2nd Workshop on Petroleum Geomechanics Testing:

Rock Physics Methods for Determining Mechanical Properties

The Westin Market Street, San Francisco

22nd June, 2013

Organized by the ISRM Petroleum Geomechanics Commission:

Tony Addis, Russ Ewy, Axel Makurat, Maurice Dusseault (PGC Chair)

And by the American Rock Mechanics Association:

Laura Pyrak-Nolte (Symposium Chair-person), Mark Zoback (ARMA President), Peter Smeallie (Executive Director)

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Rock Physics Methods for Determining Mechanical Properties

Room: Metropolitan Ballroom I, 2nd Floor

The Westin Market Street, San Francisco.
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San Francisco, CA 94103
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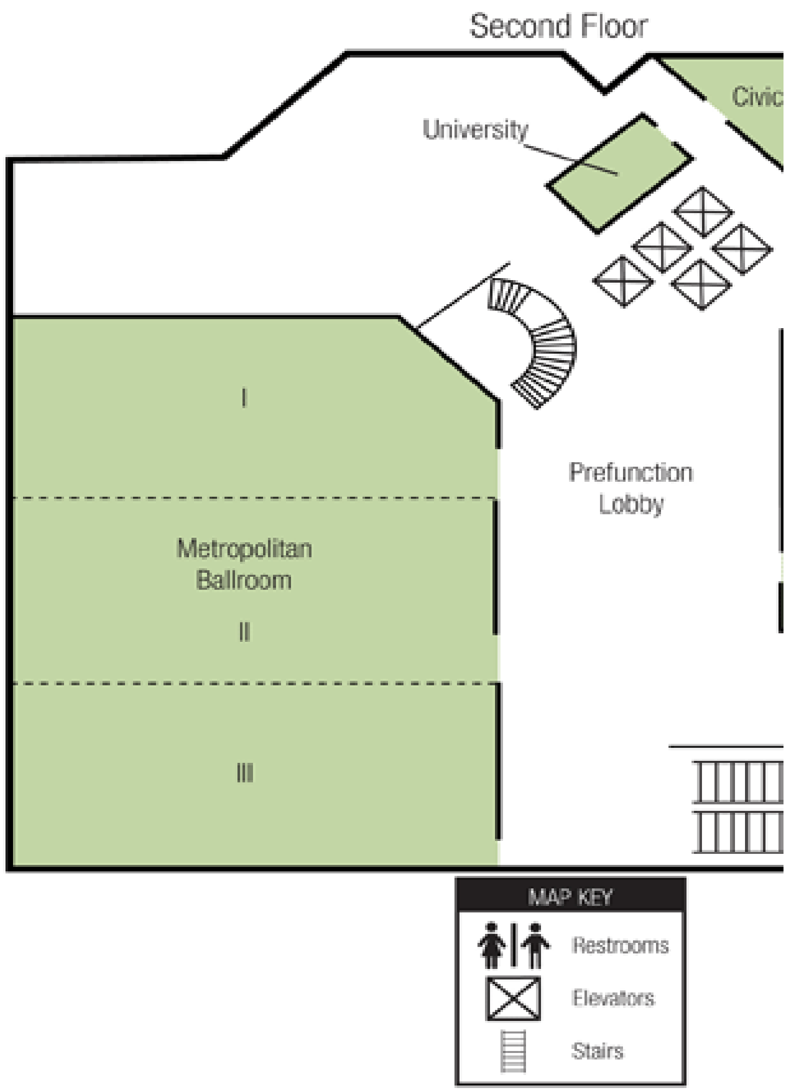

2nd Workshop on Petroleum Geomechanics Testing : Agenda

Time	Session	Title	Speaker		Company
8:00 - 8:15	Introduction	Purpose of the PGC, it's scope & this workshop,	Dusseault, Addis, Ewy, Makurat		
8:15-8:30		Review of activities from last year & Update on the Uniaxial Compressibility Working Group	John	Dudley	Shell
8:30 - 9:00	Experimental /apparatus	Integrated geomechanics and rock physics: experimental setup and procedures for mechanical and acoustic velocity c	Øistein	Johnsen	NGI
9:00 - 9:30		Impact of Experimental Studies on Unconventional Shale Reservoir Mechanisms	Richard	Rosen	Marathon
9:30-10:00		Effect of sample size and sample geometry on mechanical properties of volcanic tuff	Umesh	Prasad	Baker Hughes
10:00 - 10:15	Tea & Coffee break				
10:15 - 10:45	Static - dynamic	"Static and dynamic moduli in shale and sandstone"	Erling	Fjaer	Sintef & NTNU
10:45 - 11:15		Comparison Among Models Which Estimate Minimum Horizontal Stress	Santhosh	Narasimhan	MetaRocks
11:15-11:45		Stress Sensitivity of Acoustics Velocities and Elastic Moduli in Rocks, Implications and Pitfalls for Geomechanical Analy	Abbas	Khaksar	Baker Hughes
11:45 - 12:00		DISCUSSION			
12:00 - 13:00	Lunch				
13:00 - 13:30	Prediction from logs	Strength Prediction and Preservation in Shales through Rock Physics and Physico-Chemical Approaches	David	Dewhurst	CSIRO
13:30 - 14:00		Wave Velocities in Stressed Shales and Sands: How can we obtain representative measurements in the laboratory?	Rune	Holt	NTNU & Sintef
14:00 - 14:30		The Integration of Modern Sonic Logs with Mechanical Core Measurements in Unconventional Reservoirs	Tom	Bratton	Schlumberger
14:30 - 14:45	Tea & Coffee break				
14:45 - 15:15	Additional Applications	TWC and CSL versus log-measured elastic properties for a variety of reservoirs sandstones	Abbas[1]	Khaksar	Baker Hughes
15:15 - 15:45		The effect of CO2/brine/rock interaction on the mechanical properties of rocks	Suzanne	Hangx	Shell
15:45 - 16:15		Using continuous profiles of core properties to map heterogeneity and improve geologic core descriptions	Roberto	Suarez-Rivera	Schlumberger
16:15 - 16:30		DISCUSSION			
16:30 - 16:45	Close Out	Thanks and summary - future plans. Discussion of need (or not) for testing standards/guidelines	Dusseault, Addis, Ewy, Makurat		

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Integrated geo-mechanics and rock physics: experimental setup and procedures for mechanical and acoustic velocity characterization of anisotropy

Authors: Øistein Johnsen[1], Lars Grande[1], Gudmund Havstad[1], Harald Iwe[1], Nazmul H. Mondol[1], Magnus Soldal[1], Inge Viken[1], and Toralv Berre[1].

[1] Norwegian Geotechnical Institute, Norway

Velocity anisotropy has significant importance in seismic imaging, seismic attribute analyses, AVO analysis and interpretation of sonic log data and has become increasingly important knowledge and input for developing velocity models for seismic imaging in sedimentary basins. Recent years technological advances on seismic tools and down-hole sonic logging tools calls for better understanding and description of anisotropy as a phenomena and benchmark laboratory testing.

Driven by a general demand for complete sets of both static and dynamic moduli data from an often small and fragile volume of core material implies testing on small core samples (1 ½ ” or even 1”) for which we have strived to develop an experimental setup that join traditional triaxial rock mechanics and geophysics with as little compromise on the respective types of measurements as possible. While axial acoustic velocity measurements have been a standard attribute in addition to axial and radial LVDT strain measurements in our triaxial testing rigs for a while, the increased interest in anisotropy studies pushes instrumentation in our triaxial setups further by equipping core plugs with sonic transducers along two or more orthogonal directions. Design and production poses several considerations and challenges: Sonic transducer dimensions for maximizing signal quality versus available limited space and surface on standard 1 ½” and 1” core plugs, choices on how to best ensure contact between sensors and sample without introducing local alteration of material such as false bedding difficulties and false deformation when not fixing sensors with glue or stiffening by gluing and even failure point indication by stress concentration or intrusion. An important aspect is also that the core sleeves should be reusable since production is highly time consuming and expensive.

In-house hardware and software is designed to facilitate for sequential measurements of up to acoustic 7 channels, and also combining with a newly developed multi electrode resistivity acquisition system which requires special precautions for the hardware but also for the triaxial rigs.

We present an overview of the current experimental developments, physical considerations and design choices made up to date, as well as demonstrating its usage through various anisotropy case studies.

Impact of Experimental Studies on Unconventional Shale Reservoir Mechanisms

Authors: Richard Rosen[1], Munir Aldin[1], William Mickelson[1]

[1] Marathon Oil, Houston.

Physical properties of rocks are controlled by composition and texture. Texture can be considered the result of the many geologic processes imposed upon a rock throughout time. This includes the effects of deposition and diagenesis. Pore systems, and how they connect, are intimately related to these processes. The science of petrology is devoted to understanding these influences and provides the critical link between the geosciences and engineering applications. As such, it is a commonly held belief throughout the history of petroleum science that laboratory core measurements need to be made at representative conditions. This has always been accepted for conventional reservoirs and is no less true for unconventional ones.

Apparatus have been developed for both steady- and unsteady-state methods for nano-Darcy (nD) range finegrained shale material. The steady state method is based upon a dual pump system at high pressure using super critical fluids. Super critical fluids have the unique advantage of having low viscosity, low compressibility, and miscible at appropriate conditions. Low viscosity allows measureable flow rates and low compressibility minimizes the amount of time to achieve steady-state equilibrium by reducing the length of time of unsteady-state transients.

Specially designed and configured pump systems, seals and sleeves reduce leak rates to allow Darcy permeability determination below 1 nD. In this report we present a summary of over 200 such measurements and additionally document many of the same reservoir mechanisms long known in conventional reservoirs: stress dependency for both matrix and fractures, hysteresis, and rate dependent skin. Taken together for dual porosity reservoirs composed of matrix storage feeding fracture systems forms the basis of simulation models for these types of reservoirs. Examples are presented from Woodford, Haynesville, Bakken and Eagle Ford formations.

Effect of sample size and sample geometry on mechanical properties of volcanic tuff

Authors: U. Prasad[1], R. Maharidge[1], and J. Franquet[1],

[1] Baker Hughes Inc., Houston, TX, USA

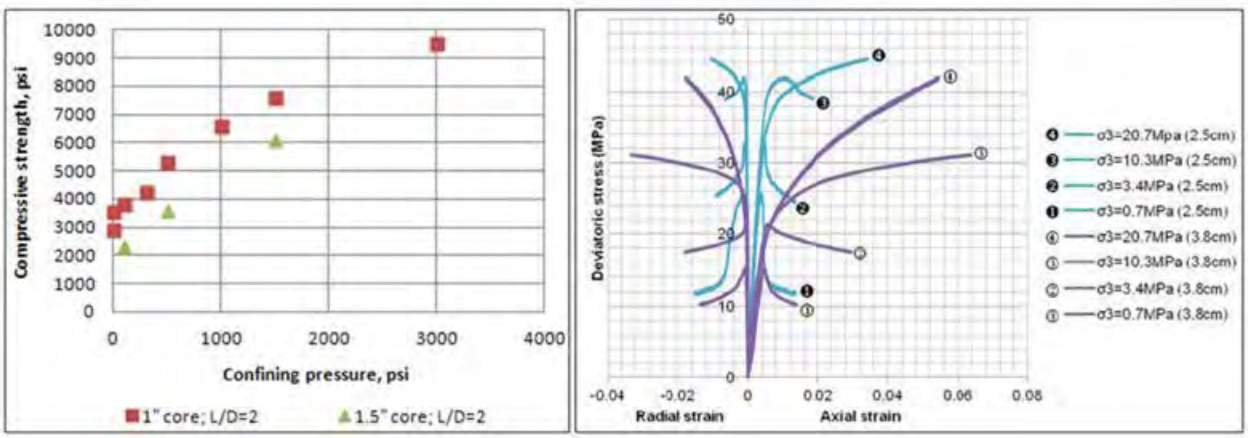
Appropriate estimate of strength and elastic properties is vital to many oil and gas exploration and exploitation processes including geothermal use. Robust sub-surface geomechanical models require such input data which truly represent the rocks involved. The appropriate sample size (cube or diameter) or sample geometry (length to diameter ratio) are noted in various standard procedures of ASTM, ISRM, USBM and AASHTO for rock, soil or even cement and concrete, but there is not enough details citing the cause of it`. This work take a step back, explores the role of sample size and sample geometry on unconfined (UCS) and confined compressive strength (CCS) and Young's monduli of rock properties. It also describes a method for qualifying and integrating physical and mechanical rock property data to assure they provide reliable values.

Strength (UCS and CCS at simulated in-situ condition) and their calculated Young's modulus are essentials to Geoscience Engineers and Professionals. These rock properties necessarily come from disparate sources. Physical samples for laboratory testing are usually limited to a few depths. Lab tests are often costly, replicating in-situ conditions can be difficult or impossible, and results frequently show wide scatter reflecting the rock's inherent variability. Electric logs provide near-continuous data, but rarely direct measurements of rock strength properties. All too often data from different sources are inconsistent, leading to uncertainty in models using those data. Therefore, a proper understanding on these properties and source of variation in these, if any, are essential steps in building a representative description of the rock.

Effect of sample size have been investigated by various authors; Bieniawsky (1968), Hoskins & Horino (1969), Hoek & Brown (1980), Hawkins (1998), Thuro et al (2001), Masoumi et al (2012). The ASTM & ISRM standard appear to be based on these works suggesting sample size (diameter of core) should be more than 10 time the maximum grain size or flaws in it. It is interesting to note that the same standard for cement suggests core diameter should be only 3 times the maximum aggregate size.

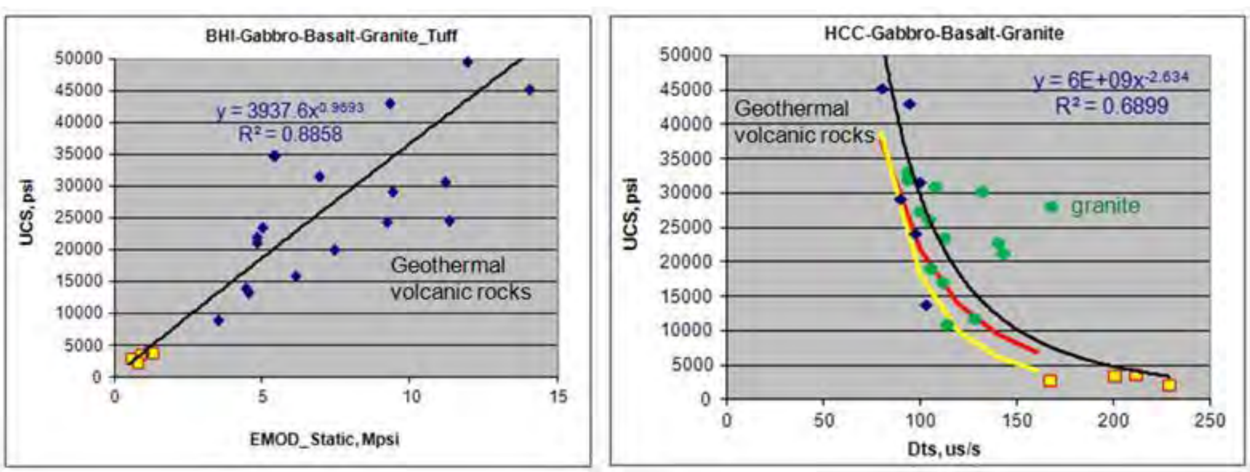
The suggested procedure also recommends suitable length (L) to diameter (D) ratio ranging from 2 to 3.5 in order to avoid bending on longer samples and allowing development of shear fracture plane in shorter samples. Some of the noted work exploring L/D ratio are Mogi (2007), Dirige & Archibald (2006), Thuro (2012) etc. It appears that UCS remains fairly consistent for L/D>2. For smaller L/D the UCS increased marginally; there is correction factor suggested by ASTM (1986) to normalize the result similar to L/D=2. However, Young's modulus remained unaffected in granite and granodiorite over L/D from 1 to 4; but increased in Karsanaite with increase in L/D. Poisson's ratio decreased for higher values of L/D. Finally, the CCS appeared to reduce the effect of L/D ratio.

The current in-house work agrees well with the past works; larger diameter volcanic tuff samples had lower UCS and lower CCS measured at different confining pressures. The Young's modulus at various confining pressures was lower in bigger samples also. Larger sample needed more confining pressure for showing ductile behavior. Finally, the measured values of UCS and CCS were QA/QCed using novel techniques of using various cross-plots and compared with correlations from the literature. Conformance with those correlations gives confidence in the data.



a) ***b)***

Figure 1: Effect of sample size a) on UCS & CCS; b) stress-strain curves at various confining pressures.



a) ***b)***

Figure 2: QA/QC on volcanic rock properties, current work compared with past works, a) Young's modulus cross plotted with UCS; b) Shear acoustic wave slowness compared with UCS together with well known empirical equations.

Static and Dynamic Moduli of Shale and Sandstone

Authors: Erling Fjær[1,2], Rune M. Holt[2,1], Jørn F. Stenebråten[1] and Anna M. Stroisz[1]

[1]SINTEF Petroleum Research, Trondheim, Norway
[2]NTNU, Trondheim, Norway

Quantitative relations between static and dynamic moduli of rocks are useful for situations where static moduli are needed while only dynamic moduli are available. Such relations can be established and calibrated by laboratory tests where both types of moduli are measured simultaneously. The tests have to be carefully conducted in order to reduce or preferably eliminate sources of uncertainty, such as anisotropy, drainage conditions, strain rate and strain amplitude. Uniaxial strain conditions are clearly preferable for elimination of uncertainty, however other stress path are better suited for model building purposes. The "non-elastic compliance", defined as

$$S_H = \frac{1}{H_{static}} - \frac{1}{H_{dynamic}}$$

for a uniaxial strain test, is found to be a useful parameter (H is the uniaxial compaction modulus). Similar definitions apply for other stress paths. By assuming that the origin of this parameter is due to a limited set of physical processes which are activated or deactivated under given conditions, quantitative models can be established for sandstone. Limited tests for shale indicate that the same models to a large extent are also relevant for shale. By applying suitable test conditions, analyses of this parameter may also be used to study elastic dispersion in the range from seismic to ultrasonic frequencies, and to provide estimates of Thomsen's delta-parameter.

Comparison Among Models Which Estimate Minimum Horizontal Stress

Authors: Santhosh Narasimhan[1], Munir Aldin[2] and Richard Rosen[2]

[1] MetaRocks, Houston.
[2] Marathon Oil, Houston.

Minimum horizontal stress is a key input parameter for many rock physical models – Hydraulic fracturing, lateral well design, wellbore stability etc. Inaccurate stress magnitudes might not provide the sensitivity necessary to determine the stress barriers above and below pay zones. Full evaluation of the multiple models assists to ultimately provide better understanding fracture network. Static and dynamic mechanical core properties were measured in several places along the length of a vertical core in an unconventional shale reservoir. The properties includes Young's modulus, Poisson's ratio, ultrasonic compressional/shear acoustic velocity and the Mohr failure parameters of friction angle and cohesion, stiffness parameters and Biot coefficients. Utilizing the determined mechanical properties the minimum horizontal stress (Sh) was estimated using the following models Ben Eaton – isotropic and anisotropic, modified Ben Eaton with correction factor, Vernik, Jaeger and Cook, Hubbert and Willis, Thiercelin – MC envelope and stiffness tensors (Cij), Segall and Penebaker. An isotropic/anisotropic comparison was completed to better understand the amount of anisotropy.

A software has been developed to enhance the process of determining in-situ stresses and evaluate the effects of various parameters affecting the calculation such as estimated gradients and Biot assumption. The focus of this presentation is to calibrate vertical sonic logs (Vp0, Vs0) using core data, determine three independent pseudo velocity logs (Vp45, Vp90 and Vs90), obtain dynamic to static correlations necessary to develop an estimated continuous anisotropic mechanical stress profile.

Stress Sensitivity of Acoustics Velocities and Elastic Moduli in Rocks, Implications and Pitfalls for Geomechanical Analysis

Author: Abbas Khaksar[1]

[1] Baker Hughes Inc., Perth Australia

Acoustic velocity logs are usually used in pore pressure modeling and to derive rock mechanical properties, which both are among the essential inputs for geomechanical evaluations. Acoustic velocities and elastic moduli in rocks themselves are stress sensitive. The rock physics basis of stress sensitivity of elastic properties are often neglected and empirical equations which are used to derive pore pressure or mechanical properties from them sometimes are used beyond their range of applicability resulting in erroneous geomechanical and petrophysical estimates. In this presentation after an introduction on the principles of stress sensitivity of acoustic properties we show situations where ignoring the state of stress and effective stress-velocity relationships could be problematic.

In general, the velocity-effective stress relationship in siliciclastic rocks is non-linear and is characterised by an initial rapid increase in velocity with effective stress increase, followed by a pronounced reduction in the rate of velocity increase with further effective stress increase beyond which the velocity changes with effective stress increase could be practically negligible. A generalized relationship between the velocity-stress plateau and porosity is defined from core measurements on rocks with a range of porosities and fabrics sampled from different geological settings. This relationship can be used to define the corresponding depth of velocity-effective stress plateau versus rock porosity for a variety of rocks.

Implication of such nonlinear stress sensitivity is that depending on the state of in situ stress and pore pressure changes, acoustic velocities and consecutively elastic properties may or may not change significantly with variations in effective stress. For depleting reservoirs, the increase of effective stress could hardly affect the overall rock porosity but acoustic velocity could raise significantly. Neglecting the stress sensitivity of acoustic velocities could lead to an underestimation of rock porosity and overestimation of rock compressive strength and elastic moduli suchad bulk and Young's modulus. In contrast, for deeply buried rocks where the in situ stress is beyond the velocity-stress plateau, changes of the effective stress may hardly affect the velocities and this in turn may lead to erroneous pore pressure estimation from generic velocity-effective stress relationships or normal compaction trends. The stress sensitivity of elastic moduli should also be considered in dynamic-static conversion and the comparison of log-derived and core measured elastic properties. Core-derived elastic moduli from triaxial tests conducted at zero or low confining pressures significantly underestimate the in situ values. For accurate core-log calibration, the static values should be measured at various confining pressures, from low pressures to values close to the in situ mean effective stresses.

Strength Prediction and Preservation in Shales through Rock Physics and Physico-Chemical Approaches

Authors: Dave Dewhurst[1], Joel Sarout[1], Claudio Delle Piane[1], Tony Siggins[2], Ben Clennell[1] and Mark Raven[3]

[1] CSIRO Earth Science and Resource Engineering, Perth.
[2] CSIRO Earth Science and Resource Engineering, Melbourne.
[3] CSIRO Land and Water, Adelaide.

Knowledge of mechanical, physical and petrophysical properties of shales has slowly increased in recent times partly through investigations of the problems they cause for drillers (wellbore stability, overpressure), further through investigations of top seal capacity and integrity (capillary and mechanical properties) and finally through the advent of shales as reservoirs for prospecting for unconventional sources of gas (flow, diffusion, strength, fracturing). In particular, understanding factors controlling the strength of 'conventional' shales (e.g. overburden shales, top seals etc which are fully saturated and clay-rich) are important for predicting wellbore stability and trap integrity, issues which if not well understood, can cost billions of dollars a year. In this paper, we look at laboratory methods of measuring the strength of shales and then try to relate them empirically to other more easily measured physical and petrophysical properties. While regularly used as a proxy for rock strength, velocity was found to be a poor indicator of absolute shale strength, although useful for determining upper bounds. Porosity and cation exchange capacity give good empirical correlations to strength on a global suite of shales. However, partial saturation complicates this picture as water content affects rock strength and stiffness in both fully and partially saturated clay-bearing shales. Strength and static mechanical stiffnesses can increase as water saturation decreases in low porosity, low clay, hard, stiff shales, as do dynamic moduli such as Young's and shear moduli calculated from velocity. This has implications for proper preservation of clay-bearing shales for laboratory testing for mechanical, physical and petrophysical properties, especially those now considered as reservoirs as well as for predicting gas shale properties from seismic data or wireline logs under partially saturated conditions.

Wave Velocities in Stressed Shales and Sands: How can we obtain representative measurements in the laboratory?

Authors: Rune M Holt[1], Erling Fjær[2], Andreas Bauer[2] and Jørn F Stenebråten[3]

[1] NTNU & SINTEF, Trondheim, Norway, Houston.
[2] SINTEF & NTNU, Trondheim, Norway
[3] SINTEF, Trondheim, Norway

With the continued development of 4D seismic, quantification of subsurface stress evolution caused by pore fluid withdrawal or injection is becoming feasible. Sensitivity of sonic well log data to the near-well stress field provides a potential to map in situ stress anisotropy, which has an important control on hydraulic fracturing as well as borehole failures. From these perspectives, it is important to be able to assess wave velocities and their stress dependence under in situ conditions from core measurements.

In this presentation, laboratory experiments on shale / clay and sandstone / sand will be shown, in order to see how differences between in situ and laboratory conditions may affect the observations. The issue of core alteration as a result of stress relief has been studied extensively by experiments on synthetic rocks formed under stress. Furthermore, the influence of stresses and pore pressure and in particular of the stress path during laboratory experiments will be focussed. Brief discussions will also be given to issues of frequency dependence (dispersion) and temperature dependence, in particular for shales.

The Integration of Modern Sonic Logs with Mechanical Core Measurements in Unconventional Reservoirs

Author: Tom Bratton[1]

[1] Schlumberger, Houston.

Correlations have typically been used in geomechanical studies to transform the relatively common dynamic sonic logging measurements to the corresponding static mechanical properties measured on a limited amount of core. Most of these correlations have been developed for conventional reservoirs that are adequately described by relatively simple laboratory experiments coupled with homogeneous and isotropic models. Unconventional reservoirs are significantly more complex, primiarly due to heterogeneity; the non-uniform distribution of dissimilar components. The heterogeneity in the formation's composition and texture causes significant anisotropy which complicates the measurements used to derive both dynamic and static properties. Heterogeneity also causes issues related to scale. Integration requires the reconciliation of the different measurement scales between log and core with the scale of the geomechanical process of interest.

A workflow has been developed to help integrate laboratory measurements made on small scale (~2 inch) samples recovered from whole core with larger scale (~4 foot) measurements made by high end sonic logs. The workflow addresses many of the complications inherent in the different measurements and multiple scales. Different examples will be presented to illustrate the workflow and how different complications can be addressed.

Tom Bratton is a both a Scientific Advisor for Schlumberger (SLB) and a visiting professor in the College of Earth Resource Sciences and Engineering at Colorado School of Mines (CSM). His activities include developing solutions for drilling and completion operations for SLB and teaching and research for CSM. He has 36 years of experience with Schlumberger specializing in geophysics, petrophysics and geomechanics and is a licensed professional geoscientist in Texas. Tom has worked in multiple SLB segments including Wireline and Testing, Drilling and Measurements, Well Services and Petrotechnical Services. He has been active in field operations as well as research and engineering and has been exposed to reservoirs worldwide including deepwater and land based operations. Tom has a BS degree in Physics from Nebraska Wesleyan University, an MS degree in atomic physics from Kansas State University and is a member of SPE, SPWLA, SEG and ARMA. He resides in Denver, Colorado.

Thick Wall Cylinder Strength and Modeling of Critical Strain Limits From Core Tests and Well Logs

Authors: Abbas Khaksar[1], Feng Gui[1], Manuel Blumenthal[1] and Sadegh Asadi[1]

[1] Baker Hughes Inc., Perth Australia

Thick Wall Cylinder (TWC) or Hollow Cylinder (HC) tests are normally used in analytical and numerical sand production predictions, quantification of sanding rate and as a scale model of wellbore or peroration cavities. In these tests a hollow cylinder is loaded under increasing hydrostatic stress until collapse occurs in the walls of the cylinder. The hydrostatic stress at which failure initiates in the internal wall is reported as the TWC-Internal and the stress that causes external wall failure is called TWC External or TWC collapse. Numerical modeling of rock failure and in particular some sand production prediction methodologies require the stress condition corresponding to the initiation internal wall failure to define the critical strain limit (CSL) beyond which sanding is expected under the wellbore flowing condition.

Identification of failure initiation during thick wall cylinder tests however is not straightforward and requires special laboratory set up and techniques or plugs seizes which are not routinely available. The standard TWC (external wall failure) tests also are not conducted routinely or the quantity of tested plugs are often not adequate to establish local correlations. Also preparation of high quality plugs for TWC tests is not straight forward and sometimes is difficult due to the shortage or the poor quality of core material. Unlike the uniaxial compressive strength (UCS) there are very few publically available empirical equations to estimate TWC from well logs and to our knowledge there is no published relationship between measured CSL and other physical properties or well logs.

In this presentation we show a series of novel empirical equations between TWC strength and other rock properties including porosity, UCS, acoustic logs and dynamic elastic moduli for a range sandstones of different geological age and lithofabrics. We then show several strong correlations between the measured and numerically modeled CSL from advanced TWC tests and measured UCS or dynamic elastic moduli for sandstones. This will follows with a discussion on the rock physics basis of observed UCS-CSL trends and their implications for the numerical sand production prediction methodologies.

The Effect of CO2/Brine/Rock Interaction on the Mechanical Properties of Rocks

Authors: Suzanne Hangx[1], Arjan van de Linden[1], Fons Marcelis[1], Andreas Bauer [2]and Kristian Eide[1]

[1] Shell, Rijswijk, The Netherlands

[2] Formerly with Shell, Rijswijk, The Netherlands, currently with SINTEF & NTNU, Trondheim, Norway

One of the most promising ways of disposing of CO2 is through Carbon Capture and Storage (CCS), entailing CO2 capture at source, followed by long-term geological storage. Possible storage sites include depleted oil and gas reservoirs, saline aquifers and unmineable coal seams. The former are particularly interesting and recognised as an important CCS route for countries with a major oil or natural gas production and transport infrastructure, such as the United States, Norway, United Kingdom and the Netherlands.

Long-term storage in depleted reservoirs is strongly dependent upon maintaining trap integrity, i.e. on maintaining caprock and fault integrity, as well as well bore integrity. Stress and strain changes accompanying reservoir depletion and/or CO2 injection into an associated reservoir may lead to deformation-induced damage to wellbore, caprock, and fault-seal systems, particularly in the long term. The importance of CO2-related creep effects, by enhanced microcracking and/or mineral dissolution-precipitation reactions, lies in their potential to cause reservoir rock compaction. In addition, chemical attack by CO2 may modify the mechanical strength and transport properties of the caprock or may promote reactivation and/or leakage of sealed faults. Overall, geological storage of CO2 in depleted oil and gas reservoirs is a complex matter, influenced by many, in their own rights complex, interlinked processes and mechanisms.

Over the past two decades, much research has focussed on elucidating some of the key questions, through geochemical as well as geomechanical modelling, and through experimental efforts. However, to date, very little experimental data exists on the effect of CO2 on coupled chemical-mechanical processes occurring in reservoir and seal formations, and indeed on purely mechanical damage, for real rocks under in-situ conditions. Understanding them and obtaining site-specific data is important for (geomechanical and geochemical) numerical modelling efforts performed to assess upcoming CCS sites, as well as predicting the long-term fate of CO2 in the subsurface. This presentation will focus on discussing the experimental work that has been done and is being undertaken to understand the effect of CO2/brine/rock interaction on mechanical properties of intact rocks. During such experiments, key mechanical parameters to be determined are generally rock strength, elastic properties, cohesion, friction angle, and if possible sonic velocities.

Using Continuous Profiles of Core Properties to Map Heterogeneity and Improve Geologic Core Descriptions.

Author: Roberto Suarez-Rivera[1]

[1] Schumberger, Terratek, Salt Lake City, Utah, U.S.A.

Understanding scale-dependent heterogeneity in tight shales and other unconventional reservoirs is important for hydrocarbon production and recovery. It is also important for characterization, modeling, and for extending our observations, experience and understanding from one scale (e.g., core-scale) to another (e.g., log- or seismic-scale). The presence of scale-dependent heterogeneity also poses additional important questions regarding sampling for characterization, including the number of samples needed, the adequate scale for sampling and others. Addressing and solving these questions will lead to significant progress on tight shale exploration and efficient production. Here, we describe continuous measurements along the length of the core that result in significant improvements to geologic core descriptions and heterogeneous rock characterization. Using multiple high-resolution measurements (e.g., of strength, thermal conductivity, CT atomic number, and XRF mineralogy) we define the principal rock classes, with similar characteristic properties, that define the heterogeneous system. The thickness and cyclic stacking patterns of these units provide quantitative information of the depositional system and its sequences. The method also differentiates transitional contacts from abrupt contacts, and provides additional information for developing a geologic model. Although the cyclic nature of shale and silt sequences is often visually apparent, the variability in properties within these sequences is only accessible by the continuous measurements. We analyze these via multivariate statistical analysis, to define rock classes with tightly constraint measured properties and visualize their variability with colors (similar colors represent similar rock classes). Results allow us to define the geologic system more quantitatively. They also allow us to understand the variability represented by larger samples used for core-based reservoir quality and completion quality evaluations.