

AML (ADVANCED MUD LOGGING): FIRST AMONG EQUALS

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Abstract. During the past ten years an enormous development in mud logging technology has been made. Traditional mud logging was only qualitative in nature, and mudlogs could not be used for the petrophysical well evaluations which form the basis for all subsequent activities on wells and fields. AML however can provide quantitative information, logs with a reliability, trueness and precision like LWD and WLL. Hence for well evaluation programmes there are now three different logging methods available, each with its own pros and cons on specific aspects: AML, LWD and WLL.

The largest improvements have been made in mud gas analysis and elemental analysis of cuttings. Mud gas analysis can yield hydrocarbon fluid composition for some components with a quality like PVT analysis, hence not only revolutionising the sampling programme so far done with only LWD/WLL, but also making it possible to geosteer on fluid properties.

Elemental analysis of cuttings, e.g. with XRF, with an ability well beyond the capabilities of the spectroscopy measurements possible earlier with LWD/WLL tools, is opening up improved ways to evaluate formations, especially of course where the traditional methods are falling short of requirements, such as in unconventional reservoirs.

An overview and specific examples of these AML logs is given, from which it may be concluded that AML now ought to be considered as “first among its equals”.

Keywords: mud logging technology, AML, LWD, WLL, mud gas analysis, elemental analysis of cuttings

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Reasons to consider applying AML technologies

The information provided by conventional mudlogging, however valuable, was only qualitative, and simply did not provide most of the measurements which are necessary for a full petrophysical well evaluation. However, now that AML is getting mature, there are three groups of techniques which can be considered for routine well evaluation programmes: AML, LWD (Logging While Drilling) and WLL (WireLine Logging). Note that coring and production testing, however valuable, i.e. even, rightfully, considered as ground truth when applied, are not suitable for routine application for all wells and intervals, and that many measurements, traditionally requiring core plugs, and thus necessitating coring, can now be done with sufficient trueness and precision on cuttings and chunks, either already in AML operations on the well site, or in laboratories.

There are numerous applications of AML for drilling purposes, e.g. monitoring of operations, including quality control of mud chemicals, well safety, and improving drilling operations. This paper will focus mainly on the AML formation evaluation aspects. Figure 1, modified marginally from earlier publications, e.g. (Loermans, Kimour et al., 2012) gives a broad overview of various techniques and their application for conventional petrophysical interpretations. Further in this paper some of these measurements are further addressed and illustrated with examples.

The reasons to include AML in an evaluation programme can be grouped into three categories: (i)

TINA (There Is No Alternative), i.e.: LWD and WLL simply cannot be run or cannot provide the necessary answers, (ii) VOI (Value Of Information) / second opinion, where AML would be one of at least two completely independent evaluation methods to reduce the uncertainty from having only one imperfect method, and (iii) Money, i.e., as the cheaper one of a few technically acceptable methods, or situations where a balancing of costs and operational risks, including well control and other safety issues is required.

TINA but AML

There are situations where only AML can provide information. When for an abandoned the cuttings are available, AML cuttings analysis may provide very useful information. For new wells with drilling conditions beyond the LWD & WLL tool limits of e.g. hole size, temperature and/or pressure. Also, however good the elemental analysis is which can be obtained from the available LWD/WLL spectroscopy tools, those measurements simply fall short of what can be obtained from e.g. XRF (x-ray fluorescence), as part of an AML system. Also, obviously, any new methods, such as TOC (Total Organic Carbon) derived from existing laboratory methods, can be carried into an AML development much faster and cheaper than into WLL and LWD.

VOI – second opinion

Our logs and our evaluation methods are not perfect, providing 100% certainty for a decision to be made

	gas chromatogr.	mass spectr.	POPI	fluid inclusions	isotope logging	LIBS	XRD	XRF	FTIR	spectral GR	"conv." core anal.	mini por. gr. dens	cutt. cap crvcs	x ray ct scanning	rock typing	IFP permcut	AGIP perm on cuttings	NMR on cuttings	sonic on cuttings	micro mud losses	image anal./PNM	nano indent.	drilling param.
net reservoir ind.	x				x					x					x	x	x	x	x	x			x
fluid contacts	X	X	x	x	x													x					
fluid type	X	X	x	X	x													x					
fluid composition																							
fluid properties	x	X	x	x	x													x					
mineralogy						x 4)	X	X	X	x				x	x					x			x
elemental comp.								X	X	x													
correlation steering					x	X		X	X	x													
bulk density											X	x		X									x
grain density						x					X	x			x								
porosity											X	x	x	X **)	X	x	x	x	x		x		x
electr. params ***)															X						x		
pore size distr																							
Swi													X		X			X				x	
cap curve													X		X			x				x	
saturation, Sh				x								x *)											
perm. - matrix												x		x	X	X	X			x	x		
perm. - fract./high k																					X		
rel.perms																						x	
vp/vs																					X		
mechanical param.															X							X	x

Fig. 1. Overview of AML measurements. *) if contact given and if virgin conditions still present. **) if matrix density known. ***) m, n, Qv. 4) LIBS has lost in potential/hope for uncalibrated lithology

on the information derived therefrom. Decision tree analysis, using Bayes' theorem then quickly shows that, in order to have any desired certainty, two independent methods are required¹. Our log interpretations, however good, when using input from only one out of the three of AML, LWD and WLL, sometimes cannot be regarded other than being based on only one set of truly independently acquired information sets. While, of course, one of the main drivers within the areas of LWD and WLL technology development over the past decades has been to provide truly independent methods, e.g. formation pressure testing and sampling to confirm interpretations based on resistivity/density logs, we have to remain conscious of the potential limits of our data sources.

Even a perfect formation pressure test graph may be misleading

To corroborate further that even our most trusted tools are not 100 % reliable, consider figure 2, showing the first set of pressure points obtained in a normal formation pressure job in an appraisal well in a mature area. The

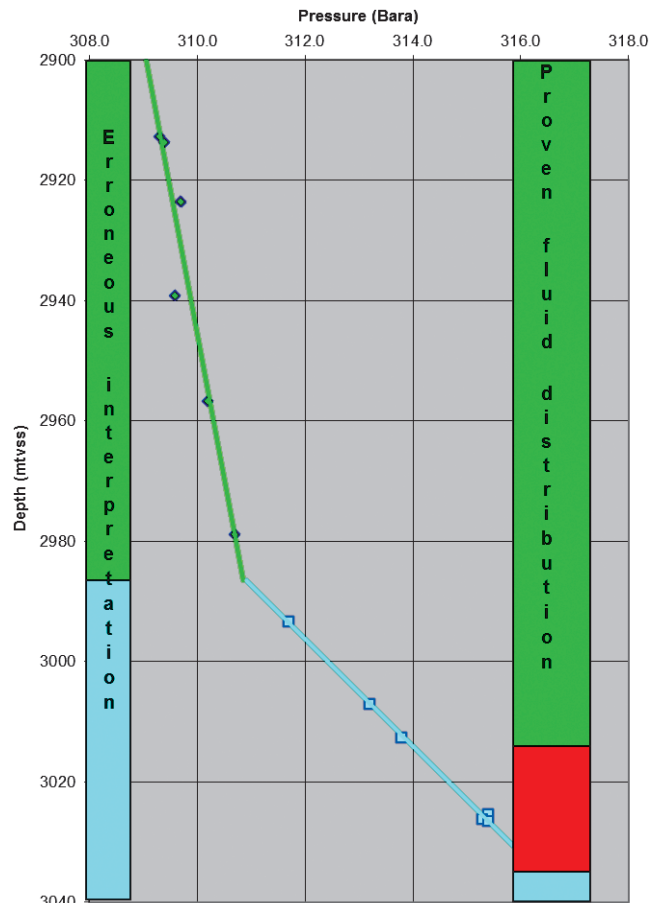


Fig. 2. Even formation pressure graphs may be misleading

¹Also, consider the following almost classical situation. A young petrophysicist having evaluated an exploration well as water bearing, and thus advising against production testing, being overruled. Such decision tree analysis will quickly show that, given the stakes and, however clear the interpretation might be, nevertheless the small risk of that interpretation being a false negative, it is often not unwise to indeed overrule such interpretation.

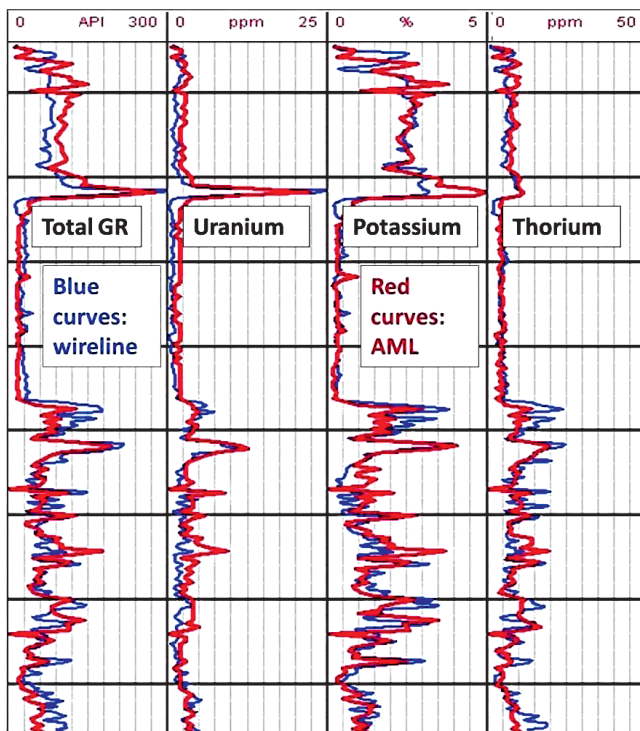


Fig. 3. Equivalence AML and WLL spectral GR curves

initial interpretation of the well site staff involved, based on the resistivity/density/neutron logs run before was for a GWC (Gas Water Contact) at the suggested FWL (Free Water Level) by the pressures, around 2984 m. All the pressure points had a good drawdown mobility, so could be considered reliable. Hence, this fluid column (green – gas, blue – water) as depicted on the left of that plot could well have been the final conclusion. However, after several more formation pressure runs (not presented in this plot), and fluid and side wall samples were taken, the interpretation as depicted on the right hand side, with some 150 ft of extra HC column, including an oil rim (red), was firmly established².

Cost savings

When there are two methods available providing technically sufficiently acceptable and equivalent information, i.e. including sufficient certainty that no “second opinion” is required, then obviously the alternative with the lowest costs, in terms of direct expenditure of acquiring the data costs and the, properly weighted, risks of mishaps associated with the alternatives, should be taken.

The spectral GR comparison in figure 3 illustrates that AML is now³ in the position where LWD was in the 1990’s: many measurements are available, but only from a few service companies and these logs are not generally recognised and accepted yet by all operators/oil companies for their qualities and business value.

² A quantitative explanation for this case is yet to be provided. The author thus welcomes any suggestion any reader might have.

³ Many examples like this have been published for more than five years already; ao. the presentation of (Marsala et al., 2012)

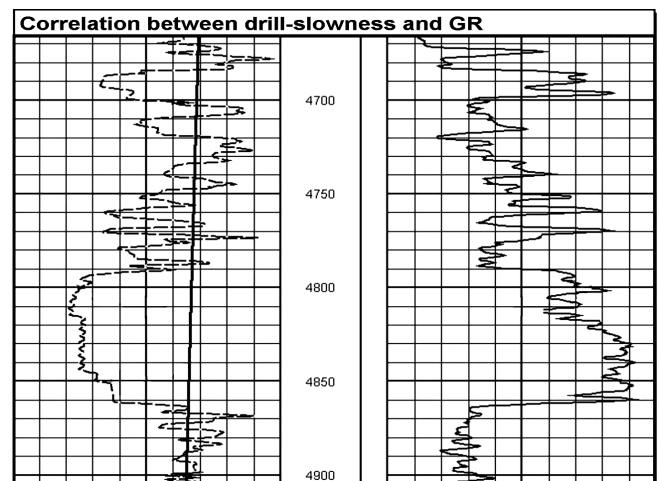


Fig. 4. ROP as possible low cost proxy for a GR. The two main curves shown in this plot are a GR and an ROP. However, scales are not shown on purpose, because each of these curves might be displayed in an unconventional manner, eg the GR might be shown in either track, with reversed scales, and not as a solid but dashed curve and resampled from its original. It is obvious that for all practical purposes, the ROP and GR curves are interchangeable. Hence, if cost saving is relevant, in cases like this one would could even save on the costs of running a GR... (The author welcomes any correspondence reasoning which curve is which.)

Proxies for certain measurements are typically used when the desired measurement cannot be obtained, i.e. the proxy then is taken as best practically possible. However, when evaluation cost reduction is very critical, i.e. when the evaluation methods are extremely well established and when in a mass operation development drilling, even low cost proxies for simple logs, might be considered. Consider figure 4, from which it is obvious that an ROP, at almost truly zero incremental costs, might serve as a proxy for a GR, thus saving this little bit of additional costs from an MWD-GR.

Note that, apart from just a low cost proxy for some other logs, the ROP, could be an indicator for mechanical properties. That is, not so much raw ROP by itself, but transcended further than modified d-exponent to Mean Specific Energy (MSE), the specific energy needed to drill a piece of rock. Such MSE is an obvious potential proxy for some rock mechanical strength parameters, vital of course to decide on the fraccability of formations. And for unconventional (shale) developments fraccability more than anything else still remains the current well evaluation golden grail.

Depth matters

Depth is the most important logging parameter, and hence depth matters matter very much also for AML. Concerns still exist with many AML is falling short of requirements because of various depth related issues, the AML sampling depth and resolution in particular. However, as will become clear in the following, the AML depth problems are smaller than often perceived, not that much different from similar issues with LWD

and WLL curves, and that there even some points where AML actually can provide significant added value.

Depth matching various AML curves to one common standard AML-depth, and subsequently matching the AML curves to the LWD and/or WLL curves is not different from depth-matching various WLL or LWD curves to each other. In any mudlogging operation, the depths for the measured drilling parameters, are to be matched to those from the mud gas readings and cuttings coming to surface. While the exact mechanisms of such process are of course different the corresponding ones to match WLL and LWD curves, e.g. especially the lag time of cuttings needs to be carefully established, as numerous examples have shown, and indeed is routine, depth matching different curves is not a problem.

Mud mixing, especially when there are many large washouts, may affect the smooth transport of cuttings, and thus have a negative impact on the depth resolution which can be obtained from cuttings samples. But when the drilling hydraulics are good, which of course also is better for the drilling and hole cleaning process, it has been shown that sampling cuttings with a resolution of about 2 ft may very well be possible. Also the high resolution response often obtained from AML mud gas readings, including isotope measurements, confirm that mud mixing and depth resolution is not a fundamental problem barring AML applications.

Given that for several AML measurements only small amounts of cuttings are needed, hand picking of cuttings for special cases is very well possible. That means that, while even with coreplugs only average properties can be measured for e.g. a package of a few feet thick consisting of 5 mm sand/shale layers, AML can separately measure the properties of those thin sand and shale layers.

Establishing the absolute correct depth, i.e. the TAH (True Along Hole) depth, is an issue which the discipline as a whole is still trying to improve on. WLL and LWD absolute depths too often clearly are simply of too poor quality and on too many a conference, problems are reported and methods to improve are proposed. In this respect AML may even help matters, especially for drillers = LWD depths. Because of the nature of mudlogging, almost intrinsic in its operations, even more so than with LWD, is a monitoring and recording of those parameters which are necessary for a TAH depth determination, e.g. friction of the drillstring as it is moved along the well trajectory. Hence, given that AML does have the operating system and computing power on site to do so, we might see a development where TAH depth as established by AML services actually become the standard depth, in a way that (long ago now already) WLL provided the logging depth as unchallenged default, with superior quality over drillers depth.

Mud gas analysis

For the mud gas analysis, during the past decade an enormous leap has been made from only qualitative to very accurate and reliable measurements now with the best available AML systems. See figure 5, showing a perfect match between HC composition (C1-C5) obtained in real time with an AML system, and the results of PVT analysis on WLL formation fluid samples. With a mud gas system like this, the LWD or WLL formation fluid sampling programme can be optimised and adjusted as needed. Sometimes taking more samples and at other points than initially anticipated, sometimes making further LWD/WLL sampling superfluous. Altogether of course an enormous added value for well and reservoir evaluation.

AML gives real time, continuous, equivalent of PVT analysis of wireline fluid sample.

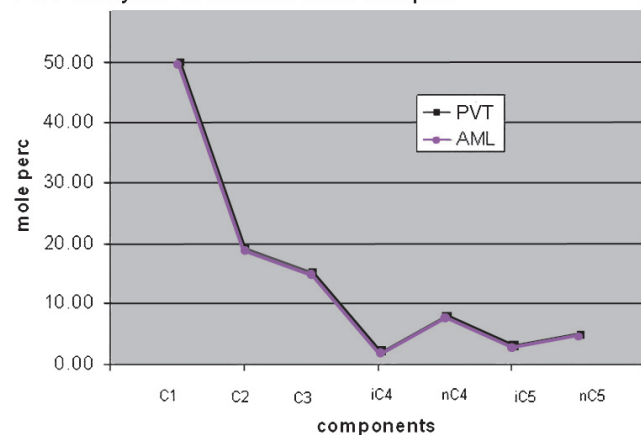


Fig. 5. Perfect match HC composition AML and PVT samples

Similarly excellent measurements of isotopes can now be made, see figure 6 for just two examples, also real time, making it also possible to do geosteering based on the encountered HC composition.

This leap forward in mud gas analysis, was possible only by concerted efforts on every part of the whole mud gas chain. Sampling, ie gas extraction from the return mud flow, traditionally certainly was the weakest link in that chain, and nowadays still might be. Many modern AML gas systems feature a high performance gas chromatograph and a mass spectrometer, located in the mud loggin unit, thus a mud gas line from the shale shakers, or flow line/bell nipple, where the gas extraction system is located. However, further development of the mud gas systems, see e.g. figure 7, eliminates not only the need for the, high capex, mass spectrometer, but achieves a size reduction and explosion proof encapsulation, eliminating the need for a gas line.

XRF and XRD analysis on cuttings

What is generally accepted as a revolution in the mud gas analysis capabilities, is on the cuttings measurements side possibly matched by XRF/XRD (x-ray fluorescence

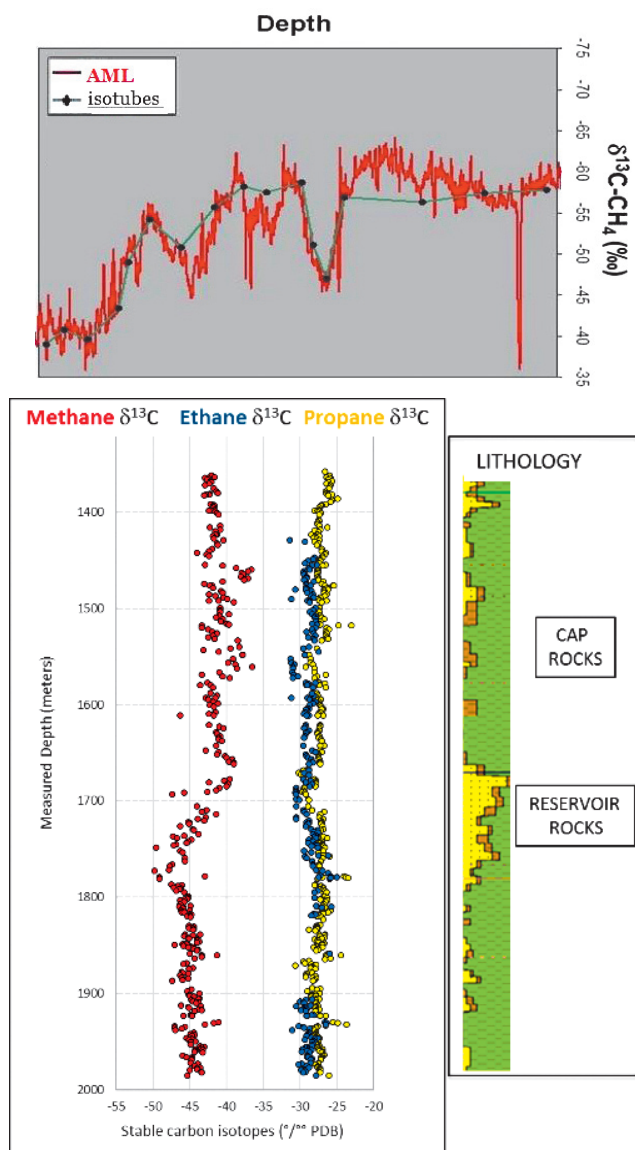


Fig. 6. Isotope logging



Fig. 7. Complete mud gas system. Note the extraction probe, and the complete system being a stand alone system, safe to be used directly near the shale shakers or flowline

and x-ray diffraction) analysis, now possible on site in AML units. XRF can give very accurate elemental composition for Na and higher atomic number elements, XRD provides mineral analysis. The enormous spectrum of elements provided by XRF in particular, has an enormous potential for evaluations in situations where conventional methods just do not suffice. See figure 8, where, to many people’s surprise, Pb, Zn and Mn from the XRF appeared to correlate with the mud gas analysis.

Calculating spectral GR from the XRF analysis is now also so well established and proven that systems where the spectral GR is measured directly, are not needed, other than for possible lower operating costs reasons, including, an aspect not to be underestimated, the lack of need for relatively elaborate sample preparation including cleaning, pulverising and pelletising, still necessary for high quality XRF. Also, like for the direct spectral GR measurement on cuttings, for for some NMR and Pulsed Neutron Spectroscopy (PNS) measurements, little to virtually no sample preparation is needed. On the other hand, the sample volume required for XRF is so small that, as mentioned under 2 above, careful selection and hand picking of the cuttings being analysed is possible.

Other measurements ... “looking better” maybe most important?

This paper does not, because it simply cannot, not do justice to all the other measurements now available. Therefore, as a last example, a reminder maybe that “looking better”, might be said to be the main feature allowing progress in our discipline, so, “just looking better at cuttings”.

The most rudimentary element of conventional mud logging was the lithological cuttings description. And on this front too, AML can do better. See figure 9, where, rather than just the conventional lithological description, a rock typing classification was done, as per standard rock classification schemes (Archie,

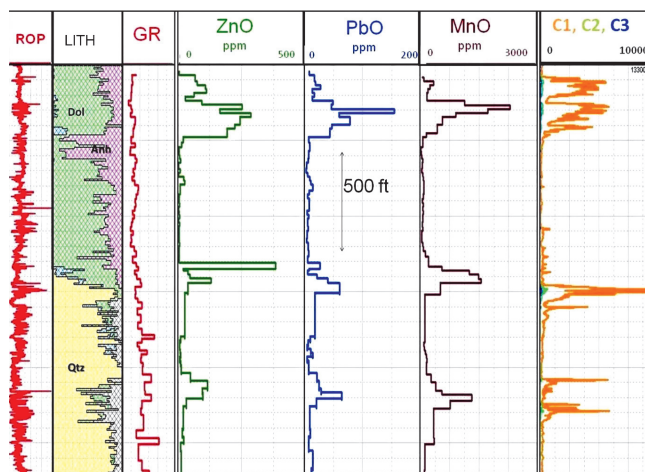


Fig. 8. Interesting correlation some trace elements from XRF with mudgas (from the (Marsala et al., 2012))

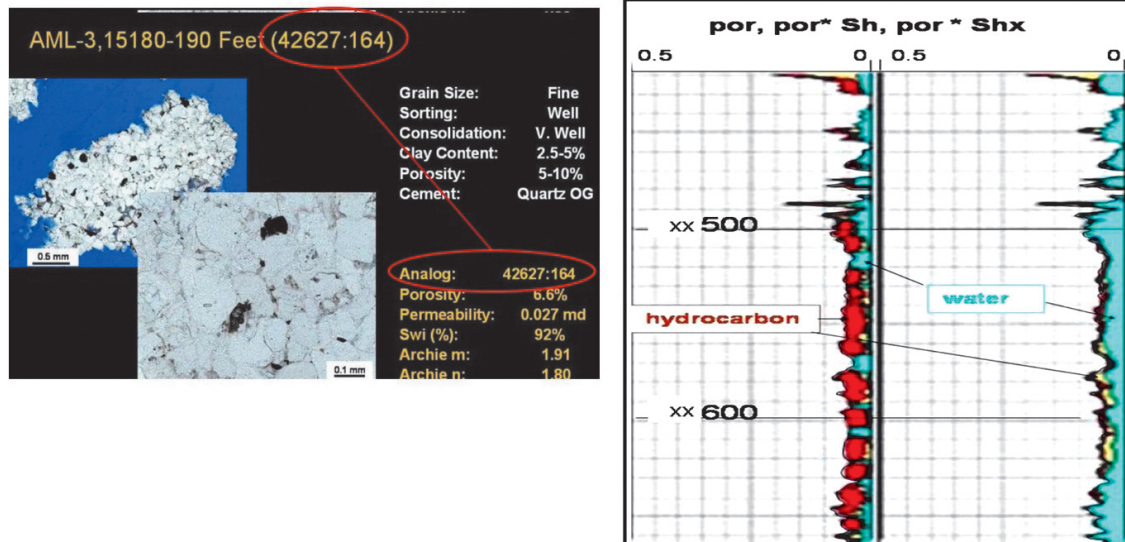


Fig. 9. "Looking better", may save expensive production tests. Using the electrical parameters from the rock catalogue for the corresponding rocks, as opposed to only regional knowledge in this area when the well was drilled, changes the evaluation from gas to water bearing.

world famous for his saturation equation, actually also did excellent rock classification work; the objective being to reduce the amount of necessary laboratory measurements). Next, with the properties then obtained from the rock catalogue, an evaluation was made. While that rock typing could have been done in real time, on site, unfortunately it wasn't. hence, for the petrophysical evaluation of that well, only general regional knowledge parameters could be used. As a result the well was interpreted as HC bearing, and thus production tested, sadly producing only water. As can be seen from the evaluation with the parameters derived from rock typing, had AML been around for this well, chances are the costs of the production test would have been saved.

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