

# Highlights of the 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation

ARMA Technical Committee on Hydraulic Fracturing

On April 3-5, ARMA Hydraulic Fracturing Community (HFC) held a joint workshop with Dhahran Geoscience Society (DGS) on the role of geomechanics in stimulation in Manama, Bahrain. The goal is to demonstrate the values of hydraulic fracturing technologies and facilitate their connections with field operations.

The three-day workshop consisted of opening reception, commercial exhibits, geomechanics training, technical presentations, keynote luncheon, discussion breakouts, social activities, etc.

In total, 109 attendees participated the meeting, representing seven operators, fifteen service providers, and fourteen technology developers. They were from the countries as far as Canada, US, Argentina, China, Switzerland, UK, Russia, South Africa, etc, as near as Saudi Arabia, Oman, Kuwait, and UAE. Participants shared knowledge and experience, discussed challenges, and demonstrated the values of geomechanics.

The event has made several records in geomechanics history as THE

- first ARMA international adventure;
- first collaboration between ARMA and DGS;
- most attended and largest technical program at HFC;
- largest sponsorship at ARMA workshops; and,
- most viewed geomechanics post at LinkedIn (10,000+).

The event success stems from 6-month diligent preparations from the cohost Dhahran Geoscience Society, the 38-member organizing committee, the 33 technical speakers, and the enthusiastic audience. Special acknowledgements to the sponsors, Saudi Aramco, Schlumberger, MetaRock Laboratories, Inc., Rockfield, FracGeo, Baker Hughes a GE company, Itasca, and Golder. Because of their generousities, we were able to invite young, enthusiastic, and eager-to-learn students, the future of geomechanics.

The deliveries are available to Hydraulic Fracturing Community (HFC) members at the ARMA TCHF website (<http://armarocks.org/sample-page/committees/technical-committee-on-hydraulic-fracturing-tchf-2/>). These include:

1. Highlights (this document);
2. Geomechanics Training materials;
3. Presentations (Releases confirmed by authors);
4. Technical Agenda (Appendix I); and,
5. Attendee list (Appendix II).

The access information including username and password is announced in the HFC newsletter.

## Geomechanics Training - “Rock with Fellows”

The workshop opened with a first-day training on fracturing-related geomechanics. It was taught by three distinguished ARMA Fellows, Profs. Prof. Mark Zoback from Stanford University, Maurice Dusseault from University of Waterloo, and John McLennan from University of Utah. The training not only covered geomechanical fundamentals but also in-depth topics.

- Prof. Zoback overviewed in-situ stresses, reservoir-scale fractures and faults, and fluid pressure. Their relationships were demonstrated through multiple case studies and literature reviews, esp. when reservoir pressure changes due to depletion or injection. A topical, titled Rethinking brittleness - Extrinsic and Intrinsic Rock Mass Properties, highlighted the importance of rock properties in stimulation design.
- Prof. Dusseault explained the physics and the approaches in fracture modeling, using shale gas as an example. From legacy PKN-KDG-Sneddon model to sophisticated numerical codes, capacities and limitations of various methods were compared with emphasis on a promising hybrid approach.
- Prof. McLennan demonstrated a workflow for stimulation design, considering properties of natural discontinuities, conductivity and proppant, refracturing and diverters, water usage, fracturing diagnostics, near wellbore frictions, chemomechanical stimulations, etc. Multiple post-design production scenarios with varying input procedures were simulated to optimize stimulation plan. He also presented a keynote on leveraging mechanical specific energy in drilling to predict dynamic rock properties.

## Technical Presentations

Followed the first day of training, 31 technical presentations were given in the sessions of operator perspectives, technology highlights, and case studies.

Operators from Saudi Aramco, Abu Dhabi National Oil Company, Shell Kuwait, Petroleum Development Oman, etc., shared experience and challenges in rock characterization, in-situ stress estimate, fracture initiation and propagation with beddings, laminations, or in high tectonic stress environment. The unique geological settings and tectonic histories differentiate the Middle East reservoirs from North American fields in terms of hydraulic fracture placement and performance.

Technology developers demonstrated and revealed significant physics involved in hydraulic fracturing. Based on the findings from lab and simulations, promising technologies were proposed to address challenges such as formation breakdown, lamination interactions, fracture interference, etc. For example,

- Omar Al-Dajani and Prof. Herbert Einstein at Massachusetts Institute of Technology observed in the lab fracture tip propagated faster than fluid, and microseismic activities occurred along rock grain boundaries. Prof. Ahmed Ghassemi at Oklahoma University confirmed a six times increase of flow rate with shear slip. High injection pressure and high net pressure were noticed with high in-situ stress contrast. Complex fracture was not necessarily favored in low stress contrast environment.
- Thomas Finkbeiner at KAUST presented a series of rock tests with Eagle Ford outcrops. A new energy-based brittleness index was proposed to incorporate rock elastic and plastic behaviors. Munir Aldin at Metarock Laboratories found a new reliable method of measuring Biot coefficient based on acoustic velocities in low porosity unconventional rocks.

- Lawrence Livermore National Lab, Schlumberger, and Saudi Aramco developed and applied various technologies such as notches to help initiate hydraulic fractures, lower breakdown pressure, and reduce near wellbore tortuosity.
- Modelers developed and advanced simulation techniques, such as
  - A Material Point Model (MPM) with anisotropic damage mechanics for hydraulic and natural fracture interactions (FracGeo);
  - A Displacement Discontinuity Model (DDM) coupled with Finite Difference Method (FDM) for fluid-driven fracture initiation and propagation (Oklahoma University);
  - A hybrid Finite Element and Discrete Element Model (FEM-DEM) for near wellbore complexity (Rockfield);
  - A Discrete Element Model (DEM) for fracture interference in Synthetic Rock Mass (SRM) (Itasca);
  - Discrete Fracture Network (DFN) for fractures and FEM for rock matrix to optimize well and stimulation design through matching production history (Golder); and,
  - A stochastic fracture model combined with DFN model for fracture development with pre-existing fractures (Sousa and Abdalla, Masdar).

The values of technologies were clearly demonstrated in fields and laboratories. The challenges were highlighted in many case studies. For example,

- In the clastic and carbonate fields across the Middle East and Asia, Hui Hai at Schlumberger and Satya Perumalla at BHGE reviewed geomechanics applications and challenges. Fracture and well designs were optimized based on composite indexes such as CQ (Completion Quality), RQ (Reservoir Quality), or iCSF (Index of Critically Stressed Fractures). Challenges remain in rock characterization (esp. in carbonate), tectonic stresses, laminations, etc. It is not unusual to observe changes of stress regimes in a single vertical or horizontal well.
- In two fields where formations were difficult to breakdown due to high pore pressure and high rock strength, Latifa Qobi at Practical Geomechanics found a threshold of Young's modulus for fracture initiation. Best practices in perforation design and pressure pumping were shared to facilitate fracture placement.
- In China, Prof. Haiyan Zhu from Southwest Petroleum University reported the first unconventional field trial of fracturing with supercritical CO<sub>2</sub>. Gas production was doubled while water usage was minimal. Prof. Weiguo Liang from Taiyuan University of Technology demonstrated the significant role of hydraulic fracturing in developing coal bed methane. Both researchers found that supercritical CO<sub>2</sub> is efficient to create complex fracture network, lower breakdown pressure, and increase permeability.
- In Eagle Ford, Brice Lecampion at EPFL showed entry frictions from fluid partitioning were significant in fracturing and could completely overshadow the stress interference from fractures. And,
- In a tight sand reservoir, Mohammed Nassir and Dale Walters at CGG applied coupled reservoir and geomechanics simulations to capture poro-thermo-elasticity, evaluate fracture height containment, and assess caprock integrity during water injection.

## Collaboration Discussions

In the last afternoon, the workshop broke into ten smaller groups to facilitate discussions. Each group discussed current status of technologies and field challenges. A spokesperson from each group then summarized and suggested ways to connect technology developers, service providers with operators.

At the closing marks, Gang Han reviewed the 2017 fracturing model benchmark efforts as one example of HFC contributions to the advancement of hydraulic fracturing studies. He pointed out probably one significant consensus from the 2018 workshop is the integration of various disciplines to maximize the value of geomechanics. For example,

- Drilling events could be indicators for hydraulic fracturing efficiency (e.g. Xu Li, Shell).
- Geological variants had direct impacts on fracture placement, such as tectonics (Hui Hai, Schlumberger), bedding planes (Abdelwahab Noufal, ADNOC), lithology (Satya Perumalla, BHGE), etc.
- Completion systems including near wellbore friction management needed to be a part of solutions for addressing the challenges in operations (Kirk Bartko, Saudi Aramco).
- Production tools such as fracture diagnostics and well test analyses provided evaluations for stimulation efficiency (John McLennan, U of Utah).
- Reservoir characterizations with 3D/4D reservoir-geomechanical models helped planning of wells and fractures (e.g. Osman Hamid and Adel Qahtani, Saudi Aramco).

Over all, as the first ARAM adventure overseas, the workshop achieved tremendous successes in terms of both technically and financially. These cannot be realized without contributions from organizing committee, presenters, sponsors, participants, exhibitors, and volunteers from Dhahran Geoscience Society. It has created long-lasting impacts in the Middle East and beyond, for Hydraulic Fracturing Community and for American Rock Mechanics Association.

Because of popular demands, particularly from the Middle East, we have decided to return to the region in 2020. More details are coming ...

## References (Presentations Confirmed to Release)

1. Adam Bere, 2018. Hydraulic Fracturing: Simulating Near Wellbore Fracture Propagation. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
2. Ahmad Ghassemi, Hydraulic Fracturing in Unconventional Reservoirs: Mechanisms and Processes. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
3. Anastasia Dobroskok, Ruqaiya Al Zadjali, 2018. Critical Look at Fracture Diagnostic through a Lens of a Geomechanicist: Oman Experience. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
4. Branko Damjanac, 2018. Numerical Investigation of Hydraulic Fracturing during Multi-Stage Stimulation. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
5. Brice Lecampion, 2018. The Importance of Coupling Wellbore Hydraulic & Simultaneous Fractures Propagation in Multistage Design. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
6. Joe Morris, 2018. Testing Stimulation Concepts for an Enhanced Geothermal System (EGS) in a Deep Mine: the US EGS Collab Project. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
7. John McLennan, 2018. Mechanical Specific Energy and At-the-Bit Measurements – The Bit as Laboratory. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
8. John McLennan, 2018. Workflow for Stimulation Design. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
9. Juan C. Chavez, 2018. Hydraulic Fracturing in HPHP and Differentially Depleted Tight Gas Accumulations in Horizontal and Highly Deviated Wells. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
10. Kirk Bartko, 2018. A Systematic Completion Approach in Overcoming Fracture Initiation Pressures. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
11. Liu Hai, 2018. Geomechanical Challenges for Unconventional Reservoirs in the Middle East and Asia. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
12. Maurice B. Dusseault, 2018. Modeling and Hydraulic Fracture Geomechanics. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
13. Mark Zoback, 2018. Rethinking Brittleness. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
14. Rashid K. Abu Al-Rub, Oraib Al-Ketan, Hazem Mubarak, 2018. Simulating Hydraulic Fracturing using Nonlocal Anisotropic Elastic-Plastic-Damage Model. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
15. Tobias Hoeink, 2018. Stimulation Simulation – Where is the Value? 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.
16. Weiguo Liang, Haojie Lian, 2018. Experimental and Numerical Study of Fracturing in Coal Seams. 2018 ARMA-DGS Workshop: the Role of Geomechanics in Stimulation. Manama, Bahrain, April 3<sup>rd</sup> - 5<sup>th</sup>.

## Appendix I: Technical Program

Sessions	Speaker	Affiliation	Title
Training: Rock with Fellows	Mark Zoback	Stanford	Stress and Pore Pressure in Hydraulic Fracturing
	Maurice Dusseault	U of Waterloo	Modeling and Hydraulic Fracturing Geomechanics
	John McLennan	U of Utah	Workflow for Stimulations Design
	Mark Zoback	Stanford	Rethinking Brittleness-Extrinsic and Intrinsic Rock Mass Properties
Operator Perspective s	Xu Li	Shell KOC	Eight Years in Unconventional Geomechanics – The Good, The Bad and The Ugly
	Francis Elisabeth	SAO	A new approach to estimate Acoustic Anisotropic Elastic Properties for Unconventional Reservoir - A case study in the Ordovician and Silurian - Northern Arabia Basin.
	Adel Gahtani/Osma n Hamid	SAO	3D Fracable Sweet Spot Modeling
	Juan Chavez Florez	PDO	Horizontal Wells Hydraulic Fracturing from Tight HPHT to Multilayer Differential Depleted Gas Accumulations in Oman
	Abdelwahab Noufal	ADNOC	Bedding Planes Corridors controls Hydraulic Fracturing Initiation and Propagation
	Anastasia Dobroskok	Shell	Critical Look at Fracture Diagnostic through a Lens of a Geomechanicist: Oman Experience
	Christophe Germay	ADNOC	Data Accuracy and Reliability on Model Robustness for Stress and Strength Predictions: Challenges and Solutions
	Kirk Bartko	SAO	A Systematic completion approach in overcoming fracture initiation pressures
Keynote	John McLennan	U of Utah	Mechanical Specific Energy for Drilling
Technology Highlights	Omar Al- Dajani, Herbert Einstein	MIT	Experimental Investigation of Hydraulic Fracture Initiation and Propagation in Opalinus Shale
	Ahmad Ghassemi	OU	Hydraulic Fracturing in Unconventional Reservoirs: Mechanisms and Processes
	Haojie Lian, Weiguo Liang	Taiyuan University of Technology (China)	Experimental and Numerical Study of Fracturing in Coal Seams
	Munir Aldin	MetaRock	A Novel Method to Characterize BIOT's Coefficient in Unconventionals

	Joe Morris	LLNL	Testing Stimulation Concepts for an Enhanced Geothermal System (EGS) in a Deep Mine: the U.S. EGS Collab Project
	Branko Damjanac	Itasca	Numerical Investigation of Hydraulic Fracturing during Multi-Stage Stimulation
	Paul LaPointe	Golder	Using 3D Discrete Fracture Network Approaches for Efficient Geomechanically Coupled Hydraulic Fracture Simulation
	Gallyam Aidagulov	Schlumberger	Notching Technique for Openhole Fracturing: from Theory to Field Trial
	Rita Sousa, Mohammad Abdulla	Masdar Institute	FracProp: Stochastic Fracture Propagation Modeling
	Rashid K. Abu Al-Rub, Oraib Al-Ketan, Hazem Mubarak	Masdar Institute	Simulating Hydraulic Fracturing using Anisotropic Elastic-Plastic-Damage Model
	Salem Algarni, Mohammad Alqam, Antonio Santagati	SAO	The Role of Rock Mechanics in Supporting Hydraulic Fracturing Treatments
Case Studies	Hai Liu	SLB	Geomechanical Challenges for Unconventional Reservoirs in the Middle East and Asia: What We Know and What We Don't Know?
	Latifa Qobi	Practical Geomechanics	The role of Geomechanics in evaluating and accessing deep tight gas opportunities in two different unconventional settings
	Brice Lecampion	EPFL Switzerland	The Importance of Coupling Wellbore Hydraulic and Simultaneous Fracture Propagation in Multistage Design
	Thomas Finkbeiner	KAUST	Comprehensive Characterization of an Unconventional Reservoir With Application to Hydraulic Fracturing
	Satya Perumalla	BHGE	Geomechanical Challenges & Optimization of Hydraulic Fracturing in Tight Reservoirs - A Middle Eastern Perspective
	Tobias Hoeink	BHGE	Stimulation Simulation – Where is the Value?
	Adam Bere	Rockfield	Influence of Geomechanics on Hydraulic Fracturing from Perforation to Fracture Tip
	Rashid K. Abu Al-Rub, Oraib Al-Ketan, Hazem Mubarak	Masdar Institute	Simulating Hydraulic Fracturing using Anisotropic Elastic-Plastic-Damage Model

	Ahmed Quenes	FracGeo	Anisotropic Damage Mechanics for Modeling Hydraulic Fracturing in a Layered Naturally Fractured Reservoir
	Haiyan Zhu	Southwest Petroleum University (China)	Experimental and Field Studies on Supercritical CO2 Fracturing of Shale Gas Reservoir
	Mohammad Nassir, Dale Walters	CGG	Water Injection Fracturing - Caprock Integrity and Height Containment



## Appendix II: Attendee List

First Name	Last Name	Affiliations
Michael	Addis	Addis & Yassir FZE
Abdelwahab	Noufal	ADNOC
Peter	Smeallie	American Rock Mechanics Assn
MUSTAFA	AL ABBAD	Aramco
Ahmed	Al Alawi	Aramco
Hamad	Al Kharra'a	Aramco
Abdulfattah	Aldajani	Aramco
Omar	Alharthi	Aramco
Haitham	Alhindi	Aramco
Adel	Ali Al Qahtani	Aramco
Khalaf	AlTemimi	Aramco
Mohammed	Duhailan	Aramco
Ahmed	Fataierge	Aramco
Elisabeth	Francis	Aramco
Shammery	Hafiz	Aramco
Osman	Hamid	Aramco
Craig	Harran	Aramco
Tariq	Mahmood	Aramco
Zillur	Rahim	Aramco
MOHAMED	TAFAT	Aramco
Saad	Alshehri	Aramco
Ali	Alsultan	Aramco
YAZEED	ALTOWAIRQI	Aramco
Rommel	Arias	Aramco
Kirk	Bartko	Aramco
Angelica	Rios	Aramco
Antonio	Santagati	Aramco
Haitham	Abdulal	Aramco
Abdullah	Alkhaldi	Aramco
Adnan	Almakrami	Aramco
IGOR	FILUPI	Aramco
Clay	Kurison	Aramco
Abdulrahman	Saif	Aramco
Aun	Al Ghaithi	Aramco
Musab	Almodrra	Aramco
Rasim	Rodoplu	Aramco
Mohammed	Al-Dossary	Aramco
Sarah	Alamer	Aramco
Mohammed	Suaid	Aramco
Khalid	Alruwaili	Aramco
Salem	Algarni	Aramco

Gang	Han	Aramco Services Company
Luis	Castro	Baker Hughes a GE Company
Johannes	Vossen	Baker Hughes a GE company
Wael	El Sherbeny	BHGE
Tobias	Hoeink	BHGE
Ivo	Nuic	BHGE
Satya	Perumalla	BHGE
Yanguang	Yuan	BitCan Geosciences & Engineering Inc.
Mohammad	Nassir	CGG Canada Services
First Name	Last Name	Company
Brice	Lecampion	EPFL - ENAC - GEL
Tanguy	Lhomme	EPSLOG
Yamina	Aimene	FracGeo
Ahmed	Ouenes	FracGeo
Radouan	Smaoui	FracGeo
Paul	La Pointe	Golder Associates
Mark	Cottrell	Golder Associates
Oluwasegun	Adeniyi	Independent
Branko	Damjanac	Itasca Consulting Group, Inc.
Dong Joon	Youn	KAUST
Rashid	Abu Al-Rub	Khalifa University
Thomas	Finkbeiner	King Abdullah University of Science and Technology (KAUST)
Eduardo	Gramajo Silva	King Abdullah University of Science and Technology
Abdulauez	Abdulmaheem	King Fahd University of Petroleum & Minerals (KFUPM)
Mohamed Elmuzafar	Ahmed	King Fahd University of Petroleum & Minerals
Abdul	Asad	King Fahd University of Petroleum & Minerals
Muhammad	Hasan	King Fahd University of Petroleum & Minerals
Nur Iman	Khamidy	King Fahd University of Petroleum & Minerals
Abdullah	Sultan	King Fahd University of Petroleum & Minerals
Ahmed	Abdelaal	King Fahd University of Petroleum & Minerals
Gowida	Ahmed	King Fahd University of Petroleum & Minerals
AbdAllah	Youssef	King Fahd University of Petroleum & Minerals
Hany	Gamal	King Fahd University of Petroleum & Minerals
Arqam	Muqtadir	King Fahd University of Petroleum & Minerals
Ahmed	Saifuddin	King Fahd University of Petroleum & Minerals
ZEESHAN	TARIQ	King Fahd University of Petroleum & Minerals
Rizwan Ahmed	Khan	King Fahd University of Petroleum & Minerals
Ibrahim	Goma	King Fahd University of Petroleum & Minerals
Ayyaz	Mustafa	King Fahd University of Petroleum & Minerals
Mohammad	Khan	King Fahd University of Petroleum & Minerals
Joseph	Morris	Lawrence Livermore National Laboratory
Rita	Sousa	Masdar Institute
Munir	Aldin	MetaRock

Deepak	Gokaraju	MetaRock
William	Mickelson	MetaRock
Nasir	Abueissa	MetaRock
Omar	AlDajani	MIT
Ahmad	Ghassemi	OU
Juan	Chavez	PDO
Anastasia	Dobroskok	Petroleum Development Oman
Latifa	Qobi	Practical Geomechanics Pty Ltd
Adam	Bere	Rockfield
Jonathan	Cain	Rockfield
Mohamed Elamin	Yousif	Saudi Geophysical
Gallyam	Aidagulov	Schlumberger
Ziad	Al-Jalal	Schlumberger
Hai	Liu	Schlumberger
Khan	Safdar	Schlumberger
Mustapha	Abbad	Schlumberger
Devon	Gwaba	Schlumberger
Xu	Li	Shell Kuwait E&P BV
Haiyan	Zhu	Southwest Petroleum University
Mark	Zoback	Stanford University
Haojie	Lian	Taiyuan University of Technology
Weiguo	Liang	Taiyuan University of Technology
Raul	Varela	Tecpetrol
John	McLennan	University of Utah
Maurice	Dusseault	University of Waterloo
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