POROSITY FROM CUTTINGS : OPTIONS AND ANSWERS

O.Meazza, M.Della Martera, A.Lyne (AGIP SpA)
M.Taylor (Baker Hughes INTEQ)
M.R. Saunders (Landmark - EAME)

ABSTRACT : RESULTS, OBSERVATIONS AND CONCLUSIONS

A representative set of control formation plugs was analyzed for grain density and porosity. From these plugs simulated cuttings of sandstone, limestone, dolomite, siltstone and shale in different size ranges (2-4 mm, 1-2 mm and 0.25-0.5 mm) were created and porosity was determined via NMR relaxometry (NMRR) and volumetric methods. From the data acquired in the laboratory, it was found that porosity could be evaluated with confidence using both methods when cuttings of dimensions greater than 2 mm are used. Both methods can be easily transferred on-site.

INTRODUCTION

Knowledge of porosity and its fluids are fundamentals of petrophysics. Primary porosity includes all pre-depositional and depositional porosity of a particle, sediment or rock. In a sedimentary rock, this is the porosity remaining during the final stages of sedimentation. Secondary porosity is that porosity developed through post-sedimentary processes, such as solution and fracturing.

POROSITY IN FORMATION EVALUATION

Traditionally, cores have been used to quantify reservoir porosity in exploration, appraisal and development wells. Upon penetrating a potential reservoir on an exploration well, cores would be routinely cut. Appraisal wells might subsequently core the entire reservoir. Over the last decade, there has been a trend away from coring exploration wells, saving that expense for the appraisal and development phases.
In the absence of core, wireline logs are routinely used to derive the actual in-situ formation porosity. Formation Evaluation Measurement While Drilling (FE-MWD) tools have been introduced in the last decade to measure porosity in-situ. Many deep wells are too hot or contain unstable formations which would either cause FE-MWD tools to exceed their thermal design criteria and fail, or risk being left behind in the hole. Although the operating window is continuously improving, either scenario is costly to both operator and service company, especially when a radioactive source is involved downhole.

Porosity from Mud Logging?

Mud logs are frequently used as a low cost, logging-while-drilling evaluation tool, and if additional quantitative information could be provided from an existing service, overall formation evaluation costs would be easier to control. Several possibilities were reviewed.

Traditional Mud Logging Data Sources

It has been widely recognized that the rate at which a bit can drill through a formation can be related to its porosity. REF MACPHERSON Various drilling porosities have been developed, although most have relied heavily on empirical relationships to drill rate, which may work well in discrete geographical areas. Mud gas has recently been used to derive a gas porosity, but this work was not available during the review phase of this project. REF WRIGHT
Thus, the obvious choice was to use the drill cuttings. Geologists have long described visual porosity in a qualitative way. One operator developed a method to derive porosity estimations from cuttings from certain geographical areas through intensive training of field and laboratory staff. REF SNEIDER ET AL. It was felt that this method may be less successful as a global tool.
Petrographic image analysis (PIA) on cuttings has aided many operators measure porosity. REF RINK ET AL. PIA appeared too labour-intensive for wellsite use, relying on accurate thin-sectioning equipment and a major capital outlay for equipment.

Porosity on Cuttings

Direct measurement of porosity on cuttings was needed. Laboratory measurements on core were initially reviewed. Traditional mercury pump pycnometry was considered unattractive for health, safety and environmental (HSE) issues. Gamma attenuation used in wellsite core logging services raised radiation issues, in addition to the challenges of scale. REF JANTZEN et al. A wellsite method using pulsed nuclear magnetic resonance on cuttings, developed by Chevron in the 1980's, was recognized as having potential. REF NIGH & TAYLOR

With the opening up of eastern Europe, other technologies become available. A wellsite cuttings porosity device was rumoured to exist and located through contacts in Europe. At the same time, it was felt that if porosity could not be measured directly, it could be derived by measuring bulk and grain densities and particle volume, and new technology was identified as having potential.
In addition to analyzing reservoir rocks, it was felt that non-commercial formations would also yield information related to abnormal formation pressures, wellbore stability, and fracturing. Geopressure evaluation required that porosities of claystones and siltstones would need to be measured, thus adding a potential level of complexity. The next step was how to move from review to research.

RESEARCH PROJECT STRUCTURE

GOALS / SUCCESS CRITERIA

Before any method could be correctly evaluated, success criteria were established. The method needed to be suitable for use on cuttings of any lithology preserving porosity. Although the prime benefit is for reservoir lithologies, the potential additional advantage of measurements on siltstones and claystones for geopressure evaluation would add to the overall value at the wellsite while drilling.
A performance triangle was established to balance the potentially conflicting needs for accuracy, speed and cost.

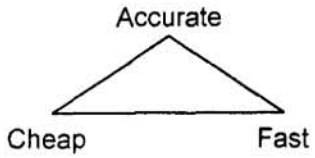

Figure 1 Success Criteria - Accuracy,Cost & Analysis Speed

Accuracy

Any proposed method would have to compete with traditional methods in the field of accuracy and repeatability. However, the issues of scale, and the inherent conservatism of cuttings porosity would result in natural differences to core porosity. Cuttings were expected to tend towards the matrix porosity of any formation.
Cuttings are measured at atmospheric pressure, to be compared to the in-situ measurements of FE-MWD and wireline logs. Hence it might be expected that relaxed formations, such as claystones, might yield higher porosities than existed in the subsurface.
Any method should be independent of atmospheric changes of pressure and temperature. This is critical for a method which may be installed in a pressurized logging unit and be at the mercy of weather changes while logging over an extended period. Additionally, such units operate in a range of working temperatures. Although they have temperature control, the unit interior would be subjected to temperature variations due to frequent exiting by the geologist to collect samples.
Bearing in mind these problems, it was felt that a suitable device should be capable of yielding a porosity within one Porosity Unit (pu). It was expected to be capable of repeatable results within one-half pu, when operated by different users.
Measurements should be possible on drill cuttings of a variety of lithologies, with the minimum sample size of three (3) by three (3) by three (3) millimetres and maximum sample size of ten (10) by ten (10) by ten (10) millimetres. The samples would be unorientable. Maximum feasible volume of samples of a particular lithology for each analysis was assessed to be two (2) cubic centimetres. Sample weighing accuracy of plus/minus 100 mg is deemed possible offshore on a floating drilling rig.

Speed

Any sample preparation in excess of thirty (30) minutes, with greater than five (5) minutes of continuous manual intervention, should be avoided. Batch preparation would be preferred. Continuous throughput of at least two (2) samples per hour, for at least twenty four (24) hours uptime, is preferred. The results should be rapidly available in digital form.
The porosity device should take no more than four (4) hours from installation to the end of calibration. Calibration duration of less than one (1) hour and calibration intervals of greater than twenty four (24) hours are recommended. The equipment was to be run at the wellsite by logging geologists, as part of a significant surface logging workload.

Cost and Dimensions

The device should cost less than US$20,000 and have a daily operating cost of less than US$20. This equipment should have a foot print of <1 m in length and <0.5 m width and height. It will be able to use the power, water and air utilities in the surface logging unit. It must adhere to both companies' HSE approved

practices, including noise limits. Because of evolving environmental regulations, neither potentially hazardous materials should be used nor result from the method.

PREPARATION OF STANDARDS

Lithologies chosen

To ensure that a representative set of control formation samples was used, sample core plugs from three different lithologies representative of Italian oil and gas reservoirs were selected: sandstones & siltstones (from both consolidated and poorly consolidated zones), limestones and dolomites. Three different sets of each lithology were chosen to check the validity of the new methods on cuttings from both hard and soft formations. During these tests, rock samples of very low volume (3.5 to 5 cm^3) were used. Porosity values of these samples ranged from 1% to 30% pu, and absolute permeability values ranged from 0.01 mD to 1 Darcy.

Core preparation and laboratory analysis

Initially, the core plugs were cleaned using chloroform to extract the residual oil, followed by a water / methanol mixture to extract residual salt. The samples were then put in a oven for 12 hours at 100 degrees Celsius. They were dry weighed and were placed in a cell, and a 10^{-4} millibar vacuum was applied for 8 hours. Then the cell was filled with the brine solution (3 g/L of NaCl) and the samples pressurized and saturated at 150 bars overnight. Finally, all samples were re-weighed to determine the saturated mass.

Sample pore volume was calculated, using:

$$V_p = (\text{Saturated mass} - \text{Dry mass}) / d \qquad (1)$$

where:

V_p = pore volume (cm^3)
d = density of brine (g/cm^3)

Total volume was determined by the difference in mass between saturated sample and saturated sample immersed in brine using Archimedes' law :

$$V_t = (\text{Saturated mass} - \text{Immersed mass}) / d \qquad (2)$$

where :

V_t = total volume (cm^3)

This procedure was followed to determine the porosity of dolomites, limestones and consolidated sandstones. To determine the porosity on poorly consolidated samples, a helium porosimeter was used.

The solid volume was determined using Boyle's law:

$$P_1 * V_1 = P_2 * V_2 = P_3 * V_3 = K \qquad (3)$$

where:

P = pressure
V = volume
K = constant

Total volume was determined using a rubber sleeve. It was adhered and pressed on the sample until a certain pressure was achieved. Total volume calibration was constructed using calibration samples. From total and solid volume, sample porosity can be calculated using :

$$\phi = \frac{V_t - V_s}{V_t} 100 \qquad (4)$$

where:

ϕ = porosity (%)
V_s = solid volume (cm^3)

Pseudo-cuttings preparation

The sample core plugs were crushed to obtain three different size ranges of cuttings with the following dimensions : **2 mm to 4 mm , 1 mm to 2 mm , 0.25 mm to 0.50 mm** .

METHOD - A

Theory

The determination of open porosity is based on the measurements of two volumes:

- solid phase volume (matrix)
- bulk (external) volume

The solid phase of the sample is measured by gas and volumetric method based on Boyle's Law, using:

$$P_1(V_1 - V_{ma}) = P_2(V_2 - V_{ma}) \quad (5)$$

where:

V_1	initial gas volume in the measuring chamber
P_1	initial pressure
V_2	gas volume in the chamber at the time when pressure P_2 is achieved
P_2	working pressure
V_{ma}	matrix volume

The bulk volume is determined by the free-flowing material volume change when a sample is placed into the measuring chamber.

Equipment

The tool consists of a measuring chamber with a piston. The measuring chamber is filled with free-flowing material comprising minute glass beads (0.3 - 0.5 mm size). These beads fill all the irregularities of the sample and permit measurements to be made of samples of any geometrical form. A microprocessor controls the acquisition and the processing of the data.
The manufacturer's tool specifications are as follows:

- Measurement range:
  - external volume 3 - 5 cm^3
  - porosity 0 - 60%
- Porosity measurements
  - accuracy 1%
- Dimension 380 x 240 x 160 mm
- Mass 9 kg
- Power consumption 60 W
- Data display digital

The tool is designed for and suitable for rig site use.

Equipment Operation

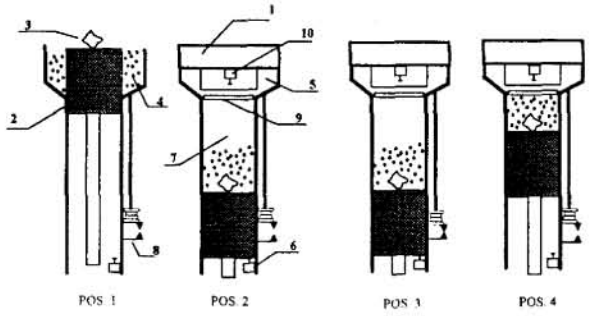

Figure 2 Method A - Equipment Operation

In the initial position (POS. 1) the cover of the tool (labeled 1 in subsequent drawings) is removed. The piston (2) is in the uppermost position, and the sample (3) is placed on the top of the piston. Free-flowing beads (4) are contained in the hopper (5).
In operation, the piston (2) moves downwards until it contacts element 6 (POS. 2). Beads pour out from the hopper (5) and cover the sample. The cover (1) seals the cylindrical chamber (7) and simultaneously plugs the hopper.
During measurement, the piston (2) moves upwards and compresses the air chamber (7) above the piston. At the moment when the pressure in space 5 above the piston reaches a certain value as determined by a pressure sensor (8), the displacement of the piston from the lowermost position is calculated and the solid phase volume is determined.
The piston continues to move upwards until the beads (4) contact a spring-loaded stop (9). At contact, the "mirror" of the latter is leveled, after which element 10 comes into action and the external sample volume can be determined.
With external sample and solid phase volumes known, the measurement is complete, and the porosity factor (K_p) can be defined using:

$$K_p = 1 - V(\text{solid phase}) / V(\text{external}) \quad (6)$$

Sample preparation

Open porosity measurements can be performed using core plugs as well as drill cuttings. The optimum sample shape is a cylinder with the cross section of 30 x 30 mm. The total volume of cuttings should not be less than 1.5 - 2 cm^3 with the volume of each fragment not less than 0.2 cm^3. For reliable results, the minimum cuttings size is 2 mm.
Before analysis, the sample should have residual fluids removed and be dried. During the analysis, the physical and chemical properties of the sample are not disturbed, making it possible to repeat the analysis or to store the analyzed sample. It is preferable to repeat each analysis three to five times for good statistics. Between each analysis, all the fragments within the measuring chamber have to be recovered. Each analysis (calibration and five repeats) take about thirty minutes.

Calibration

Before each analysis, primary and secondary calibrations are performed as follows:

- primary calibration without standard reference
- primary calibration using 20 cm^3 standard reference
- secondary calibration using 2 cm^3 standard reference

The standard references are metallic cylinders of zero porosity such that the bulk and the matrix volumes measured during the calibration should be equal or within an admissible difference.

Computations

The tool measures the bulk and matrix volumes and derives an apparent porosity. The open porosity is computed using:

$$\phi\ \% = [1 - 1.0877\ (V_{ma}/V_t) \times 100 - 10.6] \quad (7)$$

where:

V_{ma} matrix volume
V_t bulk volume

The open porosity is computed too using :

$$\phi\ \% = (1.091 \times \phi_{app.}) - 19.7 \quad (8)$$

where:

$\phi_{app.}$ apparent porosity derived by the tool

The first algorithm is preferable.

METHOD - B

Theory

This determination of porosity is based on measurement of the following :

- mass
- solid phase volume (matrix)
- bulk volume

The mass is determined by direct measurement. The mass of the sample was determined using a milligram pan balance accurate to 4 decimal places.
The solid phase volume is determined by Boyle's Law shown in equation 5, above. The dried sample is placed in a closed chamber of fixed volume, through which helium gas is passed. The helium occupies the effective porosity volume of the sample. During the test, a number of purge cycles through the chamber remove any remaining sample humidity and the changes in the gas volume are measured until the readings have stabilized. Once stabilized, a mean average of stable readings is used to derive a matrix volume (He).
The bulk volume device used was a prototype, and its design is covered by a confidentiality agreement with the manufacturer.

Equipment

The pycnometer consists of a fixed volume measuring chamber, a sample cup, and a microprocessor controller with digital display and keypad. During the test, the chamber is filled with dry helium gas and pressure, temperature and gas volume are measured. It is possible to use dry air in place of helium, but with reduced accuracy.
The manufacturer's tool specifications are as follows :

• Sample chamber sizes:	10 mL standard range 1 to 100 mL
• Sample volume:	0.5 to 100 mL
• Volumetric accuracy:	0.03%
• Volumetric precision:	0.01% - 0.02%
• Measurement range:	
• porosity	0 - 60%
• Humidity range:	20 - 80%
• Dimension	310 x 175 x 360 mm
• Mass	19.1 kg
• Power consumption	60 W
• Data display	digital

The device is suitable for bench-top wellsite laboratory use. It is robust and fully compensated for variations in temperature and ambient pressure which may take place during analysis.

Methods

The samples used were about 5 cm^3 for pycnometry and 10 cm^3 for bulk density measurements. The prepared sample was weighed in a milligram balance to determine its mass. It was placed in a sample cup, sealed into the measurement chamber of the pycnometer, and the mass entered via the keypad. The device then performs a number of programmed purge and measurement cycles until the volumetric determination was within tolerance. The device then calculated the matrix density.
Another portion of the sample was transferred to the bulk volume device and the results of both instruments were then used to derive the porosity. Attempts to derive porosity to the required degree of accuracy directly from the comparative masses of dry and wet sample were unsuccessful.

Calibration

Calibration of these instruments is essentially automatic.

Computation

The matrix volume and mass were used to derive a matrix density. The matrix density was then combined with the bulk density to give a porosity using:

$$\phi\ \% = (\text{Matrix density} - \text{Bulk density}) * 100 / \text{Matrix density} \qquad (9)$$

NUCLEAR MAGNETIC RESONANCE METHOD

Introduction

As a preliminary investigation into the determination of porosity on cuttings by the NMR technique, measurements were carried out on a reduced set of cutting samples (sandstone, limestone and dolomite) with dimensions of the order of 4mm.

Theory

Many nuclei, including the hydrogen nucleus (or proton, 1H) possess magnetic moments and angular momenta. In the earth's relatively weak magnetic field, the magnetic moments of a mass of hydrogen nuclei, as, for example, in water, are randomly orientated, and no net magnetisation is observed. In a static magnetic field, B_0, there is a slight tendancy for the magnetic moments to align themselves with the magnetic field resulting in a net magnetisation, M_0. The effect of B_0 on the angular momenta is precession of M_0 about the axis of the static magnetic field. The frequency of this precession depends on the nucleus and on the strength of B_0. Application of a second magnetic field cscillating at the precession (or resonance) frequency causes M_0 to rotate away from its alignment with B_0. In practise, this rotation is achieved through the application of electromagnetic pulses at the resonance frequency. The duration of the pulse determines the degree of rotation away from the B_0 axis. At the end of the pulse, return to equilibrium i.e. realignment along the B_0 axis, referred to as NMR relaxation, is achieved by transfer of energy from the nuclei to the surrounding lattice. The signal emanating from relaxing 1H nuclei is measured, and from its amplitude and rate of decay, various petrophysical parameters can be determined. The amplitude of the decay curve is proportional to the number of 1H nuclei and hence, to the quantity of water. Comparison of the amplitudes of standard solutions of known water content with a fully saturated sample of rock allows the calculation of the water content of the rock sample. Once the rock sample's volume is known, its volume can be calculated.

Method

Artificial cuttings of the class ">4mm" were saturated in brine following the recommended practise for core resaturation. In general, a set of three or four cuttings of average volume 0.62cm^3, were removed from the brine, patted with tissue paper to remove excess surface water, and wrapped together in clingfilm to avoid evaporation during measurement. The instrument used was a MARAN-2 pulsed NMR spectrometer which operates at a resonance frequency of 2.2 MHz. The operating temperature was set at 29°C. The CPMG sequence was used to measure the transverse (T2) relaxation curve with interecho spacings of 460μs. To increase the S/N ratio, a high number of averages was acquired for each set of cuttings. This varied from 512 to 2048, depending on the porosity, and required up to 30 minutes. Comparison of the signal amplitude from each sample to the amplitudes of three standard solutions containing known quantities of H_2O in D_2O gave the volume of H_2O in each set of cuttings. The volume of the cuttings was determined by:

$$(M_{sat} - M_{imm}) / \rho_{brine} \qquad (10)$$

where M_{sat} is the mass of the saturated cuttings; M_{imm}, the mass of the saturated cuttings immersed in brine and ρ_{brine}, the density of the brine. A milligram balance was used for theweighings. The porosity (%) is determined from:

$$\text{(Volume of brine in cuttings/Volume of cuttings)} * 100. \qquad (11)$$

RESULTS

METHOD - A

Laboratory Testing

Before planning an extensive test of the method a feasibility study was carried out. Measurements were performed with core chips and the results were compared with the porosity measurements from core plugs. This feasibility test yielded promising good results. Because of the technical limitations of the tool, it was only possible to perform analyses with the 2 - 4 mm samples. Smaller fragments were not tested because of their incompatibility with the minute glass beads.

Repeatability Testing

According to the test procedures, a preliminary test was planned to verify the measurement repeatability level. Repeatability tests performed with two sandstone and one dolomite samples suggested a standard deviation within one decimal place for bulk and matrix volume analyses. Average standard deviations of

derived porosity values is about two (2) for analyses repeated three to six times. Further analyses have confirmed a higher value of standard deviation.

Pressure and Temperature Testing

Tests were performed to evaluate the influence of temperature variations. The analyses were performed inside a thermostatic laboratory, at increasing temperature steps: **13°C - 22°C - 27°C**. Porosity decreases with temperature, but not dramatically. Starting from 13° C (Phi = 7.06% pu) to 27°C (Phi = 6.14% pu). The porosity drop was 11%.
Environmental pressure variations are very critical. One test was performed at constant temperature on a limestone sample using two pressure steps: **1001 mb - 961 mb** . Porosity values ranged from 12.58% pu at 961 mb to 6.67% pu at 1001 mb for a decrease of 54%.

METHOD - B

Laboratory Testing

A feasibility study carried out before the extensive testing gave very good results. Extensive testing was subsequently performed.

Repeatability Testing

Repeatability of bulk volume measurements is very good, with standard deviation within fourth places of decimals. Derived porosity repeatability is within first places of decimals.

Pressure and Temperature Testing

The instruments are compensated for environmental conditions and neither temperature nor pressure tests have been performed.

INTERPRETATION

Evaluation of the various techniques for the determination of porosity from cuttings was done by comparing the resulting data with the conventionally measured porosity data of the 1" x 1" cores from which the cuttings were obtained. On a plot of cuttings porosity against core porosity, one would ideally expect to find the points lying along the 45° line. Goodness-of-fit was determined by the correlation, r^2 , of the various sets of data with respect to the 45° line.

METHOD - A

It is possible to point out two different trends: one for dolomites and sandstones, and a second for limestones (Fig. 3). Sandstone and dolomite points, with the exception of one dolomite vuggy sample no. 22 (see TABLE 7 and 8) lay along a 45° best fit line.
Absolute deviation, within the range of ± 2 %, shows a good correlation between core plug and core chips porosity measurements., with correlation coefficients (r^2):

- r^2 = 0.93 (sandstones)
- r^2 = 0.67 (dolomites)

The limestone correlation trend line is quite different, due to primary porosities exhibited by sandstones and dolomites, and vuggy porosity for limestones. The correlation coefficient is worse (r^2 = 0.25) than dolomite and sandstone.

METHOD - B

Measurements by method B (Fig. 4) confirm the correlation trend from method A. Regression coefficients of dolomite and sandstone samples (2 - 4 mm size) are :

- r^2 = 0.79 (sandstone)
- r^2 = 0.78 (dolomite)

The limestone correlation coefficient is worst (r^2 = 0.26),due to vuggy porosity.
Results from 1 - 2 mm chips show worse trends and coefficients, in particular : sandstone (r^2 = 0.57), dolomite(r^2 = 0.32). Results from smallest fragments (0.25 - 0.5 mm) proved quite unreliable. 2 mm is the minimum cutting fragment size necessary to achieve meaningful porosity values.

NMR METHOD

TABLE 1 shows the porosity of the cuttings from NMR measurements compared with the porosity determined by conventional methods on the core from which the cuttings were obtained. These data are shown graphically in Fig.5. The best fit was obtained for the limestone cuttings (r^2 = 0.878). Sample L8, which has the greatest discrepancy between core and cutting porosity values, was the only vuggy sample of the limestone set. The NMR value is a measure only of the rock matrix porosity, the cuttings not including vugs, so in this case it is quite reasonable to find the NMR cuttings porosity lower than that of the core.
The dolomite cuttings, on the other hand, have the lowest corelation coefficient (r^2 = 0.524). All samples have their NMR cuttings porosity overestimated with respect to their core values. When NMR consistently overestimates porosity with respect to conventionally determined porosity, it often means that both methods are not measuring the same parameter. NMR measures the total water content, and therefore the total porosity, of a rock sample, be it core or cutting. Conventional methods, on the other hand, take account of effective porosity, which may be equal to or less than total porosity. In the case of the three dolomite formations selected for this study, all had non-connecting, water-filled pores which result in effective porosity being less than total i.e. conventionally measured values less than NMR values.
Finally, the sandstone cutting porosities are well correlated with their corresponding conventionally determined core porosities with an r^2 of 0.842.

SCALE EFFECTS CORE TO PSEUDO-CUTTINGS

Several porosity measurements were carried out on different sized chips to check if the dimensions of cuttings can affect the porosity measurement. Significant differences in porosity were found between the smallest cuttings and the original plugs. The resolution of the apparatus to determine the porosity on cuttings is believed to be satisfactory down to 2 mm cuttings.
Differences with respect to conventionally measured data arise from two factors :
- porosity from cuttings does not take vuggy porosity into account (this problem is common to all methos applied to cuttings).
- NMR measures the total porosity which is higher than the effective porosity measured by other methods whenever lithologies with non-connecting pores are concerned.

SHALE AND SILTSTONE

Porosity measurements were performed with non typical reservoir lithologies: shale and siltstone. Analyses with siltstone samples performed by method B gave reliable results, while those with shale performed by the method A were unreliable.

CHALLENGES FOR FIELD IMPLEMENTATION

Having identified different devices and identified the strengths and weaknesses of data from each, the applicability of the method to real cuttings needs to be considered. The bit / rock interaction varies with the major bit types. Roller cone bits, such as milled tooth and insert bits, crush the formation along induced fractures, which preferentially follow the paths of least resistance through the porosity. They thus preserve particles of lower than in-situ porosity, but that porosity is largely intact. Fixed cutter bits, such as poly-diamond compacts (PDC) bits, gouge the formation and deform it in the case of plastic lithologies. Brittle formations yield small particles.

Regardless of the bit type, the path from the bit to the surface collection point may result in further mechanical damage. Mixing of larger and smaller particles from one sampling interval with similar sized particles from above and below that interval results in individual thin layered lithologies being difficult to differentiate. At the surface, cuttings are usually accumulated to represent gross intervals, more at the depth resolution on seismic methods, rather than the greater resolution of wireline and FE-MWD logs, and the target resolution of core data.
Sample processing both at the wellsite has traditionally been subjective, resulting in increased error bars in cuttings data. Workload in the modern surface logging unit precludes the use of laboratory grade equipment, and the misperception of "mud logging" being only qualitative hinders the acceptance of innovative quantitative methods.

CONCLUSION

The laboratory testing of these three devices indicated that further improvements would be called for to improve the accuracy of the device A, while the system B does not deliver a satisfactory cost performance relationship, given the anticipated daily costs for the surface logging industry. The MARAN-2 spectrometer has, in the past, been successfully transported to off-shore well-sites.There, once cuttings of large enough volume (of the order of 0.5 cc) have been saturated, porosity determination can be achieved in 30 minutes.

TABLES:

1. NMR Method : Porosity results
2. Results (Methods A and B)
3. Comparisons (Methods A and B)

FIGURES

1. Success Criteria - Accuracy, Cost & Analysis Speed
2. Method - A : equipment operation
3. Method - A : core plugs vs. core chips
4. Method - B : core plugs vs. core chips
5. NMR Method : core plugs vs. core chips

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TABLE 1 NMR porosity results

Sample	phi core	phi cuttings NMR
	%	%
S1	19,9	19,2
S2	17,1	15,8
S3	12,4	10,7
S4	17,7	17,5
S5	18,3	14,8
S6	20,5	16,9
S7	26,2	28,3
S8	17,1	17,6
S9	11,7	13,5
S10	13,3	11,7
S11	14	14,5
S12	9,2	10,9
S13	6,9	9,1
S14	8,6	10,0
L1	13,09	11,3
L2	20,5	20,7
L3	18,82	19,8
L4	22,01	17,7
L5	8,45	10,0
L6	2,84	4,6
L7	5,78	7,1
L8	15,7	15,4
D1	4,7	11,3
D2	20,56	24,0
D3	1,48	7,5
D4	15,15	17,9
D5	2,28	5,9
D6	12,12	15,0
D7	6,46	7,9

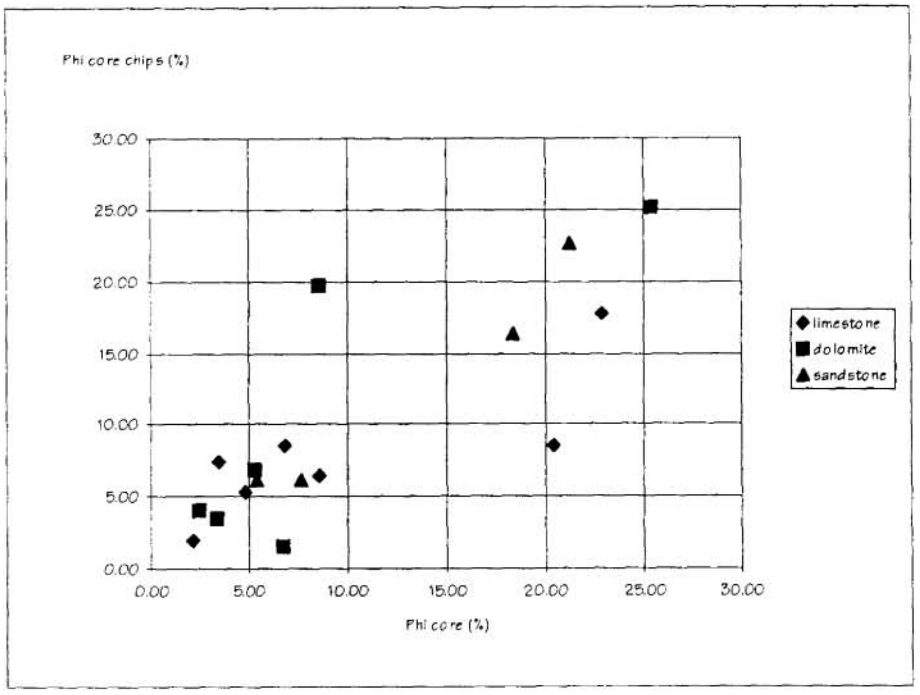
TABLE 2 Results (Methods A and B)

SAMPLE	DRILLER DEPTH	METHOD A POROSITY	METHOD B POROSITY	CORE PLUG POROSITY	WIRELINE LOG POROSITY	METHOD B DENSITY	CORE PLUG DENSITY	Ko	Kh	CORE CHIPS SIZE	LITHOLOGY
	m	%	%	%	%	g/cc	g/cc	mD	mD		
1	outcrop	22.65	21.53	21.23		2.67	2.66	581		2 - 4 mm	sandstone
2	outcrop	16.35	17.96	16.36		2.65	2.66	1021		2 - 4 mm	sandstone
3	3161.1	6.45	9.39	8.58	10.70	2.72	2.72	34.35	7.01	2 - 4 mm	limestone
4	5811.4	6.78	8.38	5.26	4.80	2.85	2.85	0.01	1.6	2 - 4 mm	dolomite
5	1567.5	6.12		3.63	nn		2.70	0.1		2 - 4 mm	sandstone
6	1567.8		9.19	5.45	nn	2.69	2.69	0.15		2 - 4 mm	sandstone
7	2798.9	6.20		7.65	7.50		2.67	0.21	0.16	2 - 4 mm	sandstone
8	2801		12.81	9.35	10.70	2.71	2.67	0.24	0.17	2 - 4 mm	sandstone
10	1189.7		35.92	27.24	15.00	2.66	2.65	549	416	2 - 4 mm	sandstone
11	1440.5	15.10		24.30	nn		2.76	0.2		2 - 4 mm	siltstone
12	1445		26.84	26.30	nn	2.70	2.76	0.24		2 - 4 mm	siltstone
13	3190.2	7.33	7.28	3.50	4.10	2.70	2.68	0.02	0.01	2 - 4 mm	limestone
14	3191.1	1.91	5.35	2.12	3.80	2.70	2.69	0.01	0.01	2 - 4 mm	limestone
15	3935.5	8.52	7.36	6.81	3.00	2.70	2.70	6.3	0.44	2 - 4 mm	limestone
16	3937	5.36	6.06	4.79	6.00	2.72	2.72	0.2	0.1	2 - 4 mm	limestone
17	3954.1	17.79	12.77	22.83	18.00	2.70	2.70	143	106	2 - 4 mm	limestone
18	3958.3	8.58	13.93	20.42	17.00	2.71	2.71	19.30	46.02	2 - 4 mm	limestone
19	5029.2	3.44	4.75	3.39	nn	2.82	2.81	0.09	0.03	2 - 4 mm	dolomite
20	5030.1	4.06	4.33	2.45	nn	2.83	2.83	0.07		2 - 4 mm	dolomite
21	5822.3	19.64	11.70	8.60	6.00	2.85	2.84	0.66	0.44	2 - 4 mm	dolomite
22	5826.2	1.55	9.23	6.76	4.00	2.85	2.84	0.19	0.54	2 - 4 mm	dolomite
23	2651.4	25.17		25.42	20.10		2.84	30.69	45.83	2 - 4 mm	dolomite
24	2653		19.91	17.78	27.50	2.85	2.84	0.11	0.1	2 - 4 mm	dolomite
25	outcrop		16.15	16.29	nn	2.66	2.65	1015		1 - 2 mm	sandstone
26	outcrop		21.13	21.23	nn	2.68	2.66	533		1 - 2 mm	sandstone
27	5818.6		6.79	1.93	4.80	2.85	2.84	0.55	4.52	1 - 2 mm	dolomite
28	3161.7		15.48	13.43	7.50	2.72	2.70	1.67	1.44	1 - 2 mm	limestone
30	1567.8		11.50	5.32	nn	2.70	2.69	0.17		1 - 2 mm	sandstone
32	1188.8		34.60	25.65	22.00	2.69	2.65	323	214	1 - 2 mm	sandstone
33	2799.5	13.40		7.46	8.50		2.66	0.21	0.14	1 - 2 mm	sandstone
34	1442		28.44	25.78	nn	2.67	2.78	0.21		1 - 2 mm	siltstone
35	3939.4		9.56	6.24	6.00	2.72	2.72	0.2	0.1	1 - 2 mm	limestone
36	3935.8		10.00	10.72	2.00	2.70	2.70	2.94	1.79	1 - 2 mm	limestone
37	3960.4		12.07	19.07	13.00	2.70	2.71	178	89.98	1 - 2 mm	limestone
38	3956.2		11.85	22.36	20.00	2.70	2.70	161	52.99	1 - 2 mm	limestone
39	3190.5	19.90	9.76	3.16	3.50	2.70	2.69	0.02	0.01	1 - 2 mm	limestone
40	5029.2		7.13	3.39	nn	2.82	2.81	0.09	0.03	1 - 2 mm	dolomite
41	5822.6		12.42	7.54	4.60	2.85	2.84	0.01	0.96	1 - 2 mm	dolomite
42	2651.8		34.73	17.55	19.50	3.38	2.83	0.8	0.17	1 - 2 mm	dolomite
43	5821.6		37.00	10.03	7.00	2.84	2.84	0.01	1.01	0.25 - 0.5 mm	dolomite
45	1189.4		38.42	27.10	26.00	2.69	2.65	564	493	0.25 - 0.5 mm	sandstone
47	1444.7		51.40	26.72	nn	2.69	2.78	0.21		0.25 - 0.5 mm	siltstone
49	3936.7		33.53	6.73	6.00	2.71	2.71	0.81	0.26	0.25 - 0.5 mm	limestone
50	3939.7		35.62	6.68	8.00	2.72	2.71	0.31	0.21	0.25 - 0.5 mm	limestone
51	3957.7		34.59	22.69	18.00	2.70	2.70	316	134	0.25 - 0.5 mm	limestone
52	3958.3		34.30	17.49	10.00	2.71	2.71	335	156	0.25 - 0.5 mm	limestone
53	5029.8		36.71	3.06	nn	2.84	2.83	0.1	0.02	0.25 - 0.5 mm	dolomite
54	5817.4		33.75	8.88	4.40	2.86	2.85	0.01	0.01	0.25 - 0.5 mm	dolomite
55	2652.4		35.34	19.98	11.70	2.85	2.82	12.65	2.03	0.25 - 0.5 mm	dolomite
56	3190.8	31.80	38.46	2.59	3.30	2.71	2.69	0.01	0.01	0.25 - 0.5 mm	limestone
Rshale1	1595.4	12.90		2.75	10.15		2.50			2 - 4 mm	shale
Rshale2	1792.2	23.41		3.93	19.48		2.59			1 - 2 mm	shale

TABLE 3 Comparisons (Methods A and B)

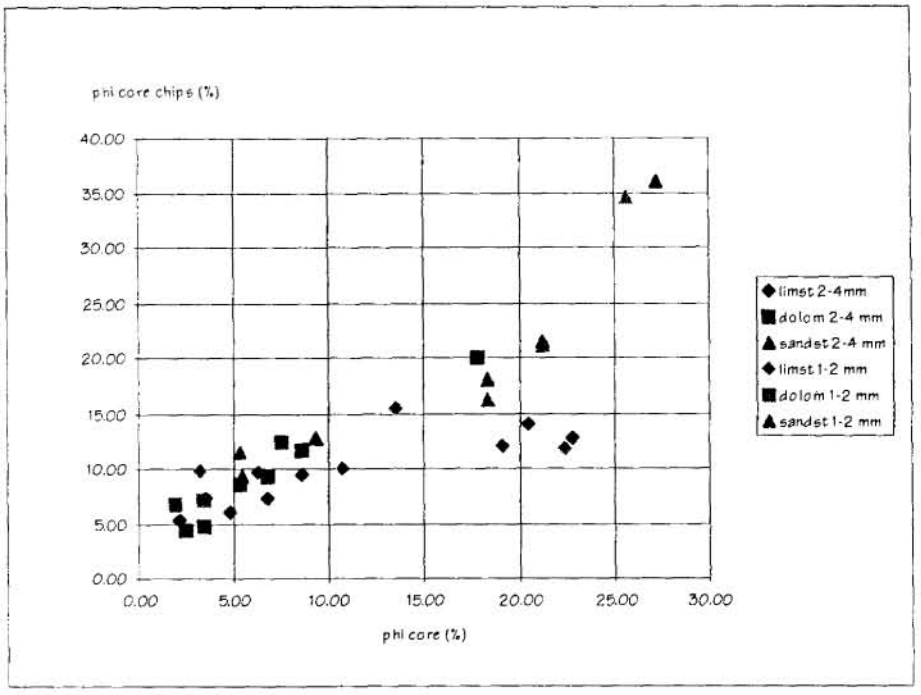
SAMPLE	METHOD A POROSITY	METHOD B POROSITY	CORE PLUG POROSITY	WIRELINE LOG POROSITY	DEVIATION vs CORE PLUG				DEVIATION vs WL			
					METHOD A ABSOLUTE DEVIATION	METHOD A %RELATIVE DEVIATION	METHOD B ABSOLUTE DEVIATION	METHOD B %RELATIVE DEVIATION	METHOD A ABSOLUTE DEVIATION	METHOD A %RELATIVE DEVIATION	METHOD B ABSOLUTE DEVIATION	METHOD B %RELATIVE DEVIATION
	%	%	%	%	%		%		%		%	
1	22.65	21.53	21.23		1.42	6.60	0.30	1.40				
2	16.35	17.96	18.36		-2.01	-10.90	-0.40	-2.10				
3	6.45	9.39	8.58	10.70	-2.13	-25.00	0.81	9.44	-4.25	-39.72	-1.31	-12.24
4	6.78	8.38	5.26	4.80	1.52	28.00	3.12	59.00	1.98	41.25	3.58	74.58
5	6.12		3.63	nn	2.49	68.50						
6		9.19	5.45	nn			3.74	68.60				
7	6.20		7.65	7.50	-1.45	-18.90			-1.30	-17.33		
8		12.81	9.35	10.70			3.45	36.90			2.11	19.72
10		35.92	27.24	15.00			8.66	31.80			20.92	139.47
11	15.10		24.30	nn	-9.20	-37.80						
12		26.84	26.30	nn			0.53	2.00				
13	7.33	7.28	3.05	4.10	4.20	140.00	4.22	138.00	3.23	78.78	3.18	77.56
14	1.91	5.35	2.12	3.80	-0.21	-10.00	3.23	152.00	-1.89	-49.74	1.55	40.79
15	8.52	7.36	6.81	3.00	1.71	25.00	0.55	8.00	5.52	184.00	4.36	145.33
16	5.36	6.06	4.79	6.00	0.57	12.00	1.27	26.50	-0.64	-10.67	0.06	1.00
17	17.79	12.77	22.83	18.00	-4.44	-19.00	-10.07	-44.10	-0.21	-1.17	-5.23	-29.06
18	8.58	13.93	20.42	17.00	-11.84	-58.00	-6.49	-31.80	-8.42	-49.53	-3.07	-18.06
19	3.44	4.75	3.39	nn	0.05	1.40	1.36	40.00				
20	4.06	4.33	2.45	nn	1.61	65.00	1.88	76.70				
21	19.64	11.70	8.60	6.00	11.04	128.00	3.09	35.90	13.64	227.33	5.70	95.00
22	1.55	9.23	6.76	4.00	-5.21	-77.00	2.47	36.50	-2.45	-61.25	5.23	130.75
23	25.17		25.42	20.10	-0.25	-0.10			5.07	25.22	-20.10	-100.00
24		19.91	17.78	27.50			2.12	11.90			-7.59	-27.60
25		16.15	18.29	nn			-2.14	-11.70				
26		21.13	21.23	nn			-0.10	-0.40				
27		6.79	1.93	4.80			4.86	251.80			1.99	41.46
28		15.48	13.43	7.50			2.05	15.20			7.98	106.40
30		11.50	5.32	nn			6.18	116.00				
32		34.60	25.65	22.00			8.95	34.90			12.60	57.27
33	13.40		7.46	8.50	5.94	79.60			4.90	57.65	-8.50	-100.00
34		28.44	25.78	nn			2.66	10.30				
35		9.56	6.24	6.00			3.32	53.20			3.56	59.33
36		10.00	10.72	2.00			-0.72	-6.20			8.00	400.00
37		12.07	19.07	13.00			-7.00	-36.70			-0.93	-7.15
38		11.85	22.36	20.00			-10.51	-47.00			-8.15	-40.75
39	19.90	9.76	3.16	3.50	16.74	529.00	6.60	209.00	16.40	468.57	6.26	178.86
40		7.13	3.39	nn			3.74	110.00				
41		12.42	7.54	4.60			4.86	64.40			7.82	170.00
42		34.73	17.55	19.50			17.15	97.70			15.23	78.10
43		37.00	10.03	7.00			29.97	269.00			30.00	428.57
45		36.42	27.10	26.00			9.32	34.40			10.42	40.08
47		51.40	26.72	nn			24.68	92.40				
49		33.53	6.73	6.00			26.80	398.00			27.53	458.83
50		35.62	6.68	8.00			28.94	433.00			27.62	345.25
51		34.59	22.69	18.00			11.90	52.40			16.59	92.17
52		34.30	17.49	10.00			16.81	96.10			24.30	243.00
53		36.71	3.06	nn			33.64	1099.00				
54		33.75	8.88	4.40			24.87	280.00			29.35	667.05
55		35.34	19.98	11.70			15.36	76.90			23.64	202.05
56	31.80	38.46	2.59	3.30	29.30	1172.00	35.87	1384.00			35.16	1065.45
Rshale1	12.90		2.75	10.15	10.15	369.00						
Rshale2	23.41		3.93	19.48	19.48	495.00						

Figure 3 Method - A : Phi core chips vs Phi core



Linear Regression coefficients	r^2
dolomite	0.67
sandstone	0.93

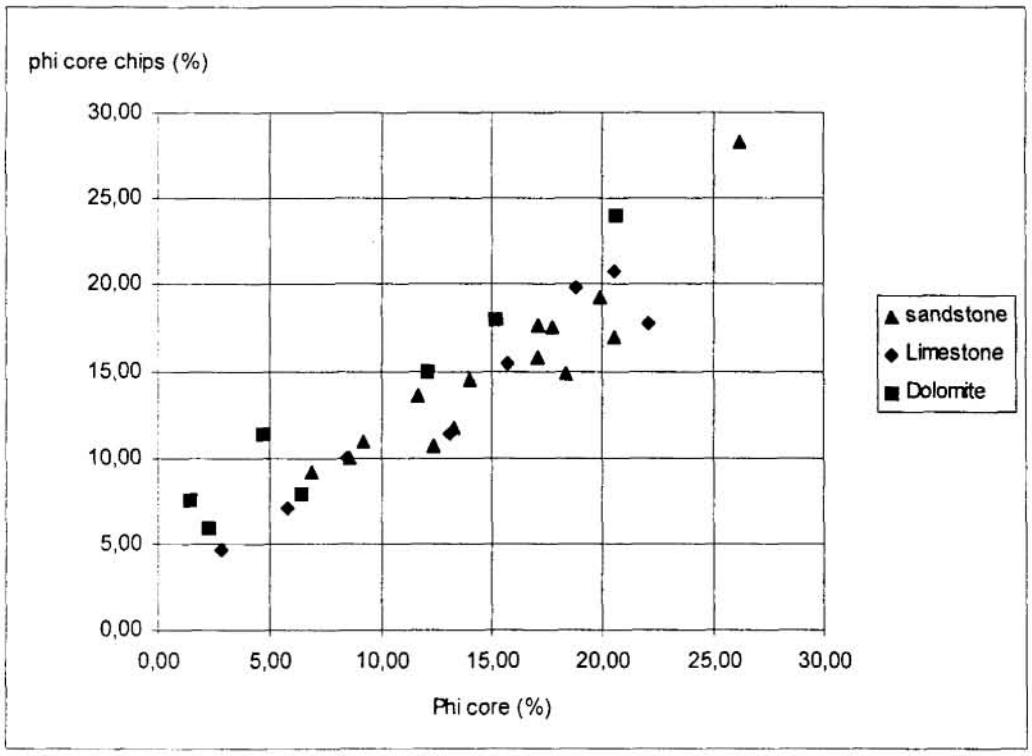
Figure 4 Method - B : Phi core chips vs Phi core



Linear Regression coefficients		r^2
2-4mm	dolomite	0.78
2-4mm	sandstone	0.79

Linear Regression coefficients		r^2
1-2mm	dolomite	0.32
1-2mm	sandstone	0.57

Figure 5 NMR Method : Phi core chips vs Phi core



Linear Regression coefficients	r^2
limestone	0.88
dolomite	0.53
sandstone	0.84