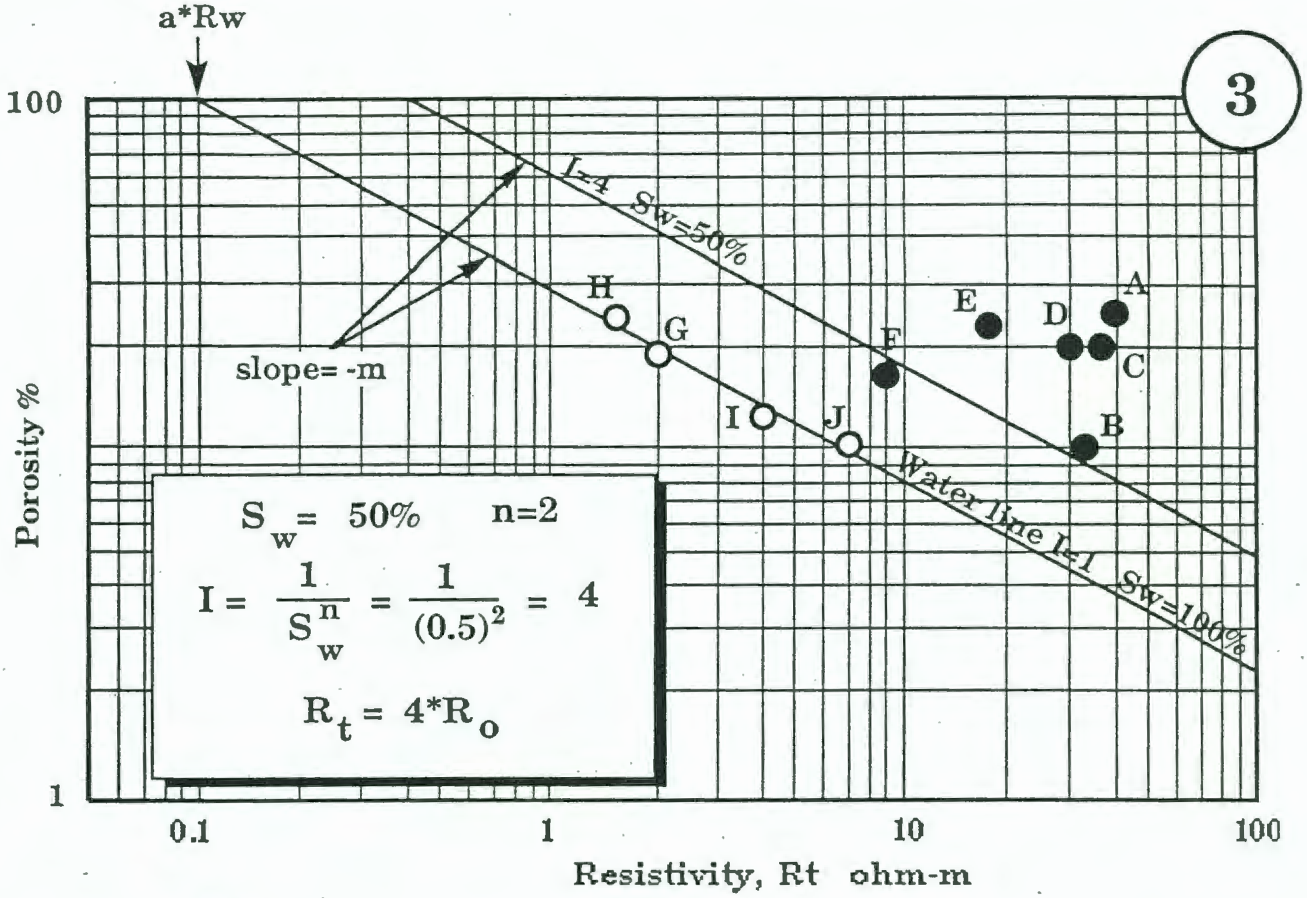
Therefore,

$$\log R_t = \log I + \log R_o$$

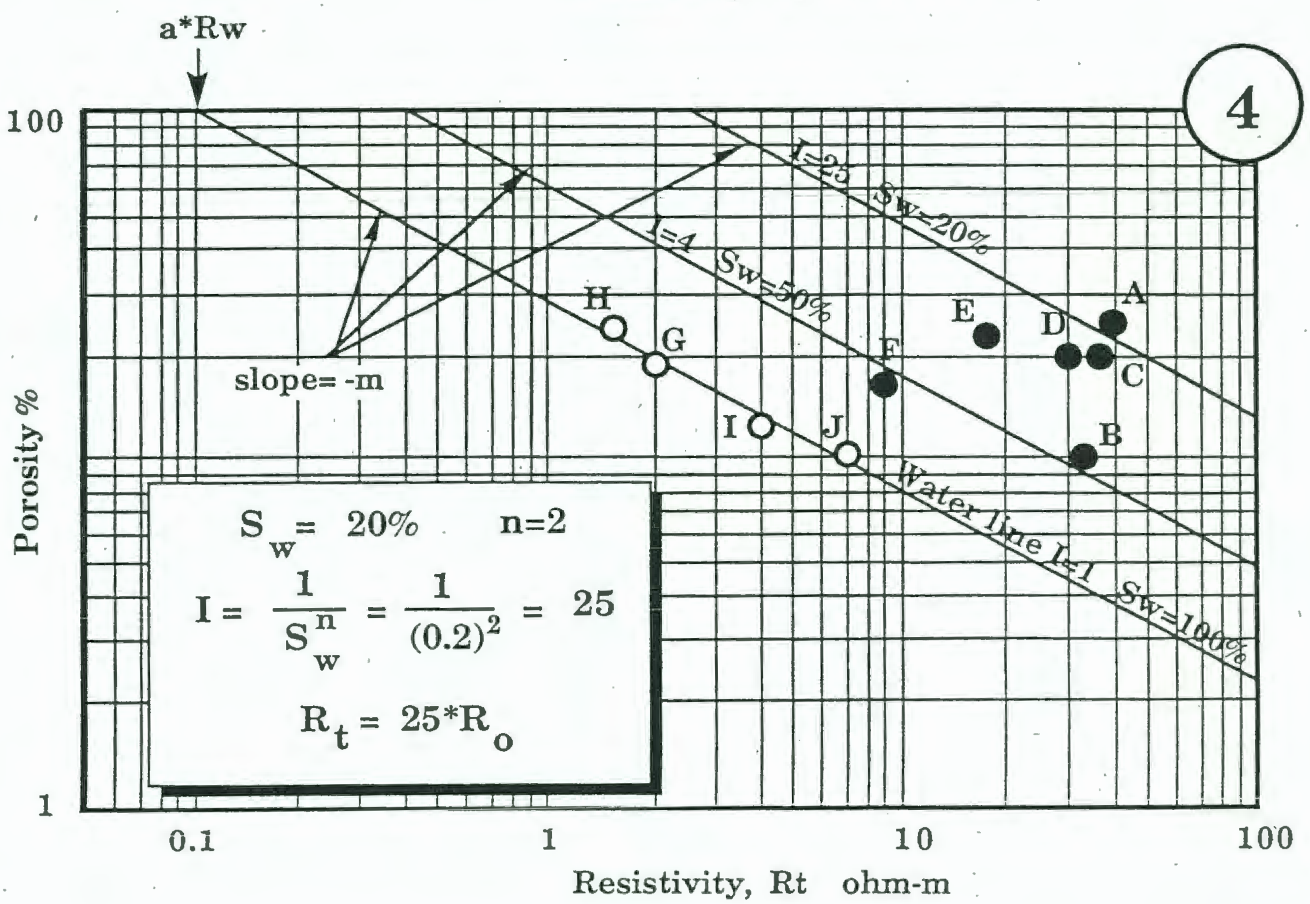
$$= \log I + \log aR_w - m \log \Phi$$

- #4: The operation of #3 is repeated with the addition of a water saturation line for 20% Sw. In this case, the resistivity index, I=25 i.e. Rt=25*Ro. The lines are drawn easily:
  (i) take an arbitrary porosity, Φ, and locate the value of Ro on the water line,
  (ii) multiply Ro by I to find Rt
  (iii) locate the point Φ, Rt and draw a line through this point parallel to the water line
  (iv) the new line is the contour of water saturation that corresponds to the value of I that is used.

Notice that the Pickett plot method does not actually require a computation of either a, m, or Rw. Once the water line is located, other water saturation lines can be drawn (assuming n is known, but n is usually taken to be 2) and then water saturation values for any zone can be read from interpolation between the water saturation lines.



3
a*Rw
100
1
0.1
1
10
100
Porosity %
Resistivity, Rt ohm-m
slope= -m
I=4 Sw=50%
Water line I=1 Sw=100%
A
B
C
D
E
F
G
H
I
J
S w = 50% n=2
I = 1/S w n = 1/(0.5)2 = 4
R t = 4*R o



4
a*Rw
100
1
0.1
1
10
100
Porosity %
Resistivity, Rt ohm-m
slope= -m
I=25 Sw=20%
I=4 Sw=50%
Water line I=1 Sw=100%
A
B
C
D
E
F
G
H
I
J
S w = 20% n=2
I = 1/S w n = 1/(0.2)2 = 25
R t = 25*R o

.:/FWC

STATE KANSAS 3-1-67 MAP NO. S-T-R 14-5S-12E WF

OPER CITIES SERVICE Oil SPOT SW SE SE INIT

700 SUTTON PLACE, WICHITA, KS 67202 CO NEMAHA WFD

WELL # 1 BECK "A" Disc ELEV 1278 KB, 1274 GR FIN

CONTR MENDENHALL DRLG CORNING

FIELD WC - 19 MI SW STRAHM (HUNT-VI)

IP IPP 65 BOPD + 11 BWPD (VI) 2462-72

API 15-131-20010 FR 11-30-77

SPUD 12-26-77, 8 5/8" @ 257 w/180

DST 1 (CHER) 1510-71, op20, si45, op30, si60, Rec 240' Mud + 240' SW, ISIP 433, FP 20-134/134-227, FSIP 483

DST 2 (HUNT) 1831-85, op45, si60, op30, si60, Rec 70' Mud, ISIP 516, FP 10-21/21-21, FSIP 516

DST 3 (VI) 2456-69, op30, si60, op30, si60, Rec 5' Oil, 55' SOCM, ISIP 820, FP 10-20/20-31, FSIP 820

DST 4 (VI) 2469-79, op30, si60, op30, si60, No Rec, ISIP 42, FP 10-10/10-10, FSIP 31

DST 5 (SP) 2636-54, op30, si45, op30, si60, No Rec, All Press 6

DST 6 (SP) 2662-72, op15, si45, op15, si45, Rec 1160' Sulph Wtr, ISIP 948, FP 31-275/257-487, FSIP 938

RTD 2755, log, 5½" @ 2573

Perf (VI) 21/2462-72, 500 Gal A, Rec load, Swbd 41 BO + 5 BW/7 hrs, P 99 BO + 18 BW/24 hrs

IPP 65 BOPD + 11 BWPD, VIOLA 2462-72

COMPLETED 2-22-78

KB LOG TOPS:

LANSING	982 + 296
KANSAS CITY	1023 + 255
PLEASANT	1245 + 33
MARMATON	1280 - 2
CHEROKEE	1409 - 131
MISS	1604 - 326
KINDERHOOK	1654 - 376
HUNTON	1832 - 554
MAQUOKETA	2400 - 1122
VIOLA	2448 - 1170
SIMPSON	2567 - 1289
PRE-CAMBRIAN	2708 - 1430
RTD	2755 - 1477
LTD	2757 - 1479

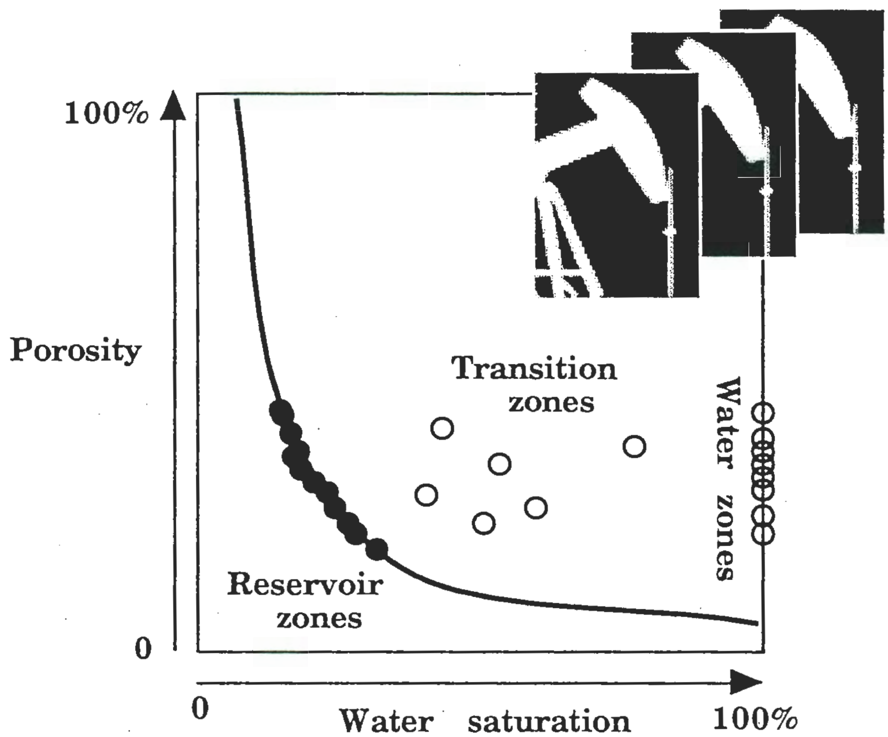
(PI) Petroleum Information

TD IN PRE-CAMBRIAN

COMP ISSUED 3-6-78

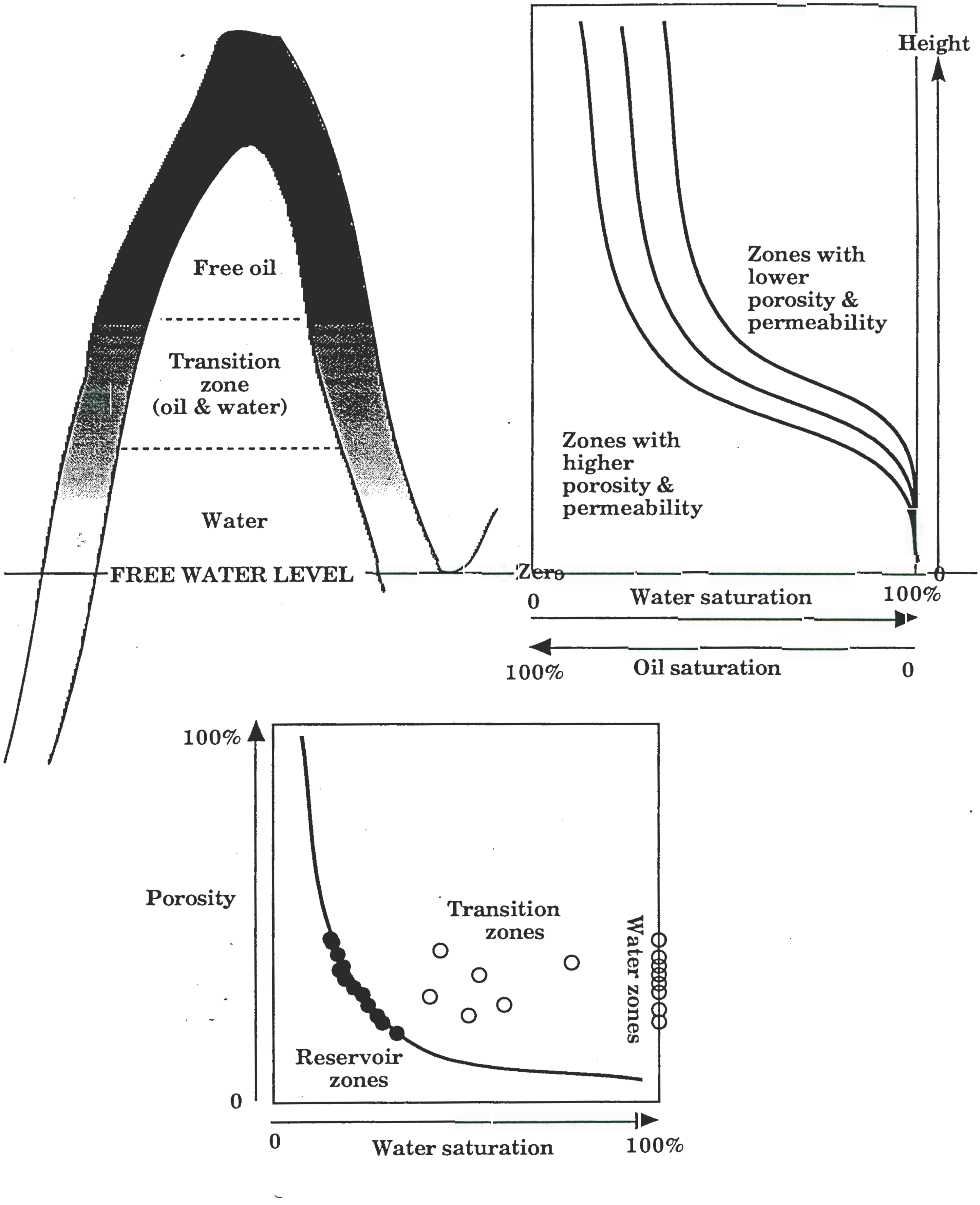
VIOLA - UNNAMED FIELD - DISCOVERY

Fluid production and permeability

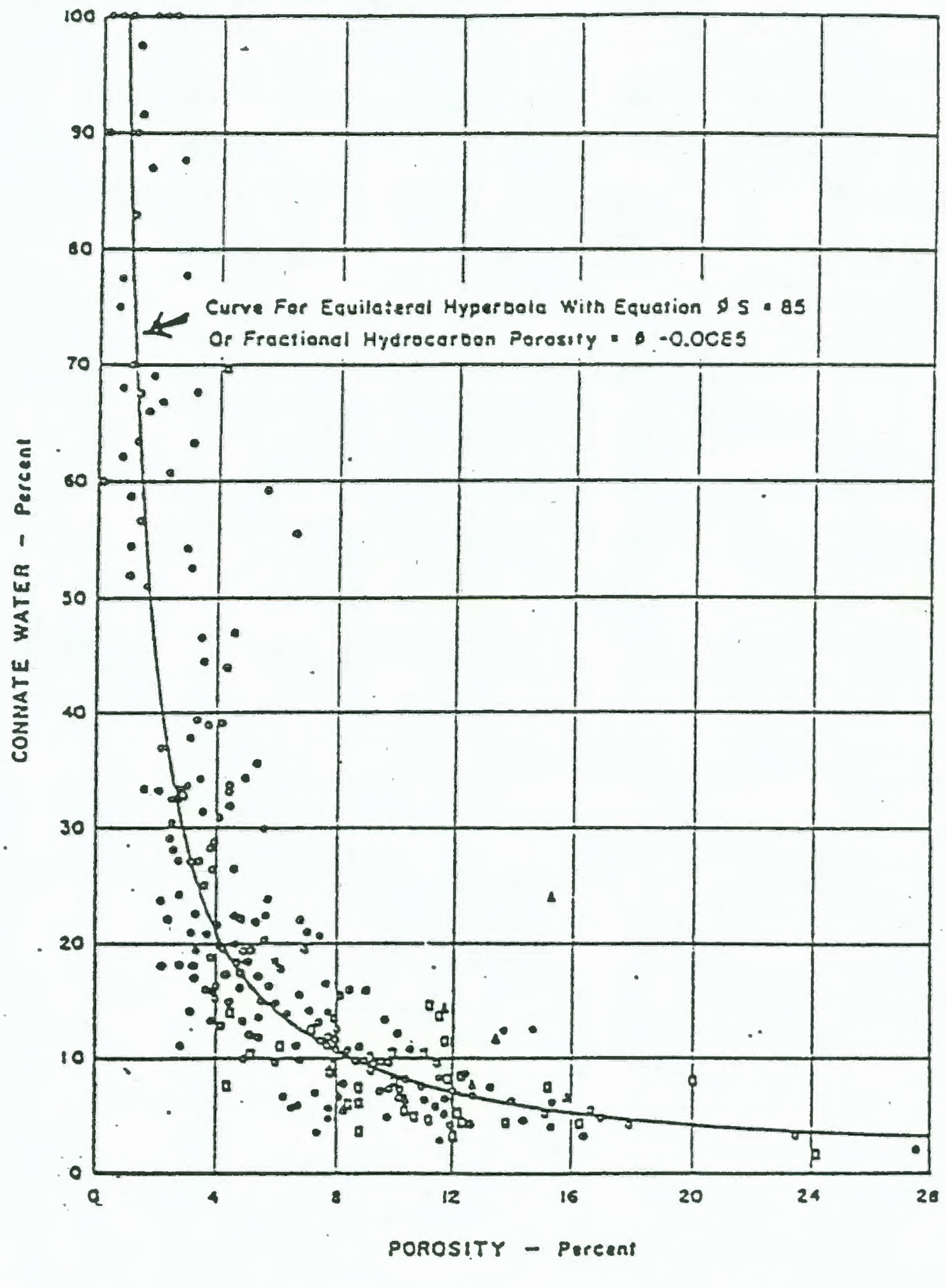


DEDUCTION OF FLUID PRODUCTION FROM THE BULK VOLUME WATER (BVW)

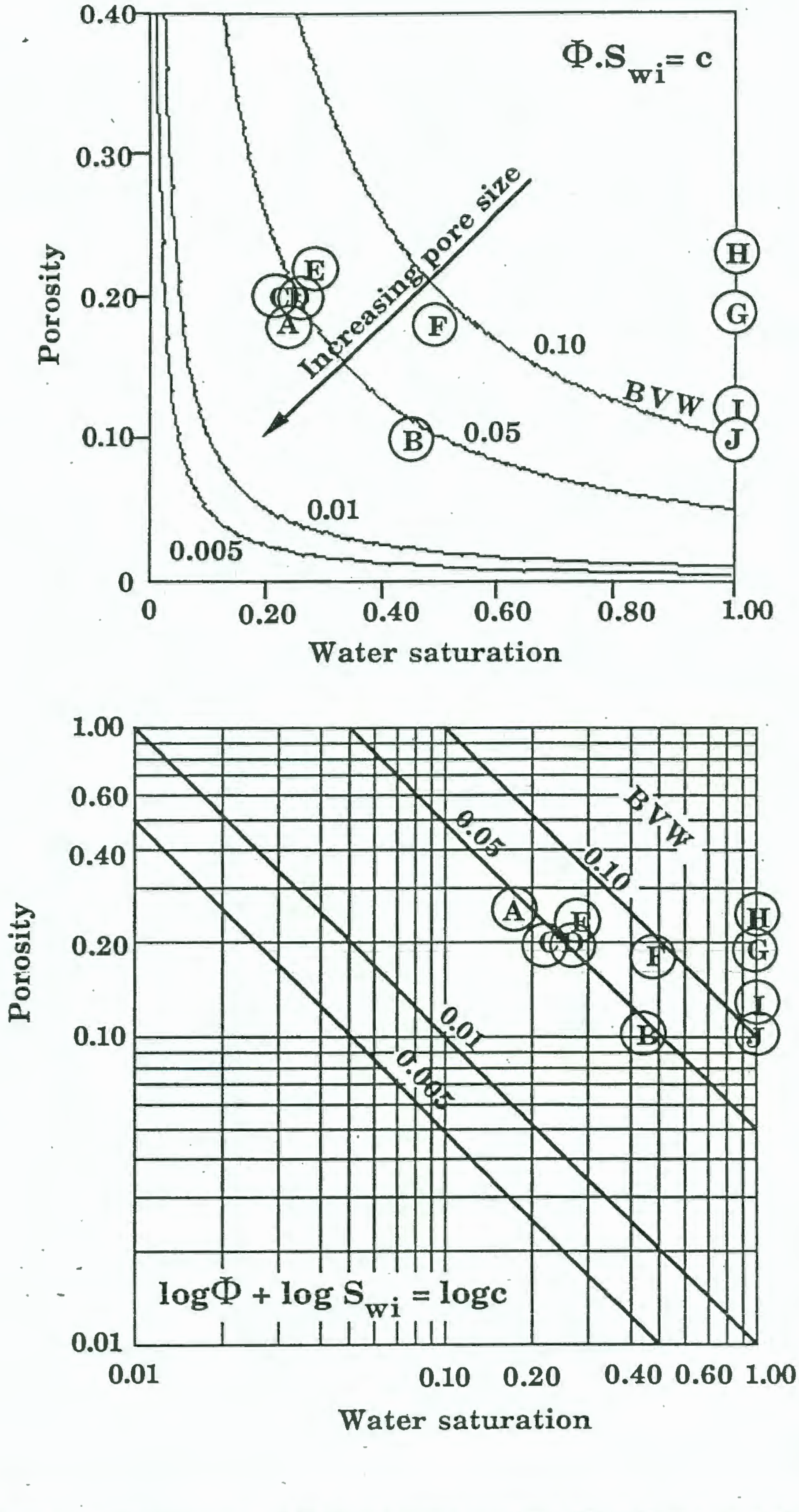
Knowledge of the porosity and water saturation of a zone is often not sufficient to determine whether the zone will produce hydrocarbons, water, or hydrocarbon-cut water. Even if hydrocarbons are produced on a test, will they prove to be economic? Although local rules-of-thumb concerning porosity and water saturation cut-offs are often quite satisfactory, there are numerous instances of zones with high water saturations that produce water-free hydrocarbons and others with low water saturations that produce high water cuts. For many years it has been known that the product of porosity and water saturation (known as the bulk volume of water, BVW, can give important clues to producibility when related to pore character and reservoir type.



Generalized reservoir profile with matched water saturation-height plot and porosity-water saturation crossplot.



Saturation - porosity relationship of the Leduc-Woodbend D-2 "A" Pool (Buckles, 1965).

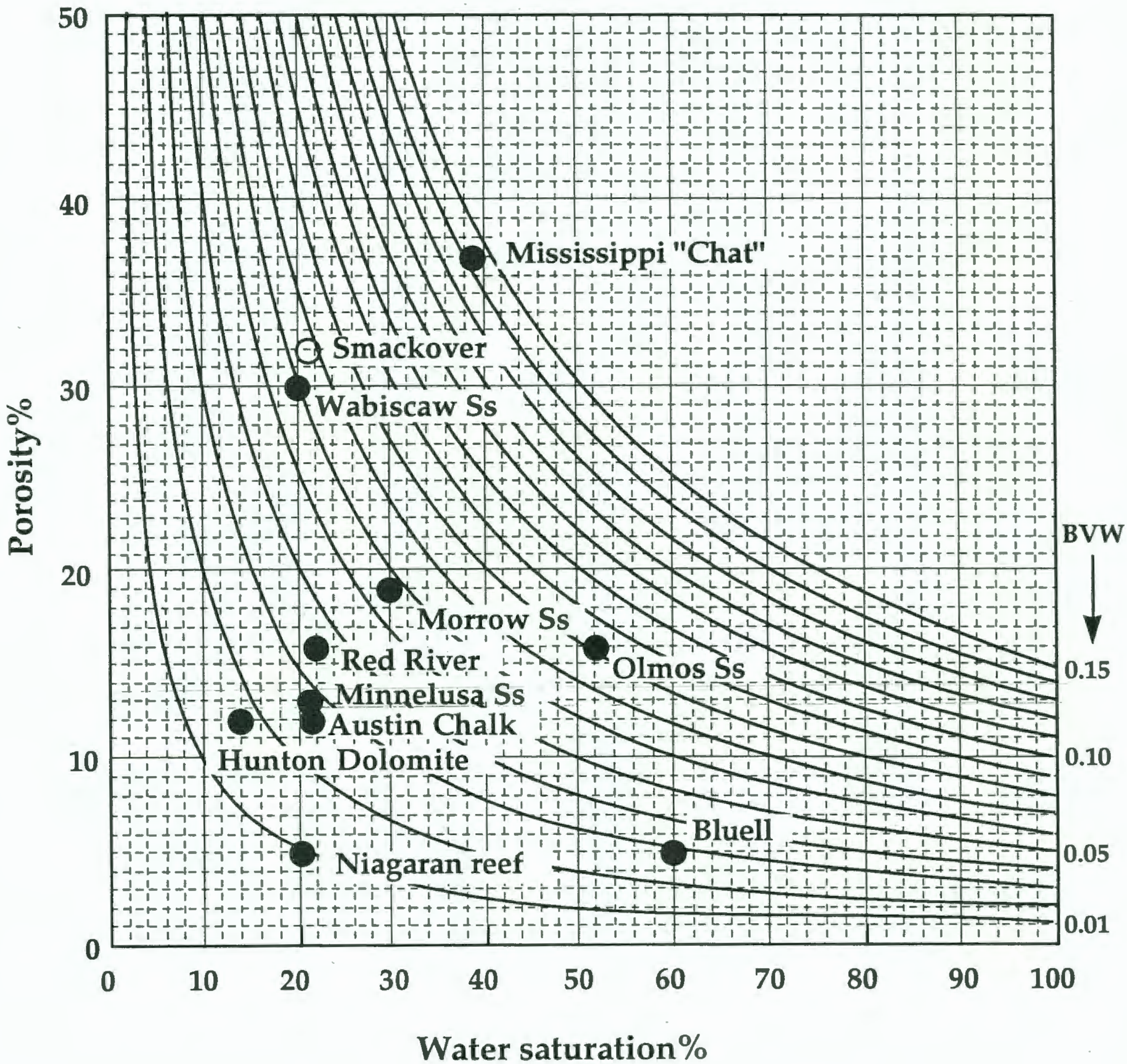


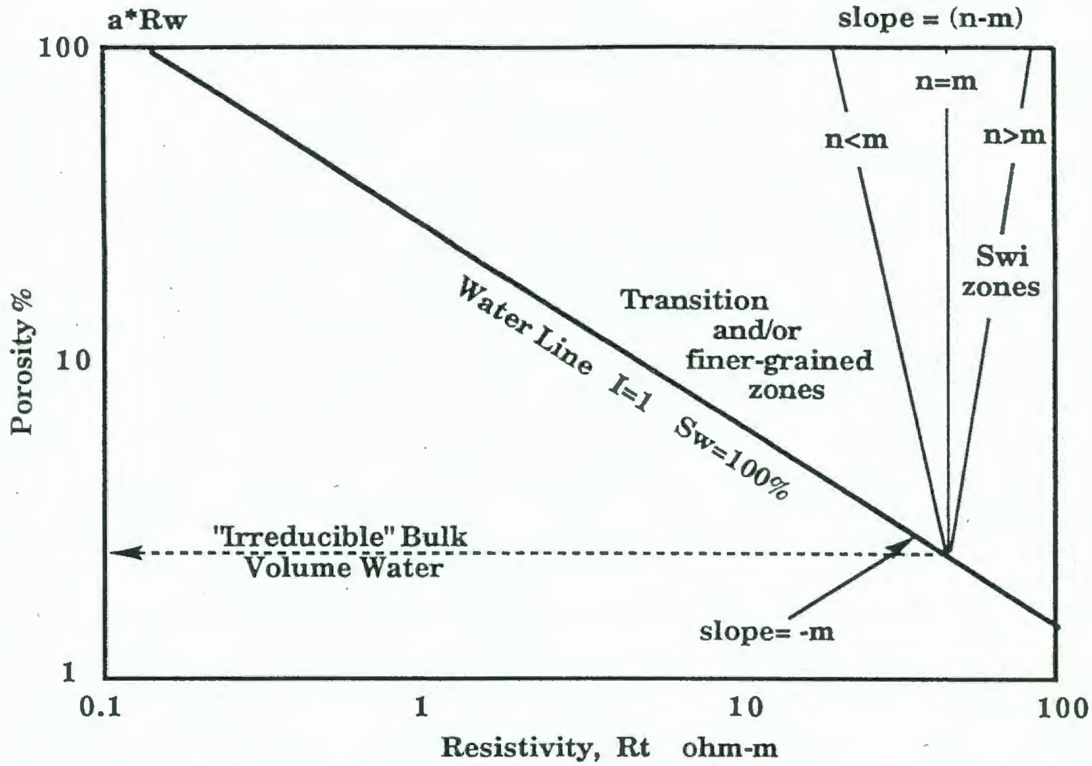
Buckles plots: Contours of bulk volume water (BVW) on graphs of water saturation versus porosity,arithmetically scaled (above) and logarithmically -scaled (below). Zones A-J are from the Rottweiler Sandstone.

	RESERVOIR	CRITICAL BVW
PERMIAN	Chase Group	
	Herington	.03-.06
	Krider	.035-.045
	Winfield	.04-.06
	Towanda	.045-.055
	Fort Riley	.05-.07
PENNSYLVANIAN	Toronto	.035
	Lansing	
	Uplift	.02-.03
	Hugoton Basin	
	Oolicastic	.04-.05
	Intergranular	.08
	Kansas City	
	Oolicastic	.02-.045
	Intergranular	.05-.08
	Marmaton	.038-.045
	Morrow	
	Clean	.01-.04
	Clay-filled	.05-.15
MISSISSIPPIAN	Dolomite	.02-.04
	"Chat"	
	Macroporosity	.06-.085
	Microporosity	.15-.25
	St.Louis	.04-.065

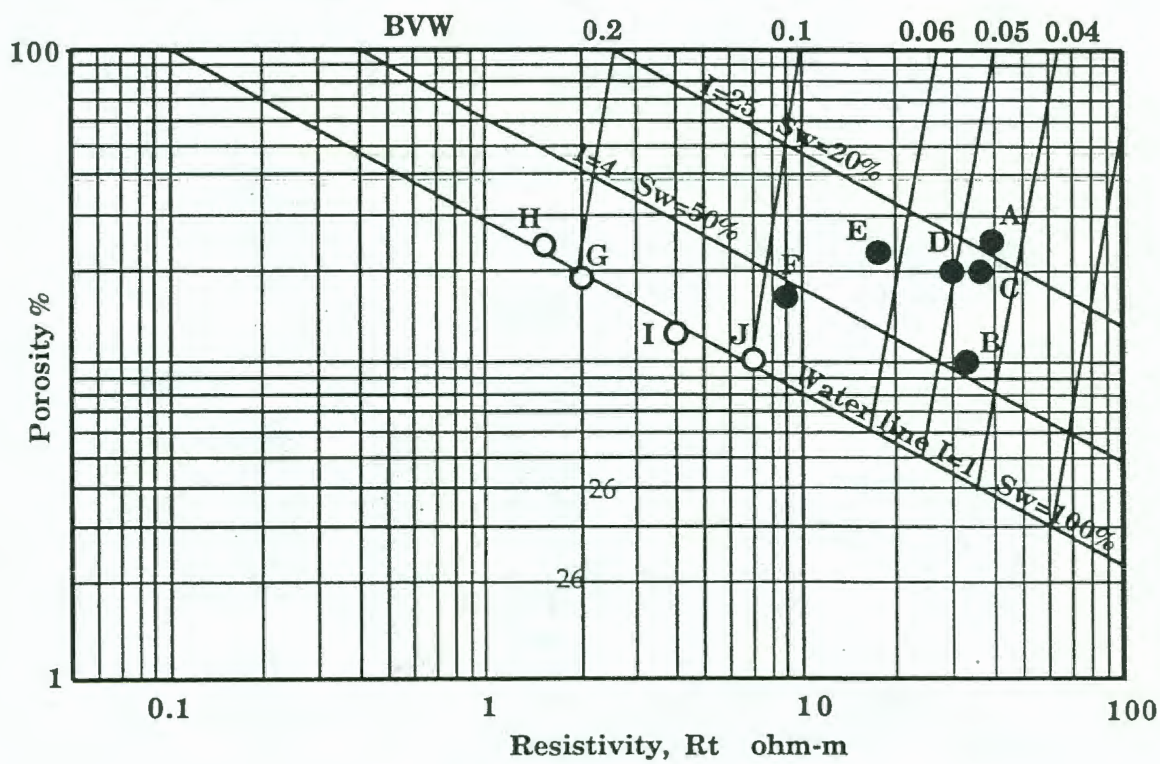
Bill Guy's critical BVWs in Kansas: Typical values for reservoir formations as "rule-of-thumb" ranges based on extensive field experience.

BUCKLES PLOT

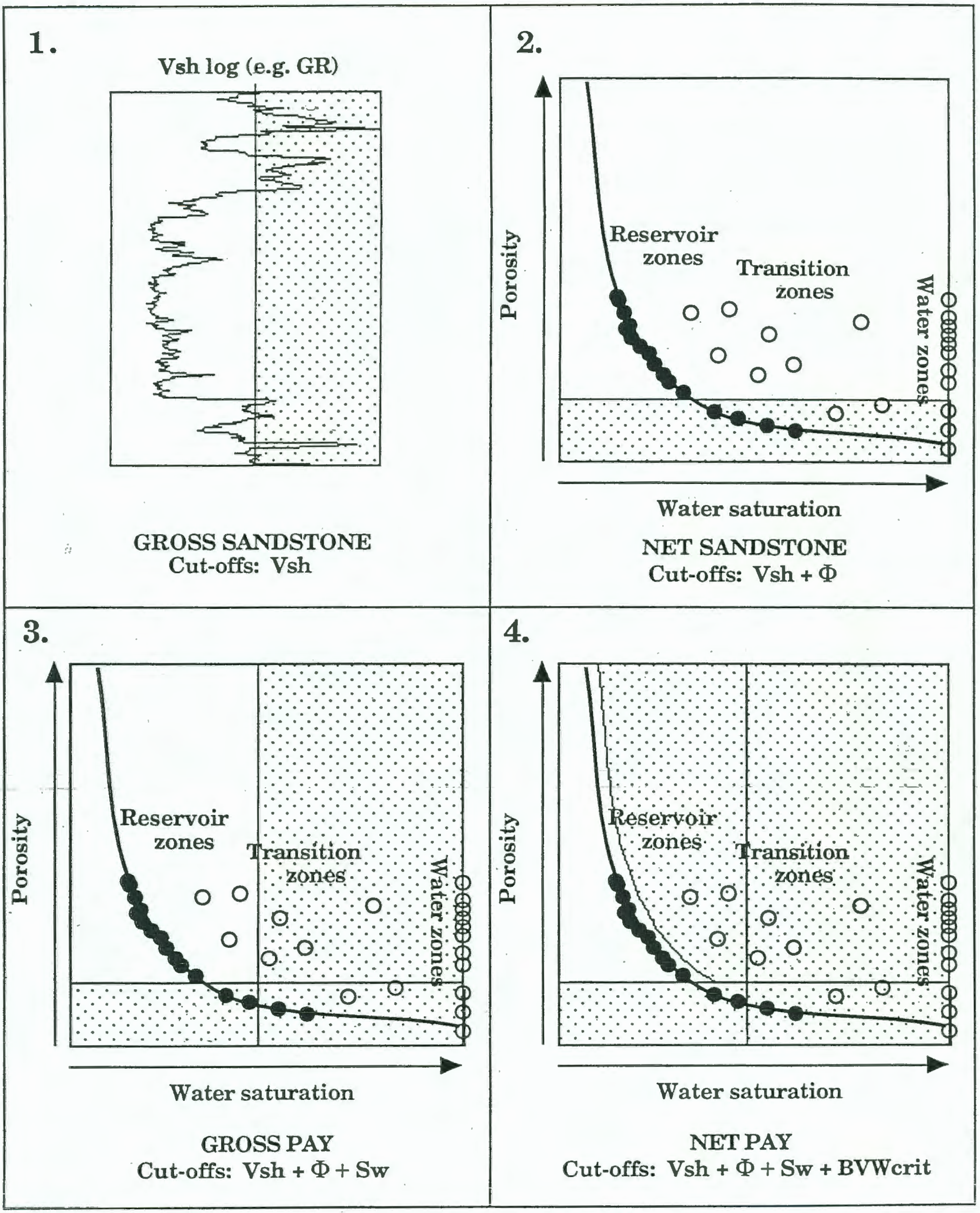




Location of an irreducible bulk volume water (Buckles number) trend on Pickett plot. Notice that any BVW line will intersect the water line at a porosity value equal to the BVW value. It will also cross the 100% porosity limit at a water saturation value equal to the BVW value.



Location of BVW (Bulk Volume Water) lines on the Pickett plot of "Oz" Sandstone data.

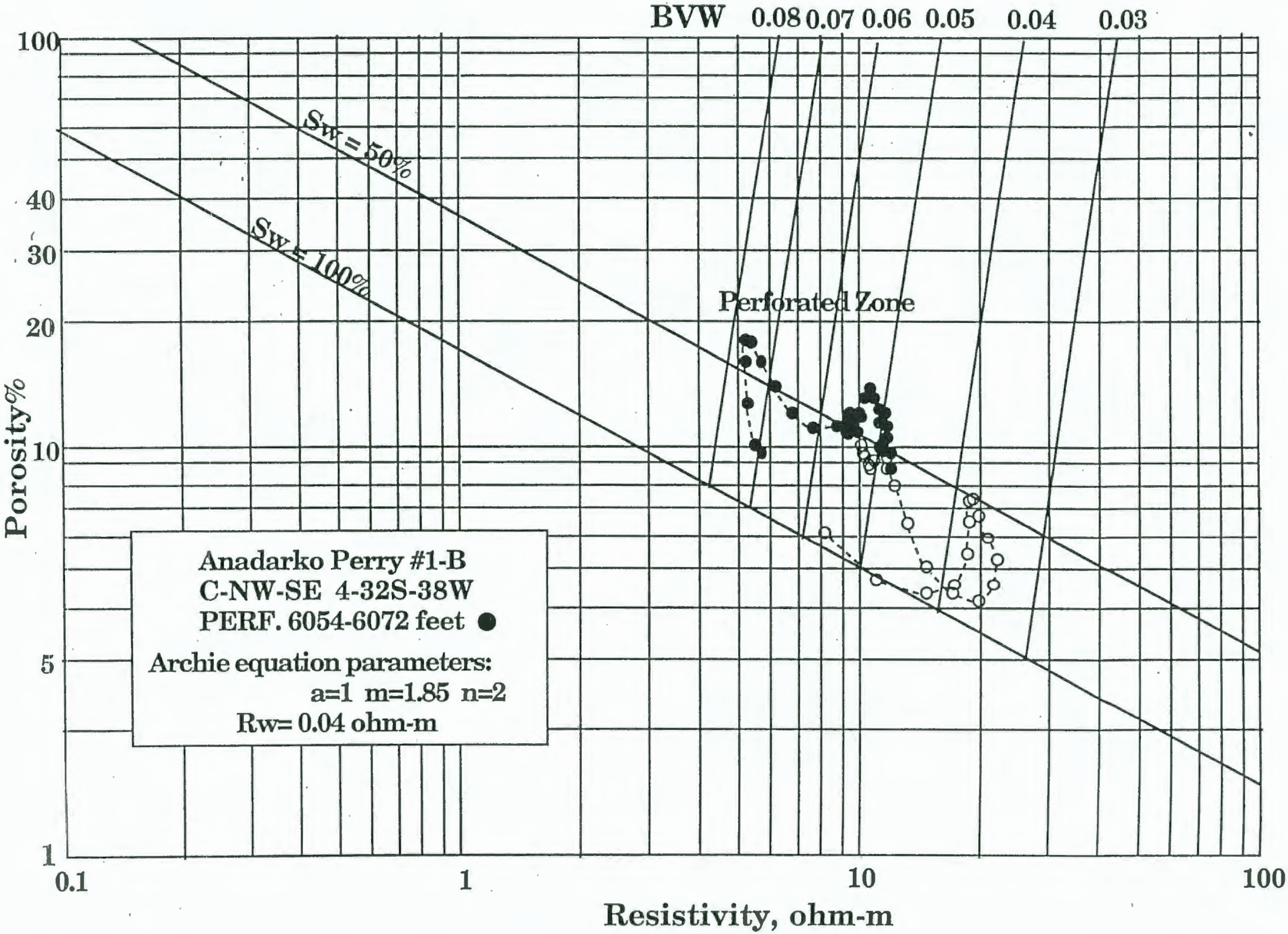


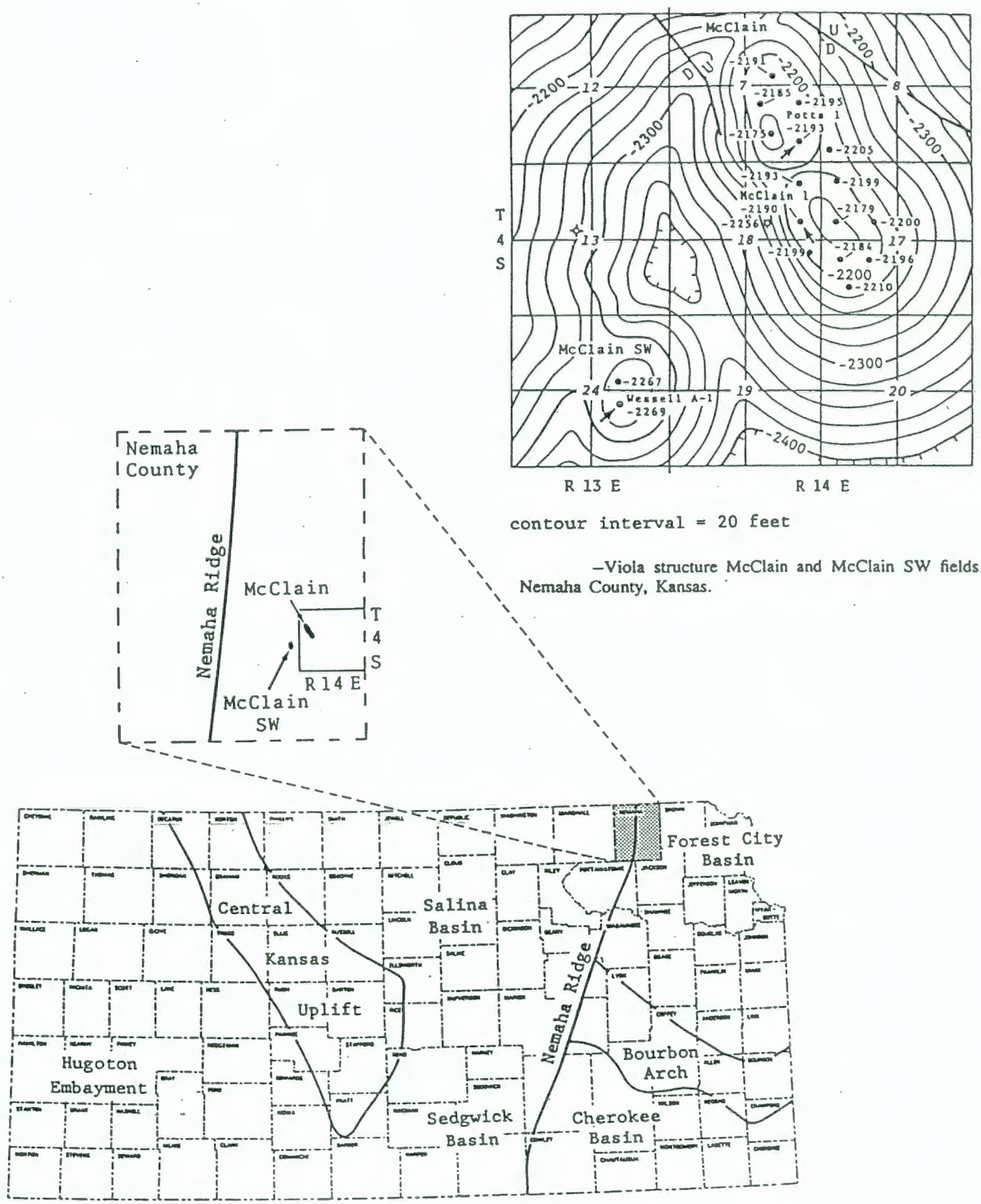
HIERARCHY OF CUT-OFF METHODOLOGY USED FOR
NET PAY DETERMINATION IN A SANDSTONE RESERVOIR

PICKETT PLOT CASE STUDIES

Because the Pickett plot shows variation of porosity and resistivity simultaneously, detailed interpretations of reservoir structure are easier to make than when looking at the individual logs alone. A good example is shown overleaf for a gas well that produced from a Pennsylvanian Morrow Sandstone unit in the Gentzler field of Kansas. A casual glance at the resistivity log might suggest a productive zone at the top of the unit (6040-6048), with a transition zone below. However the density log shows that at least some of the resistivity increase at the top is caused by the marked drop in porosity. In fact, the upper zone is a sandy limestone that overlies a calcareous sandstone (as shown by the photoelectric, Pe curve).

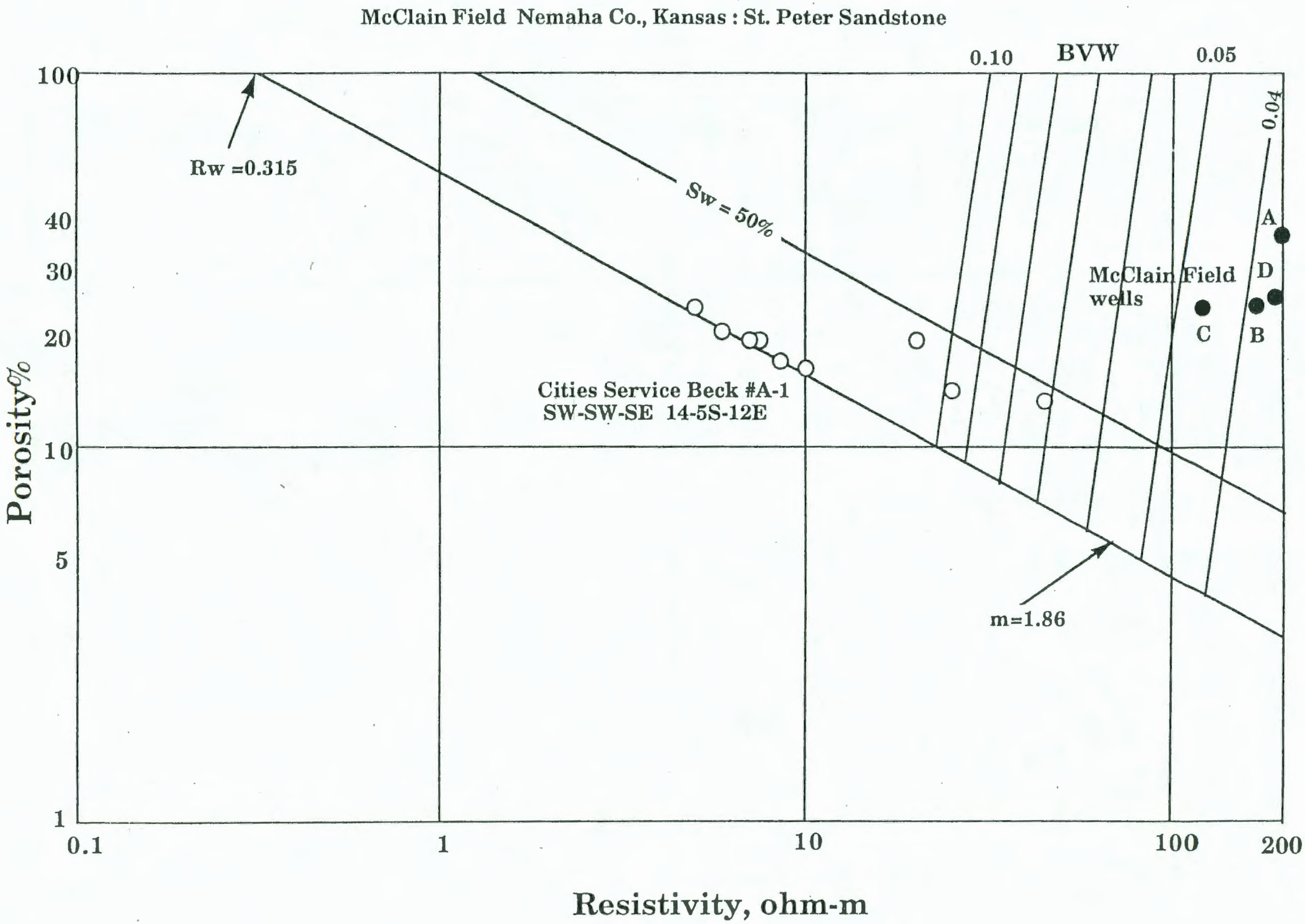
Vertical changes in the reservoir can be interpreted when the digitized logs are marked on a Pickett plot as zones and linked by lines ordered by depth. The sandy limestone at the top has porosity values generally less than 8% and water saturations in excess of 50%. The BVW values of 0.035 suggest that the limestone is at irreducible water saturation, although the low porosity probably causes poor permeability, so that the interval was not perforated as pay. Below the limestone, porosities increase to values above 10% and water saturation drops below 50% within the sandstone. A cluster of plotted zones that "hang" at a BVW of about 0.05 suggests they are at irreducible saturation. Notice that interval 6058-6065 has lower BVW values than the upper sandstone and indicates an overall increase in pore size. The lower part of the sandstone shows points trailing towards higher porosities, but lower resistivities. The pattern either reflects a trend to finer-pored sandstones towards the base of the unit, or a transition profile.


BVW 0.08 0.07 0.06 0.05 0.04 0.03
100
40
30
20
10
5
1
Porosity%
Sw = 50%
Sw = 100%
Perforated Zone
Anadarko Perry #1-B
C-NW-SE 4-32S-38W
PERF. 6054-6072 feet ●
Archie equation parameters:
a=1 m=1.85 n=2
Rw= 0.04 ohm-m
0.1
1
10
100
Resistivity, ohm-m

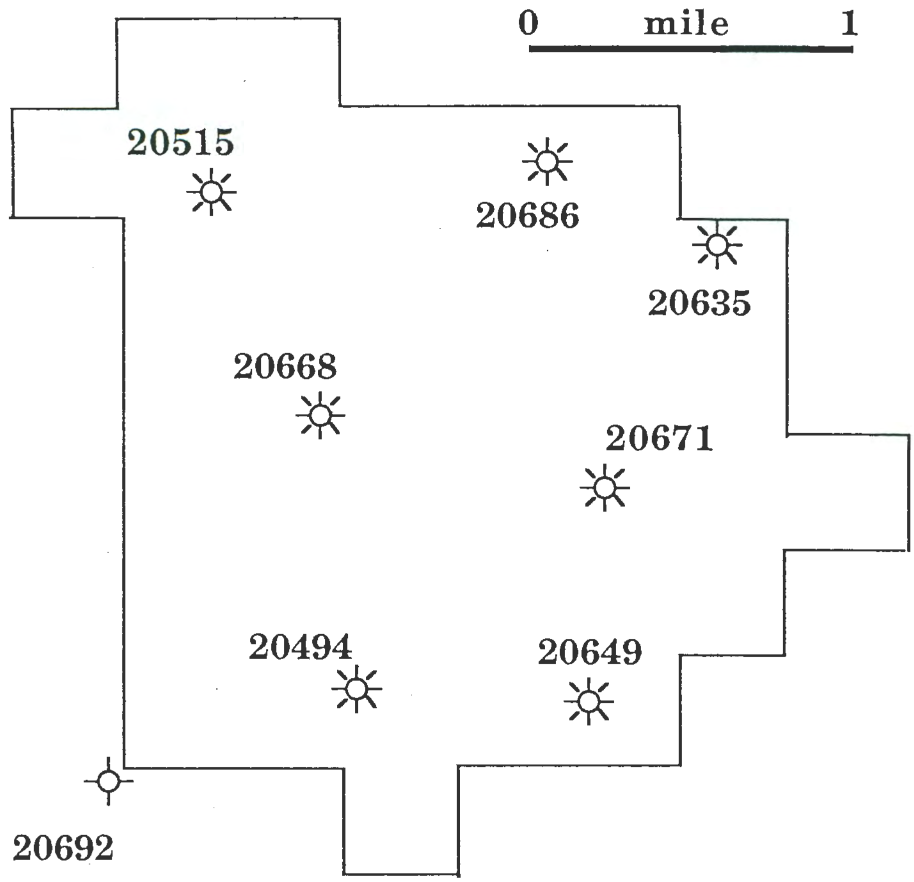


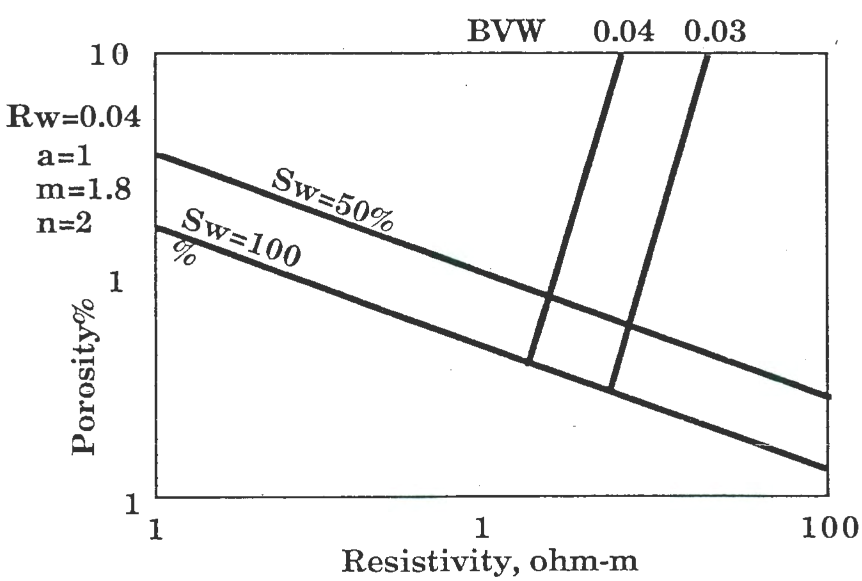
—Viola structure McClain and McClain SW fields, Nemaha County, Kansas.

Location of the McClain field
(from Caldwell and Boeken, 1985)

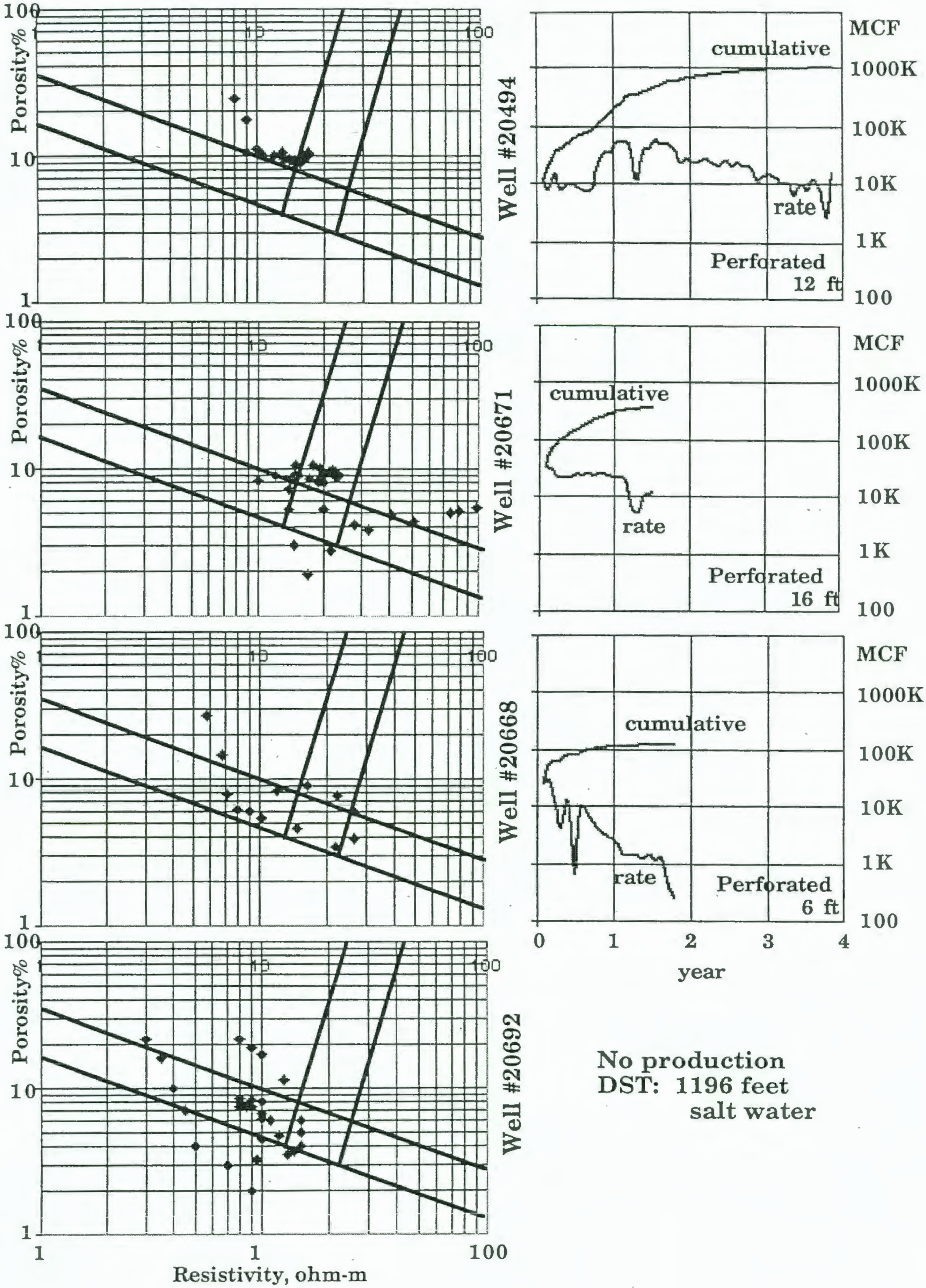


McClain Field Nemaha Co., Kansas : St. Peter Sandstone
BVW
0.10
0.05
0.04
Rw =0.315
Sw = 50%
McClain Field wells
A
B
C
D
Cities Service Beck #A-1
SW-SW-SE 14-5S-12E
m=1.86
Porosity%
100
40
30
20
10
5
1
0.1
1
10
100
200
Resistivity, ohm-m





Location of Pickett plot gas wells in the Arroyo field, together with reference Pickett plot framework.



Porosity%
Resistivity, ohm-m
1
10
100
Well #20494
Well #20671
Well #20668
Well #20692
MCF
1000K
100K
10K
1K
100
cumulative
rate
Perforated 12 ft
Perforated 16 ft
Perforated 6 ft
0
1
2
3
4
year
No production
DST: 1196 feet
salt water

The Spontaneous Potential Log

SP

SPONTANEOUS POTENTIAL (SP) LOG

In the early days of resistivity logging, natural potentials were observed to occur in boreholes which were measurable in millivolts and found to distinguish permeable formations from intervening shales. The natural "battery" was initiated by the drilling of the borehole itself, in that the use of muds with a salinity contrast with formation waters, juxtaposed solutions with different ion concentrations. The cumulative emf that is generated is comprised of a shale (or membrane) potential, a liquid junction potential and an electrokinetic potential. The electrokinetic potential is very minor when compared with the components of shale potential and liquid junction potential, which result from the permeability of shale to sodium ions but not chloride ions, and the greater mobility of chloride ions relative to sodium ions, respectively. These two types of potential are classed as the electrochemical component of the SP log and result in an electrical circuit at the boundaries of shales with permeable beds. The flow of the current is from permeable bed to shale to borehole mud and back to permeable bed.

The magnitude of the electrochemical potential is a function of the chemical activities of the formation water (a_w) and the mud filtrate (a_{mf}) :

$$E = -K \log(\frac{a_w}{a_{mf}})$$

where K is a factor which is a function of temperature. The chemical activity of a single-salt solution is inversely proportional to the salt concentration. The salt concentration is inversely related with the solution resistivity. If mud filtrate and formation waters may be approximated by pure sodium chloride solutions, the equation becomes:

$$E = -K \log(\frac{R_{mf}}{R_w})$$

This simple equation contains the general features shown by an SP log:

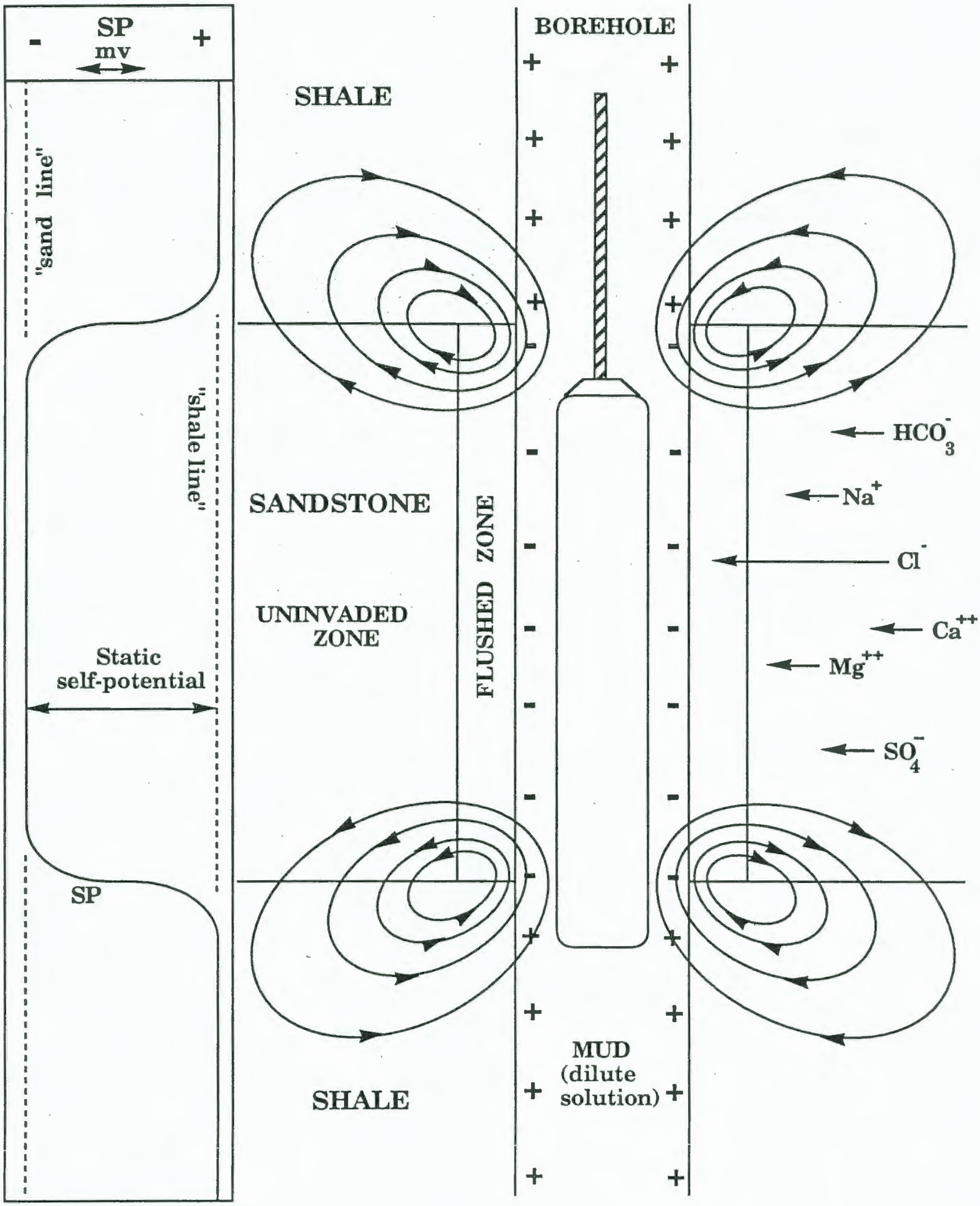
(1) When the drilling mud is fresh water (i.e. Rmf>Rw), the SP log shows a shift to the negative when moving from a shale to a permeable formation;

(2) Conversely, when the drilling fluid is a salt mud (i.e Rmf<Rw), the SP displaces in a positive sense in moving from a shale to a perme able formation;

(3) The magnitude of the shift is a function of the resistivity contrast between the mud filtrate and the formation water;

(4) Which gives another method to estimate the formation water resistivity, since the formation temperature can be estimated (giving a value for K), and the mud filtrate resistivity is measured at the well site.

THE SPONTANEOUS POTENTIAL (SP) TOOL



Rw ESTIMATION FROM THE SP LOG

Natural Gas Burke #1   C-SW-SE   27-12S-41W   Wallace County, Kansas

---

Section of interest: Nippewalla Group (Lower Permian)

Procedure:

Make a template copy of the worksheet **SPRW**
Enter values in the data box:

ST: The mean annual surface temperature of the well location
DEPTH: The approximate midpoint of the sandstone
TD: The total depth recorded on the log header
BHT: The bottom-hole temperature recorded on the log header
RMF: The mud-filtrate resistivity recorded on the log header
TMF: The temperature of the Rmf measurement on the log header
SSP: the static self-potential
Draw a "sand line" and a "shale line" on the SP log.
Estimate the distance in mv from the shale line to the sand line
Remember to add a sign to your value as either positive or negative. Negative applies to the more common situation, where the mud is fresher than the formation water.

SCHLUMBERGER WELL SURVEYING CORPORATION
HOUSTON, TEXAS

SCHLUMBERGER Induction-Electrical Log

COMPANY NATURAL GAS DRILLING Co.

WELL BURKE No. 1

FIELD Wildcat

LOCATION SEC. 27-12s-41w SW SE

COUNTY WALLACE

STATE KANSAS

COUNTY / FIELD or LOCATION / WELL / COMPANY

Other Surveys: Sonic/Caliper

Location of Well: Field Print

Elevation: D.F.:
K.B.: 3708
or G.L.:

FILING No.

RUN No.	ONE				
Date	11-29-62				
First Reading	5236				
Last Reading	267				
Feet Measured	4969				
Csg. Schlum.	267				
Csg. Driller	262				
Depth Reached	5237				
Bottom Driller	5230				
Depth Datum	KB				
Mud Nat.	Chemical				
Dens. Visc.	10.2 51				
Mud Resist.	2.21 @ 77 F	@ F	@ F	@ F	@ F
" " Res. BHT	1.47 @ 118 F	@ F	@ F	@ F	@ F
" " Rmf	1.22 @ 74 F	.78 @ 118 F	@ F	@ F	@ F
" " Rmc	@ F	@ F	@ F	@ F	@ F
" " pH	10 @ F	@ F	@ F	@ F	@ F
" " Wtr. Loss	8 CC 30 min	CC 30 min	CC 30 min	CC 30 min	CC 30 min
Bit Size	7 7/8"				
Spcgs.—AM	16"				
MN	34'6"				
IND	6FF40				
Opr. Rig Time	5 hours.				
Truck No.	2904				

Scout

SP ESTIMATION OF FORMATION WATER RESISTIVITY, Rw
USING THE BATEMAN-KONEN ALGORITHM (DEGREES FAHRENHEIT)

Well: Natural Gas Burke #1 27-12S-41W Wallace Co., Ks

Formation: Nippewalla Group (Lower Permian)

Data:

Well	ST	DEPTH	TD	BHT
parameters:	52	2800	5237	118
From	RMF	TMF	From	SSP
log header:	1.22	74	log:	-90

TF	87.287
Rmf75	1.2051
K	71.635
Rmfe/Rw	18.045
Rmfe	1.0244
Rwe	0.0568
Rw75	0.0739
RwTF	0.0642
ppmNaCl	99442

KEY:

ST = mean annual surface temperature (degrees Fahrenheit)
DEPTH = midpoint depth of the SP analyzed unit
TD = Total Depth
BHT = Bottom-hole Temperature (degrees Fahrenheit)
RMF = mud filtrate resistivity
TMF = temperature of RMF measurement (degrees Fahrenheit)
SSP = Static Self-Potential (millivolts)
RW75 = formation water resistivity at 75 degrees Fahrenheit
RwTF = formation water resistivity at formation temperature
ppmNaCl = estimated salinity of the formation water

Porosity logs

Φ

THE POROSITY LOGS

The porosity of a zone can be estimated either from a single "porosity log" (sonic, density, neutron, or magnetic resonance log) or a combination of porosity logs, in order to correct for variable lithology effects in complex reservoirs. In the carbonates, mineral mixtures are primarily drawn from calcite, dolomite, and quartz (either as sand grains or as chert); anhydrite and gypsum may also occur.

When using a single porosity log, the true porosity is calculated from interpolation between the values for the matrix mineral and the pore fluid (usually equated with mud filtrate, because of the shallow investigation of the porosity tools).

Sonic log:
If a sonic log is used for porosity estimation, the Wyllie time-average equation is commonly used:
(1) = $(\Delta t - \Delta t_{ma}) / (\Delta t_f - \Delta t_{ma})$
which is equivalent to:

$$\Delta t = \phi \cdot \Delta t_f + (1-\phi)\Delta t_{ma}$$

where Δt is the zone transit time, ϕ is the porosity, Δt_{ma} is the matrix transit time, and Δt_f is the pore fluid transit time. The computation of porosity requires the stipulation of a matrix mineral transit time, which is about 55.5 microseconds per foot for quartz, 47.5 for calcite, and 43.5 for dolomite. So, transformation of the sonic log to a porosity log generates an apparent porosity trace keyed to one or other matrix mineral, in a similar fashion to the neutron and density logs.
In recent years, there has been increasing dissatisfaction with the performance of the Wyllie time-average equation when accurate estimations of porosity are required. On crossplots of large data sets of porosity - transit time, the slight, but systematic curvature of the relationship becomes noticeable. On the basis of a mixture of trendology and theory, Raymer, Hunt and Gardner (1980) proposed the equation :

$$V = (1-\Phi)^2 V_{ma} + \Phi V_f$$

where V is velocity (reciprocal of transit time).

Density log:
Porosity is calculated from the mass-balance relationship:

$$\rho_b = \phi \cdot \rho_f + (1-\phi)\rho_{ma}$$

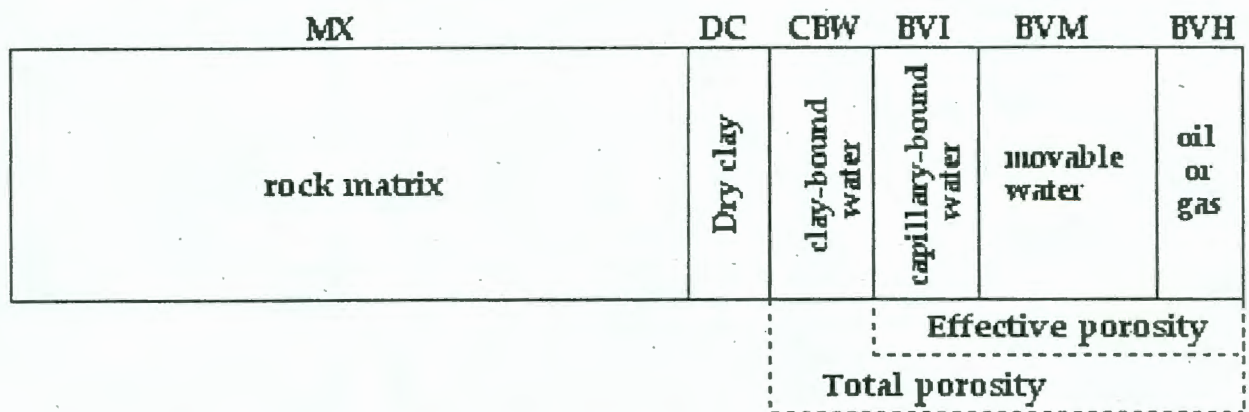
where ρ_b is the bulk density, ϕ is the porosity, ρ_{ma} is the matrix density, and ρ_f is the pore fluid density. If a sandstone, then the matrix density is 2.65 gm/cc (quartz), if a limestone, the matrix density is 2.71 gm/cc (calcite); if a dolomite, then the matrix density is about 2.87 gm/cc. The density log is scaled as bulk density in grams per cubic centimeter. If a "density porosity log" is displayed, then it will be an apparent porosity keyed to a specific mineral, usually calcite, in which case the curve will be indexed as "limestone equivalent porosity". This porosity will be in error in all lithologies whose matrix density differs from that of calcite.

THE POROSITY MODEL

Fluids within a reservoir rock can be partitioned into distinctive components that need to be considered in a realistic log analysis.

The **total porosity** corresponds to the raw value calculated (or read) from a sonic, neutron, or density porosity log.
The **effective porosity** is the shale-corrected porosity which eliminates the clay-bound water component. Where clay minerals are absent or negligible, the effective porosity is the same as the total porosity.

The **rock matrix** (MX) is the rock framework mineral assemblage that is electrically inert. The clay mineral component is partitioned between **dry clay** (DC) and **clay-bound water** (CBW). The **capillary-bound water** (BVI) is the "irreducible" bulk volume water, that is the immovable water held by capillary forces within micropores. The **movable water** (BVM) is the water in the larger pores that is free to flow, together with any hydrocarbons (BVH).



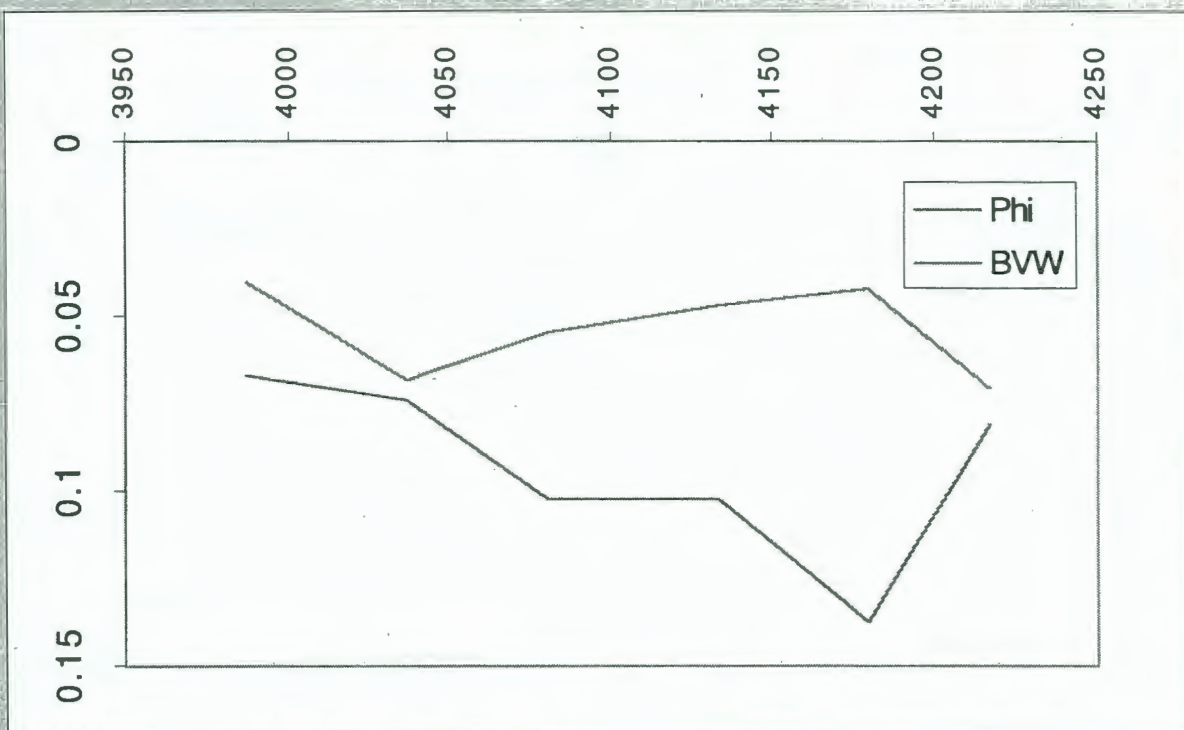
This model is used to guide log analysis of fluids from resistivity-porosity log combinations. A major limitation is the inability to distinguish movable water from capillary bound water, which is the reason why Buckles numbers, Pickett plots, and other techniques are required to supplement traditional log analysis. Alternatively, NMR logs can be run and these explicitly discriminate between movable and capillary-bound waters.

ARCHIE EQUATION AND SONIC LOG

Well:	Skelly Bartosovsky #19-1S-34W Rawlins Co., Ks
Formation:	Lansing and Kansas City Groups (Pennsylvanian)

Parameters	
a	1
m	2
n	2
Rw	0.075
Δtma	47.5
Δtf	189

Depth	Δt	Phi	Rt	Sw	BVW
3987	57	0.067	46	0.60	0.040
4037	58	0.074	16	0.92	0.068
4081	62	0.102	25	0.53	0.055
4134	62	0.102	34	0.46	0.047
4180	67	0.138	42	0.31	0.042
4217	59	0.081	15	0.87	0.071

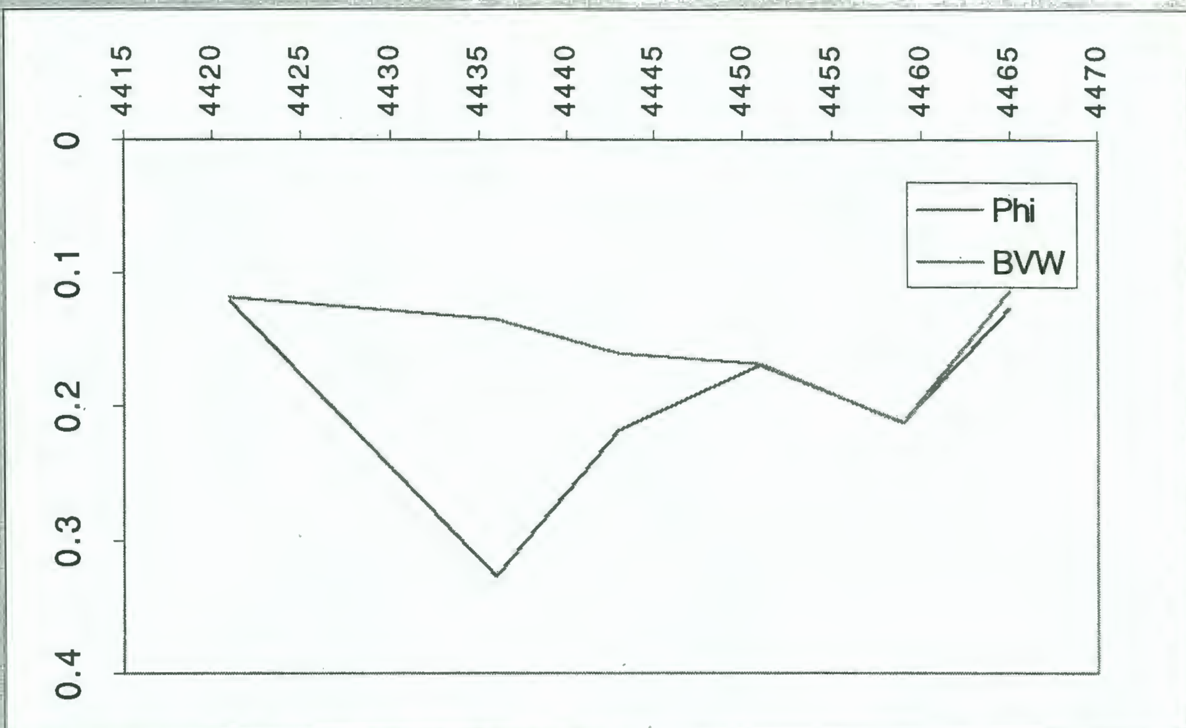


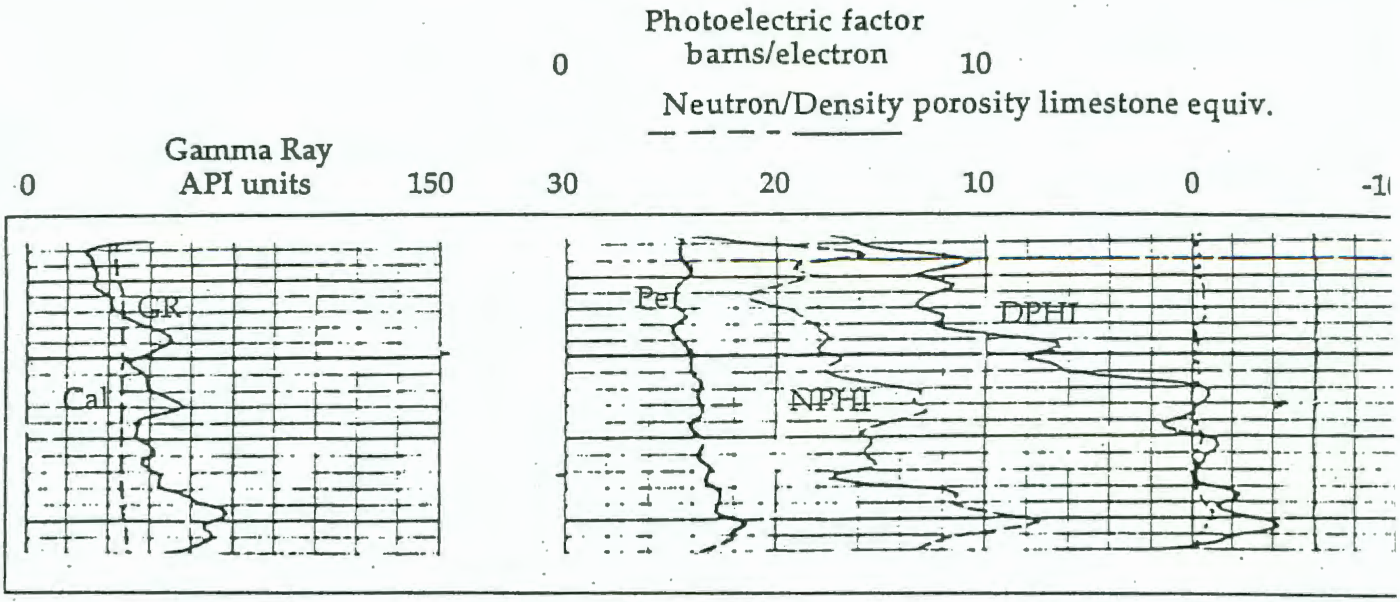
ARCHIE EQUATION AND DENSITY LOG

Well:	Holl 1-11 Tubbs-Burr 11-25S-17W Edwards Co., Ks
Formation:	Mississippi "Chat" (Osage)

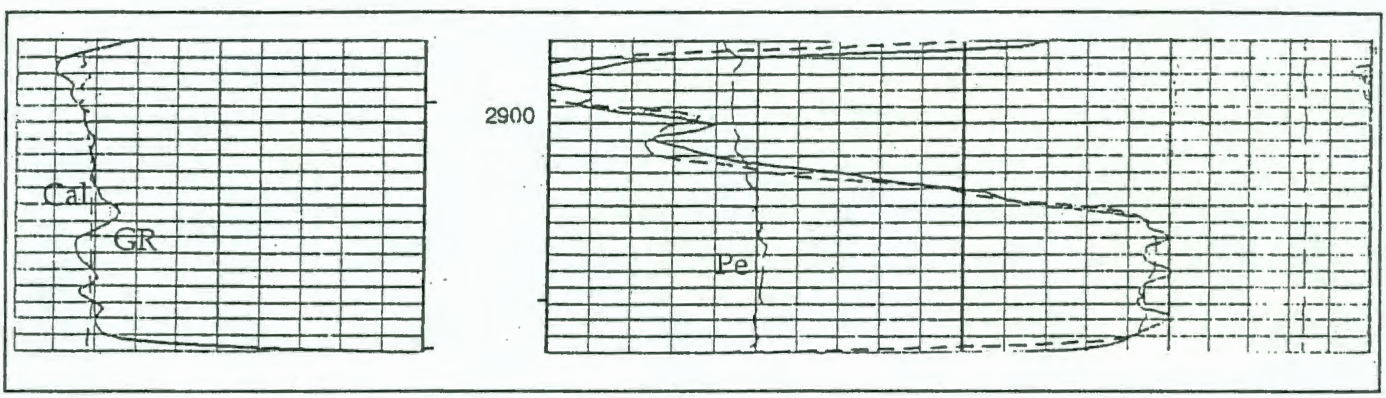
Parameters	
a	1
m	2.36
n	2
Rw	0.075
ρma	2.65
ρf	1

Depth	ρb	Phi	Rt	Sw	BVW
4421	2.45	0.121	11.3	0.98	0.119
4436	2.11	0.327	6.1	0.41	0.136
4443	2.29	0.218	5	0.74	0.161
4451	2.37	0.17	5	0.99	0.169
4459	2.3	0.212	2.9	1.00	0.213
4465	2.44	0.127	12.1	0.90	0.114

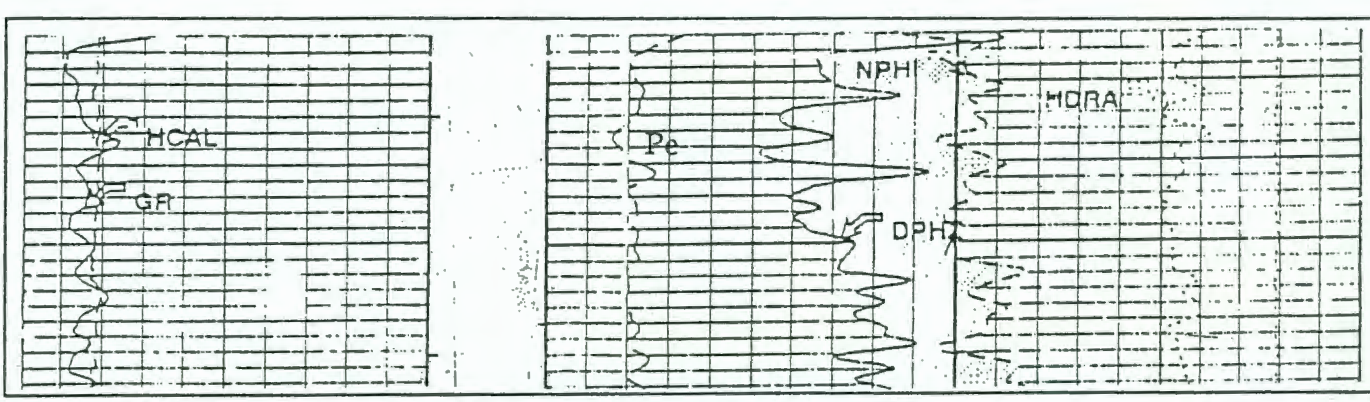




Towanda (Permian) dolomite
Sharon Gates #14-1 19-24S-30W Finney County Kansas



Pennslvanian oomoldic limestone
Murfin Carter-Colliver #1 28-14S-13W Russell County, Kansas

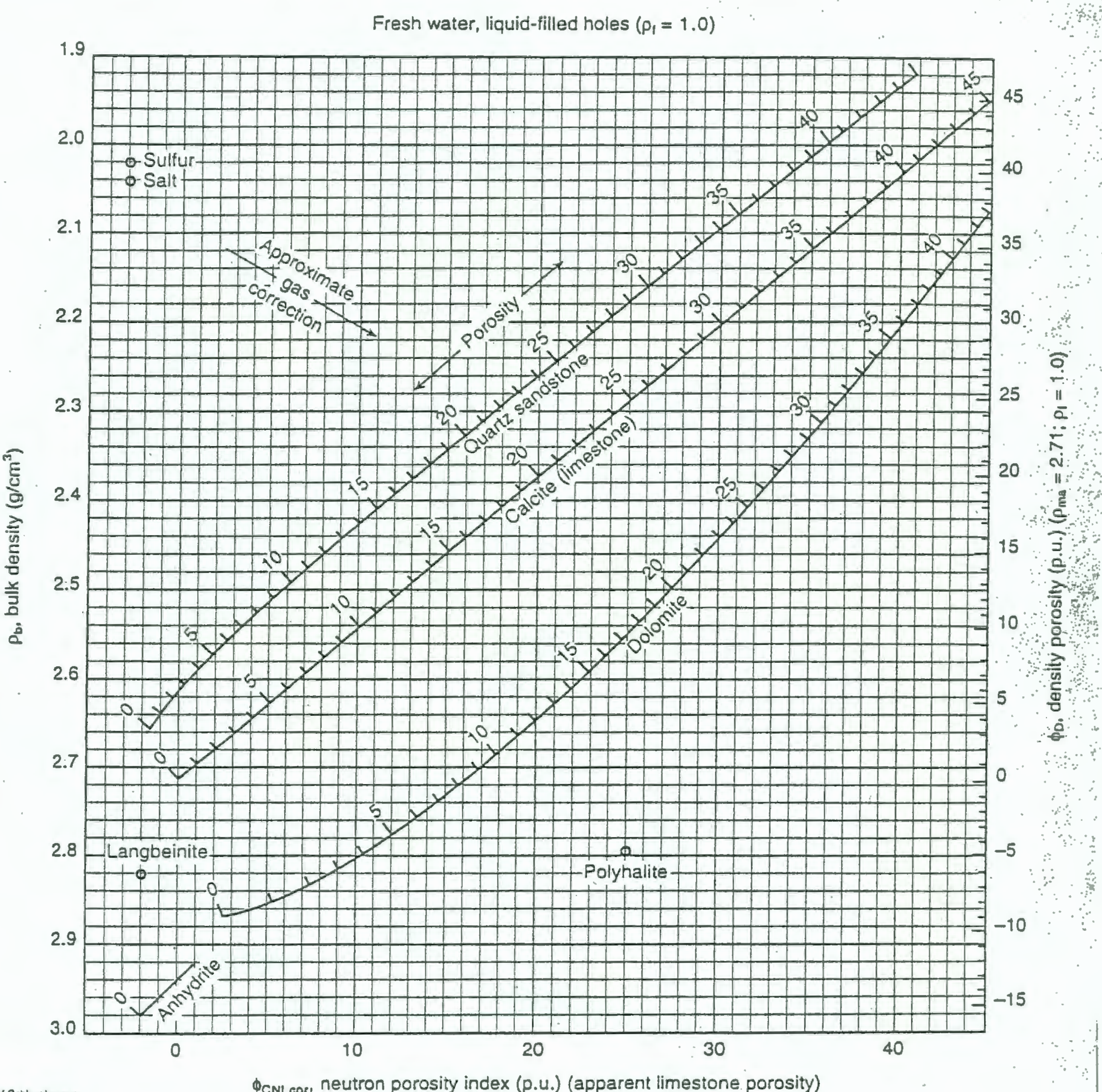


Chester (Mississippian) sandstone
Hugoton MLP Koenig #1-28 28-29S-34W Haskell County, Kansas

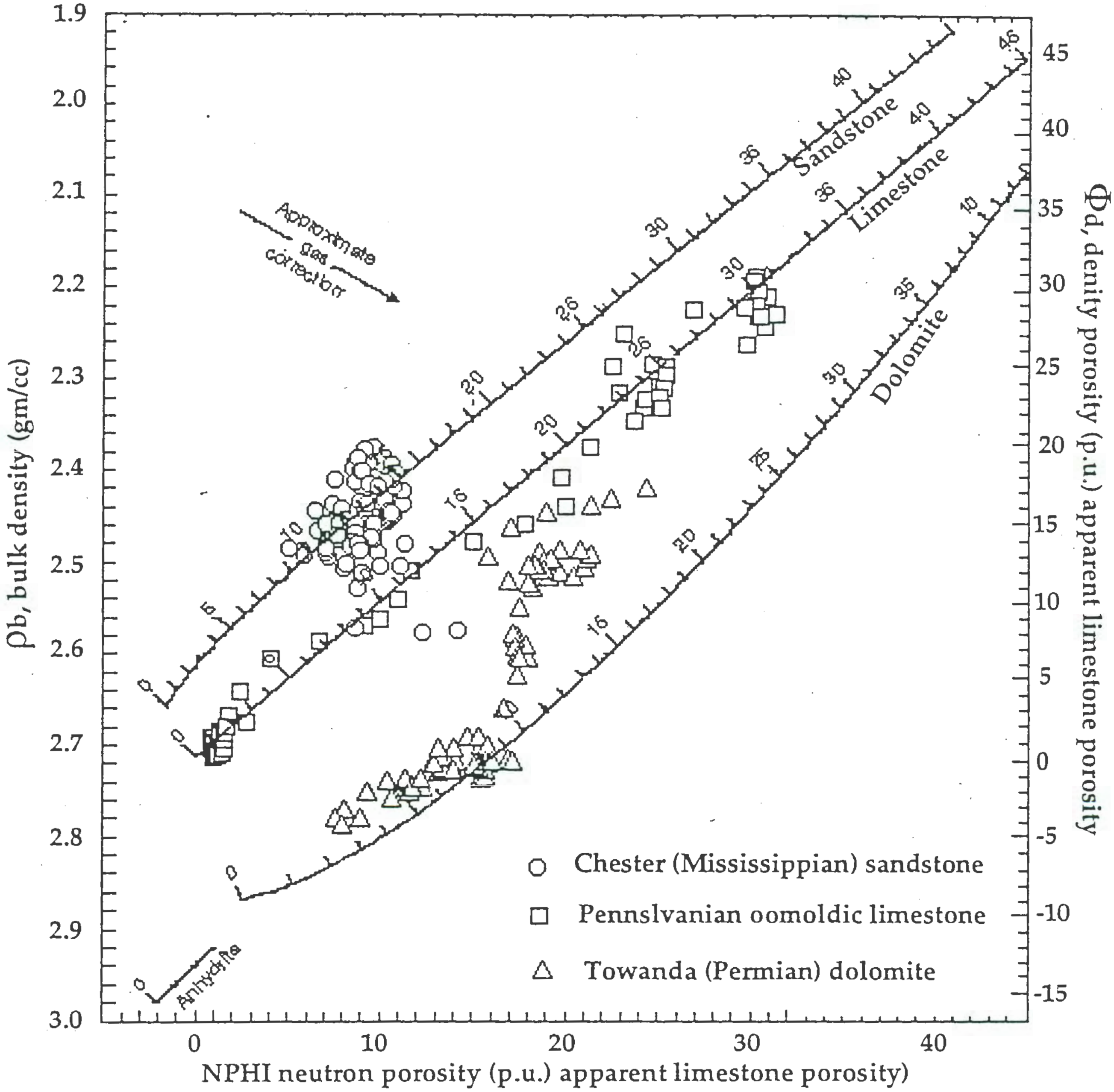
Neutron-density porosity and photoelectric factor logs of sandstone, limestone, and sandstone reservoir formations

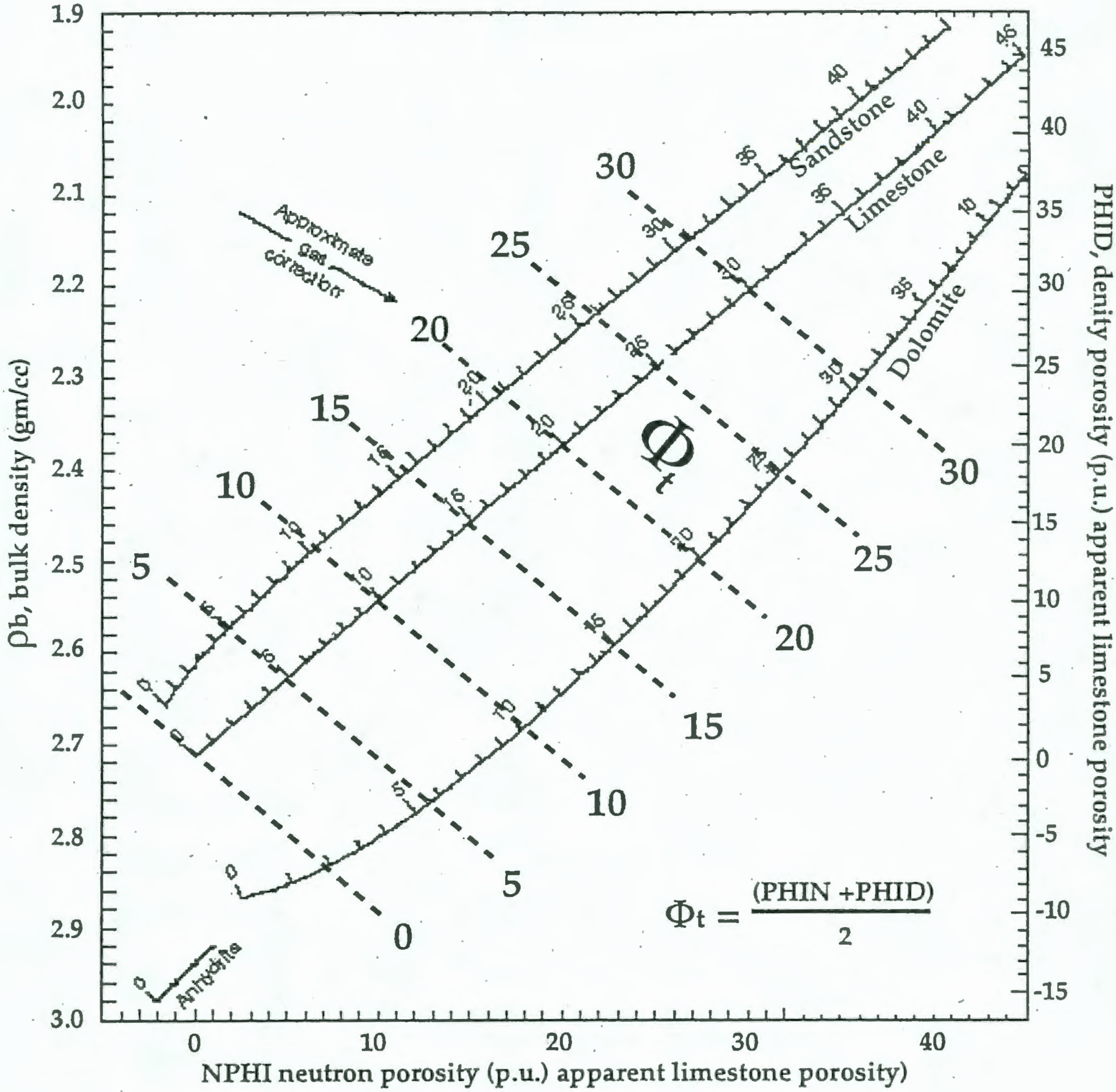
Porosity and Lithology Determination from Formation Density Log and CNL* Compensated Neutron Log

For CNL logs before 1986, or labeled NPHI



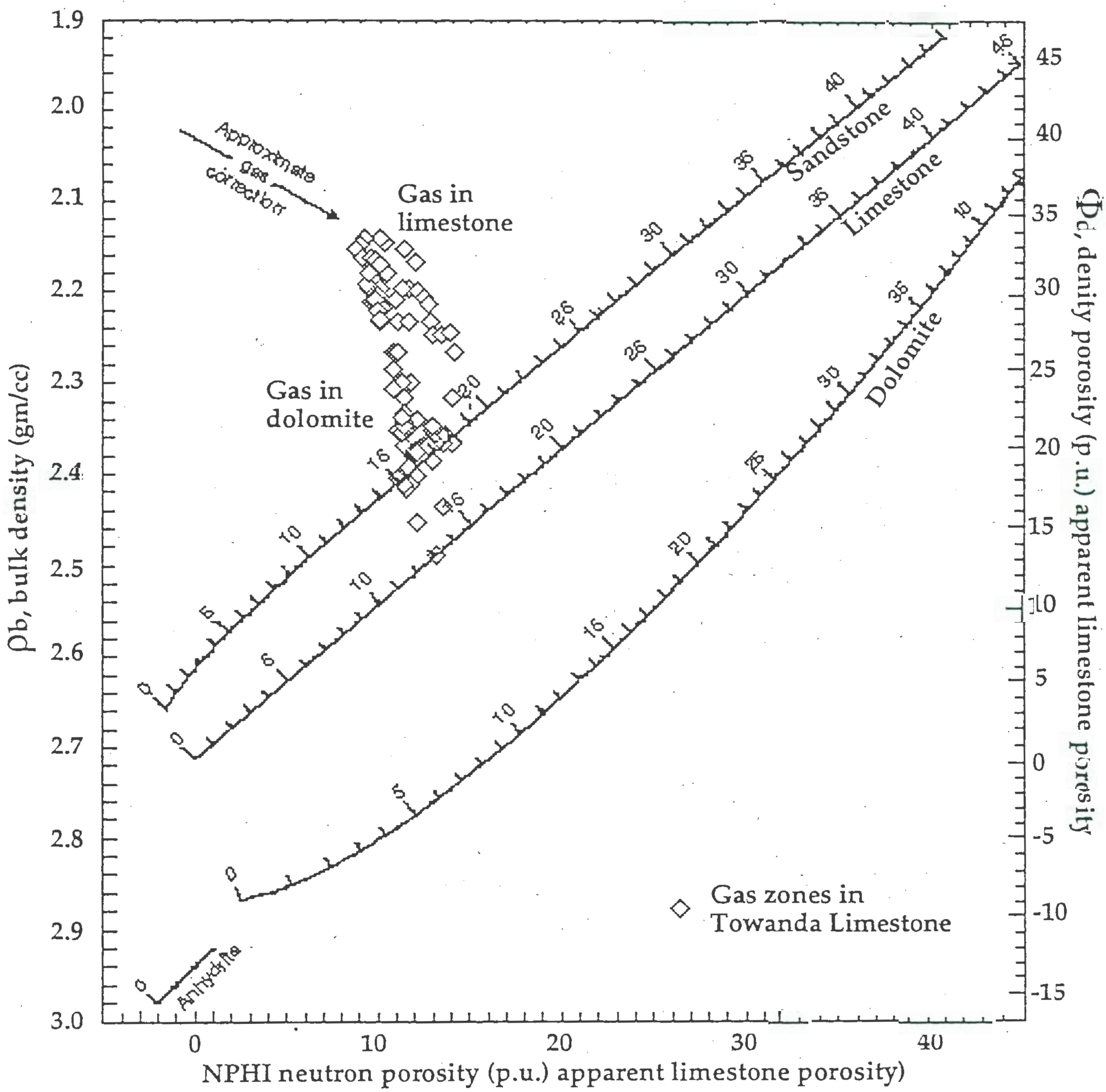
*Mark of Schlumberger


ρb, bulk density (gm/cc)
Φd, denity porosity (p.u.) apparent limestone porosity
NPHI neutron porosity (p.u.) apparent limestone porosity
Sandstone
Limestone
Dolomite
Anhydrite
Approximate gas correction
Chester (Mississippian) sandstone
Pennslvanian oomoldic limestone
Towanda (Permian) dolomite



Approximation of crossplot porosity estimation of true volumetric porosity, Φt by calculation using:

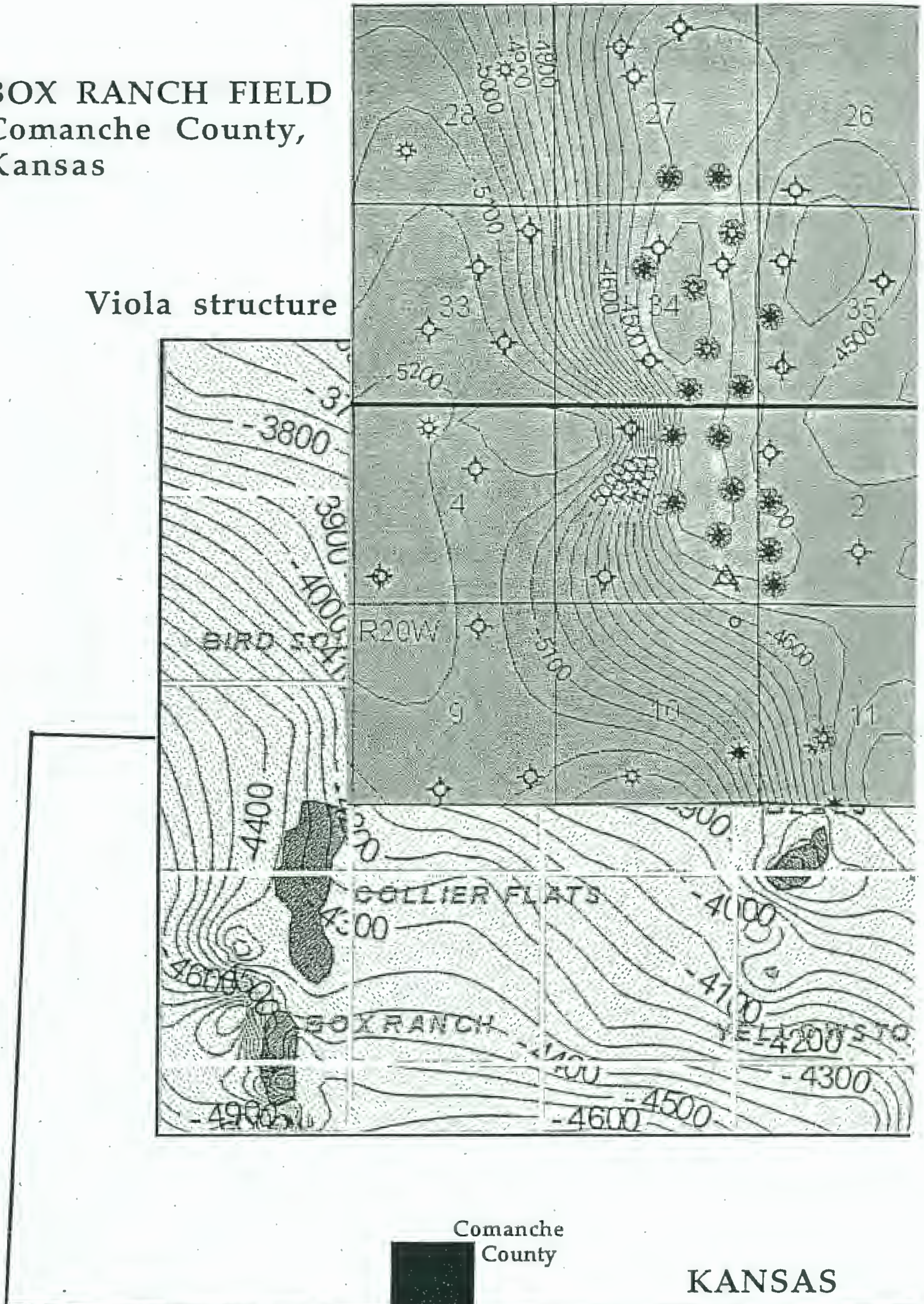
$$\Phi t = (PHIN+PHID)/2$$

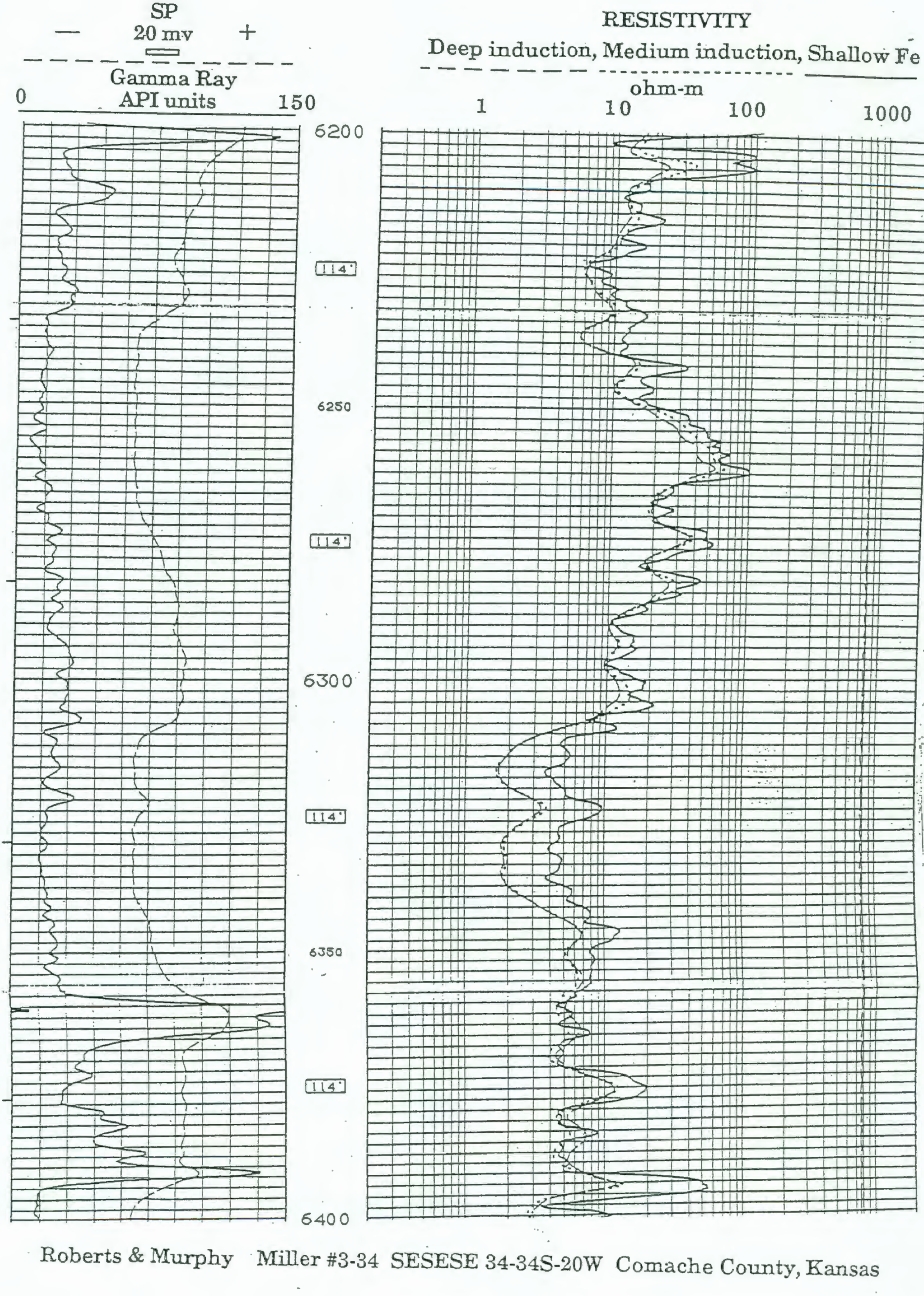


Crossplot of gas zones in the Towanda Limestone (Chase Group)
Mobil Peachy Unit #1 Well#3 24-34S-37W Stevens County, Kansas

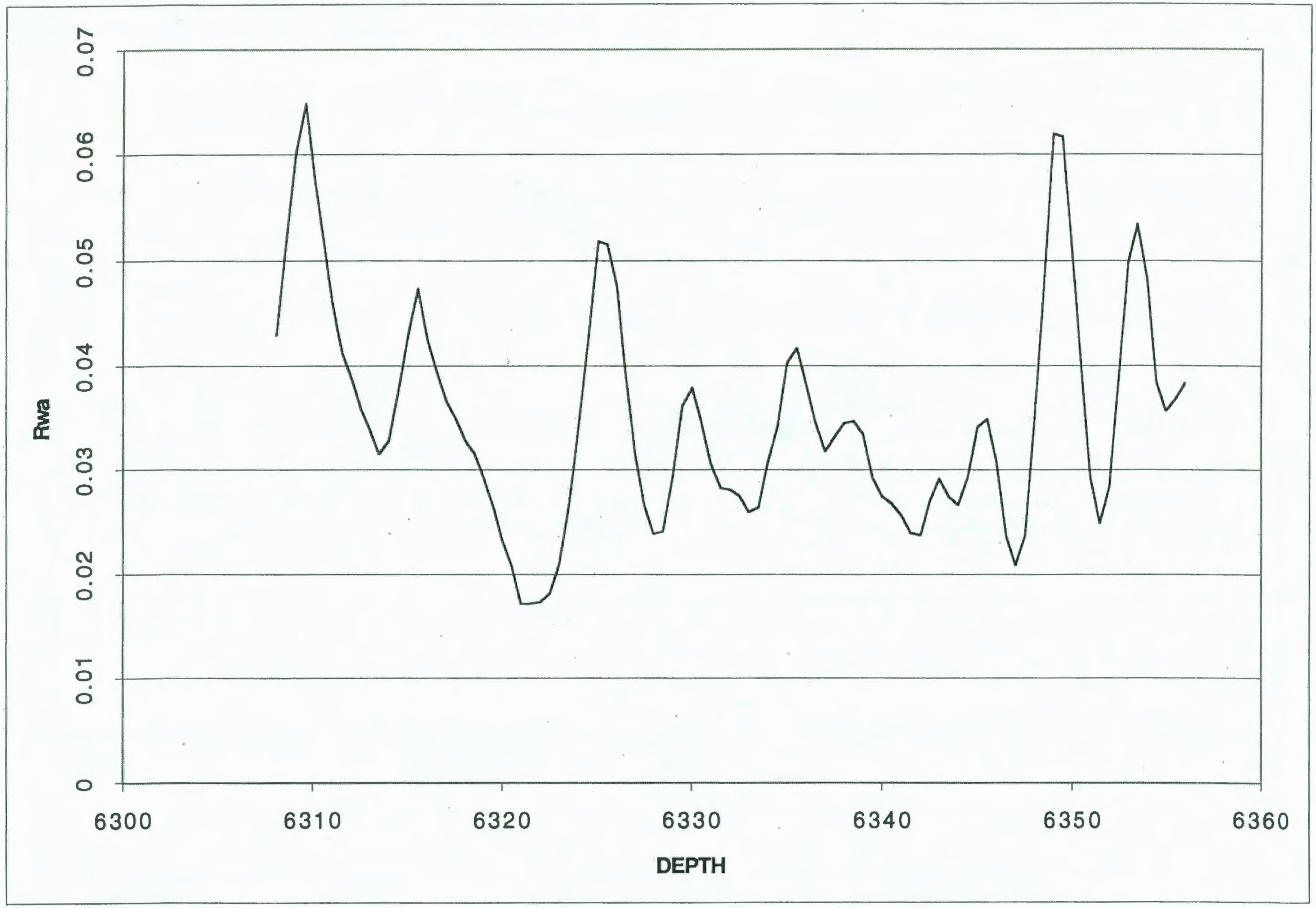
BOX RANCH FIELD
Comanche County, Kansas

Viola structure





Roberts & Murphy Miller #3-34 SESESE 34-34S-20W Comache County, Kansas


Rwa
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
6300
6310
6320
6330
6340
6350
6360
DEPTH

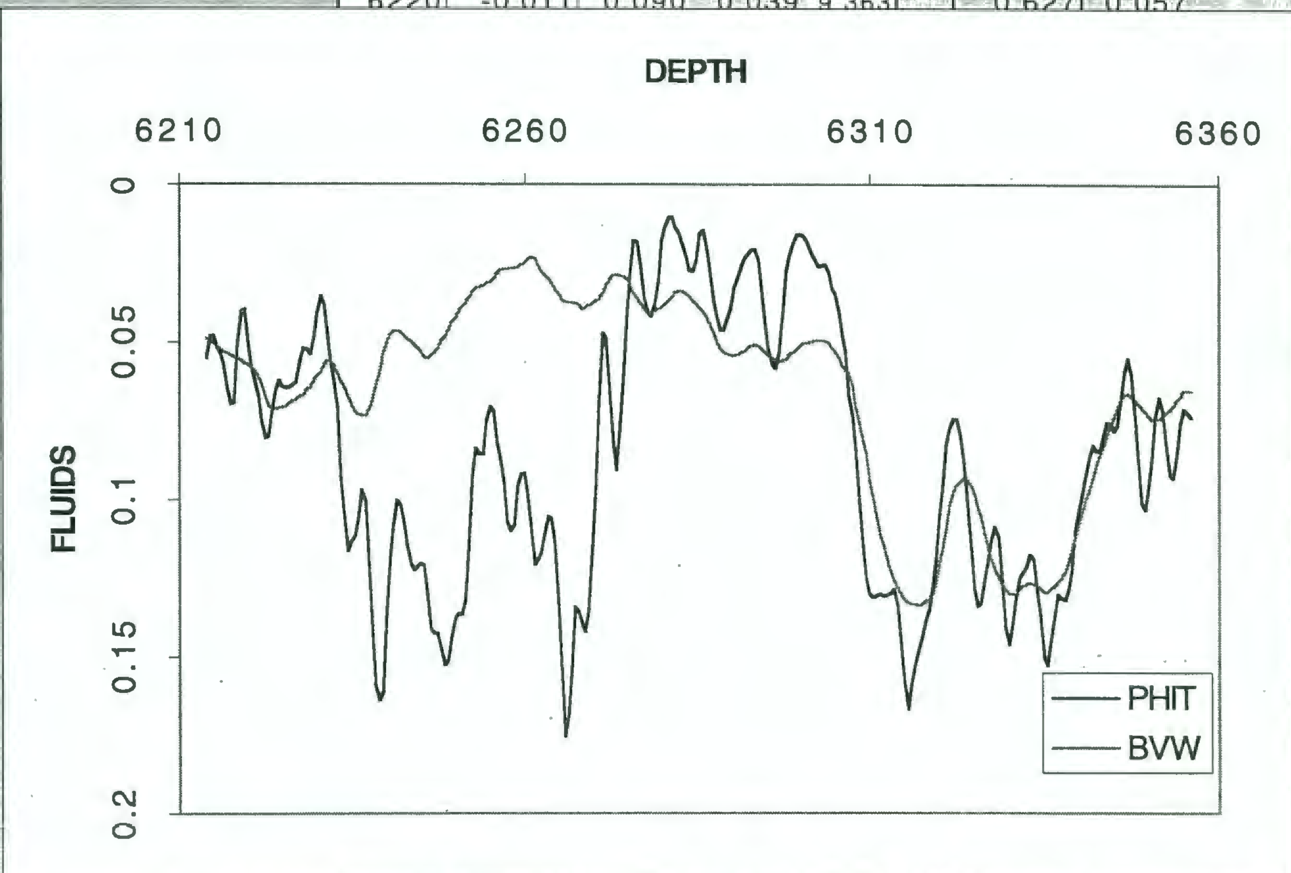
ARCHIE EQUATION WITH DENSITY AND NEUTRON LOGS

Well:	Roberts & Murphy Miller #3-34 34-34S-20W
Formation:	Viola Limestone

Parameters

a	1
m	2
n	2
Rw	0.03

Depth	PHID	PHIN	PHIT	Rt	Sw	BVW
6214	-0.001	0.111	0.055	12.59	0.44	0.049
6215	0.001	0.095	0.048	12.19	0.52	0.050
6215	0.007	0.089	0.048	11.89	0.56	0.050
6216	0.012	0.090	0.051	11.43	0.57	0.051
6216	0.014	0.092	0.053	10.99	0.57	0.052
6217	0.015	0.099	0.057	10.73	0.5344	0.053
6217	0.019	0.109	0.064	10.47	0.4912	0.054
6218	0.025	0.114	0.07	10.22	0.4756	0.054
6218	0.023	0.115	0.069	10.06	0.4757	0.055
6219	-0.002	0.104	0.051	9.901	0.5288	0.055
6219	-0.016	0.096	0.04	9.667	0.5796	0.056
6220	-0.011	0.090	0.039	9.363	0.627	0.057
6231	0.020	0.056	0.038	9.22	1.0263	0.057

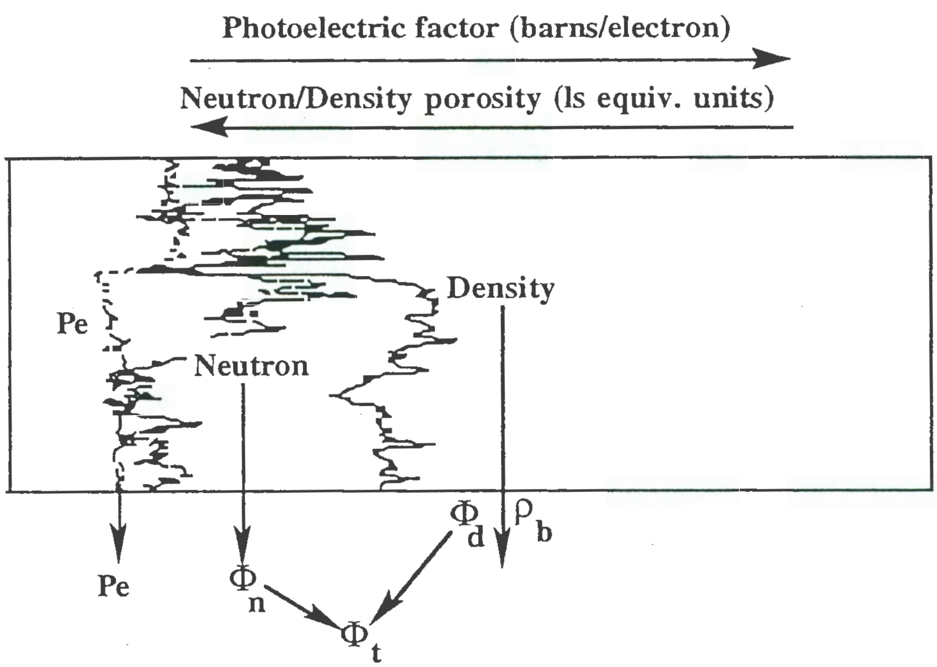


THE RHOmaa - Umaa CROSSPLOT

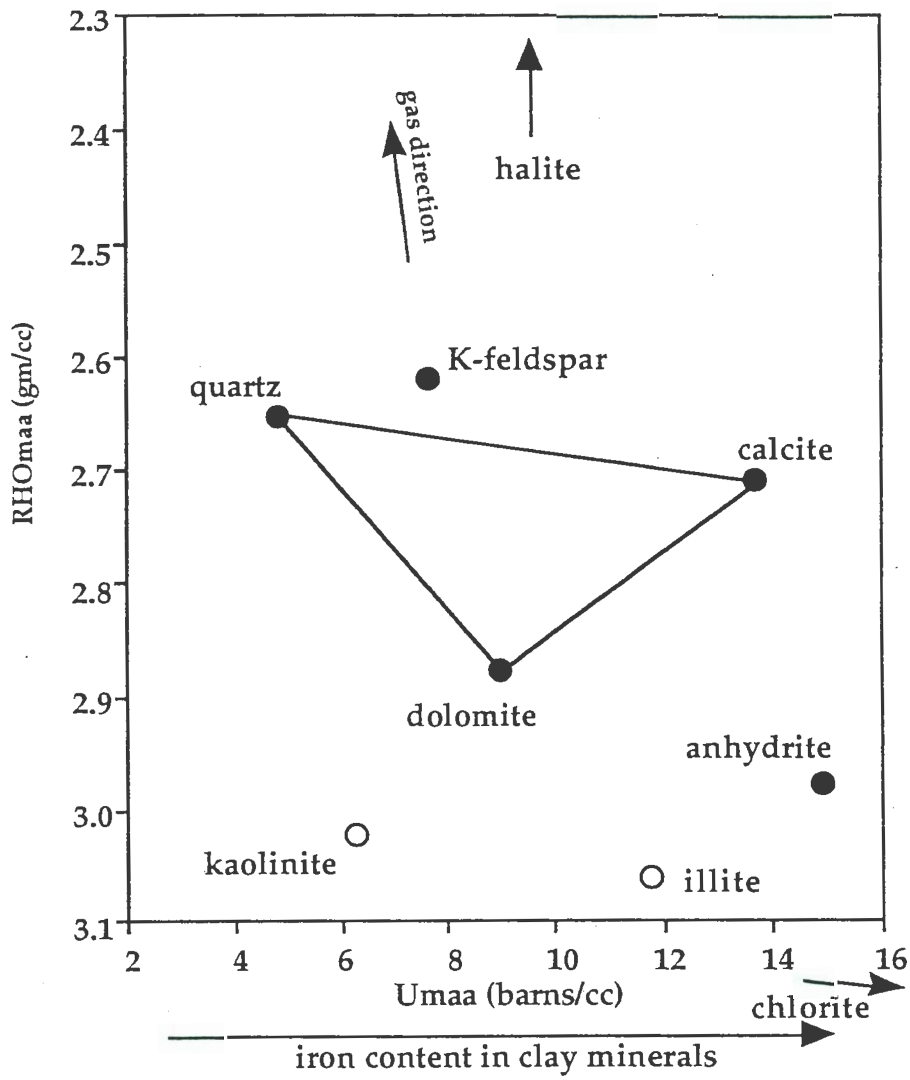
Theory

The interpretation of simple minerals and lithologies is generally straightforward from a visual inspection of the photoelectric index curve with the neutron/ density overlay. In cases of mixed lithologies or mysterious minerals, a crossplot of a zone log responses can be helpful both for purposes of identification and for semi-quantitative estimations of volumetric proportions.

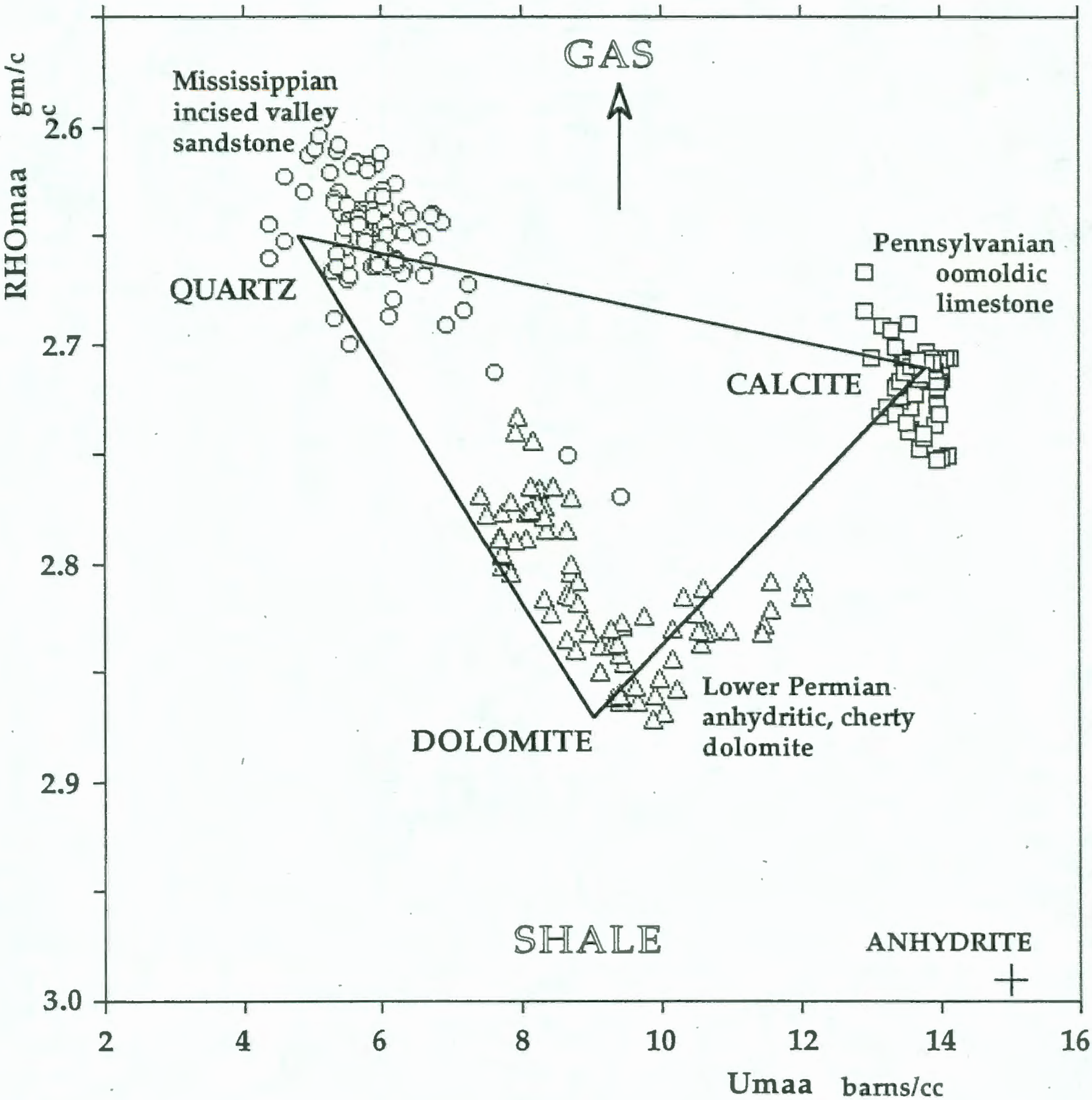
The RHOmaa - Umaa crossplot was introduced to utilize measurements of the photoelectric index, neutron porosity, and bulk density for matrix mineral evaluation. The two dimensions of the crossplot require the three log variables to be condensed in some manner. This is done with a similar approach to the M-N plot methodology, through the suppression of porosity as a variable and calculation of the apparent properties of the rock matrix. The log variables that are needed for the calculation are shown diagrammatically below.



Source of log measurements for estimation of RHOmaa (apparent grain density) and Umaa (apparent volumetric matrix photoelectric absorption).



The RHOmaa-Umaa crossplot.


GAS
Mississippian
incised valley
sandstone
QUARTZ
Pennsylvanian
oomoldic
limestone
CALCITE
DOLOMITE
Lower Permian
anhydritic, cherty
dolomite
SHALE
ANHYDRITE
RHOmaa gm/cc
2.6
2.7
2.8
2.9
3.0
2
4
6
8
10
12
14
16
Umaa barns/cc

PRIMARY AND SECONDARY POROSITY

The neutron and density logs are responses to pores of all sizes. However, field observation over many years has shown that the sonic log is a measure of interparticle (intergranular and intercrystalline) porosity but is largely insensitivity to either fractures or vugs. This discrimination can be explained largely by the way that the sonic tool measures transit time by recording the first arrival waveform which often corresponds to a route in the borehole wall free of fractures or vugs.

When sonic porosities are compared with neutron and density porosities, the total porosity can be subdivided between "primary porosity" (interparticle porosity) recorded by the sonic log and "secondary porosity" (vugs and/or fractures) computed as the difference between the sonic porosity and the neutron and/or density porosity. Typically, moderate values in secondary porosity are caused by vugs, because fracture porosity does not usually exceed 1 to 2% by volume.

The log example shows the averaged neutron-density porosity log together with a sonic log in a Pennsylvanian limestone - shale sequence in a Kansas well. They are both scaled in limestone equivalent porosity units. Notice how the neutron-density and sonic porosity logs track fairly closely at about 3% porosity in the Sniabar limestone, but in the upper part of the Bethany Falls limestone, there is a marked increase in overall porosity and a distinctive separation of the sonic from the neutron-density porosity. These features are quite common in south-central Kansas and distinguish high-porosity oomoldic limestones from low-porosity wackestones. While the neutron and density logs are sensitive to all pore sizes, the sonic log porosity does not reflect all the oomoldic pores. The distinction is commercially important because much of the oomolds are poorly connected vuggy pores that cause an increase in resistivity such that water-saturated oomoldic zones can look to be promising hydrocarbon shows and be confused with real oomoldic oil and gas producers. This has been enough of a problem to encourage the specific use of EPT (electromagnetic propagation tool) logging in some wells.

When formation resistivity factors are measured on core samples and related to porosity, computed values of the cementation exponent, m, are often high and variable. As discussed earlier in this manual, one of the modifications to the Archie equation proposed by Watfa and Nurmi (1987), subdivided porosity between connected, interparticle pores and unconnected or poorly-connected vugs such as oomoldic pores. Then, where oomoldic pores are bypassed by electrical current they do not participate in conduction and:

$$\Phi^m = (\Phi - \Phi_{nc})^2$$

where Φ_{nc} is the non-connected oomoldic pore volume. Alternatively, the equation can be rewritten in terms of the connected porosity:

$$\Phi^m = \Phi_c^{\,2}$$

If the sonic log porosity measurement, Φ_S, is used to estimate the connected, interparticle porosity and we rearrange the equation to solve for the m value that this model would predict should be measured on the core sample then:

$$m = \frac{2\log(\Phi_s)}{\log(\Phi_t)}$$

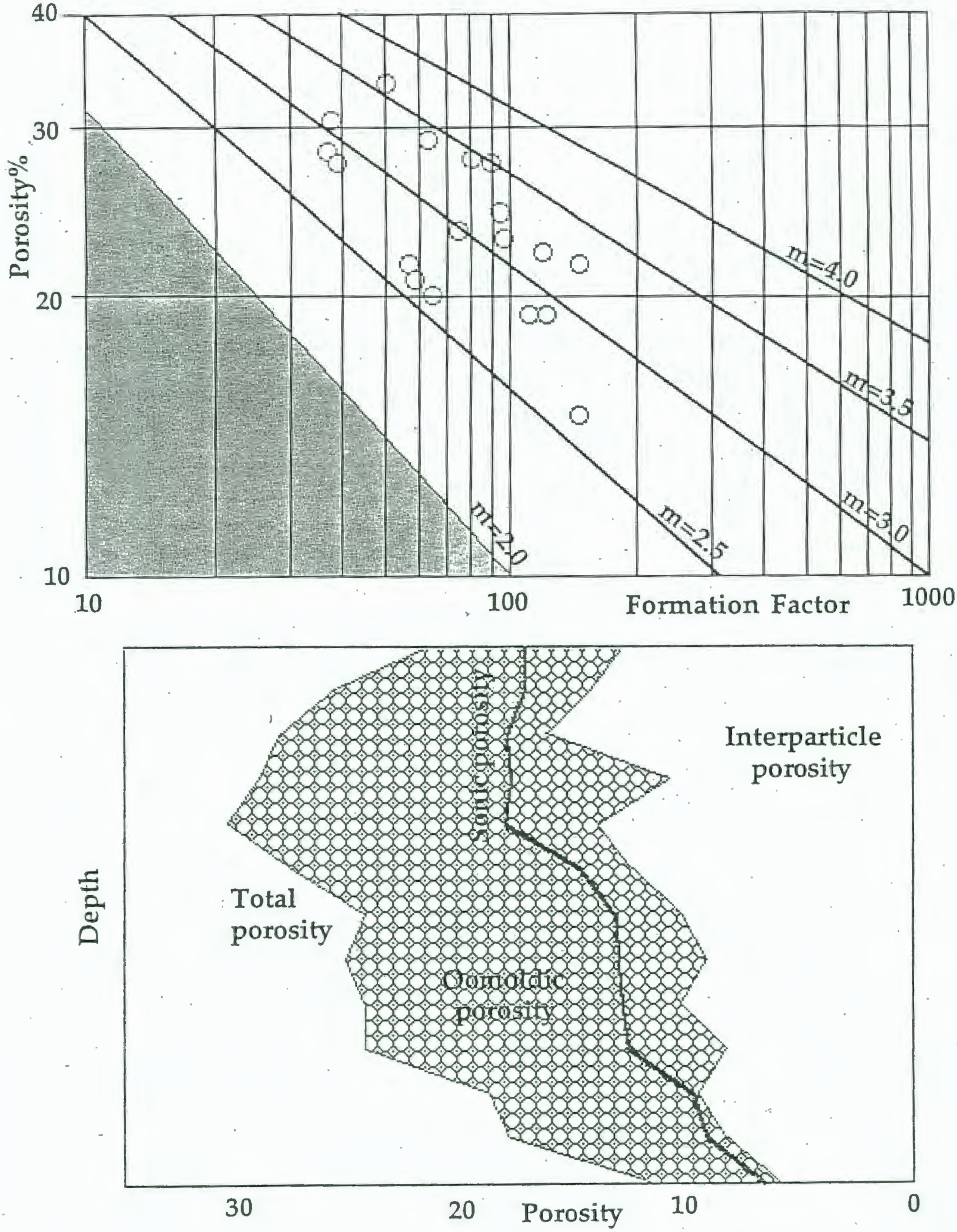
This solution for *m* in oomolds (or vugs in general) is the same as that of the widely-known "Nugent equation" (Nugent, 1984).

Based on their experience, Nugent (1984) and other log analysts, such as Asquith (1985) have noted that values of *m* are often underestimated by the Nugent equation, so it is often written as:

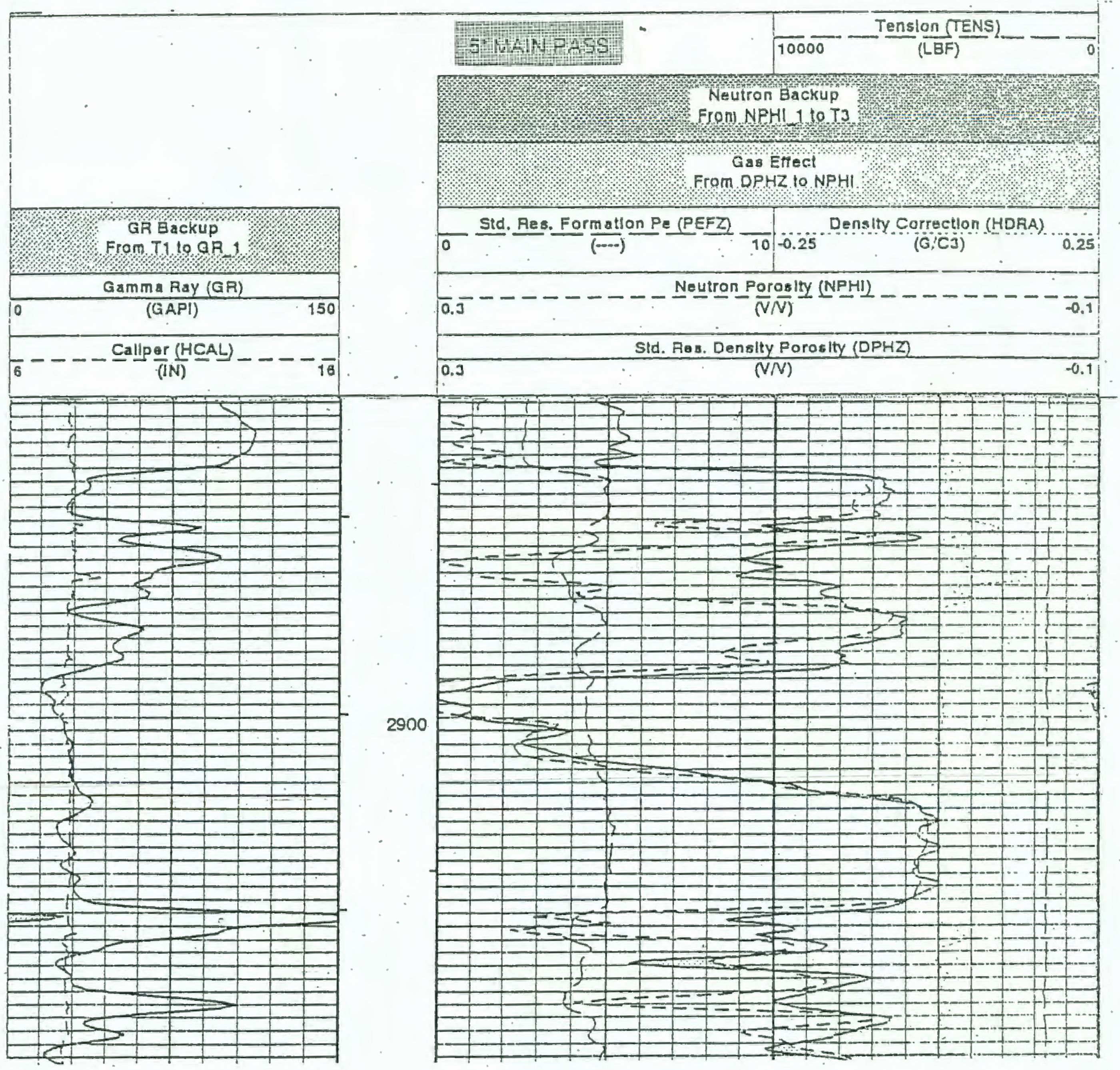
$$m \geq \frac{2\log(\Phi_s)}{\log(\Phi_t)}$$

In petrophysical terms, this implies that the sonic porosity measures the interparticle porosity and, in addition, a proportion of the vuggy porosity. Some evidence for this is suggested by the comparison between the Watfa-Nurmi equation estimates of interparticle/oomoldic porosity from core formation factor measurements with the sonic log porosity measurements (next page).

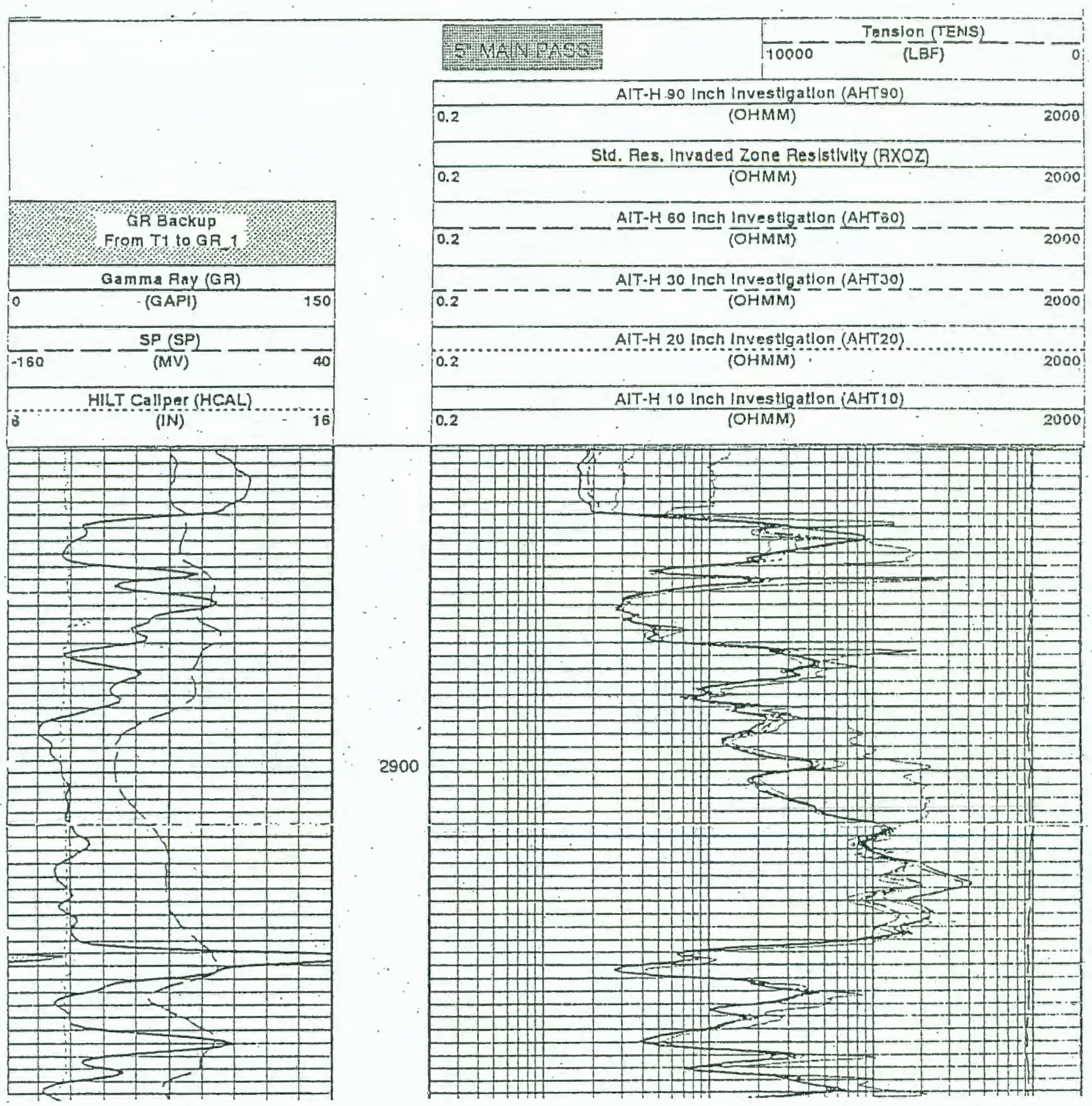
In practice, the use of the Nugent equation allows a separate calculation of the cementation exponent, m, for each zone by using the total porosity (generally the average of the neutron and density limestone equivalent porosities) in conjunction with the sonic limestone equivalent porosity. The resulting water saturations will tend to being biased towards low values, but will not be as wildly optimistic as estimations based on the use of the Archie equation with the total porosity and a cementation exponent value of 2. The log evaluation of oomoldic reservoirs remains a petrophysical analysis challenge.



Oomoldic porosity in the Lansing "C" Zone of
Murfin Carter Colliver #1 28-14S-13W Russell County, Kansas
Above: Formation factor- porosity crossplot
Below: Partition of total porosity between interparticle and oomoldic porosity computed by the Watfa-Nurmi equation overlaid by the sonic porosity.



Murfin Drilling Carter-Colliver #1 28-14S-13W Russell County, Kansas



Murfin Drilling Carter-Colliver #1 28-14S-13W Russell County, Kansas

EPISTLE TO THE JUNIOR LOG ANALYST

Lo, all ye miserable sinners entering the land of the logging trucks, harken unto my words, for I have dwelt in this land for many moons, and mine eyes have witnessed all manner of folly and woe. Gird up thy loins, my son, and take up thy slideth rule; but act slowly and with exceeding care and harken first to the counsel of a wiser and sadder man than thou.

Know thou that the Pusher of Tools is a man of many moods; when he smileth, seeketh him out, praiseth his rig and laugheth much at his jest. But when he moveth with haste and he curseth under his breath, make thyself scarce.

Damned be the Engineer called Mud; he taketh the gift certificates with a heavy hand and leaveth thee only the calendars.

Beware of the Engineer called Reservoir, for he will make you sweat; when he approacheth, look thou on the ball and hath answers at least to ten digits.

Beware of the Engineer called Research because he paineth your neck. Telleth him not of your calculations, for he believeth not; his only trust is the computer.

Expecteth not assistance from the man called Manager for the rustle of paper groweth loud in his office and he is known as the eight to five desk jockey.

Speaketh not to the man called Geologist, unless spoken to, for he will asketh many foolish questions that thou cannot answer.

Maketh the Chief Clerk thy friend lest he short stoppeth the expense account. He careth not for praise or flattery, but lend him thy liquor and he will love you.

Unto all things there cometh a time to speak and a time to be silent. Be thou like unto stone in the presence of thy superiors, and keep thy tongue still when they shall call for volunteers.

The wise man of Logs searcheth out the easy well and only a fool sticketh out his neck.

The wise man will soon move to company headquarters, but the fool shall dwell in the oil field forever.

Anno Domini 1973
Signeth Walter H. Fertl