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PRELIMINARY SYNTHESIS OF SUBSURFACE STRATIGRAPHY OF THE NIOBRARA FORMATION (UPPER CRETACEOUS) IN THE NORTHERN GREAT PLAINS

by

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ABSTRACT

The Niobrara Formation (Upper Cretaceous) in the northern Great Plains is being studied by the U.S. Geological Survey because it includes potential low-permeability reservoirs for natural gas. Subsurface investigations of the Niobrara indicate that three major chalk tongues are found within the unit. In the Dakotas, the chalk tongues grade westward into the noncalcareous shales of the Pierre Shale. However, this contrasts with the section in Nebraska where the chalks thicken and show lateral facies relationships with calcareous shales within the Niobrara. The lowest chalk tongue is confined to Nebraska and southern South Dakota whereas the middle and upper tongues are found throughout Nebraska, South Dakota, and North Dakota. Of the three, the middle chalk tongue is the most wide-spread and continuous.

The interval from the base of the Ardmore Bentonite Beds of the Pierre Shale to the base of the Niobrara was mapped throughout the northern Great Plains. This interval includes the Niobrara and equivalent shales in the Gammon Member of the Pierre. The isopach map shows an oblate area of thin sediments extending from northeast to southwest through southern South Dakota and northern Nebraska. A map of net chalk thickness within the Niobrara reveals thin chalk over the oblate area of thin sediments; however, the thickest chalks are found on the flanks of this feature.

The northeast-trending oblate area is interpreted to be a paleotectonic feature which influenced the dispersal of clastics and the accumulation of chalk. Occurrences of natural gas within the Niobrara are probably controlled by the distribution and thickness of chalk and by the depth of burial.

INTRODUCTION

The U.S. Geological Survey in cooperation with the Department of Energy is investigating the geologic setting of major natural gas resources in low-permeability reservoirs in the northern Great Plains. Chalks are one of six facies included in the studies (Rice and Shurr, 1978) and chalks in the Niobrara Formation of Colorado and Kansas are proven gas reservoirs (Lockridge, 1977; Lockridge and Scholle, 1978). Although reserves of natural gas are known to exist in Colorado and Kansas, exploration activity is only now beginning to assess the potential in states farther north, such as Nebraska and the Dakotas.

This study describes regional isopach and lithofacies variations in the Niobrara Formation over large portions of Nebraska, South Dakota, and North Dakota (fig. 1). The Niobrara is relatively continuous throughout this area, but is exposed only locally. Outcrops in northwestern Kansas have been described in detail (Hattin, 1977) and outcrops on the west flank of the Black Hills are included in the work of Robinson, Mapel, and Bergendahl (1964). In the eastern Dakotas, where the Niobrara subcrops beneath glacial drift, exposures have been described along the Missouri River in south-central South Dakota (Simpson, 1960) and in northeastern North Dakota (Carlson, 1964). Extensive petrology has been done on well core samples from northwestern Kansas and eastern Colorado (Scholle, 1977) and some geochemical data from the Niobrara are available in South Dakota (Stach, 1976).

The Niobrara Formation in the northern Great Plains is dominantly chalk and chalky shale. It is underlain by the noncalcareous Carlile Shale and overlain by the noncalcareous Pierre Shale. Both the lower and upper contacts of the Niobrara are locally unconformable. In Kansas, the Niobrara is subdivided into the Fort Hays Member at the base, which is about 20 m

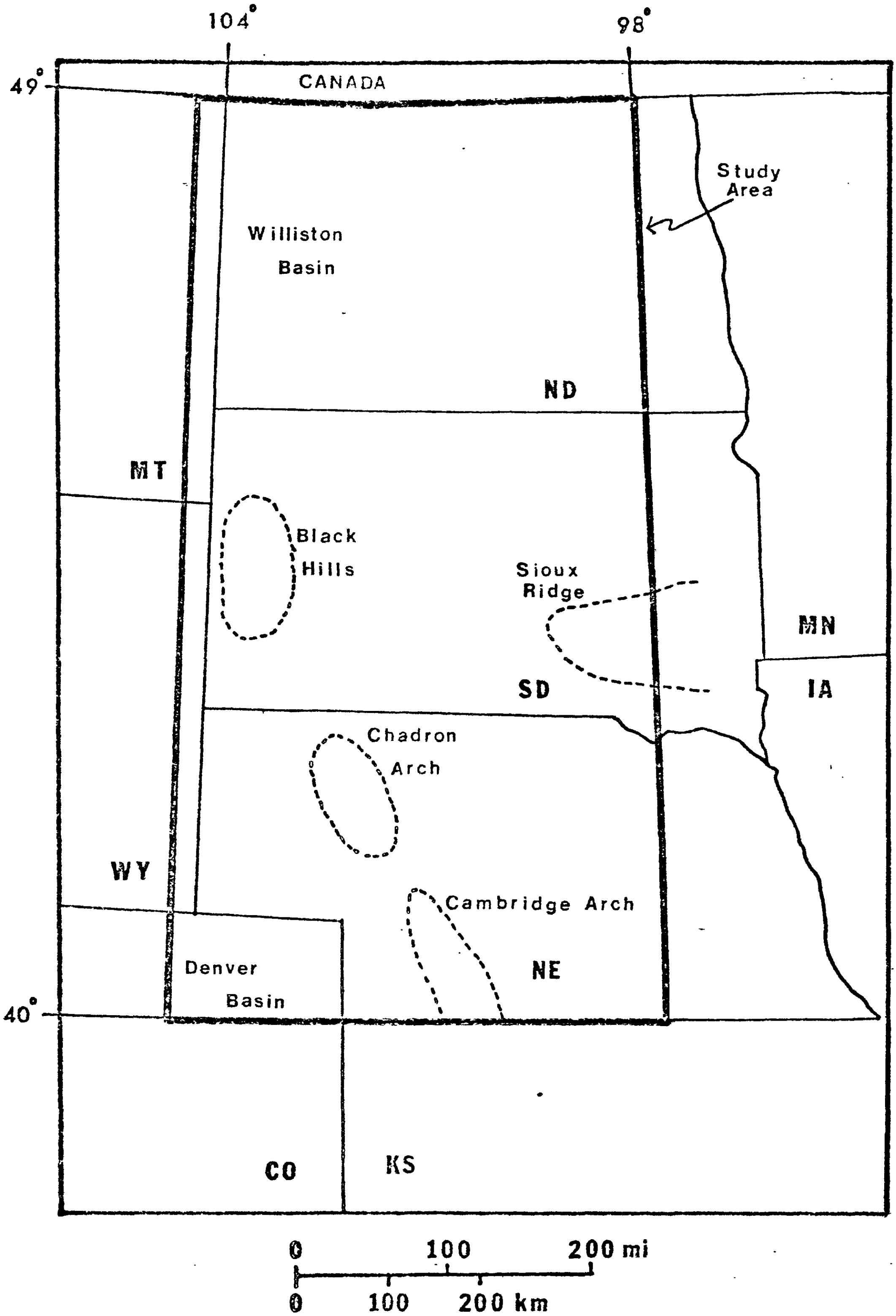

Figure 1. Index map showing location of the study area and major geologic structures.

(66 ft) of chalk, and the overlying Smoky Hill Member, which is about 180 m (590 ft) of chalky shale with some chalk (Hattin, 1977). Although some attempts have been made to apply the member terminology farther north (for example, Bolin,1952), facies changes generally obviate widespread application of this terminology. The chalks of the Niobrara are biomicrites composed largely of coccoliths which display varying degrees of diagenetic alteration (Scholle, 1977). Regionally the chalks pass westward and northward into chalky shales commonly referred to as "white specks" or "first specks" by subsurface workers. Biostratigraphic zonation of the Niobrara and of the units above and below indicate a Campanian age for the Niobrara (Cobban, 1964; Hattin, 1975).

The area described in this report encompasses a major portion of the Williston Basin, the northeastern part of the Denver Basin, and the several uplifts which separate these two basins, including the Cambridge and Chadron Arches, the Black Hills Uplift, and the Sioux Ridge (fig. 1). All of these tectonic features are clearly post-depositional, because they have expression on structure contour maps of markers above the Niobrara (for example, Shurr, 1980). However, subsurface studies in central South Dakota suggest that paleotectonism did influence Niobrara deposition (Shurr, 1978) and similar suggestions of important paleotectonic controls have come from work in Colorado (Weimer, 1978).

SUBSURFACE CORRELATION SECTIONS

In this investigation the lateral extent, external geometry, and internal variations of the Niobrara Formation are based upon interpretations of electric logs (plates 1, 2, 3). Parastratigraphic units are correlated in subsurface by employing marker beds and log characteristics. Interpretation of the lithologies represented by parastratigraphic units is facilitated by correlation of measured outcrop sections with nearby well logs. Surface-subsurface ties have been established in northeastern North Dakota (Carlson, 1964), in the northern Black Hills (Rice, 1976), and in central South Dakota (Shurr, 1971).

In general, the well-developed massive chalks of the Niobrara have a higher resistivity and spontaneous potential than the noncalcareous shales occurring above and below. This log response makes the base and top of the Niobrara easily interpreted from electric logs, particularly in areas such as the central Dakotas where the unit is predominantly chalk. In areas such as the western Dakotas where the Niobrara includes chalky shale, the top is less easily interpreted because the log response is very similar to that for noncalcareous shale. Chalky shale seems to have a resistivity and spontaneous potential which is only slightly higher than noncalcareous shale. The base of the Niobrara generally has good log expression through the northern part of the study area. However, in southern South Dakota and Nebraska the base is less well defined. This is probably due to local erosion and to local sandstones which have a log response similar to chalk.

The subsurface correlation study uses the base of the Ardmore Bentonite Beds in the Sharon Springs Member of the Pierre Shale as a horizontal datum. The top of the Greenhorn Formation is shown in the sections (plates 1, 2, 3), but it is the correlations in the Niobrara which will be discussed and which form the basis for facies and isopach mapping.

The panel of subsurface correlations in South Dakota (plate 1) is representative of regional facies and isopach variations within the Niobrara throughout the northern Great Plains. Specifically, chalks and chalky shales of the Niobrara grade laterally into the noncalcareous shales of the Gammon Member of the Pierre Shale. Where the Niobrara is dominated by chalky shale and carries little or no chalk, the Gammon is thick; where the Niobrara contains well-developed chalk, the Gammon is thin. Correlation lines running from west to east in central and northern South Dakota (for example, Rice, 1976) show two chalk tongues which grade laterally into thick shale in stratigraphic relationships almost identical with those shown from north to south on Plate 1.

In North Dakota, subsurface correlations (plate 2) show the same relationship between presence of chalk in the Niobrara and thickness of the Gammon Member of the Pierre Shale. As the Niobrara moves up-section toward the Ardmore from south to north, it becomes more chalky and the overlying Gammon becomes thinner. The local loss of chalk in the Niobrara at the north end of the section is associated with a thickening of the Gammon.

Across western Nebraska and southward into eastern Colorado, where natural gas is produced from the Niobrara, the stratigraphic generalizations described in the Dakotas are less useful (plate 3). A third chalk tongue is found in the lower Niobrara, and it appears to pass laterally into sandstone and sandy shale (chalk tongue C, plate 3). The Niobrara increases in thickness southward into Colorado and there is very little Pierre Shale between the top of the Niobrara and the Ardmore. Thickness variation within the Niobrara is illustrated by the southward thickening of chalky shale between chalk tongues B and C (plate 3).

In summary, chalk and chalky shale of the Niobrara grade laterally into the Gammon Member of the overlying Pierre Shale which is a thick unit of noncalcareous shale. This facies change takes place to the north and west, in the Dakotas. To the south and east in Nebraska and Colorado, where the chalk and chalky shale thicken as a unit, the increase in thickness is particularly striking in the lower part of the Niobrara.

SUBSURFACE MAPS

Three subsurface maps of the Niobrara were prepared on the basis of correlations summarized in Plates 1, 2, and 3. These maps are: 1) Facies map showing maximum extent of the main chalk tongues (plate 4); 2) Map of net thickness of chalk within the Niobrara (plate 5); 3) Isopach map of the interval from the base of the Niobrara to the Ardmore Bentonite Beds (plate 6).

The subsurface logs used in this investigation were part of a data array assembled for the purpose of studying the geologic setting of the Pierre Shale in the northern Great Plains (Shurr, 1977; 1980). A computer scan of the "Well History Control System", produced by the Petroleum Information Corporation, selected one well per township from the 33,000 wells which penetrated the Pierre. The resulting sample of 5,000 control points was still too large for easy manipulation, and it was reduced further by subjective evaluation of the geophysical logs. Approximately 550 logs were selected with an average spacing of 29 km (18 mi). The Niobrara was investigated in 200 logs located in the Dakotas and in 130 logs located in Nebraska.

The facies map (plate 4) shows the maximum extent of the main chalk tongues (chalk tongues A, B, C shown on plates 1, 2, 3) within the Niobrara. The three facies lines mark the approximate areas where log units characterized by high resistivity and spontaneous potential grade into units of lower resistivity and spontaneous potential. This is thought to represent the lateral gradation of massive chalk tongues into chalky shales. The positions of the facies change are only generally located on Plate 4 because the control points are widely separated. In South Dakota a more detailed configuration of the facies lines is available from a study which uses more closely-spaced data (Shurr, 1978).

The middle chalk tongue (B) has the greatest lateral extent (see plate 4). In the northeastern portion of the study area, however, the upper chalk tongue (A) is more continuous and extends into an area where the stratigraphic interval equivalent to the middle chalk tongue (B) is characterized by chalky shale. This generalization agrees with surface and subsurface studies available in northeastern North Dakota (Carlson, 1964). Near the international border in central North Dakota, the mapped extent of the middle chalk tongue (B) may actually represent a tongue in Canada which lies at a slightly different stratigraphic position than the middle chalk tongue (B) to the south (see plate 2). The maximum extent of the lower chalk tongue (C) in Nebraska and southeastern South Dakota is only approximated by the dashed and dotted line shown in Plate 4. This chalk tongue is generally well-developed south and east of the line, but similar log signatures for the chalk and for sandstone (plate 3) make the maximum extent of the tongue difficult to map. Chalk and sandstone facies complications are particularly acute in the portions of the line which are dotted (plate 4).

The net thickness of massive chalk within the Niobrara is shown on Plate 5. Chalky shale separating the chalk tongues is excluded from these data. Large areas of the western Dakotas are characterized by fairly uniform thickness values ranging up to 15 m (50 ft). These large areas mark the distribution of the middle chalk tongue (B); the maximum extent of this tongue (plate 4) corresponds with the zero line in the western Dakotas (plate 5). Thickness values increase rapidly to 31 m (100 ft) in central South Dakota (plate 5) in areas where the upper chalk tongue (A) is added above the middle tongue (B) (plate 4). The oblate area of zero values in the northeastern part of the study area (plate 5) is an area where neither chalk tongue A nor B are developed (plate 4). In eastern North Dakota minor chalk tongues are found above the upper tongue (A), which give local areas of thickness ranging up to 46 m (150 ft). The area of thickness exceeding 46 m (150 ft) in the extreme southeastern portion of the study area is generally characterized by the presence of the lower chalk tongue (C) below the middle tongue (B) (plate 4).

Net thickness of chalk is not mapped throughout Nebraska for three reasons: first, the geographic distribution of usuable logs in the data array is poor; second, the log expression of chalk in the lower tongue is difficult to distinguish from sandstone (plate 3); and third, many of the logs do not show a clear distinction between chalk and chalky shale within the Niobrara. This altered log response may be due in part to the influence of fresh water, because the problem is particularly acute in the area of Niobrara subcrop on the Chadron and Cambridge Arches (fig. 1). Correlation studies of available logs do suggest, however, that chalk thickness increases to the south and east as illustrated in Plate 3. This generalization is also supported by biostratigraphic and lithostratigraphic correlation of measured sections from exposures in Kansas and Nebraska (Hattin, 1975).

The thickness of the total interval from the base of the Niobrara to the Ardmore Bentonite Beds is shown in the isopach map of Plate 6. The non-calcareous shales of the Gammon Member of the Pierre Shale are included in these data. In the Dakotas the Pierre and Niobrara show facies relationships which make the top of the Niobrara difficult to define and hence, the clearly-defined Ardmore (plates 1 and 2) is employed as the upper datum of the isopach map (plate 6). Problems with log expression of the chalks within the Niobrara in Nebraska do not substantially affect the definition of the Ardmore or the base of the Niobrara, except in areas of local sandstone development.

An area of thin Niobrara extends northeast to southwest through southern South Dakota and northern Nebraska (plate 6). This is also an area of locally thin net chalk; thick net chalk is found flanking the area of thin sediments to the northwest and southeast (plate 5). Pronounced thickness increase to the north and west is associated with the lateral facies change from chalk and chalky shale to the noncalcareous shale of the Pierre. Local eastward projection of thick sediments in western North Dakota is associated with a re-entrant in the facies line (plate 4) which marks a local decrease of net chalk thickness (plate 5). To the south and east of the elongate area of thin sediments, the increase in thickness is gradual throughout Nebraska (plate 6). In this direction the chalks and chalky shales of the Niobrara increase to maximum values of over 183 m (600 ft) (well 21, plate 4) in the area of natural gas production in northeastern Colorado (for example, see Lockridge and Scholle, 1978).

INTERPRETATIONS

Thickness variations in the Niobrara are the result of lateral facies changes and of erosion. The decrease in thickness northward across Nebraska (plate 6) is associated with facies relationships between chalk and chalky shale (plate 3). In the western Dakotas, termination of the middle chalk tongue (B) (plates 4 and 5) corresponds to the location and orientation of the contour lines for 183 to 244 m (600 to 800 ft) (plate 6). Several areas of the map show nonparallel facies and isopach lines and these probably indicate that thickness variations may be due to erosional thinning (Krumbein and Sloss, 1963, p. 491). In northeastern North Dakota the pinchout of the middle chalk tongue (B) (plate 4 and 5) has little isopach expression (plate 6), perhaps indicating erosional thinning. Within the northeast-trending area of thin sediments (plate 6) facies and isopach lines are locally non-parallel; this may also be a site of erosion.

Erosional truncation is difficult to document in this subsurface study because the control points are widely spaced. However, erosion has been demonstrated to be present at both the base and the top of the Niobrara in several areas. Biostratigraphic zonation in the southern Black Hills (Tourtelot and Cobban, 1968; Merewether, Cobban, and Cavanaugh, 1979) indicates an unconformity at the base of the Niobrara. Biostratigraphic correlations from northwestern Kansas to northeastern Nebraska show that the magnitude of this basal hiatus increases to the north (Hattin, 1975). The erosion which produced the basal unconformity obviously did not directly influence the thickness of the Niobrara, except to suggest the existance of a paleotopographic high which may have influenced Niobrara deposition. Erosion at the top of the Niobrara has been documented in subsurface studies in the Nebraska panhandle (DeGraw, 1975) and in central South Dakota (Shurr, 1971).

In contrast, biostratigraphic correlations extending from central Montana into the northern Black Hills (Cobban, 1964) substantiate the facies relationships between the Niobrara and overlying Pierre Shale shown in Plate 1. Biostratigraphic zonation in the lower Pierre in northwestern Kansas indicates slow deposition (Gill, Cobban, and Schultz, 1972), but little or no erosion.

In general, the areas of erosion lie on or very near the northeast-trending area of thin sediments (plate 6). Furthermore, thick chalks are developed on the flanks of this feature. It is here suggested that this feature extended across the axis of the Upper Cretaceous seaway and was tectonically active at the time of deposition of the Niobrara Formation. The tectonic feature is thus analogous to the Peace River Arch which was a cross-basin feature in Canada, active during the Upper Cretaceous (Stelck, 1975). The existance of such a paleotectonic feature trending northeast and influencing Niobrara deposition in Colorado has recently been suggested by Weimer (1978). Weimer (1978) applies the phrase "Transcontinental Arch" to this Cretaceous feature. The Transcontinental Arch has usually been thought to influence only Paleozoic deposition.

In South Dakota, paleotectonic controls on Niobrara deposition have been demonstrated for specific leneament-bound structural blocks (Shurr, 1978). Two sets of lineaments define the blocks: one set trends to the northeast and one set trends to the northwest. The overall aspect of the maximum northwestern extent of the middle chalk tongue (B) corresponds to the northeast lineaments (plate 4; Shurr, 1978). The major tectonic feature trending northeast across the basin is probably also a manifestation of the northeast-trending lineaments. Thickness variations at this major feature's margins define re-entrants which relate to the northwest lineaments (plate 5; Shurr, 1978). The distinctive northwest thickness variations in net chalk in southeastern North Dakota (plate 5) may also reflect this tectonic control.

The broad northeast-trending area of thin sediments (plate 6) flanked by locally thick chalks (plate 5) is therefore thought to represent a paleotectonic feature which influenced Niobrara deposition. The existence of this feature has implications for the source of terrigenous sediments within the mapped interval (plate 6). To the northwest of the feature, terrigenous influx from the west resulted in the thickening of the interval in that direction. The paleotectonic feature limited dispersal of these western-source sediments and hence only chalky shales are associated with chalks south and east of the feature. Terrigenous components in Nebraska probably reflect an eastern source because this area was isolated from the western source areas by the paleotectonic arch.

Although interpretation of the data presented in this report has produced some interesting speculations on paleotectonics, the data may also have utility in the exploration for natural gas from the Niobrara. The Niobrara is an important natural gas reservoir in northeastern Colorado and northwestern Kansas (Lockridge, 1977) and exploration activity has subsequently increased in Nebraska and South Dakota. Chalk tongues characterized by high resistivity and high spontaneous potential (plates 1, 2, 3) are probably the best reservoir rocks within the Niobrara. The distribution of the chalk tongues (plates 4 and 5) thus gives some indication of the distribution of potential reservoir rocks. The porosity and permeability of these chalk reservoirs has been investigated by Scholle (1977) who believes depth of burial is an important factor in the distribution of chalk porosity. Estimates of porosity variation within the chalk reservoirs may be obtained by employing a map of burial depth; Lockridge and Scholle (1978) present an example using thickness data published by Reeside (1944). A map of the thickness of the Pierre Shale and overlying rocks, which is equivalent to the depth of burial of the Niobrara, has recently been made available for the northern Great Plains (Shurr, 1980). This map is at the same scale as the maps in the current report. The map of burial depth used in conjunction with the maps of Niobrara facies and thickness (plates 4 and 5) delineates areas which have the thickest and most porous chalk reservoirs, because the deeply buried chalks have lower porosity.

REFERENCES CITED

Bolin, E.J., 1952, Microfossils of the Niobrara Formation of southeast South Dakota: South Dakota Geol. Survey Report Inv. 70, 84 p.

Carlson, C.G., 1964, The Niobrara Formation of eastern North Dakota, its possibilities for use as a cement rock: North Dakota Geol. Survey Report Inv. 41, 56 p.

Cobban, W.S., 1964, The Late Cretaceous cephalopod Haresiceras reeside and its possible origin: U.S. Geol. Survey Prof. Paper 454-I, 21 p.

DeGraw, H.M., 1975, The Pierre-Niobrara unconformity in western Nebraska, in Caldwell, W.G.E., ed., The Cretaceous System in the Western Interior of North America: The Geological Assoc. of Canada Special Paper 13, p. 589-606.

Gill, J.R., Cobban, W.A., and Schultz, L.G., 1972, Stratigraphy and composition of the Sharon Springs Member of the Pierre Shale in western Kansas: U.S. Geol. Survey Prof. Paper 728, 50 p.

Hattin, D.E., 1975, Stratigraphic study of the Carlile-Niobrara (Upper Cretaceous) unconformity in Kansas and northeastern Nebraska, in Caldwell, W.G.E., ed., The Cretaceous System in the Western Interior of North America: The Geological Assoc. of Canada Special Paper 13, p. 195-210.

Hattin, D.E., 1977, Upper Cretaceous stratigraphy, paleontology and paleo-ecology of western Kansas: Mountain Geologist, v. 14, no. 3-4, p. 175-217.

Krumbein, W.C., and Sloss, L.L., 1963, Stratigraphy and sedimentation: San Francisco, W.F. Freeman and Co., 660 p.

Lockridge, J.P., 1977, Beecher Island Field Yuma County, Colorado: Rocky Mtn. Assoc. of Geol. Guidebook, p. 271-279.

Lockridge, J.P., and Scholle, P.A., 1978, Niobrara gas in eastern Colorado and northwestern Kansas, in Energy resources of the Denver Basin: Rocky Mtn. Assoc. Geologists Symposium, p. 35-49.

Merewether, E.A., Cobban, W.A., and Cavanaugh, E.T., 1979, Frontier formation and equivalent rocks in eastern Wyoming: The Mountain Geologist, v. 16, no. 3, p. 67-101.

Reeside, J.B., Jr., 1944, Map showing thickness and general character of the Cretaceous deposits in the western interior of the United States: U.S. Geol. Survey Oil and Gas Inv. Map OM-10.

Rice, D.D., 1976, Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, North Dakota and South Dakota: U.S. Geol. Survey Oil and Gas Chart OC-72.

Rice, D.D., and Shurr, G.W., 1978, Potential for major natural gas resources in shallow, low-permeability reservoirs of the northern Great Plains, in Economic Geology of the Williston Basin: Montana Geol. Soc. 24th Ann. Conf. Symposium, p. 265-281.

Scholle, P.A., 1977, Current oil and gas production from North American upper Cretaceous chalks: U.S. Geol. Survey Circular 767, 51 p.

Shurr, G.W., 1971, Facies relationships between the Pierre Shale and Niobrara Formation in central South Dakota: Geol. Soc. America Abstracts with Programs, v. 3, no. 4, p. 279.

Shurr, G.W., 1977, The Pierre Shale, northern Great Plains--a potential isolation medium for radioactive waste: U.S. Geol. Survey Open-File Report 77-776, 27 p.

Shurr, G.W., 1978, Paleotectonic controls on Cretaceous sedimentation and potential gas occurrences in western South Dakota, in Economic Geology of the Williston Basin: Montana Geol. Soc. 24th Ann. Conf. Symposium, p. 265-281.

Shurr, G.W., 1980, Geologic setting of the Pierre Shale (Upper Cretaceous) in the northern Great Plains: U.S. Geological Survey Open-File Report 80-675, 8 p.

Simpson, H.E., 1960, Geology of the Yankton area, South Dakota and Nebraska: U.S. Geol. Survey Prof. Paper 328, 124 p.

Stach, R.J., 1976, Minerology and stratigraphy of the Niobrara Formation, South Dakota: Univ. South Dakota, M.A. thesis, 51 p.

Stelck, C.R., 1975, Basement control of Cretaceous sand sequences in western Canada, in Caldwell, W.G.E., ed., The Cretaceous System in the Western Interior of North America: The Geological Assoc. of Canada Special Paper 13, p. 427-440.

Tourtelot, H.A., and Cobban, W.A., 1968, Stratigraphic significance and petrology of phosphate nodules at base of Niobrara Formation, east flank of Black Hills, South Dakota: U.S. Geol. Survey Prof. Paper 594-L, 22 p.

Weimer, R.J., 1978, Influence of Transcontinental Arch on Cretaceous marine sedimentation--a preliminary report, in Energy Resources of the Denver Basin: Rocky Mtn. Assoc. Geologists Field Conf. Guidebook, p. 211-222.