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POTENTIAL FOR GEOLOGIC STORAGE OF CARBON DIOXIDE FROM COAL-FIRED ELECTRICAL GENERATING STATIONS IN ARIZONA, USA

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Large coal-fired electrical generating stations are presently operating at four sites in northeastern Arizona. The combined carbon dioxide (CO_2) discharge at these stations in year 2000 was approximately 42 million tons. Where favorable geologic and hydrologic conditions occur, CO_2 from existing and future Arizona coal-fired power plants might be captured for long-term storage in subsurface geologic reservoirs.

Favorable geologic conditions for CO_2 sequestration include occurrence of porous and permeable geologic units, such as sandstone strata, to comprise storage reservoirs; and occurrence of poorly permeable geologic units, such as shale or mudstone strata, capping a potential reservoir. Deep reservoir units with laterally extensive or structurally closed confining seals would provide the most secure sequestration sites. Additionally, favorable hydrologic conditions include occurrence of saline groundwater and adequate hydraulic head in target reservoirs.

Opportunities for subsurface storage of CO_2 may be classified with respect to regional geologic conditions. Arizona occupies parts of two geologic provinces which are summarized in the following sections. The northeast half of the state is in the Colorado Plateau Geologic Province and the southwest half of the state is in the Basin and Range Geologic Province. The northwest trending mountainous area of the Central Highlands transition zone occurs between the two provinces, is characterized chiefly by occurrence of igneous and metamorphic rocks, and has little potential for geologic storage. Locations of the provinces and of large coal-fired electrical generating stations in Arizona are shown on **Figure 1**.

Colorado Plateau Geologic Province

The Colorado Plateau is a high plateau region where landforms are dominated by buttes, mesas, deeply incised canyons, and volcanic peaks. Much of the Colorado Plateau is underlain by a thick sequence of nearly flat-lying sedimentary strata interrupted at places by faults and gentle folds. The existing coal-fired generating stations and the extensive Navajo and Hopi Indian Reservations occur in Colorado Plateau Geologic Province. The Colorado Plateau offers significant potential for geologic sequestration of CO_2.

Favorable geologic and hydrologic conditions for storage of CO_2 occur in selected areas of the Colorado Plateau province in Arizona. The most favorable physical conditions occur in the Black Mesa basin beneath the Navajo and Hopi Indian reservations. There, potential storage reservoirs in geologic formations of Mississippian through Permian age are overlain by Mesozoic strata containing numerous confining beds. In order of increasing depth and age, porous and permeable geologic formations include strata of the Navajo Sandstone, Coconino and De Chelly Sandstones, Esplanade member of the Supai Formation and Cedar Mesa Sandstone member of the Cutler Formation, Redwall Limestone, Temple Butte Limestone, Martin Formation, and Tapeats Sandstone. Stratigraphy and structural geology of the potential reservoir units are reasonably well known and correlated in outcrop and isolated deep exploration wells occurring in the Colorado Plateau. Hydrologic conditions within the potential reservoirs, on the other hand, are poorly known in all but the Navajo and Coconino/De Chelly Sandstones. These geologic formations together with mudstone strata that serve as overlying capping or confining units are summarized in **Table 1**. A principal confining seal is the Triassic Chinle Formation, which is about 300-500 meters thick and present in much of northeastern Arizona.

The Coconino and De Chelly Sandstones are stratigraphic equivalents, range in thickness from about 100 to 300 meters, and crop out or occur in the subsurface at most locations in northeast Arizona. Beneath Black Mesa, permeability and porosity of the sandstone is reported to be small, and total dissolved solids are reported to be about 750 milligrams per liter (mg/l). The most favorable and extensive targets for sequestration in the Arizona section of the Plateau Province are believed to occur in these geologic formations. Beneath and south of Black Mesa to approximately the location of the Little Colorado River, the unit is confined by the overlying Chinle Formation. The strata have a gentle

northeast dip. The area where the Chinle confining unit is more than 100 meters thick is shown on **Figure 2**. Hydraulic head above the top of the sandstones ranges from approximately 30 to 500 meters north of the Little Colorado River and is about 750 to 1,000 meters beneath Black Mesa. The pattern of hydraulic head, shown on **Figure 3,** indicates that CO_2 would occur in a gaseous state in much of the area. Saline groundwater with total dissolved solids concentrations more than 10,000 mg/l occurs north from the Little Colorado River in an area of about 8,000 square kilometers; this saline groundwater area is shown on **Figure 3**.

Potentially favorable areas for geologic storage occur in vicinity of three of the Arizona coal-fired power plants. In the area southeast of Navajo Generating Station, multiple potential reservoirs are present in the Paleozoic section that may be suitable for CO_2 storage. The storage reservoirs are at depths ranging from approximately 900 to 1,500 meters and capped by thick and regionally-extensive shale confining beds. Site specific information on ground-water conditions and water quality is not available in this area. In the vicinity of Cholla Power Plant and Coronado Generating Station, potential storage reservoirs underlie an area about 250 kilometers long just north of and roughly parallel to the Little Colorado River. In this region, the Permian Coconino Sandstone and underlying Supai Formation contain very saline groundwater and are overlain by an extensive confining seal of Chinle Formation. The Coconino Sandstone and possibly Supai Formation may be favorable for geologic storage, but the relatively shallow depth of burial and low hydrostatic pressure in this region would require sub-critical CO_2 storage. Geologic conditions and the presence of naturally occurring CO_2 do not favor geologic storage in the vicinity of Springerville Generating Station.

Basin and Range Geologic Province

The Basin and Range province consists of broad desert basins bounded by precipitous mountain blocks. The basins in the Basin and Range Province comprise tectonically depressed troughs and have been filled to depths of 1,000 meters or more with materials eroded from the mountain blocks. This province includes the large cities of Phoenix and Tucson and more than 70 percent of Arizona's population. With the exception of Yuma region in southwest Arizona, the Basin and Range province has little potential for geologic sequestration of CO_2.

The floors of the large basins in the Basin and Range Geologic province are usually underlain by coarse-grained sand and gravel units to depths of 100 meters or more. Beneath the coarse-grained units, in the central parts of most of the large basins, thick sequences of fine-grained mudstones and evaporites occur. The evaporite deposits include gypsum and halite. The fine-grained units may comprise useful confining units, and at places overlie extensive permeable sand and gravel units. Saline groundwater conditions occur at depth in selected basins. Although select basins may have favorable characteristics for geologic sequestration of CO_2, the overall potential is poor due to limited areal extent of basin-fill sediments and the potential discontinuity of seals at basin margins.

The lower Colorado River basin area north and south of Yuma, Arizona is not typical of Basin and Range stratigraphic sequence and structural conditions. Here, the basin-filling deposits are much thicker, possibly extended to depths greater than 3,000 meters, and consist of a combination of marine and non-marine strata. This area has been tectonically depressed during the late Cenozoic. These relations indicate the sedimentary basins in the Yuma area may provide favorable areas for geologic storage.

Table 1. GEOLOGIC RESERVOIRS AND SEALS IN COLORADO PLATEAU PROVINCE, ARIZONA

Geologic Unit	*Age*	*Thickness (meters)*	*Description*	*Remarks*
Carmel Fm.	Jurassic	20-80	Claystone and sandstone	Confining bed beneath Black Mesa
Navajo SS.	Jurassic & Triassic	30-300	Fine to med.-grained eolian sandstone; porosity 25-30%	Potential reservoir beneath Black Mesa but groundwater contains <1,000 TDS
Kayenta, Wingate, Moenave Fms.	Triassic	200-250	Mudstone, siltstone, and sandstone	Primarily serve as confining beds in S. Black Mesa area
Chinle Formation	Triassic	100-400	Primarily bentonitic mudstone; some sandstone and conglomerate	Excellent confining seal in much of NE Arizona
Moenkopi Formation	Triassic	30-100	Siltstone and sandstone	Not considered an effective confining seal
Coconino – DeChelly Sandstones	Permian	100-300	Fine to med.-grained eolian sandstone	A major potential reservoir in much of NE Arizona; groundwater contains >10,000 TDS in 8,000 km^2 of southern Black Mesa area
Hermit Shale – Organ Rock mem. of Cutler Fm.	Permian	30-100	Primarily siltstone with sandstone lenses	Confining seal in Grand Canyon-Black Mesa area
Esplanade mem. of Supai Fm. – Cedar Mesa mem. of Cutler Fm.	Permian	20-200	Permeable sandstone with siltstone facies	Potential reservoir; not present in SE part of area shown on **Figures 2 and 3**
Lower Supai Fm.	Pennsylvanian	100-250	Siltstone, sandstone, and limestone; extensive halite beds in SE Black Mesa basin	Acts as both confining seal and potential CO_2 reservoir
Redwall Limestone, Temple Butte Limestone, and Martin Formation	Mississippi & Devonian	150-300	Primarily limestone and dolomite; cavernous in Grand Canyon area	Potential reservoir; not present in SE part of area shown on **Figures 2 and 3**
Tapeats Sandstone	Cambrian	50-80	Feldspathic, micaceous sandstone	Potential CO_2 reservoir

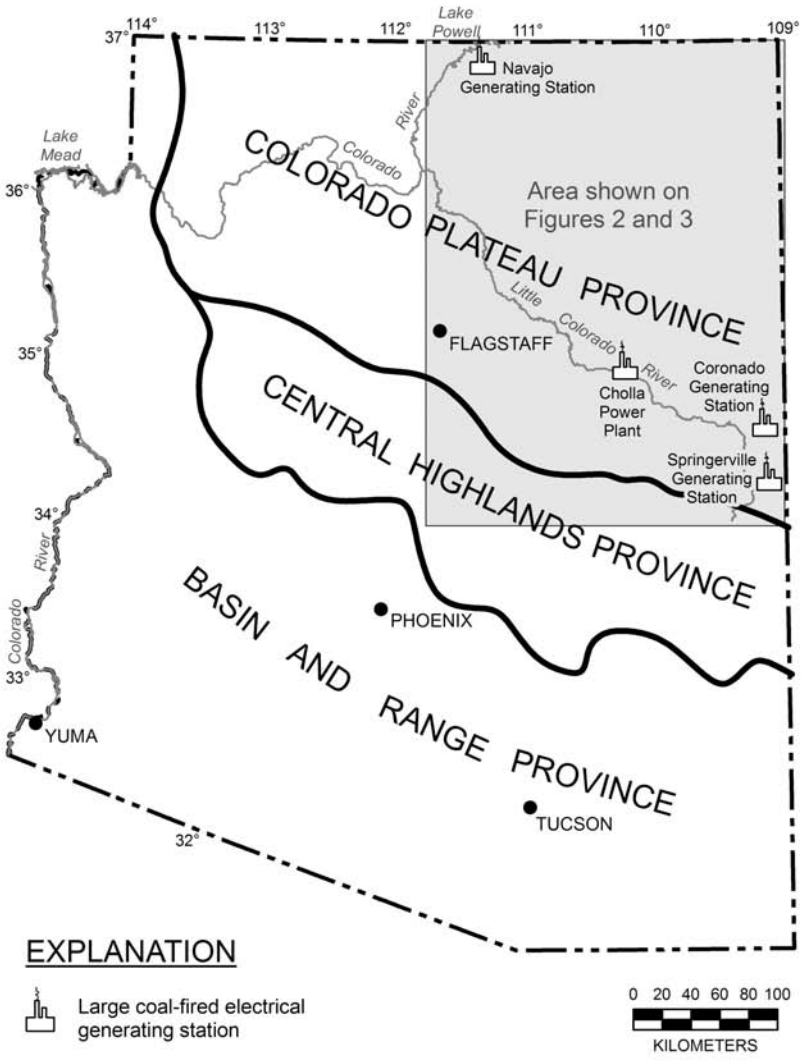

Figure 1. Arizona Geologic Provinces

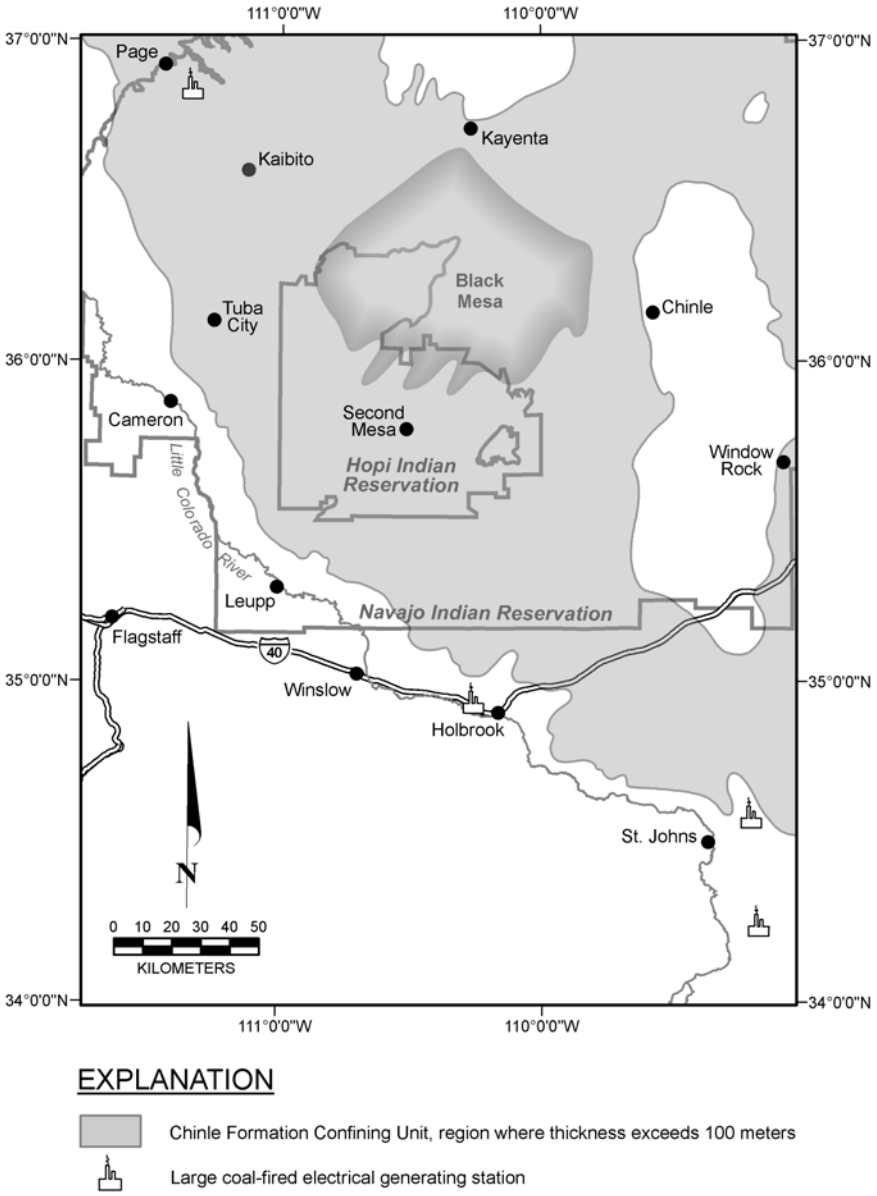

Figure 2. Aerial Distribution of Chinle Formation

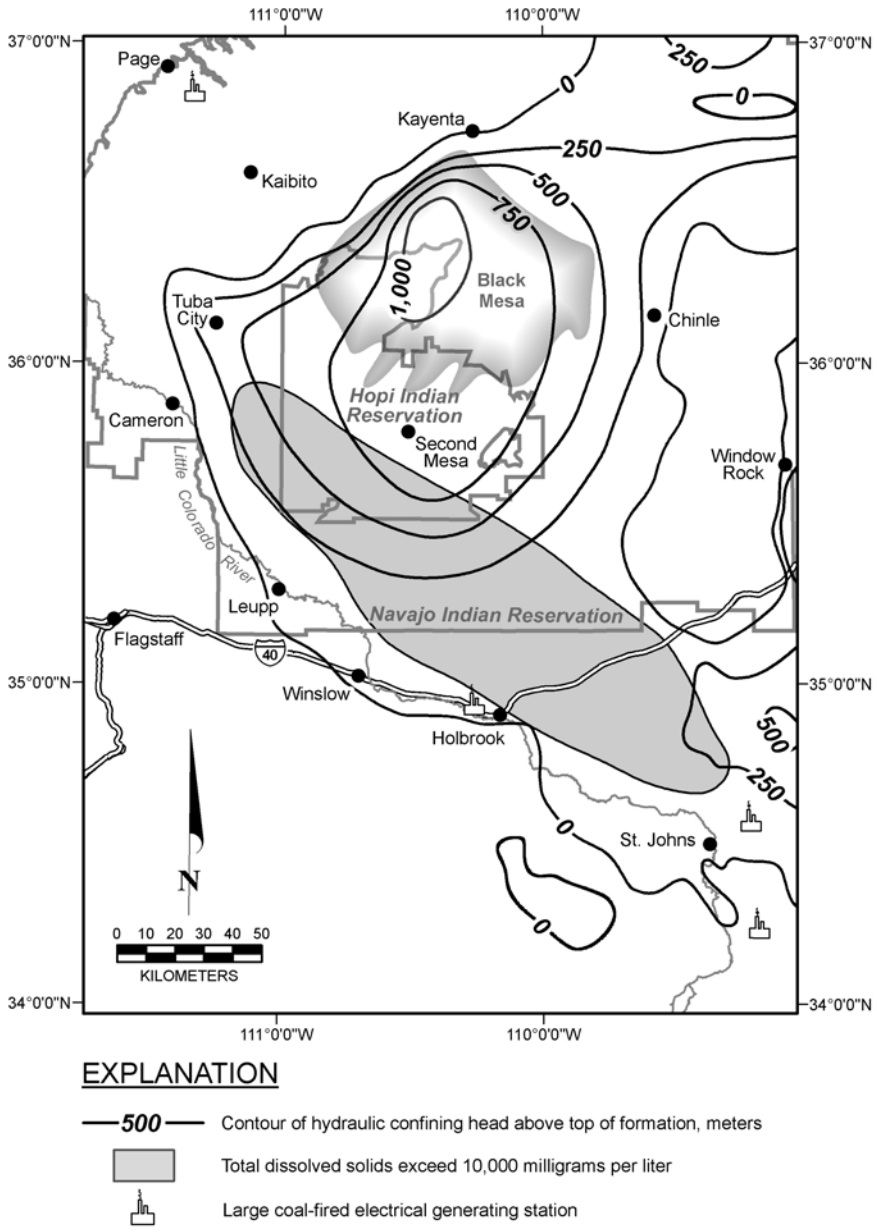

Figure 3. Hydraulic Confining Head and Total Dissolved Solids in Coconino-DeChelly Sandstones