The Rhame bed (Slope Formation, Paleocene), a silcrete and deep weathering profile, in southwestern North Dakota

Barbara D. Wehrfritz
University of North Dakota

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THE RHAME BED (SLOPE FORMATION, PALEOCENE),
A SILCRETE AND DEEP-SWEATHERING PROFILE,
IN SOUTHWESTERN NORTH DAKOTA

by

Barbara D. Wehrfritz

Bachelor of Science, St. Lawrence University, 1973

A Thesis
Submitted to the Graduate Faculty
of the
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Science

Grand Forks, North Dakota

May
1978
This Thesis submitted by Barbara D. Wehrfritz in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work was done.

Lee Clayton  
(Chairman)

W. I. Mortel

Owen O. Chaten

William Johnson  
Dean of the Graduate School
Permission

THE RHAME BED (SLOPE FORMATION, PALEOCENE), A SILCRETE AND
Title DEEP-WEATHERING PROFILE, IN SOUTHWESTERN NORTH DAKOTA

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Signature Barbara D. Wehrfritz
Date March 6, 1978
ACKNOWLEDGMENTS

I wish to thank my parents, Frank W. Wehrfritz and Charlotte N. Wehrfritz, for their moral and financial support during this entire thesis project. It could not have been finished without their assistance.

I would also like to thank the members of my thesis committee, Lee Clayton, Walter L. Moore, and Odin Christensen, for their encouragement, suggestions, and professional advice.

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I would also like to thank Laura and Gene Peters, Chuck and Karen Sunderland, of Bowman, and John Beck, of Bismarck, for their friendship and assistance.

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I would like to acknowledge the contributions of Mr. Marshall Lambert, Carter County Museum, Ekalaka, Montana, and Dr. Bill Clemens, Department of Vertebrate Paleontology, University of California at Berkeley, to this study. During field reconnaissance in Montana, I arrived in Ekalaka on the same day that Bill Clemens visited Marshall Lambert. During subsequent discussion Clemens suggested I look in the Australian geologic literature for a description of silcrete, because
the rock I was studying looked very similar. This suggestion eventually led to the interpretation of the Rhame Bed.

I am very grateful to Mrs. Lorraine Rose and Mrs. Ethel Fontaine for their professional typing of the manuscript.
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ABSTRACT

The Rhame Bed is a unit at the top of the Slope Formation (formerly part of the "Ludlow Formation") in the Fort Union Group deposited during Paleocene time.

The Rhame Bed was mapped in western Slope County and north-central Bowman County. The bed outcrops on the tops of buttes, at the present ground surface in large level areas, or in steep slopes. Although the bed is laterally discontinuous, it is a clearly mappable unit.

The Rhame Bed typically consists of two dominant lithologies: siliceous rock and white sediment. The siliceous rock is hard, gray, and made of silt-sized detrital quartz grains in a matrix of microcrystalline quartz. It contains abundant casts and molds of branches, stems or roots of plants. It is underlain by sediment that is white to medium gray, consists of sand, silt, or clay, is very irregular in thickness, and lacks calcium carbonate.

Comparison of the Rhame Bed with similar material described in Australian, African, and European literature indicates that the material in the Rhame Bed is silcrete overlying a deep-weathering profile. It probably formed during a period of little erosion or deposition, under a stable land surface covered by thick vegetation, in a warm and humid climate.
INTRODUCTION

Purpose of Study

Walter Moore (1976, p. 35-37), when doing field work in the southwestern corner of North Dakota, recognized a "white siliceous bed." He described it as aphanitic to fine grained quartz, a few centimetres to a metre thick, white on fresh fractures, yellowish on weathered surfaces, commonly overlain by lignite or lignitic shale, and underlain by a variety of sediment types, which are bleached white.

Moore found the upper contact of the Slope Formation (then included in the "Ludlow Formation") difficult to define. Formerly, the contact was based on the change from somber gray to light yellow. Because many yellow units occur in the upper part of the Slope Formation where Moore was studying it, he chose to define the upper contact at the top of the "white siliceous bed" (Moore, 1976, p. 36).

This "white siliceous bed" has been informally called the "Rhame Bed" by geologists at the University of North Dakota and the North Dakota Geological Survey. It was named for good exposures of the unit near Rhame, North Dakota. (Rhame rhymes with same.)

The purposes of this study were (1) to map the location of the Rhame Bed in the type area of Slope and Bowman Counties, (2) to measure sections of the Rhame Bed to determine lithologic variation, (3) to designate a type section of the Rhame Bed, (4) to look in the surrounding areas of South Dakota and Montana for outcrops of the Rhame Bed and boulders
from the siliceous part of the Rhame Bed, (5) to review the literature concerning the Rhame Bed, and (6) to shed some light on the possible origin of this unit and a similar unit in the lower part of the Golden Valley Formation in North Dakota.

Area of Study

The general area of study is southwestern North Dakota, northwestern South Dakota, and southeastern Montana. The Rhame Bed was mapped in western Slope County (the type area of the Slope Formation) and north-central Bowman County, an area of 20 townships (see Figure 1 and Plate 1).

This area is rolling plain with badlands along creeks and rivers. The outcrops in the map area are in the buttes south of Rhame, along the West Fork of Deep Creek, along Deep Creek, and in the breaks by the Little Missouri River.

Field Methods

Possible outcrops were first located on air photos. The Rhame Bed has two characteristic air-photo patterns. In steep outcrops the bed appears as a very thin white line, which is difficult to distinguish from other light colored units unless the approximate stratigraphic position of the Rhame Bed is already known. Where the Rhame Bed is at the present ground surface, it appears as bright white areas or flat-topped buttes. The white areas can be difficult to distinguish from salt-covered
from the siliceous part of the Rhame Bed, (5) to review the literature concerning the Rhame Bed, and (6) to shed some light on the possible origin of this unit and a similar unit in the lower part of the Golden Valley Formation in North Dakota.

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Fig. 1. Map showing the location of the study area.
Topographic maps, at the scale of 1:24 000 (7½-minute quadrangles) have recently become available for this area; many are still in preliminary blue-line form. The location of the Rhame Bed was traced on these maps, noting the elevation at the top of the unit. The final outcrop map was drawn on these maps and then transferred to Plate 1.

Stratigraphic sections were measured using a hand level and a pick handle (0.9m). The pick, an army mattock with a 3-foot maul handle, was found to be the most useful tool for cleaning outcrops in this area.
DESCRIPTION OF THE RHAME BED

Introduction

The Rhame Bed contains two dominant lithologies: siliceous rock and white sand, silt, or clay. The siliceous rock is hard, gray, and made of silt-size detrital quartz grains in a matrix of interlocking microcrystalline quartz. Plant remains, including branches, stems, or roots, have weathered out of the rock leaving holes from a fraction of a millimetre to many centimetres in diameter. These holes are haphazardly oriented or vertically aligned. The siliceous rock occurs in a bed averaging 0.4 metres thick (1.3 feet).

Although the siliceous rock may be absent, the underlying white to very light gray sand, silt or clay is always present. The white sediment may be separated from the siliceous rock by a medium gray silt or clay, averaging 1.4 metres thick. The white color is best developed on silt, producing a striking white outcrop, distinguishable from other adjacent units. The white sediment averages 6.0 metres thick (20 feet).

The Rhame Bed is normally overlain by a bed of lignite, 0.1 to 1.7 metres thick (0.03 to 0.5 feet) and underlain by a bed of lignite, clay or sand.

Previous Work

References concerning the Rhame Bed are widely scattered in the literature and have not been previously summarized. They include descriptions and, in some cases, interpretations. The descriptions, mostly of the siliceous rock, will be considered here; the interpretations will
be discussed later. Table 1 is a correlation chart of the stratigraphic names used in the previous work. The stratigraphic position of the siliceous rock is shown as a cross-hatched bar. Only the references with the most complete stratigraphic names have been listed. Table 2 gives the specific locations of the Rhame Bed identified in the literature.

Blocks from the siliceous rock of the Rhame Bed were first recognized by N. H. Winchell (1875, p. 21-66) on a trip from Bismarck, North Dakota, to the Black Hills, South Dakota, during the summer of 1874. He called the boulders "gray quartzite having the appearance of highly siliceous limestone." He saw them along the border between North Dakota and South Dakota, from the Missouri River to the North Cave Hills, where he found the "siliceous limestone" in place: ". . . very hard, but sometimes porous and of lighter color; very rough; containing silicified wood and impressions apparently of bones . . . [it] might be stylized a quartzite" (Winchell, 1875, p. 26).

Willis (1885, p. 11), while studying the lignite of the Sioux Reservation on the west side of the Missouri River in North and South Dakota, noted erratic "quartzite" blocks containing silicified wood.

. . . the fragments are pierced with casts of stems from which the core has been removed. The surfaces of the blocks are highly polished by drifting sand . . . and the silicified wood has apparently been excavated from these casts by the same means, aided by alkali.

Todd (1896), while mapping east of Bismarck, included very compact, greenish quartzitic boulders abounding with imprints of vegetation, particularly cast of vertical stems, in the lower part of the Tertiary "Loup Fork formation" (Miocene Arkaree Formation) (Todd, 1896, p. 32) or in the "Fox Hills Sandstone" (Todd, 1896, p. 54).
TABLE 1

CORRELATION CHART OF THE STRATIGRAPHIC NAMES USED IN THE PREVIOUS WORK

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<tr>
<th>Todd, 1898</th>
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<th>Winchester and others, 1916</th>
<th>Bauer, 1924</th>
<th>Hares, 1928</th>
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<tbody>
<tr>
<td>Northwestern South Dakota</td>
<td>Cannonball River (south-central N.D.) Lignite Field</td>
<td>Northwestern South Dakota</td>
<td>Ekalaka (southeastern Mont) Lignite Field</td>
<td>Marmarth (southwestern N.D.) Lignite Field</td>
</tr>
<tr>
<td>White River Group (Miocene)</td>
<td>White River Fm. (Oligocene)</td>
<td>White River Fm. (Oligocene)</td>
<td>White River(? Fm. (Oligocene?)</td>
<td>Ft. Union (?) Fm. (Eocene)</td>
</tr>
<tr>
<td>Ft. Union Fm. (Eocene?)</td>
<td>Ft. Union Fm. (Eocene)</td>
<td>Ft. Union Fm. (Eocene)</td>
<td>Ft. Union Fm. (Eocene)</td>
<td>Ft. Union Fm. (Eocene)</td>
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<tr>
<td>Lance Fm. (Eocene?)</td>
<td>Lance Fm. (Eocene?)</td>
<td>Lance Fm. (Eocene?)</td>
<td>Hell Creek Mbr.</td>
<td>Hell Creek Mbr.</td>
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<tr>
<td><strong>Southwestern North Dakota</strong></td>
<td>Southwestern North Dakota</td>
<td>Northwestern South Dakota</td>
<td>Northwestern South Dakota (Cove Hills Area)</td>
<td>Southwestern North Dakota</td>
</tr>
<tr>
<td><strong>White River Fm.</strong></td>
<td>White River Fm. (Oligocene)</td>
<td>White River Group (Oligocene)</td>
<td>Chadron Fm. (Oligocene)</td>
<td>Golden Valley Fm. (Eocene)</td>
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<td><strong>Sentinel Butte Shale Mbr.</strong></td>
<td>Ft. Union Fm. (Paleocene)</td>
<td>Ft. Union Fm. (Paleocene)</td>
<td>Ft. Union Fm. (Paleocene)</td>
<td>Ft. Union Fm. (Paleocene)</td>
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<td><strong>Tongue River Mbr.</strong></td>
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<td>Tongue River Mbr.</td>
<td>Tongue River Mbr.</td>
<td>Tongue River Mbr.</td>
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<tr>
<td><strong>Ludlow Fm.</strong></td>
<td>Ludlow Fm. (Paleo.)</td>
<td>Ludlow Fm. (Paleo.)</td>
<td>Ludlow Fm. (Paleo.)</td>
<td>Ludlow Fm. (Paleo.)</td>
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<tr>
<td><strong>Hell Creek Fm.</strong></td>
<td>Hell Creek Fm. (Cretaceous)</td>
<td>Hell Creek Fm. (Cretaceous)</td>
<td>Hell Creek Fm. (Cretaceous)</td>
<td>Hell Creek Fm. (Cretaceous)</td>
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<tr>
<td>Author, Date</td>
<td>In Placea</td>
<td>As Bouldersa</td>
<td>State</td>
<td></td>
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<td>------------------------------</td>
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<td>--------------</td>
<td>--------</td>
<td></td>
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<tr>
<td>Winchell, 1875</td>
<td>by Ludlow Cave, North Cave Hills</td>
<td></td>
<td>N.D.</td>
<td></td>
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<tr>
<td>Todd, 1898</td>
<td>2 miles north of Dell, S.D.; south end of North Cave Hills and Slim Buttes</td>
<td>Riley Pass, North Cave Hills</td>
<td>S.D.</td>
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<td>Lloyd, 1914</td>
<td>130/92/4 Spring Butte</td>
<td>129/95; 129/94; 131/93</td>
<td>N.D.</td>
<td></td>
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<tr>
<td>Winchester and others, 1916</td>
<td>22/9/34 Anarchist Butte; 22/6/19 and 27 northwest of Ludlow; 22/5; 22/10/10; 21/5/12</td>
<td>2 miles east of Strool; along Moreau River; 23/12/24 ridge; 23/9/23 and 27; 23/7 southwest corner; 22/9; 22/7 hills; 22/8; 21/9/11; 15/8</td>
<td>S.D.</td>
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<td>Bauer, 1924</td>
<td>3/59/13 and 24 Fallon County</td>
<td></td>
<td>Mont.</td>
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<tr>
<td>Hares, 1928</td>
<td>136/106/27; 135/104; 135/103; 135/102; 134/104; 133/104/26; 133/103/31; 132/104; 130/102; caps buttes:131/104; 131/102/15 and 28; 131/103; 130/104/1,2, and 3; 130/91; 131/89</td>
<td>131/103; west of Medicine Pole Hills. (See Table 3 for South Dakota and Montana locations.)</td>
<td>N.D.</td>
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<td>Laird and Mitchell, 1942</td>
<td>136/83/14 and 15; 136/82/30</td>
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<td>N.D.</td>
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<td>Benson, 1954</td>
<td>133/94/5; Stoney (or Pearl) Butte</td>
<td>136/81/31; 1.5 miles west of Elgin</td>
<td>N.D.</td>
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<tr>
<td>Author, Date</td>
<td>In Place$^b$</td>
<td>As Boulders$^b$</td>
<td>State</td>
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<td>South Dakota Maps 1955-56$^b$</td>
<td>18/11; 19/11; 19/12</td>
<td>Tepee Buttes, Johnson Outlier</td>
<td>S.D.</td>
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<td>Denson and others, 1959</td>
<td>21/5/9; 22/5/29; 22/9/34</td>
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<td>S.D.</td>
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<td>Pipiringos and others, 1965</td>
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<td>Denson and Gill, 1965</td>
<td>2/61/20 NE$^c_4$</td>
<td></td>
<td>Mont.</td>
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<td>Schmit, 1970</td>
<td>128/98 Cow Butte; 131/93; 131/104</td>
<td>133/106; 134/106; 132/98; 130/98</td>
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<tr>
<td>Moore, 1976</td>
<td>136/104/32</td>
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</tbody>
</table>

a. Arranged township/range/section.

Todd (1898), while conducting a reconnaissance in northwestern South Dakota, called the siliceous rock a "fossiliferous flint" or "buhrstone," after a similar rock in the Paris Basin, France. He noted the irregular cavities in it: "... many of them clearly traceable to the stems of plants which vary in size from one-sixteenth of an inch to three or four inches in diameter. ..." In some, "... the wood was still in the cavity ... although not so solid as the surrounding rock." He found blocks of "buhrstone" scattered widely over the "Laramie formation" but included the in-place locations in the "Miocene White River Group" (Todd, 1898, p. 60-61). See Table 1; locations are listed in Table 2.

While studying the lignite along the Missouri, Heart, and Cannonball Rivers in North Dakota, Wilder (1904, p. 40) mentioned that "... fragments of quartzite, which is regarded as residual, are very abundant, often literally paving the hill tops." His Plate VII pictures glacial and quartzitic boulders along the Cannonball River.

Lloyd (1914, p. 251), in his paper naming the "Cannonball marine member of the Lance Formation" (Table 1), noted a "peculiar" surface feature of the Fort Union and Lance Formations. "... the abundance of angular and wind-worn blocks or boulders of very hard quartzitic rock." He said it is composed of angular or slightly rounded quartz grains, with silicified plant stems of various sizes, which have been weathered out, leaving the rock full of holes. The boulders on the higher buttes are "... strewn so thickly as to make the surface almost impassable for a horse." The boulders "... are scattered over small hillocks" as far down as the "Lance formation" and are "... absent over the greater part of the flat prairies and in the valleys." He declared that "all
of these bowlders are residual remnants from two or more comparatively thin beds in the Fort Union which have been found in place near the tops of several high buttes." Table 2 lists these locations.

Winchester, Hares, Lloyd, and Parks (1916, p. 29-31), in the first complete work on the geology of northwestern South Dakota, noted a peculiar quartzitic rock, grayish white to bluish gray, soft, but on weathering well indurated and polished by wind action, composed of fine subangular grains of quartz, and perforated by impressions of roots and stems. They list many locations (Table 2), including a measured section on Anarchist Butte (Sec.34, T.22N., R.9E.). Most of the boulders are derived from a stratum in the "Fort Union formation" (Table 1) but they insist that conditions favorable to formation of the quartzitic rock existed earlier (Fox Hills time) and later (White River time).

Bauer and Herald (1921, p. 115, plate XVI) found a bed of siliceous rock in two townships (T.148N., Rs.92 and 93W.) on the Fort Berthold Indian Reservation, Dunn County, North Dakota. The rock is dark and friable when fresh, but white and very resistant when weathered. The weathered boulders show impressions of plant stems and roots. This rock is most likely part of the Golden Valley Formation or the Sentinel Butte Formation and is not correlated with the Rhame Bed in the Slope Formation.

Bauer (1924, p. 258) assessed the Ekalaka lignite field, southeastern Montana, found a bed of gray siliceous rock, 0.38m (1.25 feet) thick, with casts and molds of plant remains, none of which could be identified. (Tables 1 and 2.)

C. J. Hares (1928) mapped the Marmarth lignite field in the southwestern corner of North Dakota. This study was part of the United States
Geological Survey coal resource mapping on the Great Plains in the early 1900s.

In the description of the "Fort Union Formation," Hares (1928, p. 34-36) included an extensive section on siliceous rocks. Two types of siliceous rock are described: the siliceous rock of the Rhame Bed and a rock that looks like Knife River Flint (see Clayton and others, 1970) on top of Twin Buttes, 0.85km (0.5 miles) north of Bowman.

He described the siliceous rock of the Rhame Bed as a peculiar light gray, hard, fine-grained "quartzite," full of small holes, which are molds of plant stems and roots. He uses the phrases "quartzite layer," "extremely resistant bed of quartzite," "striking and peculiar stratum in the Fort Union of siliceous rock," "conspicuous layer of quartzite," "very persistent bed of quartzite." Boulders are described as highly resistant to weathering, breaking "... with a hackly fracture, with very sharp, knife-like edges." Thin sections reveal "... very small grains of angular quartz cemented by silica, with a few black grains, probably carbonaceous material." The holes are "... to all appearances simply molds of stems showing scars of knots and roots, but nothing identifiable has been found." The size of the holes ranges from "... half an inch to four inches in diameter, and reach two feet or more in length. Some specimens show the branching nature of roots" (Hares, 1928, p. 36).

Hares included the "quartzite" in the "Tongue River member" of the "Fort Union Formation" (Table 1). The part of the "Tongue River Member" exposed in this area includes three major lignite beds, from the top, the Harmon, Hansen, and H Beds. The "quartzite" directly underlies the H Bed.
The H Bed] is underlain in places by a peculiar, hard, resistant, fine-grained, gray quartzitic sandstone, on which the identification of this bed of lignite largely depends (Hares, 1928, p. 80).

The base of the "Tongue River member" or the top of the "Lance Formation" is placed at various distances below the "quartzite." Hares also gave distances from the "quartzite" to overlying Harmon Bed, the major economic lignite in the area. (See Table 3.)

Hares used a bed of sandstone as the base of the "Tongue River member" in the northwestern part of the area, along the Little Missouri River (the first three listings in Table 3). In the southern part of the area, south of Rhame and Bowman, Hares assumed the bed of sandstone was covered and placed the base of the "Tongue River member" about 100 feet below the "quartzite." In the northeastern part of the area, along Deep Creek, Hares placed the contact between the "Tongue River member" and the underlying "Ludlow Lignitic member" at the base of the Rhame Bed, here lacking the quartzitic rock (Hares, 1928, p. 32 and my section 35-02-31).

The distance of the "quartzite" below the Harmon Bed remains fairly constant for the entire area (Table 3). Because of this relationship, both of these strata were used to determine the regional dip of the beds. Concerning the "quartzite"

... the attitude of the remnants found in place to the south [of Rhame] is much greater than to the north and east [by MT Ranch] a fact due to the northeastward dip away from the Glendive [Cedar Creek] anticline. ... " (Hares, 1928, p. 34-35).

Data was provided on the elevation of the Harmon Bed, and a regional strike and dip, N30°W, 4.7 m/km northeast (26 feet/mile), were calculated (Hares, 1928, p. 45).
### TABLE 3
DISTANCE, IN FEET, FROM THE "QUARTZITE" (SILCRETE OF THE RHAME BED) TO OTHER BEDS, DATA FROM HARES, 1928

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance (feet) Above the Base of &quot;Tongue River Mbr&quot;</th>
<th>Distance (feet) Below the Harmon Lignite Bed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North Dakota</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.136N., R.106W.</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>T.135N., R.104W.</td>
<td>60</td>
<td>148 (clinker)</td>
</tr>
<tr>
<td>T.134N., R.104W.</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>T.132N., R.104W.</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>T.131N., R.103W.</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>T.131N., R.102W.</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>South Dakota</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.22N., R.5E.</td>
<td>250</td>
<td>150 (above &quot;Cannonball mbr.&quot;)</td>
</tr>
<tr>
<td>Anarchist Butte</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>Montana</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.2N., R.60E.</td>
<td>30</td>
<td>100 (above T Cross lignite)</td>
</tr>
<tr>
<td>T.3N., R.59E.</td>
<td>30</td>
<td>200 (below &quot;Tongue River mbr.&quot;)</td>
</tr>
<tr>
<td>T.7 &amp; 8N., R.57E.</td>
<td>100 (above T Cross lignite)</td>
<td>200 (below &quot;Tongue River mbr.&quot;)</td>
</tr>
<tr>
<td>T.34N., R.51E.</td>
<td>80 (below Richardson lignite)</td>
<td></td>
</tr>
</tbody>
</table>
Hares reviewed the literature concerning the "quartzite" and listed numerous locations for it in North Dakota, South Dakota, and Montana. The locations from the township descriptions in the Marmarth lignite field are presented in Table 2, along with two locations in Adams and Grant Counties. The South Dakota and Montana locations are in Table 3. Hares did not provide a detailed distribution of boulders. Plates 5A and 7A (Hares, 1928, after p. 24) are photographs of the "quartzite" in place.

The second type of quartzitic rock is found in place on the northeastern Twin Butte north of Bowman. Fragments are scattered over parts of Bowman County, North Dakota, and Harding County, South Dakota. This "quartzite" is vitreous, yellow, or gray to black, very brittle, easily splitting parallel to the bedding planes, and made of almost pure silica. Plant impressions are on the flat bedding plan surfaces "... usually white and about a quarter of an inch in width, although some are as much as two inches. The stratum is only two feet thick and so far as ascertained occurs only in the Twin Buttes" (Hares, 1928, p. 36; measured section, p. 93). This rock resembles Knife River Flint (see Clayton and others, 1970) and commonly occurs in the pediment gravels throughout the area.

Tisdale (1941, p. 13-14) when mapping the Heart Butte Quadrangle in northern Grant County, North Dakota, encountered two types of quartzitic rock: a silicified shale, very dense, light yellow, with numerous cylindrical holes, the walls of which show imprints of plant stems; and a silicified sandstone, very dense in texture, gray, with smooth wind-polished surfaces. He listed no in-place locations, only concentrations of boulders on the tops of hills (particularly Sec.25, T.137N., R.89W.)
He stated these boulders are associated with "Fort Union beds," probably originating from several stratigraphic horizons. The boulders are probably from the lower part of the Golden Valley Formation.

Laird and Mitchell (1942, p. 22) noticed quartzitic boulders in southern Morton County. They also described a silty gray shale or volcanic ash, which is laterally associated with quartzitic sandstone concretions. The horizon, underlying a bed of lignite, forms a prominent marker. Although no holes in the quartzitic rock are mentioned, this description is similar to the siliceous rock of the Rhame Bed (Table 2).

Hennen (1943, p. 1569-70), in his study of the structure of the Tertiary sediment in the Williston Basin, recognized a persistent marker bed, which he designated as "Sandstone 21": containing a rock described as a grayish white, flaggy to shaley sandstone, "... with silicified fossil plant stems in abundance, and here and there silicified stumps of trees 3-5 feet in diameter." He correlated his columnar sections using this unit, considering it to be one bed in the "Tongue River member" of the "Fort Union Formation."

Roland Brown (1948, p. 1269) presented a correlation of Tertiary units across the northern Great Plains. He quoted Hennen's description of "Sandstone 21" and explained that a field check (with W. E. Benson) of Hennen's locations revealed one silicified stump zone "... is about 85 feet above the clinker marking the Tongue River-Sentinel Butte contact ..." and a second zone was "... 35-40 feet below it," thus Hennen's correlation is incorrect. He declared that these zones are found throughout the entire lignitic series and referred the reader to Hares (1928) for a discussion of siliceous rocks. Brown must not have realized that
Hares was discussing two specific siliceous rocks, the lower one (associated with the Rhame Bed) being unusual in the North Dakota stratigraphic section. Brown (1948, p. 1269) concluded: "The best that can be said for any silicified 'marker-bed' is that it may be useful locally but cannot be relied on across long, concealed intervals." This attitude prevailed throughout subsequent works.

William E. Benson, of the United States Geological Survey, started working in North Dakota in the mid-1940s. His report on the Knife River Basin (Benson, 1952) covered most of the geology west of the Missouri River. He recognized the Golden Valley Formation (Table 1) and, in the discussion of the kaolinitic clay in the lower part of the Golden Valley, Benson included a description of the white sediment in the Rhame Bed:

I know of only one bed in North Dakota that can be mistaken for the lower member of the Golden Valley formation. This bed which is just above the base of the Tongue River member and 50 to 75 feet below the Harmon lignite, crops out in the southwestern North Dakota in Bowman and Slope counties and is almost identical in appearance to the lower member of the Golden Valley formation. . . . the bed has a silicified zone at the top and the yellow staining is less pronounced than in the 'marker-bed' of the Golden Valley formation. . . . Although it was not described by Hares it would seem to be an excellent local marker horizon for stratigraphic work in the Marmarth area (Benson, 1952, p. 74-75).

Hares did describe the siliceous rock ("quartzite") but he never mentioned the white kaolinitic clay anywhere in his report.

Benson (1954a, p. 14) helped prepare a North Dakota Geological Society guidebook for the southwestern part of the state (Table 1). He described two types of silicified rock: a sandstone or gray shale and a black carbonaceous shale. The first

. . . commonly six inches to eighteen inches thick, weathers as extremely hard, angular blocks of tan to gray, fine-grained quartzitic sandstone or shale. Many of them contain impressions of rush stems and roots of swamp vegetation.
The blocks resist weathering and persist as boulders even after the land surface "... has been lowered more than two hundred feet."

These rocks resemble the siliceous rock of the Rhame Bed. Silicified black carbonaceous shale "... occurs as thin, platy layers, rarely exceeding two to three inches in thickness," black when fresh, white when weathered, usually overlying, thin, impure lignite beds. These beds are more persistent laterally, "... and consequently are more useful as key horizons." Because the beds of silicified black carbonaceous shale resemble one another, and many can be exposed in one stratigraphic interval "... they are difficult to correlate where exposures are poor." Benson (1954a, p.15) also mentioned the kaolinitic clay in the lower Golden Valley formation and the clay in Slope and Bowman Counties. The locations from the roadlog of the "pseudo-quartzite" (another name for the siliceous rock) are listed in Table 2.

The South Dakota Geological Survey published areal geology quadrangle maps in the mid-1950s. Four of these maps, Strool, Cash, Sorum, and Dale, have a lithologic unit called "Tongue River Boulders-Tongue River Formation" (Bolin, 1956a, 1956b and Curtiss, 1955a, 1955b). The description of this unit is "thick concentrations of residual orthoquartzite boulders blanket the Ludlow Formation. ... the boulders are gray and possess a high degree of wind polish (venifacts) and vesicular impressions of roots and branches" (Bolin, 1956a). "Some of the boulders are 10 feet in length. One silicified petrified log, which is found in Sec. 13, T.19N., R.11E., is 72½ feet in length and 7½ feet in diameter" (Curtiss, 1955a). This ridge, two miles east of Strool, mentioned in Winchester and others (1916) has a very spectacular concentration of siliceous boulders.
On the Lodgepole Quadrangle "... a light gray siliceous silt with plant fragments ..." is included in the "Tongue River Formation." This bed is cited as "the source of some of the many 'orthoquartzite' boulders strewn on the surface of northwestern South Dakota" (Stevenson, 1956a).

From the late 1950s to mid-1960s considerable work was done on the uranium around the Slim Buttes and Cave Hills in South Dakota and the Medicine Pole Hills and Chalky Buttes in North Dakota.

Denson, Bachman, and Zeller (1959, p. 15, Fig. 4) included a quartzitic marker in their generalized stratigraphic column for northwestern South Dakota and adjacent areas (Table 1). The quartzitic rock is gray, very fine grained, and contains impressions of plant roots. The bed of quartzite is 0.6m (2 feet) thick on the southwest side of the North Cave Hills, 51.5m (170 feet) above the base of the "Tongue River member."

In Harding and Perkins Counties, South Dakota, the lowest quartzite bed persists for about 30 miles from the North Cave Hills eastward to the vicinity of Lodgepole Post Office ... [where it] may be within 100 feet of the base of the Tongue River member ... It occurs 10 to 20 feet below a widespread and persistent bed of lignite, considered to be the "Harmon lignite bed" (Denson and others, 1959, p. 19, Plate 6). (See Table 2 for locations.)

Zeller and Schopf (1959, p. 65) noted ledge-forming beds of hard sandstone and "quartzite" in the Medicine Pole Hills, underlying the "Harmon lignite bed."

Pipiringos, Chisholm, and Kepferle (1965, p. AI0) studied the uranium in the North Cave Hills, South Dakota. "Two, and possible three, ledge-forming quartzite beds are present in a zone 60 to about 100 feet above the top of the E-bed sandstone." This sandstone bed is about 30.3m (100 feet) above the base of the "Tongue River member" (Table 1). The
beds, 0.15m to 0.90m (0.5 to 3.0 feet) thick, contain tubular cavities of probable fossil root holes and can be traced laterally into a poorly cemented soft layer of silica-kaolinite flour that contains abundant analcite spherulites . . . [which] is well exposed in the west-central part of the North Riley Pass district (Pipiringos and others, 1965, p. A10).

On Anarchist Butte, the "quartzite" grades laterally into a poorly consolidated quartz sandstone that directly underlies a thin coal bed. The matrix consists principally of kaolinite and minor amounts of quartz. No analcite is present (Pipiringos and others, 1965, p. A10).

Measured sections include the "quartzite" (Pipiringos and others, 1965, Plate 2). See Table 2 for locations.

Denson and Gill (1965) briefly mentioned "... angular blocks of locally derived quartzite ... accumulated on the surface prior to deposition of the White River Group and Arikaree Formation," and therefore found in the base this group (Denson and Gill, 1965, p. 5; Fig. 3, p. 6), as part of the "Tongue River member" (Denson and Gill, p. 7, Table 1), and as fragments mixed into the Quaternary gravels (Denson and Gill, 1965, p. 19). See Table 2 for locations.

Denson and Pipiringos (1969, p. 15) discussed the Paleocene-Eocene contact on the northern Great Plains. The Paleocene Series contains beds of silicified rock, 0.15m to 0.6m (0.5 to 2 feet) thick, which generally underlie beds of carbonaceous shale or coal, with casts and molds of leaves and roots, composed of quartz silt and resembling ganister.

They have been recognized in rocks of Paleocene age in the Wind River and Powder River Basins of Wyoming and in the Williston Basin in southwestern North Dakota . . . as far as the present writers know, rocks resembling these hard, weather-resistant quartzites have never been reported from the Eocene. . . (Denson and Pipiringos, 1969, p. 15).
Brown (1962) again discussed Hennen's erroneous cross section, that used "Sandstone 21" as a datum, but cited different intervals in describing the mistaken correlation. He repeated his reference to Hares' discussion of beds of siliceous rock, and warned about using silicified beds for correlation across covered intervals (Brown, 1962, p. 19-20).

Clayton (1962, p. 52-53) referred to the siliceous rock as a "residual sandy chert," which composes "... 1 to 10 percent of the stones in and on the drift in the western half of Logan and McIntosh Counties." The chert is light to medium grayish, yellowish or reddish-brown, with numerous molds of plant stems, 1 to 10mm in diameter, and several irregular longitudinal grooves. The surface is wind-polished. The chert is made of subangular to rounded, detrital quartz grains (10 to 30 percent) surrounded by a matrix of microcrystalline quartz, 0.01mm grain diameter. No chalcedony or amorphous quartz is seen in thin section. Based on previous work, the "Tongue River Formation" was cited as the probable origin, and if so, then the chert may have been let down more than 214m (700 feet).

Leo Hickey (1966, 1972, and 1977) studied the Golden Valley Formation in western North Dakota. The Bear Den Member, the lower part of the Golden Valley Formation, includes three color zones, from the bottom: "gray zone," "orange zone," and "carbonaceous zone." The member is topped by the "Alamo Bluff lignite" and its lateral equivalent the "Taylor bed." The "Taylor bed" is a silicified siltstone, made of interlocking quartz grains, with overgrowths, in a micro-crystalline silica matrix, and riddled with stem molds (Hickey, 1977, p. 23-26). The "Taylor bed" resembles the siliceous rock of the Rhame Bed; the overlying "Alamo Bluff lignite" resembles the H Bed, the underlying "orange
zone," made of kaolinitic clay, silt, and sand, resembles the white sand, silt and clay of the Rhame Bed. Hickey recognizes the Rhame Bed, although he does not use that name:

... A large area of kaolinitic claystone, superficially resembling that of the Bear Den Member of the Golden Valley Formation (especially its white to brilliant yellow and orange color) is present near the base of the Tongue River Member in Slope and Bowman Counties, North Dakota. This 'false Golden Valley unit' was traced from the HT Horse Company on Deep Creek... to the Medicine Pole Hills. ... Despite the similarities of color and clay composition to the Golden Valley Formation, the unit occurs at least 214m [700 feet] below the latter formation in an otherwise typical Tongue River lithology. In addition, the 'false unit' is obviously confined to a single broad lens and does not possess the same sequence of color zonation or rock types that occur in the true Bear Den Member of the Golden Valley Formation (Hickey, 1977, p. 7-8).


Four types of outcrops were described: in place, as caprock on buttes, as gravel, and as boulders. The locations that are probably related to the siliceous rock of the Rhame Bed are listed in Table 2.

The rock is silica-cemented siltstone or arenaceous chert. In hand specimen, the grains appear subangular, silt-sized, in a matrix of siliceous cement. The rock ranges in color from light gray to shades of brown. The weathered surface is softer and lighter than the darker, denser core. Light and dark rings, nodular forms about 0.15m (0.5 feet) across, and mamillary structures are interpreted to be concretions. Plant fossils are wood or wood, root, and stem casts and molds. Murky, darker colors in the rock distinguish disseminated plant material from the rest of the rock. When the rock is in place, the casts or molds appear to be vertically oriented.
In thin section, the grains are predominantly silt-size quartz with some clay-size particles. Heavy mineral grains include sphene, epidote, hornblende, muscovite, and garnet. The grains are subrounded to angular, moderately well sorted, and randomly oriented. The secondary silica appears to be overgrowths or microcrystalline quartz or chert. The detrital grains may have a fringed edge around their margins.

Schmit provided a model for a depositional environment, which will be discussed later.

In the early 1970s, the United States Geological Survey started mapping a group of quadrangles in central North Dakota to determine the coal resources. Barclay (1970, 1971, 1973, 1974) described ganister blocks as boulder-size blocks or slabs of hard, dense, silicified siltstone or mudstone, buff to brownish gray, polished on the weathered surface, with tubular plant casts. In thin section, the blocks are composed of silt-size grains in a matrix of interlocking microcrystalline quartz. The blocks were probably derived from the "Fort Union Formation." They also occur as glacial erratics or lag deposits (Barclay, 1973, p. 8). Stephens (1970, 1970b), as well as Barclay, mapped these blocks as "... areas littered by silicified sandstone, siltstone, and mudstone boulders derived from the Fort Union Formation" (Stephens, 1970a). Because these boulders are sitting on the Sentinel Butte Formation, they probably came from the "Taylor bed" in the lower part of the Golden Valley Formation.

Moore (1976), in choosing the upper contact for the "Ludlow Formation" north of Marmarth, recognized a "white siliceous bed": dull white, aphanitic to fine grained quartz, with tubular to flattened holes and abundant bladelike and fibrous impressions on the surface, this bed is commonly overlain by a bed of lignite or lignitic shale and underlain by
A layer of silcrete occurs in the middle rather than at the top of a layer of white to very light gray silt and sand in measured section 36-03-36. Less than 0.4km (0.25 miles) to the southwest, in measured section 35-03-01, the Rhame Bed consists of white to very light gray silt, with no silcrete at the top or in the middle.

Despite the variation in the Rhame Bed near the HT Ranch, the sediment (the H Bed of lignite and yellowish gray silt and sand) in the Bullion Creek Formation on top of the Rhame Bed is remarkably uniform, perhaps indicating more uniform deposition occurred after the formation of the Rhame Bed.

Description of the Rhame Bed in Other Areas

On the east side of the Little Missouri River, across from the VVV Ranch (see Plate 1), the Rhame Bed is underlain by yellowish sand. Hares (1928) placed the contact of the "Lance-Tongue River" at the base of this sand. Moore (1976) had trouble deciding on the upper contact of the Slope Formation, which he called the "upper member of the Ludlow Formation," in this area, because of this yellowish sand. The Rhame Bed provides a reliable marker for this area. It outcrops continuously on the east side of the river from Sec. 33 north to Sec. 21, T.136N., R.104W. (Figure 13) and on the west side of the river from Sec. 18, northeast to Sec. 3, T.136N., R.104W (see Plate 1). The base of the Rhame Bed is very pale green in this area. (Figure 14 and measured section 35-04-4.)

The Little Missouri River bends eastward on the boundary between Slope and Golden Valley Counties. On the north side, in Golden Valley County, the Rhame Bed outcrops continuously for about 2.48km (1.5 miles). The bed dips to the east at a greater angle than the river, but has an
Fig. 13. Outcrop of the Rhame Bed in the badlands along the Little Missouri River. The Rhame Bed is between the lines. The photograph shows good color contrast: lighter, yellow units above the Rhame Bed and darker, gray units below the Rhame Bed. Photograph was taken looking north, 3.3km (2 miles) north of the VVV Ranch, in Section 21, T. 136 N., R 104 W.

Fig. 14. Outcrop of Rhame Bed showing greenish base. The silcrete of the Rhame Bed is at the horizon in the upper left. Lighter color sand of the Bullion Creek Formation is in upper right. Measured section 35-04-4. The handle of the pick is 0.9m long.
irregular surface, so the outcrops are discontinuous along the northern edge of Slope County (see Plate 1). At Walser's Crossing, Sec. 2, T.136N., R.103W, the Rhame Bed has a greenish tinge near the base. The most northeastward outcrop of the Rhame Bed in the entire study area is at the level of the river, at the base of Tepee Buttes, in Sec. 6, T.136N., R.102W., Slope County. Tepee Buttes is capped by the Sentinel Butte Formation, so the entire Bullion Creek Formation is exposed on the west-facing side, in strikingly laterally-continuous beds.

The outcrop edge of the Rhame Bed has two distinctive appearances. Along the western and southwestern sides of the study area the outcrop edge has a steep dip, 7.3 to 11 m/km (40 to 60 feet/mile). Because of this dip, isolated silcrete-capped buttes (Figure 2) are significantly higher in elevation than the nearest in-place locations. On the southeastern side of the study area, between Rhame and Bowman, the Rhame Bed outcrops in large, light-colored areas.

Other notable aspects of the Rhame Bed include a second outcrop with two layers of silcrete (measured section 35-04-21) almost directly west of the occurrence in the HT Ranch area (measured section 35-03-13); a layer of channel sand in the area of the X—X Ranch (say Ex Bar Ex), Sec. 4, 9, 16, T.136N., R.104W., which cuts out the Rhame Bed, providing more evidence for a pre-Bullion Creek time of formation; and an area of silcrete in Sec. 28, T.135N., R.104W. with a very irregular lower surface and no holes.

The Rhame Bed in Other Places

Bluemle (1977a, 1977b) mapped the contact between the Slope-Cannonball-Ludlow Formations undifferentiated, and the overlying Bullion
Creek Formation. The Slope, by definition (see Clayton and others, 1977), overlies the Cannonball and Ludlow Formations, so the contact should represent the approximate position of the Rhame Bed in North Dakota (Figure 15).

In Montana, Bauer (1924), Hares (1928), and Denson and Gill (1965) have noted the silcrete. I found the Rhame Bed at Bauer's location (see Table 2, this report) and 5.8km (3.5 miles) south of Plevna in Fallon County (see Figure 1 for location). Boulders of silcrete are scattered as far southwest as Ekalaka in Carter County (Lambert, Marshall, 1977, Personal Communication, Ekalaka, Montana) (see Figure 1 for location). A review of the United States Geological Survey coal field reports from the early 1900s revealed that no author mentioned the silcrete west of Fallon and Carter Counties, Montana.

Winchester and others (1916) were the first to recognize the silcrete of the Rhame Bed in northwestern South Dakota. In the 1950s, the South Dakota Geological Survey published areal geology maps of the region with the concentrations of silcrete boulders noted (Bolin, 1956a, 1956b; Curtiss, 1955a, 1955b; Stevenson, 1956b). Denson and others (1959), Pipiringos and others (1965), and Denson and Gill (1965), all noted, in their uranium studies, the silcrete in the North Cave Hills, Harding County, South Dakota (Figure 1, Table 6).

Jacob (1976, p. 37-38) contended that the sediment in the North Cave Hills is not part of the "Tongue River member of the Fort Union Fm," but is part of the Ludlow Formation. He based his conclusion on the abundance of volcanic rock and montmorillonite, and on three "... previously unrecognized tongues of the Cannonball Formation." Pipiringos and others (1965, p. A10) found the remains of sharks and other fishes
Fig. 15. Map of the contact between the Slope, Cannonball, and Ludlow Formations, (undifferentiated) and the Bullion Creek Formation in southwestern North Dakota (after Bluemle, 1977b). The hatchured line represents the approximate position of the Rhame Bed.
in the shale bed, at the base of the "E-bed sandstone"; Jacob included the shale and sandstone beds in his lower tongue. The identification of the other two tongues of the Cannonball Formation, higher in the section, was based on color, thickness, and bedding characteristics (Table 6). Jacob made no formal recommendation to change the stratigraphic names.

Moore (1976, p. 37) stated that

... use of the white siliceous bed [Rhame Bed] as the upper contact [of the 'Ludlow Formation'] would thus raise the contact in the Marmarth coal field. Extension of this usage to the south into the Cave Hills and other boundary buttes and mesas along the North Dakota and South Dakota border would eliminate most of mapped Tongue River Formation in these areas by including it in the Ludlow Formation.

Clayton and others (1977) defined the lower contact of the Slope Formation in North Dakota as the top of the T Cross Bed of lignite, which, they declared, is equivalent to the "Giannonatti lignite bed" (Stevenson, 1956b) or the "Carbonate No. 2 coal bed" (Pipiringos and others, 1965) in South Dakota (Table 6). They stated

This suggests that the interval between the white marker zone [Rhame Bed] and 'Carbonate No. 2 coal bed' which is included in the Tongue River Formation in South Dakota ... is probably equivalent to the newly defined Slope Formation of North Dakota.

From my observations, one layer of silcrete occurs in the North Cave Hills. The steep dip confused Pipiringos and others (1965), causing them to include three layers of "quartzite" in their stratigraphic column (their Figure 2) and two layers of "quartzite" in their stratigraphic section #5 (their Plate 2). The silcrete is underlain by white sediment (see also Pipiringos and others, 1965, p. A10). Abundant silcrete boulders occur on the east side of the North Cave Hills, all around Ludlow, South Dakota and as far east as Lodgepole, South Dakota
"... a variety of sediment types which are commonly bleached white... [extending] to depths of several tens of feet below the bed into underlying sediments." Subtle green and lavender colors are associated with the bleached zone. Where developed in a continuous layer the "white siliceous bed" resists erosion, holds up surfaces and caps buttes and benches, but where developed as a thin discontinuous nodular bed, the "white siliceous bed" forms cobble-covered shoulders on the underlying rocks. The bleached zone is locally thick and prominent, diminishing laterally to negligible thickness. The bed occurs over many townships at approximately the same stratigraphic position (Moore, 1976, p. 35-36) (Table 1 and 2).

Bluemle (1977a, p. 15-16) described many types of chert in North Dakota, including boulders of material called "pseudoquartzite" or "ganister," which are abundant on the surface in southwestern North Dakota. The rock is gray, unbedded, with irregular fracture, numerous petrified plant stems and hollow stem molds of grooved plant roots or stems.

Clayton and others (1977) redefined the "Ludlow Formation" and "Tongue River Formation" in North Dakota. The "Ludlow Formation" was apparently defined at a higher stratigraphic position in North Dakota than in South Dakota. After Moore completed a detailed study of the Ludlow Formation in North Dakota, Clayton and others (1977) designated the Ludlow Formation in North Dakota as the sediment from the top of the Hell Creek to the top of the T Cross Bed of lignite (Moore's "lower Ludlow Formation"). The Slope Formation consists of the sediment from the top of the T Cross Bed of lignite to the top of the "white marker zone" (Moore's "upper Ludlow Formation"). The "Tongue River Formation"
is renamed the Bullion Creek Formation, the lower contact being the top of the "white marker zone" (Rhame Bed) or the base of the H Bed of lignite. Table 1 shows these stratigraphic names, which are also used in this report.

In summary, these references mention the siliceous rock of the Rhame Bed because it is an unusual rock type. The underlying white to light gray sand, silt or clay is only recognized by five authors: Benson (1952), Pipiringos and others (1965), Hickey (1966, 1972, 1977), Moore (1976) and Clayton and others (1977). The association of the two units is only recognized by four authors: Benson (1952), Pipiringos and others (1965), Moore (1976), and Clayton and others (1977). The regional extent of the Rhame Bed in North Dakota is only recognized by four authors: Hares (1928), Benson (1952), Hickey (1966, 1972, 1977), and Moore (1976). The possibility of using the Rhame Bed as a stratigraphic marker unit is recognized by Benson (1952), Moore (1976), and Clayton and others (1977).

Description

As previously stated, the Rhame Bed consists of two major lithologies: a siliceous rock overlying white to light gray unconsolidated sand, silt, or clay. This section describes the Rhame Bed: (1) lithology based on hand samples, (2) distribution in the study area, (3) outcrop characteristics in the study area.

The Silcrete

The siliceous rock of the Rhame Bed has been difficult to name. Table 4 lists the names used in the previous work. "Quartzite" has been used most frequently. "Pseudo-quartzite" was introduced in the 1950s.
### TABLE 4

**NAMES USED FOR THE SILICEOUS ROCK OF** **THE RHAME BED**

<table>
<thead>
<tr>
<th>Name</th>
<th>Author, Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siliceous limestone</td>
<td>Winchell, 1875.</td>
</tr>
<tr>
<td>Buhrstone, fossiliferous flint</td>
<td>Todd, 1898.</td>
</tr>
<tr>
<td>Quartzite</td>
<td>Wilder, 1904; Winchester and others, 1916; Hares, 1928; Denson and others, 1959; Zeller and Schopf, 1959; Pipiringos and others, 1965.</td>
</tr>
<tr>
<td>Silicified sandstone</td>
<td>Tisdale, 1941.</td>
</tr>
<tr>
<td>Arenaceous chert</td>
<td>Hickey, 1966; Schmit, 1970.</td>
</tr>
<tr>
<td>Sandy, chert-cemented siltstone</td>
<td>Schmit, 1970.</td>
</tr>
<tr>
<td>Siliceous bed (white marker zone)</td>
<td>Clayton and others, 1977.</td>
</tr>
</tbody>
</table>
because the term quartzite was intended for metamorphic rocks. The 
South Dakota Geological Survey called it "orthoquartzite," a term 
reserved for sedimentary quartzite. The use of the terms "chert" or 
"sandstone" and "siltstone" depended on the recognition of, size, and 
percentage of grains and indicated an interpretation of nondetrital or 
detrital origin. Ganister is a term developed in England for sili-
ceous clay-rock of the Carboniferous Lower Coal Measures and should 
probably be restricted to those rocks. "Silcrete" is a term "for any 
material indurated by silicification" (Exon and others, 1970). This 
term was developed in southern Africa and has been used extensively 
in the literature for rocks in South Africa, Australia, Brazil, Nether-
lands, England, and other countries. All of these rocks are Tertiary, 
as is the Rhame Bed. For these reasons I propose the use of the term 
"silcrete" for the siliceous rock in the Rhame Bed. Supporting evidence 
will be presented in the Interpretation section of this report.

In hand sample, the grains in the silcrete are difficult to dis-
tinguish. They appear to range from fine sand to silt and are subangular. 
In thin section, Schmit (1970, p. 21) noted that the grains are mainly 
quartz, with some chert and heavy minerals, are moderately well-sorted, 
and randomly oriented. Some of the detrital grains show overgrowths or 
partial overgrowths of "secondary" silica. These overgrowths, although 
optically continuous, are distinguished from the grains by a thin inter-
vening layer of organic material, clay particles, or liquid or gas inclu-
sions. Other detrital grains may exhibit a fringe-like character (Schmit, 
1970, p. 21-22). Hickey (1977, p. 23) also noted the overgrowths on 
quartz grains.
In hand sample, the rock appears to be cemented by silica, but in thin section the grains are surrounded by a matrix of microcrystalline quartz or chert. Clayton (1962, p. 52) stated that the volume of the detrital grains in the rock is only 10 to 30 percent. Hickey (1977, p. 23) described the "Taylor bed," a silcrete in the lower part of the Golden Valley Formation, as "... composed of silt-sized grains, most of which are quartz, in a microcrystalline silica matrix whose volume does not exceed 25 percent." Schmit gives no estimate, stating that the "secondary" chert to detrital grain ratio ranges from site to site, between samples at the same site, and even in individual thin sections. The chert matrix ranges in color from clear to brownish-red, brown, or black. The chert matrix variably replaces the disseminated plant matter in the rock; the amount of organic matter is inversely proportional to the amount of chert. The chert matrix typically grades from finely crystalline on the margins of the replaced fragments to coarsely crystalline in the middle (Schmit, 1970, p. 21).

The unweathered rock is medium gray, very compact with uniform hardness; the rock breaks across the grains, not around them, yielding a conchoidal fracture.

Weathered silcrete in the Rhame Bed is light gray with iron-oxide staining which modifies the color to light yellowish gray, pale yellowish orange, or light brown (Figure 2). The weathered rock is usually more porous; the plant matter is removed from the rock leaving a higher percentage of holes. Boulders of the silcrete close to the original source usually have a soft, lighter-colored rind on the outside (Figure 3). As time progresses, this softer rind is removed from the boulders, leaving the harder, extremely resistant, medium gray core. Isolated boulders
The silcrete, although laterally discontinuous, should appear in drill holes. A hole drilled in Sec.12, T.132N., R.104N., near the outcrop edge of the Rhame Bed, hit the silcrete (Peters, Eugene, 1977, Personal Communication, Bowman, North Dakota). The geophysical log characteristics probably are similar to a cemented sandstone.

The fossil plant remains in the silcrete in the Rhame Bed are abundant. Casts of plant branches range in size from 0.005m to 0.1m in diameter and 0.01m to 0.5m in length. These casts show insect borings, bark imprints and knots; are curved or straight; are haphazardly arranged in the rock; and are not flattened or otherwise deformed. Many of these casts are weathered out of isolated boulders, leaving large holes. Other casts, which could be plant stems or roots, are smaller: 0.001m to 0.01m in diameter and 0.001m to 0.1m in length. These casts show no identifiable markings; are slightly flattened or wavy; are haphazardly to vertically aligned; and do not appear to be deformed. Figure 6 shows an unusual occurrence of a plant stem and node. Most of the casts and molds are well preserved.

The White Sediment

This part of the Rhame Bed is identified primarily on color and is not obvious, in the field, to the unaccustomed observer. When the sediment of the Slope and Bullion Creek Formations is dry, white salts accumulate on the surface, making many of the outcrops look white. Digging in the outcrop reveals the real color: the Rhame Bed is white, other units are generally gray or yellow. After a few days of rain the white color of the Rhame Bed can be readily distinguished from adjacent units, from which the salts have been leached.
Fig. 6. Plant casts and molds in the silcrete in Rhame Bed. Plant stems and nodes are shown here. A possible fruiting body is just below the ruler (arrow). This rock was found in a boulder pile just southeast of measured section 33-03-27.

Fig. 7. Castellate erosion surface on white clay in the Rhame Bed. Pale yellowish orange iron-oxide staining extends across the outcrop in orange bands. Moderate red to blackish red limonite (from siderite?) concretions occur on a few peaks. The unit is overlain by light gray clay of the Rhame Bed and is underlain by black lignite of the Slope Formation. Measured section 35-02-32. The handle of the pick is marked at 0.1m intervals.
The grain size of the white sediment ranges from clay size to very fine sand. Three-quarters of the units in the white sediments are clay size and/or silt size.

The Rhame Bed generally ranges from white to light gray. The larger grain sizes, fine sand to coarse silt, are generally white; the smaller grain sizes, silt to clay-size, are generally gray. The whitest outcrops commonly have yellowish orange, iron-oxide staining, which forms in bands across the surface. In some outcrops, the sediment is whiter at the base of the bed. Not all the sediment is white or light gray. Some carbonaceous, medium to dark gray clay-size and silt-size sediment may occur both above and below the whitest sediment.

The white sediment weathers into three main outcrop patterns: castellate, flaky cracked, and smooth. Castellate erosion occurs mainly on very white to very light gray silt, with steep slopes. Figure 7 shows this erosion surface. The flaky cracked weathering surface develops on silt and clay, and looks like a collection of flat-lying potato chips. Wetting welds the edges of the chips together; dryness lifts the edges up. The surface appears both mud-cracked and flaky. Rounded slopes develop with this surface. Smooth weathering surfaces usually form on fine to medium sand, and are very hard and steep.

The upper and lower contacts of the white sediment of the Rhame Bed are defined on the basis of color. The upper contact is the base of the silcrete layer or the base of a lighter and yellower layer. The lower contact is the top of a darker and more gray layer. Both the upper and lower contacts are associated with a lignite unit. The overlying lignite, present in about two-thirds of the outcrops, was designated the H Bed by Hares (1928). Its average thickness is about 0.75m (2.5 feet). The underlying lignite bed, present in about one-half the outcrops, is
about 0.3m thick (1.0 feet). The contact of the white bed with the underlying lignite bed is usually abrupt.

The thickness of the white sediment ranges from 0.5m to 7.0m, and averages about 4.4m (14.5 feet).

Bedding in the white sediment of the Rhame Bed is notably lacking. Clay size units generally have no bedding; silt units sometimes have large-scale horizontal bedding; interlayered silt and clay or silt and sand give the false impression of large-scale, horizontal bedding. Sand may be laminated, or have large-scale horizontal bedding, or no bedding, in which case it is very hard, with smooth, steep slopes.

Another distinguishing feature of the Rhame Bed is the lack of calcium carbonate. Most of the sediment in the Tertiary sequence, in this area, is characterized by calcium carbonate; the sediment directly overlying the Rhame Bed has calcium carbonate present.

Plant fossils are rare in the white sediment. Short (0.001m to 0.01m), thin (0.001m) organic pieces, haphazardly arranged, are found in very white, clay-size units. Silt and sand units rarely have fossils. Wood, probably branches, was found in one location (SE4, SE3, Sec.32, T.135N, R.102W.) beneath the silcrete.

Table 5 presents a summary of the thicknesses of the various parts of the Rhame Bed and the units directly overlying and underlying it. Data is from the measured sections in Appendix A.

Plates 1 through 4

Plate 1 is a map of the outcrop of the Rhame Bed in western Slope County and north-central Bowman County. Solid and dashed lines indicate the outcrop position of the silcrete and white sediment, or white sediment only. Dotted lines represent the inferred position of the Rhame Bed.
TABLE 5
THICKNESS (METRES) OF THE PARTS OF THE RHAME BED AND OVERLYING AND UNDERLYING BEDS

<table>
<thead>
<tr>
<th>Measured Section</th>
<th>H Bed or Overlying Unit</th>
<th>Silcrete, Other Colored Lithologies</th>
<th>White Sand, Other Colored Silt, and Lithologies</th>
<th>Total Thickness of Rhame Bed</th>
<th>Underlying Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>34-04-1</td>
<td>Clay</td>
<td>-</td>
<td>2.95</td>
<td>2.45</td>
<td>5.40</td>
</tr>
<tr>
<td>30-04-2</td>
<td>Lig 0.30</td>
<td>0.75</td>
<td>-</td>
<td>2.45</td>
<td>5.25</td>
</tr>
<tr>
<td>31-02-8</td>
<td>-</td>
<td>0.20</td>
<td>0.35</td>
<td>1.10</td>
<td>1.65</td>
</tr>
<tr>
<td>31-04-11</td>
<td>-</td>
<td>0.65</td>
<td>-</td>
<td>1.85</td>
<td>2.50</td>
</tr>
<tr>
<td>31-04-35</td>
<td>-</td>
<td>0.40</td>
<td>-</td>
<td>2.00</td>
<td>5.90</td>
</tr>
<tr>
<td>33-03-12</td>
<td>Lig 0.10</td>
<td>0.25</td>
<td>1.95</td>
<td>1.60</td>
<td>3.80</td>
</tr>
<tr>
<td>33-03-13</td>
<td>Silt</td>
<td>0.20</td>
<td>-</td>
<td>3.50</td>
<td>3.70</td>
</tr>
<tr>
<td>33-03-27</td>
<td>-</td>
<td>0.50</td>
<td>5.80</td>
<td>-</td>
<td>6.30</td>
</tr>
<tr>
<td>33-03-33</td>
<td>Lig 0.85</td>
<td>0.15</td>
<td>-</td>
<td>0.80</td>
<td>1.60</td>
</tr>
<tr>
<td>33-03-34</td>
<td>Lig 0.10</td>
<td>0.40</td>
<td>-</td>
<td>2.00</td>
<td>2.40</td>
</tr>
<tr>
<td>34-02-27</td>
<td>Silt/Snd</td>
<td>-</td>
<td>1.50</td>
<td>2.50</td>
<td>4.00</td>
</tr>
<tr>
<td>34-04-15</td>
<td>Clay</td>
<td>-</td>
<td>0.15</td>
<td>1.30</td>
<td>1.45</td>
</tr>
<tr>
<td>35-02-31</td>
<td>Lig 0.25</td>
<td>-</td>
<td>1.20</td>
<td>3.00</td>
<td>4.25</td>
</tr>
<tr>
<td>35-02-32</td>
<td>Lis 0.25</td>
<td>-</td>
<td>1.00</td>
<td>3.60</td>
<td>4.60</td>
</tr>
<tr>
<td>35-03-1</td>
<td>Lig 1.30</td>
<td>-</td>
<td>0.70</td>
<td>2.85</td>
<td>4.40</td>
</tr>
<tr>
<td>35-03-12</td>
<td>Lig 0.70</td>
<td>-</td>
<td>0.80</td>
<td>3.85</td>
<td>5.05</td>
</tr>
<tr>
<td>35-03-13</td>
<td>Sand</td>
<td>0.4/0.4</td>
<td>0.40</td>
<td>5.20</td>
<td>6.60</td>
</tr>
<tr>
<td>35-03-25</td>
<td>Lig 0.50</td>
<td>-</td>
<td>1.30</td>
<td>3.00</td>
<td>4.30</td>
</tr>
<tr>
<td>35-04-4</td>
<td>Lig 1.70</td>
<td>0.55</td>
<td>3.75</td>
<td>4.00</td>
<td>8.30</td>
</tr>
<tr>
<td>35-04-21</td>
<td>Gravel</td>
<td>0.3/0.1</td>
<td>1.20</td>
<td>4.00</td>
<td>5.70</td>
</tr>
<tr>
<td>35-04-28</td>
<td>Silt/Snd</td>
<td>0.50</td>
<td>-</td>
<td>1.10</td>
<td>2.60</td>
</tr>
<tr>
<td>36-03-25</td>
<td>Lig 1.30</td>
<td>-</td>
<td>1.15</td>
<td>4.50</td>
<td>5.65</td>
</tr>
<tr>
<td>36-03-36</td>
<td>Lig 1.00</td>
<td>(0.3)</td>
<td>0.50</td>
<td>2.50</td>
<td>4.60</td>
</tr>
<tr>
<td>36.04-9</td>
<td>Lig 0.70</td>
<td>0.50</td>
<td>0.60</td>
<td>2.20</td>
<td>3.30</td>
</tr>
</tbody>
</table>

% Occurrence

| Lig 60% | 62.5% | 66.6% | 91.6% | 29.1% |

Average

| Thick. m | Lig 0.73 | 0.41 | 1.39 | 2.94 | 1.60 | 4.39 | Lig 0.23 |

Average

| Thick. Ft. | Lig 2.42 | 1.36 | 4.61 | 9.72 | 5.28 | 14.49 | Lig 0.93 |

NOTE: Lig means lignite; Lis means lignite shale; Slt means silt; Snd means sand.
Elevation at the top of the Rhame Bed is indicated for many outcrops. The average dip is about 4.6 m/km (25 feet/mile) to the northeast. The 24 measured sections are described in Appendix A.

Plate 2 is a cross section of the Rhame Bed near the Medicine Pole Hills area south of Rhame in Bowman County. The bed is found on top of the buttes and in place within a stratigraphic sequence. Hares (1928), Denson and others (1959), and Zeller and Schopf (1959) all comment on the presence of the siliceous rock in this area. A map of the area is provided by Denson and others (1959, Plate 8).

An unusual aspect of the Medicine Pole Hills is the occurrence of two layers of silcrete (Figure 8). The appearance and stratigraphic position of the lower silcrete layer indicates that it is part of the Rhame Bed. The upper silcrete has a botryoidal to smooth upper surface, has almost no holes, and is coarser grained. The lower silcrete has a pumiceous appearance on the upper surface, has many holes, and is finer grained. The upper silcrete is not underlain by light colored sediments. The lower silcrete is underlain by light gray sediments (measured section 30-04-2), which are laterally equivalent to bright white sediments (measured section 30-04-1). The upper silcrete is confined to the central part of the Medicine Pole Hills. The lower silcrete has a consistent dip through the hills into the isolated buttes to the east.

The upper bed of silcrete may be part of the lower member of the Golden Valley Formation, the only other formation above the Slope Formation that contains silcrete. Because of this similarity, the stratigraphic nomenclature in the Medicine Pole Hills has been confused; the bright white part of section 30-04-1 has been mistaken for the Golden Valley Formation.
Fig. 8. Two layers of silcrete in the Medicine Pole Hills. The upper silcrete, at the horizon, may be a remnant of the Golden Valley Formation. The lower silcrete, center of photograph, and the underlying light gray silt, are in the Rhame Bed. The upper silcrete and the sediment underlying it are the upper part of measured section 30-04-2. The lower part of 30-04-2 was measured to the left of the photograph.

Fig. 9. Type section of the Rhame Bed near the U—U Ranch. Rhame Bed is between the arrows. West Fork of Deep Creek is in left foreground. Measured section 33-03-12.
Hares (1928) named the lignite bed above the upper silcrete bed the "Harmon bed" (part of the Bullion Creek Formation). Denson and others (1959) and Zeller and Schopf (1959) agreed. If the upper bed of silcrete is part of the Golden Valley Formation, the lignite bed above it cannot be the "Harmon bed." But the upper member of the Golden Valley Formation generally does not have lignitic beds; so the assumption that the upper silcrete is part of the Golden Valley Formation may be incorrect.

The steepest dip of the Rhame Bed in the entire study area occurs on the southwestern edge of the Medicine Pole Hills (Sec. 3, T.130N., R.104N.): 18.4 m/km (100 feet/mile). Just to the west of this is a very large boulder field (Plate 1). Many of the boulders have botryoidal surfaces with orange crusts. (No orange crusts were seen in place in the hills.) Both layers of silcrete were probably the origin of these boulders.

Plate 3 is a cross section of the Rhame Bed from northwest of Rhame to the U—U Ranch (say You Bar You), northeast of Rhame in Slope County. Most of the outcrops of the Rhame Bed in this area occur as silcrete-capped, low-relief, hills and ledges and broad light-colored areas of exposed white sediment. Hares (1928) does not mention the silcrete in his township descriptions of this area, but does include a photograph of the "quartzitic stratum of the Tongue River of Fort Union" taken in this area (Hares, 1928, Plate 6A).

The Rhame Bed in this area is underlain by light to medium gray clay or sand. The white sediment is light gray and is covered by pieces from the overlying silcrete. The Rhame Bed can be picked out easily by the presence of the silcrete, rubble-covered slopes. The bed is overlain by the H Bed of lignite, which is overlain by yellow sand. The
color sequence from bottom to top is medium gray, light gray, very light gray (silcrete) and yellow (sand). The Slope Formation is drab gray and the Bullion Creek Formation is bright yellow (Clayton and others, 1977). The Rhame Bed and sediment above and below it, in this area, form a well-defined contact.

Measured section 33-03-12 is the type section of the Rhame Bed. The type area is on both sides of the West Fork of Deep Creek, east and northeast of the U—U Ranch, 16.5km (10 miles) northeast of Rhame, North Dakota (Figure 9, 10, Plate 1, 3).

Plate 4 is a cross section of the Rhame Bed in the HT Ranch area, 29.7km (18 miles) north-northeast of Rhame, 18.2km (11 miles) west of Amidon, in Slope County. The outcrops of the Rhame Bed in this area are along steep-sided valleys. Hares (1928) recognized the silcrete ("quartzite") in this area. In his township descriptions, he defines the H Bed of lignite on the basis of the "quartzite" (see previous work, this report) and notes the "quartzite" in T.135N., R.103W. (Hares, 1928, p.79).

Hares measured a section along Deep Creek in Sec.31, T.135N., R.102W. Benson (1952) and Hickey (1966 and 1977) both comment on the Rhame Bed here (see previous work, this report). Figure 11 and my measured section 35-02-31 are part of Hares' section. Hares placed the contact of the Slope Formation, which he called the "Lance," and the Bullion Creek Formation, which he called the "Tongue River," at the base of the Rhame Bed, which he included in the Tongue River in a 4.84m (16 feet) "sandstone, clayey, soft buff, with shale partings" (Hares, 1928, p. 32). The color sequence of underlying, drab and gray (clay), light gray to white (Rhame Bed), and overlying yellow (sand) forms a well-defined Slope-Bullion Creek contact.
Fig. 10. Map of the location of the type section and type area of the Rhame Bed, Slope Formation (Paleocene). The type section is in SE\(_2\)SW\(_4\), Section 12, T. 133 N., R. 103 W. (measured section 33-03-12 Appendix A). The type area is along both sides of the West Fork of Deep Creek.
Outcrop of the Rhame Bed

10 miles to Rhome
Fig. 11. Outcrop of the Rhame Bed by Deep Creek, south of HT Ranch. The Rhame Bed is between the lines. The photograph shows good color contrast: lighter, yellow units above the Rhame Bed and darker, gray units below the Rhame Bed. Note the white sand pods in the darker color unit below the Rhame Bed. This is part of Hares' (1928) section, p. 32 and is just north of my measured section 35-02-31.

Fig. 12. Scenic Deep Creek. The Rhame Bed is exposed in the right foreground (between lines) and at the base of scoria-topped hills in the background. The Rhame Bed is overlying a white sand bed in the foreground and gray clay bed in the background. The picture was taken looking southeast into Section 32, T. 135 N., R. 102 W. Black Butte is in distance.
The Rhame Bed near the HT Ranch is developed in different grain sizes and with unusual characteristics. In both measured sections 35-02-32 (Figure 7) and 35-02-31 (near Figure 11), the Rhame Bed is underlain by drab clay and lignite, but in between (Figure 12) the bed is underlain by sand, which is white. This white sand also occurs in pods in the outcrop in Figure 11.

In measured section 35-03-25, a bed of white sand occurs above the Rhame Bed. This sand is separated from the underlying white sediment of the Rhame Bed by a calcium carbonate cemented siltstone layer and is, therefore, included in the Bullion Creek Formation. The sand layer may be part of a bed of channel sand, which occurs just to the north in Sec.13, T.135N., R.103W., and has been cut into the Rhame Bed. The white sediment from the missing Rhame Bed in part of Sec.13 may have been transported a short distance to Sec.25. Hares (1928, p. 79) noticed that

The channel sandstone of the Fort Union in sec. 13 seems to have been laid down in an old stream valley cut in the Lance Formation, and the upper surface of the Lance seems to be uneven in this township, showing a slight break in sedimentation between Lance and Fort Union time.

The unconformity between the Sec. 13 bed of channel sand and the Rhame Bed in measured section 35-03-13, indicates that the Rhame Bed must have formed before the deposition of the channel sand. The Rhame Bed formed in pre-Bullion Creek time.

Two layers of silcrete were observed in measured section 35-03-13. Because the channel sand overlying the upper silcrete has been cut into the H Bed of lignite, which normally overlies the silcrete, both layers probably formed before the channel sand was deposited. The process that forms silcrete must have occurred twice in this section.
TABLE 6

CORRELATION CHART OF LITHOLOGIC MARKER BEDS AND STRATIGRAPHIC NAMES IN THE NORTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA

The fourth column from the left is the stratigraphic nomenclature used by Stevenson (1956a, 1956b), Denson and others (1959), and Pipirigos and others (1965) The nomenclature used in this report is shown in the farthest right column. CB means the sediment is part of the Cannonball Formation.
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<tr>
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<tbody>
<tr>
<td>Orthoquartzite Lodgepole facies</td>
<td>Garner Creek lignite bed</td>
<td>Harman lignite bed</td>
<td>Quartzite</td>
<td>Tongue River ? Fm.?</td>
</tr>
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<td></td>
<td></td>
<td>Quartzite marker</td>
<td>Coal zone F</td>
<td>Cannonball Fm.</td>
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<td></td>
<td></td>
<td>Lignite bed E</td>
<td>Coal bed E</td>
<td>Ludlow Fm.</td>
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<td></td>
<td></td>
<td></td>
<td>E-bed sandstone</td>
<td>Slope Fm.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>D-bed sandstone</td>
<td>Cannonball Fm.</td>
</tr>
<tr>
<td></td>
<td>Giannonatti facies</td>
<td>Lignite bed D</td>
<td>Carbonate coal zone</td>
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<td></td>
<td></td>
<td>Lignite bed C</td>
<td>C coal zone</td>
<td>Ludlow Fm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lignite bed B</td>
<td>B coal zone</td>
<td>Cannonball Fm.</td>
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<tr>
<td></td>
<td></td>
<td>Mendenhall and Bar H lignite bed</td>
<td>Lonesome Pete coal zone</td>
<td>Ludlow Mbr.</td>
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<td></td>
<td></td>
<td>T Cross lignite bed</td>
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<td>Cannonball Fm.</td>
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<tr>
<td></td>
<td>Hilles facies</td>
<td>Hell Creek lignite bed</td>
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<td>Ludlow Fm.</td>
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<tr>
<td></td>
<td>Shade Hill facies</td>
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<td>Hell Creek Fm.</td>
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</table>

Mendenhall and Bar H lignite zone
in Perkins County. The Rhame Bed is in place on Anarchist Butte, now called Mudd Butte, Sec.34, T.22N., R.9E. on the border between Harding and Perkins Counties. This evidence indicates the Rhame Bed is present in northwestern South Dakota and the stratigraphic name, Slope Formation, should be used in this area.
INTERPRETATION OF THE RHAME BED

Previous Work

The origin of the silcrete in the Rhame Bed has been a matter of speculation since its recognition. Todd (1898, p. 61) attributed the origin of the "buhrstone" to "... silica deposited around the stems of plants while they were in their natural position [in] ... extensive marshes around the border of a lake."

Bauer (1924, p. 258) likened the "gray siliceous rock" in the Ekalaka lignite field to "... that of flint clays found in other coal fields." "Flint clays" are soil or muck deposits in which the carbon has been replaced by silica, and the rock is usually associated with lignite beds.

Hares (1928, p. 36) stated "there is some evidence that all the quartzites consist of a kind of clay or sand underlying lignite beds, which becomes hardened upon exposure."

Tisdale (1941) had difficulty in finding the exact stratigraphic position of "these indurated rocks," and concluded (p. 13)

... that the induration is strictly a surface development. Evaporation of upward moving ground water carrying silica in solution might be an explanation of this hardening and silification of the beds at the surface. Ground water in this area contains sodium carbonate which would aid in dissolving the silica from the lower bed.

Laird and Mitchell (1942, p. 22) stated the origin of the lateral transition from ash to silty clay to quartzitic sandstone concretions...
was a process of "... case hardening which operates only on the out-
crop but does not extend into the hill any appreciable distance."

Brown (1948, p. 1269) attributed the silicified stump-bearing
zones to

... silicified soils or swamp mucks ... if silicifying
conditions had been favorable, the top or bottom of every
incipient coal seam might have been a likely possibility for
the development of such a bed.

Pipiringos and others (1965, p. A10) and Denson and Pipiringos (1969,
p. 15) agreed with this interpretation.

Schmit (1970, p. 28-32) suggested a comprehensive hypothesis of
origin for "siliceous rock." The detrital grains, subangular and fine
grain, probably came from a nearby sediment source, and were deposited
in a low-energy environment. The moderately good sorting probably
resulted from a well-sorted source. The plant fossils provided evi-
dence: the good preservation indicated a low-energy environment; the
abundance of both vertical casts and molds and haphazardly-arranged
wood indicated an environment of prolific plant production, probably
a swamp or marsh, with surrounding stands of trees; the vertical casts
indicated the rock was silicified in place early in its diagenetic his-
tory. Because bentonite beds underlie the "Taylor bed," a silcrete,
Schmit postulated that the decomposition of volcanic ash to bentonite
provided the silica for the matrix. If this was the source, then the
silica must have traveled with the groundwater, in true solution or
colloidal form to a discharge area. (An acidic environment is neces-
sary for the precipitation of silica; decomposing plant matter in an
oxidizing environment produces acidity; plant decay occurs in a swamp
or marsh.) The silica-rich groundwater discharged in a swamp or marsh
and a matrix of microcrystalline quartz, or chert, and overgrowths was deposited on the grains. Because "... there is no evidence that it [the "siliceous rock"] was ever continuous over the entire extent of its range" (Schmit, 1970, p. 29), the "siliceous rock" probably formed in many local depressions which occurred in a shallow basin. In summary, the "siliceous rock" originated in a swamp or marsh environment in local depressions, in a shallow basin, which was a discharge area for a regional groundwater flow system, that contained silica-rich water from the decomposition of buried volcanic ash.

Moore (1976) recognized the association of the silcrete and the underlying white sediment, (which he called the "white siliceous bed") the variation of the grain size of the white sediment, the irregular thickness of the white sediment, and the similarity in stratigraphic position of the "white siliceous bed" over a large area. He concluded that (p. 36) "these features suggest the bed and the underlying discolored zone are associated with a surface of unconformity, and it is possible that the bed ... represents paleosol remnants." He refuted Brown's (1948) conclusion that silicifying conditions could occur above and below every lignite bed (p. 36). "I am suggesting that the silicifying conditions are related to unconformities and are relatively uncommon and incidentally associated with lignites." The fact that lignite is associated with the "white siliceous bed" is reasonable because lignite forms "... during subsidence of an area after the planation and soil formation associated with an unconformity" (Moore, 1976, p. 36).

Schmit's and Moore's interpretations differ on two critical points. Schmit's hypothesis of origin concerns only the silcrete, but Moore believes the silcrete and the white sediment are genetically
related and an hypothesis of origin should include both of them. Schmit, and most previous authors, regard the silcrete as a discontinuous bed. Moore regarded the silcrete as part of a regional unit.

Both Benson (1952, 1954b) and Hickey (1966, 1972, 1977) explain the silcrete and white sediment in the lower part of the Golden Valley Formation as two separate units. Their interpretations are considered in Appendix B.

Silcrete and Deep-Weathering Profile

Silcrete or duricrust?

The term "silcrete" was first used by Lamplugh for rocks near Victoria Falls in the Zambesi River Basin area in southern Zambia and northern Rhodesia in central Africa. In 1902, Lamplugh referred to silcrete as "sporatic masses in loose material of the 'greywether' type, indurated by a siliceous cement" (in Senior and Senior, 1972, p. 23). In 1907, he used the term for

... hard sandstone or quartzite. ... knit together by chalcedonic cement. ... the general impression that I gained, was that in most cases the silcrete represents a progressive induration of the exposed base of the sands, due to evaporation of groundwater, which has slowly percolated through the sands (in Kerr, 1955, p. 333).

Exon and others (1970, p. 23) stated

Lamplugh intended silcrete as a very general term for any material indurated by silicification, without regard for size or shape of the constituent particles or for the presence or absence of associated weathering profiles.

The term 'duricrust' was coined by Woolnough for rocks in Western Australia. In 1927, Woolnough introduced the term and indicated it should be a name for a stratigraphic unit. In 1930, he elaborated on the definition to mean
widespread chemically formed capping in Australia, resting on thoroughly leached substratum. The mineral matter deposited from solution falls into three main groups: (a) aluminous and ferruginous, (b) siliceous, (c) calcareous and magnesian. (Goudie, 1973, p. 5.)

He also stipulated that duricrusts developed on peneplains, formed at the same time, and originated from capillary-rise of water and salts (in Goudie, 1973, p. 6).

Exon and others (1970, p. 23) state

He emphasized the association of weathering with duricrust. . . . insisted that all duricrust, whatever its composition, was of the same age, being formed 'during an era of highly perfect peneplanation,' that is, he defined duricrust genetically as well as morphologically.

Exon and others (1970) advocate using the original definitions for silcrete, ferricrete, calcrete (also defined by Lamplugh), "laterite" and "duricrust." They indicate that confusion exists in the literature because of equating "laterite" and "duricrust" (see also Langford-Smith and Dury, 1965), and that "silcrete" and "duricrust" should not be used interchangeably. Goudie (1973) provides a comprehensive survey of duricrusts. He rejects both Woolnough's original definition (as too restrictive) and therefore Exon and others' plea for adherence to the original definitions. This definition of duricrust is (Goudie, 1973, p. 5)

A product of terrestrial processes within the zone of weathering in which either iron and aluminum sesquioxides (in the cases of ferricretes and alcretes) or silica (in the case of silcrete) or calcium carbonate (in the case of calcrete) or other compounds in the case of magnesicrete and the like have dominantly accumulated in and/or replaced pre-existing soil, rock, or weathered material, to give a substance which may ultimately develop into an indurated mass.

The American Geological Institute (1962, p. 150) dictionary defines duricrust:
The case-hardened crust of soil formed in semiarid climates by the precipitation of salts at the surface of the ground as ground water evaporates. It contains aluminous, ferruginous, siliceous and calcareous material.

This definition also includes genesis and there is certainly no agreement on this form of origin (see Goudie, 1973, p. 6).

Duricrust is not a descriptive term. Whatever definition of duricrust is used, the silcrete and weathering profiles are linked genetically. The term duricrust is too confusing. A review of the literature shows that silcretes are not always underlain by profiles from intensive weathering, and that weathering profiles are not always overlain by indurated rock. The best solution appears to be to describe the two units separately and then develop an hypothesis of origin which may include both of them. The terms that appear to have the least confusion attached to them are "silcrete" and "deep-weathering profile."

Silcrete is a lithologic term describing siliceous sediments. Although the depth of deep-weathering has not been defined (so as to distinguish it from shallow-weathering), and the words carry a genetic meaning (association with terrestrial processes, soils, and climate, etc.), I think "deep-weathering profile" has a clearer descriptive connotation than any other term found in the silcrete literature, or that I can think of.

Description of Silcrete and Deep-Weathering Profiles

Silcrete is found in many places in the world (Table 7). Most of the early literature on silcretes is from southern Africa and Australia, because, in these areas, silcrete forms a very obvious part of the landscape. Since the early 1960s, the Australians have published many articles about silcretes and deep-weathering profiles (see Watts,
Concerning the silcrete(s) and deep-weathering profile (WP) columns, an X indicates the unit is recognized and discussed, - indicates no recognition or discussion, ? indicates the unit may have been present, but was not mentioned in the references. A question mark under Time of Formation indicates the reference did not mention geologic age. Theories of origin, where given, explain the silcrete, or both silcrete and deep-weathering, if both are present. The references are arranged by location.
<table>
<thead>
<tr>
<th>Author, Date</th>
<th>Location</th>
<th>S</th>
<th>WP</th>
<th>Time of Formation</th>
<th>Theory of Origin</th>
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<td>Lampaugh, 1907</td>
<td>Zambezi Basin, Zambia</td>
<td>X</td>
<td>?</td>
<td>Eocene (?)</td>
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</tr>
<tr>
<td></td>
<td>(in Kerr, 1955, p. 333)</td>
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<td>Frankel and Kent,</td>
<td>South Africa</td>
<td>X</td>
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<td>Tertiary</td>
<td>Upward migrating solutions of colloidal silica meeting downward infiltrating water rich in NaCl; formed at the base of the soil.</td>
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<td>1938 (in Kerr, 1955,</td>
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<td>M. 332)</td>
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<tr>
<td>Storz, 1928 (in</td>
<td>Southwest Africa</td>
<td>X</td>
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<td>van den Broek and</td>
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<td>p. 311)</td>
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<td>Murray-Hughes,</td>
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<td>1973, p. 83)</td>
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<td>Atkinson and Haine,</td>
<td>Rhodesia</td>
<td>X</td>
<td>?</td>
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<td>1963 (in Goudie,</td>
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<td>1973, p. 83)</td>
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<td>Millot, 1964 (in</td>
<td>Sudan-Sahel zone, northern and</td>
<td>X</td>
<td>?</td>
<td>?</td>
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<tr>
<td>Goudie, 1973, p. 83)</td>
<td>western Africa</td>
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<tr>
<td>Smale, 1973</td>
<td>South Africa &amp; Australia</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>Upward-moving, silica-rich solutions meeting downward-moving alkaline solutions</td>
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<td>Woolnough, 1927 (in Langford-Smith and Dury, 1965, p. 186)</td>
<td>Western Australia, Australia</td>
<td>X</td>
<td>X</td>
<td>About Miocene</td>
<td>Seasonally arid, but sub-tropical climate</td>
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<td>X</td>
<td>X</td>
<td>Late Eocene to late Oligocene</td>
<td>Silica leached from laterites and transported by rivers to basin of interior drainage; silica precipitated by evaporation in arid environment</td>
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<td>Stephens, 1964, 1966, and 1971</td>
<td>Australia</td>
<td>X</td>
<td>X</td>
<td>Pliocene</td>
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<td>Queensland, Australia</td>
<td>X</td>
<td>X</td>
<td>Late Cretaceous to late Oligocene</td>
<td>Silcrete is younger than deep-weathering profile; weathering occurred once</td>
</tr>
<tr>
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<td>Location</td>
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<td>Time of Formation</td>
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<td>Senior and Senior, 1972</td>
<td>Southwest Queensland, Australia</td>
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<td>-</td>
<td>Tertiary</td>
<td>From silica-bearing groundwater; movement controlled by vertical differences in permeability; formed below surface</td>
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<td>New South Wales &amp; Queensland, Australia</td>
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<td>X</td>
<td>Mid-Tertiary</td>
<td>Characteristic of arid climate (?); formed at the surface</td>
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<td>Dury, 1966</td>
<td>New South Wales, Australia</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>Fluctuating water table (?); climate and soil processes important</td>
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<tr>
<td>King, 1967, pp. 315, 317, 324</td>
<td>Brazil</td>
<td>X</td>
<td>?</td>
<td>Mid-Cainozoic or Pliocene</td>
<td></td>
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<tr>
<td>Dury, 1971; p. 517</td>
<td>Ireland</td>
<td>X</td>
<td>X</td>
<td>Late Cretaceous to late Paleocene</td>
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<td>Kerr, 1955</td>
<td>Southern England</td>
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<td></td>
<td>Late Paleocene to early Eocene</td>
<td>Percipitation of silica from uprising solutions; formed at the surface</td>
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<td></td>
<td>?</td>
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<td>Germany</td>
<td>X</td>
<td>?</td>
<td>Tertiary</td>
<td>Upward migration of colloidal solution; silicification at base of soil</td>
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<td>South Limburg, Netherlands</td>
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<td>X</td>
<td>Late Tertiary</td>
<td>Soil in warm, humid climate with dry periods of several weeks</td>
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<td>Dury, 1971, p. 519 and Dury and Knox, 1971</td>
<td>Southwest-Wisconsin, USA</td>
<td>X</td>
<td>X</td>
<td>Before Mid-Miocene</td>
<td>Perennial and seasonally fluctuating groundwater table in a humid climate</td>
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<td>[Oligocene]</td>
<td>[Ogallala Fm]</td>
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<tr>
<td>Harder, 1949 and 1952 (in Dury, 1971, p. 514)</td>
<td>Southeast USA and northwest Oregon, USA</td>
<td>-</td>
<td>X</td>
<td>Paleocene-Eocene boundary</td>
<td>Bauxites: prolonged subaerial weathering on stable land surface</td>
</tr>
<tr>
<td>Allen, 1948 (in Dury, 1971, p. 514)</td>
<td>Oregon, USA</td>
<td>?</td>
<td>X</td>
<td>Early Eocene(?)</td>
<td>[deep weathering exceeds 55 m]</td>
</tr>
<tr>
<td>Friedman, 1954</td>
<td>New Jersey, USA</td>
<td>X</td>
<td>?</td>
<td>Miocene</td>
<td>[Kirkwood Formation] Lagoonal environments</td>
</tr>
<tr>
<td>Hughes, 1963</td>
<td>Mississippi, USA</td>
<td>X</td>
<td>?</td>
<td>Lower to middle Eocene</td>
<td>Boulders: indurated by silica-bearing waters</td>
</tr>
</tbody>
</table>
1974) enabling authors in other countries to recognize siliceous rock as silcrete. Table 8 lists the names used for silcrete in various countries.

The description of silcrete in the literature vary; only a few articles have been summarized here. See Table 7 for more references.

Senior and Senior (1972, p. 24) described silcrete in southwest Queensland, Australia.

Silcrete is a hard grey, whitish to buff-colored rock composed of numerous small angular to subangular quartz clasts set in an amorphous siliceous matrix. [Textures] vary from fine-grained types with small scattered quartz clasts, to those with fragments of quartz up to half an inch long. When hit with a hammer silcrete usually gives a marked 'ring' and breaks across quartz grains along subconchoidal fracture surfaces.

The beds are 1.5 to 3.6m (5 to 12 feet) thick and extend laterally for many kilometres (miles). The individual clasts of silcrete ('gibbers') are often iron-stained and polished with a characteristic desert varnish. The authors analyzed thirteen samples using x-ray diffraction and x-ray fluorescence techniques. They found relatively large amounts of titanium (0.3 to 2.0%), attributing it to the 'host' sediments. Two layers of silcrete, separated by 6m (20 feet) of sediment, were described. Silcrete beds have been used to delineate complicated structure in southwest Queensland, and have been used "... as structural markers on a regional scale..." [where] the vertical distance between silcrete beds is small" (Senior and Senior, 1972, p. 27).

Stephens (1971) wrote an extensive paper on "laterite" and silcrete in Australia. In silcrete the grains consist of a wide variety of material, including fossil organic remains. The matrix is very fine-grained, crystalline quartz. Silcrete is
<table>
<thead>
<tr>
<th>Country</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>Surface quartzites</td>
</tr>
<tr>
<td>Congo</td>
<td>gres polymorphe</td>
</tr>
<tr>
<td>Australia</td>
<td>billy, grey billy, quartzite, duricrust, siliceous duricrust, porcellanite (very fine grained, white), gibbers (individual clasts), desert sandstone</td>
</tr>
<tr>
<td>South Africa and Australia</td>
<td>terrazo silcrete, conglomeratic silcrete, Albertinia silcrete, opaline silcrete, quartzitic silcrete</td>
</tr>
<tr>
<td>(Smale, 1973)</td>
<td></td>
</tr>
<tr>
<td>England</td>
<td>Sarsen or quartitic sandstone, puddingstone or flint conglomerate, greywether, boxstone, clay-with-flint</td>
</tr>
<tr>
<td>France</td>
<td>Meulières, sidérolithique, argile à silex, Pières de Stonne, Pières de Beaumont</td>
</tr>
<tr>
<td>Germany</td>
<td>zementquartzite, Tertiary erratic blocks, Findlings Quartzite</td>
</tr>
</tbody>
</table>
... pale grey to buff to dark red and brown, but it is predominantly grey: occasionally it is white and very fine textured, in which case it is sometimes referred to [as] a porcellanite (Stephens, 1971, p. 19).

In cooler environments, "... the weathered surface is generally paler in colour than the unaffected core;" in arid environments, "... the surface of the silcrete remains harder ... reddish brown to almost black ... exhibits a high natural polish referred to as a desert varnish" (Stephens, 1971, p. 25). Silcrete, in situ, varies in thickness from a few inches to several feet" (Stephens, 1971, p. 36). "Normally there is only one horizon of silcrete in a profile or section but up to three have been observed" (Stephens, 1971, p. 37, Fig. 24). The silcrete in an area in Queensland, Australia is

... a predominantly pale grey, extremely indurated, highly siliceous rock with numerous angular quartz clasts distributed in an amorphous or cryptocrystalline matrix. Considerable variation exists in the ratio of quartz clasts to siliceous matrix, and in the size of the quartz fragments.

Exon and others (1970, p. 23) noted

... a complication in field interpretation is the presence of silcrete boulder concentrations on the crests of hills and ridges of widely different altitudes, and it is apparent that much silcrete is no longer in its original place. ... Many authors have described "plant root" cavities in the silcrete.

Even the more massive forms often contain numerous tabular cavities. ... formed by root growth, and such forms are known from the sarsens of southern England and the Botlette Beds of the Kalahari [Southwest Africa] ... (Goudie, 1973, p. 17; see also Dury, 1971, p. 518).

Goudie (1973) summarized many miscellaneous characteristics of silcretes. He provided chemical analysis of silcretes from southern Africa, Australia, England, and the United States (p. 27-29), listed various thicknesses of silcrete profiles (p. 34), cited very low porosity (0.18 to 0.95%) (p. 30), delineated some physical properties (p. 39 and Table 23, p. 41), and told of the use of silcrete for stone tools by the aboriginals of Australia and the Kalahari Desert, Southwest Africa (p. 69), and listed the "bedrock types" on which silcrete has been found (Table 30, p. 97 to 98). The underlying lithology does not appear to have an effect on the presence or formation of silcrete.

Smale (1973) distinguished five types of silcrete based on physical appearance (Table 8) in South Africa and Australia. The terrazzo type, the most abundant form, is pale buff or yellowish gray, with a framework of angular to subrounded quartz grains, set in a matrix of amorphous, cherty or opaline silica containing abundant leucoxene, which has colloform structures. The conglomeratic type is a brecciated terrazzo type, either gray or red. The Albertinia type consists almost entirely of the matrix of the terrazzo type. The opaline and fine-grained massive types are mostly pure common opal or chalcedony. The quartzitic type is a sedimentary orthoquartzite which has become a silcrete.

Hutton and others (1972) provided petrographic and chemical data on silcretes in South Australia. They delineated two forms of silcrete: massive silcrete and skin silcrete. Massive silcrete, the common variety found in Australia and South Africa, formed by the addition of silica. Skin silcrete, 0.002m to 0.2m thick, found on one surface in Australia (Beda Surface), formed by a loss of silica from quartzite and has a large
concentration of elements associated with resistant minerals (titanium and zirconium). The authors attribute the origin of the silcrete to biological conditions, particularly the character of the plant population, conducive to silica leaching at some sites and its accumulation elsewhere (Hutton and others, 1972, p. 37).

They consider these two forms as end-member types of silcrete. Clearly, silcrete has as much variation (and controversy) as any other lithologic type.

Deep-weathering profiles have been traditionally associated with "laterites." The typical "lateritic" profile consists of a "mottled zone," with red, yellow, and brown ferruginous blotches, underlain by a "pallid zone," usually bleached uniformly white with abundant kaolinite, and a "transition zone" into unchanged "bedrock" at the base. Unfortunately, the literature on the description and formation of "lateritic" weathering profiles is very confusing and difficult to understand. However, knowledge of this "lateritic" profile terminology is useful because the descriptions of deep-weathering profiles underlying silcrete use these terms.

Many authors "... apply the word laterite for where nothing above the pallid zone survives..." (Langford-Smith and Dury, 1965, p. 171), which further increases the confusion.

Exon and others (1970, p. 23) describe a deep-weathering profile in Queensland, Australia.

Although some red mottling is usually present, most of the profile is leached white with common pink, yellow and violet beds. In this area a mottled zone is seldom distinctive, although both mottled and pallid zones are commonly recognized farther south. Usually the upper part of the profile, at least, is tougher than the fresh material, although the location and degree of induration in the profile may vary from site to site.
The grainsize, distribution of rock types, and bedding characteristics are unchanged by the deep-weathering. Within the profile calcite has been completely leached, while feldspar has broken down to kaolin, some of which forms an interstitial matrix. Kaolin is also derived from labile rock fragments, and from alteration of the original clays of the matrix. Iron oxide has come from breakdown of grains of iron ore and ferromagnesian minerals. Quartz grains and resistant lithic grains have been unaffected, while white mica has broken down only high in the profile.

Deep-weathering profiles under silcrete have also been described as fossil soils. Van den Broek and van der Waals (1967) described four fossil soil profiles associated with silcrete on the South Limburg peneplain in the Netherlands. But they note (p. 329) "still the soil profiles show a remarkable identity, as if a difference in parent material did not give rise to different soils." They attribute this to (p. 329)

... the outcropping formations have been so altered by a period of exhaustive weathering that the soil profile observed now, represents the final phase of a cycle of soil-forming processes in a gradually impoverished parent material.

Deep-weathering profiles are not uniform in content or distribution but, as all authors note, they are associated with silcrete, or some form of indurated rock.

Possible Origins of Silcrete and Deep-Weathering Profiles

Many hypotheses of origin have been proposed for silcrete and deep-weathering profiles. Most of these hypotheses have focused on explaining the formation of silcrete; the most common ones are presented here (Table 7).

"Laterite," also called ferricrete, alcrete, oxisol, and a deep-weathering profile, has most often been explained by a fluctuating water table in a seasonal wet and dry subtropical climate. The "pallid zone" is considered to be beneath the water table (always saturated), the "mottled zone" is in the area of watertable fluctuation, and the indurated rock is above the watertable. This hypothesis has been extended
to silcrete and deep-weathering profiles. Since the mobilization and precipitation of silica is not well understood, and probably not the same as the mobilization and precipitation of iron and aluminum, drawing a parallel interpretation to silcrete and deep-weathering profiles is probably not reasonable.

The hypothesis of upward-migrating solutions of colloidal silica meeting downward-migrating solutions of salts, and precipitating to form silcrete, was first proposed for the coastal areas of South Africa by Frankel and Kent. Other authors have agreed with this, particularly Smale (1973), who provides more data. This hypothesis would only be reasonable for coastal areas where salt in the air is in abundance.

The capillary-rise hypothesis of origin was attached to the original meaning of "duricrust" by Woolnough in 1930. Silica-bearing groundwater rises by capillary action during dry periods and silica is precipitated at the ground surface by evaporation in an arid climate. This hypothesis has been modified to include mobilization of silica by chemical weathering of "parent material," transportation over a short distance by groundwater and deposition by evaporation (Bruckner, 1966). Goudie (1973, p. 142-143) discussed the pros and cons of this hypothesis and generally concluded that it is unfeasible.

Stephens (1964, 1966, and 1971) proposed a connection between the origin of silcrete and the origin of "laterite" in Australia. Silica was mobilized by "lateritic" weathering in eastern and northern Queensland, was transported by surface ("sheet-wash") and groundwater flow a considerable distance into an area of interior drainage and/or arid
climate, and was deposited by evaporation. He based this hypothesis on the association of silcrete with lime, gypsum, alunite, and "rolled fluvial material," and its widespread distribution (see also Goudie, 1973, p. 122-123).

Most of these hypotheses do not include climate and vegetation as the possible principle factors in the formation of silcrete and deep-weathering profiles. The hypotheses are based on a smaller frame of reference (watertable fluctuations, migrating solutions, capillary-rise, groundwater movement) with no consideration of, or speculation on (certainly no emphasis on) the larger picture. Dury (1971, p. 513), in calling for paleoenvironmental reconstruction, stated:

Add the complexities of tropical pedology, the confused time-stratigraphic relationships of deep-weathering and relict crust- ing, the continuing debate on laterite, and the dubiety of some palaeobotanical findings, and it becomes easy to see how geomorphic work on relict deep-weathering has failed to take full advantage of independent evidence. A further consideration is that accounts of relict crusts and profiles in the southern hemisphere where occurrences are abundant, are mainly of very recent date.

Van den Broek and van der Waals (1967) emphasized climate and vegetation. They pointed out for the Late Tertiary South Limburg peneplain in the Netherlands (p. 327)

A casual relationship between the existing peneplain and the soil formation and kindred silicification has seldom been proposed. Consequently the relevant descriptions of comparable phenomena are scattered in the literature.

Silcretes are usually associated with peneplains or pedeplains. Almost every reference mentioned this association. The original definition of "duricrust" included this. Van den Brock and van der Waals (1967, p. 328) found that the South Limburg peneplain was not a flat horizontal area, but sloped slightly to the north. The laterally associated absolutely flat areas were covered with heavy, sticky, waterlogged
gray clay and loam. The sloped area developed a paleo-drainage system of shallow valleys and "quiet relief" and probably had a large quantity of running water; it developed deep-weathering profiles (fossil soils). They suggested (p. 328)

The sediments on a relatively stable peneplain are rather shallow and often deposited next to each other; this is in contrast with the building up of an active sedimentation area where the formations are deposited on top of each other. On a peneplain both sedimentation and erosion are rather limited: erosion is rather shallow because of a vegetation cover...

Thus, little sedimentation was taking place (p. 320). "Only during such periods is the surface of the earth's crust affected by the influences of certain climate and vegetation."

The climate was probably warm and humid. Dury (1971) reviewed the temperature conditions of the middle latitudes during the Tertiary and concluded that most of the Tertiary was very warm; temperate zones, as we know them today, did not exist then. Van den Broek and van der Waals (1967) concluded the Tertiary climate on the South Limburg peneplain was tropical to subtropical, certainly not arid (as most Australian authors contend: see Stephens, 1971; Smale, 1973; Goudie, 1973, p. 114-115). A stable land surface and climate may have had significant roles in the formation of deep-weathering profiles.

Silcrete and deep-weathering profiles offer little information about the type of vegetation; most "root relicts" are impossible to identify. The laterally-associated sediment of the South Limberg region contained lignite and pollen-rich units which indicated "... a vegetation of rather dense forests of high trees" (van den Broek and van der Waals, 1967, p. 329). Lovering (1959) provided evidence that certain types of vegetation are capable of accumulating silica in their tissues.
Vegetation may have had a significant role in silcrete formation.

The exact length of time for the formation of silcrete and a deep-weathering profile is unknown. Dury (1971, p. 511-512) indicated that deep-weathering profiles probably belong to the Oxisol soil order. Birkeland (1974, p. 176) presented a diagram indicating that the development of a steady-state soil profile for Oxisol takes at least 100,000 years. Silcrete usually has a detrital fraction of quartz grains. It may take 100,000 years to accumulate the detrital fraction, but the formation of the siliceous matrix may have taken less time. Because "root relics" are preserved in silcrete the roots must have been present during the formation of the siliceous matrix (perhaps even contributing silica to the matrix). The roots could not have penetrated through the rock after the formation of the matrix and the plant could not have died before the matrix formed because the casts and molds of the roots would have been obliterated. Although the development of the deep-weathering profiles probably took 100,000 years or longer the silicification of the silcrete probably took a considerably shorter length of time.

Almost all occurrences of silcrete and deep-weathering profiles (as well as alcrete, ferricrete, calcrete, caliche, "duricrusts," and "laterite") occur in the Tertiary (Table 7). Goudie (1973, p. 90) pointed out "... the world's duricrust formations are of Tertiary rather than Pleistocene age. The Pleistocene was a period of too-rapid morphological and climatic changes in many areas."
**Interpretation of the Rhame Bed**

Comparison of the description of silcrete in the Rhame Bed in this report and the description of silcrete in other parts of the world quoted in this report show that the siliceous rock in the Rhame Bed is in fact a silcrete. The Rhame Bed silcrete is made of quartz grains in a microcrystalline silica matrix and is generally gray as is silcrete elsewhere. The wind-polished surfaces on the Rhame Bed silcrete are called "desert varnish" on Australian silcrete. The residual boulders of silcrete west of the Medicine Pole Hills, east of the North Cave Hills in South Dakota, and in southeastern Montana are similar to residual concentrations of boulders noted by Exon and others (1970, p. 23) in Australia. These boulders are called "gibbers" in Australia. Casts and molds of plant roots in the Rhame Bed silcrete have also been noted in other silcrete. Two layers of silcrete occur at two different locations in the study area, similar to multiple layers found in Australia (see Senior and Senior, 1972 and Stephens, 1971, p. 37). The Rhame Bed silcrete is probably the terrazzo type of Smale (1973) and a massive silcrete as classified by Hutton and others (1972).

The white sediment in the Rhame Bed is a deep-weathering profile. The white color is similar to the "pallid zone" described by Exon and others (1970, p. 23)(see quote, this report). Because of the irregular thickness of the white sediment of the Rhame Bed, the upper and lower contacts are defined on the basis of color, which is characteristic of deep-weathering profiles. The lack of calcium carbonate in the white sediment in the Rhame Bed also is characteristic of deep-weathering profiles.
Based on the previous discussion of the hypotheses of origin of silcrete and deep-weathering profiles proposed in the Australian and European literature, the Rhame Bed probably formed during a period of no erosion or deposition under a stable land surface, covered by thick vegetation with a warm and humid climate. A consideration of the dominant factors of a stable land surface, vegetation, and climate can form the larger frame of reference in which to consider the geochemical mechanisms that formed silcrete and the chemical weathering processes that produced the deep-weathering profile.

Parts of previous interpretations of the Rhame Bed are similar to my interpretation, but some interpretations differ. Todd (1898, p. 61) was on the right tract in assuming that "... the stems of plants were in their natural position. ..." when silicification took place. Many of the casts and molds of plant remains in the Rhame Bed are vertically oriented and most are rounded. The hypotheses of origin of Bauer (1924), Hares (1928), Tisdale (1941), Laird and Mitchell (1942), and Brown (1948) all assume burial before silicification. If burial occurred before silicification the plant remains would be horizontally oriented and flat, not round.

Schmit (1970) hypothesized that the silcrete of the Rhame Bed originated in a swamp or marsh environment. Lignite which contains abundant impressions of leaves, and identifiable plant material is considered to form in this type of environment. The silcrete in the Rhame Bed does not have leaf impressions although delicate structures (insect borings, knots, and impressions of bark) and delicate roots are preserved. This fact indicates that the silcrete probably formed in an environment where biological decay had destroyed the leaves and the outer bark of the
branches, but had not destroyed the entire branch. A forest floor may be a more likely environment than a marsh or swamp.

Moore (1976) recognized that the Rhame Bed may be a paleosol, although he did not use the terms "silcrete" and "deep-weathering profile."

The origin of the dip of the Rhame Bed and some of the regional aspects of the outcrop patterns of the Rhame Bed can be speculated on. The Rhame Bed dips gently to the northeast. This dip may be a result of uplift on the Cedar Creek anticline or could represent the slope of the Paleocene surface. Superimposed on the regional dip are undulations in the upper surface of the Rhame Bed of a few metres over short distances (see elevation, in feet, on Plate 1). These undulations could be due to warping associated with the Cedar Creek anticline or could represent subtle topography on the Paleocene surface. Therefore, the regional dip and local variations in dip of the Rhame Bed could be tectonically controlled or could be a result of Tertiary topography. No evidence is available to determine which of these is correct.

The Rhame Bed is laterally discontinuous in the study area. This may be due to the relation of the Rhame Bed to the Paleocene land surface (it formed only on hilltops, only on the sides of valleys or on valley bottoms), or from erosion (Tertiary to the present) of the Rhame Bed in some areas. No evidence is available to determine which of these is correct.

The silcrete is laterally discontinuous within the Rhame Bed. Its presence or absence does not seem to fit any regional pattern. Lovering (1959) discussed the importance of silica-accumulator plants in removing silica from the lower soil horizons and, in some places,
enriching the upper soil horizons with silica. The distribution of silcrete may be related to the type of vegetation that was present on the Tertiary surface as well as the rate of water runoff, biochemical influences, changes in solubility due to decomposing plant matter, and other factors. (See Lovering, 1959, for discussion and speculation on these factors.)

Moore (1976) recognized that the Rhame Bed was associated with an unconformity. Clayton and others (1977) also regarded the Slope Formation as being unconformably overlain by the Bullion Creek Formation. The Rhame Bed represents a period of time during which no deposition or erosion occurred, and therefore the top is a surface of unconformity. Silcrete and deep-weathering profiles have been used in other parts of the world to mark the top of a formation. Wopfner and others (1974) defined and described the Eyre Formation (Paleocene-Eocene) in Australia. This formation is made of conglomeratic quartz sandstone, carbonaceous siltstone, and lignite; the top is identified by a silcrete (called the "silcrete of the Cordillo surface") and underlying deep-weathering profile.

Many unanswered questions remain. The answers to these questions should be considered in the light of a stable land surface, vegetation, and climate. Did the silcrete form at the surface (see Langford-Smith and Dury, 1965; Kerr, 1955; Dury, 1971; Exon and others, 1970) or below the surface (see Dury, 1971; Senior and Senior, 1972; Frankel and Kent in Smale, 1973)? What was the source of the silica—clay or feldspar weathering to kaolinite (see Rich and Kunze, 1964, p. 17-23; Maignien, p. 86-89)? Why did the kaolinite form (see DeSegonzac, 1970)? What were the geochemical conditions during the formation of the Rhame
Bed (changes in mineralogy, causes of mobilization and deposition of silica, method of deposition of silica, role of plants in relation to silica collection and movement)? Why are the grains in silcrete uniformly made of quartz throughout the world? Why does the type of parent rock appear not to affect the presence of silcrete (see Goudie, 1973, p. 97-98)? Does silcrete represent a relative or absolute accumulation (see Stephens, 1971)? Why does silcrete contain relatively large amounts of titanium or leucocene? How can two layers of silcrete form in the same profile? Why is the rock grain-supported in some areas and matrix-supported in other areas? Did a prolific silica-producing plant evolve in early Tertiary time, causing the formation of silcrete then? A review of the literature on soils and soil formation, detailed petrographic studies of the silcrete, and geochemical studies of the sediment in the deep-weathering profile, in the light of paleobotanical studies, may yield a more detailed hypothesis of origin.

The silcrete and deep-weathering profile of the Rhame Bed are not unique in the Tertiary sediment in North Dakota. Moore (in Clayton and others, 1977, p. 2) recognized other "white siliceous beds" below the Rhame Bed in the Slope Formation. These beds are not as well developed as the Rhame Bed and are separated from it by a sufficient stratigraphic interval so as not to be confused with the Rhame Bed.

The other occurrence of a bed of silcrete in North Dakota is the "Taylor bed" in the lower part of the Golden Valley Formation. This silcrete is underlain by a deep-weathering profile, called the "carbonaceous zone" and the "orange zone." These three units are part of the Bear Den Member of the Golden Valley Formation. A brief summary of the
work done on this part of the Golden Valley Formation, previous interpretations, and reasons for this reinterpretation are presented in Appendix B.

Pettyjohn (1966) described a well-known paleosol that lies unconformably on several different formations from Early Cretaceous to Late Eocene age and is overlain by the oldest part of the White River Group (Chadron Formation). This soil profile extends from Saskatchewan to Nebraska. The soil profile is characterized by vivid colors (purple, lilac, and green on clay, greenish gray on silt, yellow, and rusty brown on sand and sandstone), lack of calcium carbonate, large concentrations of iron oxide and alumina (in the upper parts of well-developed profiles), and kaolinite and illite. Pettyjohn stated (1966, p. C65)

It probably was developed under hot and wet climatic conditions in relatively flat areas having deep and widely spaced drainage systems. Sedimentary and chemical features of the profile suggest a lateritic-type soil.

The paleosol was first recognized and studied near Interior, South Dakota; this area has been designated as the type locality. The name "Interior Formation" has not been agreed upon in the literature (see Pettyjohn, 1966, p. C61 for discussion) but is preferred in this report to Pettyjohn's name "Eocene Paleosol." Table 9 is a summary of known deep-weathering profiles in North Dakota.

Ritzma (1965) recognized a fossil soil profile at the base of Paleocene rocks in Wyoming. His generalized section clearly shows that it is a silcrete and deep-weathering profile. This soil developed on Upper Cretaceous rocks and is overlain by the Fort Union Formation; it may be equivalent to the Rhame Bed.
<table>
<thead>
<tr>
<th>LITHOLOGY</th>
<th>AGE OF WEATHERING AND LITHOSTRATIGRAPHIC UNITS INVOLVED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid(?)-Paleocene</td>
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<tr>
<td></td>
<td>BULLION CREEK FORMATION</td>
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<tr>
<td></td>
<td>H Bed lignite</td>
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<tr>
<td>SLOPE FORMATION</td>
<td>silcrete</td>
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<tr>
<td></td>
<td>Rhame Bed</td>
</tr>
<tr>
<td></td>
<td>white sediment</td>
</tr>
<tr>
<td></td>
<td>Rhame Bed</td>
</tr>
<tr>
<td></td>
<td>&quot;gray zone&quot;</td>
</tr>
<tr>
<td></td>
<td>Rhame Bed</td>
</tr>
</tbody>
</table>
| SENTINEL BUTTE FORMATION |                                   |                                   | }

**TABLE 9**

**COMPARISON OF KNOWN DEEP-WEATHERING PROFILES IN NORTH DAKOTA**
CONCLUSION

The two main purposes of this project were to conduct a field study of the Rhame Bed and to shed some light on the possible origin of this unit.

The conclusions based on field work are as follows. The Rhame Bed contains two dominant lithologies: silcrete and white sediment, both of which have a regionally consistent appearance. Therefore, the Rhame Bed is a mappable unit in the type area in Slope and Bowman Counties and is probably a mappable unit everywhere along its outcrop. The type section of the Rhame Bed is in SE₁⁄₄SW₁⁄₄, Sec. 12, T.133N., R.103W. Because the Rhame Bed is also a mappable unit in northwestern South Dakota, the stratigraphic names in this area should be revised to include the Slope Formation. The Rhame Bed does not appear to be a mappable unit in southeastern Montana and the stratigraphic names in that area should probably not include the Slope Formation.

Comparison of the Rhame Bed with similar material described in Australian and European literature indicate that the Rhame Bed is a silcrete and deep-weathering profile that probably formed under a stable land surface covered by vegetation in a warm and humid climate. The lack of erosion or deposition at the surface, the climate, and the vegetation should form the larger frame of reference in which to consider the geo-chemical mechanisms that formed the silcrete and the chemical weathering processes that produced the deep-weathering profile.
Because the Rhame Bed is a well-defined marker bed and its upper surface is an unconformity, it is used to define the top of the Slope Formation (Clayton and others, 1977).

Part of the Bear Den Member of the lower Golden Valley Formation is reinterpreted to be a silcrete and deep-weathering profile that formed as a result of the same processes as the Rhame Bed. This part of the Golden Valley Formation could remain in the Golden Valley Formation or could be included in the Sentinel Butte Formation. (See Appendix B.)
DESCRIPTION OF MEASURED SECTIONS

This appendix describes all the stratigraphic sections measured. The numbers are derived from the township, range, and section and are arranged numerically by township, range and section. Each section is located in relation to a town or ranch. Because the United States Geological Survey topographic maps for this area have a contour interval of 20 feet, the elevation at the top of the Rhame Bed has a precision of plus or minus 10 feet. The thickness of the section measured, not the thickness of the outcrop is given. The sections were originally measured in metres. The scale of the diagrammatic section is 20 mm to 1 metre or 1 inch to about 4.5 feet. Color was described using the Geological Society of America Rock Color Chart (1975). The range of colors observed, with Munsell designations, and the lithologic symbols used are listed on the following page.
COLOR

Gray
white N9
very light gray N8
light gray N7
medium light gray N6
medium gray N5
medium dark gray N4
dark gray N3
brownish black N2
black N1

Red
pale red 5R 6/2
moderate red 5R 5/4; 5R 4/6
grayish red 5R 4/2

Yellowish-Red
grayish orange pink 5YR 7/2
light brown 5YR 6/4
light brownish gray 5YR 6/1
brownish gray 5YR 4/1
dark brownish gray 5YR 3/1
moderate brown 5YR 4/4
dusky brown 5YR 2/2
brownish black 5YR 2/1
moderate yellowish brown 10YR 5/4
dark yellowish brown 10YR 4/2
grayish orange 10YR 7/2
pale yellowish orange 10YR 8/6
yellowish orange 10YR 7/6
dark yellowish orange 10YR 6/6

Yellow
light yellowish gray 5Y 8/1
yellowish gray 5Y 7/2
light olive gray 5Y 5/2
olive gray 5Y 3/2
dusky yellow 5Y 6/4

Green-Yellow
greenish gray 5GY 6/1

Blue
light bluish gray 5B 7/1
LITHOLOGIC SYMBOLS

- Gravel and loam
- Silt and clay, interbedded
- Sandstone (cemented sand)
- Silty clay
- Siltstone (cemented silt)
- Clay
- Silcrete
- Carbonaceous clay
- Sand
- Carbonaceous shale to lignitic shale
- Silt and sand, interbedded
- Lignite
- Silt
- Scoria
- Clayey silt
- Concretions
Location: SW\(\frac{1}{4}\)SW\(\frac{1}{4}\) Sec. 1, T.130N., R.104W.; 1/2 mile south of Nebo triangulation station in the Medicine Pole Hills.
Exposure: south facing, on all sides of a tributary of Alkali Creek.
Elevation at top of the Rhame Bed: 3350 feet.
Thickness: Section 27.7 m (91.4 feet); Rhame Bed 5.4 m (17.8 feet).

Sand, very fine; yellowish orange; limestone clasts; covered with gravel; 0.75 m thick.

Sand, very fine; yellowish orange; sandstone ledge at top; 4.0 m thick.

Lignite; black; prospected for uranium; 1.6 m thick.

Silt; yellowish gray; nonbedded; 1.15 m thick.

Silcrete; moderate yellowish brown; no holes; laterally covered; 0.3 m thick.

Clay; brownish gray; flaky cracked weathering surface; lignitic shale in lower part; 1.4 m thick.
Sand and silt, interbedded; light gray at top; yellowish gray at base; siltier at top; changes laterally to include 1.3 m unit of lignite and lignitic shale; 8.0 m thick.

Clay; grayish red; carbonaceous; 0.2 m thick.

Silty clay; grading downward to silt; white, stained yellowish orange in central part; cross bedded in lower part; abrupt contact with underlying unit; 2.95 m thick.
Silty clay (continued)

Lignitic shale; dark gray; 0.15 m thick.

Clay and silt interbedded; light brownish gray to light gray; interbedded with very fine sand; large-scale flat beds and large-scale cross beds; abrupt contact with underlying unit; 2.3 m thick.

Lignite; black; fissile; changes laterally to carbonaceous shale; 0.15 m thick.

Clay; brownish gray; interbedded with light gray silty units, gives banded appearance; flaky cracked weathering surface; ironstone concretions near bottom; 4.75 m thick.
Location: Sec. 2, T.130N., R.104W.; composite section: upper part in SE\textfrac{1}{4}SW\textfrac{1}{4}, bottom part in NW\textfrac{3}{4}SW\textfrac{3}{4}; 3/4 mile southwest of Nebo triangulation station in the Medicine Pole Hills.

Exposure: west facing.

Elevation at the top of the Rhame Bed: 3350 feet.

Thickness: Section 19.4 m (64.0 feet); Rhame Bed 7.25 m (23.9 feet).

Silcrete; light gray; botryoidal appearance on upper surface; holes rare; plant impressions rare; 0.5 m thick.

Silt; light gray; nonbedded; calcareous; 3.5 m thick.

Sand, very fine; pale yellowish orange; calcareous; iron-oxide concretions; thin, slabby, sandstone at base; 4.95 m thick.
30-04-2 continued

Lignite; black; soft; washed away from most of outcrop; 0.3 m thick.

Silcrete; light yellowish gray; pumiceous appearance on upper surface; holes common; plant impressions rare; breaks into blocky (0.01 m) pieces; 0.75 m thick.

Sand, very fine; light brownish gray; light yellowish gray in lower part; laminated (0.5 to 2.0 mm) soft sediment deformation structures; covered by pieces of silcrete from overlying unit; 6.5 m thick.

Lignite; black; 0.3 m thick.

Clay; grayish red; carbonaceous; fissile; 0.85 m thick.

Ironstone concretion layer; moderate red; 0.3 m thick.

Clay; dark gray; carbonaceous; breaks into 0.02 m pieces; 1.45 m thick.
Location: NE\NW\ Sec. 8, T.131N., R.102W.; 3 miles west of Bowman.
Exposure: north facing, along road cut on U.S. Highway 12.
Elevation at the top of the Rhame Bed: 2990 feet.
Thickness: Section 1.65 m (5.45 feet); Rhame Bed 1.65 m (5.45 feet).

- Silcrete; light brown; forms flat topographic surface; 0.2 m thick.
- Clay; very light gray; 0.2 m thick.
- Clay; medium dark gray; carbonaceous; laterally persistent; 0.15 m thick.
- Silt; very light gray; 0.6 m thick.
- Clay; light gray; carbonaceous at top; 0.5 m thick.
Location: NE1/4 SW1/4 Sec. 11, T.131N., R.104W.; 3½ miles south of Rhame on east side of paved road.
Exposure: west facing, old junk pile on outcrop.
Elevation at the top of the Rhame Bed: 3210 feet.
Thickness: Section 7.3 m (24 feet); Rhame Bed 2.5 m (8.3 feet).

Silcrete; dark yellowish orange; holes abundant; plant impressions abundant; broken into 0.1 m fragments; forms flat topographic surface; 0.65 m thick.

Silt; very light gray; flaky cracked weathering surface; nonbedded; 1.85 m thick.

Lignitic shale; grayish black; 0.4 m thick.

Silt; dark brownish gray; carbonaceous; fissile; 1.1 m thick.

Sand, very fine; light gray; laminated; smooth outcrop surface; 1.0 m thick.

Lignite; black; soft; 0.3 m thick.
Clay; brownish gray, carbonaceous; 0.2 m thick.

Clay; light gray; breaks into 0.02 m pieces; 1.8 m thick.
Location: NE\textsubscript{4}NW\textsubscript{4} Sec. 35, T.131N., R.104W.; 7 miles south of Rhame and 1/2 mile east of paved road.
Exposure: west facing edge of flat-topped hill.
Elevation at top of the Rhame Bed: 3310 feet.
Thickness: Section 5.9 m (19.5 feet); Rhame Bed 5.9 m (19.5 feet).

Silcrete; very light gray; pumaceous appearance on upper surface; holes abundant; plant impressions abundant; 0.4 m thick.

Silt; very light gray (dry); brownish gray (wet); covered by pieces from above; 2.0 m thick.

Silty clay; light gray (dry); dark brownish gray (wet); carbonaceous; interbedded with silt; flaky cracked weathering surface; gypsum crystals common on surface; 3.5 m thick.
33-03-12 (type section)

Location: SE\$SW\$ Sec. 12, T.133N., R.103W.; 3/4 mile northeast of the U—U Ranch.
Exposure: west facing, along West Branch of Deep Creek.
Elevation at the top of the Rhame Bed: 2890 feet.
Thickness: Section 13.2 m (43.6 feet); Rhame Bed 3.8 m (12.5 feet)

Gravel and loam; variable thickness; 2.0 m thick.

Sand, very fine to fine; yellowish gray (dry); yellowish orange (wet); laminated in places; carbonaceous pieces; thickens laterally to south; 2.0 m thick.

Silt; yellowish gray; nonbedded; 0.2 m thick.
Lignite; black; 0.2 m thick.
Clay; light gray (dry); olive gray (wet); flaky cracked weathering surface; 0.45 m thick.
Lignite; black; 0.1 m thick.
Silcrete; medium light gray; plant impressions abundant; 0.25 m thick.

Clay; light gray (dry); dark yellowish brown (wet); 1.6 m thick.

Lignite; moderate brown; fissile; 0.1 m thick.
Silt; yellowish gray; carbonaceous pieces (1.0 mm by 5.0 mm); silicified in places; 0.25 m thick.

Sand, very fine; white; nonbedded; small 1.0 mm carbonaceous pieces; abrupt contact with underlying unit; 1.6 m thick.

Lignite; black; fissile; jarosite in joints; 0.15 m thick.
Clay; light gray (dry); light brownish gray (wet); very carbonaceous; 0.3 m thick.
33-03-12 (type section) continued

Clay; light gray (dry); olive gray (wet); plant remains common; 0.9 m thick.

Sand, very fine; yellowish gray (dry); light olive gray (wet); laminated; iron-oxide staining; small (1.0 mm) plant remains common; 0.3 m thick.

Clay; light gray (dry); olive gray (wet); plant remains common; 0.9 m thick.

Lignite; black; fissile; clay partings (2.0 mm); 0.2 m thick.

Clay; light gray (dry); moderate brown (wet); very carbonaceous; plant impressions and remains common; 1.7 m thick.
Location: SW\(^{\frac{1}{4}}\)NE\(^{\frac{1}{4}}\) Sec. 13, T.133N., R.103W.; \(\frac{1}{4}\) mile east of U—U Ranch.
Exposure: north facing, on all sides of a tributary to the West Fork of Deep Creek.
Elevation at the top of the Rhame Bed: 2890 feet.
Thickness: Section 11.7 m (38.6 feet); Rhame Bed 3.7 m (12.2 feet).

Sand, very fine; light yellowish gray; ledge-forming, cross-bedded sandstone concretions at top; calcareous; 3.5 m thick.

Clay; light gray; forms bench; 1.25 m thick.

Silt; light gray; yellowish gray in lower part; 2.75 m thick.

Silcrete; light gray; pumiceous appearance on surface; holes abundant; plant impressions abundant; 0.2 m thick.

Silt; light gray to white; flaky cracked weathering surface; 3.5 m thick.
Lignite; black; 0.5 m thick.
Location: SE\(^\frac{1}{4}\)SW\(^\frac{1}{4}\) Sec. 27, T.133N., R.103W.; 5 miles northwest of Rhame.
Exposure: west facing, north and south of gravel road.
Elevation at the top of the Rhame Bed: 3000 feet.
Thickness: Section 6.3 m (20.8 feet); Rhame Bed 6.3 m (20.8 feet).

- **Silcrete:** very light gray to medium light gray; stained light yellowish gray; holes abundant; plant impressions abundant; 0.5 m thick.

- **Silt:** very light gray; covered by debris from overlying unit; 1.0 m thick.

- **Clay:** medium dark gray; carbonaceous; flaky cracked weathering surface; forms blocky pieces (0.005 to 0.01 m); 1.5 m thick.

- **Silt:** yellowish gray; laminated; includes medium gray clay 10 cm thick; 0.5 m thick.

- **Clay:** medium dark gray; changes laterally to lignitic shale; 0.5 m thick.

- **Silt and clay, interbedded:** light gray; gradational contact with above unit; 2.3 m thick.
Location: NW¼SW¼ Sec. 33, T.133N., R.103W.; 3½ miles northeast of Rhame.
Exposure: south facing, on east side of gravel road along an unnamed creek.
Elevation at the top of the Rhame Bed: 3030 feet.
Thickness: Section 5.3 m (17.5 feet); Rhame Bed 1.95 m (6.4 feet).

Sand, very fine; pale yellowish orange; 1.5 m thick.

Lignite; brownish black; fissile; lower 0.1-0.2 m is brownish gray silicified lignite; 1.0 m thick.

Silty clay; very light gray; stained light yellowish orange; 0.8 m thick.

Clay; medium light gray; 1.0 m thick.

Sand, very fine to silt; light gray; contoured bedding; changes laterally to bentonitic, light olive gray, clay; also laterally is a light gray, laminated clay with impressions of fossil leaves abundant on the bedding planes; 1.0 m thick.
Location: SW4SE¼ Sec. 36, T.133N., R.104W.; 3½ miles northwest of Rhame.
Exposure: west facing, on east side of gravel road.
Elevation at the top of the Rhame Bed: 3140 feet.
Thickness: Section 7.6 m (25 feet); Rhame Bed 2.4 m (7.9 feet).

Sand, very fine; pale yellowish orange; laminated; obscure, large-scale cross beds; 2.0 m thick.

Lignite; brownish black, soft; 0.1 m thick.
Silcrete; very light gray; iron-oxide staining on surfaces; abundant holes; plant impressions abundant; forms flat topographic surfaces; breaks into 0.1 m pieces; 0.4 m thick.

Silt; light gray; carbonaceous; plant impressions common; 2.0 m thick.

Lignitic shale; brownish black, fissile; 0.1 m thick.

Clay and silt, interbedded; light gray (dry); medium gray (wet); carbonaceous; laterally continuous bands; 1.7 m thick.

Lignitic shale; medium gray (dry); medium dark gray (wet); fissile; iron-oxide concretions in lower part; gypsum crystals on surface; 1.3 m thick.
Location: SW$_{4}$SW$_{4}$ Sec. 27, T.134N., R.102W.; 5 3/4 miles northeast of U—U Ranch.
Exposure: south facing, along Deep Creek.
Elevation at the top of the Rhame Bed: 2760 feet.
Thickness: Section 8.5 m (28 feet); Rhame Bed 4 m (13.2 feet).

Sand, very fine; yellowish gray to light gray; large-scale, cross beds; concretionary ledges at top; 1.5 m thick.

Silt and sand, interbedded; yellowish gray; 3.0 m thick.

Clay; medium dark gray; very carbonaceous; 0.5 m thick.

Clay; light gray; 1.0 m thick.

Silt; white; castellate erosion; 2.5 m thick.
Location: NW<sub>4</sub>NW<sub>4</sub> Sec. 15, T.134N., R.104W.; 1/2 miles north of Mound.
Exposure: south facing, on cutbank of creek, west of gravel road.
Elevation at the top of the Rhame Bed: 2920 feet.
Thickness: Section 15.4 m (50.8 feet); Rhame Bed 1.45 m (4.8 feet).

Gravel and loam; dusky brown; 1.0 m thick.

Sand, very fine; yellowish gray (dry); dusky yellow (wet); iron-oxide concretions; sandstone concretionary ledges; little (1.0 mm) carbonaceous pieces; 5.5 m thick.

Lignite; black; thin (5.0 mm) clay partings; 0.65 m thick.

Sand, very fine; as above; 2.0 m thick.
Lignite; black; jarosite on surface; 2.3 m thick.

Clay; medium gray; silty at top; 0.6 m thick.

Silt; very light gray; plant impressions common; siliceous; 0.15 m thick.

Silt and sand, interbedded; very light gray (dry); light olive gray (wet); 1.3 m thick.

Silt; medium dark gray (wet); carbonaceous; leaf imprints common; 0.5 m thick.

Carbonaceous shale; moderate brown; gypsum crystals abundant; 1.4 m thick.
35-02-31

Location: NE\(^\frac{3}{4}\)NE\(^\frac{3}{4}\) Sec. 31, T.135N., R.102W.; 1\(\frac{1}{4}\) miles south of the HT Horse Company Ranch.
Exposure: west and south facing, south of bridge over Deep Creek.
Elevation at the top of the Rhame Bed: 2670 feet.
Thickness: Section 21.3 m (70.3 feet); Rhame Bed 4.25 m (14 feet).

- Sandstone, fine; grayish orange; ripple cross-beds; 0.4 m thick.

- Sand, fine; pale yellowish orange to dark yellowish orange; 1.6 m thick.

- Lignitic shale; brownish gray; fissile; jarosite and gypsum crystals common; 1.0 m thick.

- Clay and silt, interbedded; medium light gray; alternating clay and silt layers gives a banded appearance; abrupt contact with underlying unit; 2.6 m thick.

- Lignite; black; jarosite and gypsum common; 0.7 m thick.

- Clay; light gray; layer of iron-oxide concretions near base; 1.3 m thick.

- Lignite; black; silicified at base; 0.25 m thick.

- Silty clay; grayish orange pink; plant impressions and remains common; 1.2 m thick.
Clay and silt, interbedded; white; castellate erosion; yellowish orange staining; limonite (from siderite?) concretions; lower part is yellowish gray, fine, sand; abrupt contact with underlying unit; 3.0 m thick.

Lignite; black; 0.2 m thick.

Silty clay; medium light gray; 0.6 m thick.

Sand, fine; light gray; smooth cliff surface; abrupt contact with underlying unit; 0.9 m thick.

Silt and clay, interbedded; medium light gray; 0.6 m thick.

Lignite, shaley; brownish black; 0.25 m thick.

Clay; medium light gray; flaky cracked weathering surface; 2.0 m thick.

Lignite, shaley; brownish black; 0.7 m thick.

Clay; medium light gray; flaky cracked weathering surface; 1.0 m thick.
Clay (continued).
35-02-32

Location: SW\(^4\) NE\(^4\) Sec. 32, T.135N., R.102W.; 2 miles southeast of the HT Horse Company Ranch.
Exposure: peninsula of sediment, west of prairie trail.
Elevation at the top of the Rhame Bed: 2700 feet.
Thickness: Section 8.75 m (28.9 feet); Rhame Bed 4.6 m (15.2 feet).

Siltstone; light brown; calcareous; laterally continuous; 0.1 m thick.

Silty clay; light olive gray; flaky cracked weathering surface; 1.4 m thick.

Lignitic shale; brownish gray to medium dark gray; contains thin peaty layers; 0.25 m thick.

Clay, very light gray to light bluish gray; flaky cracked weathering surface; 1.0 m thick.

Clay; white; pale yellowish orange staining; moderate reddish orange limonite (from siderite?) concretions; castellate erosion; upper 1.5 m slightly darker; 3.6 m thick.

Lignite; black; fissile; 0.4 m thick.

Clay; olive gray; flaky cracked weathering surface; 2.0 m thick.
Location: NW\(\frac{1}{4}\)NW\(\frac{3}{4}\) Sec. 1, T.135N., R.103W.; 2\(\frac{1}{4}\) miles south of Jacobson Ranch.
Exposure: southwest facing, on cut bank of Deep Creek.
Elevation at the top of the Rhame Bed: 2580 feet.
Thickness: Section 12 m (39.6 feet); Rhame Bed 4.4 m (14.5 feet).

Sand and silt, interbedded; yellowish gray; 3.5 m thick.

Lignite; black; jarosite; covered by sand above; 1.3 m thick.

Silt; light gray (dry); brownish gray (wet); flaky cracked weathering surface; 0.7 m thick.

Silt; white; lower portion is bright white; castellate erosion; large (2.0 m) blocks of cross-bedded sandstone from top of bluff lie on surface, and form pedestals; 2.85 m thick.

Silt; very light gray; flaky cracked weathering surface; laterally changes to white silt; abrupt contact with underlying unit; 0.85 m thick.
35-03-1 continued

Lignitic shale; dark brownish gray; 0.3 m thick.

Clay and silt, interbedded; medium dark gray; carbonaceous; alternating 0.1 m bands of medium gray silt and clay give a banded appearance; ironstone concretions at base; rounded slopes; 2.5 m thick.
35-03-12

Location: NW\SE\ Sec. 12, T.135N., R.103W.; 2½ miles northwest of HT Horse Company Ranch.
Exposure: west facing, on cutbank by Deep Creek.
Elevation at the top of the Rhamme Bed: 2620 feet.
Thickness: Section 17.45 m (57.6 feet); Rhamme Bed 5.05 m (16.7 feet).

Siltstone; light brown; calcareous; 0.25 m thick.

Sand, very fine; light yellowish gray; flat-bedded; micaceous; 1.75 m thick.

Lignite; black; fissile; small gypsum flakes common; 0.3 m thick.

Sand, very fine; light yellowish gray; smooth outcrop surface; concretion layers near base; abrupt contact with underlying unit; 2.0 m thick.

Silt and clay, interbedded; light yellowish gray; flaky cracked weathering surface; 1.1 m thick.

Siltstone; light brown; calcareous; 0.3 m thick.
Clay; medium gray; flaky cracked weathering surface; 0.5 m thick.
Lignite; black; fissile; 0.7 m thick.

Silcrete; very light gray; yellowish stains; holes abundant; plant impressions abundant; 0.4 m thick.
Silty clay; pale red to brownish gray; carbonaceous; 0.4 m thick.
Silt and clay, interbedded; very light gray; varies laterally to medium gray, carbonaceous clay; 0.4 m thick.
Silt; white to very light gray; grading downward to medium clay; castellate erosion; laterally cut out to south by channel sand; 3.85 m thick.
Clay; light gray; interbedded with medium gray, clay; popcorn erosion; includes silt, and very carbonaceous clay; 5.5 m thick.
Location: NE\(\frac{1}{4}\)SE\(\frac{1}{4}\) Sec. 13, T.135N., R.103W.; 1 3/4 miles northwest of HT Horse Company Ranch.

Exposure: south facing, along cutbank of tributary of Deep Creek.

Elevation at the top of the Rhame Bed: 2650 feet.

Thickness: Section 15 m (49.5 feet); Rhame Bed 6.4 m (21.1 feet)

Sand, medium to fine; yellowish gray; large-scale, cross-bedded sandstone concretions; calcareous; 2.5 m thick.

Silcrete; light gray; stained yellowish gray; plant impressions abundant; 0.4 m thick.

Silt and sand, interbedded; very light gray; castellate erosion; 3.4 m thick.

Clay; medium gray; flaky cracked weathering surface; 0.4 m thick.

Silcrete; light gray; forms pedestals; irregular bottom; 0.4 m thick.

Sand and silt, interbedded; white; castellate erosion; stained yellowish orange; flat-bedded; 1.8 m thick.
Clay; medium gray; flaky cracked weathering surface; ironstone concretions near base; laterally pinches out; 1.8 m thick.

Sand and silt, interbedded; yellowish gray; laterally thicker; 2.25 m thick.

Clay; medium gray; flaky cracked weathering surface; 2.05 m thick.
Location: NW\(^{4}\) Sec. 25, T.135N., R.103W.; 2 miles southwest of HT Horse Company Ranch. Exposure: north and west facing, south of gravel road and bridge over creek. Elevation at the top of the Rhame Bed: 2690 feet. Thickness: Section 14.35 m (47.2 feet); Rhame Bed 4.3 m (14.2 feet).

Silt; yellowish gray; obscurely cross-bedded; 3.0 m thick.

Lignite; black; 0.7 m thick.

Silt, grading downward to sand; very light gray to white; 4.3 m thick.

Siltstone; dark yellowish orange; calcareous; 0.15 m thick.

Silty clay; light gray; flaky cracked weathering surface; on north side of road alternating gray clay and 0.05 m peaty zones; 1.0 m thick.
35-03-25 continued

Clay; light brownish gray; carbonaceous; plant remains abundant; forms resistant ledge; 0.4 m thick.

Lignite; black; fissile; siliceous in places; 0.5 m thick.

Clay; medium light gray; carbonaceous; flaky cracked weathering surface; forms resistant ledge on north side of road; 1.3 m thick.

Silt and sand; interbedded; very light gray; castellate erosion; yellowish orange staining on surface; 3.0 m thick.
Location: SW 4 SW 4 Sec. 4, T.135N., R.104W.; 3½ miles southeast of VVV Ranch (Yule).
Exposure: west facing edge of flat-topped butte.
Elevation at the top of the Rhame Bed: 2740 feet.
Thickness: Section 20.2 m (66.7 feet); Rhame Bed 8.3 m (27.4 feet).

Gravel and loam; moderate brown; 1.0 m thick.

Silty clay; light gray; 2.0 m thick.

Silt; light gray; carbonaceous; interbedded with clay; 0.7 m thick.

Sand, very fine to fine; yellowish gray; laminated; laterally continuous thin, ripple cross-bedded, sandstone and calcareous, siltstone concretions; abrupt contact with underlying unit; 4.5 m thick.
Lignite; black; flakey; cut in every direction by flat plates of gypsum; thin (0.01 m) clay beds; 1.7 m thick.

Silcrete; light gray; in places surrounded by lignite; forms flat topographic surface; irregular bottom; 0.55 m thick.

Silt or weathered lignite; pale red; soft; 0.5 m thick.

Silt; yellowish gray; obscurely laminated; flakes of gypsum common on surface; supports vegetation; 1.55 m thick.

Lignitic clay; light gray; 0.1 m thick.

Clay; medium gray; plant remains common; 0.35 m thick.

Lignitic shale; medium gray; fissile; stems, leaves, and lignitized wood abundant; 0.35 m thick.

Silt; yellowish gray; nonbedded; 0.6 m thick.

Siltstone; light brown; noncalcareous; forms prominent ledge; 0.2 m thick.

Silt; light brownish gray; carbonaceous; 0.1 m thick.

Silty clay; greenish gray at base; white at top; castellate erosion at base; nonbedded; large-scale, flat beds present laterally; iron-oxide concretions; 4.0 m thick.
Clay; light gray; ironstone concretions at top; 1.6 m thick.

Siltstone; light brown; calcareous; 0.4 m thick.
Location: NW1/4SE1/4 Sec. 21, T.135N., R.104W.; about 6 miles north of Mound.
Exposure: south facing edge of flat topped butte.
Elevation at the top of the Rhame Bed: 2900 feet.
Thickness: Section 26.95 m (88.9 feet); Rhame Bed 5.7 m (18.8 feet)

Gravel and loam; moderate brown; 1.0 m thick.

Silcrete; light gray; plant impressions abundant; pumiceous appearance on top surface, irregular bottom surface; 0.2 m thick.

Clay; pale yellowish orange; iron-oxide staining; 1.2 m thick.

Clay; very light gray to white; 2.0 m thick.

Silcrete; white; holes common; 0.3 m thick.

Clay; white (dry); medium gray (wet); flaky cracked weathering surface; 2.0 m thick.

Sand, very fine; yellowish gray (dry); medium light gray (wet); sandstone concretionary ledges, up to 0.6 m thick; iron-oxide mottling; top marked by ironstone concretion layer; siltier at bottom; 13.0 m thick.
Sand (continued).
Lignite; black; jarosite common on surface; 2.2 m thick.

Silty clay; grayish orange pink; discontinuous silicified stump layer at base; 0.8 m thick.

Clay; very light gray (dry); light olive gray (wet); flaky cracked weathering surface; rounded slopes; ironstone concretions; siltier at top; gypsum crystals common in upper part; 4.25 m thick.
35-04-28

Location: NW 1/4 SW 1/4 Sec. 28, T.135N., R.104W.; 5 miles north of Mound.
Exposure: southwest facing, in badlands area.
Elevation at the top of the Rhame Bed: 2890 feet.
Thickness: Section 10.35 m (34.2 feet); Rhame Bed 2.6 m (8.6 feet).

Sand, very fine to fine; light gray; massive; micaceous; 2.0 m thick.

Silt; light yellowish gray; carbonaceous; 1.0 m thick.

Siltstone; dark yellowish orange; calcareous; 0.3 m thick.

Silt; dark yellowish orange to brownish gray; clay layers; alternating hard calcareous cemented layers with soft layers; 2.0 m thick.

Clay; dark gray; carbonaceous; smooth feeling; 0.25 m thick.

Silt and sand; interbedded; light gray (dry); yellowish orange (wet); 0.8 m thick.

Silcrete; white; pumiceous appearance on upper surface; root holes rare; 0.5 m thick.

Silt and clay, interbedded; very light gray; laminated; soft on surface; 1.1 m thick.

Sand, very fine; medium light gray; laminated; iron-oxide concretions and staining; 0.8 m thick.

Clay; light gray; carbonaceous; 0.2 m thick.
Lignite; dusky brown; shaley; fissile; 0.15 m thick.

Silt; yellowish gray; flaky cracked weathering surface; 1.25 m thick.
36-03-25

Location: NE\(^2\)SE\(^4\) Sec. 25, T.136N., R.103W.; 1 mile south of Jacobson Ranch.
Exposure: southwest facing, on cutbank of Deep Creek.
Elevation at the top of the Rhame Bed: 2540 feet.
Thickness: Section 16.2 m (53.7 feet); Rhame Bed 5.65 m (18.6 feet).

Scoria; moderate red; large (2 m) pieces common; 2.25 m thick.

Silt and sand, interbedded; yellowish gray to light gray; 4.5 m thick.

Lignite; black; pieces of fibrous, white gypsum abundant; jarosite common; 1.3 m thick.

Clay; light gray to brownish gray; 1.15 m thick.
Silt; white; castellate erosion; laterally (to south) this unit is about 1/2 as thick and is underlain by silt, clay and carbonaceous clay about 6 m thick; 4.5 m thick.

Sand, very fine; light brownish gray; hard on outcrop surface; sandstone concretionary layers; 2.5 m thick.
Location: SE\textsuperscript{1}SW\textsuperscript{\frac{1}{4}} Sec. 36, T.136N., R.103W.; 2\frac{1}{4} miles south of Jacobson Ranch.
Exposure: south facing, on sharply dissected tributary valley of Deep Creek.
Elevation at the top of the Rhame Bed: 2560 feet.
Thickness: Section 18.6 m (61.4 feet); Rhame Bed 4.6 m (15.2 feet).

- Scoria; moderate red; variable thickness; 0.5 m thick.

- Silt and clay, interbedded; light gray; 1.5 m thick.

- Sand; light yellowish gray; obscurely cross-bedded; 4.0 m thick.

- Silt and clay, interbedded; light gray; flaky cracked weathering surface; 2.0 m thick.

- Lignite; black; fissile; 1.0 m thick.
Clay; medium gray; 0.5 m thick.

Silt; white to very light gray; cross-bedded sand in lower part; castellate erosion; 2.5 m thick.

Silcrete; very light gray; plant impressions abundant; 0.3 m thick.

Silt and clay, interbedded; very light gray; gradational contact with underlying unit; 1.3 m thick.

Clay; medium gray; interbedded with silt and carbonaceous clay; 5.0 m thick.
Location: SE1/4 SW1/4 Sec. 9, T.136N., R.104W.; 3/4 mile southwest of the X-X Ranch.
Exposure: east facing edge of flat-topped terrace (?) level.
Elevation at the top of the Rhame Bed: 2640 feet.
Thickness: Section 19.6 m (64.9 feet); Rhame Bed 3.3 m (10.9 feet).

- Gravel and loam; moderate brown; 0.8 m thick.

- Sand, very fine; yellowish gray (dry); light gray (wet); thin calcareous, sandstone concretion layers; 2.3 m thick.

- Silt and clay, interbedded; yellowish gray; steep slope; flaky cracked weathering surface; 4.5 m thick.

- Clay; medium gray; 0.2 m thick.

- Lignite; black; laterally oxidized to a red powder; 0.7 m thick.

- Silcrete; light gray; reddish tinge where baked by burned lignite; vertical plant impressions abundant; irregular bottom; 0.5 m thick.
Silty clay; light olive gray; lignite pieces and plant remains common; 0.6 m thick.

Clay; white; nonbedded; castellate erosion; 2.2 m thick.

Clay; light brownish gray; flaky cracked weathering surface; 1.0 m thick.

Clay; light gray; plant remains abundant; flaky cracked weathering surface; 1.0 m thick.

Lignitic shale; grayish black; forms ledge; 0.3 m thick.

Silt; light gray; flaky cracked weathering surface; 2.0 m thick.

Clay; light brownish gray to brownish gray; interbedded with lignitic shale; flaky cracked weathering surface; round slopes; 3.5 m thick.
APPENDIX B

BEAR DEN MEMBER, GOLDEN VALLEY FORMATION
Benson (1952, 1954b) and Hickey (1966, 1972, 1977) have described the Golden Valley Formation in North Dakota. Hickey recognized five lithologic units in the lower member, which he recently named the Bear Den Member (Hickey, 1977, p. 17-28). The lower three units are defined by color. The bottom unit is the "gray zone," made of medium gray silt and clay containing abundant Paleocene fossils. The upper contact of this unit may shift higher or lower laterally through lithologic beds; it is defined on the basis of the position of the color of the overlying unit. The "orange zone" contains white, kaolinitic, clay and silt, which weathers to yellow and orange and forms a striking marker bed. The "carbonaceous zone" contains very dark gray to light brownish gray shale, silt, and clay with abundant kaolinite. The "carbonaceous zone" is overlain by two laterally equivalent beds: the "Taylor bed" and the "Alamo Bluff lignite." The "Taylor bed" contains (Hickey, 1977, p. 23) silicified siltstone composed mainly of silt-size grains, most of which are quartz, in a microcrystalline silica matrix... the rock is massive and light brownish gray when weathered; it breaks into irregular blocks riddled with stem molds. The "Alamo Bluff lignite" may not be the lateral equivalent of the "Taylor bed." In some areas, the "Alamo Bluff lignite" overlies the lower three zones, whereas a short distance laterally the "Alamo Bluff lignite" overlies the "Taylor bed." Hickey interpreted these relationships to represent "... an inferred transgressive replacement of the Alamo Bluff lignite by the Taylor bed in a westward direction" (Hickey, 1977, p. 25).
The lithologic sequence of the Bear Den Member of the Golden Valley Formation resembles the lithologic sequence of the Rhame Bed (Table 9). Hickey chose to define the "gray zone" and the "carbonaceous zone" below and above the "orange zone." These darker colored units are present below and above the white sediment in the Rhame Bed; they were not distinctive enough to warrant separate names. Hickey interpreted the "Taylor bed" and the "Alamo Bluff lignite" to be laterally equivalent. The silcrete in the Rhame Bed and the H bed could have been regarded the same way. An alternative viewpoint is to regard the more laterally persistent lignite of the H bed to overlie the laterally discontinuous silcrete.

Hickey (1977, p. 23) attributed a poorly consolidated siltstone in the "Taylor bed" to case hardening: "Recent cementation of these grains by surface water near the outcrop face has produced a well indurated rock consisting of a mosaic of interlocking quartz grains with overgrowths." But Hickey (1977, p. 25) also links the "Taylor bed" and the "Alamo Bluff lignite":

The numerous standing plant stems in the siltstone are evidence that deposition took place in areas of shallow water where vegetation was growing, such as a swamp or marsh. A higher pH in the Taylor bed swamps than in those where the Alamo Bluff lignite was accumulating would have favored the precipitation of silica over the accumulation of peat.

Freas (1962) analyzed the kaolinitic clay in the Bear Den Member and concluded (p. 1359) that "the stratigraphic variation in clay mineralogy within the clay deposits are consistent with the theory of weathering in place." But Freas stated that significant evidence against this conclusion included (1) the lack of a recognizable unconformity, (2) the "... stratiform nature, widespread distribution, uniformity and succession of stratigraphic units [which are] also difficult
to explain by this theory," (3) "... plagioclase, amphibole, pyrite, and siderite. ... which certainly would not survive weathering conditions...," and (4) "... parallel kaolinite and muscovite crystals [which is] difficult to explain..." (Freas, 1962, p. 1359). Hickey considered that this data and the grain-size distribution of the "gray" and "orange zone" indicated that these zones are fluvial (Hickey, 1977, p. 101):

The only reasonable explanation seems to be low-gradient stream transport of sediment from intensely weathered source areas of intermediate relief that were located a moderate distance from the Williston Basin.

Benson (1952, p. 92-93) interpreted the "kaolin" in the lower part of the Golden Valley Formation to have

... not weathered in situ but was transported from some source area... The Kaolin seems to have been transported as Kaolin and deposited as one continuous or nearly continuous blanket over southwestern North Dakota... Even so, it is still difficult to understand how such a large blanket of relatively pure kaolin could be brought in by streams without having that kaolin mixed with montmorillonite clays or with large amounts of other materials.

Part of the Bear Den Member can be reinterpreted as a silcrete and deep-weathering profile. The "Taylor Bed" is a bed of silcrete. The underlying "carbonaceous zone," "orange zone," and perhaps part of the "gray zone" constitute the deep-weathering profile. Therefore Freas' initial conclusion is correct; the evidence against his initial conclusion is actually evidence for this reinterpretation. The unconformity is present at the top of the "Taylor bed," the characteristics of the units are the result of fluvial processes (these units underlay the weathering surface), plagioclase and amphibole are not found in the "orange zone" (see Freas, 1962, Fig. 8., p. 1356), and if the kaolinite formed from the muscovite, it would be reasonable to expect to find
parallel, aligned crystals. Freas provided even more evidence indicating that the kaolinite in the Bear Den Member originated from deep-weathering: the kaolinite is poorly crystallized (p. 1349), and there is no relationship between the degree of crystallinity and sediment grain size (p. 1350).

The Bear Den Member occurs in a sequence of beds of the same color as the Rhame Bed. The underlying beds (in the Sentinel Butte or Slope Formations) are drab and gray. The overlying beds (in the Camels Butte Member of the Golden Valley Formation or the Bullion Creek Formation) are bright and yellow.

Although earlier workers had considered the entire Golden Valley Formation to be Eocene Age (Benson, 1952, 1954a, 1954b; Freas, 1962), Hickey placed the Paleocene-Eocene boundary at the top of the "Alamo Bluff lignite," including the entire Bear Den Member in the Paleocene. He based this boundary on the presence of Salvinia preauriculata Berry, a floating fern that is unique to the Eocene. A careful scrutiny of the stratigraphic locations of Salvinia in Hickey's dissertation and publication and Benson's report, revealed that Salvinia was found no lower than the "Alamo Bluff lignite," and was found in the "Alamo Bluff lignite" (see Table 10). (See Benson, 1952, p. 89-91.)

The sediment in the Bear Den Member was originally part of the Sentinel Butte Formation and has subsequently been weathered. Perhaps the part of the Bear Den Member below the "Alamo Bluff lignite" should be included in the Sentinel Butte Formation, just as the Rhame Bed is included in the Slope Formation. This would place the unconformity and the series boundary at the top of the silcrete bed ("Taylor bed") or,
Benson (1952) divided the Golden Valley Formation into two members at the top of the "Alamo Bluff lignite." In the Hickey's (1966 and 1977) locations, the first number in parenthesis is from Hickey (1966) and the second number in parenthesis is from Hickey (1977). Salvinia occurs ten times in the lower member or within 2 feet of the "Alamo Bluff lignite"; seven times in the upper member or 3 feet above the "Alamo Bluff lignite."
orton County
Benson, 1952
SE¼, Sec.3, T.140N., R.90W.--Upper 1/3 of lower member
NE¼, Sec. 11, T.140N., R.90W.--Upper 1/3 of lower member
Hickey, 1966 and 1977
SW¼SE¼, Sec.3, T.140N., R.90W.--in A.B. lignite (7-15-1)(14052)
SW¼SW¼, Sec.4, T.140N., R.90W.--6 inches to 2 feet above A.B. lignite (7-8-1)(14053)
SE¼SE¼, Sec.8, T.140N., R.90W.--0 to 1.2 inches above A.B. lignite (7-16-2)(14056)
SW¼SW¼, Sec.6, T.140N., R.90W.--28.2 feet A.B. lignite (L-13-2)

Liver County
Benson, 1952
NW¼, Sec.27, T.141N., R.86W.--Upper 1/3 of lower member

Mercer County
Benson, 1952
NE¼, Sec.29, T.143N., R.90W.--Upper 1/3 of lower member
Hickey, 1966 and 1977
SW¼SE¼, Sec.34, T.141N., R.90W.--28.2 feet above A.B. lignite (L-13-2)
NW¼SE¼, Sec. 31, T.146N., R.88W.--80 feet above A.B. lignite (656)(14099)

Junn County
Hickey, 1966 and 1977
SE¼SE¼, Sec.27, T.141N., R.96W.--13 feet above A.B. lignite (6570)(14117)
NE¼NW¼, Sec.35, T.142N., R.96W.--3.5 to 3.9 feet above A.B. lignite (A-6-1)(14091)
SE¼NE¼, Sec.27, T.142N., R.96W.--3½ inches above A.B. lignite (A-7-1)(14092)
NE¼NE¼, Sec.24, T.142N., R.97W.--9 inches above A.B. lignite (A-13-2)(14094)

Stark County
Benson, 1952
NW¼, Sec.32, T.139N., R.97W.--Upper member
SE¼, Sec. 4, T.137N., R.96W.--Upper member
Hickey, 1966 and 1977
SW¼, Sec.29, T.139N., R.97W.--40 to 45 feet above A.B. lignite (W.B)(14048)

Hettinger County
Hickey, 1966 and 1977
SW¼SW¼, Sec.12, T.135N., R.95W.--in carbonaceous zone below A.B. lignite (6585)(14125)
where the silcrete is not present, at the top of the deep-weathering profile ("orange zone"). The "Alamo Bluff lignite" would be included in the Camels Butte Member of the Golden Valley Formation.

Because the silcrete and deep-weathering profile in the Bear Den Member is associated with the Paleocene-Eocene contact, the age of the weathering is unknown; it could be Late Paleocene or Earliest Eocene. Hickey (1966, p. 52 and 1977, p. 26) discussed making the Bear Den Member a separate formation (because of its distinctive appearance), but concluded that the recognition of the Camels Butte Member often depends on the presence of the Bear Den Member. Perhaps the Bear Den Member should remain as part of the Golden Valley Formation.
REFERENCES
REFERENCES


Hughes, R. J., 163, A geologic investigation of some residual orthoquartzite boulders in the Lower Eocene of southwestern Union County, Mississippi: Journal of Sedimentary Petrology, v. 33, p. 53-63.


1898, A reconnaissance into northwestern South Dakota: South Dakota Geologic Survey Bulletin 2, p. 43-68.


MAP OF THE RHAME BED, SLOPE FORMATION (PALEOCENE),
IN SLOPE AND BOWMAN COUNTIES, NORTH DAKOTA

PLATE 1
Wehrfritz, 1976

GENERAL LEGEND

Outcrop of the Rhame Bed
Inferred position of the Rhame Bed
Wedge-shaped outcrop at the surface of the ground
Outcrop of the Rhame Bed, depth in feet

LOCATION MAP

SCALE

NORTH DAKOTA

GEOLGIC LEGEND

Bullion Creek Fm.
Slope Fm.

GENERALIZED SECTION

SCALE

1.63360

20 mi

20 km

Bullion Creek sand which has replaced the Rhame Bed

Rhame Bed (Ignite)
Silcrete
White sediment of the Rhame Bed

Fig. 2: Measured section, see Appendix A

NORTH DAKOTA STATE HIGHWAY DEPARTMENT
TRANSPORTATION SERVICES DIVISION
IN COOPERATION WITH THE
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
PLATE 3
Wehrfritz, 1978

STRATIGRAPHIC CROSS SECTION FROM RHAME TO U-U RANCH

LOCATION MAP

LITHOLOGIC SYMBOLS

- Grooved sand
- Silt
- Clay
- Carbonaceous shale to lignite, shale
- Silt and clay
- Silcrete
- Cemented sand
- Gravel and loam
- Sand
- Silt
- Carbonaceous clay
- Silt and clay
- Clay
- Lignite

Datum is the top of the Rhame Bed

Vertical Scale 1.0 inch = 4.5 feet
Horizontal Scale 1.0 inch = 4 miles

CROSS SECTION FROM RHAME TO U-U RANCH