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**Preliminary Inventory of Pre-Cenozoic
Clay Shales and Argillites of the
Conterminous United States**

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PRELIMINARY INVENTORY OF PRE-CENOZOIC CLAY SHALES AND ARGILLITES OF THE CONTERMINOUS UNITED STATES

Introduction

This report inventories shale and argillite strata in the conterminous United States that might be of potential interest in siting a nuclear waste repository. Because of the vast nature of this task, the only guideline considered in this compilation of rock units is stratigraphic thickness; depth of a given unit below the surface is specifically not considered. Following the suggestion of Shurr,¹ a minimum thickness of 150 m (500 ft) is assumed to be required.

The report is divided into three main sections. First is a brief summary of the locations and compositions of shales of Late Cretaceous age, which are by far the most widespread clay shales in the western United States (Figures 1 and 4). The second section is a preliminary inventory of Phanerozoic shales throughout the conterminous United States (Figures 5-16). Third is a summary of the occurrences of Precambrian shale and low-grade metamorphosed shale (argillite) (Figures 17-18). Other geological factors that need to be considered ultimately for a shale inventory (and which are graphically summarized in Figures 19-24 at the end of this report) include seismic activity, structural complexity, rainfall and runoff, the location of economically important ore deposits, coal, and hydrocarbons, and location with respect to glacial deposits.

Upper Cretaceous Shale

The thickest and most widespread shale units in the western part of the United States are Upper Cretaceous. They were deposited in a large trough lying east of an uplifted and deformed area to the west (Figure 1).

The total thickness of Upper Cretaceous strata in the western part of the trough is nearly 6 100 m (20 000 ft); this sequence generally thins eastward (Figure 2). Accompanying this eastward thinning from the source area is a general increase in abundance of shale, with limestone becoming a minor constituent (Figures 2 and 3). Tongues of sandstone and local conglomerate interfinger complexly to the west because of pulses of uplift in the source area and because of migrations of the shoreline in the shallow sea that was receiving the sediment.

After deposition of the shale in Late Cretaceous time, the trough was fragmented by uplifts from which the strata were subsequently eroded (Figures 20 and 1). Thus, Cretaceous rocks are mostly confined to basins of the Rocky Mountain region and to the Great Plains, as can be seen from the outcrop pattern (Figure 4).

Numerous formation names have been applied to clay shale-rich rock units in different areas of the western United States. Table 1 summarizes these names for Upper and Lower Cretaceous clay-rich strata.

The most stable seismic and tectonic area of the western United States is in the northern Great Plains (Figures 16 and 20, respectively). Here widespread outcrops of thick, relatively homogeneous clay shale of the Pierre Shale have been studied extensively.²⁻⁵ In addition, potential repository sites have been selected within the area underlain by the Pierre Shale in Colorado, South Dakota, and North Dakota.¹

Figure 1. Upper Cretaceous Shale

Figure 2. Generalized West-to-East Stratigraphic Sections--Upper Cretaceous Strata, West-Central Wyoming to Northeastern Nebraska

Modified From: Stratigraphic Atlas of North and Central America, 1975

Figure 3. Generalized South-to-North Stratigraphic Sections--Upper Cretaceous Strata, Southeastern Nebraska to Montana-Canada Border

Figure 4. Upper Cretaceous Outcrops

TABLE 1

Generalized Correlation Chart of Cretaceous Shales,
Western Interior of the United States

Age	Northern Great Plains (Dakotas, E. Montana, S. Wyoming)	Southern Great Plains (E. Colorado, Kansas, Nebraska)	Rocky Mountain Region	
			Four Corners Region (Including Colorado, Utah, New Mexico)	Northern Rocky Mountains (Wyoming, Montana)
Upper Cretaceous	Pierre Shale	Pierre Shale	Lewis Shale	Pierre Shale Bearpaw Shale Claggett Shale
	Niobrara Formation	Niobrara Formation	Mancos Shale	Steele Shale Baxter Formation Hilliard Formation
	Carlile Shale	Carlile Shale	Carlile Shale	Frontier Formation Colorado Shale
Lower Cretaceous	Belle Fourche Shale	Graneros Shale	Graneros Shale	Warm Creek Shale
	Mowry Shale	Kiowa Shale	Mowry Shale	Mowry Shale
	Skull Creek Shale		Aspen Shale	Skull Creek Shale Thermopolis Shale
	Fuson Shale		Cedar Mountain Shale	Kootenai Formation Cloverly Shale

Data adapted from Shell Oil (1975) and Heeside (1944).

The Pierre Shale is generally considered a typical marine-clay shale in terms of composition.^{2,4} Its composition shows most variation in the western outcrop area of Montana and Wyoming where significant amounts of nonmarine shale and sandstones were deposited in the trough; overall the Pierre Shale averages 70% clay minerals. Mixed-layer clays are strongly dominant and average 75% to 85% of total clay content; varying proportions of illitic (nonexpandable) and montmorillonitic (expandable) mixed-layer clays are present throughout. The rest of the clay-sized fraction includes (in decreasing order of abundance) illite, chlorite, and kaolinite; kaolinite is locally abundant to the west. The nonclay fraction averages 30% and is dominated by silt-sized grains of quartz and feldspar. Organic carbon is present but is generally less than 2%. Calcite, though locally abundant in fossiliferous concretions, is a minor constituent in most shales. Discrete bentonite layers are present and often laterally continuous. Uncombined pore water and water chemically bound in clays are present in generally equivalent amounts, totalling an average of 9% by weight. Pore water in unweathered samples may be as high as 10% in saturated shale at depth if the average 25% porosity is completely filled by water. Local trace constituents include gypsum, pyrite, dolomite, siderite, and the zeolite clinoptilolite. A detailed analysis of the composition and properties of the Pierre Shale should be available soon.⁵

Other Phanerozoic Shales

Table 2 and the maps it refers to (Figures 1, 4-16) summarize the location, lithology, approximate maximum thickness, formation names, and outcrop areas of Phanerozoic shale-rich strata greater than 150 m (500 ft) in thickness. The principal source for these data is Shell Oil Company's Stratigraphic Atlas of North and Central America.⁶ The table lists the shale-rich rock units according to geologic age and geographical area. Age units were selected on the basis of abundance of shale units; thus two maps are required to show the extensive shales of the Permian System, and other maps show smaller subdivisions of rock systems on single maps.

TABLE 2

Summary of Phanerozoic Shales, Continental United States

System-Series Stage			Location	Lithology*	Approximate Maximum Thickness (m/ft)	Formation Names*	Figure
Cretaceous	Upper	California, Oregon	Black and gray sh, sandstone, minor limestone, chert, volcanics	3000/10 000	Great Valley Seq, Panoche Gp, Moreno Sh, Forbes Sh, Uhalde Fm, Marlite Sh, Funks Sh, Redil Fm, Yolo Sh, Val Hills Sh	1, 4	
	Upper	Gulf Coastal Plain-Texas, Louisiana, Alabama, Georgia, Mississippi	Black and gray sh, lesser sandstone, limestone	1500/5000 thins to north	Eagle Ford Sh, Tuscaloosa Sh, Bonham Sh, Eutaw Sh, Navarro Sh, Taylor Fm, Austin Fm	1, 4	
	Upper	Western Interior-Rocky Mountains and Great Plains	Black and gray sh, minor limestone, sandstone, bentonite	1500/5000	See Table 1	1, 2, 3, 4	
Cretaceous	Lower	Northern Great Plains and Central Rocky Mtns Utah, Wyoming, Montana	Black and gray sh, lesser sandstone, limestone, local bentonite	600/2000	See Table 1	5	
Cretaceous	Lower	California, Oregon	Black and gray sh, lesser chert, and volcanics	3000/10 000	Wissner Fm, Uno Fm, Pascua Fm, Rector Fm, Davis Canyon Fm, Days Creek Fm, Panoche Fm	5	
	Lower	Louisiana, Texas	Black and gray sh, some limestone, sandstone, evaporites	300/1000	Rodessa Sh, Paluxy Sh, Glen Rose Gp	5	

*Abbreviations:

Fm - Formation

Gp - Group

Sh - Shale

Seq - Sequence

TABLE 2 (cont.)

<u>System-Series-Stage</u>	<u>Location</u>	<u>Lithology*</u>	<u>Approximate Maximum Thickness (m/ft)</u>	<u>Formation Names*</u>	<u>Figure</u>
Jurassic Upper	East Central Oregon	Black and gray sh, local limestone	3000/16 000	Trowbridge Fm Lonesome Fm	6
Upper	Western Wyoming, Utah, Colorado	Black and gray sh, green sh, subordinated sandstone	300/1000	Summerville Fm Morrison Fm	6
Upper	Northeast Montana	Red, green, gray sh, lesser sandstone	240/800	Redwater Sh Swift Fm Morrison Fm	6
Upper	Southern Arkansas	Red sh, minor evaporites	450/1500	Lower Cotton Valley Gp	6
Upper	Gulf Coastal Plain- Texas, Louisiana, Alabama, Mississippi	Gray and black sh, lesser sandstone, minor limestone	900/3000	Bossier Sh Cotton Valley Gp	6
Middle	Northeast Montana, Northwest North Dakota	Gray and black sh, red sh, limestone, sandstone	150/500	Upper Sundance Fm Rierdon Fm	6
Middle	Wyoming, Utah	Red, gray, green sh, some limestone, siltstone	180/600	Lower Sundance Fm Carmel Fm	6
Lower	West Central Nevada	Black and gray sh, minor limestone	1500/5000	Dunlap Fm Sunrise Fm	6

TABLE 2 (cont)

System-Series-Stage		Location	Lithology*	Approximate Maximum Thickness (m/ft)	Formation Names*	Figure
Triassic	Upper	Gulf Coastal Plain-- Texas, Louisiana, Alabama, Mississippi	Red sh, siltstone, sandstone, minor intrusives, volcanics	900/3000	Eagle Mills Redbeds	7
	Upper	Atlantic Coastal Region, "Triassic Basins"	Red sh, siltstone, sandstone, minor intrusives, volcanics	3000/10 000	Newark "Series" Pekin Fm Sanford Fm	7
	Upper	Four Corners Region (Including New Mexico, Arizona)	Red sh, lesser sandstone, minor limestone	450/1500	Chinle Fm	7
	Upper	Eastern New Mexico, Northwest Texas	Red sh, lesser siltstone, sandstone	600/2000	Dockum Gp	7
	Lower	Western Wyoming Southwest Montana	Red sh, some sandstone	270/900	Woodside sh Chugwater Fm	7
	Lower	Eastern Utah	Red sh, some sandstone	900/3000	Woodside Sh Moenkopi Fm	7
Permian	Guadalupian	Texas, Oklahoma	Red sh, local sandstone and evaporites	300/1000	Delaware Mtn Gp Artesia Fm	8
	Leonardian	Texas, Oklahoma, Kansas	Green and red sh, minor evaporites	760/2500	Clear Fork Fm Bone Spr. Fm, Hennessy Fm Lyons Fm, Minnekahta Fm	8
	Leonardian	Arizona, New Mexico	Red and green sh, minor sandstone	300/1000	Supai Fm	8
	Wolfcampian	Four Corners Region (Including New Mexico, Arizona)	Red sh, minor sandstone, limestone	300/1000 300/1000	Abo Fm, Cutler Fm, Supai Fm	9
	Wolfcampian	Texas, Oklahoma	Black and gray sh minor limestone, sandstone	450/1500	Wolfcamp Fm, Wichita Fm, Council Grove Fm, Minnelusa Fm	9

TABLE 2 (cont)

System-Series-Stage			Location	Lithology*	Approximate Maximum Thickness (m/ft)	Formation Names*	Figure
Pennsylvanian	Upper	Central New Mexico, Four Corners Region	Gray and red sh, sandstone, limestone	300/1000	Madera Fm Hermosa Fm	10	
	Upper	Texas, Oklahoma, Kansas, Nebraska	Gray and black sh, minor limestone, sandstone	450/1500	Virgil and Missouri sh, local names	10	
	Lower	Texas, New Mexico, Oklahoma, Kansas, Iowa, Missouri, Arkansas, Alabama, Mississippi	Gray and black sh, minor limestone and sandstone	1500/5000	Aloks, Morrow, Des Moines sh, and other local names	11	
	Lower	Illinois Basin-Illinois, Indiana, Kentucky	Black and gray sh, lesser sandstone	300/1000	McLeansboro Fm, Carbondale Fm, Tradevater Fm	11	
	Lower	Appalachian Foreland-Kentucky, Virginia	Gray and black sh	300/1000	Kanawha Gp New River Gp	11	
Mississippian	Chesterian	Oklahoma, Arkansas, Alabama, Mississippi	Gray and black sh, minor limestone	900/3000	Chester Sh Springer Sh	12	
	Chesterian	Appalachian Foreland-West Virginia, Virginia, Pennsylvania, Kentucky	Red sh, some sandstone, limestone	1050/3500 (?-control poor)	Avis Sh	12	
	Chesterian	Illinois Basin-Southern Illinois	Red sh, siltstone, sandstone, limestone interbeds	300/1000	Menard Fm, Golconda Fm, Glen Dean Fm	12	
Chester and Pre-Chester	Eastern Nevada, Western Utah, Idaho	Black and gray sh, limestone, minor sandstone	450/1500	Manning Canyon Sh Chainman Sh	12		

TABLE 2 (cont)

<u>System-Series-Stage</u>	<u>Location</u>	<u>Lithology*</u>	<u>Approximate Maximum Thickness (m/ft)</u>	<u>Formation Names*</u>	<u>Figure</u>
Mississippian					
Pre-Chesterian	Illinois Basin-Southern Illinois	Gray and black sh, minor sandstone, limestone	300/1000		12
	Pre-Chesterian Michigan Basin-Michigan	Gray and black sh, minor sandstone	600/2000		12
Devonian	(all) Central Nevada	Dark sh and chert	900/3000	"Devonian Sh"	13
	Upper Northern Appalachian Foreland-New York, Pennsylvania, West Virginia, Kentucky, Ohio	Gray and black sh, sandstone lenses to east	2400/8000 thins to west	Mahantango Fm Chumung Gp	13
	Lower Northern Appalachian Foreland-New York, Pennsylvania, West Virginia	Gray and black sh, sandstone in east, limestone in west	900/3000	Portage Gp, Ohio Sh, Hamilton Gp	13
Silurian	(all) North Central Nevada	Gray and black sh	300/1000	Four Mile Canyon Sh	14
	(all) Arkansas, Oklahoma	Gray and black sh	600/2000	Missouri Mountain Sh	14
	(all) Appalachian Foreland-New York, Pennsylvania, West Virginia, Kentucky	Red, green, and gray sh, lesser sandstone, limestone, dolomite	300/1000	Rochester Sh, Rose Hill Sh, Williamson Sh	14

TABLE 2 (cont)

<u>System-Series-Stage</u>	<u>Location</u>	<u>Lithology*</u>	<u>Approximate Maximum Thickness (m/ft)</u>	<u>Formation Names*</u>	<u>Figure</u>
Ordovician (all)	New York, Pennsylvania, West Virginia, Ohio	Gray and black sh, minor sandstone, limestone, metamorphosed in east	900/3000	Reedsville Sh, Martinsburg Slate, Lorraine Sh, Snake Hill Sh, Normanskill Sh, Deepkill Sh, Schaghticoke Sh, Sequatchie Sh	15
Cambrian	Upper Central Nevada	Black and gray sh, minor limestone	900/3000	Preble Sh Dunderberg Sh	16
	Upper Montana, Dakotas, Wyoming, Utah	Black and gray sh, minor limestone	240/800	Park Sh, Ophir Fm, Deadwood Fm	16
	Middle Central Nevada	Black and gray sh, minor limestone	900/3000	Preble Sh Picotte Sh	16
Cambrian	Middle Montana, Wyoming	Black and gray sh, minor limestone, sandstone	240/800	Wolsey Sh Depass Sh	16
Cambrian	Middle West Virginia, Kentucky, Tennessee	Gray and black sh, lesser green sh, minor limestone, sandstone	1500/5000	Rome Fm, Rogersville Sh, Hollichucky Sh, Conasauga Sh, Waynesboro Fm	16

Source of data: Shell Oil Company, Stratigraphic Atlas of North and Central America, Princeton University Press 1975.

Figure 5. Lower Cretaceous Shale

Figure 6. Jurassic Shale

Figure 7. Triassic Shale

Figure 8. Middle Permian Shale (Guadalupian, Leonardian)

LOWER PERMIAN SHALE (WOLFCAMPIAN)

- Permian outcrops (undivided)
- Area underlain by Leonardian shale-rich strata 500 ft thick
- Area underlain by Guadalupian shale-rich strata at least 500 ft thick

Source: Shell Oil Company, Stratigraphic Atlas of North and Central America, 1975

Figure 9. Lower Permian Shale (Wolfcampian)

Figure 10. Upper Pennsylvanian Shale (Missourian, Virgilian)

Figure 11. Lower Pennsylvania Shale (Atokan, Morrowan, Des Moinesian)

Figure 12. Mississippian Shale

Figure 13. Devonian Shale

Source: Shell Oil Company, Stratigraphic Atlas of North and Central America, 1975

Figure 14. Silurian Shale

Figure 15. Ordovician Shale

Figure 16. Cambrian Shale

The maps (Figures 1, 4-16) were constructed by screening isopach thickness) maps in the stratigraphic atlas for section thicknesses in excess of 150 m (500 ft) and then screening these areas with lithofacies map, to yield areas underlain by shale-dominated sequences in excess of 150 m (500 ft). Outcrops shown represent all rocks of similar age exposed in the vicinity of shale-rich strata but are not exclusively shale. In general, shale-rich strata exposed at the surface can be expected to be thinner because of erosion than the same strata in the subsurface away from outcrop areas. Rock types that are locally abundant may be omitted because of the generalized regional nature of this compilation (such as a thick sandstone lens in a dominantly shale sequence). In areas where these variations have been recognized, they have been mentioned under "Lithology" in Table 2. Detailed specification of lithologic variation must be considered in more detailed future investigations, and "Formation Names" are included as key words for this purpose.

Precambrian Shale and Argillite

Table 3 and the accompanying maps (Figures 17-18) summarize the location, lithology, approximate maximum thickness, formation names, and outcrop areas of Precambrian sedimentary and low-grade metamorphic strata that may contain clay-rich strata greater than 150 m (500 ft) in thickness. The information in Table 3 is generally less reliable than the same information for Phanerozoic strata (Table 2), primarily because the base of research data is much less extensive for the Precambrian than for Phanerozoic strata. A notable exception to this generalization among the rock units listed in Table 2 is the Belt Supergroup of the Northern Rocky Mountains, which has been the subject of some detailed stratigraphic study.⁷

TABLE 3

Precambrian Rocks Containing Significant Thicknesses of Shale and/or Argillite, Continental United States*

Precambrian Age	Location	Lithology*	Approximate Maximum Thickness (m/ft)	Formation Names*	Figure
Z	Southwestern Appalachian Foreland	Mostly graywacke turbidites with thick-to-thin units of dark sulfidic argillite; metamorphosed in east	7000/25 000 largely allochthonous	Ocoee Supergroup: Walden Creek, Snowbird, and Great Smoky Gps	18
Z	North-Central Utah	Red-purple quartzite and red-to-green sh	360/1200	Mutual Fm	18
Z	Nevada-Utah Border Region, Southern Idaho	Includes several persistent quartzite units separated by units of argillite and siltstone; minor marble layers	2700/9000	McCoy Creek Gp, Sheeprock Series	18
Z	California-Nevada Border Region	Sh and argillite with subordinate carbonate beds	3000/10 000 thins eastward	Deep Spring Fm, Wynan Fm, Johnnie Fm	18
Y	Needle Mountains, Southwestern Colorado	Quartzite and interbedded slate, tightly folded	2400/8000	Uncompahgre Fm	17
Y	Uinta Mountains, Eastern Utah, Colorado	Dark sh, siltstone, and minor quartzite	1500/5000	Red Pine Sh (of Uinta Mountains Gp)	17
Y	North-Central Utah	Quartzite and interbedded varicolored sh	5000/16 000	Big Cottonwood Fm	17
Y	Western Montana, Idaho	Siltstones grading into argillites and quartzites; often highly metamorphosed near granitic plutons (Figure 2)	15 000/50 000 (of Supergroup) largely allochthonous	Belt Supergroup: Prichard Fm, Ravalli and Missoula Gps	17

*Abbreviations:

Gp - group
Fm - formation
seq - sequence
sh - shale

TABLE 3 (cont)

<u>Precambrian</u>			<u>Approximate Maximum</u>		
<u>Age</u>	<u>Location</u>	<u>Lithology*</u>	<u>Thickness</u>	<u>Formation Names*</u>	<u>Figure</u>
			<u>(m/ft)</u>		
Y (incl. some Z)	Southeastern California	Quartzite and sh below and above medial carbonates; extensively intruded by diabase sills	1200/4000	Crystal Spring Fm	17
Y (incl. some Z)	Arizona	Red sh and argillites; some varicolored argillite with thin limestone beds	2000/6000 (of Groups; shales thinner)	Sixty Mile Fm (Chuar Gp) Hakati Sh (Unkar Gp) Pioneer Sh (Apache Gp)	17
X	Black Hills- South Dakota	Graywacke, slate, graphitic chert, pillow lava; often highly metamorphosed		Upper Kenoran Seq	17

Source of data:

King, P. B., Precambrian Geology of the United States (an explanatory text to accompany the geologic map of the United States) US Geological Survey Professional Paper 902, 1976, 85 pp.

Figure 17. Precambrian X and Y Shale/Argillite

Figure 18. Precambrian Z Shale/Argillite

The primary source for Table 3 contains a large bibliography that could serve as a base for further study.⁸ The age designations used in Table 3 follow current US Geological Survey usage:

<u>Designation</u>	<u>Age (yr)</u>
W	More than 2.5 billion
X	1.6 to 2.5 billion
Y	0.8 to 1.6 billion
Z	570 to 800 million

No suitable strata of W age are believed to exist, primarily because of high-grade metamorphism. Only one potential site of X age was located, but information on thicknesses and lithology is poor. Most of the areas and rock units listed (Table 3) are of Y and Z ages since these strata are generally less disturbed by metamorphism. For many of these rock units, the thicknesses given are for the entire sequence rather than for shale or argillite units.

Summary

Cretaceous shales of the Western Interior occur in vast quantities and frequently are relatively homogeneous with thicknesses ~150 m (500 ft). Some earlier Mesozoic, Paleozoic, and Precambrian shales and argillites also appear to have sufficient thickness and lateral extent to be further considered as potential host media for nuclear waste repositories. In addition, the older rock units often have a lower proportion of expandable clays and lower water content.^{9,10}

Figure 19. Areas of Potential Seismic (Earthquake-Hazard) Activity

Figure 20. Generalized Tectonic Features

Figure 21. Average Annual Precipitation and Runoff

Figure 22. Economically Important Coal Deposits

Figure 23. Economically Important Hydrocarbon Deposits (Petroleum, Natural Gas, Oil Shale)

Figure 24. Generalized Glacial Geology

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