COAL BED SEQUESTRATION OF CARBON DIOXIDE

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Introduction

Geologic sequestration of CO_2 generated from fossil fuel combustion may be an environmentally attractive method to reduce the amount of greenhouse gas emissions. Of the geologic options, sequestering CO_2 in coal beds has several advantages. For example, CO_2 injection can enhance methane production from coal beds; coal can trap CO_2 for long periods of time; and potential major coal basins that contain ideal beds for sequestration are near many emitting sources of CO_2.

One mission of the Energy Resources Program of the U.S. Geological Survey is to maintain assessment information of the Nation's resources of coal, oil, and gas. The National Coal Resources Assessment Project is currently completing a periodic assessment of 5 major coal-producing regions of the US. These regions include the Powder River and Williston and other Northern Rocky Mountain basins (Fort Union Coal Assessment Team, 1999), Colorado Plateau area (Kirschbaum and others, 2000), Gulf Coast Region, Appalachian Basin, and Illinois Basin. The major objective of this assessment is to estimate available coal resources and quality for the major producing coal beds of the next 25 years and produce digital databases and maps. Although the focus of this work has been on coal beds with the greatest potential for mining, it serves as a basis for future assessments of the coal beds for other uses such as coal bed methane resources, *in situ* gasification, and sites for sequestration of CO_2. Coal bed methane production combined with CO_2 injection and storage expands the use of a coal resource and can provide multiple benefits including increased methane recovery, methane drainage of a resource area, and the long-term storage of CO_2.

Project Description

In preparation for an update of the National Coal Resource Assessment and as part of the USGS Project entitled "Assessment of Geologic Reservoirs for Carbon Dioxide Sequestration", a task for coal bed evaluation is to qualitatively and quantitatively assess the potential of unminable coal beds to sequester CO_2. The work focuses on the geological and geochemical controls on storage capacity and distribution using coal properties, geochemistry, and geology to assess methodology development contributing to this newly emerging field.

The objectives of the project for coal bed reservoirs are to characterize the specific adsorption capacity (volume of gas per volume of reservoir) of coal beds of different rank and composition; model the total capacity of coal bed repositories relative to potential sites of CO_2 generation; and provide data to evaluate the potential economic benefits of CO_2 sequestration in combination with coal bed methane production.

Approach

One goal of this effort is to build a dataset of coal properties using samples from several coal basins that differ in rank, type, and geologic age. In cooperation with ongoing USGS research projects and private company partnerships, we are collecting and characterizing samples from coal core for gas adsorption testing by a third party laboratory. These samples are characterized by chemical, petrographic, and physical tests to complete a dataset for selected coal basins. Presently, samples from the Powder River Basin, Williston Basin, Rock Springs, Wyoming area, and Gulf Coast are being collected. Through the efforts of other USGS projects, additional samples will be collected from the Appalachians and other basins in the Colorado Plateau. Also, refined testing methods are being developed to allow characterization of adsorption potential under various ranges of pressure and temperature to simulate thermal gradients and depth.

Sampling involves obtaining fresh coal samples from drill core in 2-foot long increments. For thick beds as in the Powder River Basin, this can amount to 40-60 samples per core. Each increment is placed in a canister and the methane is carefully desorbed at a constant temperature (Stricker and others, 2000). Following desorption, the core segments are X-radiographed as digital images that are processed to produce an x-ray density log. This step aids in the discrimination of high ash layers, fusain layers, and thin partings in the coal that may escape visual description particularly in low rank coals. The visual description involves splitting the core along cleats to enable description of the coal lithotypes. From the 2-foot core segments subsamples approximately 6 – 8 inches long are selected from single lithotypes and submitted for methane and carbon dioxide adsorption isotherm testing. All segments are pulverized in stages and tested in accordance with ASTM standards for as-received moisture, C, H, O, N, S, and segments selected for isotherm testing are tested for specific gravity, calorific value, and equilibrium moisture. Representative splits from the stage crushing are reserved for subsequent detailed petrographic and palynologic analysis.

Coal Rank

As coal rank increases from lignite to anthracite, the density of the coal initially decreases from lignite to high volatile bituminous coal rank as a result of expulsion of water and compaction and the formation of micropores. In low rank coals which are less than 75 percent C, on a dry, ash-free (daf) basis (lignite and subbituminous ranks), surface areas have been interpreted as primarily contained in macropores >20 nm (Gan and others, 1972; Sharkey and McCartney, 1981). In contrast, density of the high volatile bituminous to anthracite coals increases as a result of coalification processes that drives off hydrogen and oxygen. Pores in these higher rank coals are primarily micropores (<2nm) and to a lesser extent transitional pores (2-20 nm). Other work contradicts the interpretation for subbituminous coals. Parkash and Chakrabartty (1986) conclude for a study of subbituminous coals, that micropores rather than macropores are responsible for porosity at this lower rank.

Because the adsorption capacity is both a function of the amount and reactivity of surface area contained in pores and possibly fractures, understanding the relationships of adsorption of CO_2 and coal rank and of CO_2 adsorption and coal composition require adsorption test data on representative coal samples that cover wide ranges of rank and composition. Rank is known to have an effect on the amount of carbon dioxide that can be adsorbed into the coal porosity (Gan, and others, 1972, Mahajan, 1989). Low rank coals have surface areas that are as high as anthracites and low volatile bituminous coals whereas lower values are obtained for bituminous coals of about 80 percent carbon (daf). Surface areas are influenced by the interaction of the quadrupole moment of the CO_2 molecule with oxygen functional groups on coal surfaces (Sharkey and McCartney, 1981; Mahajan, 1989); solubilization or extraction of low-boiling hydrocarbons absorbed tightly in micropores; and swelling (Mahajan, 1978).

Coal Composition

Coal can be viewed as being composed of water, minerals, and organic components (macerals). The percentage of water in coal (inherent moisture) is used to differentiate coals by rank up to the high volatile bituminous stage (ASTM, 2000). Rank is a classification of coal beds that indicates the degree of metamorphism, or progressive alteration, from lignite to anthracite (ASTM, 2000). Low rank coals therefore contain more water than higher rank coals. Minerals are considered contaminants in most commercial uses of coal. Macerals are the most combustible components of coal and can vary in chemical composition both among maceral varieties within a single coal bed and among coal beds. The general groups of macerals are vitrinite, liptinite, and inertinite. Macerals originate from partially decomposed plant parts that are altered through the coalification process. Their dominant chemical composition is primarily a mixture of carbon, hydrogen, oxygen, nitrogen, and sulfur. Of the major maceral groups, liptinite is richer in hydrogen and inertinite is richer in carbon than vitrinite. All macerals change chemically through the coalification process but at different rates.

As a result of differing peat-forming conditions and plant assemblages, organic components are transformed into macerals which arrange structurally into lithotypes that, in turn, comprise facies or the major subunits of a coal bed (Fig. 1). Adsorption properties of coal beds vary with composition of the coal. Gases should be adsorbed most by vitrain-rich facies that contain low amounts of minerals (Clarkson and Bustin, 1997a). The most permeable facies are those rich in fusain layers; and the most impermeable layers contain discrete mineral layers, impure coal facies that are rich in minerals, or attrital lithotypes (Clarkson and Bustin, 1997b). Water may compete with some gases such as methane for adsorption sites in maceral pores. In the case of carbon dioxide, CO_2 may be dissolved in water and displace water and methane in adsorption sites (Gentis, 2000).

The stratigraphic and geographic distribution of facies define subunits of a coal bed that have variable holding capacities for carbon dioxide and methane depending on their continuity and composition. Variations in these properties that define facies are not only observable among beds but within individual bed profiles (fig. 2; gas data from McGarry, D.E., 2000).

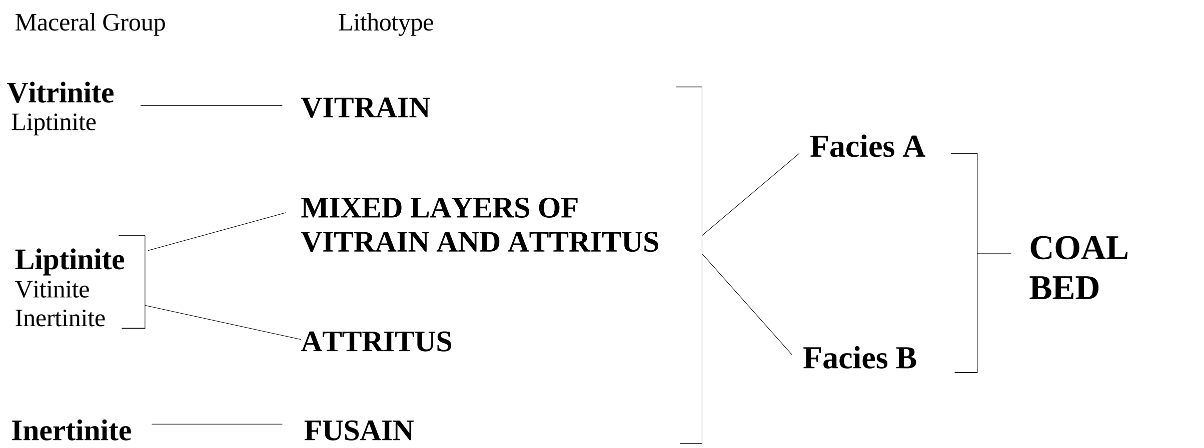

Figure 1. Structural relationships among macerals and lithotypes that compirse facies of a coal bed

Physical properties of a coal bed can also be a significant factor in the adsorption of CO_2. Such properties include fracture intensity, degree of fracture filling, overburden and seat rock permeability, coal rank, reservoir pressure, and the degree of folding and faulting of the coal bed.

Geologic Age

Geologic age may affect the adsorption capacities of coals because coals of different age have different compaction characteristics that can affect the pore size and distribution of pores. Coals of differing age are also composed of plant materials that have different particle dimensions and which, on a bed-scale, can affect the pore size and permeability or interconnectivity of pores. For example, Carboniferous coal beds contain plant remains composed of flattened hollow stems of periderm-rich plants that compact to about less than 0.5 inches in thickness. In contrast, Tertiary age coal beds are composed of the remains of woody plants that can range in thickness from inches to feet. Coal beds of different ages not only differ in lithologic texture but also in the architecture of the facies comprising the bed. The facies architecture of a coal bed will affect its gas-holding

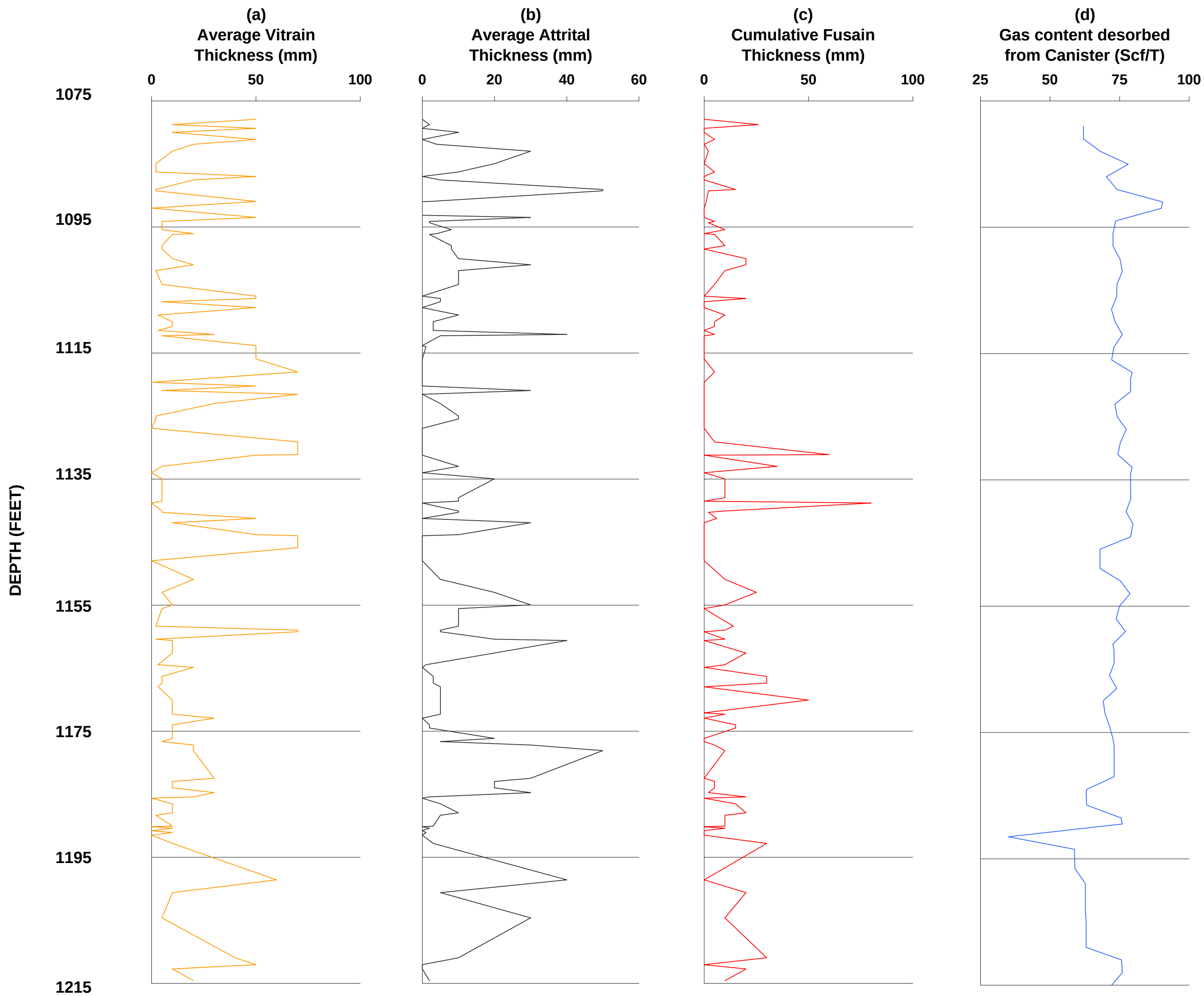

Figure 2 -Variations of megascopic descriptive data with depth of canister samples of a single coal bed core, Powder River Basin. (a) Average vitrain thickness; (b) Average attrital thickness; (c) Cumulative fusain thickness; (d) and Desorbed gas content.

capacity. Simply put, coal beds are very heterogeneous in composition both in vertical section and across an area, which may play a major role in the use of a bed as a storage site for CO_2.

Results

Our preliminary gas adsorption results for thirteen samples are shown in Figures 3a-3c. Each figure uses a different reporting basis to emphasize compositional effects of the same samples: Figure 3a on an as-received basis; Figure 3b on a moist, ash-free basis; and Figure 3c on a dry, ash-free basis. Note that the scales are different for each graph. Samples consist of nine subbituminous samples from the Powder River Basin (labeled PRB), two lignite samples from the Williston Basin (labeled WB), one subbituminous sample from the Rock Springs area (labeled RS), and one lignite sample from the Gulf Coast Region (labeled GC). Comparison of data in Figure 3a indicates that on an as-received basis, CO_2 adsorption is more than four times that of CH_4 adsorption. Figure 3b (same data but on a moisture containing, ash-free basis) compared to Figure 3a demonstrates the dilution effect that mineral content has on CO_2 adsorption. Comparison of the data on a dry, ash-free basis (fig. 3c) is even more dramatic and demonstrates the effect that moisture has on the adsorption characteristics; the spread among the lines can be attributed to differences in lithotype and rank and temperatures under which the test was conducted which ranged from 60 to 86 degrees F to simulate reservoir temperatures.

On a dry, ash-free basis, results of this work indicate the adsorption ratio of CO_2:CH_4 is as much as 10:1 (fig.3c). Arri and others (1992) present data that suggest a ratio of 2:1 on the basis of an isotherm of a low volatile bituminous coal sample from the San Juan Basin. Our new data for subbituminous coal and lignite show that if the ratio of 2:1 is used to infer the CO_2 adsorption capacity for low rank coals, it will grossly understate the storage potential for these comparatively thick widespread coal beds.

Surface area measurements of coal can be affected by swelling phenomena in low rank coals when injected with CO_2 (Mahajan, 1989). Because of this effect, surface area measurements made using CO_2 of low rank coals are unreliable (Mahajan, 1989). However, for the purpose of understanding the adsorption capacity of low rank coals, this phenomenon has significant implications. Injecting CO_2 into low rank coal beds may swell the pore structures thereby increasing pore surface areas and hence adsorption capacity.

In a scenario where CO_2 is stored as part of enhanced coal bed methane recovery from a low rank coal resource, swelling may play a role in increasing pore surface areas. Because dewatering is necessary for methane production, CO_2 would be injected into a bed that has less moisture than original inherent bed moisture thereby providing space for swelling of the coal.

Application and Future Activities

This USGS project addresses policy issues on appropriate technology for amelioration of atmospheric buildup of greenhouse gases. Given the internationally recognized need to reduce emissions and carbon dioxide in the atmosphere, the results of this project will provide a scientific basis to evaluate possible technical solutions to this problem. Our research provides fundamental, new information on the capacity of coal bed reservoirs to serve as long-term storage sites for carbon dioxide.

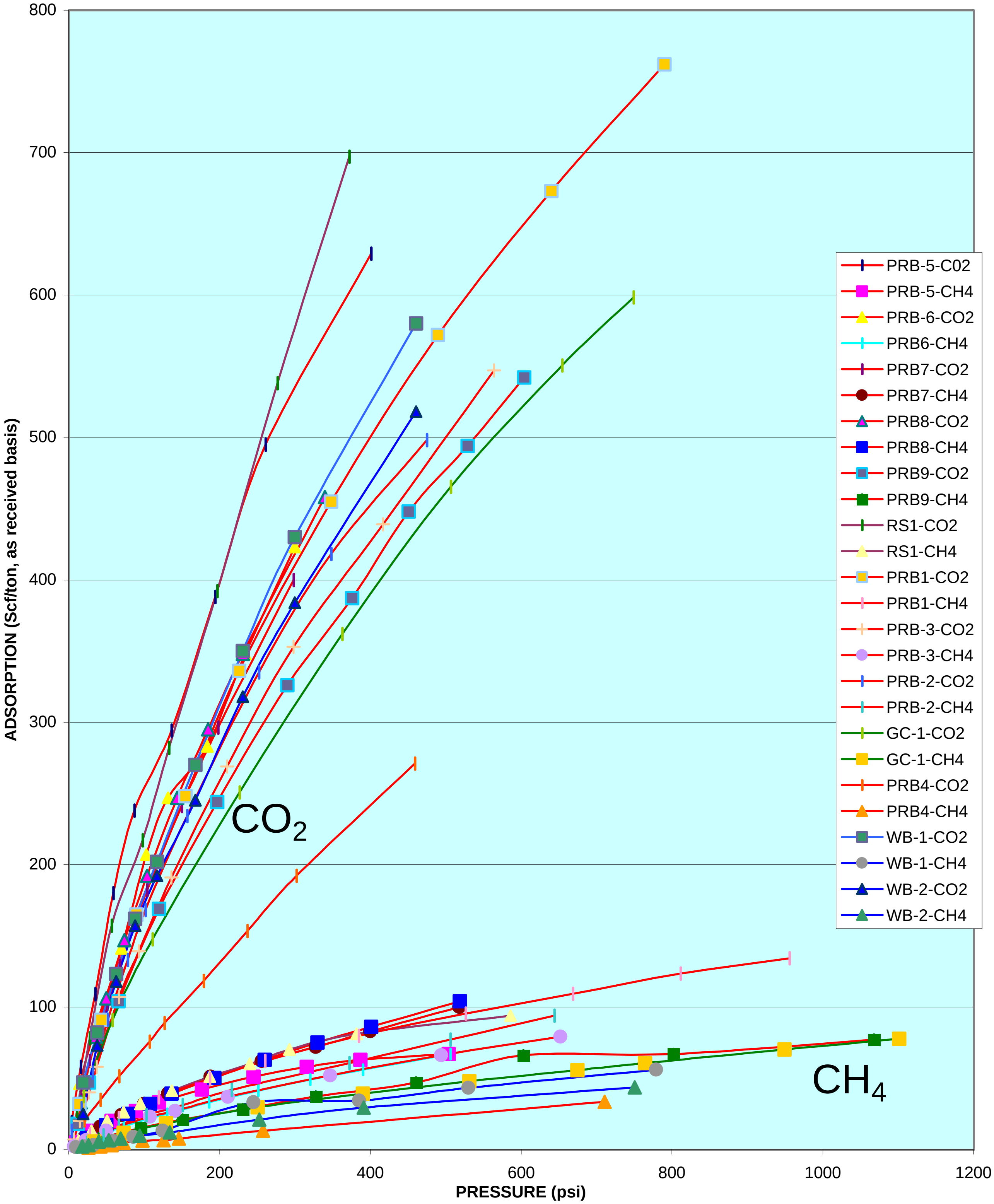

Figure 3a- Methane and Carbon Dioxide Adsorption data for 13 low rank US Coal Samples (as-received basis)

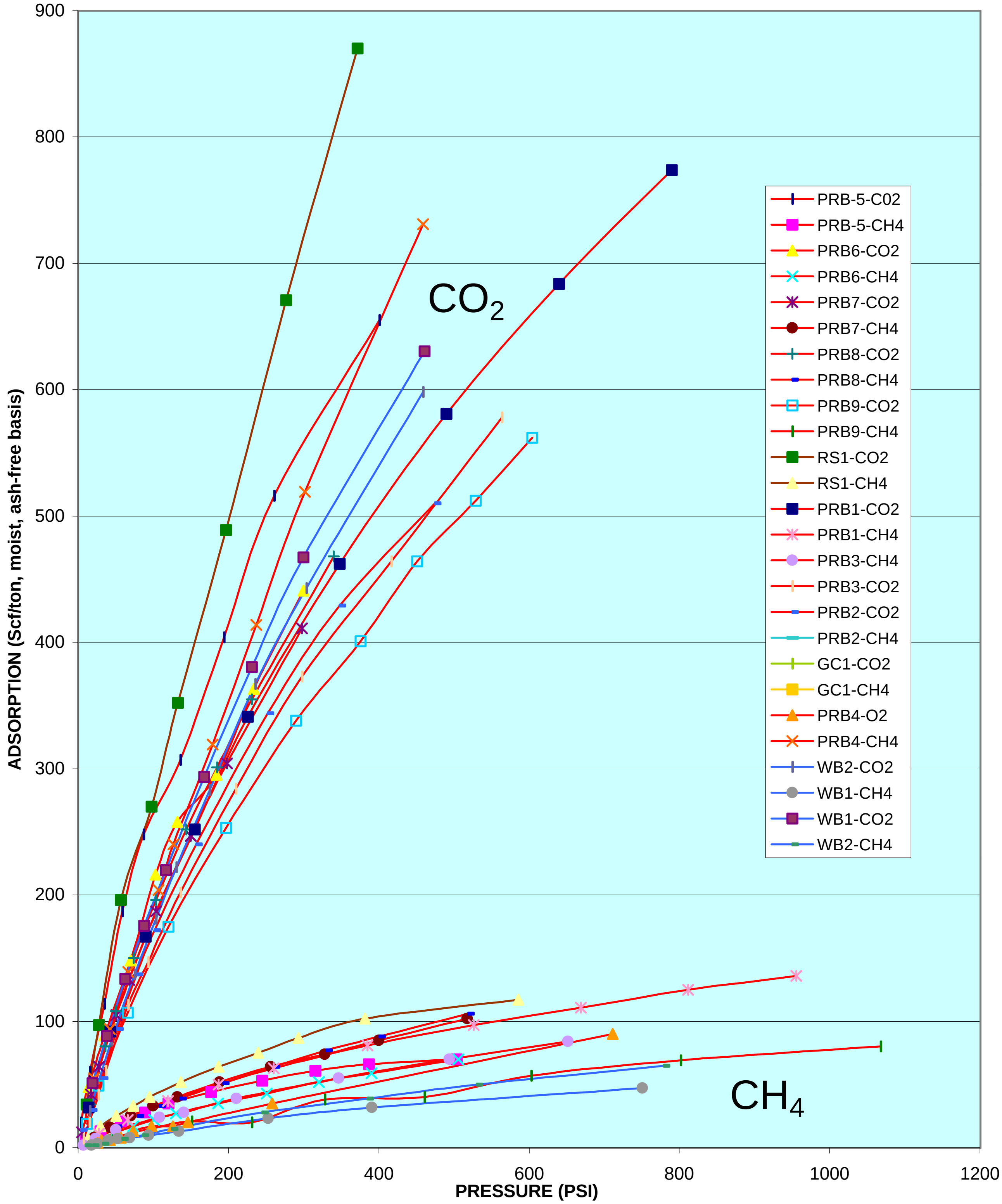

Figure 3b- Methane and Carbon Dioxide Adsorption data for 13 low rank US Coal Samples (moist, ash-free basis)

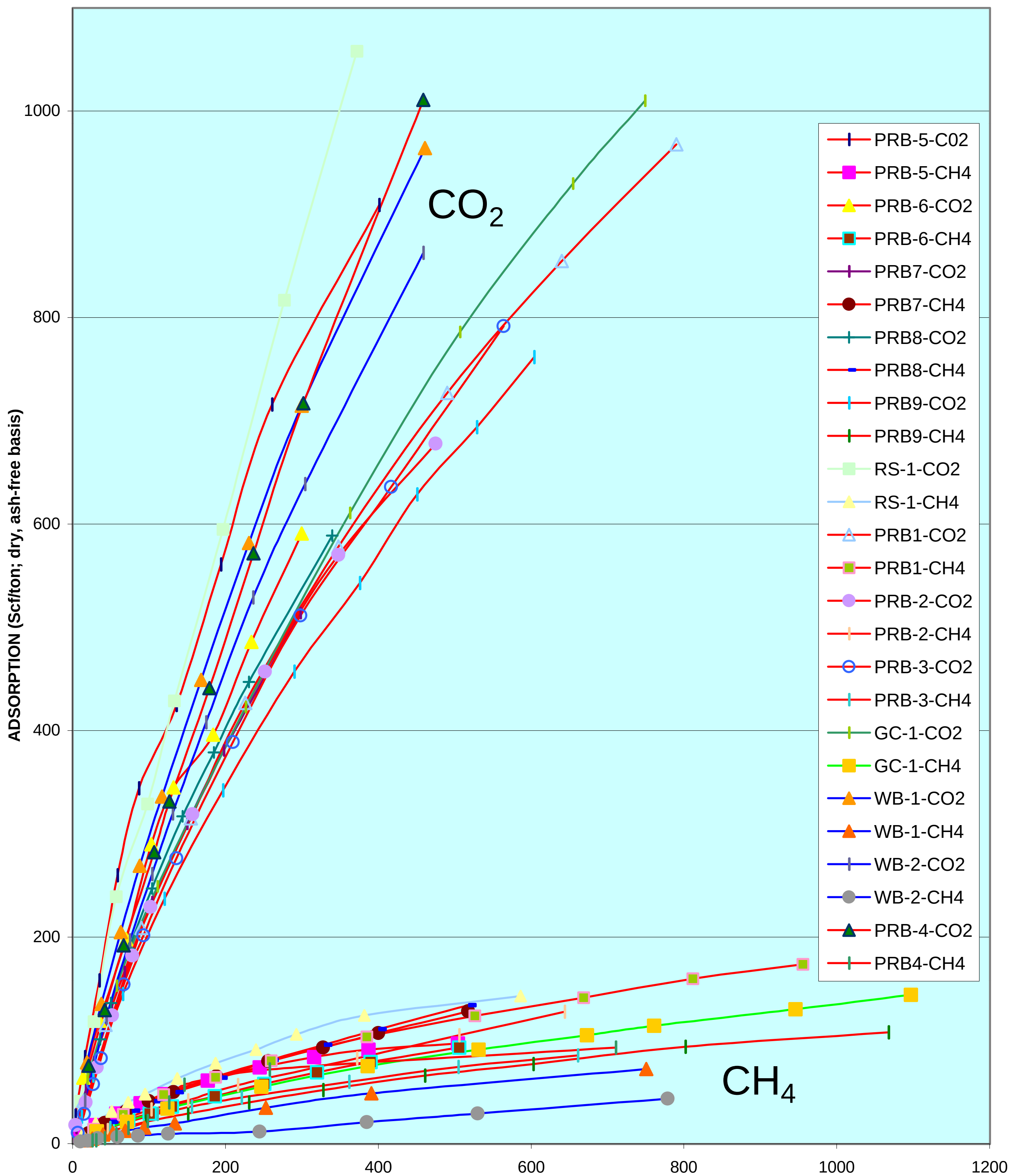

Figure 3c- Methane and Carbon Dioxide Adsorption data for 13 low rank US Coal Samples (dry, ash-free basis)

Results will also provide national and regional information for evaluation of the land-use impact of establishment of repositories. If the methodology for quantitative assessment of total storage capacity is successful, it may prove applicable worldwide. This could allow better international assessment of carbon sequestration capacity because coal is widely distributed worldwide.

The CO_2 adsorption values obtained in this study place a new importance on CO_2 storage in low rank coal beds, especially those that are too deep to mine but have methane production potential. Current estimates of the sequestration capacity of US coal beds are based on previously published data applicable to higher rank coals and therefore may be greatly understated for low rank coal beds. Past USGS assessments of coal resources have focused primarily on coal beds that could be mined down to a depth of 3000 feet. Assessment of the coal resources applicable for carbon dioxide sequestration should focus primarily on those beds that have no future minability but may have coal bed methane production potential. Injection of CO_2-rich gases into low rank coal beds can aid in the enhanced recovery of coal bed methane.

An example of CO_2 storage capacity can be calculated from the recent USGS assessment of coal resources in the Powder River Basin (Fort Union Coal Assessment Team, 1999) in which 326 billion tons of coal are estimated just in the Wyodak-Anderson coal zone below 500 ft (152 m). This coal zone alone could, theoretically, sequester about 290 Tcf CO_2. In addition, coal resource estimates below the Wyodak-Anderson coal zone are 460 billion short tons (Flores, 2001). These deeper coal beds could sequester another 400 Tcf CO_2.

All coal beds of the US do not have the same chemical and physical properties. In fact, there is great variation among coal basins of the US in rank, age, facies architecture, and fracturing characteristics. To fairly compare data among coal basins or coal beds, comparable data must be obtained. Such data requires standardized methods for testing. ASTM standards (ASTM, 2000) have long been in use for the sampling and analysis of chemical properties of coal. Standard methods for canister gas desorption and isotherm determinations are needed to fairly compare resources, particularly when the goal is to identify or assess the optimal use of the resource.

In any assessment of the use of coal beds to sequester CO_2, consideration should be given to the following:

(1) Potential storage capacity of the coal which is affected mainly by rank, quality and geology;
(2) Proximity of coal beds to power plants supplying carbon dioxide and any land use restrictions;
(3) Use of the carbon dioxide to enhance coal bed methane recovery from economically viable coal beds; and
(4) Depth of the bed so as not to preclude its future mining potential.

The future plans of the USGS are to further document the storage capacity of a variety of well collected coal samples of different type, rank, and age. These data will be used to model the factors that can control CO_2 adsorption and affect the CO_2 storage potential of the Nation's coal resources.

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