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A QUALITY CONTROL PROGRAM IN CORE ANALYSIS

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Abstract

Mobil's core analysis quality control program has two major parts. The first is a lab evaluation that we use to pre-qualify labs in various areas of core analysis. The second is a consistency check of routine and special core analysis data. Routine property measurements are repeated on a sub-set of samples at a second lab. Special core analysis data are compared against a database of measurements on similar samples tested under similar conditions.

Provided that consistent procedures are used, it is possible for most core analysis laboratories to reproduce measurements on high quality check plugs to +/- 0.3% in porosity, +/- 15% in permeability, and +/- 0.01g/cc in grain density. Some of the scatter remaining in the data appears to be systematic, and would probably be larger for plugs that are more irregular, smaller, or have lower porosity.

Introduction

Core analysis data are essential to log calibration, volumetric hydrocarbon-in-place calculations, recoverable reserve estimation, reservoir quality evaluation and other reservoir engineering calculations. Since 1992 Mobil Exploration and Producing Technical Center has coordinated a quality control program in core analysis for most Mobil E&P affiliates. The project originated with a need to document objectively the qualifications of 5 American labs performing a large volume of work for a major overseas affiliate. Since that time, we have evaluated 30 labs on 5 continents where Mobil has activities.

The QC program has two phases. The first is a lab evaluation that we use to pre-qualify labs in various areas of core analysis. It includes routine property measurements on a set of standard plugs and an on-site visit. The second phase is a consistency check of routine and special core analysis data. Routine property measurements are repeated on a sub-set of samples at a second lab. Special core analysis data are compared against a database of measurements on similar samples tested under similar conditions.

In this paper we will first describe the lab evaluation process, and discuss our interpretation of routine property measurements on check plugs reported by various labs. We will then describe several cases where follow-up internal consistency checks were used to identify data problems that would have otherwise gone unrecognized.

Lab Evaluation

The lab evaluation process is generally initiated by a Mobil affiliate, in preparation for an upcoming coring program. (Frequently these labs are located near that affiliate, and specialize in the services appropriate for local reservoirs.) A set of check samples is circulated among candidate labs. We request routine porosity, permeability and grain density measurements. Several whole core samples are also available to use where appropriate.

In addition, we collect information from Mobil personnel on their experiences with each lab. Generally this is the only source of information that we need to document a lab's business practices, including communication, documentation, reliability, etc. We also examine final reports on projects previously performed by each lab for Mobil, when they are available. Finally, we conduct an on-site inspection of each lab with a representative from the local Mobil affiliate that initiated the project.

All available information is used to develop a summary of the strengths and weaknesses of each lab in various categories. We also provide that affiliate with an overall recommendation, whether a lab is qualified or unqualified in areas of core analysis required to meet the needs of upcoming projects. Pricing is not considered as part of the lab qualification process.

On-Site Inspection

When Mobil has no recent project experience with any given lab, on-site inspections become the primary means of evaluating a lab's equipment and the qualifications of their personnel. We investigate and document technical capabilities in a wide range of activities, including wellsite services, core handling, screening, petrology, routine core analysis, and special core analysis. We ask them to describe their experience in each area, and we determine whether the equipment on hand is suitable to perform each type of analysis.

We also document a lab's business practices, which includes responsiveness, quality control practices, and the knowledge and experience of the personnel. We try to identify a few key technologists who will ensure that all tests will actually be performed properly. Interviews with experienced Mobil personnel are the primary basis of evaluating a lab's responsiveness.

Routine Property Measurements on Check Plugs

Ideally, check plugs should have the following properties:

(1) strength, in order to resist mechanical damage and changes due to repeated applications of stress; and

(2) stability, in order to assure that the measured properties are not strongly sensitive to environmental conditions, such as humidity and temperature.

Weak rocks, and those containing an appreciable amount of clay should be avoided.

Our QC check plug collection contains two general types of samples: (1) porous and permeable monolithic materials, including sandstones, limestones and ceramics, and (2)

composite assemblies which are enclosed in a thick wall metallic casing. The monolithic materials were obtained from various sources, while the composite metal assemblies were purchased commercially as a set.

Most of the samples that we routinely circulate are cylinders 3.8 cm in diameter and between 5.0 and 7.6 cm long. All of the data presented in this paper are for samples 3.8 cm in diameter.

The labs were given a set of general guidelines on how to prepare the samples and make the measurements. We requested that samples be dried in a vacuum oven at a temperature not to exceed 150 degrees F., and allowed to cool in a desiccator. Permeability was to be measured at a confining stress of 400 psi.

We also preferred that the labs measure pore volume at 400 psi, and use a combination of pore volume and grain volume to calculate porosity. However, some labs have used a bulk volume determination at ambient pressure. The labs are now prohibited from contacting the QC samples with liquids, so labs without an overburden pore volume capability must use a caliper method to determine bulk volume. Archimedes method may have been used by a few labs early in the program before we explicitly prohibited its use. (It is still the preferred method for bulk volume determination on whole core.)

Accurate porosity, permeability, and grain density measurements on these check-plug samples are a minimum standard for lab qualification. Generally, consistency with other labs is the only basis we have of gauging the reliability of a lab's measurements. We will show that most labs are reasonably consistent with one another on most measurements and on most samples. We will also show that some variability remains, probably caused by sample instability or details of technique or equipment.

Permeability Measurements

Figure 1 shows permeability measurements on a subset of samples at various laboratories. The data that we have on some samples and from some labs have been omitted deliberately in order to reduce unnecessary detail, and clarify the figure.

In general, the measurements on the lower permeability samples show much more consistency than the measurements on the higher permeability samples. All labs are challenged by permeability measurements above a certain upper limit. That limit varies from lab to lab, depending on equipment, expertise and experience. Undoubtedly, similar inconsistencies would have been observed at very low permeability if we had used samples in this range, as described by Thomas and Pugh (1). We currently use samples covering the range from 0.1 mD to about 40,000 mD.

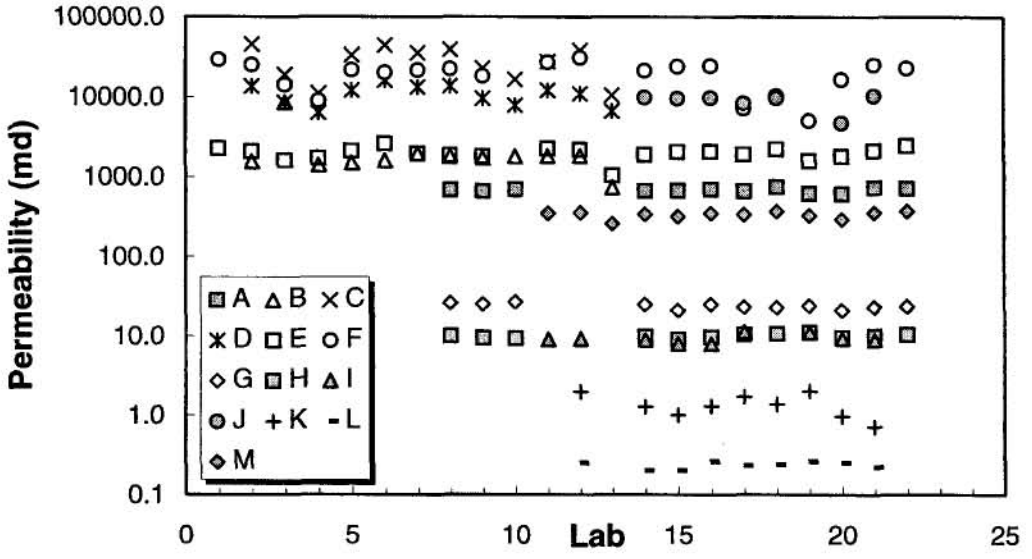

Figure 1. Permeability measurements on selected samples at various labs.

Lab 13 reported very low permeability values on all samples, even the one around 300 mD., and was classified as unqualified. Nine other labs could make reliable permeability measurements on samples as high as 2000 mD. Fourteen labs could extend the range of permeability measurements to above 20,000 mD.

The labs that understand fully the limitations of their equipment will report an upper limit on permeability when the samples exceed a certain threshold. (These lower limit data are not plotted in this figure.) Of the 9 labs with limited capabilities above 2000 mD., only one of them seemed to recognize it; 8 labs reported measurement with significant errors.

In this dataset we also observe that the least permeable sample (Sample "L") shows less scatter than the second least permeable sample (Sample "K"). On the basis of the expected error in measuring low flow rates, we would expect the least permeable to have the most error. In this case, we believe that Sample "K" itself is unstable. It is one of the metal encased composite assemblies, and contains numerous internal parts and rubber seals. We have observed on occasion that this, and several other composite samples, have produced very erratic permeability readings, deviating by orders of magnitude from the norm. We speculate that all of these inconsistencies may be explained if some of the seals within the assemblies are not functioning perfectly. (We should acknowledge that Sample "L" is also a metal composite sample, even though it had generally been more consistent.)

Grain Density Measurements

Grain density measurements on selected samples from various labs are shown in Figure 2. Some measurements are not included, as discussed in the previous section. We observe that lab-to-lab variations in grain density are usually no more than 0.01 g/cc. The values reported by Lab 16 are obviously erratic, and this lab has been classified as unqualified. The measurements reported by Lab 27 are consistently 0.01 to 0.02 g/cc low, suggesting a small systematic error. The lab subsequently checked the calibration of their balance and found that it did not meet specifications.

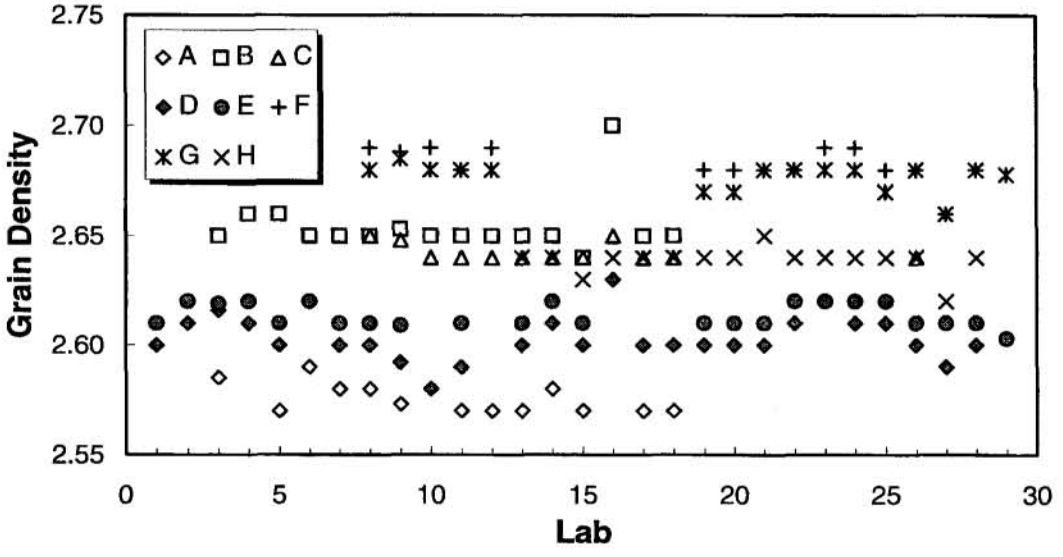

Figure 2. Grain density measurements on selected samples at various labs.

We also observe that grain density measurements on some samples are not as reproducible from lab to lab as they are on others. For example Sample "D" shows significantly more variation than other samples. It is plausible that the sample contains moisture absorbing minerals, and their density and volume change depending on sample handling procedures and laboratory conditions. We observed that this sample also showed a large variability in porosity.

Porosity Measurements

We have not required that the labs use one standardized method for determining porosity. Therefore, we found it useful to subdivide the data into two parts, depending on whether the labs used an overburden pore volume measurement or an ambient pressure bulk volume measurement.

The data plotted in Figure 3 actually represent the difference between the measured porosity and the median porosity for each sample using the overburden pore volume method. The median was used in preference to the mean because it is less sensitive to points deviating significantly from the main population.

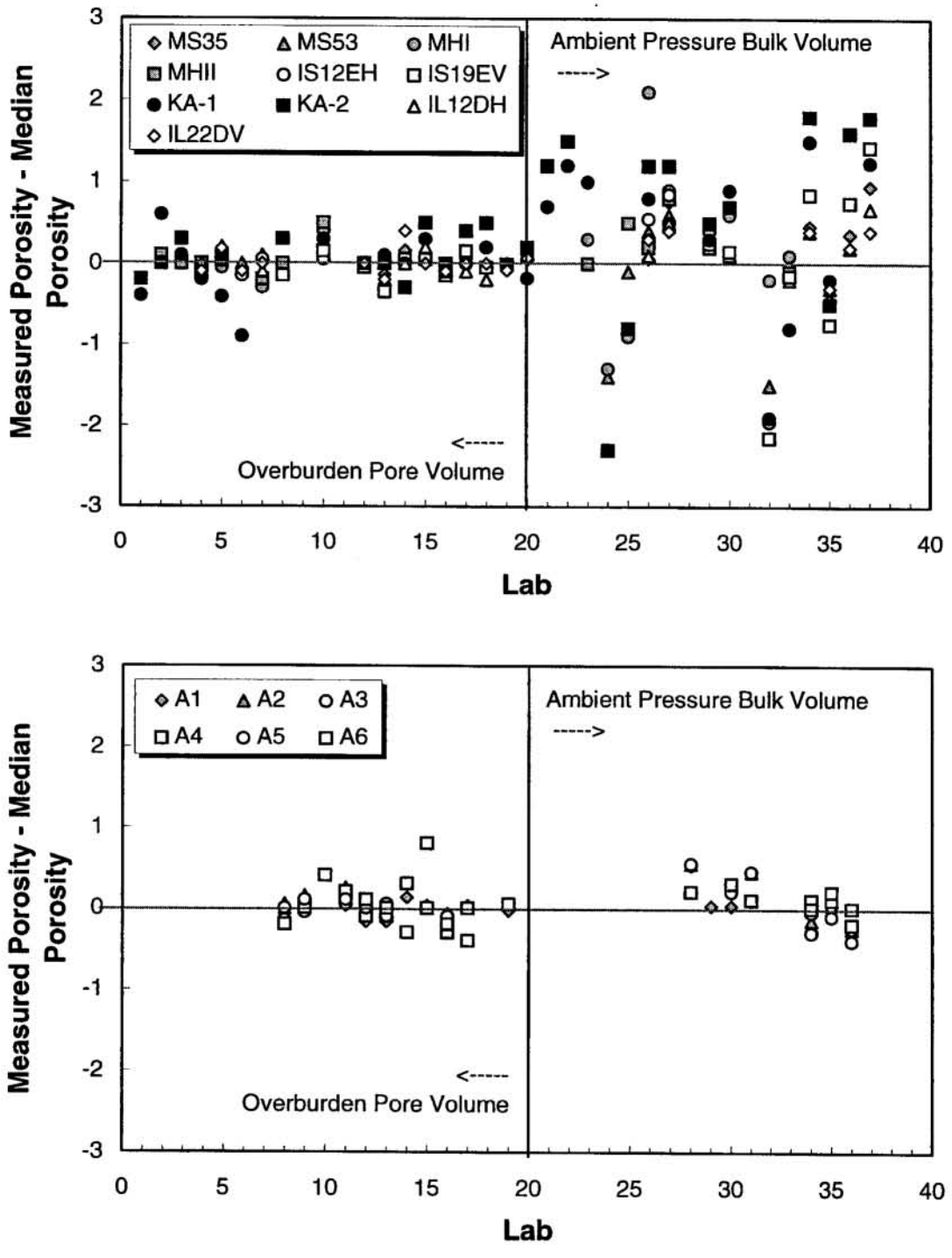

Figure 3. Difference between measured porosity and median porosity for samples in each of two classes: rocks and ceramics (top) and metal encased composite assemblies (bottom.).

We observe the following:

(1) Measurements using the overburden pore volume method are much more consistent than those using the ambient pressure bulk volume method.
(2) Porosity measurements on the metal encased composite assemblies tend to show more consistency, both from lab to lab and from method to method, than the rock and ceramic samples.
(3) Some rock and ceramic samples tend to show more variability than others, even when the method is the same. The most variable samples are KA-1 and KA-2.

Most of the inconsistencies in the data are readily explained by sample irregularity and surface roughness. Both KA-1 and KA-2 are coarse grained sandstones. Compared with other samples, they have a more irregular diameter, less straight axes, more chipped corners, and larger pores. The scatter in the porosity measurements on these samples, among the labs using a bulk volume determination, are readily explained by the intrinsic inconsistency of caliper measurements, and the cylindrical approximation.

The porosity values measured on these samples also tend to be more variable than on other samples, among the labs using the overburden pore volume method. This variability could also be related to sample shape: labs with thinner or softer boots would measure less pore volume than the labs using thicker or harder boots. This is because thin, soft boots would penetrate surface pores more effectively.

When the pore volume is determined directly under overburden pressure we can generally expect consistency of +/- 0.3% porosity. There is considerably more spread and a bias toward high porosity when it is determined from ambient pressure bulk volume measurements.

Discussion of Porosity, Permeability and Grain Density Data

On the basis of the data presented above, we would classify only one lab as entirely unqualified to meet any of Mobil's core analysis needs. (The lab singled out for irregularity in each of the three data sets was, in fact, the same lab). Other labs cannot produce reliable measurements on the high permeability samples, but most of them work primarily on low permeability rocks. Some of them also tended to do very well in whole core analysis.

Labs can generally produce porosity data consistent to +/- 0.3%, provided that pore volumes are determined directly at overburden stress. Grain density is generally consistent to +/- 0.01 g/cc. Permeability is consistent to +/- 10% among the samples with less than 1000 mD. permeability. The labs that do well with higher permeability samples can be consistent to +/- 15%.

The most disturbing inference from these data is that some labs do not appear to understand the limitations of their equipment. Of the 9 labs which cannot measure permeability reliably above 10,000 mD., only one appeared to know it. One other provided a quantitative estimate of error, but it was much too optimistic.

Repeat Measurements of Routine Properties on Selected Samples

While consistent check plug measurements are a minimum standard for lab reliability, they do not capture all of the potential problems of a routine core analysis job. We normally recommend that a sub-set of plugs, generally about 5%, be re-measured at a separate lab. In the last several years two significant lab problems have been identified when other labs could not reproduce the first lab's measurements.

Case 1. Low Permeability Measurements on Poorly Consolidated, High Permeability Sands

The lab performing the routine core analysis job had previously demonstrated consistent measurements on even the most permeable check plug samples. Furthermore, the technical skills of their staff were regarded as very strong. When a subset of plugs were re-measured at other labs much higher permeability values were reported. Some of these data are presented in Figure 4. When the samples were returned to the first lab, they once again reported low values.

The lab was presented with the data and they immediately acknowledged that they had a problem. After several days of testing their instrument, they determined that the problem was inside the cell at the interface between the loading pistons and the sample. Evidently, the screens on the ends of the plugs had extruded into the shallow distribution channels on the piston face, where they had become impacted with fines. As a result, the gas flow was restricted to the central orifice, resulting in low apparent permeability. The lab offered to remeasure permeability on the entire set of plugs from this core at no additional cost.

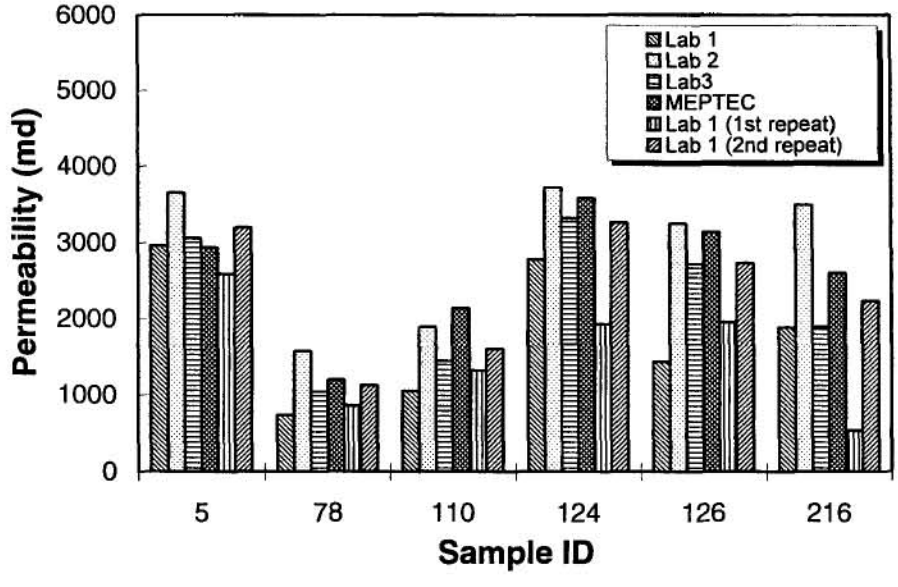

Figure 4. Permeability measurements on selected plugs repeated at various labs. The sequence of measurement is from left to right.

Case 2. Low Porosity Measurements on Clay-Rich Sands

The lab performing the routine work on this poorly consolidated core reported much lower porosity on the lowest porosity plugs compared with 3 other labs. This is illustrated in Figure 5. When we made the measurements in our lab we observed that it took as long as 15-20 minutes to fully equilibrate pressure on the lowest porosity samples. Since an unequilibrated pressure reading would explain a low apparent porosity, we questioned the lab about the criteria which they use to judge complete equilibration. They now acknowledge that they need to be more careful on this matter, have modified their procedures, and have offered to remeasure all of the lower porosity samples at no additional cost.

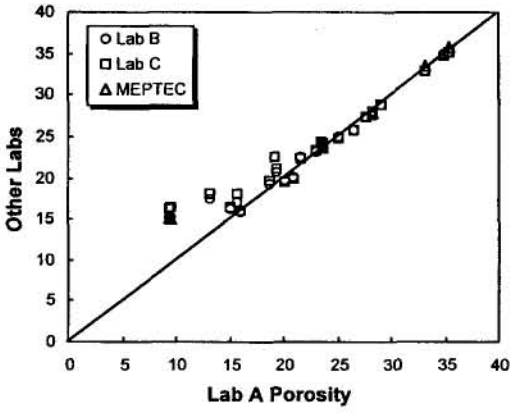

Figure 5. Porosity measured by primary lab compared with repeat porosity measurements at three other labs.

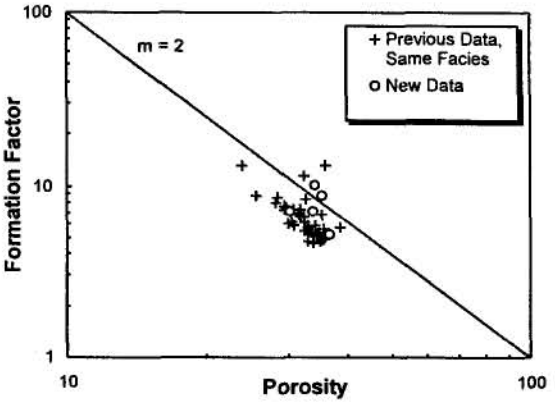

Figure 6. Formation factor measurements compared with previous data on similar samples.

Comparing Special Core Analysis Data With Database

It is usually impractical, and sometimes impossible, for tests involving multiphase flow to be repeated at a second lab. This is sometimes a matter of time and expense, but reproducing a wettability condition should also be a concern for multiphase displacement tests.

In some cases it is reasonable to expect some consistency between new data and those reported previously on similar samples under similar conditions. A good example is illustrated in Figure 6. A lab reported some new formation factor measurements and we compared them with measurements which we already had on very similar rocks. Clearly, some of the new data were inconsistent with the main population of previous measurements. In this case, we had the opportunity to remeasure the formation factors in our lab. We measured lower values, consistent with the main population, on the samples where anomalous data were reported. A plausible explanation for the inaccurate data is that the lab did not have all samples fully saturated at the time of the measurement. The lab offered to re-test all of the samples on which they reported anomalous data at no additional cost.

Discussion

The lab evaluation process described in this report does not ensure reliable core analysis. It does, however, reduce the chances that our affiliates will contract with unqualified labs to meet their core analysis needs.

In general, labs are most reliable with the services they perform most frequently. This is because experience is a very important factor in core analysis. This is especially true of the advanced tests such as capillary pressure and relative permeability.

The variability in routine property measurements presented in this paper can be interpreted as an indication of accuracy. We have shown that some labs measure a porosity that is systematically high on some samples, while others are systematically low. The differences are not especially large, around +/- 0.5% on some samples, but even the roughest and most irregular of these QC check samples would be regarded as an excellent plug for most standard applications. Greater variability among the labs can be expected if plugs are smaller (2.54 cm. in diameter), less smooth, or more irregularly shaped. Measurements near the extreme end of a distribution could, in some cases, be the most accurate.

Ensuring reliable core analysis data requires experience and effort. There are real costs associated with this process, on the parts of both the service providers and the consumers. Most service providers can do a better job at QC, but this will happen only if the consumers recognize its value and reward the lab for it. The alternatives for the consumer are to spend more time monitoring the work, or to accept unreliable data at face value.

Conclusions

Provided that consistent procedures are used, it is possible for most core analysis laboratories to reproduce measurements on high quality 3.8 cm. diameter plugs to +/- 0.3% in porosity, +/- 15% in permeability, and +/- 0.01 g/cc in grain density. These numbers are in good agreement with those reported previously by Thomas and Pugh (1). The remaining variability is systematic from one lab to the next; it appears to depend on environmental effects, specific procedural details, or specific properties of lab equipment. This systematic variability from one lab to the next will probably be larger for plugs that are less ideally shaped, have lower porosity or smaller size.

The pre-qualification process can be used to screen labs in a large number of specific areas. However, it does not ensure reliable core analysis data. Sometimes problems have been intercepted by repeating tests on selected samples at a second lab. Problems in special core analysis data have also been found by checking against a database of previous measurements on similar samples.

References

(1) Thomas, D.C. and V.J. Pugh, "A Statistical Analysis of the Accuracy and Reproducibility of Standard Core Analysis", *Proceedings of the 1987 International Symposium of the Society of Core Analysts*, Paper Number 8701.

Acknowledgments

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