TECHNOLOGY CONNECTIONS
PETROLEUM TECHNOLOGY TRANSFER COUNCIL

2000 BASIN-CENTERED GAS SYMPOSIUM

BOTTOM LINE

Basin-centered gas production from "unconventional" tight sands is a huge resource that, if developed, could significantly revive onshore exploration in the United States.

PROBLEM ADDRESSED

It is becoming critical that the U.S. industry more fully develops the Nation's large "unconventional" gas resources. At present about 15% of the U.S. total gas production is from "unconventional" basin-centered (synclinal) gas resources. Basin-centered gas production is in its infancy, but will increase as more explorationists become aware of this enormous gas resource. More effective exploration and exploitation strategies will be necessary in the near future to meet the increasing emphasis on this resource. This symposium was presented to increase the industry's knowledge of basin-centered gas systems and to stimulate new exploration ideas.

KEY WORDS:
Abnormal Pressure
Basin-Centered Gas Systems
Pressure & Hydrocarbon Cells
Tight Gas Sands
Unconventional Gas Reservoirs

TECHNOLOGY OVERVIEW

Industry analysts predict that present U.S. gas consumption of 22 TCF per year will double by 2020. Increased gas production to meet these increased needs must come from the U.S. and Canada because it can't be carried by tanker or transported across the deep oceans by pipelines.

Based on a symposium co-sponsored by PTTC's Rocky Mountain Region, the Rocky Mountain Association of Geologists and the Gas Technology Institute on October 6, 2000, in Denver, Colorado.

SPEAKERS:

What is a Basin-Centered Gas System?
B. E. Law, Pangea Hydrocarbon Exploration, LLC

The Spatial Relationships of Basin-Centered Gas Cells, Pressure Cells and Lithologic Surfaces in the Rocky Mountain Region, Canada and U.S
John R. Forster, The Wetterhorn Co.

A Review of the Natural Gas Petroleum Systems, Known or Hypothesized, of the Uinta Basin
Logan MacMillan, Litmus EPO, LLC

Causes of Anomalous Deep Basin Fluid Pressure in Rocky Mountain Basins and their Relation to Regional Gas Accumulation
Fred Meissner, Consultant

A New Game: New Concepts are Needed for Onshore U.S. Exploration
John A. Masters, Direct Detection Experts, LLC

New Perspectives on Basin-Centered Gas from Horizontal Drilling, Frontier Formation, SW Wyoming
Lee F. Krystinik, Krystinik Litho-Logic

For the past 150 years the U.S. industry has been content with what was found using oil seeps, anticlinal buoyancy theory and seismic. At this symposium John Masters said that all of these concepts are now obsolete. We face a Revolution dictated by doubling of gas demand, dependency on U.S. onshore gas, old traps have been discovered and/or depleted, new onshore gas is largely in basin-centered fields, and that known large basin-centered fields have so far been found largely by luck with very little science involved.

What Is A Basin-Centered Gas System?

Part of the reason for inaccurate production data for all basin-centered gas accumulations (BCGAs) in the U.S. is the generally poor knowledge of the definition of a BCGA. Understanding the definition and attributes of basin-centered gas systems (BCGSs) will raise levels of awareness and increase exploration effectiveness. BGCAs are a component of BCGSs that Law defines as "an abnormally-pressured, gas-saturated accumulation in low-permeability reservoirs lacking a down-dip water contact". Although "tight gas sands" are an important type of basin-centered gas reservoir, not all of them are BCGAs.

Attributes common to BCGSs include:

- Regionally pervasive gas accumulations
- Reservoirs may be single and isolated or vertically stacked
- Abnormally-pressured (over- or under-pressured)
- Gas accumulations are down-dip from normally-pressured, water-bearing reservoirs
- Gas accumulations do not have down-dip water contacts
- Low permeability (<1.0 md)

- Porosity < 13%
- Gas–saturated reservoirs
- Gas of thermal origin
- Water most often present as irreducible water
- Thick, regionally pervasive accumulations commonly contain interbedded water-bearing reservoirs

There are two basic types of BCGSs: direct and indirect. A direct type is defined as having a gas-prone source rock while an indirect type is defined as having an oil-prone source rock.

Attributes of direct and indirect BCGSs include:

Attributes Of Direct BCGS
Gas-prone source rock
Pressure mechanism-hydrocarbon generation
Under-/over-pressured
Relative permeability/capillary block seal
Variable temporal integrity of seal
Top cuts across structural/stratigraphic boundaries
Gas migrates short distances
Top Of BCGA Commonly >0.7% Ro

Attributes Of Indirect BCGS
Oil-prone source rock
Pressure mechanism - oil cracking
More likely under-pressured
Lithologic seal
Long temporal integrity of seal
Top conformable with bedding
Gas migration distances can be short or long
Top of BCGA >1.3-1.4 Ro

The differences in attributes for *direct* or *indirect* type BCGSs have implications for design of exploration strategies. For example, burial and thermal history reconstructions are much more important in the exploration for *indirect* BCGAs than when exploring for *direct* BCGAs. Because of the important role of structure and stratigraphy in the accumulation of indirect BCGAs, it is essential to determine the temporal relationships among hydrocarbon generation, expulsion, migration and trap formation. At this time there are more *direct* than *indirect* BCGSs. This may be because the *indirect* types have not yet been adequately explored for.

Spatial Relationships of Basin-Centered Gas Cells, Pressure Cells and Lithologic Surfaces in the Rocky Mountain Region, Canada and US

Cells and Surfaces

With the development of each new exploration method, from surface mapping to subsurface methods and eventually to 3–D seismic programs, significant new discoveries were made. Now, the mapping of pressure and hydrocarbon cells that crosscut stratigraphic surfaces are producing the "next generation" of hydrocarbon discoveries.

Pressure and Hydrocarbon Cells

Only recently has the concept of large, stratigraphically independent, hydrocarbon accumulations been accepted. If sufficient data were available, every hydrocarbon accumulation could be visualized as a three dimensional body with transitional edges, a fuzzy envelope of hydrocarbons. Isolated, stratigraphically–bound accumulations may actually be producing zones in a much larger hydrocarbon saturated system. These systems are referred to as BCGAs or hydrocarbon cells.

Hydrocarbon plumes and pressure cells are three-dimensional bodies defined as a significant variation in fluid content or pressure value from an expected regional norm. The hydrostatic pressure gradient and presence of interstitial subsurface water are the expected norms. Hydrocarbon and pressure cells have shape with a top, a base and an internal distribution. Visualization of cells is aided by referring to them as plumes, which reflects their irregular shape. The actual shape of a hydrocarbon plume is a function of the hydrocarbon source, rate of hydrocarbon generation, regional tectonic configuration, pressure domains and distribution of permeability zones. The shape of the cell, therefore, is the result of a dynamic system involving the generation of hydrocarbons and the ability of the local geologic system to dissipate the hydrocarbons generated.

Mapping Methods

Mud logs, drill stem test recoveries and production figures all can be applied to the definition of hydrocarbon cells. The first indication of subsurface hydrocarbons appears as produced gas while drilling and is reported as gas or oil flowing to the surface or as mud gas detected in mud logging procedures.

By applying a fluid ratio cut-off, the depth to a hydrocarbon plume can be determined. Similarly, applying a pressure gradient cutoff can generate the topology of a pressure cell. Production data should be used to support the concept, and gas-to-water ratios should remain high in a basin-centered gas accumulation. Boundaries between the structural, reservoir and stratigraphically independent subsurface properties, such as hydrocarbon/pressure cell surfaces, define the hydrocarbon accumulation. Computer visualization software is required to co-locate the multiple surfaces and define trapped hydrocarbons.

Rocky Mountain Regional Considerations:

Uinta Basin Natural Gas Petroleum System

Seven unconventional (continuous type) natural gas plays have been characterized in the Uinta Basin. These resources have characteristics of BCGAs, including low matrix permeability, areally-large deposits, limited water production from gas intervals, lack of obvious trap or seal, close association with source rocks and regional hydrocarbon structural relationships commonly described as "water over gas". The plays include Tight Gas Uinta Tertiary East, Tight Gas Uinta Tertiary West, Basin Flank Uinta Mesaverde, Deep Synclinal Uinta Mesaverde, Uinta Basin Book Cliffs, Uinta Basin Sego and Uinta Basin Emery.

Distinction between each of the plays as well as distinction between them and updip, conventional resources are often better explained conceptually than with field data. Causes for lack of distinction are "tight" data, commingling of production, infrastructure bottlenecks, completion techniques and failure to recognize subtle stratigraphic intervals, gas shows and variable reservoir water resistivities.

The largest field in the basin, Greater Altamont-Bluebell, is in the deepest part of the basin where BCGSs might be expected. This field meets all of the criteria for being a BCGS except for water being produced throughout the producing section and the stratigraphic trapping. These anomalous conditions may be explained by the relationship between source rock, reservoir facies and the lack of migration of much of the generated oil and gas. A more typical BCGS may exist below the field in the fluvial channel-form sandstones in the Wasatch and North Horn formations and the Mesaverde Group. This system would be based on gas derived from coals of the Mesaverde Group.

Causes Of Anomalous Deep Basin Fluid Pressures In Rocky Mountain Basins

The major processes associated with deep basin hydrocarbon accumulation are related to hydrocarbon generation and accumulation dissipation. In two contrasting cases, anomalously pressured sediments are present in the Upper Cretaceous Mesaverde Group.

Anomalously high pressures in the Mesaverde section of the Eastern Green River Basin are related to current active gas generation in contained coals. Hydrocarbon generation initiated in the Lower Tertiary Overpressure is basically caused by two volume changing processes: shrinkage of maturing kerogen accompanied by creation of compactable non-equilibrium porosity and creation of fluid hydrocarbons whose volume exceeds both original and created porosity. Pressure is maintained in the bottom of the basin by a rate of generation and reservoir charge that exceeds the migrational rate capacity of the system as controlled by the capillary entry pressure of confining non-source rocks. Hydrocarbon generation overpressures have created hydraulically induced fractures that have enhanced the low matrix permeability of nearby sandstone reservoir rocks.

Gas generation from coals in the Mesaverde Group of the San Juan Basin took place during a Middle Tertiary heating event and is not presently active. Anomalously under-pressured deep basin gas is primarily related to the imbibition of updip water as gas is being lost from a dynamic (originally over-pressured) deep basin. Hydrodynamic conditions indicate that gas loss is not occurring in an updip direction. Gas is most likely being lost vertically upward through the caprock by either low-rate continuous-phase flow or "leakage," according to Darcy's Law, or by solution and diffusion in groundwater according to Fick's Law.

The pressure conditions present in these two example basins may represent a cycle of gas charge and discharge in deep basin reservoirs. The existence of anomalously-pressured dynamic hydrocarbon accumulations in unsealed regional synclinal positions does not fit well with standard trap classification schemes and requires the addition of new classes.

New Perspectives On Basin-Centered Gas From Horizontal Drilling, Frontier Formation, SW Wyoming

The Greater Green River Basin Production Improvement Project (GGRBPIP) is a multi-year partnership between the oil and gas industry and the U.S. Department of Energy's Federal Energy Technology Center (FETC), now the National Energy Technology Laboratory (NETL).

Results of the GGRBPIP drilling effort have resulted in a number of observations about basin-centered gas from the Frontier Formation of SW Wyoming, including:

- The Frontier Formation reservoir appears to be divided into a number of isolated pressure cells.
- The matrix sandstone appears to be regionally gas saturated.
- Large numbers of open fractures can occur along large linear, strike-slip or shear faults.
- These fractures can be highly productive of gas or water
- Open and productive fractures appear to be related to shear reactivation.
- Water production is related to structural position (gas above water) within each pressure cell.
- Water production, where encountered, does not appear to suggest an infinite aquifer.

Log, core and production test data from an offsetting well, combined with regional 3-D seismic data were critical to site selection for the horizontal well (RI 4-H). The over 400 open fractures intersected in a 1,750 ft long horizontal leg contributed to production being more than 14 MMCF/D. Cores from the horizontal leg indicate two sets of differentially mineralized, nearly orthogonal, vertical fractures. The numerically subordinate N-S striking fracture set may play a local role in connecting the dominant open E-W set. Unfractured gaps documented in the horizontal core greatly increase the risk of a vertical well missing the fracture system. Local reactivation of shear related to motion along a nearby Laramide, right-lateral wrench fault appears to be the key to creating significant fracture permeability.

Many of the fractures may be filled with water under initial reservoir conditions. The fractures are permeable to water as well as natural gas. It is likely that gas and water in varying ratios will occur in association with other fault/fracture pressure cells in the Frontier Formation. It is possible that producing water from a fracture system of limited extent might allow economic quantities of gas to flow from the gas-saturated matrix sandstone, in a fashion similar to dewatering coal bed methane wells.

Lessons Learned

The future for exploration cannot be with the familiar, conventional anticlinal and stratigraphic buoyancy traps. In the U.S. most of these traps have been discovered. All of the major companies agree with that conclusion and have shifted their investment to the Gulf and Overseas.

New onshore gas will largely be from basin-centered gas systems. At present most basin-centered gas fields have the following parameters: thermal gas, sandstone reservoirs, Cretaceous age, gas shows, permeability less than 3 md, are widely fractured requiring fracs for commercial production, are synclinal or on basin flanks and are roughly parallel to strike, are downdip from water, and can be large to extremely large. Exploration competency in the new basin-centered fields will require more flexibility and more highly-experienced subsurface technical expertise than was necessary for discovering fields related to buoyant traps.

For information on PTTC's Rocky Mountain Region and its activities contact:

Sandra Mark, Director, Colorado School of Mines
Department of Geology and Geological Engineering, Golden, CO 80401-1887
ph 303-273-3107, fax 303-273-3859, e-mail smark.95@alum.mines.edu

CONNECTIONS:

Ben E. Law
Pangea Hydrocarbon Exploration, LLC
12343 W. Louisiana Avenue
Lakewood, CO 80228
Phone: 303-989-7252, Fax: 303-989-7252
E-mail: BELAW@worldnet.att.net

John R. Forster
The Wetterhorn Co.
7450 S. Harrison Way, Suite 100
Littleton, CO 80122
Phone: 303-771-9640, e-mail: jforster@4dvision.net

Logan MacMillan
IPAMS
518 16th Street, Suite 620
Denver, CO 80202
Phone: 303-623-0987, Fax: 303-893-0709
E-mail: lmacmillan@ipams.org

Fred F. Meissner
Consultant
7080 Fillmore Ct.
Littleton, CO 80122
Phone: 303-892-6509, Fax: 720-528-8430
E-mail: TYKEMEIS@cs.com

John A. Masters
Direct Detection Experts, LLC
5335 West 48th Ave. Suite 300
Lakewood, CO 80033
Phone: 303-480-0880, e-mail: NowyP@Frontier-risk.com

Lee F. Krystinik
Krystinik Litho-Logic
3825 W. 4th Street
Fort Worth, TX 76107
Phone: 817-735-9584, e-mail: amethyst@fastlane.net

The not-for-profit Petroleum Technology Transfer Council is funded primarily by the US Department of Energy's Office of Fossil Energy, with additional funding from universities, state geological surveys, several state governments, and industry donations.

Petroleum Technology Transfer Council, 2916 West T. C. Jester, Suite 103, Houston, TX 77018
toll-free 1-888-THE-PTTC; fax 713-688-0935; e-mail hq@pttc.org; web www.pttc.org