Tight-Gas Sands Committee Report
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by
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Introduction

Tight gas is an unconventional type of hydrocarbon resource within reservoirs that are low permeability (millidarcy to microdarcy range) and low porosity, as in 'tight sand'. In these types of reservoirs the gas cannot be extracted easily or economically without expending much technological effort to artificially enhance the permeability, such as by fracturing and/or acidizing the formation.

The U.S. Energy Information Administration ((EIA)) estimates that about 310 Tcf (8.8 trillion cubic meters) of technically recoverable tight gas exists within the United States, with worldwide estimates of > 7,000 to > 30,000 Tcf (210 – 850 trillion cubic meters) of gas in tight sands. The fraction of this energy resource that can be produced depends upon the applicability of new and enhanced technologies [such as 3-D seismic, microseismic, horizontal drilling along with stimulation and porosity/permeability enhancement by multi-stage hydraulic fracturing (cf. King. 2012)], economics (well completion and drilling costs and gas prices), and environmental concerns (impacts on water resources, remediation, GHG emissions). At present, natural gas production from tight sandstones (those with permeabilities < 0.1 millidarcies) is currently about 6 trillion cubic feet (Tcf) (170 billion cubic meters) per year in the United States, comprising nearly 25% of its total annual gas production.

In light of the definitions of tight-gas sands, under present market conditions, it is clear that tight-gas sands must also include a high-liquids component to become profitable – that is, many of the successful plays may be commingled with 'fringe' deposits from otherwise conventional oil and gas plays, including liquids-rich gas from organic-rich, fine-grained, mixed-bed lithologies (siltstone, marl, mudstone, very fine sandstone, and/or carbonate along with the 'tight-gas sands'). It is also likely that as development of these plays continue to evolve by multi-stage horizontal drilling, with hydraulic fracturing, that there will be a continuum from fringe conventional oil and gas plays → unconventional tight-gas sands → unconventional tight-shale gas, and that the present distinctions between these various hydrocarbon commodities will become less clear. Some of these more "distal" unconventional tight-gas sands (those with a high sandy silt/siltstone content and relatively low clay/shale content, but with self sourced organics) have more recently been called "hybrid shales."

Tight-gas sand plays are being tested and developed in many countries outside of the U.S.A., including Canada (Western Canada Sedimentary and Maritimes Basins), Australia (Perth, Gippsland, and Copper Basins), China (see below), and the Ukraine (Donetsk-Dnepr Basin). In Canada, tight-gas sand plays have been pursued (and produced actively) since about 2005, with the plays ranging from Triassic to Late Cretaceous in age, and hosted within a large range of sedimentary environments from deep-water distal turbidites (similar to the Lewis Shale of Texas) to alluvial fan/braid-plain conglomerates. This broad suite of tight-gas sandstone plays were initially exploited using techniques imported from the U.S.A.; however, since the initial drilling and completion work was done, it has been found that many of these plays in the Western Canada Sedimentary Basin need completion and drilling strategies that are geo-tailored to the subsurface geology of the area.

To date, those tight-gas sandstone projects with large production histories include multiple projects in the United States.Those plays with long production histories may provide insights and analogs for the appraisal and development of the new emerging areas; however, in the case of these types of plays many are like 'snowflakes,' where no two are alike. In the following sections four of the more developed plays are discussed for the U.S.A., with emerging and newly-developed plays including three from Canada, and one from China.

Play Summaries

This report summarizes tight-gas sand characteristics and activities in eight key plays: Dew-Mimms Creek Field, East Texas Basin, U.S.A.; the Jonah and Wamsutter fields, Green River Basin, Wyoming, USA.; the Mamm Creek Field, Piceance Basin, Colorado, USA; the Cardium, Nikanassin and Montney formations, Western Canada Sedimentary Basin, Alberta and British Columbia, Canada; and the Shuixigou Group, Taibei Depression, Hami Basin, Kekeya Area, China. Most of the material is taken from the following sources: 1) the Tight Gas Sands Committee contribution to the bi-annual EMD publication in Natural Resources Research (Jenkins, 2011); 2) compilations from previous EMD Tight Gas Committee annual and mid-year reports on the EMD Members' Only website (Jenkins, 2010; Hein and Jenkins, 2011); and, 3) Hart's Unconventional Gas Center (www.ugcenter.com), which provides up-to-date information about these and other tight-sand plays.. A map showing the different basins discussed in North America is given in Figure 1.

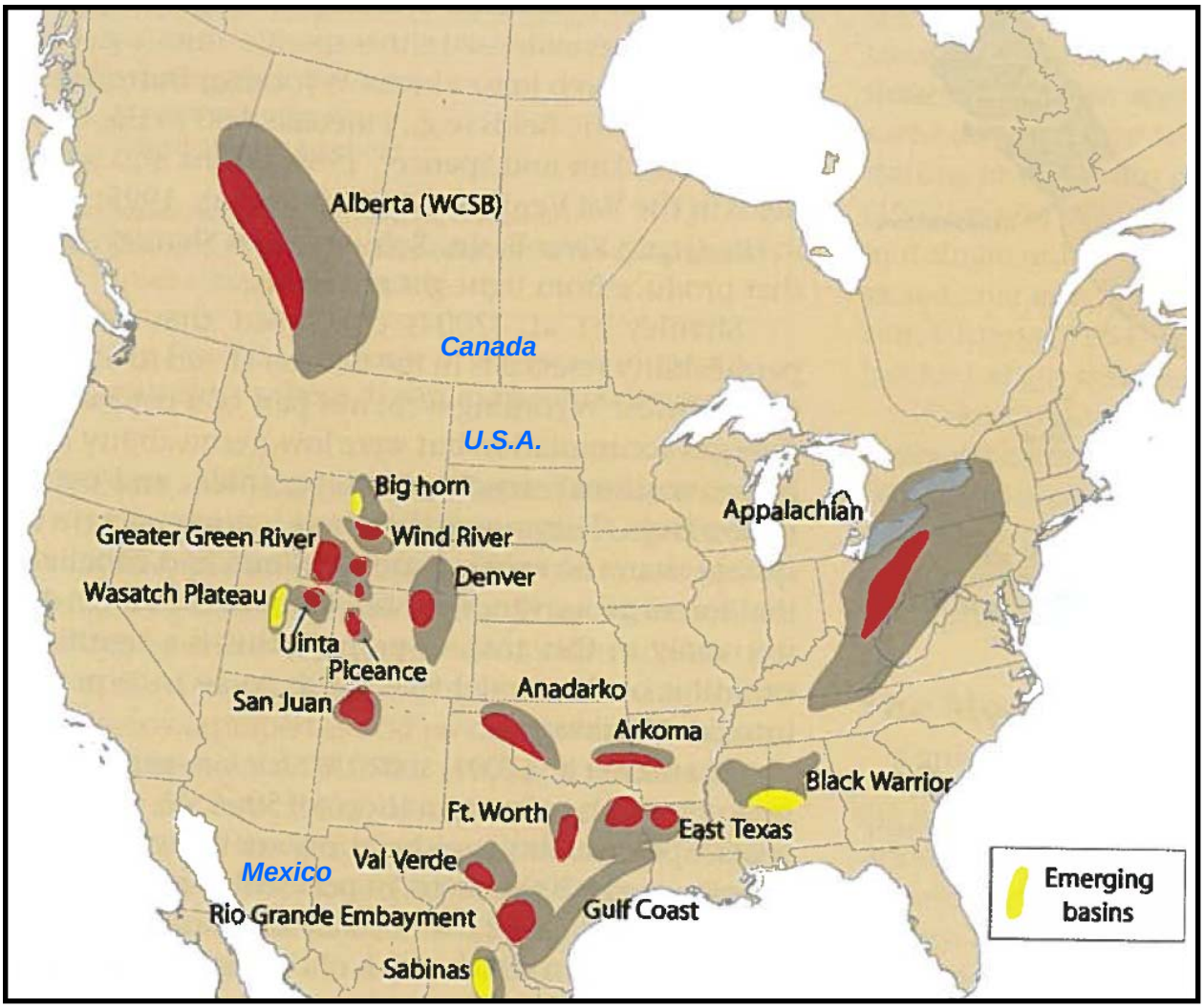

Figure 1. Basins in North America with long-term tight-gas sandstone production (red) and more prospective areas (yellow). Tight-gas sandstone plays discussed in this section are in the East Texas, Green River, Piceance basins of the U.S.A. and the Western Canada Sedimentary Basin (WCSB) of Alberta, Canada (modified from Meckel and Thomasson (2008).

1. Dew-Mimms Creek Field, East Texas Basin, U.S.A.

The Bossier Formation sandstones in the Dew-Mimms field are part of the Jurassic Cotton Valley Group that accounts for about 1% of the production from the East Texas Basin. The Cotton Valley Group is a succession of sandstone, shale and limestone that underlies most of the northern coastal plain of the Gulf of Mexico from Alabama to East Texas. The Cotton Valley Group is the first major input of clastic sediments into the ancestral Gulf of Mexico, with major depocenters in Mississippi, along the border of Louisiana-Mississippi, and in northeast and eastern Texas. Along the updip margin of the East Texas Basin, during the first phases of deposition of the lower Cotton Valley Group (Bossier sands), small alluvial fan-deltas developed, which through time evolved into more mature drainages. Through time, alluvial fan-

deltas prograded basinward into wave-dominated delta systems at the northwestern limit of the ancestral Gulf of Mexico.

Individual sandstones with the Bossier Formation and the Cotton Valley Group are typically highly lenticular, with difficulty in correlating between wells. One strategy is to commingle production from multiple sandstones in each wellbore to facilitate recovery from marginal sandstones that would otherwise not be produced. This has resulted in field consolidations, with commingling of the Cotton Valley Sand, the Bossier Sand, and the deeper Cotton Valley limestone (also known as the Cotton Valley Lime, equivalent to the Haynesville).

The Dew-Mimms Creek field produces from a series of stacked sand-shale successions containing 75-100 feet (23-30 m) of net sand with average porosities ranging from 6-10%, absolute permeabilities from 1 microdarcy to 1 millidarcy, and water saturations ranging from 5-50%. The play seeks to exploit an overpressured cell by drilling for gas close to the overpressure ceiling which is at depths of 12,400 – 13,200 feet (3,780-4.023 m). The Dew-Mimms Creek field is being developed on 80-160 acre (32.4-64.8 ha) well spacing. Wells are fracture stimulated with small to large slickwater fracs by pumping 100,000 to 350,000 pounds (45,360 to 158,757 kg) of proppant. Initial well rates range from 2-5 million cubic feet per day (MMcfd) (56.6-141.5 thousand cubic meters per day) and declines are hyperbolic with flows stabilizing after 2-3 years at 500-900 thousand cubic feet per day (Mcfd) (14.2-25.5 thousand cubic meters per day). Estimated ultimate recoveries (EURs) per well range from 1-4 billion cubic feet (Bcf) (28.3-113.2 million cubic meters). Geological factors controlling well success include the ability to locate main channel sand trends where sands are thicker and of better quality, and to established sustained economic production rates from inferior reservoirs through improved completion practices.

2. Jonah Field, Green River Basin, Wyoming, USA.

The Cretaceous Lance Formation sands are located in the Jonah field, northwestern Green River Basin, Wyoming. In the 1990s, the Jonah field was one of the largest onshore gas discoveries in the U.S.A., which is remarkable since the productive sandstones have an average porosity and permeability that would normally not be considered reservoir rock at the time of discovery, but rather as a cap rock or seal. What distinguishes the Jonah field are the large net pay thickness of the low-permeability sandstones and the large areal extent of the field. The Jonah field is located in the greater Green River Basin with the primary producing interval being the Lance Formation. The Lance Formation unconformably overlies undifferentiated units of the Mesaverde Group, and is unconformably overlain by unnamed Tertiary successions. Although the Jonah field is one of many basin-centered accumulations within the greater Green River Basin, it is considered by industry to be typical of the unconventional tight-gas sandstone types in the area. Debate exists as to whether these basin-centered accumulations are part of a single regionally extensive accumulation, or if they are discrete accumulations with conventional subtle traps. In either case, the Jonah field is a sweetspot that is delineated on a structural feature that has converging faults along flanks of a major anticline (the Pinedale) with updip trapping against boundary faults. It thus appears that the Jonah field is an unconventional, basin-centered accumulation with conventional trapping mechanisms. The top-seal for the field is mudstone from the upper Mesaverde, Lance and Tertiary succession. Most of the Lance Formation sandstones were

emplaced as either individual fluvial channel sands, or as amalgamated and stacked fluvial channel systems. A number of studies show variable paleocurrent trends (SW to NE, and NW-SE), which may indicate either multiple sources, switching of paleoflows associated with braided fluvial systems, and/or tectonic influences on paleodrainage divides related to synsedimentary faulting in the area. The majority of the Lance reservoir sandbodies have widths that are significantly less than the typical well spacing of 40 acres. Tight-gas production at Jonah is from a zone where permeability is enhanced due to the confluence of two major faults.

The Jonah field is fault-bounded and contains a stacked succession of 20–50 fluvial channel sands in an interval that is 2,800-3,600 feet (853-1,097 m) thick, and occurs at depths of 11.000-13,000 feet (3,353-3,962 m). Sandstone bodies occur as individual 10-25 foot (3.0-7.6 m) thick channels that are stacked into channel sequences up to 200 feet (61 m) thick. Porosity ranges from 5-14%, with permeability of 1-30 microdarcies and water saturation from 30-60%. The pressure gradient is 0.55 – 0.60 psi/foot (37.9-41.3 millibars/0.3 m). Wells are completed by pumping multiple fracture treatments (8-20) into wells that are nearly vertical through the Lance Formation. The hydraulic fracturing design includes 100,000-400,000 pounds (45,360-181,440 kg) of sand in a cross-linked borate gel and a 25-50% nitrogen assist in each stage which is typically < 200 feet (61 m) long. Current development is on a 20-40 acre (8.1-16.2 ha) well spacing with 10-acre (4 ha) and 5-acre (2 ha) pilot areas). Cumulative It was estimated that 67% of the original gas in place (OGIP) can be recovered at a 10-acre (4-ha) spacing and 77% at a 5-acre (2-ha) spacing. Initial well rates ranged from 1.3 to 6.1 MMcfd with EURs ranging from1.5 to 5.7 Bcf per well.

In the Jonah field there are currently 1876 gas wells, 73 dry holes or suspended wells (likely plugged), and 112 permitted locations or actively/completing wells. Cumulative production reported to date (to 2013) for 1818 wells (97% of wells in the Jonah field) are: 3860 BCFG, 36.4 MMBO, 39.6 MMBW, WGR 10.3 bbls/MMCF.

3. Mamm Creek Field, Piceance Basin, Colorado, USA.

The Mamm Creek field accounts for about 20% of the current gas production from the Piceance Basin of northwestern Colorado. The Mamm Creek field produces from the tight fluvial sandstones of the Williams Fork Formation (depth 5000 feet), with an additional contribution from other marine sandstones of the Corcoran, Cozzette and Rollins Members (7000 feet deep). The Williams Fork Formation is mainly a low-porosity and low-permeability tight-sandstone that is within a basin-center gas accumulation. The Williams Fork deposits are fluvial channel sands, crevasse splays, overbank and floodplain mudstones and coals that were deposited within an evolving paleogeography of meandering/braided fluvial → marsh, mire, swamp, estuarine → shoreface/deltaic and coastal/alluvial plain systems tracts. Pay sands are mainly within the point bars, braid bars, and marine sandstone units. The complexity of the fluvial-marginal marine systems has resulted in a very heterogeneous connectivity of the tight-sandstone reservoirs, with variations in sandstone connectivity dependent upon lithology, stratigraphic architecture, and shoreline stacking patterns. In addition to the original sedimentological controls, other variables relate to the main fault types, the distribution of fractures within the reservoirs and other associated basin-center accumulations.

In the Mamm Creek field the main producing interval is the 2,000-foot thick, overpressured Williams Fork Formation which consists of lenticular fluvial to marine sands at depths of 4,500-8,500 feet (1,372-2,591 m). Packages of "stacked sands" can be correlated over areas of 30 – 70 acres (12-28 ha). Results from 200 well tests showed permeability ranging from 1-100 microdarcies with half the tests indicating the presence of open fractures. Each development pad contains 12-16 wells that are vertical through the reservoir and completed with 4-10 slickwater fracture stimulation stages using 50,000-500,000 lbs (22,680-226,800 kg) of sand and 2,000-13,000 barrels (318-2,067 cubic meters) of water per stage. Larger treatments lead to longer half-lengths, which in turn result in higher production and EURs. Each well costs about 1.2 million dollars (MM$) which is equally divided between the drilling and completion costs. Wells have been downspaced to 20 acres (8.1 ha) and recent evidence indicates that it may be optimal to downspace to 10 acres (4 ha) in order to recover 75% of the OGIP.

In the Mamm Creek field there are currently 2649 gas wells, 42 dry or suspended, and 463 permitted locations or actively/completing wells. Drilling has slowed considerably in the Piceance Basin due to depressed gas prices. Cumulative production reported to date (to 2013) for 3780 wells are: 1222 BCFG, 10.5 MMBO, 69.9 MMBW, WGR 57.2 bbls/MMCF.

4. Wamsutter Development Area, Green River Basin, Wyoming, USA.

The Wamsutter development area covers a 50 square mile (129 square kilometer) area in the greater Green River Basin of Wyoming, and contains an estimated 50 Tcf (1.42 trillion cubic meters) of OGIP. The reservoir consists of stacked marine and fluvial sands of the Upper Cretaceous Almond Formation, Mesaverde Group, and numerous turbidites within the Lewis Shale. Regionally, the thickness of the Almond Formation ranges from 250 to > 500 feet (76 – 152 m), with variations in thickness and lithologies related to basement block-fault structures. The Almond Formation represents deposition associated with a major overall transgression and superimposed smaller transgressive-regressive cycles. The Main Almond is mainly a brackish to nonmarine succession of interbedded sandstone, siltstone, shale and coals with the Upper Almond consisting of mainly amalgamated marine 'bar' complexes. The Upper and Main Almond units are separated from one another by a transgressive regional marine shale. Sedimentologically, the Main Almond consists of discontinuous, lenticular tidal flat and tidal channel sandstone bodies that are encased within more muddy bayfills and estuarine shale successions. Individual sequences are bounded by continuous coals and carbonaceous shales. There is a marked heterogeneity of the reservoir sands, where little connectivity exists between sand bodies. Most of the Main Almond reservoir sandbodies have a width that is significantly less than typical well spacing. Conditions within the Almond Formation become more marine up-section associated with a major transgression resulting in an increase in connectivity of the reservoir sandstones. The Upper Almond is an amalgamated succession of laterally continuous, amalgamated shoreface deposits, which are cut by tidal channel complexes. The main producer is the Upper Almond with supplemental production from the underlying Main Almond. Productivity from different sandstones varies significantly and is influenced by a variety of factors, including reservoir connectivity, lithology, matrix, fracture density and the presence of nearby faults, and proximity to coal sources.

I n the Wamsutter field , the Almond Formation is generally encountered between depths of 8,500 and 10,500 feet (2,590 and 3,200 m) with reservoir pressure varying from initial conditions (0.54-0.58 psi/ft; 37.2-40 millibar/0.3 m) in the Lower Almond to varying stages of pressure depletion in the Upper Almond. Sands typically have 8-12% porosity and 2-30 microdarcies of permeability. The average net pay footage ranges from 50-80 feet (15-24 m) per well. Completion depths range from 7,000 feet (2,133 m) for shallow Lewis Shale wells to 12,200 feet (3,718 m) for deep Mesaverde wells. The Mesaverde is completed in 2-3 stages, and the Lewis is completed in 1-2 stages. Fracture stimulations total 40,000 gallons (151 cubic meters) of borate-crosslinked guar fluid and 175,000 pounds (79,380 kg) of 20/40 mesh sand or lightweight ceramic proppant. A typical initial gas rate for a fracture stimulated well is 1 MMcfd (28 thousand cubic meters per day) with an average recovery of 2 Bcf (56.6 million cubic meters) per well). Since 2004, one of the big operators in the Wamsutter field (BP) has drilled over 300 eighty acre (32.4 ha) infill wells and recently has been evaluating the possibility of infilling with wells at a 40 acre (16.2 ha) spacing.

The greater Wamsutter area consists of over 15 federal units and different companies define the area differently. Taking the deep basin gas as "Wamsutter," there are currently (as of 2013) over 4000 wells in the area, consisting of > 3600 gas wells, ~ 100 dry or suspended, and 365 permitted locations or actively/completing wells. According to BP, they have achieved dramatic cost reductions through moving to multi-well pad development which allows them to continue development in a challenging gas-price environment. Cumulative production reported to date (to 2013) for 3730 wells are: 3385 BCFG, 52.7 MMBO, 53.6 MMBW, WGR 15.8 bbls/MMCF.

Note: All three areas discussed above (Jonah, Mamm Creek, and the greater Wamsutter area) produce at water/gas ratios (WGR) substantially in excess of the water-vapor content of natural gas at reservoir conditions (2-5 bbls/MMCF depending on depth and temperature). This is corroborated by the salinity of the produced water, which although variable, is not as fresh as water of condensation would be. This is a common aspect of tight-gas production in the Rocky Mountains, where the fields all make water and management of this produced water is an issue.

Western Canada Sedimentary Basin, Alberta, Canada

In Alberta, at present, it is difficult to classify the remaining established gas reserves as 'conventional' or 'unconventional.' Traditionally, Cretaceous conventional reservoirs account for ~ 75% of the province's remaining established reserves of marketable gas and continue to be an important future source of natural gas. Recent advances in drilling and completions technologies have opened up what may now be considered, unconventional, low-permeability zones for economic production. These include tight sand gas, tight liquids-rich sand gas, tight sand oil, and hydrocarbon-rich tight, mixed-bed lithologies. These types of deposits are the more

continuous gas accumulations in the basin center and transition zones (Figure 2).

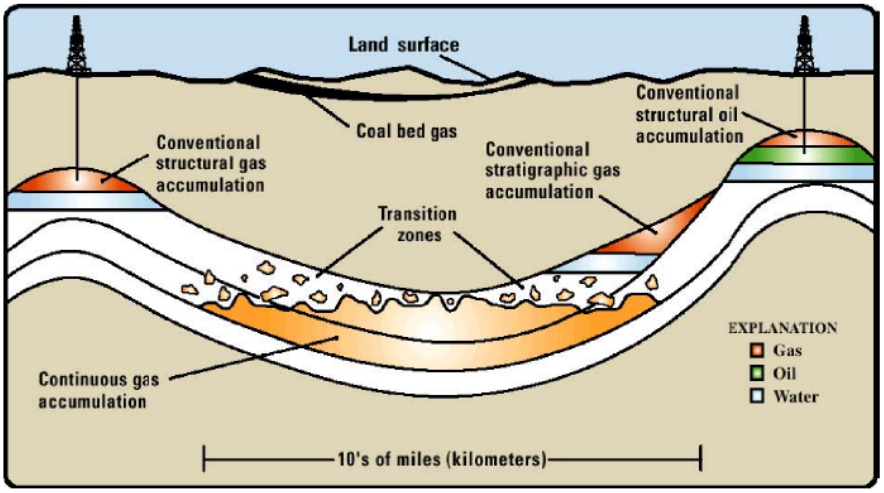

Figure 2. Schematic illustrating the different types of onshore natural gas plays. Conventional resources are buoyancy-driven hydrocarbon accumulations, with secondary migration and structural and/or stratigraphic closures. Unconventional, continuous gas accumulations, in basin centered and transition zones, are controlled by expulsion-driven secondary migration and capillary seal (from US Geological Survey Inventory of Onshore Federal Oil and Natural Gas Resources and Restrictions to Their Development (2008) ("EPCA Phase III Inventory") (p. 46).

In Alberta, recent drilling statistics (since 2009) show a dramatic decrease in the number of vertical wells being drilled and completed, along with a corresponding increase in the number of horizontal wells, to the extent that now most of the wells being drilled in Alberta are horizontal (Figure 3). On a formation-basis, a large percentage of the total rig count in Alberta has focused on the Cardium and Montney plays (Figure 4), with generally less than 10% on other deep-basin, tight gas plays, such as the Nikanassin (Figure 4).

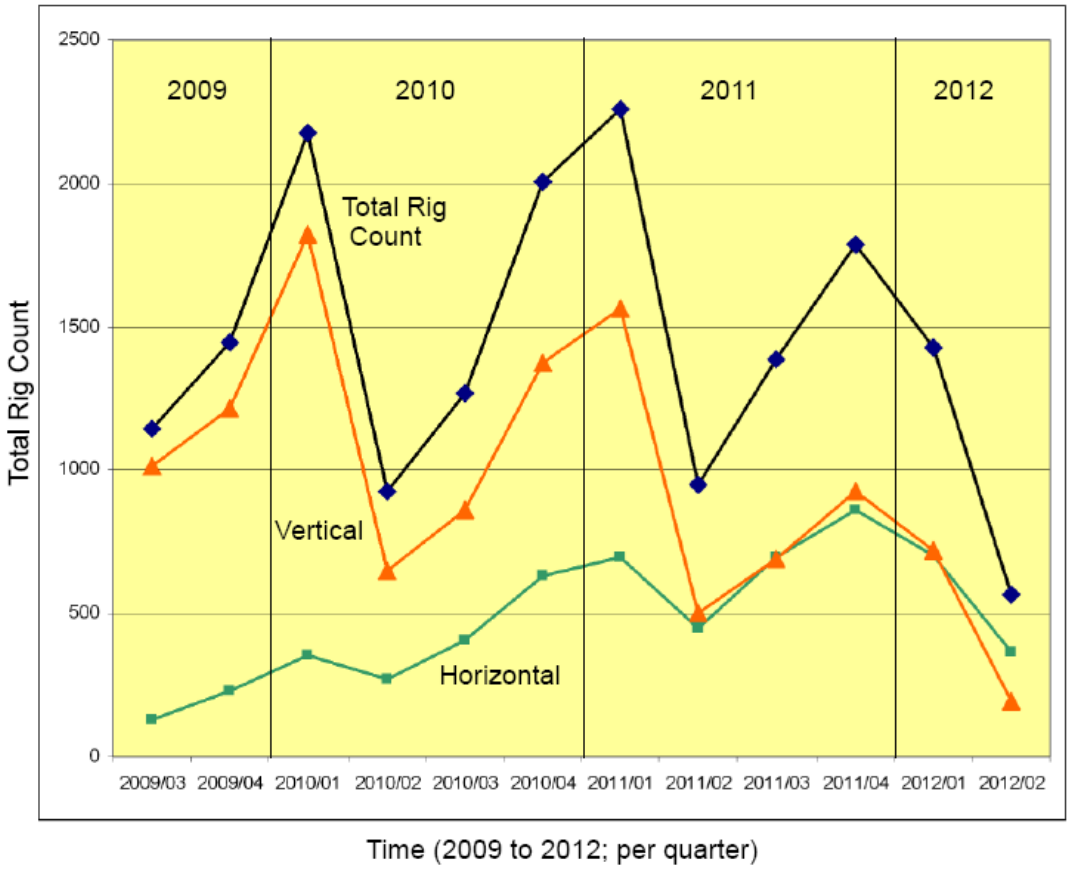

Figure 3. Drilling statistics related to total rig count, number of vertical and horizontal wells completed on a quarterly basis from 2009 to 2012 in the Alberta portion of the Western Canada Sedimentary Basin.

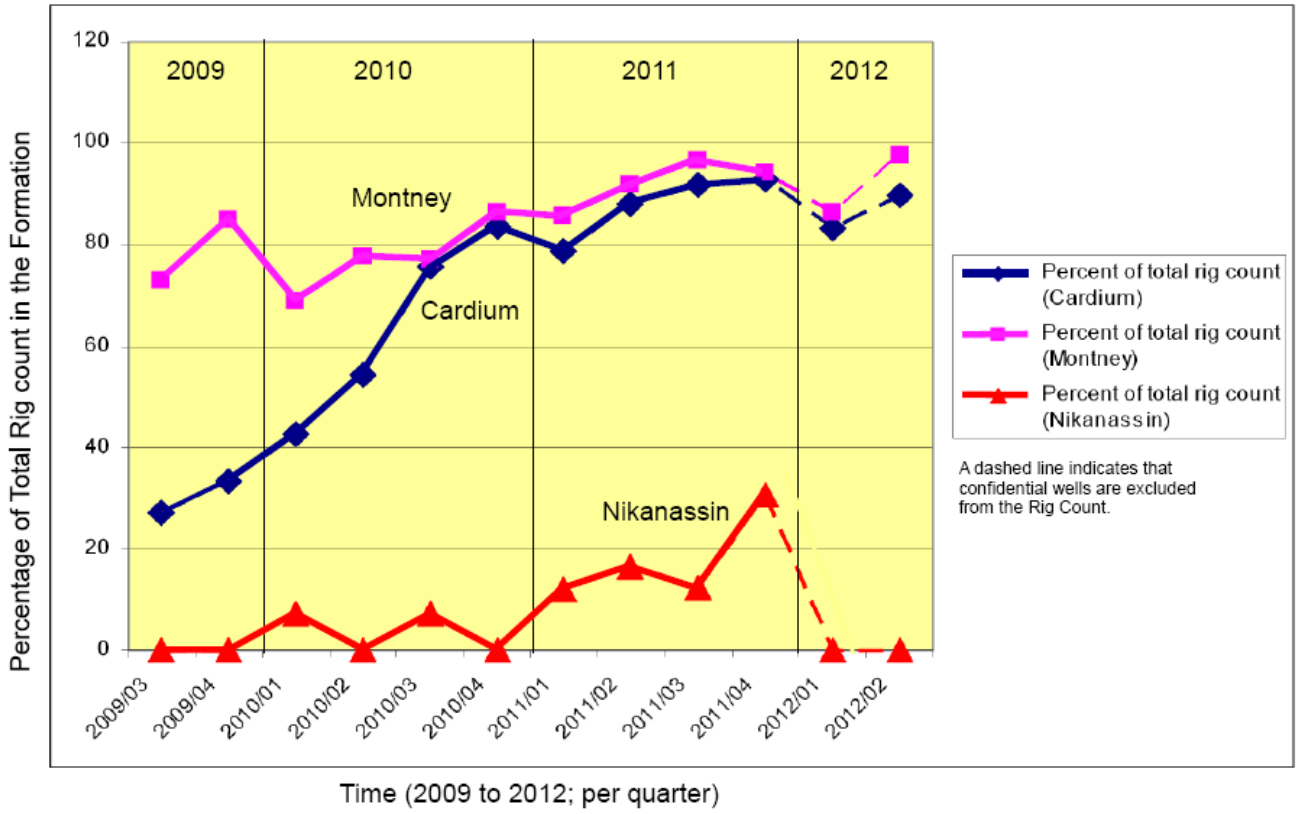

Figure 4. Drilling statistics for non-confidential wells related to total rig count, for the Montney, Cardium and Nikanassin, completed on a quarterly basis from 2009 to 2012 in the Alberta portion of the Western Canada Sedimentary Basin.

Unconventional technologies are being used for enhanced hydrocarbon recovery from what were previously depleted conventional fields, and for the surrounding transition zone and basin-centered accumulations. Thus, there appears to be a 'blending' of the conventional versus unconventional (transition and basin-centered accumulations) in these technology-driven plays – everything is being produced, the gas, the liquids-rich gas, and the oil from the artificially-fractured (and often commingled) conventional, conventional fringe, transition, and basin-centered accumulations. For these reasons, the Cardium-play, in particular, appears to be a hybrid of both conventional and unconventional resources, with most of the production, at present, coming from the low-permeability liquids-rich gas zones and/or oil zones; hence, it was decided to discuss this play-area under the tight gas sandstone commodity, although parts of it would also fall into the unconventional oil shale or conventional hydrocarbon commodities.

5. Cardium Formation, Western Canada Sedimentary Basin, Alberta, Canada.

Much of the current investment in the Western Canada Sedimentary Basin of Alberta is focused on the liquids-rich gas held in the fine-grained fringe deposits (or 'halos') of the Cretaceous Cardium Formation of the Colorado Group. The Cardium Formation hosts about 25% of Alberta's discovered conventional oil with > 10 billion barrels of oil-in-place, and cumulative production (1957-2009) of ~ 1.75 billion barrels. The recovery of only 17% of the pools has been

accomplished using conventional drilling and completions strategies with vertical wells and a combination of primary and enhanced oil recovery (EOR). Beginning in late 2008, there has been significant redevelopment of the Cardium Formation using multi-stage horizontal wells and hydraulic fracturing. Production has significantly increased both by renewing development in under-developed areas of the conventional pools and hence recovering by-passed pay, and by new development between the conventional pools. As of June 2010 over 120 of these wells have been placed on production, largely in the Pembina and Garrington/Caroline fields. Cardium reservoirs typically occur at depths between 3,937-9,186 feet (1200-2800 m) and have mainly light oil with varying amounts of dissolved gas, along with a number of rich-gas pools. Conventional sand and conglomerate reservoirs are relatively thin (13-32 feet or 4 – 10 m), porosity of 6 – 15% and > 200 millidarcy permeability. There are few data representing porosity and permeability of the unconventional pools that are published, available data appears similar to other tight-gas sandstones being exploited in the U.S.A. Cardium fracs typically take 25-40 tons of proppant, compared to 200-300 tons of proppant of typical shale-gas fracs.

The Cardium Formation is regionally extensive in central and southern Alberta, spanning about 150 townships (each township is 36 square miles or 23,040 acres). Sandstone reservoirs are largely in three-stacked successions of largely marine sandstones that formed part of the clastic wedge in the Western Canada Sedimentary Basin. Most of the conventional sand-reservoirs were emplaced in offshore tidal-shelf settings, as mainly coarsening-up successions associated with transgressions following relative falls in base-level throughout the basin. Locally, regressive and early transgressive reservoir sands include incised estuarine valley fills, marginal marine and shoreface settings. Surrounding the conventional sand reservoirs are ‘lobes’, ‘halos’ or ‘fringes’ of the largely tight, thin-bedded, bioturbated, mixed lithologies of very fine sandstone, siltstone, mudstone and shale. Permeability in these thin-bedded mixed lithologies is much less than the associated conventional reservoir sands (<< 0.5 millidarcies). These fringes are what are largely being developed by the multi-stage fractured horizontal wells. Early production data shows that horizontal wells with longer lengths seem to consistently outperform those horizontal wells with shorter lengths in these fringe areas. Due to lack of long production time on these wells it is impossible at this early stage to comment on the impact of the number and type of fracture stages that are optimal per well. 3-D and stochastic modeling results indicate that for the Pembina field, horizontal fractured well drilling and completions for bypassed pay within the conventional pools, commingled with the associated liquids-rich gas in the fringe deposits, may yield up an additional 13% hydrocarbon after about 25 years of production.

Since fall 2009, the Cardium play has had a sharp increase in horizontal play activity, initially largely focused on the Pembina and Garrington fields of central Alberta. The Cardium occurs at 4,265 feet (1300 m) (vertical depth) at Pembina, and at 5,905 feet (1800 m) (vertical depth) at Garrington. Each well costs between 2.8 and 3.0 million dollars (MM$) per well, divided between the drilling and completion costs (Anderson, 2011). Wells have been downspaced to 20 acres (8.1 ha) and recent evidence indicates that it may be optimal to downspace to 10 acres (4 ha) in order to recover 75% of the OGIP. Initial horizontal wells in the Pembina area were drilled by industry with a monobore design, and then fractured with oil-based systems, using interstage fracture distances of 328 feet (100 m) over horizontal well lengths of 2,625-4,593 feet (800 – 1400 m). By 2011, the company switched to a frac density of 18 frac stages per 4,593 foot (1400

m) horizontal well, and switched from oil-based to water-based fracturing. The resultant cost savings were estimated to be ~ $500,000 per well (Anderson, 2011).

Part of the strategy for economic recovery of liquids-rich gas or recovery of both gas and oil is to horizontally drill both the fringe and the remnants of the conventional pools, thereby making the commingled bypassed pay in the conventional pool and new pay in the fringe areas economic. Operators have found that several of the fringe wells produce at lower initial rates than the vertical wells centrally located within the conventional Cardium pools, but have similar low annual decline rates as the conventional pools. First-month initial production rates in other Cardium areas, such as Williston Green and Buck Lake, range from 300-500 barrels per day, which is expected to level off to 80-100 barrels/day. The main challenge for operators to develop the induced fractured fringe areas is to find ways to push the boundaries of conventional pools with existing pay cutoffs of liquids rich gas and/or light oil, and to add the additional potential of the un-drained volumes of the distal portions of the Cardium pools, which until now, have not been economic to produce. This particular example is one in which there is a clear continuum of fluids, reservoir, and development strategies between the older (but now renewed) conventional pools, and the emerging fringe tight-gas and liquids-rich gas accumulations in the distal edges of the conventional pools.

6. Nikanassin Formation, Western Canada Sedimentary Basin, NE British Columbia and NW Alberta, Canada.

The Late Jurassic-Early Cretaceous Nikanassin Formation occurs in the northern mountains, foothills and plains of the Western Canada Sedimentary Basin as an easterly-thinning wedge of largely non-marine sediments. The Nikanassin Formation has a maximum thickness > 3,281 feet (1,000 m), and is generally encountered at depths of 3,281 feet (1,000 m) in the northern plains and up to 11,483-13,123 feet (3,500-4,000 m) in the deep foothills. On average, the lithology of the Nikanassin Formation consists of about 30% sandstone. Thinner reservoir sands (16 – 49 feet or 5 – 15 m thick) are fluvial channel fills, many as fining-upwards successions, interbedded with siltstone/shale, with associated coals. The thicker sandstone successions (> 164-1,640 feet or 50 – 500 m) were deposited as stacked fluvial channel sands within non-marine incised valley-fills. Porosities range from 6-10% with a relatively low permeability of 0.01-1 microdarcies (µmd). Sandstones lack original primary porosity, having been destroyed by cementation with little development of secondary porosity. Reservoir sandstones are brittle and glassy with breakage across sand grains; however, where tight sands are productive they are extensively fractured. Gas was generated in the associated coals with a regional conventional trapping mechanism (either stratigraphic or structural), similar to the Mesaverde Group of Colorado.

Development of the Nikanassin has been within tight-gas sandstone pools that align with structural trends of the thrust belt of northeastern British Columbia and the adjacent areas of northwestern Alberta. The structural grain of the fold and thrust belt is NW-SE, and the main fairways of development are along the leading edges of the thrust faults. The Nikanassin is largely a structural play where deformation associated with the thrust belts has fractured the brittle sandstones to create sufficient porosity and permeability for productive wells. Generally,

Nikanassin pools off the trend of the thrust-faults are non-productive. A maximum of five zones within the Nikanassin are drilled and completed with each zone stimulated separately by hydraulic fracturing. There is a relatively short period of production from these wells, but early returns show production up to 3.2 BCF (90, 000,000 cubic meters) per well, some of which may be commingled with uphole reservoirs. Since 1979, one of the Nikanassin wells has produced 20.4 BCF (577, 000,000 cubic meters). Representative tight Nikanassin horizontal well costs are not readily available; however, for vertical conventional wells, a typical Nikanassin well costs 7.5 million ($MM) per well to drill and complete, with initial production of 10 million to 15 million cubic feet per day (June-Warren Nickels, 2012).

7. Montney Formation, Western Canada Sedimentary Basin, NE British Columbia and NW Alberta, Canada.

Although the Triassic Montney Formation has typically been considered a 'shale gas,' it is actually (in large parts of the formation) a thin-bedded succession of mixed lithologies, including lower shoreface/distal delta fringe deposits of stacked siltstone and very fine sandstone (with little shale or mudstone components) that overlie a deeper basinal facies of fine-grained, organic-rich mudstone/shale, cut by low stand turbidite sandstones. Production is essentially from two areas: the foothills of northeastern British Columbia, and the deep basin area of northwestern Alberta. The delta fringe/shelf siltstones in British Columbia have an estimated gas-in-place of 25-40 BCF/section, with the lower Montney turbidites having gas-in-place of 30-50 BCF/section; predicted development programs are projected to sustain production of 50-100 MMcf/d. The Triassic Montney Formation occurs in the northwest plains and deep basin areas of the Western Canada Sedimentary Basin of Alberta and British Columbia. The successions were deposited as a broad ramp on the western edge of the North American craton during Triassic time. The traditional 'good' conventional reservoirs are located in the more shallow, updip portions of the continental ramp, mainly in northwestern Alberta. By contrast, the deeper, downdip portions of the continental ramp succession (largely located in the deep basin areas of both Alberta and British Columbia) are the distal unconventional shale gas reservoirs, with a continuum of conventional to unconventional reservoirs through time and space. Historically, the lower Montney Formation has been the focus of deep exploration by conventional development of the distal sandstone turbidites, which have fairways that have been exploited with moderate reservoir qualities in western Alberta and northeastern British Columbia. Since 2003, the more unconventional, updip portions of the upper Montney tight-gas sandstones and siltstones have been developed using multi-stage multi-frac horizontal wells.

The upper Montney represents the stacked distal shoreface/delta fringe and shelf sandstone and siltstone packages which have aggregate thicknesses up to 512 feet (156 m) thick. The upper Montney, again historically called a 'shale-gas', is really a thinly interlaminated succession of largely siltstone, with very fine sandstone, and dark, organic and pyritic mudstone, with stacked reservoirs attaining thicknesses > 328 feet (100 m). Porosities in these unconventional reservoirs are typically <3% - 10%, with < millidarcy permeabilities. Initial development in 2005 in northeastern British Columbia used several stages of hydraulic fractures first in vertical wells, now being developed solely by horizontal wells, with average initial flow rates of >4 million cubic feet per day (MMcf/d), and initial decline rates on the order of 60%, stabilizing at single-

digit rates of decline with a 'long-producing tail.' The more recent drilling in the Montney is focused on liquid-rich gas or oil prone areas. In the Western Canada Sedimentary Basin, where infrastructure is in place, with short tie-ins, average horizontal well costs are ~ 4 million ($MM) per well, including drilling and completions.

8. China's Tight Gas Sands and the Shuixigou Group, Taibei Depression, Hami Basin, Kekeya Area, China

The tight-gas sandstone exploration started from 1970s in China, and, at present, the proved reserves are estimated to exceed 18,879 billion barrels (3,000 billion cubic meters). The tight-gas sandstones are widely distributed in a number of basins including the Ordos, Hami (including the Taibei Depression, located in the Tu-Ha Basin, also called the 'Turpan-Hami' Basin), Sichuan, Songliao, Tarim, and deeper parts of the Junggar Basin (Figure 3, Table 1), with the favorable prospective areas exceeding 300,000 square kilometers. In early 2012, the tight gas sands were considered one of the most promising unconventional resources in China (Xiaoguang Tong and Kechang Xie, pers. comm.., 2012). This largely due to three factors: 1) the confirmed assessments of the tight gas-sands resource in China; 2) the advanced state of technological development for tight gas-sands production; and, 3) the distribution of tight gas-sands in many previously developed areas for conventional gas plays, with existing infrastructure in place (Chengzao Jia, former vice-president of Petrochina, pers. comm.., 2012).

Shell International is drilling 17 wells for tight-gas sandstone and shale gas in southwestern China from early 2011on – a result of a 30-year agreement between Shell and Petrochina for exploitation in "Jinqiu" tight-gas block in Sichuan Basin in 2010. In July 2012, Shell International expressed that their company planned to invest $500 million US in both tight gas-sands and shale-gas drilling in China , with an anticipated 20 new wells drilled in 2012. Additional plans include the establishment of a research center for unconventional gas in China, and a joint venture company for unconventional gas production between Shell International and Petrochina.

The tight-gas sandstone exploration in Tuha oil field (Hami Basin) has made great progress in 2011, with drilling of the Ge-18 well in the field that had 3140 m^3/d yield of gas in Shuixigou Group in May 2011. This is the only well of five exploratory wells within new formations that had a significant gas flow. These results will increase the confidence for the tight-gas sandstone exploitation in Shuixigou Group in Taibei Depression. Another well is the Hongtai 21 (Tu-Ha Basin) which acquired commercial oil and gas flows in the Jurassic Sangonghe Formation in October 2011, indicating great progress for tight-gas sandstone exploration in Hongtai area. In December 2011, Sinopec commenced exploration and development for tight-gas sandstone in Ordos Basin.

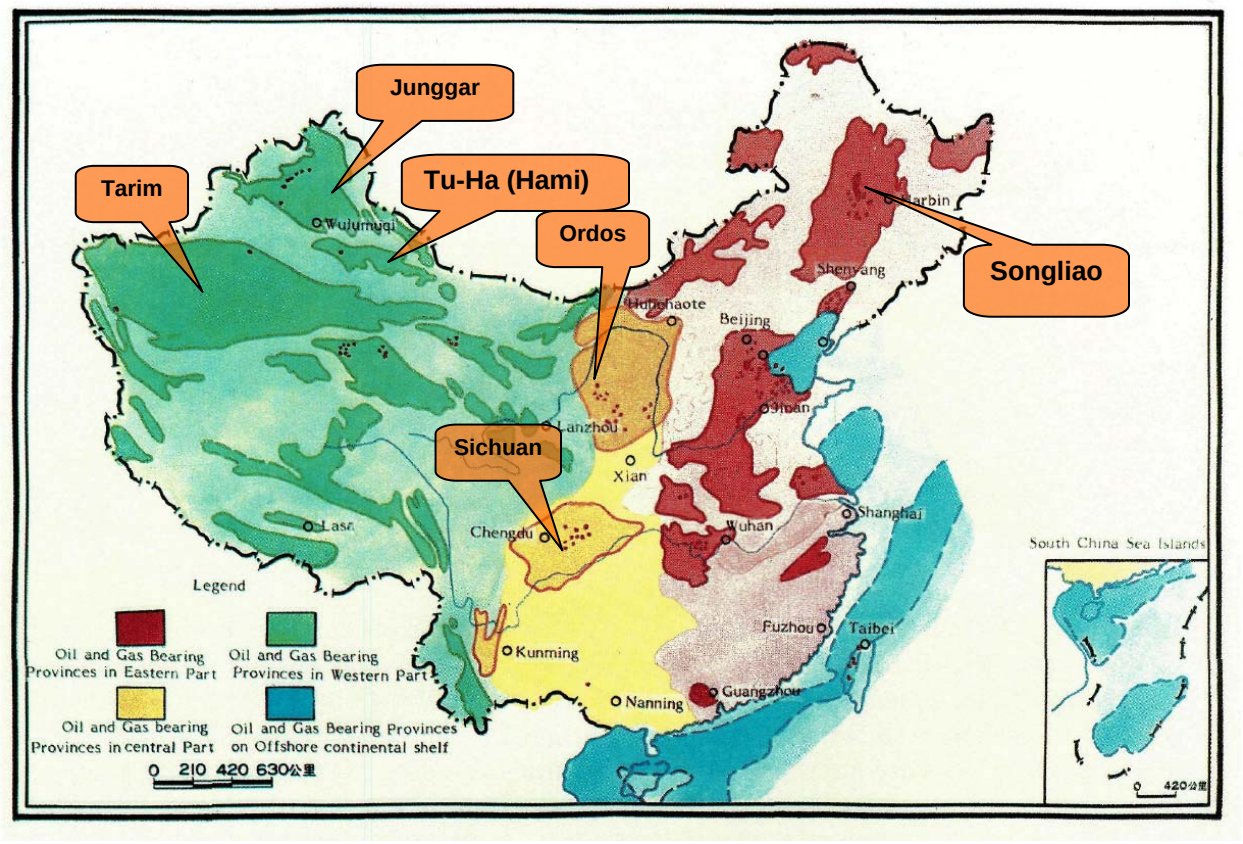

Figure 3. Location of China's major tight-gas sandstone deposits (Ma, 2009; Carroll et al., 2010; Guang-Ming, 1986).

Basin	Depth (m)	Amount of Resources (TCM)
Ordos Basin	2500 – 4500	8.4
Sichuan Basin	1500 – 4500	3.5
Faulted Depression Beneath the Songlaio Basin	1500 - 6000	Not Estimated
Southern Deep Layer in the Junggar Basin	4000 - 7000	Not Estimated

Table 1. Characteristics of main tight-gas sandstone reservoirs in China (Yukai et al., 2011).

The lower Jurassic Shuixigou Group sands in Taibei Depression, Hami Basin (part of the Tu-Ha Basin) in the Kekeya area of China contains three stacked successions of tight-gas sandstones within braided delta-front reservoirs that debouched into a largely lacustrine basin, with associated thick coal measures (1,640-3,609 feet or 500 – 1100 m thick). Burial depths of the tight-gas sandstone reservoirs range from 9,186-14,108 feet (2,800 – 4,300 m). The field produces from a series of stacked sand-pebbly sand, interpreted mainly as subaqueous braided delta front channel-fills, with porosity of 4-8.4 % and permeability of 0.077 – 3.61 millidarcies. Within the three gas-bearing successions, individual sand reservoirs range from 59-180 feet (18–55 m), with a gross thickness of the stacked successions between 344-919 feet (105 – 280 m). The play seeks to exploit fractured reservoirs with the highest production from fractured (micro- and macro-scale,) reservoirs on structural highs, and the lowest production in the relatively

unfractured zones within adjacent structural lows. Single well gas productions vary from 1.9 – 7.6 x 10^4 m^3/d. Natural gas traps are conventional, combined stratigraphic-structural traps, including faulted anticlines, and fault block horst-and-graben structures. The high-production tight-gas sandstone reservoirs are largely controlled by the tectonic setting of the area and the nature of the natural fracture/fault system. The most favorable areas for tight gas are located on structural highs with a high density of fractures and thick top coals (66-98 feet or 20 – 30 m thick). The second-most favorable areas are located also on structural highs with a high fracture density, but in areas where the thickness of the sand and pebbly sands reservoirs are variable, and the coal top is quite variable. The geological factors that control the productivity of single wells within the typical tight-gas reservoirs relate to the structural location, the sedimentary facies, intensity (or density) of natural fractures, and close proximity to thick and continuous top coal measures.

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Books, Papers, Posters and Webpostings.

This section summarizes books, and recent reports, activities, and websites (mainly 2010 -2011) of interest to those geoscientists focus on exploration and development of tight-gas sandstones.

AAPG Books

AAPG's online bookstore contains a number of books that may be of interest to those working on tight gas sands: http://bookstore.aapg.org

Understanding, Exploring, and Developing Tight-Gas Sands – 2005 Vail Hedberg Conference: 2008, S. P. Cumella, K. W. Shanley, and W. K. Camp, eds., AAPG Hedberg Series No. 3, 250 p. plus CD, ISBN 978-0-89181-902-8.

Society of Exploration Geophysicists (SEG) Special Section on Tight Gas Sands

In the December, 2010, edition of *The Leading Edge*, seven papers have been collected which address some of the key technological challenges associated with tight gas sandstone reservoirs. The papers are listed below along with brief summaries from the "Introduction to this special section: Tight gas sands" written by Tad Smith, Colin Sayers, Chris Liner. The abstracts for these papers can be viewed at http://segdl.org/tle/ and all of the papers can be downloaded for free if you are a SEG member.

1. **Petrophysics in tight gas reservoirs – key to challenges still remain**. Mike Miller and Keith Shanley provide an overview of the significant petrophysical issues in tight sands. Their work indicates that new measurements and models will be required in order to more accurately predict reserves and well performance from log data.

2. **Microstructural controls on electric and acoustic properties in tight gas sandstones: Some empirical data and observations.** Tad Smith, Carl Sondergeld, and Ali Ousseini Tinni examine the relationships between acoustic and transport properties (e.g. permeability and resistivity) for seven tight gas sandstone samples. Both resistivity and velocity are strong functions of pore geometry, but the causal mechanisms are quite different.

3. **3D porosity and mineralogy characterization in tight gas sandstones**. Alexandra N. Golab, Mark A. Knackstedt, Holger Averdunk, Tim Senden, Alan R. Butcher, and Patricio Jaime identify and quantify, in three dimensions, the primary and secondary porosity of a tight gas sandstone using X-Ray micro-CT imaging at the pore scale.

4. **A rock physics model for tight gas sand**. Franklin Ruiz and Arthur Cheng use a model to estimate elastic properties of tight gas sandstones. The results agree with log data provided that appropriate pore shapes and volume fractions are used. In particular, low-aspect-ratio pores are required to understand the elastic behavior of these rocks.

5. **Sensitivity of velocities to overpressure within heterogeneous tight gas sand reservoirs**. Colin M. Sayaers and Sheila Noeth examine the relation between acoustic-wave velocity and pore pressure using data from the U.S. Department of Energy Multiwell Experiment in the Rulison gas field, Piceance Basin, Colorado.

6. **Estimating natural fracture producibility in tight gas sandstones: Coupling diagenesis with geomechanical modeling**. Jon E. Olson, Stephen E. Laubach, and Peter Eichhubl present a method for estimating the permeability enhancement due to natural fractures in tight gas sandstones. The work combines observations of fractures in outcrops with geomechanical modeling and diagenetic characterization.

7. **Seismic petrophysics and isotropic-anisotropic AVO methods for unconventional gas exploration**. Bill Goodway, Marco Perez, John Varsek, and Christian Abaco apply rock mechanics, petrophysics, and conventional isotropic AVO to map tight gas sandstone reservoirs. They also clarify some fundamental ambiguities in 3D amplitude variation with azimuth (AVAZ) inversion to correctly detect the orientation and intensity of anisotropy due to stress or fractures.

AAPG Search and Discovery Abstracts and Papers

AAPG's Search and Discovery website contains a number of recent presentations related to tight gas sands presentations at various AAPG conferences in 2011, 2012 and 2013.

1. **Abstracts for the 2011 AAPG Annual Convention and Exhibition (ACE),** April 10-13, 2011, Houston, Texas are given in AAPG Search and Discovery Article #90124.

2. **Gas-Water Distribution and Development Strategy of Xujiahe Tight Gas Reservoir in Sichuan Basin, China**: 2012, Lidau Li, Guang Ji, Ailin Jia, Liang Zhao, and Dong Bo He: AAPG Search and Discovery Article #40864.

3. **Unconventional Gas in Italy: The Rebolla Basin**: 2012, Roberto Bencini, Ello Bianchi, Roberto de Mattia, Alberto Martinuzzi, Semone Rodorigo, and Guiseppe Vico: AAPG Search and Discovery Article #80203.

4. **Understanding Unconventional Resource Potential by Conventional Petroleum Systems Assessment**: 2011, Daniel M. Jarvie and Ronald J. Hill: AAPG Search and Discovery Article #40840.

5. **Petroleum System Modeling for (Un) Conventional Hydrocarbon Resources Assessment, the Broad Fourteens Basin, The Netherlands**: 2011, Rader Abdul Fattah, Hanneke Verweiji, Johan ten Veen, and Nora Witmans: AAPG Search and Discovery Article #80202.

6. **Geological Modeling of Makhul Formation in Minagesh Field: Integrating Sedimentological, Petrophysical, Geophysical and Well Test Data, An Example of a Tight and Complex Reservoir from Kuwait**: 2011, Heyam M. Alammar, Ahmad Manowar, Banek Nikhil, Hanan Al-Owihan, Saifullah Tanoli, Badruzzam an Khan, Sudhakar Rao Mushnuri, and Marco Alvarez: AAPG Search and Discovery Article #20118.

7. **Tight Gas Sands and Natural Fractures in the Cretaceous Mesaverde Group, Greater Natural Buttes Field, Uinta Basin, Utah**: 2011, Stephanie M. Carney, Thomas C. Chidsey., Jr., Craig Morgan, and Michael D. Laine: AAPG Search and Discovery Article #50499.

8. **Nano-Scale Porosity Analysis of a Permian Tight Gas Reservoir**: 2011, Phillipp Antrett, Alexandra Vackener, Uwe Wollenberg, Guillaume Desbois, Peter Kukla, Janos Urai, Harald Stollhofen, and Christoph Hilgers: AAPG Search and Discovery Article #40821.

9. **Development of Mechanically Layered Haynesville-Bossier Shale-Gas Play**: 2011, Amgad I. Younes, Holly Moore, Nathan Suurmeyer, Paul R. Smith, and Melissa Sandstrom: AAPG Search and Discovery Article #50460.

10. **Failure of Microseismic Analysis: Integration of Monitoring and Reservoir Simulation**: 2011, Leo Eisner, Vladimer Grechka, and Sharilyn Williams-Stroud: AAPG Search and Discovery Article #40784.

11. **Microseismic Monitoring Reveals Natural Fracture Networks**: 2011, Shoshana Goldstein, Margaret Seibel, and Theodore Urbancic: AAPG Search and Discovery Article #40782.

12. **Facies, Organic Content, and Composition of Carlile and Niobrara Formations, Southwestern Saskatchewan and Southeastern Alberta**: 2011, Samantha E. Taylor, Per Kent Pedersen, Ron Spencer, Haiping Huang, Steve Larter, and Andrew Aplen: AAPG Search and Discovery Article #50450.

13. **Innovative Methods to Flow Unit and Pore Structure Analysis in a Tight Gas Reservoir, Montney Formation, N.E. B.C., Canada**: 2012, Per K. Pedersen, Chris Clarkson, Jerry Jensen, Omar Dender, and Melissa Freeman: AAPG Search and Discovery Article #50439

14. **Seismic Technologies for Unconventional Reservoir Characterization: Wamsutter Field Case Study**: 2011, Rosemarie Geetan, Brian Hornby, and Ricko Wandhana: AAPG Search and Discovery Article #10159.

15. **Potential of Tight Gas in Pakistan: Productive, Economic and Policy Aspects**: 2011, Shahab Alam: AAPG Search and Discovery Article #80149.

16. **Geological Features and Exploration for Tight Sand Gas, Shale Gas and Other Unconventional Oil/Gas Resources in China:** 2011, Cai-Heng Zou, Shi-Zhen Tao, Tang Ping, Xiao-Hui Gao, Zhi Yang, Qiu-Lin Guo, Da-Zhong Dong, and Xin Jing Li: AAPG Search and Discovery Article #80135.

17. **Diagenesis and Depositional Heterogeneities: Renewing a Complex Issue in Reservoir Modeling of Mature and Marginal Assets:** 2011, Jose Daudt: AAPG Search and Discovery Article #50381.

18. **Unconventional Oil Petroleum Systems: Shales and Shale Hybrids:** 2011, Daniel M. Jarvie: AAPG Search and Discovery Article #80131.

19. **Stratigraphy and Depositional Dynamics of the Haynesville-Bossier Sequence: Inferences from Whole-Rock Elemental Data:** 2011, Michael C. Dix, David Spaen, Colin Walling, Jennifer Sane, Nicolo Casarta, and Allison Richardson: AAPG Search and Discovery Article #10298.

20. **Identification of Subtle Oil/Gas Reservoir in Junggar Basin of West China:** 2011, Gang Cai, Qingzhou Yao, Shuangwen Li, Ximin Lu, and Honglin Gong: AAPG Search and Discovery Article #40691.

21. **Recurrent Issues in the Evaluation of Unconventional Resources:** 2011, William J. Haskett and P. Jeffrey Brown: AAPG Search and Discovery Article #40674.

22. **A Petrophysical Method to Evaluate Irregularly Gas Saturated Tight Sands Which Have Variable Matrix Properties and Uncertain Water Salinities:** 2011, Michale Holmes, Domenic Holmes, and Antony Holmes: AAPG Search and Discovery Article #40673.

23. **Evaluating, Classifying and Disclosing Unconventional Resources:** 2011, David C. Elliott: AAPG Search and Discovery Article #70090.

24. **Fluid Detection in Carbonate Reservoirs utilizing Gas Analysis-A Case Study**: 2013, Ali Abu Ghneej1, Jalal Dashti, Badruzzaman Khan, Heyam Ammar, Abdulrazaq AL-Nabhan, Sunil K. Singh, Talal Al-Adwani, and Nacif Marai: AAPG Search and Discovery Article #41116.

25. **Characteristics of Hydrocarbon Accumulation and Distribution of Tight Oil in China: An Example of Jurassic Tight Oil in Sichuan Basin**: 2013, Zou Caineng, Tao Shizhen, Yang Fan, and Gao Xiaohui: AAPG Search and Discovery Article #10386.

26. **Mesaverde Tight Gas Sandstone Sourcing from Underlying Mancos-Niobrara Shales: 2012, Steve Cumella1 and Jay Scheevel**: AAPG Search and Discovery Article #10450.

27. **Effect of Laramide Structures on the Regional Distribution of Tight-Gas Sandstone Reservoirs in the Upper Mesaverde Group, Uinta Basin, Utah**: 2012, Raju Sitaula1 and Jennifer L. Aschoff: AAPG Search and Discovery Article #10452.

28. **How Porosity is Developed or Preserved in Unconventional Hemipelagic Carbonate Reservoir? Case Study in SE France (Provence, Durance Area)**: 2012, Pierre-Olivier Bruna1, Yves Guglielmi1, Juliette Lamarche1, Marc Floquet, François Fournier, Jean-Pierre Sizun, Arnaud Gallois, Lionel Marie, Catherine Bertrand, and Fabrice Hollender: AAPG Search and Discovery Article #120041.

29. **Challenges and Current Advances in the Rock Physics of Carbonate Rocks**: 2012, Tiziana Vanorio, Yael Ebert, and Ammar El Husseiny: AAPG Search and Discovery Article #120094.

30. **Discriminating Gas Bearing Sands from Shale Using Rock Physics Guided Inversion**: 2012, Ahmed W. Daghistani, Aiman M. Bakhorji, and Husam M. Al-Mustafa: AAPG Search and Discovery Article #40909.

31. **Quantifying Anisotropy for Geomechanics**: Tom R. Bratton: AAPG Search and Discovery Article #40920.

32. **Resolving Water Saturation Estimation in Thin Carbonate Reservoirs Using Resistivity Inversion**: 2012, Amr M. Serry, Sabah K. Aziz, Omar Al-Farisi, Mariam Al-Marzouqi, and Sultan Budebes: AAPG Search and Discovery Article #40931.

33. **Creation of Porosity in Tight Shales during Organic Matter Maturation**: 2012, Jeremy Dahl, J.M. Moldowan, Joel Walls, Amos Nur, and Juliana DeVito: AAPG Search and Discovery Article #40979.

34. **Insights into Gas Geochemistry of Large Tight Gas Sandstone Reservoirs from Fluid Inclusions**: 2012, Jiun-Chi Chao1, Wipawon Phiukhao1, Donald Hall1, and Nicholas B. Harris: AAPG Search and Discovery Article #41001.

35. **Mapping Rocky Mountain Fractures: GIS Methods for Resource Plays**: 2012, Laura Kennedy, Eric Erslev, and Karen Aydinian: AAPG Search and Discovery Article #41031.

36. **Relationship between Reservoir Quality and Hydrocarbon Signatures Measured at the Surface**: 2012, Paul Harrington and Alan Silliman**:** AAPG Search and Discovery Article #41078.

37. **The Impact of Mechanical Stratigraphy on Hydraulic Fracture Growth and Design Considerations for Horizontal Wells**: 2012, Jennifer L. Miskimins: AAPG Search and Discovery Article #41102.

38. **Hydrocarbon Potential of Tight Sand Reservoir (Pab Sandstone) in Central Indus Basin-Pakistan**: 2012, M. Anwar Moghal, M. Ishaq Saqi, and M. Athar Jamij: AAPG Search and Discovery Article #50608.

39. **Impacts of Heterogeneous Fluvial Depositional Environments on Hydraulic Fracture Propagation in Tight Gas Reservoirs**: 2012, Donna S. Anderson, Mary M. Carr, Patricia H. Cuba, and Jennifer L. Miskimins: AAPG Search and Discovery Article #5061

40. **Preliminary Facies Analysis, Regional Sequence Stratigraphy and Distribution of Stratigraphically Controlled Mechanical Units of the Middle and Upper Williams Fork Formation, Piceance Basin, Colorado**: 2012, Michele Wiechman and Jennifer L. Aschoff: AAPG Search and Discovery Article #50619.

41. **Constraining Uplift in the Piceance Basin Using Diagenetic Modeling of Quartz Cementation in Upper Cretaceous Williams Fork Sandstones, Colorado**: 2012, Aysen Ozkan, Stephen E. Laubach, Kitty Milliken, and Linda Bonnell: AAPG Search and Discovery Article #50679.

42. **Timing and Mechanisms of Fracturing within the Irish Canyon-Vermillion Creek Area, Moffat County, Colorado: 2012,** John P. Detring, Scott M. Larson, and Eric A. Erslev: AAPG Search and Discovery Article #50758.

43. **Using Cutting-Edge Surface Geochemical Techniques to Indicate Porosity, Pressure, and Hydrocarbon Phase in Shale Plays**: 2012, Rick Schrynemeeckers**:** AAPG Search and Discovery Article #70115.

44. **MWX - The Multiwell Experiment in the Piceance Basin, Colorado: Reprise from 30 Years Ago**: 2012, John C. Lorenz1: AAPG Search and Discovery Article #70129.

45. **Geological Conditions for Upper Paleozoic Shale Gas Enrichment in the Ordos Basin, China:** 2012, Jingzhou Zhao, Qing Cao, Yuanfang Fan, Yubin Bai, and Xiaomei Wang: AAPG Search and Discovery Article #80209 (2012)

46. **Quasi-continuous Lithologic Accumulation System: A New Model for Tight Gas Occurrence in the Ordos Basin, China:** 2012, Jingzhou Zhao, Jinhua Fu, Xinshan Wei, Xinshe Liu, Xiaomei Wang, Qing Cao, Yanping Ma, and Yuanfang Fan: AAPG Search and Discovery Article #80210.

47. **Devonian and Mississippian Hydrocarbon Generation and Migration in Southern West Virginia, Appalachian Basin**: 2012, Scott McCallum and Chris Willan: AAPG Search and Discovery Article #80220.

48. **Characteristics, Accumulation Conditions, and Exploration Prospects of Tight Oil in China: 2012,** Caineng Zou: AAPG Search and Discovery Article #80230.

49. **Shale Gas and Tight Oil Development: An Adaptive Model Resulting from Real Long-term Solutions that Incorporate Water Resources Management and the Public Trust: 2012,** Gary Hanson: AAPG Search and Discovery Article #80253.

50. **Mesoproterozoic Unconventional Plays in the Beetaloo Basin, Australia: The World's Oldest Petroleum Systems**: 2011, Matthew Silverman and Thomas Ahlbrandt: AAPG Search and Discovery Article #10295.

AAPG Search and Discovery Posters

AAPG's Search and Discovery website contains a number of recent poster presentations related to tight gas sands posted in 2010:

1. **Using 3-D Property Models to Optimize Infill Drilling in an East Texas Tight Gas Play**: 2010, Terngu Utim, Celine E. Caithamer, and Omar Minhaj: AAPG Search and Discovery Article #40490.

http://www.searchanddiscovery.net/documents/2010/40490utim/ndx_utim.pdf

2. **Conditions of Quartz Cementation in Mt. Simon Sandstone: Evidence from in situ Microanalysis of Oxygen Isotopes**: 2010, Anthony Pollington, Reinhard Kozdon, Takayuki Ushikubo, Noriko T. Kita, and John W. Valley: AAPG Search and Discovery Article #50351.

   http://www.searchanddiscovery.com/documents/2010/50351pollington/ndx_pollington.pdf

3. **Compaction and Quartz Cementation Modeling for Reservoir Quality Prediction in Sub-Salt Reservoirs of the Deepwater Gulf of Mexico**: 2010, David Eickhoff and Nathan Blythe: AAPG Search and Discovery Article #50348.

   http://www.searchanddiscovery.com/documents/2010/50348eickhoff/ndx_eickhoff.pdf

4. **Stratigraphy and Petrophysics of Gas-Produciing Parasequences in the Rollins Sandstone of the Mesaverde Group, Mamm Creek Field, Piceance Basin, Northwest Colorado**: 2010, Steve Cumella: AAPG Search and Discovery Article #20092.

   http://www.searchanddiscovery.com/documents/2010/20092cumella/ndx_cumella.pdf

5. **Detailed Stratigraphic Architecture of the Mesaverde Group Determined from Principle-Component Analysis of 3D Seismic Data, Mamm Creek Field, Piceance Basin, Northwest Colorado**: 2010, Jay Scheevel and Steve Cumella: AAPG Search and Discovery Article #20095.

   http://www.searchanddiscovery.com/documents/2010/20095scheevel/ndx_scheevel.pdf

AAPG Bulletin Papers

AAPG's Bulletin includes the following papers related to tight gas sands that were published in 2010, 2011, 2012 and 2013:

1. **Stratigraphic controls on production from a basin-centered gas system: Lower Cretaceous Cadotte Member, Deep Basin, Alberta, Canada**: March 2010, Tim McCullagh and Bruce Hart: AAPG Bulletin, V. 94, N. 3, p. 293-315.

2. **Sandstone reservoir quality prediction: The state of the art**: August 2010, Joanna M. Ajdukiewicz and Robert H. Lander: AAPG Bulletin, V. 94, N. 8, p. 1083-1091.

3. **Sandstone diagenesis and reservoir quality prediction: Models, myths and reality**: August 2010, T. R. Taylor, M. R. Giles, L. A. Hathon, T. N. Diggs, N. R.

Braunsdorf, G. V. Birbiglia, M. G. Kittridge, C. I. Macaulay, and I. S. Espejo: AAPG Bulletin, V. 94, N. 8, p. 1093-1132.

4. **Origin and timing of late diagenetic illite in the Perian-Carboniferous Unayzah sandstone reservoirs of Saudi Arabia**: August 2010, Stephen G. Franks and Horst Zwingmann: AAPG Bulletin, V. 94, N. 8, p. 1133-1159.

5. **A model for fibrous illite nucleation and growth in sandstones**: August 2010, R. H. Lander and L. M. Bonnell: AAPG Bulletin, V. 94, N. 8, p. 1161-1187.

6. **Prediction of deep reservoir quality using early diagenetic process models in the Jurassic Norphlet Formation, Gulf of Mexico**: August 2010, J. M. Ajdukiewicz, P. H. Nicholson, and W. L. Esch: AAPG Bulletin, V. 94, N. 8, p. 1189-1227.

7. **Reservoir quality modeling of tight-gas sands in Wamsutter field: Integration of diagenesis, petroleum systems, and production data**: August 2010, Rick C. Tobin, Tony McClain, Robert B. Lieber, Aysen Ozkan, Laura A. Banfield, Ann M.E. Marchand, and Lee E. McRae: AAPG Bulletin, V. 94, N. 8, p. 1229-1266.

8. **The impact of diagenesis on the heterogeneity of sandstone reservoirs: A review of the role of depositional facies and sequence stratigraphy**: August 2010, S. Morad, Khalid Al-Ramadan, J. M. Ketzer, and L.F. De Ros: AAPG Bulletin, V. 94, N. 8, p. 1267-1309.

9. **Biogenically enhanced permeability: A petrographic analysis of *Macaronichnus segregatus* in the Lower Cretaceous Bluesky Formation, Alberta, Canada**: November 2010, John B. Gordon, S. George Pemberton, Murray K. Gingras, and Kurt O. Konhauser: AAPG Bulletin, V. 94, N. 11, p. 1779-1795.

10. **Microfracturing in the Upper Triassic Sichuan Basin tight-gas sandstones: Tectonic, overpressure, and diagenetic origins**: December 2010, Lianbo Zeng: AAPG Bulletin, V. 94, N. 12, p. 1811-1825.

11. **Overpressures in the Taranaki Basin: Distribution, causes, and implications for exploration**: March 2011, Mark Webster, Stephen O'Connor, Bitrus Pindar, and Richard Swarbrick: AAPG Bulletin, V. 95, N. 3, p. 339-370.

12. **New hydrocarbon trap models for the diagenetic transformation of opal-CT to quartz in Neogene siliceous rocks**: March 2011, Takashi Tsuji, Yasuhiro Masui, and Satoru Yokoi: AAPG Bulletin, V. 95, N. 3, p. 339-370.

13. **Discussion and Reply: Pore-throat sizes in sandstones, tight sandstones, and shales: Discussion**: August 2011, Wayne K. Camp: AAPG Bulletin, V. 95, N. 8, p. 1443-1447.

14. **Discussion and Reply: Pore-throat sizes in sandstones, tight sandstones, and shales: Reply**: August 2011, Philip H. Nelson: AAPG Bulletin, V. 95, N. 8, p. 1448-1452.

15. **The place of tubular concretions in hydrocarbon cold seep systems: Late Miocene Urenui Formation, Taranaki Basin, New Zealand**: September 2011, Stephanie L. Nyman and Campbell S. Nelson: AAPG Bulletin, V. 95, N. 9, p. 1495-1524.

16. **Prediction of lithofacies and reservoir quality using well logs, Late Cretaceous Williams Fork Formation, Mamm Creek field, Piceance Basin, Colorado**: October 2011, Aysen Ozkan, Stephen P. Cumella, Kitty L. Milliken, and Stephen E. Laubach: AAPG Bulletin, V. 95, N. 10, p. 1699-1724.

17. **From outcrop to flow simulation: Constructing discrete fracture models from a LIDAR survey:** November 2011, Christopher E. Wilson, Atilla Aydin, Mohammad Karimi-Fard, Louis J. Durlofsky, Amir Sagy, Emily E. Brodsky, Oliver Kreylos, and Louise H. Kellogg: : AAPG Bulletin, V. 95, N.11, p. 1883-1905.

18. **Testing the basin-centered gas accumulation model using fluid inclusion observations: Southern Piceance Basin, Colorado**: December 2012, Andras Fall, Peter Eichhubl, Stephen P. Cumella, Robert J. Bodnar, Stephen E. Laubach, Stephen P. Becker: AAPG Bulletin, V. 96, N. 12, p. 2297–2318.

19. **Impact of arid surface megacracks on hydrocarbon reservoir properties**: July 2012, Philipp Antrett, Anna Alexandra Vackiner, Peter Kukla, Norbert Klitzsch, Harald Stollhofen: AAPG Bulletin, V. 96, No. 7, p. 1279–1299.

20. **Diverse fracture properties and their impact on performance in conventional and tight-gas reservoirs, Saudi Arabia**: The Unayzah, South Haradh case study: March 2012, Mohammed S. Ameen, Keith MacPherson, Maher I. Al-Marhoon, Zillur Rahim: AAPG Bulletin, V. 96, N. 3, p. 459–492.

21. **Comparison of petroleum resource assessments of China by the U.S. Geological Survey and the China National Petroleum Assessment Team**: August 2012, Chenglin Liu, Changbo Che, Jie Zhu, Hulin Yang, Wenping Liu, Wei Zhao: AAPG Bulletin, V. 96, N. 8, p. 1415–1427.

22. **Light volatile liquid and gas shale reservoir potential of the Cretaceous Shaftesbury Formation in northeastern British Columbia, Canada**: July 2012, Gareth R. L. Chalmers, R. Marc Bustin: AAPG Bulletin, V. 96, N. 7, p. 1333–1367.

23. **Three-dimensional modeling study of the low-permeability petroleum system of the Bakken Formation**: October 2012, Philipp P. Kuhn, Rolando di Primio, Ronald Hill, James R. Lawrence, Brian Horsfield: AAPG Bulletin, V. 96, N. 10, p. 1867–1897.

24. **Organic geochemistry of the Woodford Shale, southeastern Oklahoma: How variable can shales be?**: March 2012, Andrea Miceli Romero, R. Paul Philp: AAPG Bulletin, V. 96, N. 3, p. 493–517.

25. **Damage and plastic deformation of reservoir rocks: Part 1. Damage fracturing**: September 2012, Seth Busetti, Kyran Mish, Ze'ev Reches: AAPG Bulletin, V. 96, N. 9, p. 1687–1709.

26. **Damage and plastic deformation of reservoir rocks: Part 2. Propagation of a hydraulic fracture**: September 2012, Seth Busetti, Kyran Mish, Peter Hennings, Ze'ev Reches: AAPG Bulletin, V. 96, N. 9, p. 1711–1732.

27. **Fracture evolution in oil-producing sills of the Rio Grande Valley, northern Neuquen Basin, Argentina**: July 2012, Jan Witte, Massimo Bonora, Carlos Carbone, Onno Oncken: AAPG Bulletin, V. 96, N. 7, p. 1253–1277.

28. **Thermomechanical origin of regional fracture systems**: September 2012, Joseph M. English: AAPG Bulletin, V. 96, N. 9, p. 1597–1625.

29. **Fractured tight sandstone oil and gas reservoirs: A new play type in the Dongpu depression, Bohai Bay Basin, China**: March 2013, Lianbo Zeng, Hui Su, Xiaomei Tang, Yongmin Peng, Lei Gong: AAPG Bulletin, V. 97, N. 3, p. 363–377.

30. **Organic matter-hosted pore system, Marcellus Formation (Devonian), Pennsylvania**: February 2013, Kitty L. Milliken, Mark Rudnicki, David N. Awwiller, Tongwei Zhang: AAPG Bulletin, V. 97, N. 2, p. 177–200.

31. **Permeability and flow impact of faults and deformation bands in high-porosity sand reservoirs: Southeast Basin, France, analog**: March 2013, Elodie Saillet, Christopher A. J. Wibberley: AAPG Bulletin, V. 97, N. 3, p. 437–464.

Society of Petroleum Engineers (SPE) Papers

Various SPE papers of interest to geoscientists that were published in 2010, 2011, 2012 and 2013 are listed below. These are available for purchase at http://www.onepetro.org

1. **Comparison of core/log and well test permeabilities – A closer look "Sawan Tight Sands"**: Amir Riaz Ahmed, Mansoor Ahmad, and Attique Ur Rehman: Paper # 142836-MS. (2010).

2. **Petrophysical integration to approach tight gas sand reservoir characterization problems in Cuervito Sur field, Mexico**: L. Muñoz, A. Ochoa, M. Acosta, and F. Brito: Paper # 135615-MS.(2010).

3. **Lower Safa sedimentological study, new insights in the reservoir quality distribution of the Obaiyed field, Western Desert, Egypt**: Ahmed Saad, Michiel de Groot, and Savier le Varlet: Paper # 128015-MS.(2010).

4. **Deriving quantitative fracture properties from whole core description: A practical link between geological observation and flow simulation**: Jiajie (Jeff) Chen: Paper # 130725-MS.(2010).

5. **Fracturing in tight gas reservoirs: Application of special-core-analysis methods to investigate formation-damage mechanisms**: B. Bazin, S. Bekri, O. Vizika, B. Herzhaft, and E. Aubry: Paper # 112460-PA. (2010)

6. **An evaluation of microseismic monitoring of lenticular tight-sandstone stimulations**: N. R. Warpinski, C. K. Waltman, and L. Weijers: Paper # 131776-PA.(2010)

7. **Gas reserves estimation in resource plays**: W. J. Lee and R. E. Sidle: Paper # 130102-MS.(2010).

8. **Cumulative gas production distribution on the Nikanassin tight gas formation, Alberta and British Columbia, Canada**: Nisael Solano, Liliana Zambrano, and Roberta Aguilera: Paper # 132923-MS.(2010)

9. **Selecting drilling technologies and methods for tight gas sand reservoirs**: N. Pilisi, Y. Wei, and S. A. Holditch: Paper # 128191-MS.(2010)

10. **Using maps of microseismic events to define reservoir discontinuities**: David P. Craig and Roger Burkhart: Paper # 135290-MS.(2010)

11. **Petrophysical analysis method to identify "sweet spots" in tight gas reservoirs: Case study from the Punta Rosada Formation in Neuquen Basin, Argentina**: C. Naides: Paper # 121313-MS.(2010).

12. **Overview of tight gas field development in the Middle East and North Africa Region**: Ahmed Shehata, Ahmed Aly, and Lee Ramsay: Paper # 126181-MS.(2010).

13. **Numerical modeling of multistranded-hydraulic-fracture propagation: Accounting for the interaction between induced and natural fractures**: Arash Dahi-Taleghani and Jon E. Olson: Paper # 124884-PA (2011)

14. **The Importance of Saturation History for Tight Gas Deliverability**: David R. Spain, German Merletti, Mike Webster, Lindsay Kaye: Paper # 163958-MS (2013).

15. **How Geomechanical Data Integration helped constrain the Placement of the first Horizontal Well in a new Tight Gas Field**: Kevin J Bate, PDO, Latifa Qobi and Suleiman Kindy: Paper # 163954-MS (2013).

16. **Optimizing Borehole Imaging for Tight Gas Exploration: Evolving a Go - No Go Decision Tree in Tight Gas Reservoirs of the Sultanate of Oman**: Chandramani Shrivastava, Sultan Al-Mahrooqi, Rifaat Mjeni, Suleiman Kindy, Feraz Hosein, Hafidh Al-Busaidi, Jokha Al-Busaidi, Robert Laronga, Paper # 152446-MS (2012).

17. **Water Distribution in the Montney Tight Gas Play of the Western Canadian Sedimentary Basin**: Significance for Resource Evaluation: J.M. Wood: Paper # 161824-MS. (2012).

18. **New Approach for the Prediction of Klinkenberg Permeability In Situ for Low Permeability Sandstone in Tight Gas Reservoir**: Mehdi Tadayoni and Mina Valadkhani: Paper # 152451-MS (2012).

19. **Nanopore-Structure Analysis and Permeability Predictions for a Tight Gas Siltstone Reservoir by Use of Low-Pressure Adsorption and Mercury-Intrusion Techniques**: C.R. Clarkson, J.M. Wood, S.E. Burgis, S.D. Aquino and M. Freeman: Paper # 155537-PA (2012).

20. **Improved Reservoir Characterization of Tight Gas Sands Through the 3D Integrated Reservoir Modeling of Queen City Basal, Burgos Basin, Mexico**: S. D'Alessio, L. Muñoz, A. Ochoa, E. Garza, F. Brito: Paper # 152679-MS (2012).

21. **A Complete Petrophysical Evaluation Method for Tight Formations From Only Drill Cuttings in the Absence of Well Logs**: Camilo Ortega and Roberto Aguilera: Paper # 161875-MS (2012).

22. **Petrophysical Parameters Evaluation in Unconventional Reservoirs by Well Logging and Mud Logging Data Interactive Correlation Method**: Hrvoje Jurčić, Zoran Čogelja, Srećko Maretić: Paper # 150961-MS (2012).

23. **Quantifying the Role of Hematite Cement in Controlling Permeability in a Deep Tight Gas Reservoir from the North Sea**: Arfan Ali, Salem Abdalah and David K. Potter: Paper # 152382-MS (2012).

24. **Influence of Rock Properties and Geomechanics on Hydraulic Fracturing: A Case Study from the Amin Deep Tight Gas Reservoir, Sultanate of Oman**: Satya Perumalla, Antonio Santagati and Tony Addis, Sultan Al-Mahrooqi, Joe Curtino, Andreas Briner, Rifaat Mjeni and Latifa Qobi: Paper # 153227-MS (2012).

25. **Drill Cuttings and Characterization of Tight Gas Reservoirs - an Example from the Nikanassin Fm. in the Deep Basin of Alberta**: N.A. Solano, C.R. Clarkson, and F.F. Krause, R. Lenormand, J.E. Barclay, and R. Aguilera: Paper # 162706-MS.

26. **Parametric Study of Fracture Treatment Parameters for UltraTight Gas Reservoirs**: Kelvin Abaa, John Yilin Wang, and Mku Thaddeus Ityokumbul: Paper # 152877-MS (2012).

27. **Integrating Geology, Hydraulic Fracturing Modeling, and Reservoir Simulation in the Evaluation of Complex Fluvial Tight Gas Reservoirs**: Kelly M. Ramirez, Patricia H. Cuba, Jennifer L. Miskimins, Donna S. Anderson, and Mary M. Carr: Paper # 151931-MS (2012).

28. **Advances in Measurement Standards and Flow Properties Measurements for Tight Rocks such as Shales**: S.Sinha, E.M. Braun, Q.R. Passey, S.A. Leonardi, A.C. Wood III, T. Zirkle, J.A. Boros, and R.A. Kudva: Paper # 152257-MS (2012).

29. **Using the SPE/WPC/AAPG/SPEE/SEG PRMS To Evaluate Unconventional Resources**: Phillip Chan, John R. Etherington, and Roberto Aguilera: Paper # 134602-PA (2012).

Government Publications and Websites for Tight Gas Sandstone Plays

Two U.S. Department of Energy (DOE) projects funded by the Office of Fossil Energy's National Energy Technology Laboratory provide quick and easy web-based access to sought after information on tight-gas sandstone plays. Operators can use the data on the websites to expand natural gas recovery in the San Juan Basin of New Mexico and the central Appalachian Basin of West Virginia and Pennsylvania. The first project, led by the New Mexico Institute of Mining and Technology, uses a GIS (geographic information systems) database of well logs, core analysis data, and natural gas production results for the Dakota sandstone reservoirs in the San Juan Basin. The second study, done by West Virginia University, the West Virginia Geological and Economic Survey, and the Pennsylvania Geological Survey, provides public access to well-specific and regional data for five tight-gas sandstones of the central Appalachian Basin: the Mississippian/Devonian Berea/Murrysville Sandstone Play, three Upper Devonian sandstone plays (Venango, Bradford, and Elk), and the Lower Silurian Clinton/Medina Play. Compiled data includes newly scanned well logs, core and production data, reports, and theses, all available through a GIS-based delivery system.
http://www.netl.doe.gov/publications/press/2009/09050-DOE_Showcases_Websites.html

In 2009, the National Energy Board (NEB) of Canada released an energy briefing note, "A Primer for Understanding Canadian Shale Gas" (November 2009). The NEB briefing note gives a definition of shale, the petroleum history and source of natural gas in shale, shales as reservoirs, drilling and completions, well costs, infrastructure and relevance to Canadian production, and descriptions of prospective Canadian gas shales. Although this publication does not address "Tight Gas Sands" per se, there are a number of "hybrid" gas shales, where the original deposits had a very high sand and/or silt content, and, therefore having naturally higher permeability and greater susceptibility to hydraulic fracturing than "normal" mudstones or true shales. One example, the Triassic Montney Formation, is so rich in sand and silt that it is often called a 'tight gas,' however, in contrast to many more typical tight-gas sand plays, the gas in the

Montney is sourced from its own organic matter, more similar to a shale-gas play. This example shows that there is a likelihood of a continuum of play-types from distal conventional → unconventional tight gas sand → unconventional tight gas sand and silt → unconventional gas shale. This report can be accessed by email: publications@neb-one.gc.ca

In 2009, Ma Xinhua presented the status and development prospects of China's unconventional natural gas exploration and exploitation, as part of the Ninth Sino-US Oil and Gas Industry (Ma2009) . An overview of the unconventional natural gas resources of China was given, with estimates of the magnitude of the tight gas sand resources, although the delineation of this resource is not that clear. Tight-gas sandstone resources were estimated to represent > 20% (56 TCM) of the amount of total gas resources of the country. More detailed resource description of the tight-gas sands are given for the Ordos and Sichuan basins, along with a discussion of exploration and exploitation techniques. Comparisons of the development prospects of the tight-gas resources are compared with other unconventional gas resources in China, such as coal-bed methane (cbm), shale gas, gas hydrates, and water-soluble gas: http://www.uschinaogf.org/Forum9/pdfs/Xinhua_English.PDF. In 2011, the International Unconventional Oil and Gas Conference was held in Qingdao, China (IUOGC). Papers addressing tight-gas sandstones included: a discussion on the deposition and reservoir characteristics of a tight-gas reservoir within the Shuixigou Group in the Kekeya area[5]; a review of the geology of the northwest Junggar Basin, which has prospective tight-gas sands (Feng et al., 2011) among others: jianhuazhong57@hotmail.com.

In 2010, the Energy Resources Conservation Board of Alberta released a bulletin outlining those zones in the province that were eligible for shale gas fluid codes to provide guidance for designation of production in the Petroleum Registry of Alberta. This was done, in part, to guide industry in the designation, which in some cases, may lead to royalty relief. Shale gas zones were pervasive, and were predominantly mudstone or shale successions, that have the potential to produce natural gas. The information included representative maps and cross sections for six major stratigraphic units, including the Colorado Group, Wilrich and Bantry formations, the Fernie Group, Exshaw/lower Banff, and Ireton/Duvernay formations and equivalents. As with the NEB 2009 release, included in the formations and groups lists are a number of thinly interbedded, mixed lithologies of shale/mudstone and tight sandstone/siltstone; additionally, some of the "shale/mudstone" when analyzed may have < 10% clay-size material, with the mudstones being dominantly siltstone or sandy-clayey-siltstone, or clayey-siltstone. As with the Montney Formation discussed above, these units have so much silt/siltstone and or sand/sandstone that they may be called a "tight gas" or a "hybrid shale." It is for these reasons, especially, in light of the continuum of play types, that this reference is included under tight gas sandstone plays, although the title indicates a "shale gas" designation. http://www.ercb.ca/docs/documents/bulletins/Bulletin-2010-28.pdf

The Energy Resource Appraisal (ERA) group of the Geology, Environmental Sciences, and Economics (GESE) Branch of the Energy Resources Conservation Board in Alberta ,Canada is pleased to announce the release of a report titled " Summary of Alberta's Shale- and Siltstone-Hosted Hydrocarbon Resource Potential". The report consists of a risked estimation of the

resource endowment of oil, gas and liquid, along with appropriate maps, in seven organic-rich strata, namely the Duvernay, Muskwa, Montney, Lower Banff/Exshaw, Wilrich, Nordegg and Colorado formations. The report can be downloaded at this web address: http://ags.gov.ab.ca/publications/abstracts/OFR_2012_06.html. Data accompanying the report will be released as soon as possible.

Selected U.S. Geological Survey Unconventional Petroleum Publications

Attanasi, E. D. and Meyer, R. F., 2007, **Natural bitumen and extra-heavy oil**, *in* Survey of Energy Resources 2007, eds. J. Trinnaman and A. Clarke: World Energy Council, p. 119-143. http://www.worldenergy.org/publications/survey_of_energy_resources_2007/default.asp

Bartberger, C.E., Dyman, T.S., and Condon, S.M., 2002, **Is There a Basin-Centered Gas Accumulation in Cotton Valley Group Sandstones, Gulf Coast Basin, USA?**, *in* Nuccio, V. F., and Dyman, T.S., eds., Geologic Studies of Basin-Centered Gas Systems: U.S. Geological Survey Bulletin 2184-D, 38 p.
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http://pubs.usgs.gov/bul/b2184-e/

Burruss, R.C., 1997, **Migration of Hydrocarbon and Nonhydrocarbon Gases From the Deep Crust; Composition, Flux, and Tectonic Setting, Chapter M**, *in* Dyman, T. S., Rice, D.D., and Westcott, W.A., eds., Geologic Controls of Deep Natural Gas Resources in the United States: U.S. Geological Survey Bulletin 2146-M, p. 211-215.
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Crysdale, B.L., Schenk, C.J., and Meyer, R.F., 1992, **Tar sands and heavy oils; resources, recovery, and realism**, *in* Carter, L. M. H., ed., U.S. Geological Survey Research on Energy Resources--1992 Program and Abstracts Eighth V.E. McKelvey Forum on Mineral and Energy

Resources, Houston, TX, February 17-20, 1992: U.S. Geological Survey Circular 1074, p. 15-16. http://pubs.er.usgs.gov/pubs/cir/cir1074

Dolton, G.L., and Crovelli, R.A., 1997, **Assessment Methodology for Deep Natural Gas Resources, Chapter O,** *in* Dyman, T. S., Rice, D.D., and Wescott, P.A., eds., Geologic Controls of Deep Natural Gas Resources in the United States: U.S. Geological Survey Bulletin 2146-O, p. 233-239.
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Tight Gas Sandstone-Related Conferences (post October 2012)

AAPG: http://www.aapg.org

10-12 Dec 2012: AAPG GTW on Hydrocarbon Trapping Mechanisms in the Middle East, Ceylan InterContinental Hotel, Istanbul, Turkey.

28-30 Jan 2013: AAPG GTW on Fracture Monitoring Using Passive Seismic, Dubai, UAE.

25-27 Feb 2013: AAPG GTW on Geosteering & Well Placement, Sharm El Sheikh, Egypt.

26-27 Feb 2013: AAPG GTW on Solving Water Problems in Oil and Gas Production: New Technologies for Cost Savings and New Revenue Flows, Fort Worth, Texas, USA.

17-18 Apr 2013: AAPG GTW on ‘Code-Cracking’ of Asia’s Ultra-Low Permeability Reservoirs, Bali, Indonesia.

22-24 Apr 2013: AAPG GTW on Exploring and Producing Fractured Reservoirs in the Middle East, Dead Sea, Jordan.

19-22 May 2013: AAPG 2013 Annual Convention and Exhibition (ACE), Pittsburgh, Pennsylvania, USA; http://www.aapg.org/pittsburgh2013/index.cfm

06-09 Apr 2014: AAPG 2014 Annual Convention and Exhibition (ACE), Houston, Texas, USA;

31 May – 03 Jun 2015: AAPG 2015 Annual Convention and Exhibition (ACE), Denver, Colorado, USA;

19-22 Jun 2016: AAPG 2016 Annual Convention and Exhibition (ACE), Calgary, Alberta, Canada;

02-05 Apr 2017: AAPG 2017 Annual Convention and Exhibition (ACE), Houston, Texas, USA.

SPE: http//www.spe.org/events/

30 Oct – 1 Nov 2012: SPE Canadian Unconventional Resources Conference, Calgary, Alberta, Canada.

04-09 Nov 2012: SPE Forum, Novel Techniques for Reservoir Management, Santa Fe, New Mexico, Canada.

05-07 Nov 2012: SPE Workshop, Unconventional Gas Fracturing: Leveraging Experience from Success and Failure, Dubai, UAE.

05-07 Nov 2012: SPE Workshop, Produced Water Handling, Muscat, Oman.

05-07 Nov 2012: SPE Workshop, Complex Reservoir Fluids, Houston, Texas, USA.

06-Nov 2012 (0930 am EST), SPE Webinar, Nanotechnology Applications in Drilling Fluids.

07-08 Nov 2012: SPE Workshop, Hydraulic Fracturing in the Latin America Region, Opportunities and Challenges, Medellin, Colombia.

28 – 30 Jan 2013: SPE Unconventional Gas Conference and Exhibition, Muscat, Oman.

27-29 Jan 2014: SPE Unconventional Gas Conference and Exhibition, Manama, Bahrain.

Other

26-28 Mar 2013: International Petroleum Technology Conference (IPTC) 2013, Beijing International Convention Center (BICC), Beijing, China; http://www.iptcnet.org/2013/

12-14 Apr 2013: Unconventional Resources Technology Conference, SPE-AAPG-SEG, Colorado Convention Center, Denver, Colorado.

Tight-Gas Sandstone Weblinks

Alberta Energy Resources Conservation Board: http://www.ercb.ca
Alberta Geological Survey: www.ags.gov.ab.ca
BLM New Mexico, Texas, Oklahoma, Kansas: http://www.blm.gov.nm/st/ed.html
British Columbia Oil & Gas Commission:
http://www.empr.gov.bc.ca/OG/oilandgas/Pages/default.aspx
Bureau of Economic Geology: http://www.beg.utexas.edu/
Canadian Geoscience Council: http://www.geoscience.ca
Canadian Society of Exploration Geophysicists: http://www.cseg.ca/
Colorado BLM: http://www.blm.gov/co/st/en.html
Colorado Department of Natural Resources: http://dnr.state.co.us/
Colorado Division of Water Resources: http://water.state.co.us/
Colorado Geological Survey: http://geosurvey.state.co.us/
Colorado Oil & Gas Association: http://www.coga.org/
Colorado Oil & Gas Commission: http://oil-gas.state.co.us/
CSUR Canadian Society of Unconventional Resources: http://www.csur.ca/
East Texas Geological Society: http://www.easttexasgeo.com/publications.asp
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Energy Information Administration http://www.eia.doe.gov/
European Association of Geoscientists and Engineers: http://eage.org/index.php
Gas Technology Institute: http://www.gastechnology.org/
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Jonah Interagency Mitigation Office: http://www.wy.blm.gov/jonah_office/index.htm
Louisiana Department of Natural Resources: http://dnr.louisiana.gov/
Louisiana Geological Survey: http://www.lgs.lsu.edu/
Louisiana Mid-Continent Oil and Gas Association: http://www.lmoga.com/
Natural Resources Canada: http://www.nrcan-rncan.gc.ca/com/index-eng.php
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Texas Independent Producers and Royalty Owners Association: http://www.tipro.org/
U.S. Dept. of Energy Office of Scientific and Technical Information: http://www.osti.gov/
University of Wyoming Geology & Geophysics: http://home.gg.uwyo.edu/

Wyoming BLM: http://www.blm.gov/wy/st/en.html
Wyoming Department of Environmental Quality: http://deq.state.wy.us/
Wyoming Geological Association: http://www.wyogeo.org/
Wyoming Oil and Gas Commission: http://wogcc.state.wy.us/
Wyoming State Geological Survey: http://www.wsgs.uwyo.edu/