COLORADO GEOLOGICAL SURVEY

ROCK TALK

VOLUME THREE, NUMBER THREE JULY, 2000

COALBED METHANE—COLORADO'S WORLD CLASS COMMODITY

A story of turning a dangerous and sometimes deadly byproduct of coal mining into a useful and environmentally friendly energy source.

Prior to the nineteenth century, wood was humankind's primary source of thermal energy. But wood could not efficiently supply the great amount of thermal energy required to fire blast furnaces, smelters, steam locomotives, and other large facilities—the sort of facilities and machines that increasingly dominated America's industrial growth. Coal could. A relatively modest pile of coal could supply the same amount of energy as a giant stack of wood.

In the early 1800s, Americans burned coal in small amounts—usually as a domestic fuel. As the pace of industrialization quickened, America's appetite for coal grew more ravenous. In the three decades from 1800 to 1830, America's annual coal production increased tenfold, from about 100,000 tons to one million tons. But that was just the beginning. By 1885, the nation mined 110 million tons each year. By 1900, the figure had more than doubled to 243 million tons a year. Currently, as we move into the 21st century, the nation's annual coal production has risen to more than 1,100 million tons a year.

The majority of America's coal in the early part of the industrial revolution came from the Appalachian Mountains. Colorado did not become a coal producer until the 1870s. By 1900, Colorado production was nearly 7.5 million tons a year. Nearly half of that production was used in the CF&I Steel Mill in Pueblo, which was built in 1880 by General William Palmer, the founder of the Denver & Rio Grande Railroad. Currently, Colorado produces approximately 30 million tons of coal annually.

Usage of mined coal has changed since the nineteenth century from being an important component in the production of steel to generating electricity by burning the coal in boilers to run stream driven turbines. Electric utilities now consume about 90 percent of the nation's annual coal output.

Underground mining for any commodity has always been a risky activity, especially in the early 19th and 20th centuries. Injury and loss of life from underground rock fall, fire, mishandling of explosives, accidents with mining tools and machines, and "bad" air was an all too common occurrence.

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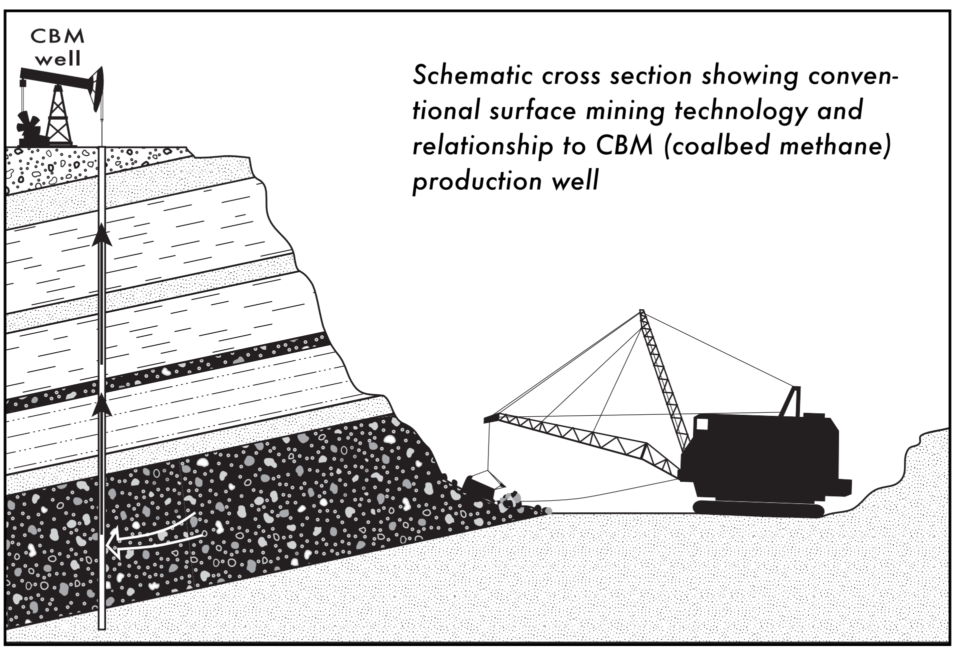
Focus on Coalbed Methane



Schematic cross section showing conventional surface mining technology and relationship to CBM (coalbed methane) production well

Field Notes from the Director

Colorado's Coalbed Methane (CBM) is the topic of this quarter's *RockTalk*. With increased natural gas prices, increased CBM production, and residential growth increasing in areas where natural gas production occurs, coalbed methane is a topic of great interest to Colorado's gas and oil companies, state and local planners and regulators, and citizens.

Estimates from the National Petroleum Council indicate that as a nation, our demand for natural gas will increase from 22 trillion cubic feet (TCF) to 30 TCF in the next decade. Consumption of natural gas within Colorado in 1998 totaled 312 billion cubic feet (bcf). Colorado produced 705 bcf that same year, meaning our state consumed about 44 percent of our production. Colorado ranks 6th in the nation in terms of dry gas production.

For a variety of reasons including geologic and market conditions, natural gas has become the most important part of the gas and oil industry within Colorado, and CBM dominates the natural gas picture. From 1988 until 1999, natural gas production in Colorado steadily increased, while oil production

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COLORADO'S HOT COMMODITY cont. from p. 1

Underground coal mining undoubtedly has suffered the heaviest human toll over other mining commodities such as gold, silver, precious stones, copper, etc. because of an additional hazard unique to coal: storage of highly explosive methane gas in the micropore structure of coal seams. The release of methane from coal in underground coal mines and the consequent explosion of this gas has resulted in horrific losses of life. One particular example occurred in 1910 when a methane explosion in the Primero Mine, located some twenty miles west of Trinidad, Colorado, killed more than 100 men.

United States private industry and government in the late 1960s, both individually and collectively, initiated research programs directed toward making coal mining safer by developing methods of de-gassing coal seams prior to mining. These early pilot programs carried out in the Midwest and Appalachia eventually turned a "lemon into lemonade."

By using standard oil and gas field recovery and production technologies, this dangerous coal gas (mostly high quality methane) could be recovered and utilized. Industry, particularly Amoco Production Company (now BP-Amoco) initiated programs to develop methane gas from subsurface coal seams in several of the nation's sedimentary basins regardless of mining activity associated with the coalbed sequence. Because of Amoco's pioneering efforts, the San Juan Basin of southwestern Colorado and northwestern New Mexico eventually became the "Crown Jewel" in coalbed methane (CBM) production. This basin's production stream of CBM gas outshines the rest of the world's sedimentary basins in CBM production.

CBM extraction has, in 30 years, changed primarily from a mine safety matter into a significant factor in both U.S. natural gas production and gas reserve base. Currently, CBM accounts for about 7 percent of U.S. dry natural gas production.

Colorado CBM production totaled about 390 billion cubic feet in 1999, which placed Colorado in second place nationally behind New Mexico's 570 billion cubic feet. By way of perspective, U.S. natural gas production totaled nearly 19,000 billion cubic feet in 1999. The Gulf of Mexico Federal Offshore and the State of Texas were the nation's leading producers of natural gas with volumes respectively of about 4,800 billion cubic feet each.

The majority of Colorado's CBM production has come from Fruitland Formation coal seams (Upper Cretaceous in age) in the San Juan Basin. In recent years, CBM gas production has also expanded significantly in the Colorado portion of the Raton Basin of south central Colorado and northeast New Mexico.

Did You Know?

The "natural gas" delivered to Colorado's homes, retail businesses, and industries is actually a mixture of hydrocarbon gases composed almost entirely of methane, but containing small amounts of other heavier hydrocarbon gases, including ethane, propane, butane and pentane. Methane is composed of a molecule of one carbon atom and four hydrogen atoms (CH_4).

HOW COAL IS FORMED

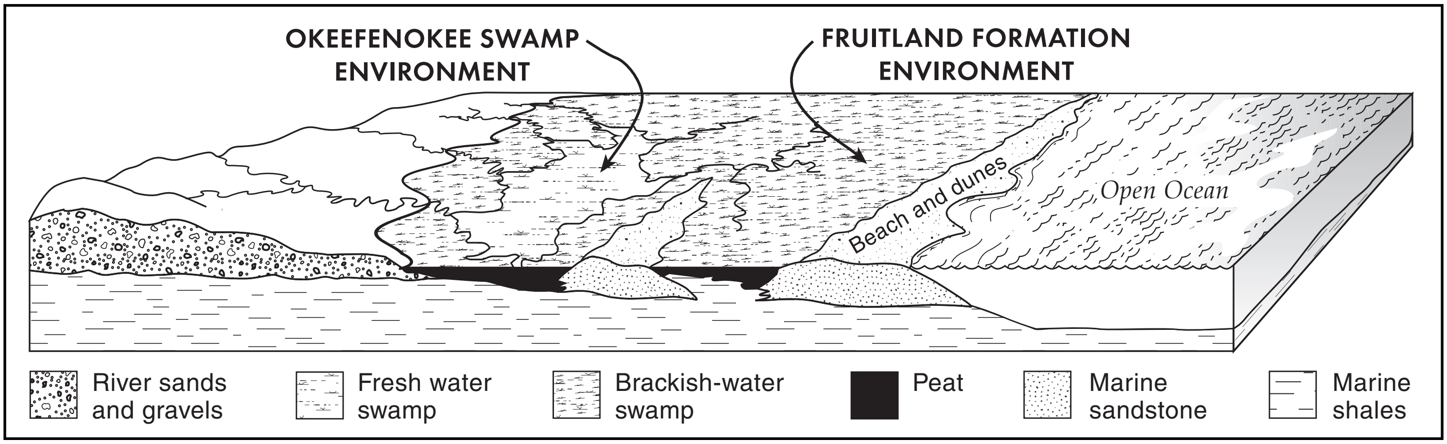
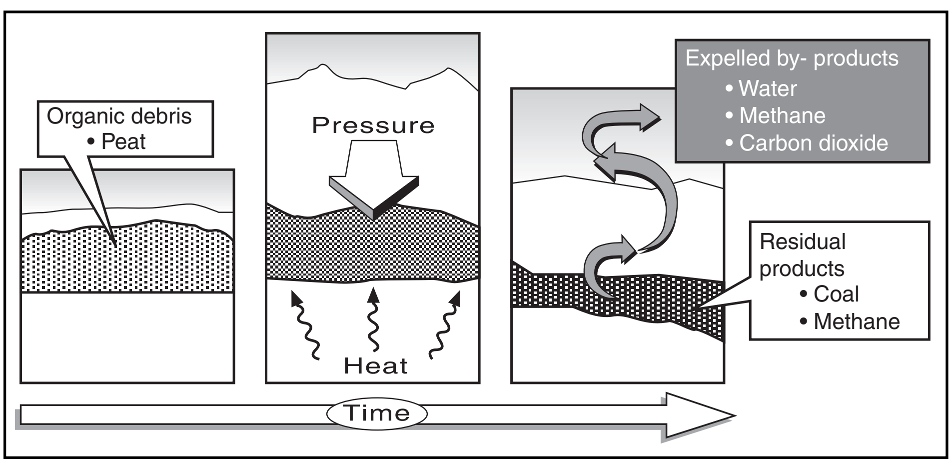


Diagram of a swamp showing peat, sand and shale accumulations in a cross section view

Coals are derived from ancient peat deposits that formed in both fresh water and brackish-water swamps (above). A wide range of vegetation such as trees, shrubs, grasses and other plants thrives in swampy or marshy areas. The continuous accumulation of this vegetation in the swamps eventually forms peat. When peat is buried by thousands of feet of overlying rock layers such as sands and muds, a process which can take millions of years, it is converted to coal with the aid of elevated geothermal temperatures and burial pressures. These conversion processes compact the vegetative layers, driving off water and enhancing the transformation of some organic material into gases, specifically methane and carbon dioxide (below). The original peat composition becomes more depleted in hydrogen and oxygen while the relative concentration of carbon increases (graph, p. 4). This transformation causes the original peat to become more dense, harder, and enriched in carbon over time because of increased geothermal temperature and burial pressure. Each coal designation (lignite, bituminous, and anthracite) relates to the depth of burial and associated pressure and temperature regime of the original peat accumulation.



Formation of coal from peat over time by heat and pressure

Modified from Ayers et al., 1990

"Snapshot in time" of active coal swamp facies from drawing of Colorado coal swamp of 80 million years ago Braginetz from SP 35

Most of Colorado's abundant coal deposits were formed in coastal swamps along the western edge of an extensive inland sea approximately 50 to 70 million years ago during Late Cretaceous and early Tertiary times (map, p. 4). When we think about modern-day swamps, we look at

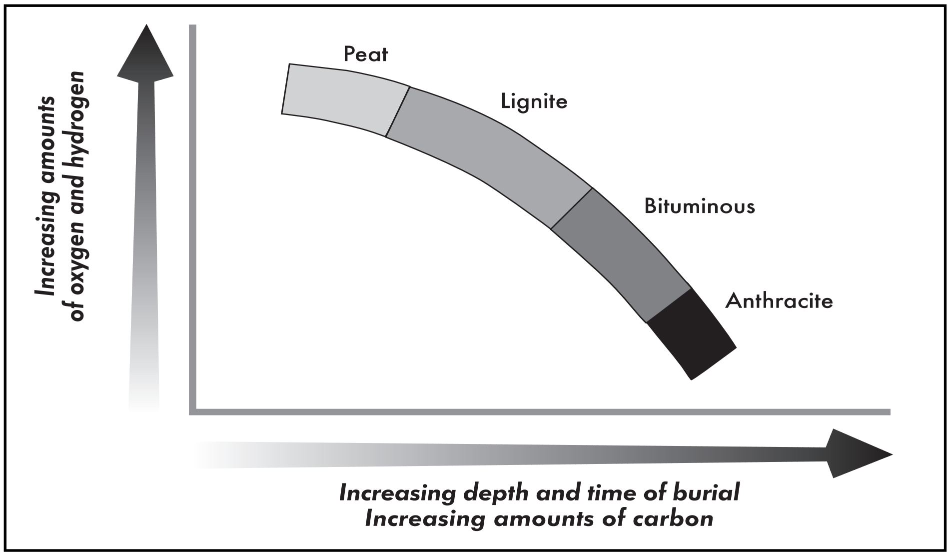
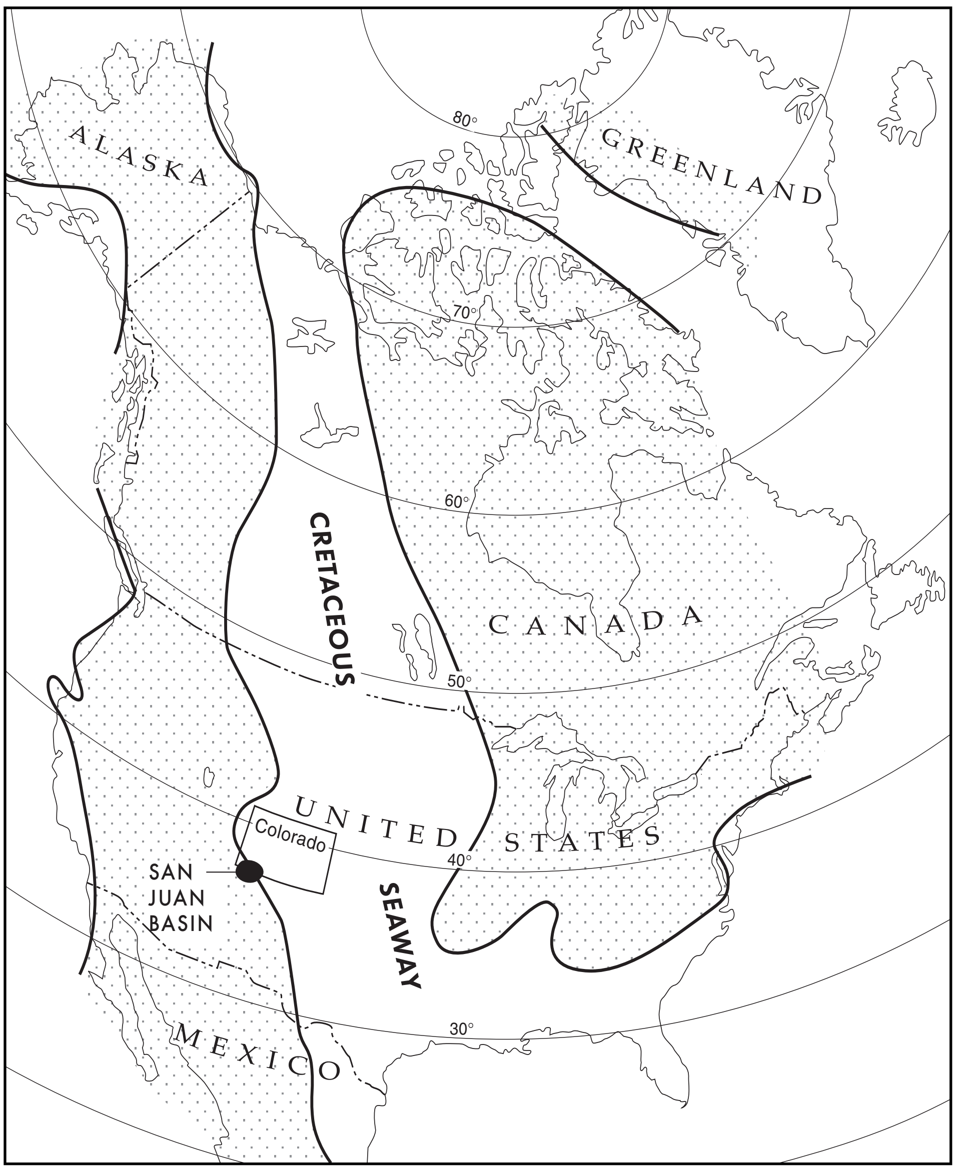


Diagram showing the change in elemental composition of coal during burial



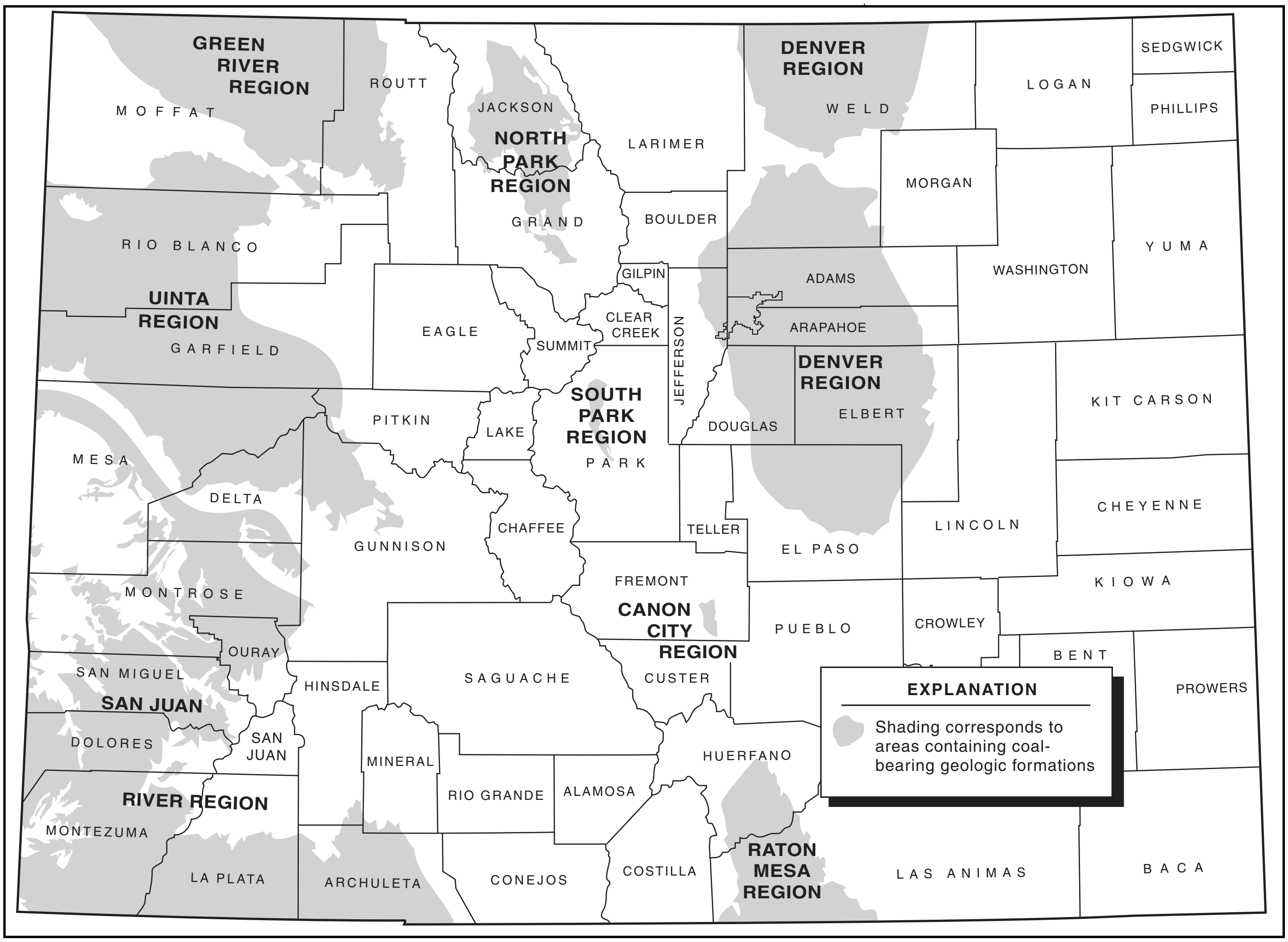
Paleogeographic map of the Late Cretaceous Seaway in North America

the Okeefenokee Swamp in Florida as a prime peat-producing environment. Colorado coals were formed in swamps much closer to the shoreline than the Okeefenokee Swamp is to the Atlantic Ocean (see drawing of swamp on p. 3). The paleogeography (ancient geography) was markedly different then from what it is today. One of the reasons we know that is because of the extensive coal deposits that exist in the state. Back then, vast areas of temperate climate coastal swamps flourished for several million years along the western edge of a shallow marine sea that covered central North America from northern Canada to southern Mexico (lower left). Present day Colorado and the other Rocky Mountain states are situated along the former shoreline swamps and shallow seas. Those swamps produced the ancient peat deposits that are today's coal fields in Colorado (map, p. 5).

HOW METHANE IS STORED IN THE COALS

Most of the methane in coals is adsorbed or attached inside the micropore spaces or microscopic holes in the coal. Water contained within the fractures (cleats) exerts pressure on the adsorbed methane, keeping it from moving out of these micropores into the fractures or cleats in the coal. By removing a large volume of the water in the coal, the methane gas is free to desorb or move from the coal micropores to the cleats where it can flow more freely through the coal (diagram, p. 5).

Many conventional gas reservoirs—those found in sandstones or limestones—have the potential to produce gas almost immediately



Colorado coal regions

once they have been drilled and completed properly if they contain very little water. The measure of a good conventional gas reservoir is the quantity of gas that will be produced in a given amount of time. Some conventional gas reservoirs do have water in them. The greater the amount of water, the less efficient the gas production will be, because the water inhibits the flow of gas. The water also has to be collected, separated from the gas, and disposed of in some manner, thus adding to production costs.

CBM reservoirs are different in most cases. Large volumes of water exerting the pressure necessary to keep methane adsorbed or confined in the coal micropores must be removed from the coal before the methane itself is finally

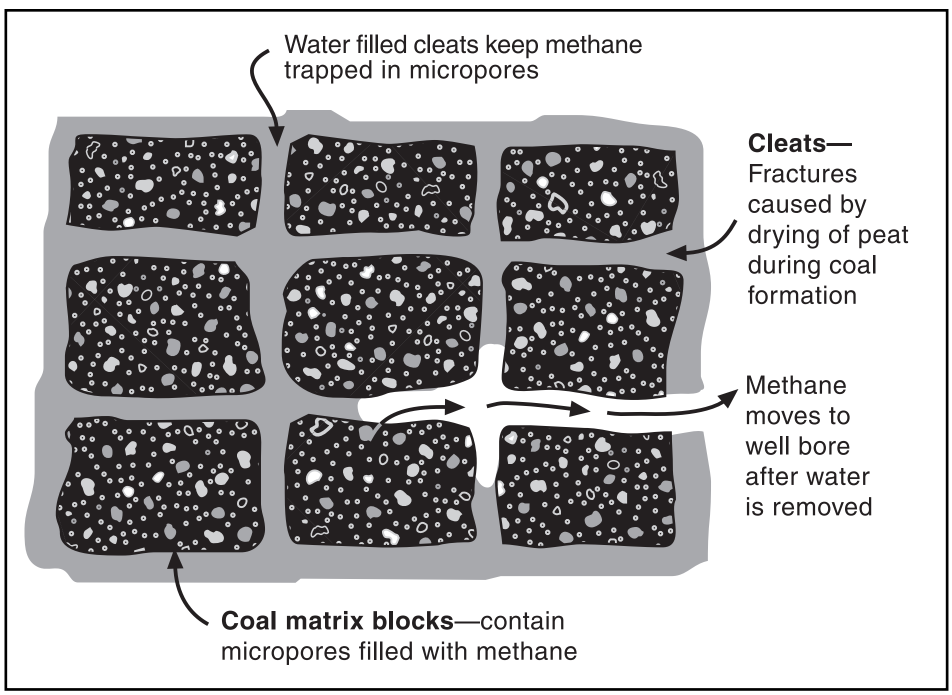


Diagram showing methane gas recovery from coal

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Open-File Report 80-2
Deep Coal Bed Methane Potential of the San Juan River Coal Region, Southwestern Colorado $30.00

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CBM well surface equipment

free to flow. The water has to be pumped from the coal using the familiar pumpjack surface equipment (shown in left of center in photo above). Pumps are needed to lift significant amounts of water "uphill" to the ground surface, which can be as much as 4,000 feet above the producing coals. Once a significant amount of water has been pumped out of the coals, the gas will flow by itself to the surface where it is transported to market via a pipeline (center right in photo above).

Though often produced in large quantities at the beginning of a well's life, the amount of water pumped from a coalbed reservoir will generally decrease over time during all three stages of the life of a coalbed methane well as shown in the graph below. If there is a sufficient amount of methane stored within the coal, the volumes of methane gas being produced will increase over time during the dewatering and stable production stages of the typical well. At some future time, the

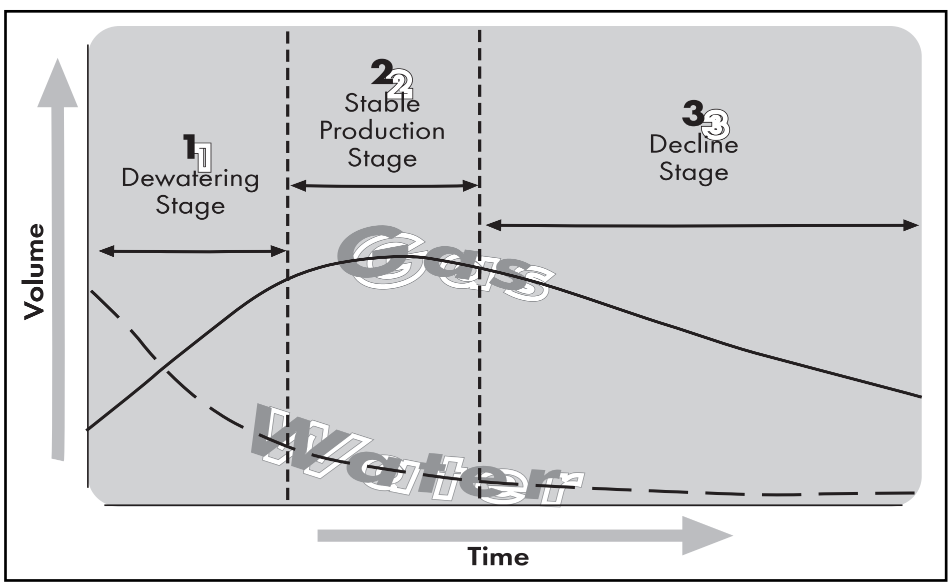
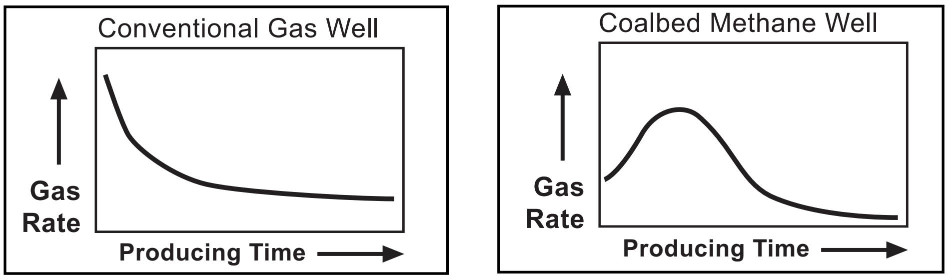


Diagram showing production stages of a typical coalbed methane well
From Kuuskraa, 1990

amount of recoverable methane in the reservoir will decrease and production will decline steadily to the economic limit of the well. This is represented as the decline stage in the diagram on p. 6. This production profile of a CBM well is the reverse of what it is for most conventional gas wells in which the methane or gas production rate begins at its highest point after the well is completed and progresses through a steady decline throughout the life of the well (below). It is easy to understand why it is difficult to estimate the gas rate profile for a CBM well when the initial production rates for gas are low and production rates for water are high. The actual volume of gas that will be produced, as well the length of time for which that rate continues can vary substantially in CBM wells.



Gas recovery:conventional vs coalbed

Most U.S. natural gas is produced, sometimes along with oil, by drilling in the earth's crust into pockets of porous rocks, usually sandstone, limestone or dolomite, where natural gas was trapped thousands to millions of years ago. The gas trapped in subsurface coalbeds compositionally differs somewhat from "conventional" natural gas accumulations. The hydrocarbon component of coalbed gas is almost always pure methane. "Conventional" natural gas reservoirs often contain significant amounts of the heavier hydrocarbon gases.

Colorado's Coalbed Methane Contribution

In 1993, coalbed methane represented about 3 percent of the nation's total gas production. At present, coalbed methane production has grown to about 7 percent of U.S. natural gas production. Colorado's coalbed methane production in 1993 totaled about 125 billion cubic feet, about 17 percent of this component of the nation's total gas production. In 1999, Colorado's production of nearly 390 billion cubic feet of coalbed methane represented a 35 percent contribution. Clearly these numbers indicate Colorado's growing importance to the national energy equation as a source of clean burning natural gas.

Field Notes continued from page 2

has been steady or slightly decreasing. In 1998, CBM made up about 54.5 percent of Colorado's total gas production. According to national figures, about 56 percent of the total supply of proven coalbed methane reserves in the lower 48 states are located in the San Juan Basin. This important basin, much of which is located within the borders of Colorado, is truly a world class gas basin. Recently, new natural gas pipeline developments are also allowing Raton Basin CBM to reach consumers.

Production of CBM is not without its difficulties. As you'll read here, CBM has long been a safety hazard to coal miners. Developing our CBM resources required new ways of thinking about exploration and production techniques. Predicting and managing CBM is different than conventional oil and gas drilling. And throughout Colorado CBM behaves as a natural geologic hazard.

The Colorado Geological Survey (CGS) studies coalbed methane for a variety of reasons. In 1994, CGS released a statewide alert to citizens about coalbed methane as a geological hazard, since approximately one-third of the state is underlain by coal. The CBM does escape from shallow coal seams and this colorless, odorless, and non-toxic gas can be explosive if it is trapped by structures on the seeping outcrop. Historic reports of active CBM seeps go back decades in many places in Colorado.

CGS has been active in CBM studies since 1978, when our earliest CBM publications reported on mine-gas emissions and explosions. Subsequent gas content measurements of coal core samples helped document an in-place CBM resource that is greater than 100 TCF. CGS studies continue today to help delineate the detailed structure of the San Juan and other CBM basins, and to assist state and local government officials as well as industry and citizen workers who are trying to safely produce CBM.

SAN JUAN BASIN—BIRTHPLACE OF COALBED METHANE PRODUCTION IN COLORADO

The San Juan Basin of southwest Colorado and northwest New Mexico is a natural resource mecca for coal and coalbed methane. Most of the economically important coalbeds in this basin are in the Late Cretaceous-age Fruitland Formation. High-quality coal has been mined at or near the surface since the late 1800s. For as long as the mines were operated, the deadly presence of methane in the coal caused coal mine explosions resulting in loss of human life and property damage.

The earliest reference to CBM in the San Juan Basin is from an 1892 article in the *Durango Board of Trade* that states that Professor Arthur Lakes of the Colorado School of Mines recognized coal oil and natural gas within four miles of Durango. Lake was instrumental in causing the first petroleum well to be drilled between 1890 and 1900 near Durango. After the well reached a depth of 1,500 feet, drilling equipment was lost in the hole and the investors ran out of money, putting an abrupt end to that well. (Emery C. Arnold and Thomas A. Dugan, 1971, *Western Oil Reporter*, August, 1971, p. 24). In 1902, gas was discovered in a well just outside of Durango at a depth of 940 feet, possibly from the Fruitland Formation coals. (Amoco Production Company, 1994, Pine River Fruitland Coal Outcrop Investigation, p. 1). The well probably was never produced commercially.

While fledgling gas and oil wells were being drilled, coal mining continued to grab the media headlines. Mine explosions and fires were common and many miners lost their lives from deadly methane buildups in the mines both in the San Juan Basin mines as well as in mines throughout the rest of Colorado. One report from the *Bayfield Blade* on January 11, 1924 is particularly significant in terms of an early recognition of the potential value of this methane. The article reported that a "gas gusher" measuring one million cubic feet of gas per day rushed out of the Tendick Mine located approximately 10 miles northeast of Bayfield. This gusher was initiated after a dynamite shot was detonated about 200 feet inside the mine in a seam of coal. The roar from the rush of gas exiting the mine could be heard over a half a mile away. The article acknowledged the flow as methane gas, a source for lighting and heating, but was particularly prescient in this quote: "...if the heavy flow holds up and a way can be found to stop the flow, we will have a valuable resource in this natural gas."


Fruitland coal in the San Juan Basin with two monitoring wells

The earliest recorded CBM well, the Stanolind Oil and Gas Company Ute D-1 well, was drilled in 1951 just outside Ignacio, Colorado. The coals, distributed throughout 400 to 500 feet of the Fruitland Formation, were perforated through steel casing that was placed in the hole. Solidified nitroglycerine, packed in the hole at the depth of the Pictured Cliffs Sandstone, which underlies the Late Cretaceous Fruitland Formation coalbeds, was detonated to produce fractures. The initial flow rate reported from this discovery well was 1.9 million cubic feet of gas per day, which is a respectable initial rate for a CBM well. Unlike other wells in the basin, these early Fruitland CBM wells produced very little water initially. As the water production increased over time, the early wells were plugged because the costs of handling the water made the wells uneconomic with gas prices of $0.11

per thousand cubic feet. By comparison, today's prices in June 2000 vary between $3.25 and $4.00 per thousand cubic feet, allowing more monetary leeway in paying the costs for pumping and disposing of the water.

For over 20 years, the shallow gas targets were the sandstone and not the coals in the Fruitland Formation. Fruitland coals had been mined historically along the outcrop, but it would take some industry ingenuity and technology to recognize the potential of the coalbeds as methane-producers alone. Coal completions in subsurface wells were done only as a last resort or in combination with sandstone completions. The exploration seed for CBM from the actual coalbeds was sown again in 1977 by Stanolind's successor, Amoco Production Company. The Amoco Cahn Gas Com No. 1, drilled just over the border in New Mexico, was completed as a Fruitland Formation coalbed methane well. Although the well had an initial production rate of less than 100 thousand cubic feet of gas per day, an order of magnitude less than the Ute D-1, it was heralded as the CBM discovery well for the San Juan Basin because it demonstrated the potential for methane production solely from coalbeds. Ever since then, industry scientists have conducted extensive tests on the coalbeds, their gas content, and on methods to efficiently and economically produce the methane gas.

Today, the San Juan Basin in Colorado is undergoing another wave of CBM drilling, prompted by the increase in gas price and the recognition that more gas is stored in the coals than previously recognized. The largest producer to date, the Amoco Gardner A-1, has produced over 20 billion cubic feet of gas, a huge volume for a single domestic gas well. Total production from the coals in the Colorado portion of the San Juan Basin is about 2.1 trillion cubic feet of gas. By comparison, the next closest producing reservoir in the basin, developed by conventional gas wells, is the Mesaverde Formation, which has only produced about 712 billion cubic feet of gas, one-third the volume of the CBM production.

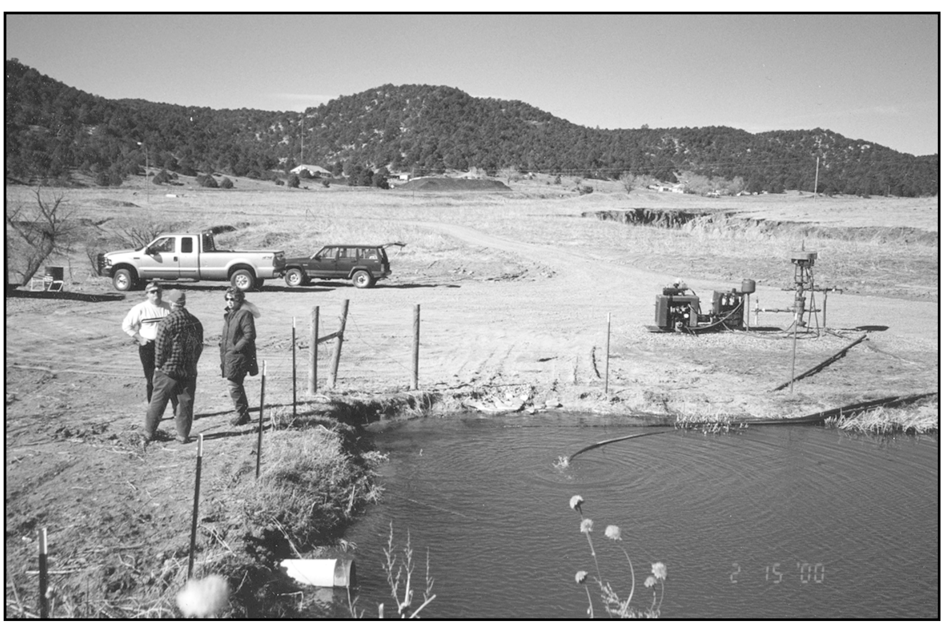
Estimates for CBM resources in the San Juan Basin of Colorado and New Mexico hover around 50 trillion cubic feet, of which Colorado may be expected to have 40 to 50 percent. Clearly, these resource numbers, coupled with record high gas prices, explain the feverish pace at which CBM wells are being drilled.

Colorado's second CBM success story takes place in the Raton Basin in the south-central part of the state, near the town of Trinidad (see map on p. 5).

RATON BASIN—FINALLY PRODUCING CBM AFTER YEARS OF DELAY

The methane content of a coalbed can be measured in the field with core samples from vertical boreholes. This method, commonly referred to as "desorption", measures the gas released by the coal core in an airtight container. The resulting gas content determination of the coal per unit weight can then be extrapolated to estimate the subsurface gas resource of the sampled coalbed.

Desorption tests run on Vermejo Formation and Raton Formation coalbeds collected from four U.S. Geological Survey test holes in 1978 in the central Raton Basin west of Trinidad, Colorado clearly established that these coalbeds had high CBM production potential. Several exploratory drill holes were completed during the 1980s. Commercial development of this identified CBM resource, however, was stalled for nearly 25 years because of a lack of gas transportation out of the basin. In 1994, Colorado Interstate Gas (CIG) working with Amoco Production



Raton Basin coalbed methane well

Company and Meridian Oil Inc., fixed the region's gas marketing problem by laying approximately 35 miles of pipeline from their main line near Trinidad to the coalbed methane fields. This line, which CIG refers to as the Picketwire lateral, is capable of transporting 30 million cubic feet of gas a day. Access to markets triggered an active CBM exploration and development program in the basin that continues to the present. In 1997, CIG built a second line, the 115-mile Campo lateral, which added an additional 100 million cubic feet per day of natural gas transportation capacity out of the basin. In December 1999, El Paso Energy Corp. announced plans for an additional interstate pipeline to transport gas between the Raton Basin and Moore County in the Texas Panhandle. This proposed project involves the construction of 185 miles of 24-inch pipeline, with an initial capacity of 175 million cubic feet of gas per day.

The Colorado Oil and Gas Conservation Commission reports that at year-end 1999 approximately 400 wells were producing 80 million cubic feet of gas per day from Vermejo and Raton Formation coalbeds in the Raton Basin. Cumulative CBM production stood at 56 billion cubic feet. Evergreen Resources is the most active operator with 252 gas wells connected to pipeline at year-end 1999. Other active players in the basin include Shenandoah Energy Inc., KLT Gas Inc., Sonat Exploration, J. M. Huber, and Petroglyph Energy Inc. Active development in the basin is expected to continue during 2000 driven in large part by Evergreen's recent announcement of plans to drill 100 additional wells by year-end.

OTHER CBM OPPORTUNITIES IN COLORADO

Some coal basins in Colorado do not have established economic CBM resources. The Uinta and Green River coal regions in the western part of the state (map on p. 5), located within the Piceance and Sand Wash Basins have been drilled to test the Late Cretaceous–Early Tertiary coals. Low gas content, possibly due to depth of burial of the coals, and/or low permeabilities that restrict producing rates, have prevented economic gas recoveries. Compared to the producing depths in the San Juan Basin of less than 4,000 feet, coal targets of 9,000 foot depth in the Uinta and Green River regions pose severe economic limitations for exploration drilling.

Coals in the Denver Coal region, east and northeast of Denver, also referred to as the DJ Basin in petroleum references, have been penetrated by thousands of wells that were drilled to deep gas and oil reservoirs. The CBM potential appears minimal at this point in time. However, rising gas prices and continued demand for natural gas may spur development of these poorer quality, deeper, and thinner coalbeds.

CBM ENVIRONMENTAL ISSUES

As with any gas or oil well, regulations have been established and are enforced to protect surface water, vegetation, wildlife, and subsurface groundwater. CBM reservoirs have the added distinction of producing large quantities of water. Some coals contain potable water that can be used for irrigation and livestock. Other coals produce more saline, and thus non-potable, waters that must be disposed of properly. Water disposal frequently involves reinjecting the produced waters back into a deeper, porous rock layer. This water then becomes a resource for some future use. Regardless of the quality of the produced water, it is not mixed with the shallow aquifers that serve as a source of drinking water.

DID YOU KNOW?

In the U.S. about 46 percent of natural gas is used in the industrial sector, providing energy for everything from processing foods and mined mineral resources to manufacturing chemicals for farmers and ranchers. Generating electricity consumes about 15 percent. Another 15 percent is used in the commercial market—for heating and cooling office buildings, schools, shopping malls and cooking in restaurants. Most of the remaining 24 percent is used in the residential sector, for home heating, clothes drying, dish washing, cooking, and air conditioning.

REFERENCES FOR THIS ISSUE

Amoco Production Company, 1994, Pine River Fruitland coal outcrop

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Publications continued from page 6

Open-File Report 80-4
The Coal Bed Methane Potential of the Raton Mesa Coal Region, Raton Basin, Colorado $15.00

Open-File Report 80-5
Conservation of Methane from Colorado Mined/Minable Coal Beds: A Feasibility Study $10.00

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Coal Bed Methane Potential of the Sand Wash Basin, Green River Coal Region, Colorado $25.00

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Coal Bed Methane Potential of the Piceance Basin, Colorado $30.00

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Coalbed Gas Composition in Upper Cretaceous Fruitland Formation, San Juan Basin, Colorado and New Mexico $10.00

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Demonstrated Reserve Base for Coal in Colorado: Yampa Coal Field $4.00

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Availability of Coal Resources in Colorado: Somerset Coal Field, West-Central Colorado $9.00

Upcoming Events Involving CGS

August 9–11
Colorado Oil and Gas Assoc. (COGA) 12th Annual Rocky Mountain Natural Gas Strategy Conference and Marketing Fair, participant, exhibit, Laura Wray, (303) 866-3519

September 1–4
Taste of Colorado, Colorado Mining Exhibit Foundation exhibit, informational/educational materials, participant, Guy Johnson, (303) 969-0365

September 15–17
Denver Gem and Mineral Show, publication sales, exhibit, informational/educational materials, Carol Smith, (303) 233-2516

September 24–27
"Abandoned Mined Land 2000" Annual Conference, Association of AML Programs speaker, exhibit, Loretta Pineda, (303) 866-3819

September 29
Colorado Science Teachers Convention, exhibit, speaker, Marie Sullivan, (719) 598-4976

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