CUTTINGS: **AN** UNDERUSED ASSET IN FORMATION EVALUATION

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Abstract

Formation evaluation is the process of the application of technology to gain or improve understanding the physical characteristics of subsurface rock formations and the nature and distribution of their contained fluids for the purpose of identifying and developing commercial hydrocarbons.

Cores and rotary sidewall cores are prized as actual samples of subsurface rock formations and their contained fluids and the opportunity they represent for direct measurements and observations of rock and fluid properties. Because of their expense, these assets are not commonly available to formation evaluators. Cuttings, however, are an inescapable by-product of every well drilled.

Cuttings provide petrophysical information such as mineralogy, texture and pore system characteristics of all penetrated formations, as well as stratigraphic information through their appearance and content. They also provide fluid samples for relative hydrocarbon saturation estimates and geochemical characterization. This information can be broadly applicable in all phases of the petroleum industry: exploration, reservoir management, and drilling and completion.

The process of assuring cuttings circulated to the surface are properly located on depth requires completion of a circulation lag check. The data gathered to calculate lag time can be used further to determine a lag time openhole caliper in near real time, and **an** average openhole diameter profile of a new wellbore can be developed during ongoing drilling using this information. A new evaluation element based on openhole diameter trends, the cavings factor, is proposed to quantify anticipated cuttings sample quality during drilling. If value is placed on acquisition of valid formation evaluation data in general, and cuttings samples in particular, real time remediation is possible through this focused awareness on the developing geometry of a new wellbore.

The skills and the interest in cuttings espoused by subsurface formation evaluators in the early history of the oil and gas industry has atrophied. Today, the proliferation of digital data and mathematical models permits calculation and generation of impressive volumes of formation evaluation output without ever examining those broadly and readily available natural earth samples, cuttings, to validate the results. Should a binocular microscope sit next to every computer on the desk of every technical professional in this industry?

As exploration and development proceeds into the next century, formation evaluators should focus on what is central to their profession and strive to use cuttings classically and innovatively. **As** a sample of subsurface rock material and surface-retained fluids, this inescapable asset can be used to reduce risk and uncertainty in prospecting and development operations and maximize the value of formation evaluation in the oil and gas industry.

Introduction

Making a profit is the fundamental goal in any commercial business and the commercial entities engaged in the oil & gas business are no different in that regard. What oil and gas companies produce, however, can't be examined or measured directly before product development investment is required. This is opposite the case of many profitable businesses that apply "specifications" to designs and materials used to develop their products before investments are made. ***A Priori*** specifications are the rule in the upstream side of the petroleum industry.

Just how are ***apriori*** product specifications developed in the petroleum industry? It involves making assessments on the location, size and producibility of subsurface accumulations of oil and gas before it is known that the accumulations are in fact there at all, and can be produced as planned. The phrase generally employed to describe this assessment process is Formation Evaluation.

What is Formation Evaluation

First use of the phrase "Formation Evaluation" in terms of methods in petroleum industry was not uncovered in this study. However, it was noted that formation evaluation has been described variously over the years and the focus has ranged from very specific to very broad.

- Vance, 1960, in reference to formation evaluation, considered only the determination of the cost benefit of running pipe after a well is drilled.
  - " The methods of securing and interpreting the data to be obtained from the drilling of a well so the operator may decide whether or not it will pay to set pipe in the new well."
- Archie, 1967, in discussing formation evaluation, focused on the wellbore as the primary data source.
  - "The process of using information obtained from a borehole to determine the physical and chemical properties of the rocks and their fluid content, especially hydrocarbons."
  - Formation evaluation methods can be subdivided into two categories:
    - Those used while drilling is in progress
      - Analyses of cores, cuttings and drilling fluids
    - Those used after the hole has been drilled
      - Drill-stem testing, wireline logs
- Clark and Shearin, 1955, represent a producing-oriented focus on formation evaluation, but with no specific limits on source of data, or on technical disciplines involved. They included the idea that formation evaluation is a process-based effort.
  - "Formation evaluation encompasses the processes of gathering appropriate, accurate, and detailed data on the physical characteristics of the formation rock, the occurrence and distribution of fluids within the formation rock, and the processes for interpreting those data for accuracy and reliability so that proper use can be made of the information in developing and operating oil and gas reservoirs."
  - Formation evaluation addresses two fundamental questions:
    - Is oil and gas present and in paying quantities?

        - How should the deposit be produced for maximum economic return?
    - Clark and Shearin implied a much broader frame of reference for this process when they concluded, “the story of formation evaluation is virtually the story of the oil industry itself...”
- R.M. Bateman, **1985,** explicitly considered formation evaluation to be the application of technology in both the exploration and producing segments of the petroleum industry. The consequent result is the inclusion of data sources well beyond an individual wellbore, or an individual field, or even the world itself by including satellite imagery, down to the most minute units of the industry, the individual rock grain and rock pore through SEM imagery.
    - “Formation Evaluation is an extremely broad term and can encompass many different disciplines. In its broadest sense, formation evaluation can include everything from macroscopic studies of an entire geologic basin down to microscopic studies of individual mineral grains. This interaction between a spectrum of different formation evaluation methods makes the whole process of evaluating subsurface formations a dynamic and viable science. Each formation evaluation method leans on it neighbor for support.”
    - Bateman then went on, however to say, “Formation evaluation presupposes that a reservoir has been located and is to be defined by drilling as few wells as possible.”
        - “. ..The complete task involves defining a reservoir’s limits, storage capacity, hydrocarbon content, produceability, and economic value.”

Bateman credits the interdisciplinary nature of formation evaluation for its viability. The ***complete task*** noted by Bateman, however, more appropriately fits a subsurface box than a subsurface rock formation. The sedimentologic, stratigraphic, and structural complexities of subsurface formations are why interdisciplinary interaction is necessary for successful formation evaluation.

An important precept in this paper is that formation evaluation is the process of developing the ***apriori*** specifications required to fund and direct the investment in exploration for a hydrocarbon-productive reservoir as well **as** defining the limits and economic value of an already discovered reservoir, and how best to develop it. Fulfillment of the second set of conditions dictates the necessity of the first.

Formation Evaluation is the overarching technological process employed by the full span of technical disciplines in the exploration and producing industry to evaluate and characterize the nature of the rock properties and contained fluids **of** subsurface formations in order to explore for and develop commercial hydrocarbon and mineral resources. It is **an** integrated system of processes involving the application of technology to the purpose of location, detection, evaluation, and economically efficient development of hydrocarbon accumulations. **If** all technical disciplines consider themselves formation evaluators first and discipline-specific technical professional second, interdisciplinary integration should follow naturally.

Historical Development of Formation Evaluation

Pirson, **1950,** chapter **1,** compiled a list of virtually a century of fundamentally important, ground-breaking engineering studies of reservoir rock properties and rock – fluid interactions, from Poiseuille in **1846** to Purcell in **1949.** These early investigators recognized that the goal of recovery of fluids, water or oil & gas, from subsurface formations meant first dealing with the challenge of understanding the complex nature of the repository of such fluids, the rocks. Thus from the earliest practitioners, the ideas fundamental to formation evaluation were based on rock awareness.

In the days of cable tool drilling for oil, the mid - late 1800's and early 1900's, the bailer provided an operator with on-depth formation rock samples in which oil could be easily detected. In addition to high quality cuttings samples, cable tool procedures also provided the operator with essentially a continuous, albeit ungauged and uncontrolled, open hole DST. Direct evaluation for oil within formations, hence, formation evaluation, was straightforward.

The advent of rotary drilling procedures with mud-filled boreholes brought a measure of pressure control to subsurface drilling. However, the gain in safety was accompanied by a concomitant loss in readily available, direct formation evaluation information.

Cores, sidewall cores, electric logging and drillstem testing methods were developed to address the need for formation evaluation information that had been lost in the change from cable tool to rotary drilling. The electric logging method provided only indirect measurements of formation rock or fluid characteristics, however, and cores and tests were still required for direct analysis of rock and fluid properties.

Cores represent on-depth, intact samples of subsurface formations, however, their recovery is both cost- and time-intensive. Finally realizing that cuttings may also provide useful information, mudlogging was developed about 1938 (Clark and Shearin, 1955). Mudlogs were used to provide operators with a continuous record of the physical characteristics and fluid content of penetrated formations through analysis of the mud returns for gas content and cuttings returns for oil and gas content as well as lithology and textural information.

Wireline logging has been the most prolific borehole formation evaluation measurement tool of those tools developed for use in rotary drilled wells. Wireline technology expanded slowly at first from electrical logging to neutron porosity and natural gamma ray logging. Acoustic and density logging were added through the 1950's and 60's, but the framework was still porosity and resistivity data recovered to the surface as analog signals. By the 1980's digital signal telemetry and storage was the rule in wireline logging operations and service companies could measure more data and more types of data.

The shift to a digital focus in both data gathering and data analysis has led formation evaluators far from their cable tool and early rotary beginnings. Data can now be sent via satellite from the field to the office and formation evaluation analyses completed on a computer without ever looking at a single grain or pore of a single rock. The petroleum industry moved into the age of mathematical modeling. This is progress, of course, and has opened wonderful opportunities to address the most difficult questions in formation evaluation. Increasing reliance on mathematical models brings with it the responsibility to examine any results with the question "How does this really fit the rocks?'

The concern posed here is broadly recognized and model calibration with core analysis data is routine. However, the ratio of cores to wireline logs requires more and more dependence on the mathematical models by formation evaluators. Logs are calibrated by cores wherever possible, and then the logs become literally ground truth away from the cored intervals or wells. Forgotten in all this is the most ubiquitous formation evaluation information available from top to bottom in every well drilled, the cuttings.

Formation Evaluation Methods

The range of formation evaluation methods and tools reflect the formation evaluation continuum from prospecting to discovery, field development from early to mature stages, and finally, ultimate decline and abandonment. They are designed to obtain the information necessary to improve understanding the physical characteristics of formation rock layers in the subsurface and the nature and distribution of the fluids contained in the layers. On the prospecting side, surface-accessed sources of data are predominant when well control **is** limited to nil. Toward the producing side of the continuum, wellbore-accessed formation evaluation data is predominant, although it is generally applied to refine and add detail to the geologic framework established during the prospecting phase.

Present usage in field development studies often includes the term ***Reservoir Characterization*** as essentially synonymous or even a replacement for ***Formation Evaluation.*** This is not the case. Formation evaluation is the data acquisition, data analysis and interpretive process, reservoir characterization is the result of all that effort. Technical professionals engaged in profitable E. & **P.** efforts are, first and foremost, ***Formation Evaluators,*** who seek to characterize the physical elements of a reservoir: location, geometry, composition, texture, fluid content, and rock – fluid interactions, as well **as** the geologic history responsible for the genesis of those physical elements.

Petroleum engineering and geoscience are the two main technical disciplines in the petroleum industry, and there is, today, ready and rapid access to large volumes of digital-format data, including production history data, wireline log data, or seismic data, among others. It's possible today for formation evaluators to spend large blocks of time marshalling and manipulating such data through a desktop computer or work station, generating impressive, voluminous output. It is incumbent on today's technical professionals that they not allow software manipulation skill to become a substitute for basic formation evaluation awareness.

The rock pore network that receives, stores and transmits hydrocarbon fluids is a product of the geologic history of the rock matrix and the consequent fabric imposed on the grain or crystal matrix framework and included void spaces that comprise the pore network. Formation evaluation efforts lead ultimately to this goal, therefore it is incumbent on formation evaluators to avail themselves of any opportunity to examine actual subsurface formation rock samples whenever possible. Investing in a binocular microscope to accompany the computer on every formation evaluator's desk could be an important first step in reintroducing the formation evaluation value and the requisite skills in cuttings analysis.

When is a rock not a rock

It is natural for individual investigators to focus on the elements and properties of formations that relate most directly to their own responsibility. Potential for difficulty arises when the systems are considered as stand-alone products rather than inter-related elements of the overarching process. Table 1 is a list of systems that formation rocks can assume based on the focus of any individual formation evaluator. If each technical professional realizes these individual systems represent one part of the complete evaluation of the formation rock as a natural earth system, the list can be constructive. If awareness of the importance of the contribution of each technical professional within a complex natural earth system is not understood, the evaluation model of the formation rock may or may not include all of the critical pieces, or the individual pieces can be brought together in adhoc fashion. A rock is not a rock.

Formation rocks are the integrating elements of the formation evaluation process. Rocks can be viewed as individual discipline systems for analysis and interpretation, but always with the awareness that integration as multiple disciplinary rock systems is fundamental to effective formation evaluation.

Cuttings Utility

If rock properties are the primary system underlying formation evaluation methods and relationships, then samples of actual penetrated formations should be of primary importance to all formation evaluators. Cuttings are samples of penetrated formations that are an inescapable byproduct of every well drilled, but in many cases, especially in mature fields, they are discarded to the reserve pit with all the appreciation of an unavoidable, useless expense. Even in mudlogged wells, mudlogs are scrutinized for shows by professionals perhaps with only limited awareness of show evaluation concepts, and cuttings samples warehoused for some vaguely defined posterity.

There are a variety of published examples in which cuttings are used in much the same way as cores. John Masters (1991), of Canadian Hunter, described what he called "invisible frontiers" in which thick intervals penetrated routinely by scores of dry holes, perhaps tested with poor results, or even wet, become visible with a concerted effort that is based on first recognizing through well cuttings sample study that an interval is composed of rocks with holes in them. Once such sections are identified, formation evaluation data acquired by earlier operators is re-examined by Hunter in light of a more complete awareness of the nature of the rocks.

Hunter builds small teams of individuals who understand and are skilled in the methods in which rock properties are interwoven with formation evaluation success. They create "artificial brains" to maximize ongoing formation evaluation processes. Cuttings samples are prized by these groups. Their thorough microscopic analysis, direct examination of pore geometry, is the first step in detecting and evaluating opportunities in the invisible frontier. The analysis of tests whose results provide the tester only an indirect image of the reservoir, such as rate or volume of fluid recovery, and require an assessment of rock properties to proceed from this indirect evidence, are completed after the results from microscopic analysis are integrated into the interpretation. Company makers have been discovered in the invisible frontier using this approach.

Archie, 1942, 1950, 1952, explicitly included the study of cuttings for pore structure as part of petrophysical analysis. Swanson, 1981, investigated the utility of small pieces of percussion sidewall cores or drill cuttings to determine reliable estimates of permeability in producing formatons based on mercury capillary pressure data. He developed a correlation between brine and air permeabilities and capillary pressure data in the form of a nomograph. Nigh and Taylor, 1984, reported the results of their work on the application of nuclear magnetic resonance analysis of drill cuttings to determine porosity and permeability "one lag time" after recovery at the well site.

When extraordinarily large cuttings are needed for analysis of porosity and permeability, or for other purposes, it is helpful to circulate in reverse of the usual manner (Hill, 1951). Reverse circulation is an option to obtain larger cuttings fragments for more detailed analyses. Circulation down the annulus and back up through the drill pipe places the newly drilled cuttings in a higher velocity, smaller volume environment. Higher velocities provide for carrying larger cuttings and the cuttings are exposed to the erosive effects of mud transport for a much shorter period of time. Application of this method needs to be considered carefully with regard to maintaining adequate pressure control.

Cuttings should be considered for any type of analysis that can be completed on outcrop or core samples; discard them as not appropriate only after careful review and trial of the preparation and analytical procedures. They represent that which will be assessed indirectly through post-drilling tests, consequently formation evaluators should strive to extract as much information from them as possible. Petrography, for mineralogy-lithology and textural information, analyses for stratigraphic, sedimentalogic and geochemical data, determination of burial history information through interpretation of diagenetic overprint and level of maceral maturity (that can then be cross-referenced against stratigraphic analysis) are just some of the possibilities. First, however, it is necessary to put cuttings on-depth and interpret penetrated from caved content.

Cuttings Acquisition in New Wellbores

In cable tool wells, the cutings brought to the surface in the bailer represented the interval just penetrated. Cuttings reach the surface in rotary wells some interval of time after having been penetrated by the bit. The length of time is proportional to the depth of the well, and is called the "lag time". If a drilling break indicates a potential reservoir has been penetrated, it is necessary to know when those cuttings fragments reach the surface so they can be specifically collected to examine for shows of hydrocarbons. Further, valid lag time is necessary to put all cuttings samples on-depth so the drilled section can be compared to any other measurements made in the borehole, such as wireline logs or drill-stem tests.

Valid lag time determination is a question of volumes in the wellbore circulation system. Figure 1 schmatically illustrates the elements involved in a round-trip circulation of mud through the wellbore. Round-trip circulation time is the sum of two elements: surface-to-bit time and bit–to– surface time. Lag time equals bit-to surface time.

Transit times involved are based on ***volume to be traversed*** and the ***volume/time*** output of the mud pump. Surface-to-bit volume can be determined with a high level of certainty because the dimensions of the inside of the steel drill string are known and can be expected to remain consistent. Bit-to-surface annular volume consists of two separate elements, the cased hole annulus and the open hole annulus. **As** in the condition inside of the drill string, the annular volume inside casing is known and consistant. The open hole portion of the bit-to-surface annular volume can not be known consistantly because the open hole includes formations that can wash out to varying degrees unlike the steel drill string and casing string. The one real-time measurement required is the measured round trip time determined from a lag check control item placed into the drill string on the drill floor during a connection. This is usually carbide, which produces acetylene gas when wetted by mud contact, or oatmeal flakes or even colored paint (red works fine).

Table **2A** is a spreadsheet composed of the elements necessary to determine all the volumes and times involved in a round trip circulation and can be used to calculate lag time at any point in the drilling history of a well. However, having taken the trouble to calculate lag time, it is possible to go just a few steps further to extract from the information the average diameter of the open hole section of the wellbore, and from that value, to calculate a "cavings factor" to help quantify expected cuttings sample quality. Table 2B lists all the elements in each cell of the spreadsheet and describes how the cell values are determined.

Figure **2** illustrates diagramatically how this type of data can be used. If, for example, a lag time caliper value is determined once every six hours in "fast drilling" or every 200 ft. in "slow drilling", a near real time profile of the well can be built. If the average openhole diameter is consistantly increasing, then remedial steps with the mud and hydraulics program can be started. Of course this method won't identify which part of the open hole is most actively washing out, but rigorous sample descriptions can help to refine it.

Severe washouts can make it difficult to assure zonal isolation behind pipe with cement jobs and add difficulty to obtaining valid wireline logs or good packer seats. But the reason it is considered useful in this paper is that it can provide a measurement of the quality of the cuttings samples. **As** the cavings factor increases above 1.00, the sample describer is made aware that less and less of any lagged sample represents actual drilled formation.

If cuttings are to be considered important assets in formation evaluation, then assessing which part of each sample interval is actually from that interval becomes a very important responsibility. It must be presumed that the sample describer is as capable at his job as are all other formation evaluators involved in any project, and further, that real time evidence that cuttings samples are being diluted with cavings will be treated with priority and changes made in real time to upgrade the cuttings sample quality.

After samples are dscribed at the well site, they can be prepared for further analysis. **A** useful first step is photo documentation to accompany the actual sample descriptions. Figure 3 shows a drawing of a sample tray that can be useful in this kind of documentation. When such trays are combined in groups of three, cuttings samples can be laid out in 300 ft. intervals, and, with good samples, almost outcrop quality changes in lithology and color can be readily noted. Figure **4** schmatically illlustrates the potential.

Tops, unconformities, reservoir, source or seal formations can be noted and analytical tests identified to help meet the formation evaluation goals of a project. In addition, this type of display can be a useful addition to wireline logs when correlating between wells in fields with structural complexity. It facilitates the geologist becoming familiar with his sections of interest and enhances awareness of intervals to be examined for additional potential. Further, if questions of stratigraphic position arise, either due to structural complexity or in a zonal ownership conflict, this type of display, from spud to TD, and the stratigraphic analyses completed from the samples, can help bring order to an interpretation and facilitate convincing anyone with standing or presiding in a conflict resolution.

Interpreting Lithology Distribution Within the Sampled Interval

Making hole requires mechanical force to penetrate rock layers of varying degrees of hardness at varying depths within the earth. Drilling engineers are concerned with optimizing drilling efficiency by trying to maximize penetration with minimum expenditure of energy. Bingham, 1965, introduced the concept of a “drillability equation”.

$$\frac{R}{N} = a\left(\frac{W}{D}\right)^{b}$$

R	Rate of Penetration (ft. / second)
N	Rotary Speed (Revolutions / second)
D	Bit Diameter (ft.)
W	Weight on Bit (pounds)
a	Dimensionless Constant (related to rock properties)
b	Dimensionless Constant (related to rock properties)

W/D, pounds of loading per foot of bit diameter, represents a force applied term related to the energy input required. R/N is a drilling response term representing the increment of penetration per revolution of the bit. Certain assumptions regarding hole cleaning, tooth efficiency and pressure balance at the bottom of the hole (chip hold-down pressure), are required to use this relationship, but, essentially, it provides a means of monitoring rock properties in the penetrated section. The parameters, W, D, and N relate directly to managed drilling conditions, so if these elements are held constant, then variations in the element, R, should represent changing rock properties.

Porosity and matrix strength are two rock properties that affect drillability (Whittaker, 1985, p. 35), therefore rate of penetration, ROP, responds to changes in both porosity and rock type. Experience has demonstrated to the writer that in carbonate rocks, ROP correlates well with a sonic porosity curve; more porous rocks exhibit faster ROP. In siliciclastic intervals, the ROP correlates better with the SP or Gamma Ray curve, where increased ROP correlates to SP or GR deflections to clean or permeable beds. An ROP increase, a drilling break, therefore indicates potentially clean, porous reservoir beds. Further, the ROP curve provides the means to correlate a mudlog or sample log to wireline logs.

In addition to ROP, hydrocarbon show variability can help to interpret the distribution of lithologies and textures in a ten-foot lagged sample, for instance. Gas shows are commonly thought of as sample shows, and do represent hydrocarbons liberated from the formation by bit penetration at depth, but in reality the gas shows have been sampled from the returning mud stream at the surface rather than cuttings samples. Gas shows too, should be lagged to depth, and thereby associated with the proper cuttings samples from the formation level at which the gas was liberated by bit penetration. It would be better, though, to be able to extract hydrocarbons directly from cuttings samples at the surface, then the association is made directly without the lag interface.

Visible cut is that type of show. What is often referred to as "cut" at a wellsite is in fact "cut fluorescence", an electronically assisted test that is useful in detecting very weak or very high gravity shows. Visible cut refers to the color and opacity taken on in normal light by an initially water-clear organic solvent that is pored over oil-bearing rock fragments. The solvent extracts oil from the cuttings (much like a Dean-Stark test) and the solvent is colored based on the volume of oil extracted. API gravity and crude color affect this test; darker colored crudes require less oil to impart a dark color to the solvent than higher gravity, paler crudes. Awareness of initial crude color is important in this test. In rocks of uniform porosity, saturated by the same crude, differences in cut color should reflect differences in oil saturation if the solvent to sample ratio remains consistant. Conversely, in non-uniform samples, differences in cut color may reflect differences in porosity.

Hillis, **1937,** demonstrated the value of the visible cut method of determination of oil saturation differences using samples from two fields in California. Hillis was grappling with being able to distinguish partially depleted reservoir zones that had taken on edge water, from undrained reservoir zones still at irreducible water saturation. He determined that if the undrained zones were perforated selectively, the result was greater absolute oil volume and smaller water cut in the production stream. The differences were economics-sensitive, so it was an important distinction.

Hillis understood he could extract oil from reservoir samples by placing the samples in a vial of organic solvent. Figure 5 shows the arrangement used by Hillis to test his subsurface samples, which were crushed core material. This setup was arranged to facilitate maintaining a consistant solvent to sample ratio among all samples. Hillis also created a set of standards of known oil concentrations, low to high, by diluting samples of each reservoir's oil with varying amounts of organic solvent. The transmitted light colors of his standard suite ranged from pale yellow (low oil concentration) to very deep red (high oil concentration). Hillis compared the colors developed from the solvent- rock sample mixtures to his standard suite and achieved the distinction between partially drained and undrained zones with a high level of success.

Wyman and Castano, **1974,** in an excellent review of oil show description techniques, including stain, odor, and fluorescence, expanded on the use and interpretation of visible cut, and specifically used the test on cuttings. Figure *6* illustrates the suite of Hillis-type standards they created, the color descriptions and the relative show value ascribed to each category of visible cut standard. Visible cut can aid in determination of presence or absence of oil in a formation, and, further, in distinguishing relative concentration differences in those samples that contain oil.

Collier, et al, **1995,** reported that Wyman and Castano's visible cut evaluation system had been used to pick the sweet spot for laterals in horizontal wells Mobil Oil drilled in the San Andres formation in the Levelland field in Cochran and Hockley counties, TX. Further, Mobil formation evaluators used visible cut in lieu of wireline logs to pick completion intervals within the overall lateral interval.

It is important to remember that this extracted oil is zone specific without the necessity of a DST or RFT. If it is possible to read through or reduce the effects of the solvent on the extracted oil then cuttings could be considered to provide samples for oil property analysis for fluid flow studies or in oil to source correlation studies. In waterfloods, it may be possible to use zone-specific oil samples extracted from cuttings to examine for the effects of water washing on the oil molecules to determine if one zone has been more completely flooded than another.

Figures **7, 8,** and 9 are schematic examples of cuttings sample analysis that reflect different conditions of oil saturations or bed thickness. The ROP curve in figure **7** indicates a thick, uniform reservoir. Because the reservoir thickness is greater than the ten-ft. sample interval, each ten-ft. sample through the reservoir will contain predominantly oil-saturated cuttings and every ten-ft. sample across the reservoir interval will yield a uniform, dark brown visible cut if the cavings factor is close to 1.00.

The ROP curve in figure **8** also indicates a thick, uniform reservoir, however, this section of the reservoir includes intervals in the gas cap, the zone at irreducible water, the transition zone, and the zone at residual oil. Ten-ft. sample intervals fall so that none of the samples will contain **100%** of the cuttings at maximum oil saturation. Therefore, visible cut analysis of a suite of ten-ft. samples through this reservoir in figure **8** will not yield any samples with the dark brown visible cut similar to that obtained from the reservoir in figure **7.** The high quality oil zone in this reservoir will be masked by cuttings from the intervals with lower oil saturation values. Presumably gas shows would help the mudlogger to recognize that it will be necessary to examine hand-picked cuttings fragments to find the zones at irreducible water and to separate the gas cap from the oil leg.

The ROP curve in figure 9 indicates the section is a shale section with thin-bedded reservoirs, relative to the sample interval, included in the gross section. The thin-bedded reservoirs are themselves of varying reservoir quality. Once again, individual ten-ft. samples would not exhibit the dark brown visible cut from figure 7, even though high quality, oil-saturated reservoirs at irreducible water saturation are present. In this case, the ROP should encourage the sample describer to hand-pick the best looking reservoir cuttings from the ten-ft. sample and test their visible cut in a spot plate. If individual fragments yield a darker cut than the ten-ft. sample, it validates the presence of high quality, thin bedded reservoir zones.

Conclusions

1. Formation evaluation is the overarching technical process in the oil and gas industry. It is an integrated system of processes based on evaluation of rock and rock-fluid interaction properties. Its practioners are Formation Evaluators.

2. Formation rocks are the integrating element in formation evaluation. Individual formation evaluation disciplines, formation evaluators, should view their efforts as discipline systems that contribute to the complete model of the formation rock system. In this way complete integration will be assured.

3. The early history of formation evaluation relied heaviliy on the study of rock properties because the rocks were the predominant formation evaluation asset.

4. Recent formation evaluation history finds indirect measurements of rock properties in digital format as the dominant formation evaluation asset, and application of mathematical models built to match formation response as an important goal of formation evaluation.

5. Cores are used as much as possible to calibrate the mathematical models, but they are stratigraphically and geographically overwhelmed by the volume of digital data.

6. Cuttings are an inescapable byproduct of every well drilled, but are an underused asset.

7. A lag time caliper can be used to generate a cavings factor to assess the represenative quality of cuttings samples that reach the surface. Using this information, changes to the drilling program to reduce washout and cavings can be made in near real time in new wells if sufficient value is placed on acquisition of accurate formation evaluation data in general, and cuttings samples in particular. It could also improve the effectiveness of cement – formation bond in achieving zonal isolation behind pipe.

8. Cuttings can be documented photographicaly across broad intervals to illustrate major changes in lithology and color in the penetrated section from which other formation evaluation tasks can be planned. In conjuction with sample descriptions and analytical results, this method also prepares the geologist to develop important familiarity with the complete stratigraphic section in the area of interest whenever questions of additional potential or stratigraphic position arise.

9. Cuttings represent actual pieces of subsurface formations and formation evaluators should strive to maximize their utilty in characterizing the geologic nature of a reservoir, and especially in calibration of mathematical models developed to represent the reservoir and its performance.

10. Visible cut can be used on cuttings to determine presence – absence of oil in subsurface formations, and differences in relative concentrations of oil in those samples that contain oil.

11. Cuttings can help bring special focus to the invisible frontier. Thin-bedded reservoirs that lay below logging tool bed resolution when the well was drilled, or tight reservoirs with a complicated pore geometry that confounds standard interpretation practices represent opportunities to those who have the skills and formation evaluation awareness to see them.

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Table 1

Rock System	Elements	Properties
Reservoir	Pressure Vessel, Fluid Storage, Fluid Transmittance	Fluid Recovery, Economic Value
Petrophysics	Electrical, Nuclear, Mechanical	Porosity, Permeability, Fluid Content, Saturation
Stratigraphic	Litho, Bio, Time, Isotope, Sequence	Lithology, Fauna/FloraContent, Isotope Content, Genetic Content
Lithologic	Carbonate, Siliciclastic, Evaporite	Mineralogy, Texture
Sedimentologic	Depositional Genesis	Lithology, Bedding, Bedding Internal Characteristics
Geochemical	Inorganic/Organic Composition	Mineralogy, Kerogen, Fluids
Barrier	Trap Seal, Hydrocarbon Migration	Flow Prevention Boundary
Structural	Post-depositional Genesis	Burial History, Trap Configuration, Tectonic History
Geophysical	Matrix and Bulh Density, Magnetic Suscentibility	Structure, Stratigraphy, Lithology, Fluid Content

Table 2A - Lag Time Caliper Borehole Diamter and Cavings Factor Spreadsheet

1	2	3	4	5
TD	DCSD	DCID	DCIDV	BS = GHD
8500	4200	1.0729	3797.149203	0.9375
6	7	8	9	10
OHGHV	DPSL	DPID	DPSIDV	ColSL
2968.2528	7900	0 3408	720 6363	600
11	12	33	14	15
ColID	ColSIDV	TotIDV	DPOD	CHDPSODV
0 4934	114 7201	835.3564	0 3750	463 8758
TotCHAV	OHDPSODV	ColOD	ColSODV	TotOHSODV
3333 2/34	4UB 6525	U 5521	143 6404	552 2929
21	22	23	24	25
PGTotOHAV	PGTotAV	MPOPS	MPSPM	MPC
2415 9599	5/49 2333	0 2030	60	2 7800
26	27	28	29	30
PGSTBT	PGBTST	PGRTT	MsdRTT	MsdBTST
12 2149	84 0672	96 2821	130 0000	117 7851
31	32	33	34	35
MsdCHATT	MsdOHATT	PGOHATT	ExOHATT	ExOHAV
48 7402	69 0449	35 3270	33 7179	2305.9212
36	37	38	39	40
MsdOHAV	MsdTotOHV	AvgMOHA	PrvAvgMOHD	UpdAvgMOHD
4721.8811	5274.1740	1.2266	0 9375	1 2497
41				
CF				
1.3330				

Table 2B

Col #	Col Heading	Column Content	Content Source	Units
1	TD	Total Depth	Input Parameter	Ft.
2	DCSD	Deepest Casing Shoe Depth	Input Parameter	Ft.
3	DCID	Deepest Casing Inside Diameter	Input Parameter	Ft.
4	DCIDV	DpstCsng Inside Diameter Volume	Col 2 x Pi x ((Col 3 / 2)^2)	CuFt.
5	BS	Bit Size = Gauge Hole Diameter	Input Parameter	Ft.
6	OHGHV	Open Hole Gauge Hole Volume	(Col 1 – Col 2) x Pi x ((Col 5 / 2)^2)	CuFt.
7	DPSL	Drill Pipe String Length	Col 1 – Col 10	Ft.
8	DPID	Drill Pipe Inside Diameter	Input Parameter	Ft.
9	DPSIDV	DP String ID Volume	Col 7 x Pi x ((Col 8 / 2)^2)	CuFt.
10	ColSL	Collar String Length	Input Parameter	Ft.
11	ColID	Collar Inside Diameter	Input Parameter	Ft.
12	ColSIDV	Collar String ID Volume	Col 10 x Pi x ((Col 11 / 2)^2)	CuFt.
13	TotSIDV	Total String (DP + Col) ID Vol.	Col 9 + Col 12	CuFt.
14	DPOD	Drill Pipe Outside Diameter	Input Parameter	Ft.
15	CHDPSODV	Cased Hole DPS OD Volume	Col 2 x Pi x (Col 14 / 2)^2)	CuFt.
16	TotCHAV	Total Cased Hole Annular Vol.	Col 4 – Col 15	CuFt.
17	OHDPSODV	Open Hole DPS OD Volume	(Col 7 – Col 2) x Pi x ((Col 14 / 2)^2)	CuFt.
18	ColOD	Collar Outside Diameter	Input Parameter	Ft.
19	ColSODV	Collar String OD Volume	Col 10 x Pi x ((Col 18 / 2)^2)	CuFt.
20	TotSOHODV	Total String OH OD Volume	Col 19 + Col 17	CuFt.
21	PGTotOHAV	Perfectly Gauge Ttl OH Ann Vol	Col 6 – Col 20	CuFt.
22	PGTotAV	Perfectly Gauge Total Annular Vol	Col 16 + Col 21	CuFt.
23	MPBOPS	Mud Pump Bbl Output Per Stroke	Input Parameter	BPS
24	MPSPM	Mud Pump Strokes Per Minute	Input Parameter	SPM
25	MPC	Mud Pump Capacity (Bbls / Min)	Col 23 x Col 24	BPM
26	PGSTBT	Perf. Gauge Surface to Bit Time	(Col 13 x 0.1781 Bbls/CuFt) / Col 25	Min.
27	PGBTST	Perf. Gauge Bit to Surface Time	(Col 22 x 0.1781 Bbls/CuFt) / Col 25	Min.
28	PGRTT	Perfectly Gauge Round Trip Time	Col 26 + Col 27	Min.
29	MsdRTT	Measured Round Trip Time	Input Parameter (from Lag Check)	Min.
30	MsdBTST	Measured Bit to Surface Time	Col 29 – Col 26	Min.
31	MsdCHATT	Msd CH Annular Transit Time	(Col 16 x 0.1781 Bbls/CuFt) / Col 25	Min.
32	MsdOHATT	Msd OH Annular Transit Time	Col 30 – Col 31	Min.
33	PGOHATT	PerfGauge OH Ann. Transit Time	(Col 21 x 0.1781 Bbls/CuFt) / Col 25	Min.
34	ExOHATT	Excess OH Annular Transit Time	Col 32 – Col 33	Min.
35	ExOHAV	Excess Open Hole Annular Vol.	(Col 34 x Col 25) / 0.1781 Bbls/CuFt	CuFt.
36	MsdOHAV	Measured OH Annular Volume	Col 35 + Col 21	CuFt.
37	MsdTotOHV	Measured Total OH Volume	Col 20 + Col 36	CuFt.
38	AvgMOHA	Average Msd Open Hole Area	Col 37 / (Col 1 – Col 2)	SqFt.
39	PrvAvgMOHD	Previous Avg. Msd. OH Diameter	Input Immed. Previous Calc. Value	Ft.
40	UpdAvgMOHD	Updated Avg Measured OH Diameter	((Col 38 / Pi)^0.5) x 2	Ft.
41	CF	Cavings Factor	Col 40 / Col 39	None

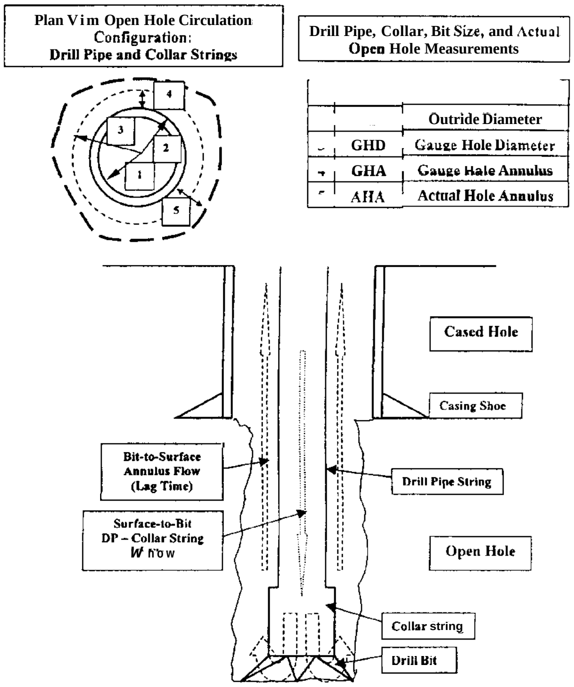


Figure 1 - Lag Time Circulation System Geometry

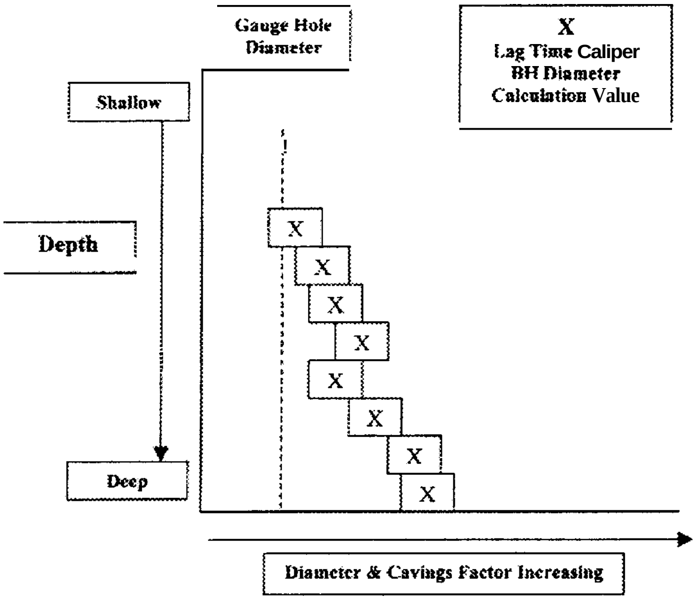


Figure 2 - Lag Time Caliper Average Openhole Diameter

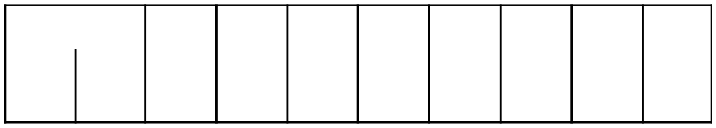


Figure 3 - Ten-Cup Sample Tray, Flat Black Color, 15" Long, 2" Wide for Photographic Cuttings Sample Documentation

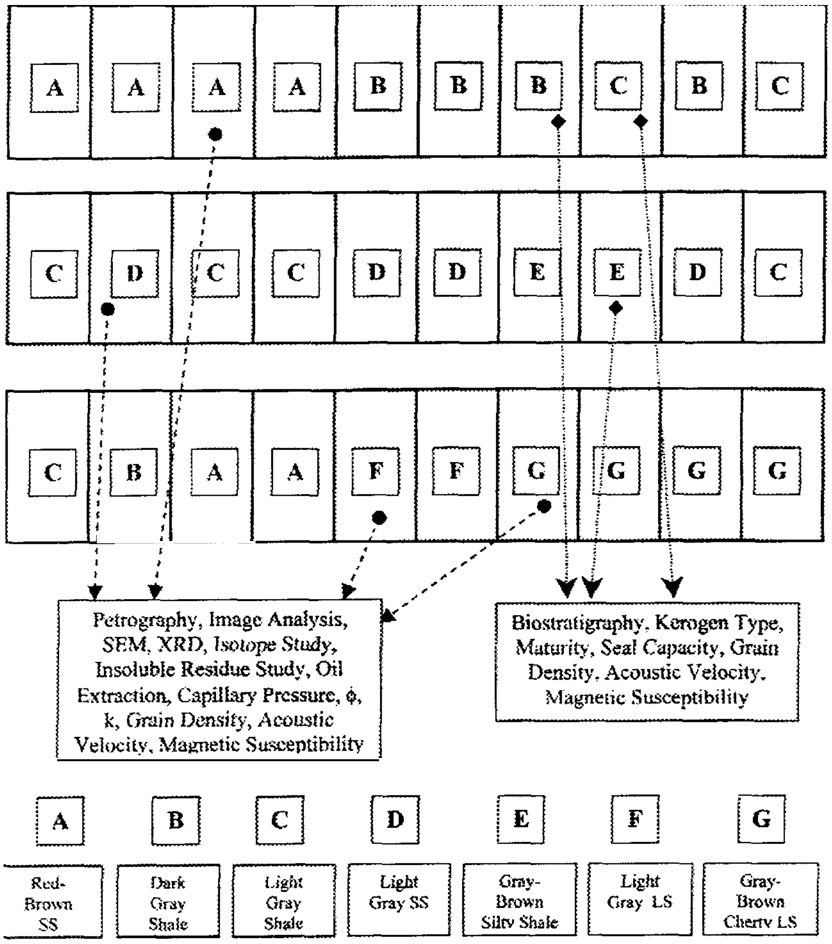
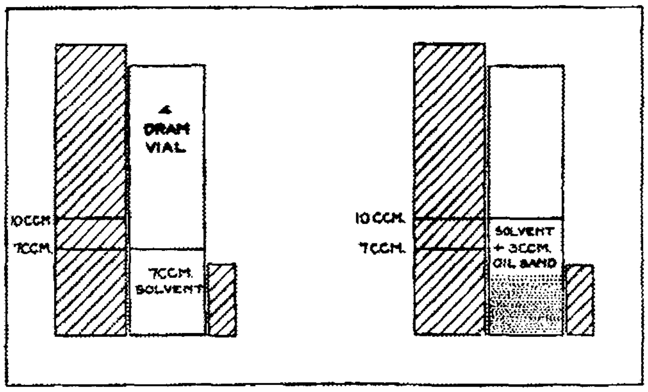
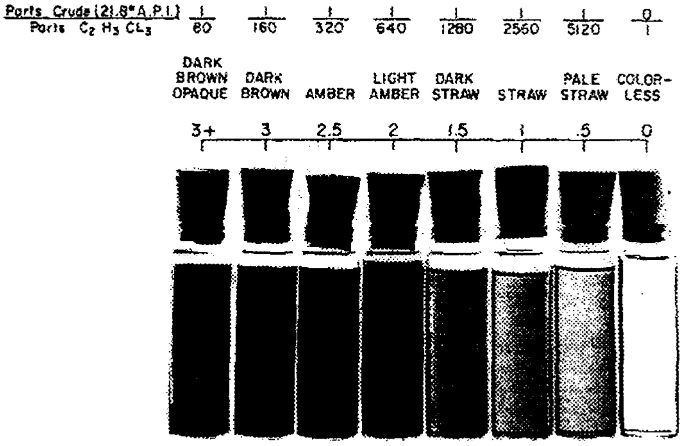


Figure 4 - 300 Foot-Interval Cuttings Documentation Sample Set
Note Potential to Record Lithologic and Stratigraphic Trends, and Analytical Task Assignments



From Hillis, 1937

Figure 5 - Diagram Showing Measuring Rack for Colorimetric Testing of Core Samples



From Wyman and Castano, 1974

Figure 6 - Trichloroethane Cuts (from color photograph)

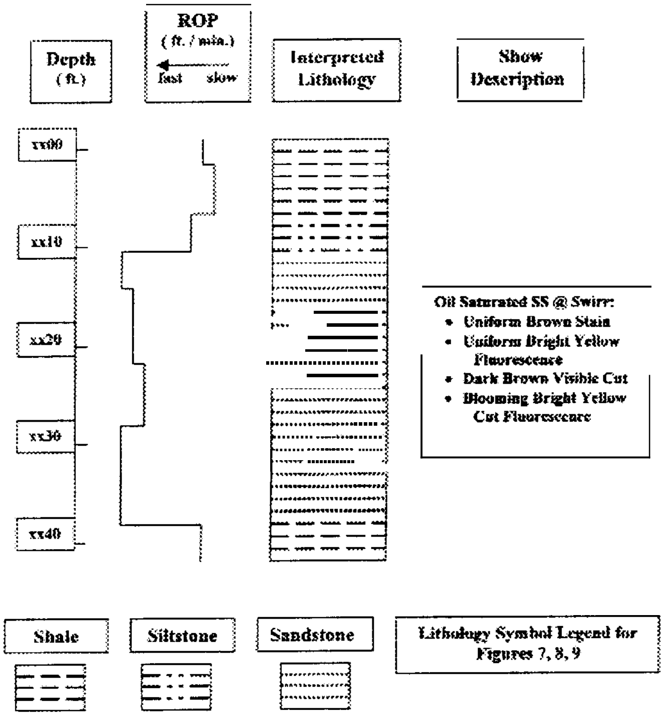


Figure 7 - 100% Stained Cuttings in Representative 10' Sample Uniform Reservoir

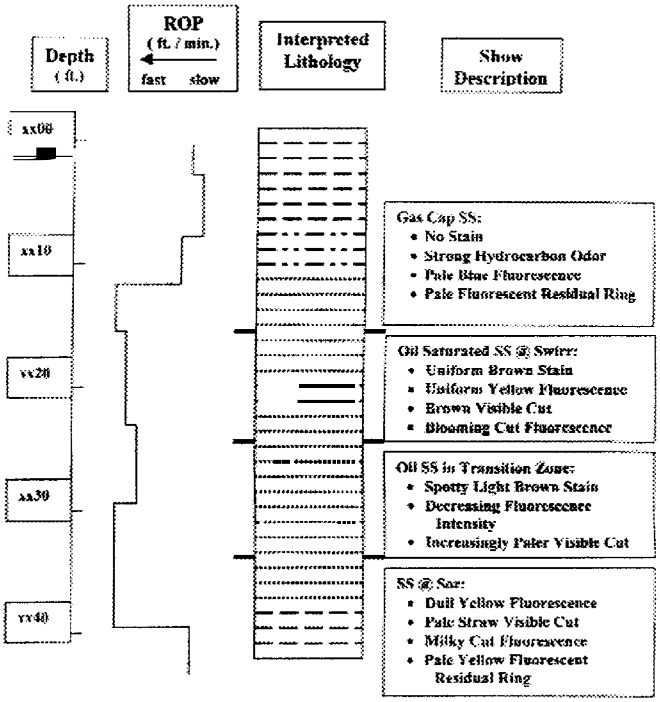
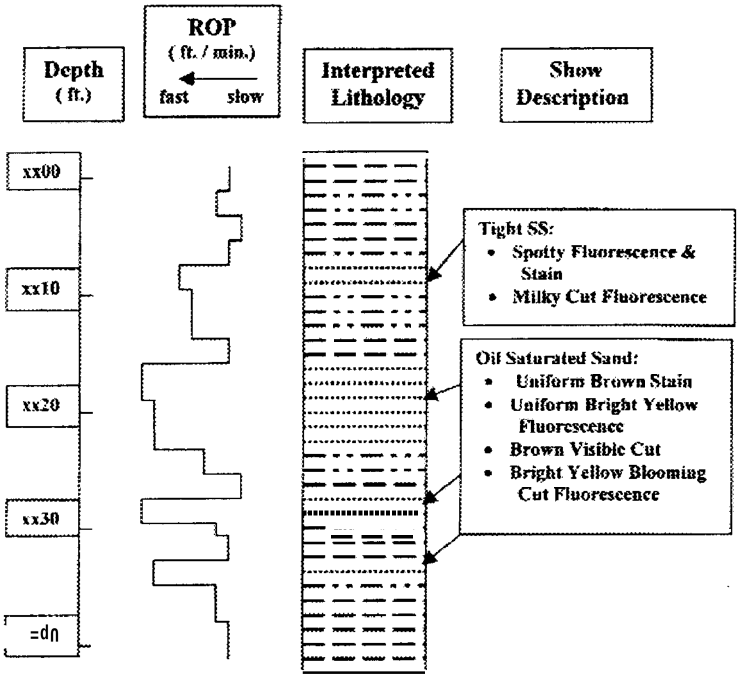


Figure 8 - 100% Stained Cuttings in Representative 10' Sample Uniform Reservoir



< 100% Stained Cuttings in Representative 10' Sample
Thin – Bedded Reservoir

Figure 9 - 100% Stained Cuttings in Representative 10' Sample Uniform Reservoir