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GEOLOGIC SETTING OF THE PIERRE SHALE, NORTHERN GREAT PLAINS

by

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CONTENTS

ABSTRACT

An understanding of the geology of the Pierre Shale (Upper Cretaceous) in the northern Great Plains aids in the exploration for natural gas in the underlying Niobrara Formation. A configuration map of the Ardmore Bentonite Beds of the Pierre shows the major structural features of the area. Maps of thickness of the Pierre and of rocks above the Pierre summarize regional patterns of Niobrara burial depth. Niobrara burial depth is also summarized on a map of depth to the base of the Pierre Shale. The distribution of burial depths suggest that the Niobrara may have porosity values of greater than 30 percent over large areas of the northern Great Plains.

INTRODUCTION

The geologic setting of the Pierre Shale (Upper Cretaceous) in the northern Great Plains is described on the four maps which constitute this open-file report. The maps are:

Plate 1 Configuration of Ardmore Bentonite Beds

Plate 2 Thickness of Pierre Shale

Plate 3 Thickness of rocks above Pierre Shale

Plate 4 Depth to base Pierre Shale

The maps were initially compiled to assess the Pierre as a medium for radioactive waste disposal and were published as single-page illustrations (Shurr, 1977). These data are now being made available at the scale of the original work sheets, 1:1,000,000 (10km/cm; 16 mi/in), because of their possible utility in the exploration for shallow natural gas resources. This subsequent work has been carried out as a part of investigations of low porosity and permeability, "tight", natural gas reservoirs in the northern Great Plains. Funding was provided by the Department of Energy.

The data compiled on the four maps are based upon subsurface records of boreholes drilled for oil and gas exploration or production. A computer-based "Well History Control System", produced by the Petroleum Information Corporation, was the primary basis for the study. In June, 1975, the compilation included locations, drilling history, and geologic data for 34,000 wells in the study area; of these, 33,000 penetrated the Pierre Shale. A computer scan of this data base narrowed the sample by selecting one well per township, for a total of 5,000 data points. This sample, still too large for easy manipulation, was then further reduced by subjective evaluation of geophysical logs. The evaluation which operationally defined markers corresponding with the top and base of the Pierre, employed a primary correlation grid of some 150 wells and 14 outcrops. It should be emphasized that the study makes use of lithologic interpretation of electric-log characteristics and hence the stratigraphic units are "parastratigraphic" units in the terminology of Krumbein and Sloss (1963).

The four maps thus show a limited data set which constitutes a geographic sample objectively selected from a much larger array. The limited data set consists of some 550 control points, spaced an average of 29 km (18 mi) apart. Data from the well logs were processed by computer, using simple iterative calculations, and maps at a scale of 1:1,000,000 (10 km/cm; 16 mi/in) were plotted automatically. All contouring was done by hand and the contours were transposed from the computer-plotted working copies to a base map showing major drainages and political boundaries. This procedure resulted in positions of contour lines that in places only approximately reflect the position as indicated by the data base. Extrapolation between data points as plotted on the maps of this report may produce alterations of the contour-line configuration. However, the contour positions were within reasonable limits of accuracy for the scale at which they were originally published. Map users may choose to recontour specific areas of interest on the maps to assess these limitations.

The Pierre Shale is underlain by the Niobrara Formation throughout all of the northern Great Plains and the Niobrara is the target of extensive recent exploration for natural gas. The Pierre is covered by units of Late Cretaceous, Tertiary, and Pleistocene age. It appears that the burial depths of chalk reservoirs control reservoir characteristics (Scholle, 1977). Therefore, thickness variations and structural attitudes in the Pierre and its overlying units probably influence the distribution of natural gas in the Niobrara.

CONFIGURATION OF ARDMORE BENTONITE BEDS

A series of bentonite beds found in the Pierre Shale is virtually continuous throughout the northern Great Plains and has utility as a structural datum (plate 1). The beds are as much as 5 m (16 ft) in total thickness. The beds are collectively termed the Ardmore Bentonite Beds of the Sharon Springs Member of the Pierre Shale in the southern Black Hills (Spivey, 1940), are informally referred to as the "I" bentonite bed in the northern Black Hills (Knechtel and Patterson, 1962), and are found in the Pembina Member of the Pierre Shale in North Dakota (Gill and Cobban, 1965). In Montana and Wyoming, the Bentonite unit is near the top of the Eagle Sandstone and Shannon Sandstone Member (of the Gammon Shale in Montana and of the Steele Shale in northeastern Wyoming), respectively. The bentonites are expressed on electric logs as units of low resistivity and positive spontaneous potential. The base of the unit is employed as a marker bed to map structure.

The configuration map (plate 1) clearly shows the major structural features of the northern Great Plains. The area is dominated by the large Williston and Denver Basins. Smaller uplifts which separate these basins include the Sioux uplift, Black Hills uplift, Chadron arch, and Cambridge arch. Portions of the Kennedy Basin (A), Powder River Basin (B), and Hartville uplift (C) are also present in the study area. Smaller structures which have expression on the map include the Cedar Creek anticline (D) and Nessen anticline (E).

In Colorado, Nebraska, and throughout most of South Dakota, the Ardmore is found near the base of the Pierre and thus elevations in these areas approximate the top of the Niobrara Formation. Areas where the Ardmore has been removed by erosion are taken from DeGraw (1975) and from state geologic maps.

THICKNESS OF THE PIERRE SHALE

The thickness of the Pierre Shale is shown on plate 2. The Pierre essentially covers all of the northern Great Plains, except where it is locally removed by erosion on uplifts. The unit is dominately a clay shale, but includes wide areas of sandstone and siltstone in the western part of the study area and marls and calcareous shales in the east. The lateral limits of the non-shale lithologies have been previously mapped (Shurr, 1977, figure 8) and all of the rocks are potential low porosity, low permeability gas reservoirs (Rice and Shurr, 1978).

The top of the Pierre Shale in the Williston Basin is taken in this study, at the base of the lowest well-defined sandstone unit in the Fox Hills Sandstone. In the Denver Basin the top is arbitrarily defined for this study, as the base of the silty and sandy transition member of the Pierre. Along the eastern margins of the Williston and Denver Basins and on the uplifts separating these basins, the top of the Pierre is erosional and the contact with coarse overlying units is clearly shown on electric logs. Thickness data are minimum values in these areas of erosion and in areas where well records start below the top of the Pierre, such as central South Dakota.

The base of the Pierre Shale in the Williston basin is gradational with the calcareous shale and marl of the underlying Niobrara Formation (Shurr, 1971). A slight increase in resistivity and spontaneous potential marks the top of the Niobrara. In the Denver basin the facies gradation is more abrupt and the base of the Pierre is more easily recognized. In the area of uplifts separating the basins, the top of the Niobrara is eroded (DeGraw, 1975, and Shurr, 1970) and hence the base of the Pierre has clear electric-log expression.

THICKNESS OF ROCK ABOVE THE PIERRE SHALE

The Pierre Shale is poorly exposed over most of the northern Great Plains. Plate 3 shows the thickness of rock above the Pierre. Areas in which Pierre Shale or older rocks crop out are most common in South Dakota and are enclosed by the zero contour on the thickness map. The lithologies of overlying rocks include Cretaceous sandstones in the Williston Basin of North Dakota and the Denver Basin of Colorado, Tertiary sandstone and claystone throughout most of Nebraska, and Pleistocene glacial material in the eastern Dakotas. The distribution of these overlying rock types is shown by Shurr (1977, figure 2).

The thickness of rock above the Pierre added to the thickness of the Pierre is equivalent to the depth of burial of the Niobrara Formation. Burial depth has been shown to strongly influence the porosity and permeability of marls in the Niobrara which are potential gas reservoirs (Scholle, 1977).

DEPTH TO THE BASE OF THE PIERRE SHALE

The base of the Pierre Shale coincides with the top of the Niobrara Formation. Therefore, the depth from the surface to the base of the Pierre Shale (plate 4) is equivalent to the present depth of burial for chalk reservoirs in the Niobrara Formation. The depths shown in the Williston and Denver Basins probably represent the maximum burial experienced by the chalks. The present minimum depths shown on the uplifts between the basins do not represent maximum burial depths because these areas have experienced several episodes of exposure and erosion.

Depths to the base of the Pierre over much of the study area, suggest that porosity and permeability values for chalks in the underlying Niobrara are relatively unchanged by burial diagenesis. The contours of depth can be calibrated in terms of chalk porosity by employing a relationship between depth of burial and porosity described by Lockridge and Scholle (1978). At depths of 3,000 feet (915 m), chalks have 30 percent porosity; at 2,000 feet (610 m), they have approximately 38 percent porosity; and at 1,000 feet (305 m), 40 to 45 percent porosity. As a result, it appears that over very large areas of the northern Great Plains chalks in the Niobrara have porosity values in excess of 30 percent. The areas of higher porosity values as defined by shallow burial depths are similar to those derived by Lockridge and Scholle (1978) using more generalized depth values. The burial depth-porosity relationship is for relatively pure chalks and will probably be different for shaley chalk and chalky shale. Hence the size and shape of areas with potentially high porosity may be altered in the Dakotas where the Niobrara becomes shaley and interfingers with the Pierre.

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