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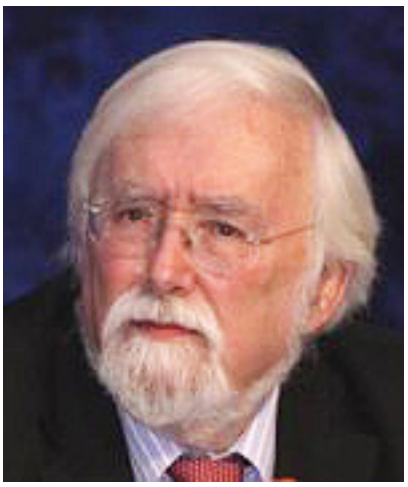
Brief Tribute to John Hudson. February 13, 2019



It is with deep sadness that we inform you that our esteemed colleague, Professor John Anthony Hudson, passed away February 13, 2019 in London, UK from complications of a stroke several weeks before. John was a central member of the initial group of international graduate students who, in the mid 1960 - 1970's, helped establish the 'Minnesota School' and tradition of rock mechanics, that went on to influence rock mechanics and engineering world-wide. John obtained his Ph.D. from Minnesota in 1971, staying there another two years to serve as a Post- Doctoral Fellow and to help establish/build the Minnesota tradition. Returning to England, he became Professor in the Department of Earth Sciences and Engineering at Imperial College; London. From there his reputation and influence on all aspects of rock mechanics/engineering, scholarly and industrial, spread world-wide.

There is perhaps no individual whose influence has been as broad – ranging in international rock mechanics. Recognition included election to Fellow of the Royal Academy of Engineering (FREng) UK (1998); Fellow, American Rock Mechanics Association (2009); President, International Society for Rock Mechanics (ISRM) (2007-2011); Editor-in-Chief, International Journal of Rock Mechanics and Mining Sciences. Shining through all of these accomplishments was a warm human spirit and genuine interest in the welfare of others, everywhere. He leaves a large void, and will be sorely missed. To his wife Carol and the family, our sincere condolences.

A more comprehensive tribute will be published in a future issue of *ARMA Letters.*

Editor's Note

This 2019 winter issue of ARMA Letters *comprises of one research article, this time about a novel method of recovering coalbed methane (CBM), using hydraulic fracturing. This gas is a clean, high-quality energy source and can serve as a chemical raw material. Hence, it is attracting increasing attention all over the world.*

A second article, entitled "A Rant about Carbonates", deals with a common problem in field applications that do not distinguish between types of carbonates, such as between limestone and dolomite, which have different properties.

The next several issues of ARMA Letters will be dedicated to specific topics, such as

1. *"The role of Geomechanics in Unconventional Reservoir Characterization", June, 2019, topic suggested by Azra Tutuncu.*
2. *"In situ stress and Its Measurement", October, 2019, topic suggested by Bill Pariseau and Jay Napola.*
3. *"Geothermal Geomechanics", February, 2020, topic suggested by John McLennan, and supported by Maurice Dusseault.*
4. *"Permeability of Fracture Systems", October, 2020, topic suggested by Bill Carey.*
5. *"Deep Underground Laboratories", date to be decided, topic suggested by Mathew Ingraham and Xiaodong Ma.*

As stated earlier, this is an ambitious plan, and its success depends entirely on the commitment of the proposers and the support of potential authors.

This message gives me the opportunity to call on all those who proposed the topics listed for the next five Special Issues, as well as ARMA members at large, to begin the process of securing appropriate articles for these issues.

Bezalel Haimson, Chair
ARMA Publications Committee

Advances in Coalbed Methane Recovery Using Fracturing Technology

Submitted by P. Wu, W. Liang, H. Lian, and Y. Jiang; College of Mining Engineering and Key Laboratory of In-situ Property-improving Mining , Ministry of Education; Taiyuan University of Technology (China).

Coal-bed methane (CBM) is a gas, containing main-ly methane, which occurs naturally in coal seams. CBM is a clean, high-quality energy source and can serve as a chemical raw material. CBM is attracting increasing attention all over the world. At the beginning of the 21st century, 35 of the 69 countries that possess coal reserves were conducting CBM surveys, and 29 of them began carrying out CBM research, exploration and development.[1]

Development of CBM technology

Reserves of CBM resources all over the world within a depth of less than 2000 meters are approximately 240 trillion cubic meters, which is more than twice the conventional natural gas reserves. The major coal-producing countries in the world have placed great importance on the development of CBM. The United States, United Kingdom, Germany, Russia and other countries have begun the development and utilization of CBM. In the early 1980s, the United States tried out hydraulic fracturing technology for extracting CBM and achieved breakthrough progress, marking a new stage in the development of the world's CBM.

The development of CBM in the United States and Australia is now relatively mature. They are at the forefront of the world in the application of fracturing techniques to increase coal permeability. Twelve other countries around the world had also achieved commercial production of coalbed methane by the end of 2014.

The fracturing technology developed from (1) initial active water with sand fracturing, with or without assistance from liquid nitrogen and CO2, (2) the initial single-coal fracturing to multi-coal segmented fracturing, and (3) the initial fracturing of the coal bed to indirect fracturing of the rock layer above the roof, enabling the induced fracture to penetrate the coal seam.

Issues related to hydraulic fracturing technology in CBM exploration

Despite the initial success of hydraulic fracturing in CBM production, the efficacy of the technique in high-stress, soft, and low-permeability coal seams to enhance strata permeability is not optimal.

Today, CBM wells with commercial production are all distributed in coal seams of high brittleness, high CBM reservoir pressure, and superior permeability. However, there have been unsuccessful cases of large-scale CBM development in fractured, soft, and low-permeability coal seams.[2,3] These types of coal seams are often located in complex geological environments, with abundant joints and low strength fissures. CBM wells are prone to collapse in these types of coal seams during drilling. The output of such wells during production is low and declines very fast.

There are other issues associated with the cur- rent fracturing technology. The hydraulic fractures generated in the coal seams are often short and wide, and cannot effectively form a fracture network. They also tend to penetrate into the adjacent rock layers. Further, the coal depositional environment severely restricts the application of hydraulic fracturing technology in CBM exploitation.

Advances in new fracturing technology for CBM development

In an effort to improve CBM resource development and utilization, researchers have conducted a series of studies on CBM extraction in soft and low-permeability CBM resources. In 2003, Olsen et al. proposed the concept of indirect fracturing.[4] The basic idea was to directly fracture the rock strata immediately above the coal seams first, and then let the induced cracks penetrate into the coal seams through the interface.[5]

For hydraulic fracturing at the interfacial boundary, Anderson[6] conducted an experimental study to investigate the extension of hydro-fractures under uniaxial loading. The results show that whether the crack can propagate through the interface is mainly determined by the normal stress and the friction coefficient of the interfaces, and there is a stress threshold.

Hanson et al.,[7] based on the theoretical analysis from the stress intensity factor, confirmed that fractures in high elastic modulus material are conducive to crack propagation.

Yang et al.[8] and Cheng et al.[9] studied the effects of geostress, natural cleat cracks, interlayers, and interface properties on the hydro-fracture propagation behavior of coal using large-size true triaxial test systems. The study pointed out that the vertical com-

pressive stress and interface properties above the interlayer are the main factors that determine whether the hydraulic fracture can penetrate the layer.

Wu et al.[10] studied the crack propagation of coal and rock under three experimental conditions based on laboratory experiments. The results show that the crack propagation from the layer of rock of higher brittleness to the layer of coal of lower brittleness is favorable to the formation of multiple cracks.

Zhang et al.[11] proposed a cross coal-rock strata interface horizontal fracturing drainage technology based on the geological environment of coalbed methane in China, and provided a new method for low-permebility coal seams.

Wu et al.[12] and Liang[13] of Taiyuan University of Technology in China conducted a series of hydraulic fracturing experiments in coal-rock combinations. It was found that fracturing in the coal seam roof stratum through the interface to the coal seam tends to form a complex multi-fracture system, and thus fracturing the adjacent rock strata can serve as a promising technology for CBM extraction. Figure 1 shows a typical specimen and crack propagation pattern from a number of laboratory tests.

Summary and prospects

CBM is an important natural resource, which plays a critical role in ensuring global energy security and in alleviating the high demand for natural gas. As a new type of clean resource, CBM exploitation is still far from being mature in research and in practice. The key to effectively promoting large-scale commercial exploitation of CBM is fundamental research targeted at understanding the strong heterogeneity of reservoirs, and the complex way of CBM accumulation and enrichment in coal-bearing basins.

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[3] Cao Y., Zhang J., Tian L., et al. Research and application of CO2 gas fracturing for gas control in low permeability coal seams. Journal of China Coal Society, 2017, 42(10): 2631-2641.

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[5] Olsen T.N., Bratton T.R., et.al. Application of Indirect Fracturing for Efficient Stimulation of Coal-bed Methane. SPE 107985 presented at SPE Rocky Mountain Oil & Gas Technology Symposium held in Denver, USA., 2007, April 16-18.

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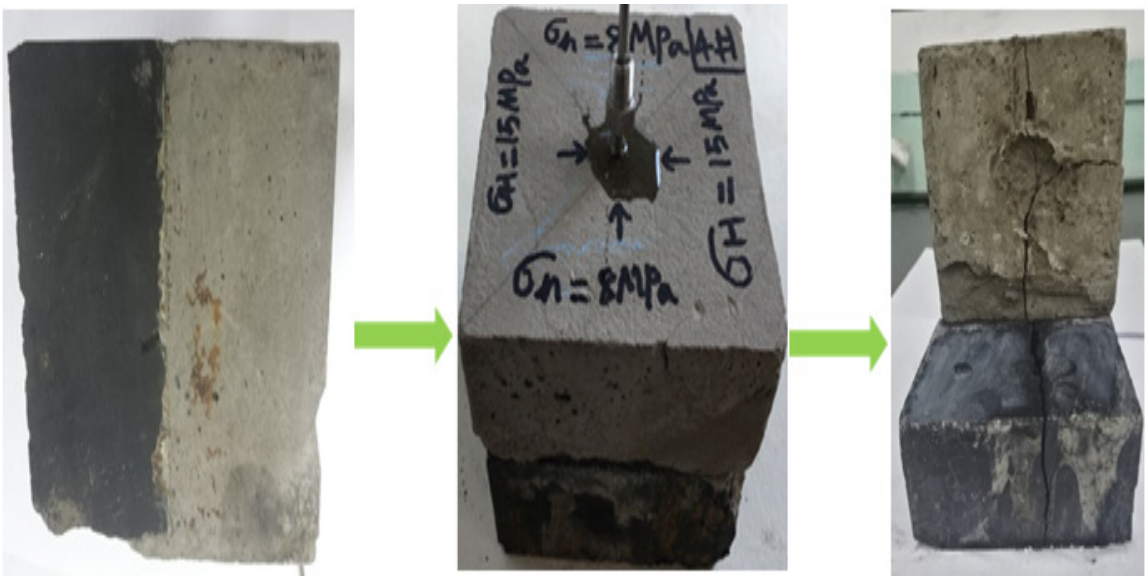

Figure 1. A fracture pattern of indirect fracturing of 100×100×100 mm specimen combination (top: sandy mud stone, bottom: coal)

[7] Hanson M.E., Shaffer R.J. Some Results from Continuum Mechanics Analyses of the Hydraulic Fractures Process. Symposium on Low-Permeability in Denver. 1979, 20-22.

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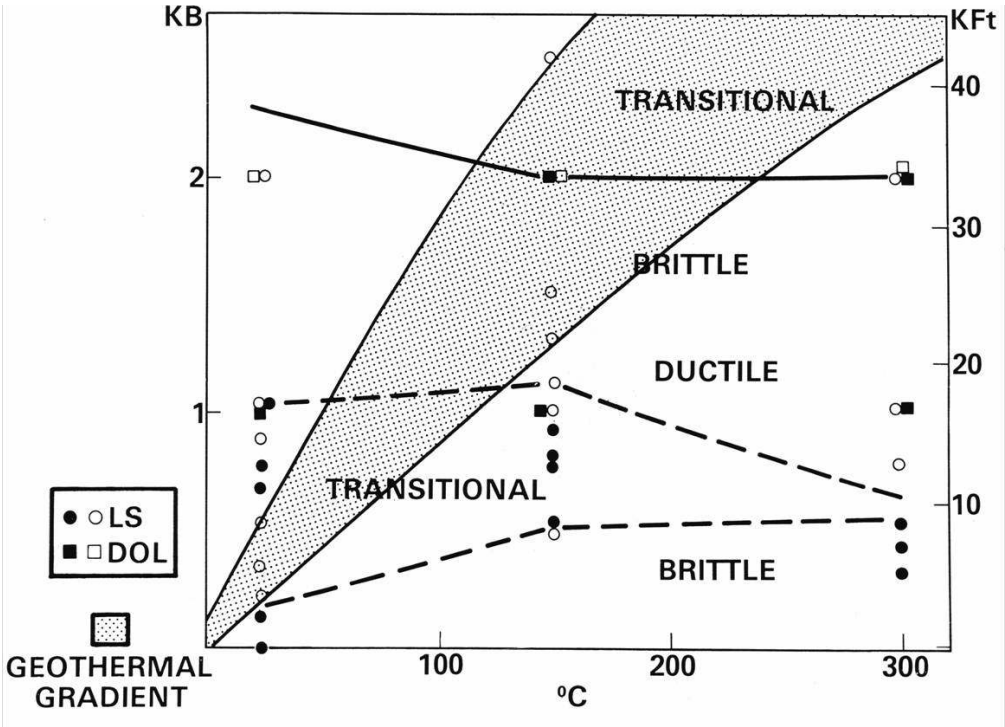
A Rant about Carbonates

Submitted by Kate H. Baker, ARMA Fellow

People in civil, mining and petroleum engineering rattle on about carbonates. Seldom do they clarify whether said carbonates are limestone (CaCO3) or dolomite (CaMg(CO3)2) or some mixture of two. Civils can perhaps be excused for this, miners less so – especially those involved in deep underground mining operations, but no way can petroleum engineers treat carbonates as a single class of rock. The strength and especially the ductility of the two are different in the relevant range of pressure and temperature conditions.

In the mid 1970's, I put together this figure: In it, the solid symbols represent observed brittle behavior and the open ones represent ductile behavior. The dashed lines suggest the boundaries between brittle-transitional and transitional-ductile behavior in limestone. The solid line represents the brittle-transitional boundary for dolomite.

Sadly, I have lost the origins of the rock mechanical data – which I took from the literature under the tutored eyes of people such as Bill Brace and John Handin. The range of geothermal gradients is my invention and again, I have no record of what informed my opinion at the time. None of these shortcomings weaken the point I seek to make. Subsequent laboratory investigations have repeatedly confirmed the general shape of the brittle ductile fields shown, and rather than using a generalized geothermal gradient, one should select a gradient appropriate to the particular site under investigation, informed by tectonic setting, heat flow and hydrodynamic data, if actual steady-state subsurface temperature measurements are unavailable.



The implications of the difference in ductility are profound.

Limestone seldom hosts commercial oil and gas accumulations below 10,000 ft true vertical depth. Of course, abnormal pressure (pore pressure in excess of what would be predicted at a given depth using a hydrostatic pressure gradient[1]) can maintain porosity at greater depths, but on production, the decline curve of such accumulations will look like a plumb bob line owing to the pressure drawdown in the near wellbore region.

Carbonates can be dolomitic limestone or limey dolomites. How much dolomite is needed for a formation to take on the mechanical properties of dolomite vs limestone? Tests by Cleven (2008) demonstrated that at approximately thirty to forty-five weight percent dolomite, dolomite is interconnected by a grain network that provides load-bearing capacity. I recall conversations with Nigel Higgs, who investigated this in the early 1980s, suggesting a similar transitional composition.

Grain size and porosity of carbonates can also affect their mechanical properties. Chalk, a very fine-grained limestone, is an extreme case. Especially in the presence of water, it can flow like toothpaste even at modest confining pressures and temperatures. This serves to remind us that, in the earth, we may need to contend with the full thermal, mechanical, hydraulic and chemical system to anticipate rock mass response. We need to start with adequate characterization of the rock matrix. "Carbonate" may not be a sufficient description.

Reference:

Cleven, N.R., 2008, The Role of Dolomite Content on the Mechanical Strength and Failure Mechanism in Dolomite-Limestone Composites (B.S. Thesis), University of British Columbia, 2008.

[1] A normal regional hydrostatic pressure gradient is usually somewhere between 0.433 - 0.465 psi/ft, or 9.792 - 10.516 kPa/m, depending upon the salinity of the formation waters.