Session: Unconventional Hydrocarbons Resources

Unconventional oil and gas resources and the geological storage of carbon dioxide: overview

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Abstract: The 'Unconventional oil and gas resources and the geological storage of carbon dioxide' section of the *Proceedings* is designed to provide new insights from recent research and exploitation within these major growth areas in applied geology. Research and innovation on unconventional oil and gas have been driven by market needs – specifically concerns over oil and gas supply – as well as technological development. A cross-section of this work is highlighted in the current set of papers, covering ultra-heavy oil, shale oil, shale gas, basin-centred gas, tight gas and clathrates. Unsurprisingly, much of this research has been pioneered in North America. This work is complemented herein by some initial studies from Europe. Similarly, the geological storage of CO_2 is not simply a story of technological advance but also a response to an urgent societal imperative. Carbon dioxide sequestration is recognized as an important method for reducing greenhouse gas emissions in the near future, and is expected to have growing relevance to the oil and gas industry and the energy sector. Recent findings from current commercial carbon capture and storage projects in the North Sea and North Africa are presented and are complemented by an overview of major research programmes established in North America.

Keywords: unconventional hydrocarbons, heavy oil, shale gas, shale oil, gas hydrates, CO_2, carbon capture and storage

The Seventh Petroleum Geology Conference, held in London in 2009, reflected the significant interest in the geology of unconventional oil and gas resources that has developed over the past 5–10 years. Market drivers, specifically the concerns over supply, which culminated in wildly inflated oil and gas prices during 2008, probably provided the main impetus for this research. Given this perception, it is no surprise that much research and innovation regarding the exploration and development of unconventional oil and gas resources has been pioneered in North America, where these resources already have a long history of exploitation, contribute significantly to current production, and represent very large future energy sources (e.g. Jarvie *et al.* 2007; Ross & Bustin 2008). Nine of the papers in this section provide a good cross-section of research into the commercial exploration and exploitation of unconventional resources in North America and internationally, including ultra-heavy oil, shale oil, shale gas, basin-centred gas, tight gas and clathrates.

Although there is some history of commercial carbon dioxide (CO_2) injection or reinjection as a means of enhancing oil recovery, the current growth of interest in carbon capture and storage (CCS) is primarily driven by societal imperatives, with concerns about climate change raising the need to stabilize atmospheric concentrations of CO_2. The geological storage of CO_2 is gaining recognition as an important large-scale option for reducing greenhouse gas emissions in the near and foreseeable future. Four papers in this section describe very different approaches to CCS in the North Sea, North Africa and the USA.

Unconventional oil and gas resources

Unconventional oil and gas resources can be characterized by either intractable rock with very low permeability or intractable fluids (or in the case of clathrates, solids) where some form of stimulation is typically required for commercial production. These resources overturn many of the exploration and production paradigms that are applied to conventional hydrocarbons. For example, some unconventional gas resources are found in synclines rather than anticlines. In some cases, oil and gas is reservoired in rocks previously considered sources or seals. In other cases water is encountered updip of gas. In fact, many unconventional hydrocarbon resources lack fluid contacts. Whereas conventional gas resources are buoyancy-driven deposits, which form discrete accumulations in structural and/or stratigraphic traps, unconventional gas resources do not share these characteristics (e.g. Law & Curtis 2002). Unconventional hydrocarbons are commonly described as continuous or regionally pervasive in nature. Although the total in-place resource volume may be large, the overall recovery factor is commonly relatively low (e.g. Schmoker 2002; Sonneberg & Pramudito 2009). Completely dry holes cannot be drilled within the boundaries of such accumulations, but it is very possible to drill wells that are not economic. In other words, these resources are heterogeneous with commercial 'sweet spots', which are controlled by geological parameters such as structure, stratigraphy and diagenesis (e.g. Law 2002; Sonneberg & Pramudito 2009). Economically speaking, unconventional hydrocarbons are usually (but not always) characterized by high break-even product prices and, as such, become the focus of attention as conventional resource supplies diminish or become unavailable to the multinational companies.

Tight oil/shale oil

North America has a long history of producing oil from shales or very tight reservoirs, and considerable interest currently focuses on the Devonian–Mississippian Bakken petroleum system of the Williston Basin in central North America. This formation is generally regarded as a prime example of a continuous, unconventional tight oil exploration play, that is, a petroleum system where the source, seal and reservoir are the same unit, and prospectivity is not constrained by conventional trapping mechanisms. The play is commonly described as self-contained, with short migration

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distances from mature source rock of the Bakken Formation (Sonneberg & Pramudito 2009). High pressure within the formation has been attributed to the generation of hydrocarbons within the Bakken and only limited fluid expulsion. However, there is some debate regarding the degree of migration of the hydrocarbons generated. Insight into this question is provided by Kuhn *et al.* through careful examination of geochemical parameters. The authors conclude that there is probably more migration within the Bakken Formation than previously assumed, and that the system can in fact be described as partially 'open'.

Shale gas

During the Sixth Petroleum Geology Conference held in 2004, a single paper by Richard Selley drew attention to the use of shale gas in parts of the USA and to the potential for exploitation of this resource in the UK (Selley 2005). Since then there has been an astonishing growth in research on the exploration and exploitation of shale gas plays. Harnessing this resource has converted a local curiosity into a multi-billion dollar international business, and has helped transform the North American market from gas starvation to guaranteed supply for 20 years or more. It is a classic example of market-driven research, whereby both innovation and pre-existing technology are brought together by economic necessity. This significant change was reflected by the high interest in shale gas shown at the Seventh Conference.

As with shale oil, shale gas systems are considered discrete, self-enclosed systems in which the source, seal and reservoir are one and the same. Shale gas is a very important exploration target in North America, where the resource falls into two distinct types: biogenic and thermogenic, although there can also be mixtures of the two gas types (Jarvie *et al.* 2007 and references therein). Known shale gas systems have been characterized by a number of parameters including total organic carbon content, thermal maturity, kerogen transformation, the efficiency of the source rock to retain its generated hydrocarbon products and the nature of the storage system. However, examination of productive shale gas systems indicates that the current parameters used to assess shale gas prospectivity vary greatly and may not provide a strong predictive model. Consequently, additional criteria, such as the clay and mineral content of the shales, the burial history and the precise nature of the gas storage and retention systems are fertile grounds for further research (e.g. Ross & Bustin 2008).

No major economic shale-gas enterprises are currently known from outside of North America, but many parts of Europe contain targets for shale gas exploration and commercial production is considered purely a matter of time. In this volume, Schulz *et al.* provide an overview of black shale successions that may be attractive for shale gas exploration in European basins, where conventional production is declining, underutilized gas gathering infrastructure exists and markets are accessible. Smith *et al.* follow Selley's pioneering work in providing a summary of organic-rich shale successions in the UK that may offer potential for shale gas resources. While no bonanzas equivalent to the Barnett or Marcellus Shales of the USA are envisaged, particular attention is drawn to the potential regional importance of the Mississippian Bowland Shales of northern England.

Basin-centred and tight gas

The basin-centred gas exploration play within the Western Canada Foreland Basin is characterized by a regionally pervasive gas saturated accumulation in low permeability, abnormally pressured reservoirs, with a lack of downdip water contact. Within this unconventional gas play, zones with commercially favourable reservoir producibility characteristics are controlled by a number of geological factors. For commercial success, Boettcher *et al.* highlight the importance of fully understanding the stratigraphy, sedimentology, rock properties and structure. They show that a process of long-term regional migration of undersaturated gas from source rocks into adjacent reservoir rocks, and the associated expulsion of water, is particularly important.

Kiraly *et al.* describe a basin-centred gas exploration play within the Pannonian Basin, Hungary, where thick Upper Miocene shales provide excellent pressure sealing above the significantly overpressured Upper and Middle Miocene formations. Within the overpressured zone, thick and poorly consolidated turbidite sandstones, as well as the shales, form unconventional reservoirs for basin-centred hydrocarbon accumulations.

Gas within unconventional fine-grained reservoirs is commonly extracted using hydraulic fracture treatments. Horizontal wells with multiple fracture stimulations are currently the most economic means of producing gas from tight reservoirs. Such wells are very expensive and typically suffer from a steep early production decline. Natural fractures, which are present in most shale units, act as weak planes that reactivate during hydraulic fracturing. Gale and Holder explain how knowledge of the geometry and intensity of the natural fracture system is therefore necessary for effective hydraulic fracture treatment design. Commonly occurring fracture types are reviewed and evaluated as to whether they are relevant to gas production.

Ultra-heavy oil

Ultra-heavy oil is too heavy or viscous to be produced by conventional flow from a reservoir. Biodegradation is generally responsible for the specific gravity and viscosity. Consequently, such accumulations are often found shallowly buried or even at surface. Again, there has been a resurgence of interest in exploiting ultra-heavy oil driven by the price rises of the mid-2000s. This enterprise is, however, technically and logistically demanding and is characterized by high break-even prices. Concerns also exist over the environmental challenges of exploiting this resource, since such enterprises can be seen as environmentally disruptive and CO_2-intensive. The heavy oil deposits of Canada are a case in point. With an estimated 1.7×10^{12} barrels in place, some assessments rank Canada second behind Saudi Arabia in terms of oil resources. Heavy oil makes up 98% of this resource, with the Athabasca Oil Sands of the Lower Cretaceous McMurray Formation in northern Alberta containing approximately 900×10^9 barrels in place. Depending upon the amount of overburden, the oil sands are developed through either surface mining or thermal *in situ* techniques, including steam-assisted gravity drainage. Like most unconventional resources, the accurate prediction and location of 'sweet spots' is critical. In this volume, Peacock shows how the development of an understanding of the regional distribution of fluvial–estuarine point bars, which comprise the principal reservoir rocks, is critical to maximizing commercial production from the Athabasca Oil Sands. For heavy oil thermal developments, the understanding and prediction of reservoir characteristics is particularly important because mudstone units within the reservoir can have a dramatic effect on steam chamber growth and the subsequent oil recovery.

Gas hydrates (clathrates)

Geoscientists have long speculated that gas hydrate accumulations could eventually be a commercially producible energy resource. The gas hydrates are naturally occurring 'ice-like' combinations of natural gas and water that have the potential to provide an immense resource of natural gas from the world's oceans and polar regions. The amount of gas in the world's gas hydrate accumulations is thought to exceed the volume of known conventional gas resources. However, until recently significant technical and economic hurdles made gas hydrate development seem a distant goal. This view began to change in recent years with the realization that this unconventional resource could possibly be developed with existing conventional oil and gas production technology. In this volume, Collett summarizes the most significant recent developments in this regard, such as gas hydrate production testing conducted during 2002 at the Mallik site in Canada and, more recently, the testing of the 'Mount Elbert Prospect' gas hydrate accumulation on the North Slope of Alaska.

Coal gasification

Coal has commonly been seen as a potential fall-back fossil fuel resource as hydrocarbons become depleted. Younger *et al.* describe how deep-seated coal resources may be exploited by means of underground coal gasification (UCG) with the possibility for coupling the technique to CCS. Significantly for the petroleum industry, the technological requirements for UCG, using directionally drilled boreholes from ground level, are far more akin to those of oil and gas production than they are to those of deep mining.

Geological storage of carbon dioxide

There is a range of options regarding the geological storage of CO_2. One possibility is the use of CO_2 in enhanced oil recovery and this is already commercial in some circumstances. The other main options are storage within depleted oil and gas fields or saline aquifers, while other techniques, such as storage in coals with enhanced coal bed methane, remain at an early stage. A key challenge for wider deployment of CO_2 geological storage is the requirement for the technique to be accepted as safe and verifiably effective. Senior *et al.* describe a commercial project that has been operating at In Salah in Algeria since 2004. CO_2 recovered from the natural gas production of the Krechba Field amounts to 1×10^6 tonnes per year, and this is injected into the water leg of the gas reservoir for the purpose of geological storage.

Injection of CO_2 commenced at the Sleipner Field in the Norwegian sector of the North Sea in 1996, and over 10×10^6 tonnes is currently stored in the late Cenozoic Utsira Sand saline aquifer. As a means of verifying its effectiveness, a comprehensive seismic monitoring programme of the storage site has been implemented, with repeat time-lapse 3D surveys that image the progressive development of the CO_2 plume. The total amount of CO_2 injected is known, and Chadwick and Noy show that independent verification of this amount can be achieved from the seismic data. Encouragingly, their observations of the laterally spreading CO_2 plume at Sleipner seem to confirm the integrity of the topseal to the Utsira Sand. Of equal significance, however, is their observation that history-matching techniques do not adequately predict the flow pathways indicated on the time-lapse 3D seismic, suggesting that our ability to model fluid behaviour in complex reservoirs remains at a simplistic level. Hermanrud *et al.* describe how monitoring of the CO_2 plume at Sleipner provides insights into the processes of subsurface fluid migration, especially with regard to vertical migration.

Esser *et al.* provide an insight into research by one of the seven major Regional Carbon Sequestration Partnerships in the USA and Canada, which aim to establish the best practices for permanently storing CO_2 in different geological formations. The research will help develop regulations and infrastructure requirements for future sequestration deployment and also includes a deep saline test in a structural dome 120 miles south of Salt Lake City, Utah, where deep saline formations are major targets for commercial-scale sequestration associated with the coal-fired power plants currently planned for the area.

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