PROPOSAL FOR ESTABLISHING A WORKING GROUP ON ISRM SUGGESTED METHOD FOR UNIAXIAL-STRAIN COMPRESSIBILITY TESTING

Introduction

Rock frame (bulk volume) and pore volume compressibility are key parameters needed for an accurate understanding of the formation deformation response to pore pressure changes in rocks and sands. They can have a critical impact on both the economics and containment risks associated with fluid withdrawal or injection operations, particularly in the petroleum industry (where, e.g., reservoir compaction and subsidence impacts can be many millions of US$). It is well known that rock properties, including compressibilities, are often stress-path dependent. The uniaxial-strain (zero-lateral-strain) stress path is often the most representative stress path for many petroleum-related recovery processes, as it normally approximates the underground boundary conditions active during recovery. The accurate measurement of these compressibilities under reservoir stress and uniaxial-strain conditions generally requires specialized equipment and expertise, but unfortunately, there are currently no standards or suggested test methods for such uniaxial-strain measurements. Given the importance of these measurements, we believe the ISRM should develop and publish a Suggested Method for Uniaxial-Strain Rock Compressibility Testing. This proposal is to form a Working Group (WG) of industrial and academic experts in the field of petroleum geomechanics testing, with the goal of drafting such a Suggested Method over the two years.

Purpose

Stress-path dependence of rock properties has been documented in a large number of publications (a small selection of which are among the papers in the Reference section). As stated above, formation rock frame and pore volume compressibilities are generally made under reservoir uniaxial-strain conditions as the most representative stress path. The WG intends to incorporate the knowledge and testing experience gained through published works, plus the personal and institutional experience of the WG members, to develop a Suggested Method for Uniaxial-Strain Rock Compressibility Testing. A key function of the WG will be to distill down the collective experience into a SM that captures the critical aspects of this type of compressibility testing, while maintaining the necessary flexibility required to apply the SM to the broad range of formation materials and stress conditions of importance to the Petroleum Geomechanics community.

Proposed Working Group Members

The chairman of the proposed WG is John Dudley, Subject Matter Expert for Experimental Rock Mechanics & Geomechanical Testing Core Analysis, Royal Dutch Shell. Members of the WG are all persons with extensive experience in petroleum geomechanical core testing, and are drawn from petroleum industry companies, core testing service companies and academia. All members of the WG and their titles and affiliations are listed in Table 1.

Table 1. Members of the Proposed Uniaxial-Strain Compressibility Testing Working Group.

Member Name	Position/Title	Affiliation	E-mail contact
Ahmed Abou-Sayed		Advantek International	asa@advantekinternational.com
Tony Addis		Baker Hughes	tony.addis@bakerhughes.com
Munir Aldin		Marathon Oil	MhSharfAldin@MarathonOil.com
Greg Boitnott		New England Research	boitnott@ner.com
Marco Brignoli		ENI	marco.brignoli@eni.com
Rick Chalaturnyk		University of Alberta	rjchalaturnyk@ualberta.ca
Brian Crawford		Exxon-Mobil	brian.r.crawford@exxonmobil.com
John Dudley	SME Experimental Rock Mechanics & Geomechanical Testing Core Analysis	Royal Dutch Shell	john.w.dudley@shell.com
Russ Ewy	Research Consultant, Geomechanics	Chevron	RussEwy@chevron.com
Di Jiao		Core Laboratories	di.jiao@corelab.com
Gang Li	Sr. Technical Advisor, Geomechanics	Halliburton	gang.li@halliburton.com
Jack Liu		Core Laboratories	jack.liu@corelab.com
Axel Makurat		Royal Dutch Shell	axel.makurat@shell.com
Philippe Marchina		Total	philippe.marchina@total.com
John McLennan		University of Utah	jmclennan@egi.utah.edu
Michael Myers		University of Houston	mtmyers@central.uh.edu
Ganerico Ramos		Conoco-Phillips	rico.g.ramos@conocophillips.com
Thurman E. Scott		Royal Dutch Shell	thurman.scott@shell.com
John Shafer		Reservoir Management Group	kwakushafe@yahoo.com
Eduard Siebrits	Geomechanics Division Manager	TerraTek/Schlumberger	siebrits1@slb.com
Jorn Stenebraten		SINTEF	Jorn.Stenebraten@sintef.no

Brief definition of the SM to be developed

The Suggested Method for Uniaxial-Strain Compressibility Testing primarily addresses the measurement of formation frame and pore volume compressibilities under stress and boundary conditions appropriate to represent in-situ behavior of reservoirs undergoing production and/or disposal processes. As such, the method needs to incorporate specifications for the sample preparation, equipment and its calibration, details of allowed testing protocols, and calculation of measured compressibilities and other geomechanical parameters determined from the specific test protocol. For example, a guideline from a service vendor for a Uniaxial-strain Compressibility test protocol using the pore pressure depletion method is listed in Table 2. This protocol incorporates latitude for client specification of how the sample is handled, but the impact of some of the 'client choices' are something the proposed SM will provide comment on. An outline of the proposed SM is given in the next section.

The SM will not encompass oedometric-type consolidation testing. Standards for soil consolidation testing already exist, and such testing is not applicable for the uniaxial-strain testing from in-situ reservoir conditions that is of interest to the Petroleum Geomechanics community.

Table 2. Example of guidelines uniaxial-strain compressibility measurements from a service laboratory

Uniaxial-Strain Compressibility Measurements – Pore Pressure Depletion Method

1. ***Sample size:*** Nominal 1.5-inch diameter by approximately 3-inch length *or* 1-inch diameter by approximately 2-inch length.
2. ***Sample orientation:*** Vertical is preferred, such that the compaction direction matches that in the reservoir.
3. ***Saturation:*** Directed by the client – can be as-received and topped off with inert laboratory oil or formation brine, or solvent-cleaned and topped off with inert laboratory oil or formation brine.
4. ***Test temperature:*** Directed by the client – can be ambient or elevated conditions.
5. ***Pore pressure:*** Controlled – initially, the pore pressure is increased to the client-specified *in-situ* reservoir pressure condition.
6. ***In-situ stress:*** The vertical stress is the maximum principal stress. Refer to the *in-situ* stresses provided by the client.
7. ***Initial loading conditions:*** Instrument and install the sample in the testing vessel. Initialize data acquisition to obtain a complete record of the sample volumetric deformation. Fill the confining vessel with laboratory oil. Apply 50 psi effective confinement at a rate of 5 psi/s and allow strain equilibration.
8. ***Pore pressure:*** Connect to pore pressure control intensifier. Vacuum-flood the sample with the appropriate saturating fluid. Connect the pore line to the intensifier.
9. ***Apply In-Situ Stress Conditions:*** Increase the pore pressure and the confining pressure simultaneously to their target values at a rate of 1 psi/s (hydrostatic loading - target values are initial *in-situ* reservoir stress conditions). During this loading segment, grain compressibility can be determined. At this point, the confining and pore pressures are held constant while the axial stress is increased at a rate of 1 psi/s to the *in-situ* overburden stress condition (triaxial loading) – bulk compressibility can be determined from this loading segment. Biot's coefficient alpha may be calculated from the grain and bulk compressibility values.
10. ***Initiate pore pressure depletion under uniaxial strain:*** Switch into uniaxial strain control (supplementary radial strain is prevented). Maintaining uniaxial strain boundary conditions (no radial deformation) and constant total axial stress (constant overburden stress), decrease the pore pressure at a rate of -0.1 psi/s to the target value (e.g., the reservoir abandonment pressure). Confining stress will vary due to the imposed uniaxial strain boundary conditions.
11. ***Ultrasonic velocity measurements (if applicable):*** For pore pressure depletion tests conducted with concurrent ultrasonic velocity measurements, capture ultrasonic velocity (P-wave and S-wave) waveforms at selected intervals throughout the duration of the uniaxial strain portion of the test.
12. ***Pore pressure loading and unloading cycles (if applicable):*** If desired, the pore pressure may be cycled during the uniaxial strain portion of the test to replicate re-pressurization.

Outline of Proposed Suggested Method

The ISRM "Suggested Method for Uniaxial-strain Compressibility Testing" will include the following sections:

1. Introduction
2. Scope
   2.1. Purpose
   2.2. Limitations
3. Apparatus
   3.1. Equipment Capabilities & Guidelines
   3.2. Instrumental Effect Calibration Procedures
4. Sample Preparation
5. Testing Protocols
6. Calculation of Measured Parameters
7. Reporting of Results
8. Notes and Recommendations
   [Comments & references on issues not explicitly addressed in this SM, but are important considerations to uniaxial-strain (and perhaps other) compressibility testing]
9. Acknowledgements
10. References

Proposed Time Schedule

Many of the WG member's institutions have established protocols for uniaxial-strain compressibility testing. The WG will develop the SM using these established protocols as input, and include additional information deemed important to uniaxial-strain compressibility testing. An initial draft SM will be developed in the first year, and circulated in the Petroleum Geomechanics community for comment. A final SM is anticipated to be submitted to the Commission within two years of acceptance of this proposal.

References

Andersen, M.A., and F.O .Jones (1985) A Comparison of Hydrostatic-Stress and Uniaxial-Strain Pore-Volume Compressibilities Using Nonlinear Elastic Theory, ARMA85-0403-1

Bai, M., X. Shen, G.Li (2010) Alternative Method to Determine Pore Volume Compressibility Attributable to Production-Induced Reservoir Compaction, SPE 130212

Brignoli, M. and A. Di Federico (2004) Compaction of Unconsolidated Sands and Stress Path Effects: Laboratory Evidence, ARMA04-615

Crawford, B.R. and D.P Yale (2002) Constitutive Modeling of Deformation and Permeability: Relationships Between Critical Sate and Micromechanics, SPE 78189

Crawford, B.R., D.W. Webb and K.H. Searles (2008) Plastic Compaction and Anisotropic Permeability Development in Unconsolidated Sands with Implications for Horizontal Well Performance, ARMA08-160

Crawford, B.R., P.F. Sanz, B. Alramahi, N.L. DeDontney (2011) Modeling and Prediction of Formation Compressibility and Compactive Pore Collapse in Siliciclastic Reservoir Rocks, ARMA11-384

Dietrich, J.K. and J.D. Scott (2007) Modeling Thermally Induced Compaction in Diatomite, SPE 97849

Dudley, J.W., M.T. Myers, R.W. Shew and M.M. Arasteh (1994) Measuring Compaction and Compressibilities in Unconsolidated Reservoir Materials by Time-Scaling Creep, SPE 28026 & 51324

Hathon, L.A. and M.T. Myers (2011) A Survey of the Production Time-Scale Compaction Behavior of Unconsolidated Sands, ARMA11-229

Lachance, D.P., and M.A. Andersen (1983) Comparison of Uniaxial Strain and Hydrostatic Stress Pore-Volume Compressibilities in the Nugget Sandstone, SPE 11971

Nguyen, V.H., N. Gland, J.Dautriat, C. David, J. Guelard and J. Wassermann (2012) Experimental Study and Modeling of the Hydromechanical Behavior of a Weakly Consolidated Sandstone under Proportional Triaxial Compression Stress Paths, ARMA12-430

Rhett, D.W. and L.W. Tuefel (1992) Effect of Reservoir Stress Path on Compressibility and Permeability of Sandstones, SPE 24759

Ruistuen, H., and L.W. Teufel (1996) Influence of Reservoir Stress Path on Deformation and Permeability of Weakly Cemented Sandstone Reservoirs, SPE 36535

Schutjens, P.M.T.M, T.L. Blanton, J.W. Martin, B.C. Lehr and M.N. Baaijens (1998) Depletion-Induced Compaction of an Overpressured Reservoir Sandstone: An Experiments/Approach, SPE 47277

Scott, T.E. (2007) The Effects of Stress Paths on Acoustic Velocities and 4D Seismic Imaging, The Leading Edge, May

Shafer, J.L., G.N. Boitnott and R.T.Ewy (2008) Effective Stress Laws for Petrophysical Rock Properties, SPWLA 2008, v49GG

Wu, B., M.A. Addis, C.P. Tan and R.H.T. Cox (1999) Computer Aided Stress and Strain Path Tests and Their Effects on Mechanical Behaviour of Rocks, ISRM99-205

Wu, B. (1995) The effects of stress path on compressibilities of coal, ARMA95-0121

Yi, X., S.H. Ong and J.E. Russel (2005) Characterizing Pore Compressibility, Reservoir Compaction and Stress Path under Uniaxial Strain Condition for Nonlinear Elastic Rock, ARMA05-791

Zheng, Z. (1993) Compressibility of Porous Rocks Under Different Stress Conditions, ARMA93-0577