THE SCRATCH TEST AS A MEAN TO DERIVE HIGH RESOLUTION ROCK STRENGTH PROFILES FOR GEOMECHANICAL AND PETROPHYSICAL EVALUATIONS.

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ABSTRACT

The scratch test was developed in the late 90's at the University of Minnesota as a simple, non-destructive, fast and robust rock testing technique, to provide a direct measure of the rock strength equivalent to the uniaxial compressive strength. It produces a high resolution profile of strength (with centimeter steps), revealing the distributions of small heterogeneity length scales along the core samples.

In this paper we show (i) how the difference in resolution scales of plug and well log measurements, added to the discrete sampling of properties (plugging) could lead to a misinterpretation of apparent correlations between petrophysical properties, and (ii) how the early mapping of small heterogeneity length scales could reduce the uncertainty in the integration of core and wireline data. We show with some examples how rock strength profiles averaged to the relevant length scale could be correlated with other petro-physical properties measured both on core plugs or inferred from well logs. Finally, we discuss how planning the scratch test at an early stage in a data acquisition effort would open new perspectives for routine and special core analysis workflows.

INTRODUCTION

Rock properties are evaluated at the reservoir scale by a combination of field measurements (coring, wire line logs, well testing, seismic surveys), calibrated against the results of laboratory test on core plugs (Chang et al., 2006; Blasingame, 2008; Khaksar et al., 2009). The calibration of field data requires measurements on plug samples (a few centimeters in diameter) to be representative of average values inferred from wireline logs or seismic sections at a lower resolution (half meter to a few meters). However, rock heterogeneity includes length scales smaller than the average size of core plug samples (Haldorsen, 1996). The difference in resolution of wireline logs and plug samples, combined with small heterogeneity length scales of rocks and the discrete sampling of properties on cores could lead to misinterpretation of correlations found between properties measured in the field and in laboratories. Selecting a large number of samples may circumvent this issue with the build-up of a representative statistical data set to minimize the impact of outliers. However, extensive plugging strategies are not always viable (for instance in the cases of rock mechanic testing or special core analysis programs). Alternatively, the continuous, high resolution strength profile generated from the scratch test, provides some useful elements for the mapping of small length scales of rock heterogeneity, filling the resolution gap between plug measurements and well logs.

THE SCRATCH TEST

The scratch test consists in tracing a groove of constant depth *d* on the surface of a rock sample with a cutting tool while imposing a constant cutting velocity *v*. The amplitude and orientation of the force acting on the cutting blade are recorded with a high sampling frequency and a high precision. The raw force signals are averaged over segments of 1cm in length in order to filter out the high frequency components and strengthen the signal content related to rock properties variations. Results from a series of successive passes performed on the same sample are interpreted to provide the Intrinsic Specific Energy, which for suitable sets of operating parameters (depth of cut, cutter geometry and inclination) is equivalent to the uniaxial compressive strength of the material (Detournay and Defourny, 1992), (**Fig. 1**c). Epslog SA has developed a state of the art semi-automated apparatus (“the Wombat”**)** to perform scratch tests on core samples up to 3 feet long and from ½ to 6 inches in diameter **Fig. 1**a. An experienced operator could test and analyze up to 3 meters (9 feet) of core per hour (in competent material) with the Wombat. The scratch test is highly repeatable and produces continuous profiles of rock strength along core samples (**Fig. 1**d) with a spatial resolution of the centimeter (**Fig. 1**b).

HETEROGENEITY MAPPING AND PLUG SELECTION

Fig. 2a shows strength logs with a 5 cm resolution in which two relatively heterogeneous sections can be identified in contrast with two rather homogeneous sections, where the level of heterogeneity is related to the dispersion of the signal around the mean value (given here by the strength log at the 50 cm resolution). **Fig. 2**b displays the neutron porosity well log and the plug porosity values. The mismatch between well log and plug porosity is more pronounced in the “heterogeneous” sections of the scratch profile.

The cross-plot in **Fig. 2**c displays an overall high degree of correlation between well log and plug porosity values, although with some dispersion we argue in part consequence of the mismatch between the measurements resolutions. The three linear trends illustrate how scarce plugging not taking into account the distribution and small scale heterogeneity along the core sample can result in misleading correlations between measurement on plug (strength in this example) and well logs.

Let us define the number η as the ratio of the strength averaged over 50 cm to the strength averaged over 5 cm. The evolution of the mean and standard deviation of η with depth (estimated over a 10cm window to account for possible errors in the exact plug locations) can be used to guide plug selection and reduce the uncertainty associated with the mismatch between measurement length scales, see **Fig. 2**d.

ROCK STRENGTH VS. OTHER PETROPHYSICAL PROPERTIES

Fig. 3a and **Fig. 3**b display correlations between strength averaged over the typical plug sample size (a few centimeters) and porosity or permeability for three cores (10 to 25 m long) from different clastic reservoirs. These figures reveal that a correlation observed in one well or reservoir does not necessarily apply to other wells or reservoirs: empirical laws should not be regarded as universal even across similar lithologies (clastic in the example of **Fig. 3**). In a given litho-facies however, one can derive a strength vs. porosity or permeability mathematical relationship which, when applied to the strength profile, yields high resolution porosity or permeability profiles (**Fig. 3**c and d). Note that the three lowest values of porosity and permeability labelled as SST1- b, off the general trend for SST1–a, correspond to a sandstone unit with a higher average shale content than SST1.

Correlations between rock strength (averaged to the logging tool resolution) and rock properties derived from well logs (porosity, sonic and density) are shown in **Fig. 4**, revealing trends varying from one rock type to another (clastic, carbonate, shale) but also from one well or reservoir to another. These results re-emphasize that empirical laws relating strength with other petro-physical properties are not universal, as previously concluded by Khaksar et. al. (2009) in their comprehensive review. The authors showed that empirical models (listing about 40 of them found in the literature) are not generic enough and need to be enriched to account for facies and the impact of diagenesis. As an example, **Fig. 4**c shows a high level of correlation in one well and a much lower one in **Fig. 4**d for data gathered from a different well in the same reservoir.

APPLICATIONS

The Scratch test yields a continuous, high resolution (centimeter) log of Intrinsic Specific Energy (ISE), a robust indicator of rock strength that is equivalent to the uniaxial compressive strength (UCS) of the material with the reliability associated with laboratory controlled conditions. Such a profile is a quantitative measure of the rock heterogeneity at the centimeter scale which, together with well logs, enables the recognition of several litho-facies along cored intervals and the formulation of efficient plugging strategies for both routine and special core analysis workflows. Scheduling the scratch test early in the core analysis workflow (
Fig. 5) may be very valuable for the following reasons:

- Probe permeability values can be measured in the groove prior to slabbing.
- Grooves expose virgin rock, enabling UV or white light photography before slabbing.
- Strength profiles, gamma-ray, profile permeability, pictures and fresh core surface accessible prior to slabbing can be combined in an early step towards rock typing;
- Strength profiles averaged to wireline log resolution are matched against well-logs to estimate core-shift values, in particular in formation with low gamma ray activity;
- Strength profiles can be combined with well logs to establish correlations of strength with other properties (porosity, density, sonic velocity) prior to slabbing & plugging;
- Strength profiles can be used to screen regions of interest for geomechanical studies (borehole stability, sand production, and compaction) and guide the selection of plugs

for laboratory testing (triaxial test, compaction test, thick wall cylinder);

- Strength profiles provide quantitative descriptions of small heterogeneity length scales along cores, which combined with correlations with petrophysical properties, improve the selection of limited numbers of plug samples (rock mechanics, SCAL).
- Repeating the scratch test over time would provide a quantitative measure of the aging or weathering of cores, which is of particular interest when further sampling is performed at a later stage of the field development.

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FIGURES

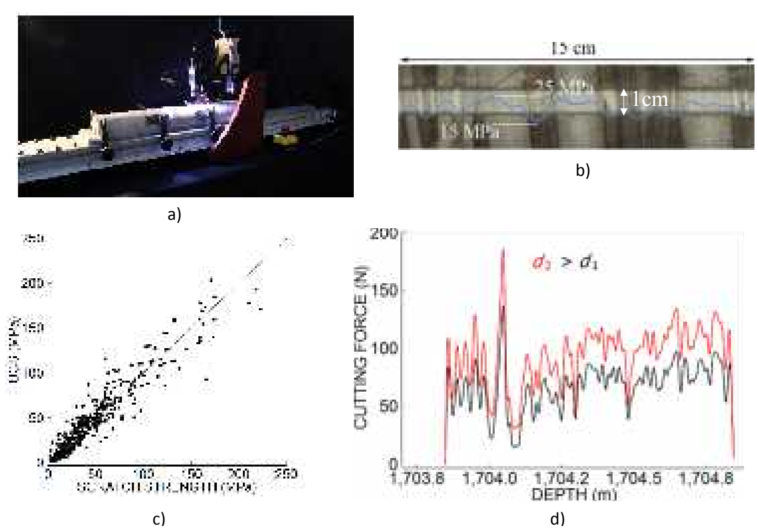

Fig. 1: a) The Wombat. b) Strength profile superimposed on a core photo. c) ISE vs UCS (for several rock

types). d) Two profiles of cutting forces acquired in the same groove at different depths of cut.

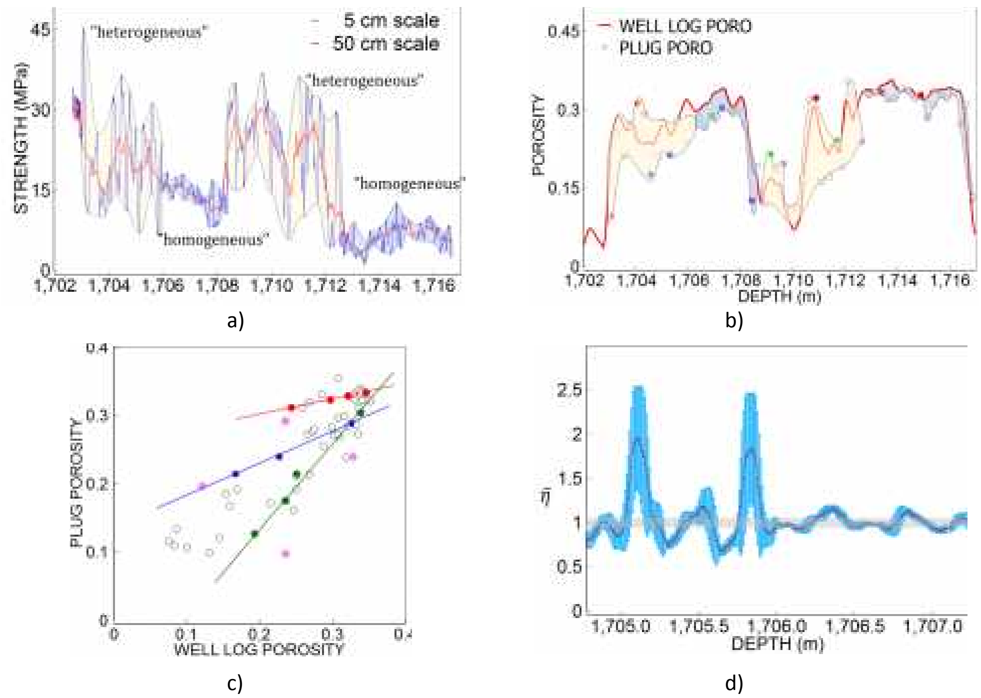

Fig. 2: a): Strength profiles at high and low spatial resolution. b): Well log porosity and plug porosity measurements (marker colors indicate 3 different plugging series). c): Plug vs well log porosity cross-plot, the 3 colors correspond to the 3 plugging series shown in Fig. **2**. d) Evolution of η with depth (zoom between 1704.8 and 1707.2 m). Red line for the mean of η, blue bars for the standard deviation.

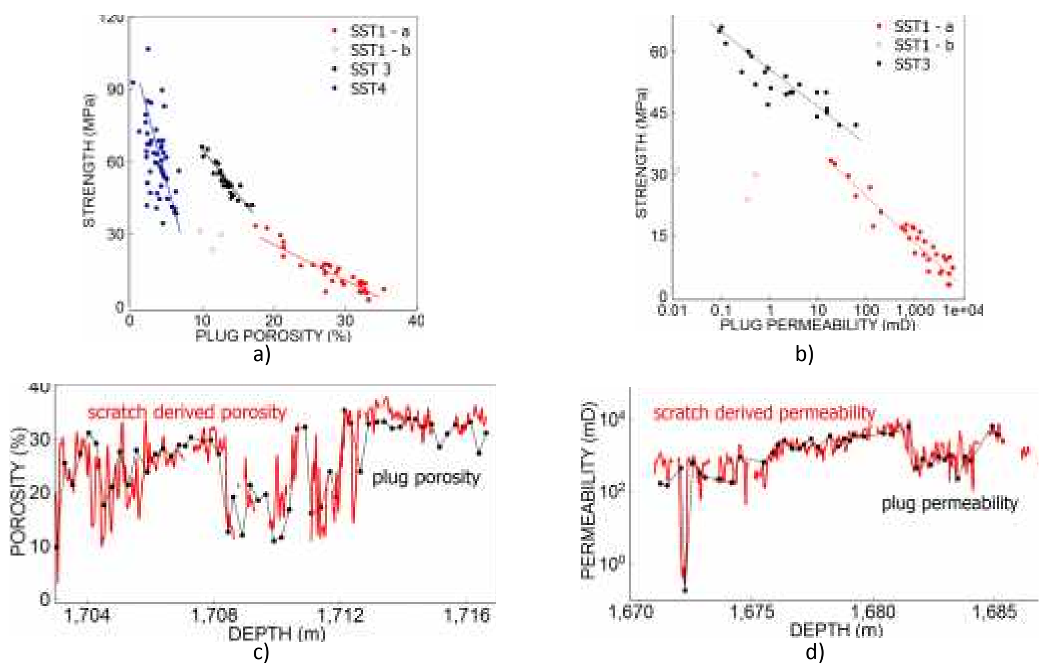

Fig. 3: Correlation of strength (scratch) vs. a) porosity and b) permeability measured on plugs. High resolution logs of c) porosity & d) permeability derived from scratch profile compared to porosity &

permeability measured on plugs

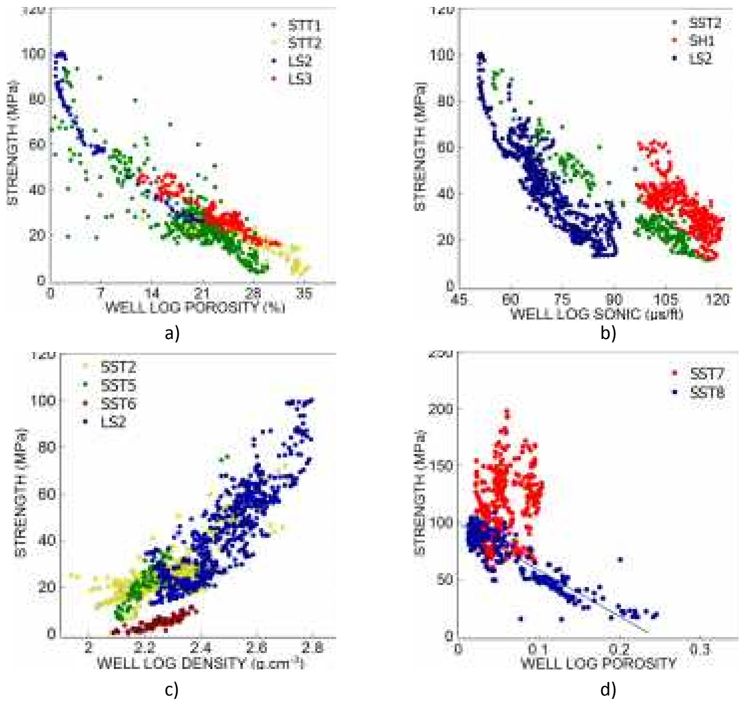

Fig. 4: Well logs vs rock strength (averaged over 50 cm) for core samples from different wells: **a)** total porosity: clastic (SST1 and SST2), carbonate (LS2 and LS3). **b)** Sonic: clastic (SST2), carbonate (LS2) and shale (SH1). **c)** Density: clastic (SST2, SST5, SST6), carbonate (LS2). **d)** Porosity: 2 wells (SST7 and SST8) drilled in the same clastic reservoir.

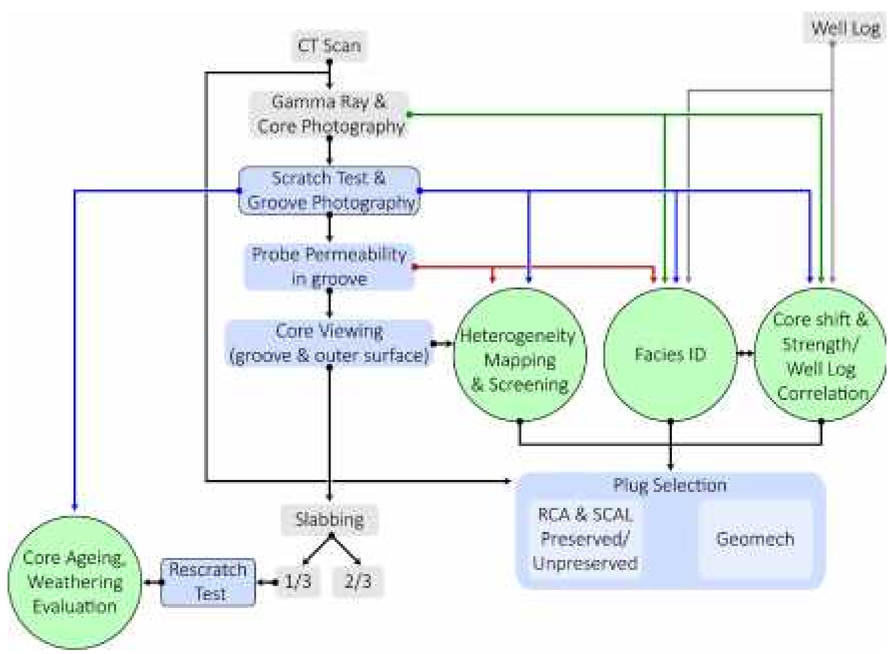

Fig. 5: Core analysis workflow including the scratch test