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MARLIN A-1
(FORMERLY GIPPSLAND SHELF NO 4)

DETERMINATION OF THE FORMATION RESISTIVITY FACTOR AND CEMENTATION FACTOR OF CORE SAMPLES FROM RESERVOIR SANDS OF THE EOCENE LATROBE VALLEY COAL MEASURES

by

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

MINERAL RESOURCES BRANCH

PETROLEUM TECHNOLOGY SECTION

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Determination of the Formation Resistivity Factor and Cementation Factor of core samples from reservoir sands of the Eocene Latrobe Valley coal Measures

INTRODUCTORY NOTE

The Marlin A-1 well was drilled in 1965/66 on Petroleum Exploration Permit No. 38, issued to the Haematite Exploration Pty. Ltd. Esso Exploration Australia Incorporated, joined with Haematite as a farm-in partner and acted as operator on the drilling programme.

The well was drilled to a total depth of 8485 feet. Four separate strings of casing were set from surface to 317', 728', 2252' and 6289' respectively. A liner was hung in the last string of casing at 5733' and bottomed at 8398'. The fourth string of casing was perforated with 2 shots per foot over the gross interval of 4562' to 5137' for a net length of 63 feet. The liner was opened between 7406' and 7574' with 4 shots per foot for a net opening of 120 feet.

The perforations in the fourth string of casing produced gas, oil and condensate from sands of the Latrobe Valley Coal Measures of Eocene age, while the Upper Cretaceous (unnamed) formations produced gas and condensate from perforations in the liner (7406' - 7574').

The Completion Report in respect of this drilling operation was submitted by Esso Exploration in 1966. The operation was approved for subsidy payment under the Petroleum Search Subsidy Act 1959-1965.

PRELIMINARY COMMENTS

The matrix of most petroleum reservoir rocks is non-conductive of electricity. Any electrical flow which does occur in a formation is by virtue of the aqueous fluids contained in the pore spaces of the rock. Electrical flow through the pore spaces is, in turn, controlled by the salinity and distribution of the formation water in addition to the porosity of the rock.

The electrical properties of a reservoir rock are measured in terms of resistivity. This is defined as the resistance in ohm-meters to current flow through a volume of rock having a unit of length and a unit of cross-sectional area.

A fundamental concept in considering electrical properties of reservoir rocks is that of the Formation Resistivity Factor (FF). This represents the electrical resistivity (Ro) of a porous medium saturated with water, to the resistivity (Rw) of the water itself.

This is an important relationship in electric log interpretation, for knowing Rw, and FF in a particular formation, Ro can be calculated to give the resistivity of the formation when fully saturated with formation water. Any additional resistivity measured in the formation must therefore be due to oil and gas (non-conductors).

The Formation Resistivity Factor is a constant for water of varying salinities, and as such can be related to formation porosity by the following formula :

$$\frac{Ro}{Rw} = FF = \frac{1}{\phi^m}$$

The exponent (m) of this formula is derived from the slope of the porosity vs Formation Factor plot. It is called the Cementation Factor, and is also a constant. It indicates the degree of induration or cementation of a reservoir rock, and ranges from 1.4 for very loosely-cemented, to more than 2.0 for very highly-cemented rocks.

The correlation which exists between porosity and FF for a given formation, generally allows a simple evaluation of one parameter in terms of another. Thus, knowing the porosity, and the Cementation Factor from a lithologic investigation, a value for the Formation Resistivity Factor can be predicted. A somewhat similar relationship exists for permeability and FF but is much more subject to variation from heterogeneity of a formation, making the predictions in this case rather unreliable.

PROCEDURE AND APPARATUS

Sixteen $1\frac{1}{8}$-inch diameter plugs were diamond-drilled parallel to bedding out of five cores, and trimmed to a minimum length of $1\frac{1}{4}$ inches. They were extracted with toluene and oven-dried at 110°C for 24 hours. Porosity was then determined in a Ruska mercury porosimeter, and permeability (to dry nitrogen) in a rubber-sleeve Hassler-cell permeameter.

Formation resistivity tests were carried out in a Core Laboratories type core resistivity apparatus (Figure 1). This equipment consists of a dip-cell for measuring the resistivity of formation water, and a core sample holder with spring-mounted electrodes for determining core resistivity.

The resistivity tests were commenced by saturating the core samples with a 16000 ppm NaCl brine. The samples were allowed to remain in the brine for a period of 4 to 5 days, to establish ionic equilibrium.

Then, using the dip-cell as previously mentioned, the resistivity of the brine simulating the formation water was determined. Subsequently, the brine-saturated samples were each separately tested for resistivity by placing them between the electrodes of the core holder. A constant current of five milliamperes was induced through each of the samples, and the potential drop across the electrodes was measured with the system voltmeter. Electrical resistance in the core samples was calculated by means of the formula $R = \frac{E}{I}$. This value was then converted to resistivity in ohm-meters using the following formula :

$$Ro = R \left(\frac{A}{L}\right)$$

where A and L respectively represent the cross sectional area $(\text{meters})^2$ divided by the core length (meters).

Finally, to obtain a Formation Factor for each sample, core resistivity was expressed as a fraction of formation water resistivity $\left(\frac{Ro}{Rw} = FF\right)$. The slope derived from the plot of the Formation Factor values, vs. the porosity values is the Cementation Factor (1) of the formation.

DISCUSSION OF RESULTS

Results of these tests comprising porosity, permeability, and Formation Resistivity Factor determinations are listed in Table 1. A plot of the Formation Factor as a function of porosity is presented in Figure 2, while the position of samples used in the tests is shown in Figure 3.

The plot of porosity and Formation Factor (Figure 2) shows a good correlation between these parameters. Although the sixteen samples selected for testing covered a wide range of porosity (10% to 28%), deviations from the straight line plot through the points were at a minimum.

The Cementation Factor (m) derived from the slope of the above line was found to be 1.65. Using the classification system developed by Archie (1) and Pirson (2), this factor value places the formation in a slightly to moderately well-cemented category, with porosity ranging from less than 15% to more than 20%. This is consistent with the lithology of the formation samples and their porosities as shown in Tables 1 and 2.

A very poor correlation exists between permeability and the Formation Resistivity Factor of these samples. An attempt was made to plot these parameters, but point scattering was very severe. Archie (3) has stressed the hazzards of relying on permeability values predicted from a given Formation Factor or porosity, unless the formation is thick and of a very uniform nature. He has also shown that pore interconnections (pore structure) greatly affect the permeability, but have relatively little effect on electrical conductivity; this being the case where fluid flow and electrical flow are not analogous.

Since considerable heterogeneity exists in the lithology of the samples used in these tests, the poor correlation between the permeability-Formation Factor parameters is, therefore, not surprising.

CONCLUSIONS

Laboratory tests on cores from Marlin A-1 comprising porosity, permeability and Formation Resistivity Factor have shown that :-

1. Porosity of the samples tested varied from moderate to high (10% to 28%)

2. Permeability values for these samples were very erratic, ranging from 3 md. up to a maximum of 4700 md.

3. The formation resistivity factor values correlated well with porosity, giving a Cementation Factor of 1.65. There was a very poor correlation between the Formation Factor and permeability, emphasizing the heterogeneity of the pore structure in this formation.

REFERENCES

1. ARCHIE, G.E. "The electrical resistivity log as an aid in determining some reservoir characteristics". T.P. 1422; Transactions AIME; January, 1942.

2. PIRSON, S.J. "Oil reservoir engineering"; 2nd edition; page 107.

3. ARCHIE, G.E. "Electrical resistivity - an aid in core analysis interpretation". Bulletin AAPG; Volume 31, No. 2, page 350.

TABLE 1

Core Number	Sample Depth (feet)	Permeability (to dry nitrogen) (md.)	Porosity (% bulk volume)	Formation Factor
7	5066	3.0	17.2	18.3
8	5071	18	20.8	14.2
8	5075	87	27.0	7.6
8	5084	4.0	21.6	14.0
9	5097	13	15.3	19.6
9	5120	792	25.5	7.8
9	5121	667	27.7	8.5
9	5124	35	21.2	10.6
9	5128	350	26.3	9.8
10	5132	530	25.4	8.5
10	5146	172	9.9	48.0
10	5148	2020	16.4	20.2
10	5161	4700	25.8	9.6
11	5196	3400	20.1	15.9
11	5171	1100	21.3	12.8
11	5175	640	17.3	17.8

TABLE 2

Sample Depth (feet)	Sample Description
5066	Sandstone - very fine to fine grained, minor silt, shale and carbonaceous laminae.
5071	As above, slightly micaceous
5075	Sandstone - very fine grained, traces thin carbonaceous laminae
5084	As above
5097	Sandstone - fine to medium grained with traces silt and carbonaceous laminae
5120	Sandstone - fine grain, well sorted
5121	As above
5124	Sandstone - as above with traces of thin silty carbonaceous laminae
5128	Sandstone - fine grained, well sorted, slightly micaceous
5132	Sandstone - fine to medium grained, carbonaceous, slightly silty
5146	Conglomerate - coarse to pebbly, sub-angular grains in matrix of fine to medium grained sandstone
5148	Conglomerate - very coarse to pebbly consolidated inclusions, in matrix of medium to coarse grained sandstone
5161	Sandstone - medium to coarse grained
5169	Sandstone - medium to very coarse grained to pebbly
5171	Sandstone - fine to medium grained, sub-angular with well consolidated inclusions of medium to coarse grained sandstone
5175	Sandstone - as above

FIGURE 1.

CORE LABORATORIES TYPE RESISTIVITY APPARATUS.

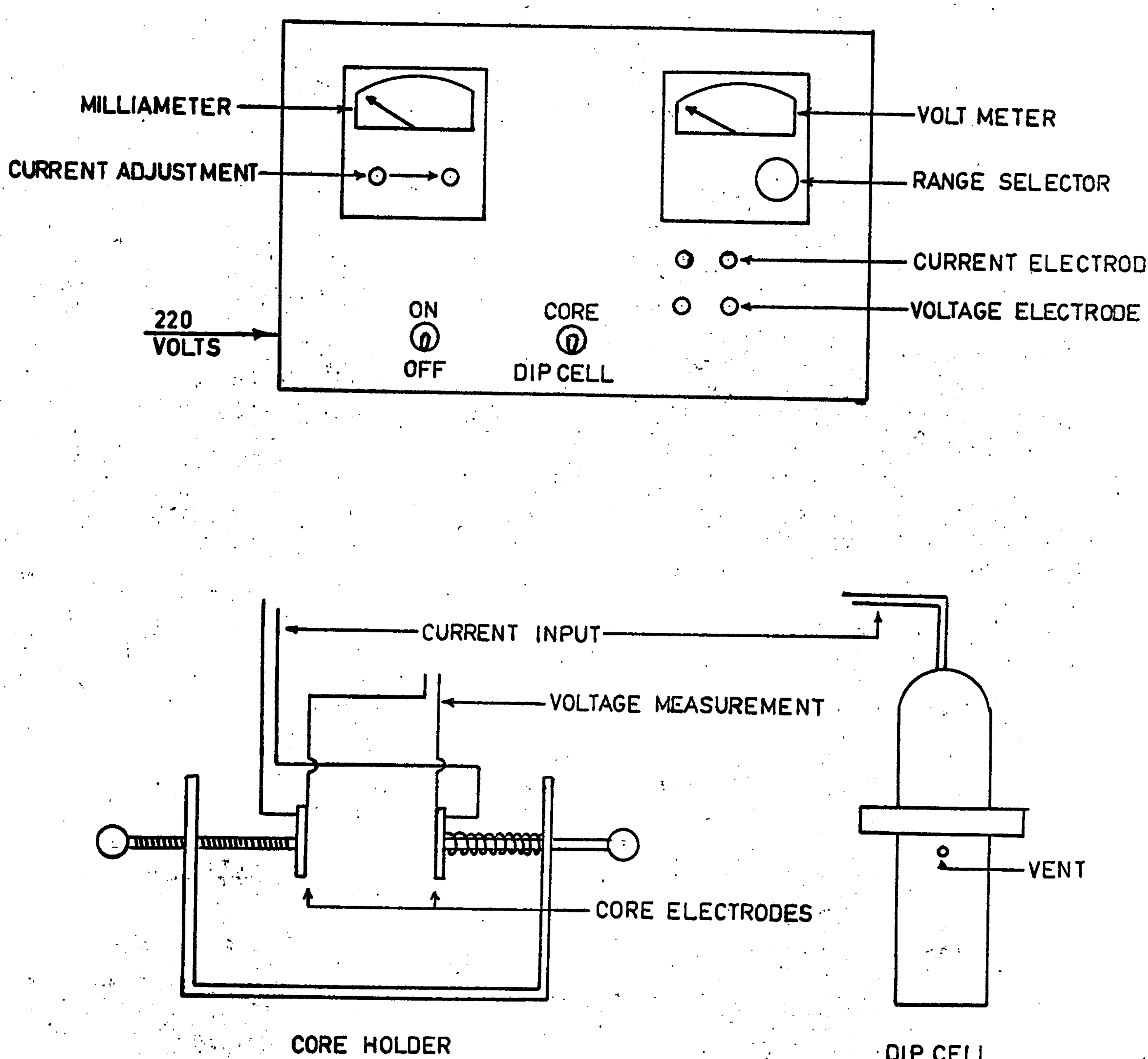

FIGURE 2

FORMATION FACTOR Vs POROSITY

WELL NAME AND NUMBER - MARLIN No A1

DEPTH INTERVAL - 5066' - 5175'

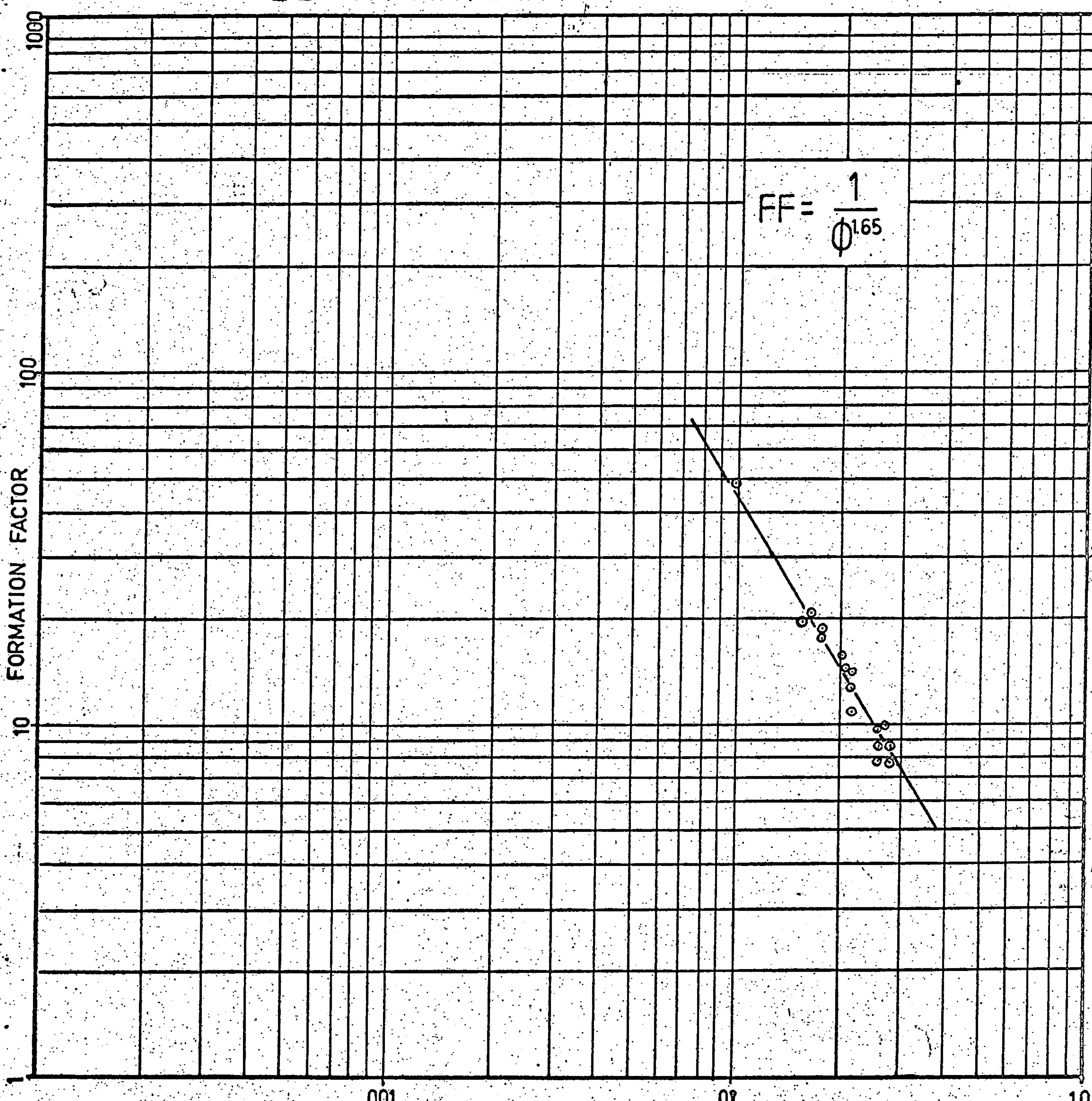

FIGURE 3

MARLIN No. A-1 ELECTRICAL LOG