1973

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Harold M. DeGraw
Conversation and Survey Division, Nebraska
Geological Survey, Nebraska Hall,
University of Nebraska, Lincoln, 68508.

Reprint from

THE GEOLOGICAL ASSOCIATION OF CANADA SPECIAL PAPER NUMBER 13

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Conservation and Survey Division, Nebraska Geological Survey, Nebraska Hall, University of Nebraska, Lincoln, 68508.

ABSTRACT

The Pierre-Niobrara unconformity, one of several significant unconformities in the Cretaceous System of the Western Interior region, has not generally been recognized. Detailed correlation of electric logs of a large number of wells in western Nebraska provides evidence of its existence. Isopach maps of the beds occupying three identifiable stratigraphic intervals – a redefined Niobrara Formation, an unnamed uppermost Niobrara unit, and an unnamed basal Pierre unit, which includes the Ardmore Bentonite – provide recognizable geologic patterns that permit reconstruction of the stages of development of the unconformity.

The upper part of the Niobrara Formation has been truncated in several areas of western Nebraska. Truncation is most pronounced in northwestern Nebraska, where the unnamed uppermost Niobrara unit, elsewhere more than 100 feet thick, is entirely absent. Throughout much of western Nebraska, however, such truncation is subtle and not easily recognized.

The unnamed basal unit of the Pierre Shale consists of silty shale and bentonite. Although discontinuous, it attains a thickness of more than 60 feet in at least one locality. Early Pierre topography appears to have been structurally controlled, uplands tending to coincide with uplifts. The basal Pierre unit is especially well developed in two south-southwest-trending troughs which appear to coincide with synclines. The silty shale well may be of fluvial origin, having been derived from the Niobrara strata of adjacent uplands.

Detailed mapping and analysis of unconformities, such as the one between the Niobrara and Pierre Formations, enables the geologic history of the Cretaceous Western Interior region to be interpreted more fully.

RÉSUMÉ

La discordance stratigraphique Pierre-Niobrara, une des plus importantes du Crétacé de l'Intérieur ouest, n'a pas été généralement reconnue. Une corrélation détaillée de diagrammes électriques d'un grand nombre de sondages de l'ouest du Nebraska témoigne de sa présence. Des cartes isopaques de couches de trois intervalles stratigraphiques identifiables – la Formation de Niobrara redéfinie, une unité sans nom du Niobrara supérieur, et une unité sans nom de la partie basale de la Formation de Pierre, qui inclu la bentonite d'Ardmore – révèlent des modèles géologiques reconnaissables, ce qui permet la reconstruction des stades de développement de la discordance.

La partie supérieure de la Formation de Niobrara est tronquée à plusieurs endroits dans l'ouest du Nebraska. Cette troncature se montre plus marquée dans le nord-ouest du Nebraska où l'unité non-nommée du sommet de la Formation de Niobrara est absente, quoiqu'elle mesure au-delà de 100 pieds d'épaisseur à d'autres endroits. Dans presque tout l'ouest du Nebraska cependant, cette troncature est subtile et peu facile à reconnaître.

L'unité non-nommée du schiste Pierre est composée de schiste silteux et de bentonite. Quoique discontinue, elle mesure plus de 60 pieds à au moins une localité. La topographie au temps Pierre inférieur semble avoir été contrôlée par des structures, les terres hautes ayant tendance à s'accorder avec les soulèvements. L'unité basale de la Formation de Pierre est particulièrement bien développée dans deux dépressions de direction sud-sud-ouest qui semblent s'accorder avec des synclinaux. Le schiste argileux peut fort bien avoir une origine fluviale, ayant été dérivé de couches de la Formation de Niobrara des terres hautes adjacentes.

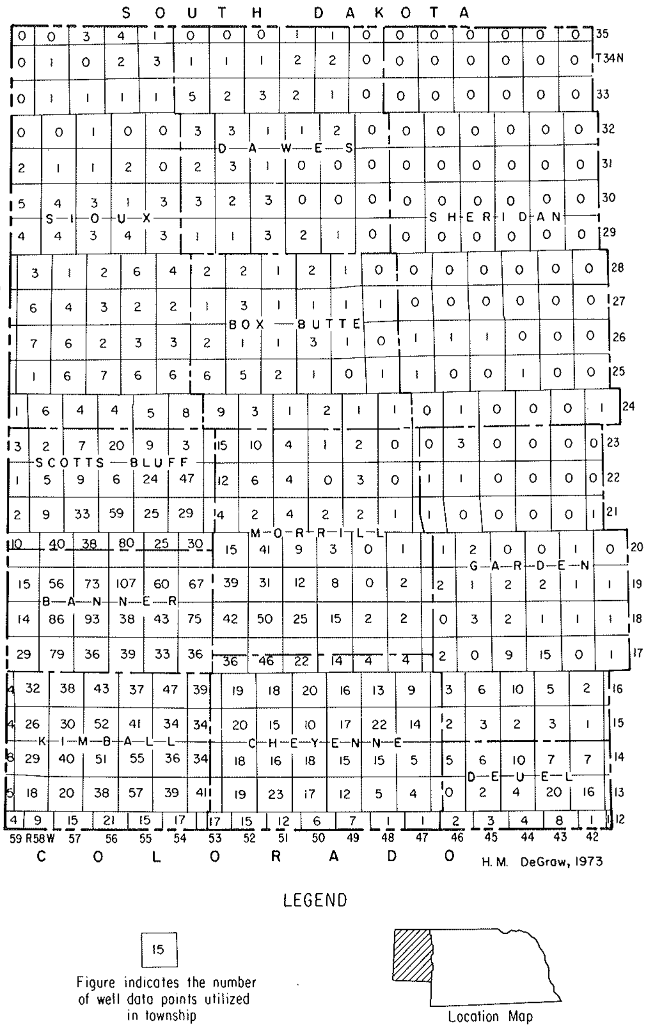
La cartographie et l'analyse détaillée des discordances stratigraphiques, telle que celle entre les Formations de Niobrara et de Pierre, nous permettent d'interpréter plus profondément l'histoire géologique du Crétacé de l'Intérieur ouest.

INTRODUCTION

The unconformity between the Pierre and Niobrara Formations is probably one of the most important unconformities in the Cretaceous System of the Western Interior. Its extent, and its significance in terms of historical reconstruction, however, have not yet been appreciated adequately.

Detailed study of the Pierre and Niobrara Formations in the Nebraska panhandle (Text-fig. 1) and adjacent parts of Colorado, South Dakota, and Wyoming provides evidence of the existence of the unconformity and enables the stages of its development to be interpreted. This area is underlain by the northern part of the Denver-Julesburg basin, and it is defined broadly by either the Cretaceous outcrops or the subcrops beneath sediments of Tertiary, Pleistocene, and Holocene age on the flanks of the principal, surrounding uplifts. Within the area of study, the Pierre and Niobrara Formations lie in the subsurface, and data on them have been gathered mainly from the electric logs of oil and gas exploration wells. Approximately nine thousand wells have been drilled in the northern part of the Denver-Julesburg basin, and approximately three thousand eight hundred well logs were used for this study (Text-fig. 1). Supplementary data were obtained from the outcrop on the flank of the Chadron arch in northeastern Dawes County, Nebraska. The procedures followed in using the electric logs were similar to those adopted by Asquith (1970) who, in his study of the Pierre and Niobrara strata in the eastern Powder River basin, was able to differentiate a number of " time-stratigraphic " units. In assessing the stratigraphic sequence and parts of it that may be missing in the Nebraska subsurface, as in the subsurface of other parts of the Western Interior, care must be taken to discriminate between effects due to unconformities and those due to facies changes and to normal faults.

Although the Pierre-Niobrara unconformity has been recognized in some parts of the Western Interior for more than a century, detailed evidence of its existence in Nebraska began to accumulate only in 1954, when B. H. Burma recorded in the files of the Nebraska Geological Survey his observations on the missing section of the Niobrara Formation. Tourtelot (1956) mentioned the unconformity in western Nebraska, and DeGraw (1969) identified five local unconformities in the " Transition zone " of the Pierre Formation in northeastern Colorado and the adjacent southern part of the Nebraska panhandle. More recently, Shurr (1970) recorded evidence for the unconformity in the outcrop of central South Dakota.



Text-figure 1. Index map of western Nebraska showing area of study and distribution of well data points.

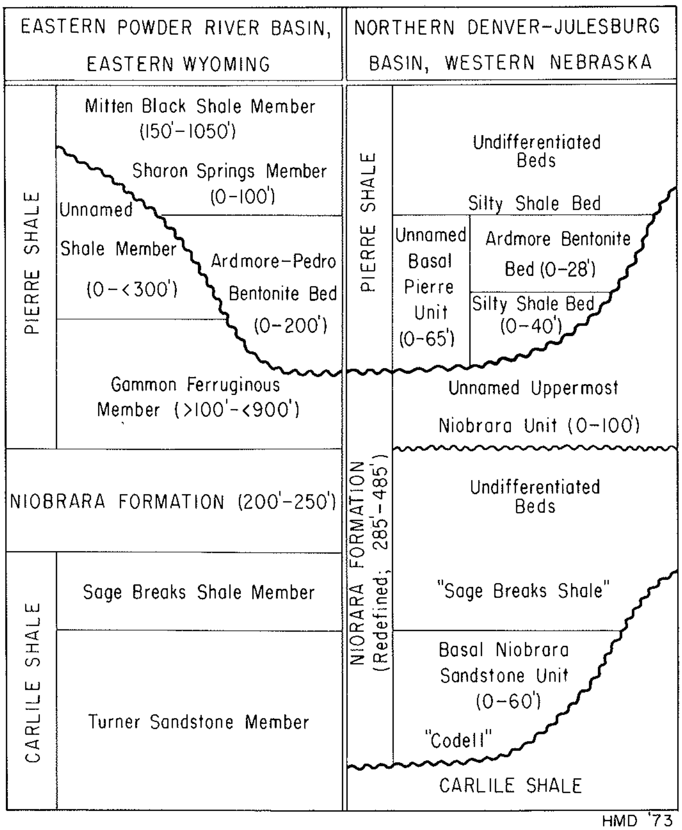
Unconformities, such as that between the Pierre and Niobrara Formations, are preferred horizons for the concentration and localization of natural resources (*see,* for example, Tourtelot, 1956 ; Martin, 1966 ; and McCubbin, 1969). The Niobrara and time-equivalent strata, together with the overlying, basal, Pierre strata, are proven petroleum reservoirs in several areas of the Rocky Mountain region (McAuslan, 1959 ; Harnett, 1968). DeGraw (1972) demonstrated that many palaeotopographic surfaces were structurally controlled and that the locations of many oil and gas fields in Nebraska coincided with palaeotopographic " highs. " Thus a detailed analysis of the Pierre-Niobrara unconformity in western Nebraska and adjacent areas is important not only in terms of achieving more accurate stratigraphic correlations and a better understanding of historical events, but also in terms of evaluating the bounding formations for their economic potential.

STRATIGRAPHIC RELATIONS

Although emphasis in this paper is placed on stratigraphic relationships at the Pierre-Niobrara contact in western Nebraska, attention is given also to the Benton and Carlile Shales underlying the Niobrara Formation, to the total thickness of the Niobrara, and to the basal part of the Pierre Shale in order to provide a broader framework of interpretative data. Only the basal Pierre is included because much of the formation in western

TABLE I

Stratigraphic sequence in the northern portion of the Denver-Julesburg basin of western Nebraska (right-hand side). The correlation table also shows the relation of the sequence in western Nebraska to that in the eastern Powder River basin of Wyoming, which is discussed later in the paper.



Nebraska is so consistent lithologically that it lacks readily identifiable electric-log characteristics. For the most part, the Niobrara has diagnostic characteristics, and individual beds can be traced easily.

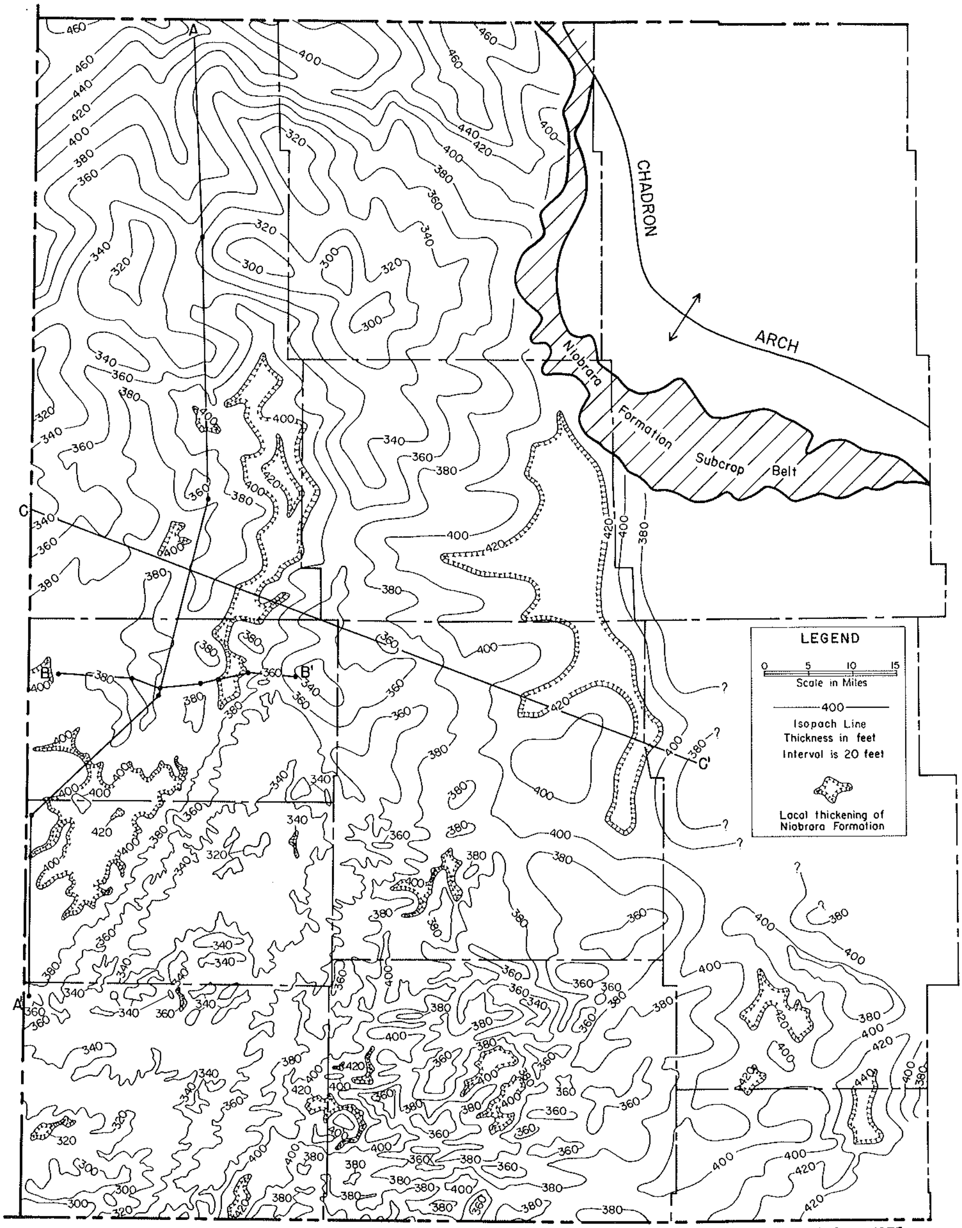
Redefined Niobrara Formation

The Niobrara Formation is redefined locally so that a consistent nomenclature can be applied to it throughout western Nebraska. Particular attention is given to selection of contacts and to application of nomenclature that seems to fit best the original definition without requiring application to a single lithology. The most difficult problem in the Niobrara is to establish and trace the basal contact. The loss of chalk beds in the lower part of the formation in the northwestern panhandle creates a basic correlation problem. The practice in the past has been to shift the contact upward as shale becomes the dominant lithology, but this approach has proved too subjective. Previous isopach maps reflect this lithological change. As redefined, the Niobrara Formation contains a basal sandstone in part of the area, and shale interbedded with chalk and calcareous shale. Calcareous shale, chalk, and limestone are dominant in the Niobrara of much of central and eastern Nebraska, as they are in northwestern Kansas. In northwestern Nebraska, shale is dominant.

The contact between the redefined Niobrara Formation and the underlying Carlile and Benton Shales was selected on the basis of stratification patterns. In the westernmost panhandle, particularly in Banner and Scotts Bluff Counties, Nebraska, and in Goshen County, Wyoming, pronounced truncation occurs at the base of a thick sandstone. The underlying shales dip eastward, so that over 200 feet of them subcrop beneath the sandstone. As this is the most pronounced break with the greatest regional significance in this part of the stratigraphic section, it is logical to interpret it as the base of the Niobrara. The basal sandstone attains a thickness of more than 60 feet in western Scotts Bluff County, Nebraska, and adjacent parts of eastern Wyoming. Eastward and southward, it thins and becomes finer grained, and northward it is discontinuous. In places where the sandstone is absent, as in much of Box Butte County, the Niobrara-Carlile contact is extremely difficult to identify. It is in this area that the contact has been placed at several different horizons by different workers.

Owing to its lithology and stratigraphic position, the basal Niobrara sandstone in western Nebraska generally has been called the Codell Sandstone Member of the Carlile Shale. However, stratification evidence indicates that it is related to the Niobrara, which suggests, in turn, that it is not the same as the Codell at the type area in Kansas. Additional detailed studies will be required either to confirm or to disprove this interpretation. The stratigraphic relationships of this western Nebraska basal sandstone, however, are similar to those of the Codell Sandstone Member of the Carlile Shale (Benton) in southeastern Colorado, as described by Krutak (1970), and the basal sandstone is believed to be a correlative. Thus, it is possible that the Codell in southeastern Colorado likewise is not equivalent to the Codell of the type locality.

Preliminary investigations indicated that considerable lithologic and stratigraphic change occurs about the contact between the Niobrara and Pierre Formations, but no criteria, other than a bentonite marker bed near the base of the Pierre, had been established previously to differentiate the formations in the contact zone. Detailed electric-log correlations and mapping of the units in the contact zone establish the formational relationships.

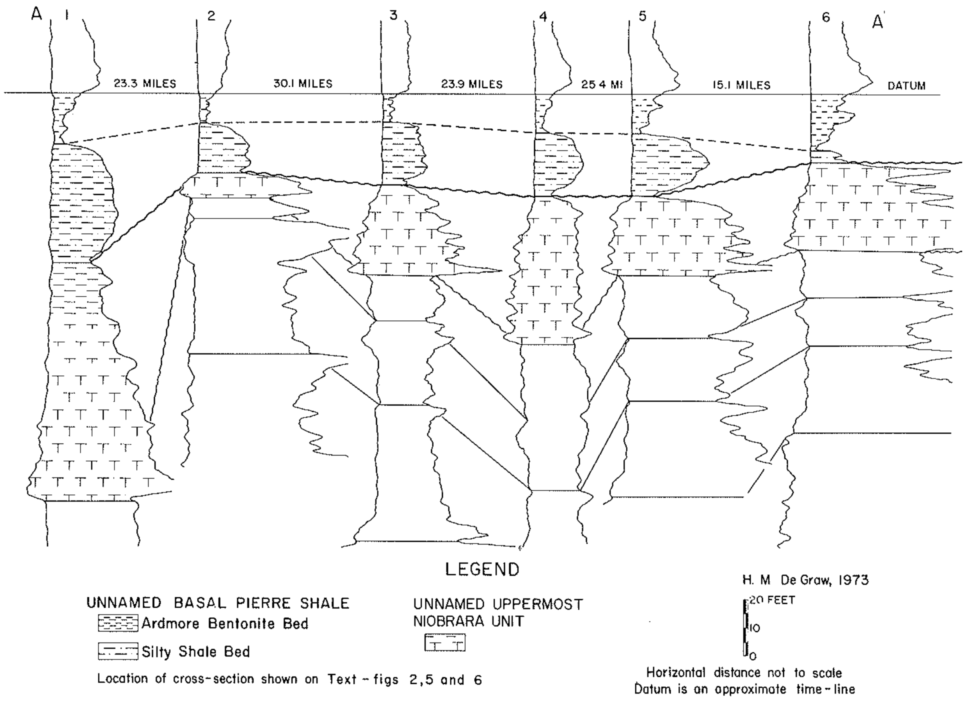


Text-figure 2. Isopach map of the redefined Niobrara Formation in western Nebraska.

The contact between the Niobrara and the Pierre in western Nebraska is an unconformity. The upper part of the Niobrara has been truncated, and the overlying basal Pierre beds are discontinuous. Thus, as redefined, the Niobrara Formation in western Nebraska is bounded by significant unconformities. These unconformities appear to extend into adjacent parts of the Western Interior.

An isopach map of the redefined Niobrara Formation (Text-fig. 2) shows the thickness distribution in western Nebraska to be complex, but the formation generally to be thinnest in the southwest and becoming thicker to the northwest. The thickness difference for all of western Nebraska is in excess of 160 feet – from less than 300 feet in southwestern Kimball, eastern Sioux, and southwestern Dawes Counties to more than 460 feet in northern Sioux County. There are numerous areas of local thinning and thickening, however, and thickness differences of more than 60 feet occur within 2 or 3 miles. The thickness-distribution of the redefined Niobrara Formation reflects relief on the underlying surface and truncation of the upper surface. Where there is a trend to one of the surfaces, the trend is reflected in the isopach pattern.

Although the thickness differences and distribution pattern of the Niobrara Formation in western Nebraska are important, they are relatively unimpressive when viewed on a regional scale. The thickness of the Niobrara and its equivalents in the Rocky Mountain region ranges from less than 300 feet in northeastern Colorado and western Nebraska to more than 3,000 feet in western Wyoming (McAuslan, 1959).



Text-figure 3. North to south electric-log cross-section A-A[1] showing relationship of basal Pierre and upper Niobrara strata in western Nebraska.

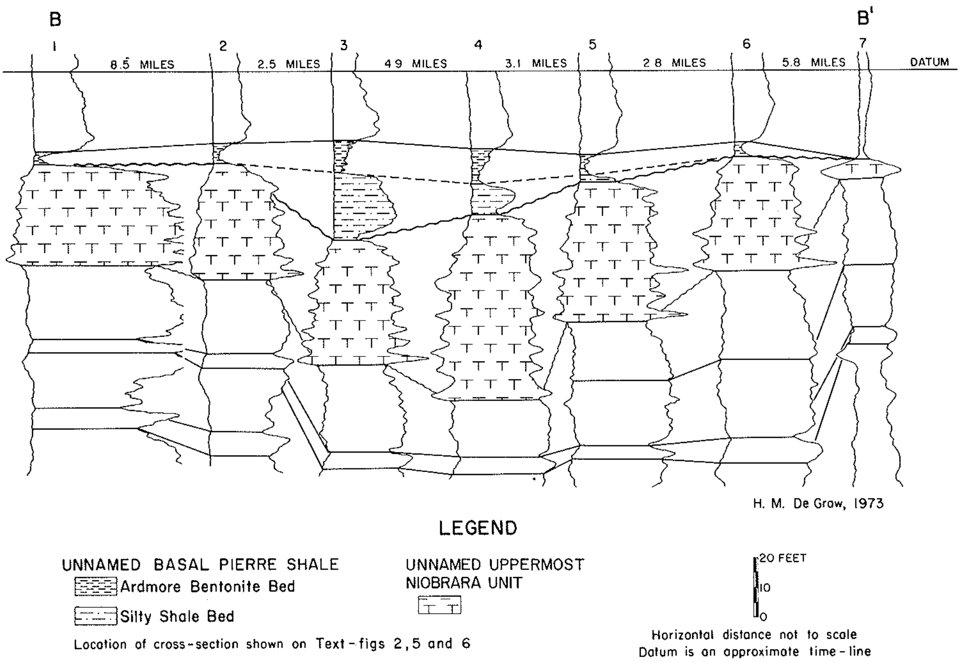
Unnamed Uppermost Niobrara Unit

Recognition is given to an uppermost Niobrara unit because of its stratigraphic relationship to the Pierre-Niobrara contact. Other stratigraphic units of the Niobrara are recognizable and also need to be mapped separately. As is true for the basal Niobrara sandstone and the uppermost Niobrara unit, not all of these units extend throughout the Nebraska panhandle.

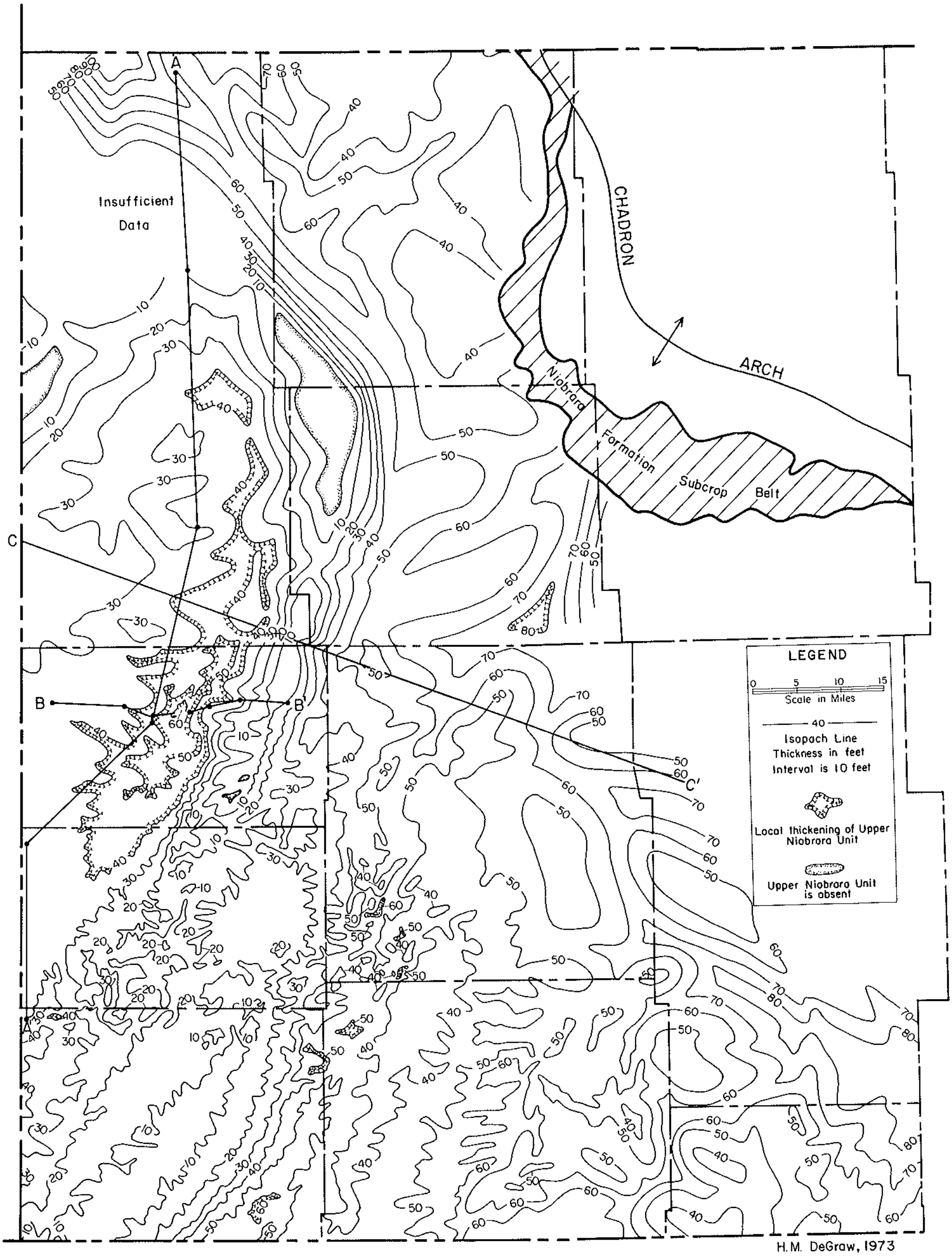
The uppermost Niobrara unit is similar to the entire redefined Niobrara Formation in that it also is bounded by unconformities. It shares a common upper boundary with the redefined Niobrara Formation, and in most places unconformably overlies and truncates a Niobrara shale unit. The unconformable relationship with the underlying shale is easily recognized on the B-B[1] electric-log cross-section (Text-fig. 4). In other areas, the stratigraphic changes are so subtle that the contact appears to be conformable.

For the most part, electric-log characteristics are sufficiently diagnostic to make the uppermost Niobrara unit readily identifiable (Text-figs. 3 and 4). Some difficulty arises in the areas of its greatest thickness where the additional section in the upper part is atypical of both this Niobrara unit and the overlying basal Pierre.

The uppermost Niobrara unit is characterized by a calcareous shale in the lower part and a non-calcareous shale with thin bentonite beds in the upper part. The contact is gradational and appears to reflect continual deposition and gradual upward decrease in carbonate content. The calcareous shale is the more extensive ; the non-calcareous shale is restricted to those areas where the thickness of the unit usually exceeds 40 feet.



Text-figure 4. West to east electric-log cross-section B-B[1] showing relationship of basal Pierre and upper Niobrara strata in Scotts Bluff County, Nebraska.



Text-figure 5. Isopach map of the unnamed uppermost Niobrara unit in western Nebraska.

The thickness distribution of the uppermost Niobrara unit in western Nebraska is shown in text-figure 5. This unit is locally absent in the northern part of the area and in two small areas in southeastern Scotts Bluff County. It exceeds 100 feet in thickness in northern Sioux County, near the South Dakota boundary. Although there is a considerable variation in thickness throughout the region, there is a noticeable trend for thickening in a southeastward direction.

As the uppermost Niobrara unit is bounded by unconformities, the isopach map reflects both the depositional pattern at the basal contact and truncation at the upper contact.

Unnamed Basal Pierre Unit

The unnamed basal Pierre unit is the oldest Pierre in western Nebraska and unconformably overlies the redefined Niobrara Formation (Text-figs. 3 and 4). An isopach map (Text-fig. 6) shows this basal unit to be absent or relatively thin over much of the region. The dominant thickness distribution pattern is one of arcuate, southwest to north belts, but a southeast to northwest trend also is recognizable locally. The unit thickens to the east and to the north where it locally exceeds 60 feet.

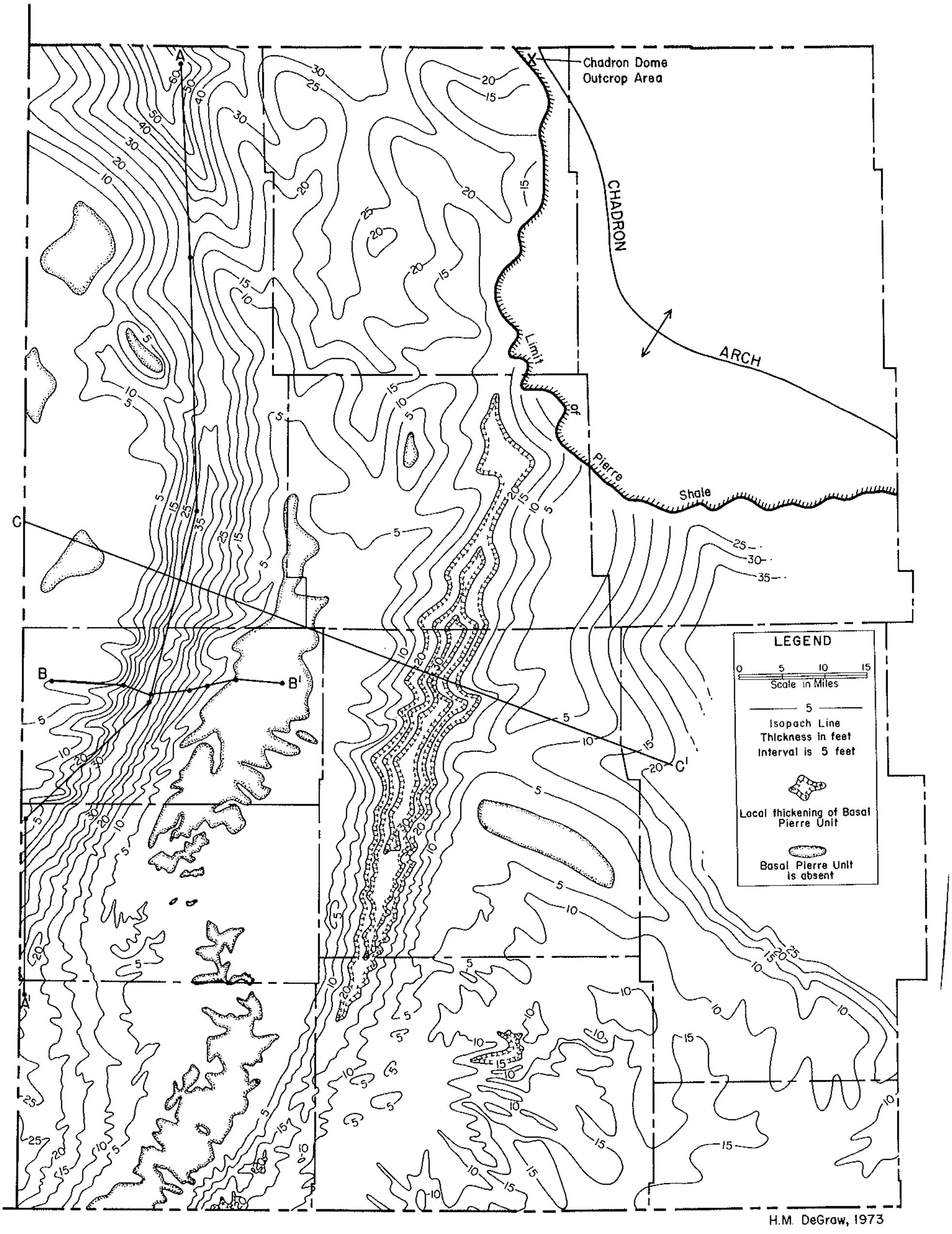
The basal Pierre unit consists of two, dominant, lithologic subunits – a basal silty shale and a bentonite correlative with the Ardmore Bentonite of southwestern South Dakota and called by that name. A lithofacies map (Text-fig. 7) shows the areal distribution of these beds in western Nebraska. The basal silty shale ranges in thickness from a feather-edge to more than 40 feet. It is considerably more restricted than the Ardmore Bentonite and lies mostly in the areas where the basal Pierre unit is thickest. The Ardmore Bentonite is locally absent but attains a thickness of more than 25 feet in some areas. This bentonite conformably overlies the silty shale and overlaps it to overlie unconformably the uppermost Niobrara unit. The top of the Ardmore Bentonite appears to be conformable with an overlying silty shale bed throughout its extent. This overlying silty shale is also locally absent over that part of the area where the Ardmore Bentonite is absent, and younger shale beds of the Pierre rest unconformably on the Niobrara.

The Ardmore Bentonite is easily recognized from its electric-log and lithologic characteristics, and it has served previously as a marker for "picking" the top of the Niobrara Formation in the subsurface. The Pierre-Niobrara contact has been placed at the base of this bentonite bed, which is an unconformable surface over much of the region. This practice, however, resulted in the basal silty shale, where present, being included in the Niobrara. Tourtelot (1956) considered the Ardmore Bentonite to be part of the Sharon Springs Member of the Pierre Formation.

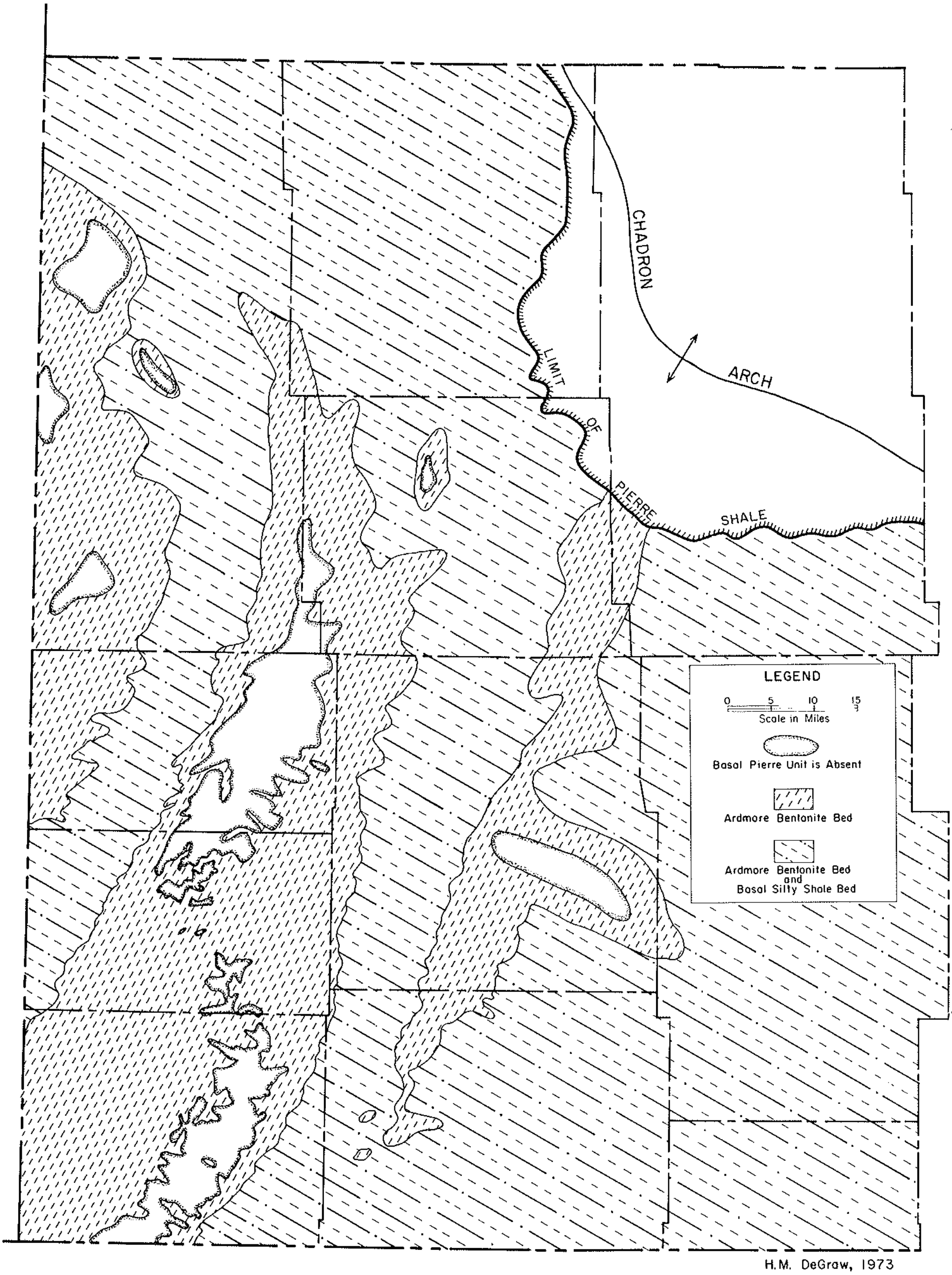
The basal Pierre unit differs from the uppermost Niobrara unit and the redefined Niobrara Formation in one important, structural aspect. Although bounded by an unconformity at its base, the upper contact of the basal Pierre unit is a bedding plane which appears to be consistent throughout most of western Nebraska.

Chadron Dome Outcrop Area

Although subsurface evidence indicates a regional unconformity at the Pierre-Niobrara contact in western Nebraska, evidence for such an interpretation has not been reported from any outcrop areas in the region. Several years ago, a preliminary investigation was made of the stratigraphic section containing the contact in the Chadron dome area of northeastern Dawes County, as this is the only place in western Nebraska where the Pierre-Niobrara contact crops out at the surface.



Text-figure 6. Isopach map of the unnamed basal Pierre unit in western Nebraska.



Text-figure 7. Lithofacies map of basal Pierre strata in western Nebraska.

The Pierre-Niobrara contact was found to be located 8 to 10 feet above the horizon at which it had been recognized previously, locally coinciding with the present land surface. Stratigraphic relations were found to be complex. The complexity was assumed to have been caused by structure, because the section is located near the edge of the Chadron uplift, and by recent and possibly pre-Tertiary erosion and weathering. It now appears that part of the complexity is due to the Pierre-Niobrara unconformity.

Material collected from basal Pierre strata, mostly below the Ardmore Bentonite, at this exposure is compatible with its having formed in a subaerial environment. The material collected consists of reworked baculite fragments, some worm bored and filled with " worm droppings " or fecal pellets ; coprolites, some also worm bored and filled with fecal pellets ; unsilicified fossil wood ; cone-in-cone structures, some calcareous and some silicified ; and limonite and hematite concretions. The dominance of the iron-oxide concretions in the silty shales above the Ardmore Bentonite indicates that the total non-marine section is not included in the unnamed basal Pierre unit.

The baculite fragments with their worm borings, filled and partly filled with fecal pellets, are similar to those figured by Gill and Cobban (1966a, Pl. 7). These specimens are poorly preserved, but R. K. Pabian (pers. comm.) tentatively identified them as *Baculites codyensis* Reeside or *Baculites aquilaensis* Reeside.

INTERPRETATION

Palaeogeomorphology

The relief and configuration of the pre-Pierre landscape and the early Pierre drainage pattern which developed on it can be interpreted readily from the isopach maps. Additionally, consideration can be given to the sources of the sediment that filled the palaeotopographic " lows. "

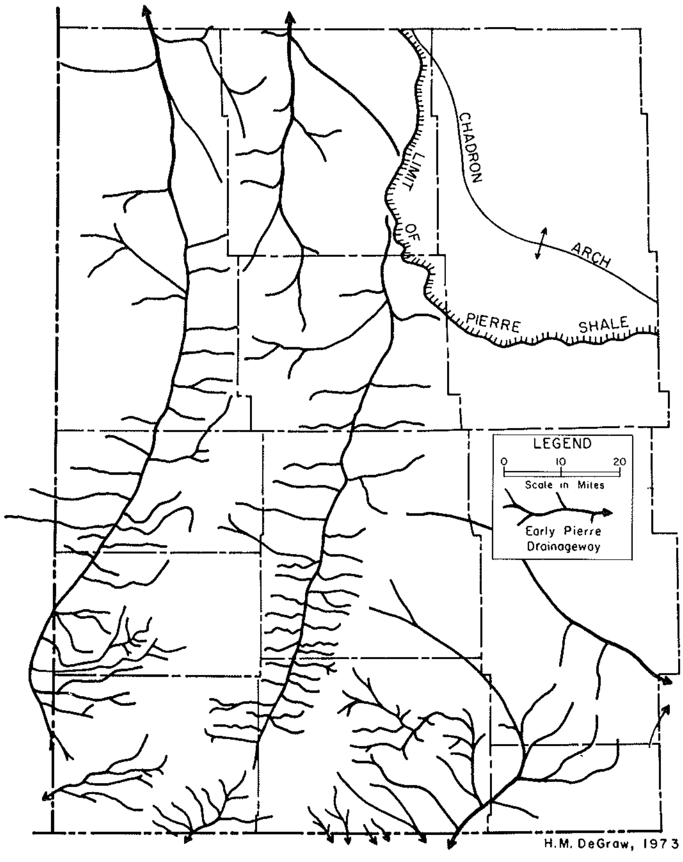
The processes that developed the ancient, pre-Pierre landscape were both destructive and constructive. Even locally, erosion of the palaeotopographic " highs " was complemented by contemporaneous deposition in the palaeotopographic " lows, " and the final relief on the ancient surface was considerably less than the relief attained at an earlier stage in the development of the surface.

An excellent method for determining the character of the pre-Pierre surface in western Nebraska is the one termed by Andresen (1962) the *datum plane-valley floor isopach method* which uses an upper datum for reference. Martin (1966) described this method as in effect making a " cast " of the underlying landscape.

As the upper contact of the Ardmore Bentonite approximates a time-plane that is assumed to have been essentially horizontal throughout western Nebraska, the isopach map of the basal Pierre unit (Text-fig. 6) provides a " cast " of much of the pre-Pierre surface. Isopach lines showing thickness of the basal Pierre unit can be viewed as contour lines showing configuration of the underlying landscape. Areas where the basal Pierre strata are absent or thin indicate uplands and ridges ; areas where the basal Pierre is thick indicate depressions and valleys. Early Pierre topographic relief in western Nebraska was greatest to the north, where the difference exceeded 60 feet, and least in the south, where the difference was generally less than 20 feet. Along the prominent ridges and valleys, the difference in initial relief was at least 35 to 40 feet.

Reconstruction of the early Pierre drainage system (Text-fig. 8), derived from the isopach map of the basal Pierre unit, reveals a complex pattern. Principal drainage was to the north ; secondary drainage was to the southeast, and some drainage was to the southwest. This multi-directional drainage suggests that western Nebraska was part of a major drainage divide.

The two, prominent, north-to-southwest, arcuate valleys are characterized by a trellis drainage pattern. Possibly the closed " contours " of these valleys indicate the initial existence of shallow lakes, as much as 6 to 8 miles wide and 70 to 80 miles long.



Text-figure 8. Early Pierre drainage pattern in western Nebraska.

Basal Pierre sediments were derived principally from two different sources. The basal silty shale was mostly locally derived and consists of coarser sediments eroded from the exposed Niobrara Formation in adjacent uplands and ridges. The overlying Ardmore Bentonite, indicative of a major volcanic eruption to the west, was formed by devitrification of volcanic ash, probably in a subaerial environment. The ash undoubtedly mantled the landscape but was washed from the uplands and concentrated in the valleys.

Stratigraphic Correlations

Subsurface correlation of the redefined Niobrara Formation can be extended northward into South Dakota. The Ardmore Bentonite, the type area for which is in Fall River County, South Dakota, provides an excellent stratigraphic marker for precise correlation. The Pierre-Niobrara contact recognized in outcrop (Rothrock, 1949) appears to be at about the same stratigraphic horizon as in the subsurface farther south. The thickness of the redefined Niobrara Formation in the subsurface, however, ranges from about 460 to 520 feet, which is in sharp contrast to the 260 to 315 feet recognized in outcrop by Rothrock. Comparison of thicknesses for the Carlile Shale in the subsurface and in outcrop shows that the Niobrara-Carlile contact in the outcrop area has been placed at the base of the principal chalk bed, approximately 200 feet higher than in the present study. Thus, Niobrara shale underlying the prominent chalk has been included with the Carlile Shale. The disagreement as to the placement of the Niobrara-Carlile contact may be related to the Sage Breaks Shale problem. The Sage Breaks in Wyoming has been included in the upper part of the Carlile Shale on lithological grounds, but it contains fossils typical of the Niobrara Formation.

In the Pueblo area of southeastern Colorado, Scott and Cobban (1964) recognized eight lithologic units in the Niobrara Formation, which is about 740 feet thick. Although this thickness is considerably greater than in western Nebraska, the lithologic sequence is similar. However, not all of the lithologic units recognized by Scott and Cobban appear to be present in the study area and, conversely, some present in western Nebraska seem to be absent at Pueblo. It appears that the unnamed uppermost Niobrara unit may be the correlative of the 8 foot-thick upper chalk unit of Scott and Cobban. This tentative correlation is based on lithology, stratigraphic position, and on the fact that, with respect to western Nebraska, the Pueblo area is aligned on the dominant trend shown on the isopach maps (Text-figs. 5 and 6).

Correlation of the " time-stratigraphic " units in the Niobrara and lower Pierre Formations (Asquith, 1970) from western Nebraska into the Powder River basin is also tentative. More detailed work is required to confirm it. The easiest unit to recognize in both regions and the most reliable for correlation is the Ardmore Bentonite, which Asquith (1970) called the Ardmore-Pedro Bentonite beds, the basal unit of the Sharon Springs Member of the Pierre Shale. The underlying basal Pierre silty shale was not recognized by Asquith in the Powder River basin, but it appears to be present in the eastern part of the basin where it is about 65 feet thick. As Asquith (1970) and Gill and Cobban (1961) placed the Sussex Sandstone Member of the Steele Shale below the Ardmore-Pedro Bentonite Bed in Wyoming, the basal Pierre silty shale of the unnamed basal Pierre unit tentatively is correlated with the Sussex Sandstone.

The uppermost Niobrara unit in western Niobraska appears to correlate with the Gammon Ferruginous Member of the Pierre Shale in Wyoming, a conclusion also reached by Asquith (1970, p. 1,192). Additionally, Asquith (1970, p. 1,201) recognized evidence for " submarine " erosion at the base of the Sharon Springs Member where the Ardmore-Pedro Bentonite beds are absent and the Sharon Springs rests on the Unnamed and the Gammon Ferruginous Members of the Pierre Shale in the Powder River basin. This unconformable contact correlates with the Pierre-Niobrara unconformity in western Nebraska. Thus, if these correlations are valid, the Pierre-Niobrara unconformity in western Nebraska becomes an intraformational Pierre unconformity in the Powder River Basin.

Structural Evolution

The evidence of the thickness distribution patterns, stratigraphic relationships, and early Pierre drainage pattern combines to make a strong case for structural (fold) control of the pre-Pierre surface. The arcuate north to southwest-trending valley and ridge pattern and the closed basins of the pre-Pierre topography, shown on the isopach map of the basal Pierre unit (Text-fig. 6), suggest structural control. The trellis drainage pattern, shown on the early Pierre drainage map (Text-fig. 8), also supports such control. The fact that the structural pattern is similar to that of the pre-Niobrara strike valleys in northwestern New Mexico, recognized by McCubbin (1969), may have significance. Further evidence lies in a comparison of the thickness distributions of the uppermost Niobrara and basal Pierre strata (Text-figs. 5 and 6), which show a partial coincidence, most pronounced in the arcuate north to southwest belts in which the strata are either relatively thick or relatively thin and absent. Also, the thickness pattern of the entire redefined Niobrara Formation (Text-fig. 2) is similar but less easily recognized as such because the isopach map reflects the configuration of both the lower and upper unconformable contacts.

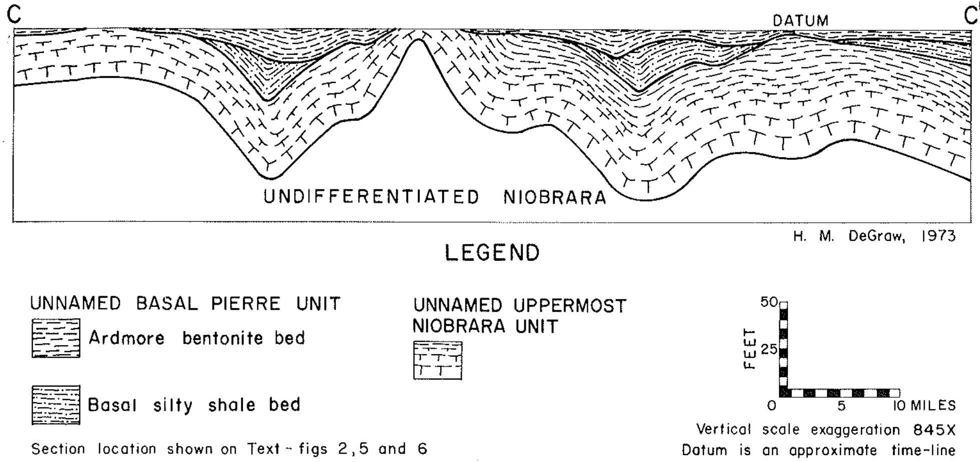
The coincident thickness patterns for strata both overlying and underlying the unconformity, combined with the stratification evidence shown in the cross-section B-B^1 (Text-fig. 4), show that much of the local thinning of the uppermost Niobrara is due to truncation. The local structural features had an early influence on the pre-Pierre landscape, and the early Pierre drainage modified this landscape by eroding the Niobrara strata on the uplands and ridges and protecting the Niobrara strata of the valleys by deposition.

Reconstruction of the stratigraphic relationship between the basal Pierre and uppermost Niobrara is based upon using the top of the Ardmore Bentonite as the datum, on the premise that it once approximated a horizontal surface. Although highly exaggerated, the cross-section of text-figure 9 illustrates the structural influence on the pre-Pierre surface and its continued effect on the deposition of the basal Pierre strata.

Thus, the basic structural pattern, reflected best by the isopachs of the basal Pierre unit (Text-fig. 6), involves two recognizable trends which coincide with the dominant palaeotopographic trends. The difference in initial structural relief, however, was greater than that in ultimate palaeotopographic relief shown by the basal Pierre isopachs because the uplands were subdued by early Pierre erosion. The uppermost Niobrara unit (Text-fig. 5) is thin or absent along the ridge axes, and approximately 30 to 40 feet of strata were removed. The difference in pre-Pierre structural relief for western Nebraska, therefore, is estimated at 100 feet.

The fold pattern suggests a compressional force with a northwest-southeast component that had a greater intensity to the northwest. As the dominant structures in western Nebraska are subparallel to the Hartville uplift in eastern Wyoming, possibly the structures are genetically related and this uplift was the locus of maximum deformation.

The thickness pattern of the Ardmore-Pedro Bentonite in the Powder River Basin (Asquith, 1970, fig. 15) provides support for this interpretation. This bentonite, which correlates with the bentonite in the basal Pierre unit, is shown to lie just north of the Hartville uplift. It has a north-south trend and locally exceeds 200 feet in thickness. This alignment and thickness suggest that the structural and palaeotopographic relief of the underlying surface in this area was much greater.



Text-figure 9. Northwest to southeast, diagrammatic section C-C[1] showing the relationship of basal Pierre to underlying uppermost Niobrara strata during early Pierre time in western Nebraska.

As Krutak (1970) also interpreted a pre-Laramide, northwesterly, stress alignment, this structural trend may have regional significance for this part of Cretaceous time. Krutak's interpretation is based on his observation that the surface of the upper Carlile Shale in southeastern Colorado was flexed into northeasterly trending "protosynclines" and "protoanticlines."

The southeast-trending anticline in eastern Morrill and southern Garden Counties (Text-fig. 6) is another product of the same stress. This structure was recognized by DeGraw (1969), who believed it to be solely a Laramide feature. The current study, however, indicates a prior history of deformation.

Geologic History

Analysis of the stratigraphic relationships at the Pierre-Niobrara unconformity in western Nebraska indicates a relationship between eustatism, tectonism, and vulcanism.

Niobrara deposition ended in western Nebraska with marine withdrawal probably in response to, and synchronous with, regional uplift. The epeirogenic movement was accompanied by low-intensity tectonic movement, which resulted in small-scale folding in western Nebraska but which increased in intensity westward, possibly reaching a maximum in the vicinity of the present-day Hartville uplift.

The structural surface provided the primary control for the early Pierre landscape and drainage system. Sediments, eroded from the anticlinal ridges, were deposited in the adjacent synclinal valleys. Principal drainage was northward following the structural grain, but the thicknesses of the basal Pierre, the absence of coarse clastics, and the diversity of drainage directions suggest that the region may have been part of a major drainage divide.

An episode of vulcanism, probably in the west, resulted in mantling of the landscape with volcanic ash. Sufficient topographic relief was maintained, however, so that the ash was washed from the ridges and concentrated in the valleys and valley slopes.

The subaerial environment persisted, but the rate of local erosion and deposition was slowed owing to the greatly subdued relief on the landscape. As a result, a series of thin palaeosol horizons, consisting in part of limonite and hematite, was formed. Subsequently, the sea advanced across the area in response to regional subsidence, and marine environments were re-established.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of Prof. T. M. Stout, who, as a teacher and colleague, contributed significantly to developing concepts for the interpretation of Cretaceous stratification patterns. He is indebted also to E. C. Reed and V. H. Dreeszen, who provided encouragement and support for the study of the Cretaceous stratigraphy of Nebraska.

M. P. Carlson and Ray Bentall critically reviewed the manuscript. D. J. Neale compiled the well data and designed the illustrations.

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