Mineralogy and Stratigraphy of the Lower Part of the Pierre Shale, South Dakota and Nebraska

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By LEONARD G. SCHULTZ

STUDIES OF THE PIERRE SHALE IN THE NORTHERN GREAT PLAINS

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Mineralogical data that clarify stratigraphic relations of the Gregory and Crow Creek Members

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MINERALOGY AND STRATIGRAPHY OF THE LOWER PART OF THE PIERRE SHALE, SOUTH DAKOTA AND NEBRASKA

By Leonard G. Schultz

ABSTRACT

Mineralogic and stratigraphic studies of the lower part of the Pierre Shale of Late Cretaceous age along the Missouri River indicate correlations different from those generally accepted.

In central South Dakota, rocks of the Sharon Springs Member at the base of the Pierre and rocks of the lower part of the overlying Gregory Member are notably less montmorillonitic and generally less chloritic and more kaolinitic than rocks higher in the Pierre. The Crow Creek Member, a sandy-based marl unit above the Gregory, contains appreciable amounts of dolomite, particularly in its basal part. Marls in the Gregory Member are not sandy and they contain no dolomite, only calcite or rarely a calcian dolomite. Rhodochrosite-bearing manganiferous nodules are very abundant just above the Crow Creek and less abundant just below it. Thus, the most pronounced compositional differences or changes occur in or just below the Crow Creek Member.

In southeastern South Dakota, similar compositional changes occur. Here, however, they occur not in or just below what has been called the Crow Creek, but rather near a lower marlstone unit at the base of what has been called the Gregory Member.

General stratigraphic relations and consideration of the possible origin of the compositional variations in the lower part of the Pierre indicate that the Crow Creek Member of central South Dakota must be the same as the sandy-based dolomitic marl at the base of the Gregory Member in southeastern South Dakota. Nomenclature at type sections of members of the Pierre in the two areas are conflicting.

The Gregory Member is redefined at its type section so that the new correlations cause a minimum of change in current nomenclature of the Pierre Shale along the Missouri River. As the type section of the Gregory Member is now mostly under water, other reference sections are given.

INTRODUCTION

The lower part of the Pierre Shale in southeastern South Dakota has long been divided into members chiefly on the basis of units of marlstone in a sequence of otherwise clayey rocks. Recent stratigraphic and mineralogic studies, however (Tourtelot and others, 1960; Tourtelot, 1962), indicate that the correlations of several of the marlstone units along the Missouri River are different from those previously accepted by most geologists.

The new correlations established in this report and shown in figure 1*A* can be compared with the previous correlations shown in figure 1*B*. The Crow Creek Member of the Chamberlain area is now correlated with the lowest of the marlstone units in the area between Wheeler Bridge and Yankton rather than with a higher prominent marlstone unit. In earlier interpretations the name Gregory was applied to rocks below the Crow Creek Member in the Chamberlain area and to rocks mainly above the Crow Creek Member between Wheeler Bridge and Yankton. As Chamberlain is in the general type area of the Crow Creek Member and Wheeler Bridge is the type locality of the Gregory Member, the new correlations necessitate deviation from previous usage in one area or the other.

The purposes of this paper are to present evidence for the new correlations and to resolve problems of formal nomenclature that result from them. First, the evolution of the stratigraphic terminology and correlations of the lower part of the Pierre Shale along the Missouri River is reviewed, largely in connection with different interpretations of sections in three key areas—White River-Chamberlain, Wheeler Bridge, and Yankton (pl. 1). Second, the stratigraphic observations made for this study are described and are compared with previous observations; for this purpose the stratigraphic sections for this study shown on plate 1 are repeated on plate 2 together with other sections from intermediate localities. Third, compositional data, summarized in figure 2, are interpreted in terms of different correlations of the marlstone units; only one correlation (fig. 1*A*) seems possible. Fourth, fossil evidence is reviewed. Last, nomenclature is considered.

PREVIOUS DIVISIONS OF THE PIERRE SHALE

The first detailed division of the Pierre Shale in the Missouri River area was made by Searight (1937), who divided the formation into five members. The upper three of these members—the Elk Butte, Mobridge, and Virgin Creek—have remained virtually unchanged into current usage and have no bearing on this report. Searight's next lower member—the Sully—is reviewed briefly in the following paragraph, and his lowest member—the Gregory—is the chief subject of this report.

Searight (1937) subdivided the Sully Member into three zones: in descending order, the Verendrye, the Oacoma, and the Agency. The Verendrye zone contained shale, many flat siderite concretions, and a few bentonite beds. The Oacoma zone contained bentonitic shale, many thin bentonite beds, and conspicuous zones of black-weathering manganiferous concretions. The Agency zone contained hard light-gray siliceous shale. Searight (1937, p. 23) recognized the Agency zone only north of Crow Creek in Buffalo County (see index map, pl. 2); to the south, the siliceous shale of the Agency grades laterally into bentonitic shale in the lower part of the Oacoma zone (Searight, 1938, p. 137; Gries and Rothrock, 1941, p. 23–24; Gries, 1942, p. 17). Because the Agency and the Oacoma zones graded laterally into each other, Gries (1942) combined the two into a single Agency-Oacoma zone. Crandell (1950) pointed out that the combined Agency-Oacoma zone was neither completely nor typically represented at either of the type localities of the individual zones (see index map, pl. 2). He therefore selected a new type section near DeGrey, Hughes County, where both parts of the combined unit are well represented and completely exposed. He renamed the combined unit DeGrey and distinguished a bentonitic facies and a siliceous shale facies corresponding to Searight's Oacoma and Agency zones. Crandell did not use Searight's Sully Member but established the Crow Creek, DeGrey, and Verendrye as members of the Pierre Shale, and these designations are used in this report. In the area of this report between Chamberlain and Yankton (pl. 1), the DeGrey Member consists entirely of the bentonitic facies.

Searight (1937, p. 10) established the name Gregory for the basal member of his Pierre Formation from outcrops along the Missouri River in eastern Gregory County, S. Dak. The type section was in a cutbank at the south end of Rosebud Bridge (now commonly known as Wheeler Bridge), south of Wheeler. The Gregory Member contained several rock types, whose general nature is shown on pl. 1. At the type locality (pl. 1, col. *D*), Searight (1937, p. 14–15) subdivided the

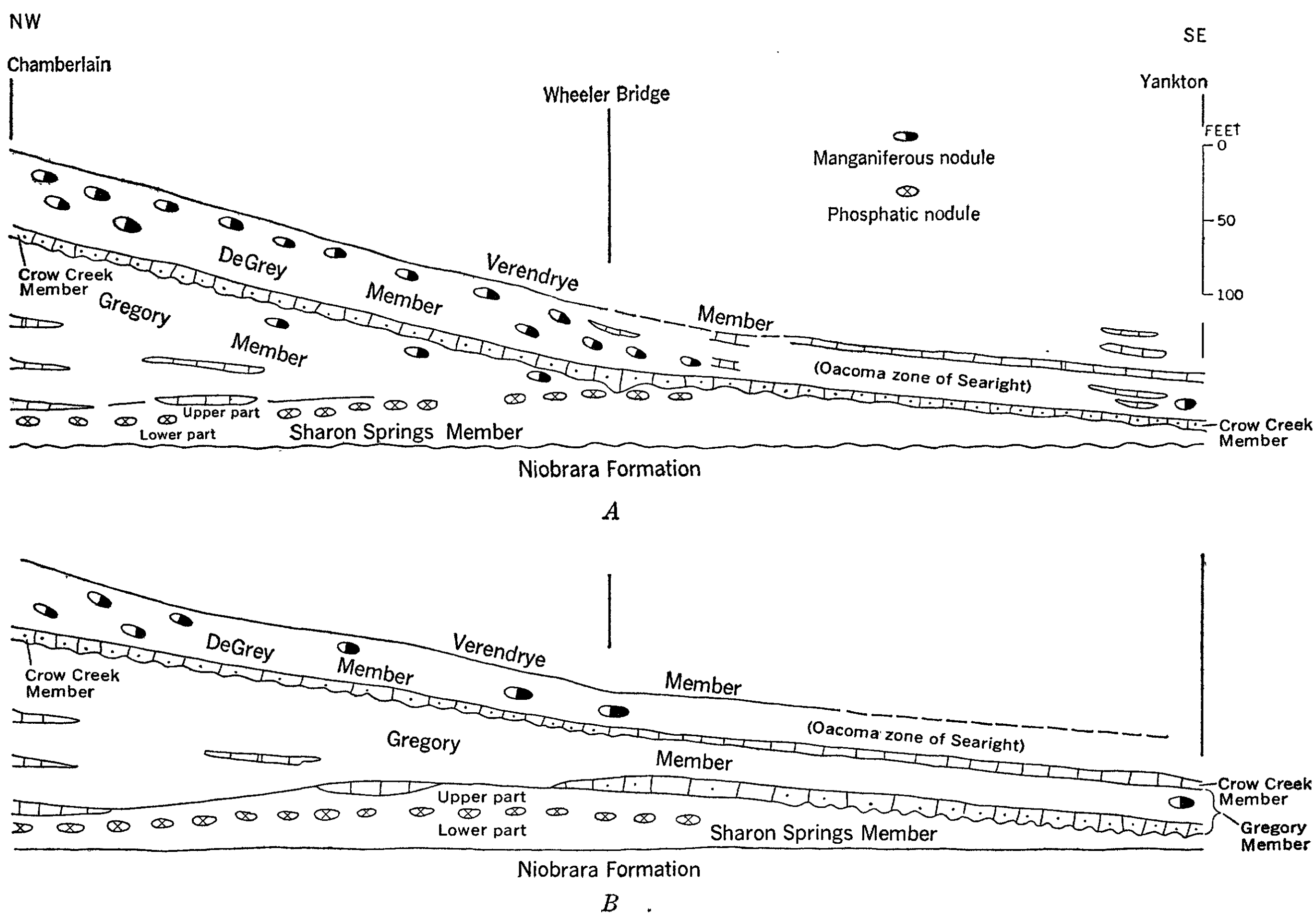

FIGURE 1.—Alternate interpretations of correlation of marlstone units in the lower part of the Pierre Shale. *A*, this report; *B*, previous interpretations (1941–61).

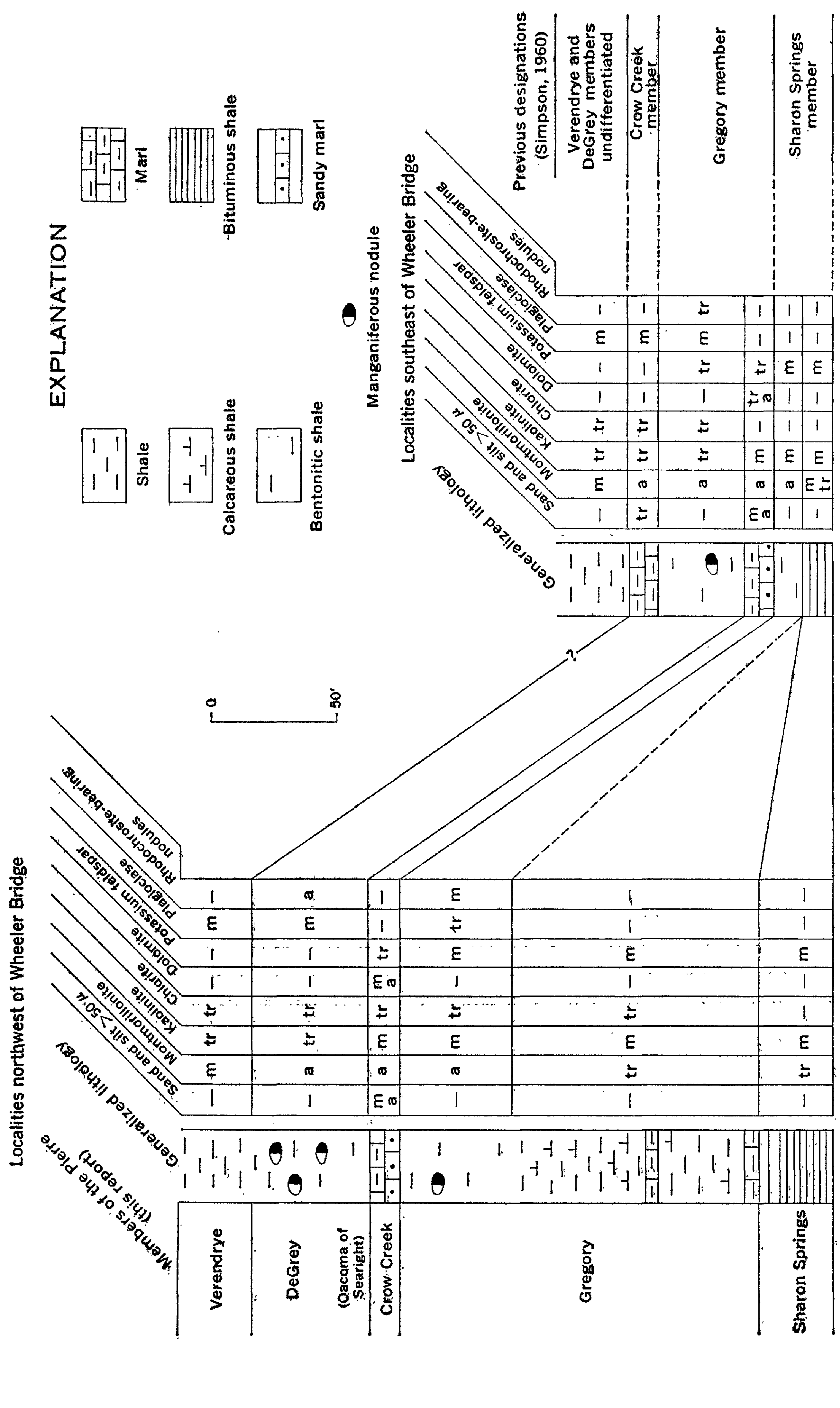

FIGURE 2.—Correlations indicated by mineralogy and lithology, lower part of the Pierre Shale, Missouri River area. a, abundant; m, moderately abundant; tr, trace or minor; —, absent.

"lower Gregory" into (1) a lower part 37 feet thick consisting of hard, buttress-weathering fissile organic-rich shale containing abundant fish scales and many thin beds of bentonite and (2) an upper, poorly exposed part only 5 feet thick and consisting of somewhat softer shale without abundant fish remains or bentonite beds. Searight (1937, p. 12, 20) attributed the considerable increase in thickness of the Gregory Member northwestward from the type locality (pl. 1, col. *A*) mainly to thickening of the upper part of the "lower Gregory." His generalized section for the White River-Chamberlain area (pl. 1) was reconstructed from partial sections and from his textual statements. Significantly, Searight did not mention calcareous beds below his "upper Gregory" marl. The decrease in thickness of the Gregory Member southeastward from the type locality was attributed by Searight (1937, p. 16) to thinning of the "lower Gregory," which is only 7 feet thick at Yankton Quarry (pl. 1, col. *H*).

In 1938 Searight revised the nomenclature of the lower part of the Pierre Shale in South Dakota. He recognized an unconformity between the "upper Gregory" and the "lower Gregory" of his 1937 classification and, because the microfauna of the "upper Gregory" was closely related to the microfauna of the overlying Sully Member, Searight (1938, p. 137) restricted the name Gregory to the "upper Gregory marl" and made it the basal zone of the Sully Member (pl. 1, cols. *A*, *D*, *H*). In 1938 he also assigned the name Sharon Springs to the beds that he had designated the "lower Gregory" in 1937, on the basis of their stratigraphic position and their lithologic similarity to the Sharon Springs Member at the base of the Pierre in western Kansas (Elias, 1931). Searight later (in Moxon and others, 1939, p. 20–21) subdivided the Sharon Springs Member into upper and lower parts corresponding to those he had proposed for the "lower Gregory" in 1937.

In 1941 Gries and Rothrock redescribed the type section of the Gregory Member at Wheeler Bridge. Graphic interpretations of Searight's and Gries and Rothrock's sections at Wheeler Bridge are shown on plate 1, columns *D* and *E*. Only those bentonite beds which are an inch or more thick are shown. Also, one interpretation of Searight's (1937, p. 14–15) published section requires explanation. The sum of the thicknesses given by Searight for 39 individual beds in the "lower Gregory" is 51 feet 8⅝ inches; however, the total thickness tabulated by Searight for the "lower Gregory" is only 42 feet. On page 20 in the same paper, Searight again gave the total thickness of the "lower Gregory" as 42 feet, and this figure has been generally accepted. Apparently a typographical error of 9–10 feet was made in listing the thickness of one of the individual beds. In the graphic section on plate 1 (col. *D*), Searight's bed 16, reportedly 10 feet thick, is assumed to be actually 10 inches thick. Thus, Searight's comment (1937, p. 12) in reference to the Wheeler Bridge section that "17 of the 19 bentonite beds observed occur in the lower 14 feet of the lower Gregory" is satisfied; the position of these bentonites agrees generally with those in Gries and Rothrock's section, and the total thickness of individual beds is reduced to 42 feet 6⅜ inches.

Gries and Rothrock's (1941, p. 31–32) observations at Wheeler Bridge (pl. 1, col. *E*) were in reasonably good agreement with those of Searight (pl. 1, col. *D*) except for the presence of a thin marl unit 26 feet above the thick marl which Searight (1937) had designated as his "upper Gregory". Above their upper marl unit, Gries and Rothrock described "numerous bands of iron-manganese concretions and many bentonite beds," both features that are generally accepted as indicative of the Oacoma zone. Between the two marl units they described "numerous flat brown concretions" of unspecified type. Gries and Rothrock (1941, p. 11) concluded that Searight (1937) had miscorrelated his "upper Gregory" marl at Wheeler Bridge (pl. 1, col. *D*) with the persistent sandy-based marl that is about 150 feet above the base of the Pierre in the area near the mouth of the White River and near Chamberlain (pl. 1, col. *A*). Instead, Gries and Rothrock correlated their newly discovered 2-foot upper marl unit at Wheeler Bridge (pl. 1, col. *E*) with the sandy-based marl unit to the northwest (pl. 1, col. *B*). Because of their new correlation, Gries and Rothrock redefined the Gregory Member at its type section to include all beds between the base of the lower thick marl and the base of the 2-foot upper marl unit (pl. 1, col. *E*). Their redefined Gregory Member thus included two zones at its type section: a basal chalk zone that was the same as Searight's (1937) "upper Gregory" marl (pl. 1, col. *D*) and an upper shale zone that included the lower 26 feet of Searight's (1937) Oacoma zone. Gries and Rothrock made a new unit at the base of the Sully Member and called it the Crow Creek zone for exposures at the mouth of Crow Creek in Buffalo County (pl. 2); in this new unit they included the sandy-based marl of the Chamberlain area (pl. 1, col. *B*) and their newly discovered 2-foot upper marl at Wheeler Bridge (pl. 1, col. *E*).

At Wheeler Bridge (pl. 1, cols. *D* and *E*), Gries and Rothrock (1941) accepted Searight's (1938) designation of Sharon Springs for beds that he had earlier (1937) called the "lower Gregory." Gries and Rothrock were also tentatively in accord with Searight's (in Moxon and others, 1939) subdivision of the Sharon Springs into upper and lower parts, and they mentioned a layer of 1- by 2-inch white concretions between the two parts at all examined exposures (shown as phosphatic nodules on pl. 1).

Gries and Rothrock (1941) disagreed with Searight's (in Moxon and others, 1939, p. 21) northward correlation of the Sharon Springs Member to include all the Pierre below their Crow Creek zone near the mouth of the White River and near Chamberlain (pl. 1, col. *A*). Gries and Rothrock (pl. 1, col. *B*) excluded the upper 125 feet of partly calcareous shale from their Sharon Springs Member and correlated it with their redefined Gregory Member at the type locality (Wheeler Bridge). Northwest of the type locality, Gries and Rothrock did not observe the marl zone as a distinct unit at the base of their Gregory Member, but they believed that the interval was marked intermittently by limestone, calcareous shale, limestone concretions, and, near the mouth of the White River and near Chamberlain (pl. 1, col. *B*), a much thicker unit of interbedded shale and calcareous shale in the lower part of their Gregory Member.

Gries and Rothrock (1941) did not discuss the correlation of marlstone beds southeast of Wheeler Bridge. Later, Gries (1942, p. 10) mentioned that the basal part of the Gregory was seen at only one place southeast of Wheeler, near Rising Hail Colony,[1] where "there appears a 2–3 foot layer of concretionary limestone overlain by a thin calcareous shale." The hard limestone layer referred to by Gries changes laterally into a sandy-based soft marl designated as the Crow Creek Member in this report (pl. 2). Gries (1942, p. 10) also mentioned and apparently accepted the prior correlation by Searight of Gries' basal chalk of the Gregory at Wheeler Bridge with "A 5 foot impure chalk overlying the Sharon Springs in the old cement plant quarry west of Yankton * * * (Searight, 1937, p. 16)." However, although both Gries and Searight called the marl at Yankton Quarry a Gregory marl, Searight's (1937, p. 13) Gregory marl was at the top of his Gregory Member (pl. 1, cols. *D* and *H*), but Gries' marl unit was at the base of his Gregory Member (pl. 1, cols. *E* and *I*).

Near Yankton and in adjacent parts of Nebraska, a second marlstone unit, about 30 feet above the Gregory marl of Searight (1937) and Gries (1942) and unknown to either of them, was found by Schulte,[2] Simpson (1960), and Lee and others (1961). Gries' (1942) implied designation of the lower of the two marl units as the basal marl zone of the Gregory Member (pl. 1, col. *I*) has been generally accepted (Schulte,[2] p. 27; Kepferle, 1959, pl. 50; Simpson, 1960 (pl. 1, col. *J*, this report); Lee and others, 1961 (pl. 1, col. *K*, this report). The upper of the two marl units has been designated as the Crow Creek (Schulte,[2] p. 30; Crandell, 1952, p. 1761; Simpson, 1960 (pl. 1, col. *J*, this report)) or, less commonly, as a marl at the top of the Gregory Member (Lee and others, 1961 (pl. 1, col. *K*, this report)). The shale between the two marl units at Yankton, as at Wheeler Bridge, has become known as the upper shale of the Gregory Member (pl. 1, cols. *I*, *J*, *K*), rather than the Oacoma as originally designated by Searight (1937, p. 16 (pl. 1, col. *H*, this report)), which equals the DeGrey of this report (pl. 1, col. *L*).

Searight (1937, p. 13) was the first to mention a feature that seems to be of considerable significance as a correlation guide in the lower part of the Pierre Shale along the Missouri River—a layer containing abundant coarse sandy grains which contrasts with the otherwise uniformly fine-grained rocks. At the base of his "upper Gregory" marl (pl. 1, col. *A*), Searight described

> a thin bed of fine-grained, thin bedded, slabby sandstone * * * that pinches out and has not been observed more than a short distance south of the mouth of Bull Creek [see index map pl. 2] but everywhere to the north it is persistent. * * * In many places, particularly in the area surrounding the type locality [pl. 1, col. *D*], * * * the upper Gregory contains many small flattish worn pebbles of dense gray shale.

Searight did not specifically mention sand grains at Wheeler Bridge or farther southeast. Gries and Rothrock (1941) mentioned not only these shale pebbles in the "basal Gregory marl" at Wheeler Bridge but also sand grains scattered in both the "basal Gregory marl" and the Crow Creek zone at Wheeler Bridge (pl. 1, col. *E*). Crandell (1952), in his study of the Crow Creek Member, noted an increase in maximum grain size in the basal sandy layer as far southeast as Wheeler Bridge (pl. 1, col. *G*); farther southeast, however, the sandy layer was reportedly missing, even though the nonsandy part of the marl unit seemed to extend as far as Yankton. Mendenhall (1954) noted the occurrence of a silty bed at the base of the Crow Creek Member in the northeast corner of Nebraska. Simpson (1960, p. 34) commented on the absence of a basal sandy zone in his Crow Creek Member in the Yankton area (pl. 1, col. *J*, this report), but he described a sandy layer at the base of his Gregory marl that contained "small phosphatic nodules identical with those in the upper part of the underlying Sharon Springs member." Across the Missouri River from Yankton, in Knox County, Nebr., Schulte [2] (p. 27, 31) mentioned sand grains mixed with chalk in the basal part of marlstones in both the Gregory and Crow Creek Members. Thus, reports of the occurrence of sand in the marl beds of the lower part of the Pierre are not consistent.

[1] Gries referred to this locality as Rising Hill Colony, which does not agree with current maps or local usage.

[2] Schulte, J. J. 1952, The bedrock geology of Knox County, Nebraska: Nebraska Univ. unpub. master's thesis.

In summary, from 1941 to 1961 the general understanding of the nature of units in the lower part of the Pierre was as follows. (See fig. 1*B*.) The Sharon Springs Member consisted of two parts: a lower, major part composed predominantly of black flaky shale containing abundant fish scales and bones and numerous thin beds of nonswelling bentonite, and an upper part composed of less fissile and less organic-rich shale commonly separated from the lower part by a layer of small white nodules. In the area northwest of Wheeler Bridge, the Gregory Member consisted of interbedded shale or claystone, limy claystone, and thin beds of marlstone; a marlstone or some other calcareous unit commonly occurred at its base. At Wheeler Bridge and to the southeast as far as Yankton, the Gregory consisted of a 5- to 10-foot bed of marlstone locally containing shale pebbles and a conspicuously sandy layer at the base, overlain with about 30 feet of bentonitic claystone. The Crow Creek Member, which overlies the Gregory Member, consisted of a single marlstone unit. Northwest of Wheeler Bridge the Crow Creek was conspicuously sandy in its basal part, but to the southeast the unit contained only a few scattered sand grains. The bentonitic facies of the DeGrey Member (Oacoma zone of Searight), overlying the Crow Creek, was characterized by abundant manganiferous nodules between Wheeler Bridge and the Chamberlain area. Southwest of Wheeler the DeGrey was ill defined and not easily distinguishable from the overlying Verendrye Member.

As previously mentioned and as indicated in figure 1*A*, the general understanding of the lower part of the Pierre stratigraphy from 1941 to 1961 seems to be incorrect. The sandy-based marl in the Chamberlain area is the same as the sandy-based marl at Wheeler Bridge and in the Yankton area. This interpretation is the same as that of Searight (1937; pl. 1, cols. *A*, *D*, and *H*, this report), but he called the unit the "upper Gregory marl." In subsequent parts of this report, the sandy-based marl is designated as the Crow Creek Member, and previous designations, where necessary, follow in parentheses; other units are treated similarly.

FIELD OBSERVATIONS FOR THIS STUDY

NORTHWEST AREA

The Sharon Springs Member consists of an upper and a lower unit in most of the area northwest of Wheeler Bridge. The lower unit is composed, in part, of highly fissile dark bituminous buttress-weathering shale containing abundant fish scales—a lithology generally considered typical of the lower part of the Sharon Springs—and, in part, of dark, bituminous shale lacking the other features. The upper unit contains shale that is also fairly dark and organic-rich but is less fissile, contains few fish scales, and is notably softer and, therefore, weathers to a gentler slope than does the shale typical of the lower part of the Sharon Springs. The two units are separated by a layer of white nodules, as reported by Gries and Rothrock (1941, p. 9). The white nodules are composed of apatite, and they commonly occur in yellowish-brown granular "trash" layers a few inches thick that are mostly composed of limonite-stained gypsum and, locally, of other sulfate and phosphate minerals; at some localities, bone, shale, and bentonite fragments are common. An association between accumulations of phosphatic material and unconformities has long been recognized (Pettijohn, 1949, p. 352). The sulfate minerals in the "trash" layers of the Pierre are secondary alteration products of pyrite. The pyritic and phosphatic debris apparently accumulated during a hiatus when little or no normal detrital materials were deposited. Although phosphate nodules and "trash" commonly occur together in the same bed—only in the layer between the upper and lower parts of the Sharon Springs Member—phosphatic nodules are sparsely scattered in shale in the upper part of the Sharon Springs, and several "trash" layers without conspicuous phosphatic nodules may occur in the lower part of the Sharon Springs. Thus, several periods of nondeposition or very slow deposition probably occurred during Sharon Springs time; the lateral extent of these periods is problematical and will be discussed later.

The shale of both the lower and upper parts of the Sharon Springs generally is slightly darker than the shale of the Gregory. The color change generally occurs at the bottom of the lowest marl bed in the Gregory, and thus the base of the marl serves as a suitable contact between the two members. Where the basal calcareous beds of the Gregory are absent, as at Platte Bridge (pl. 2), the contact between the upper part of the Sharon Springs and the Gregory is obscure.

Lenticular beds of marlstone may occur at several levels in the lower part of the Gregory Member (see pl. 2, Chamberlain and Landing Creek sections). The marls seen during this study are not sandy, and they grade both up and down into less calcareous claystone. In contrast, the marlstone composing the overlying Crow Creek Member is sandy in its lower part and has a sharp, apparently disconformable, lower contact with the shale of the Gregory Member. Shale in the upper part of the Gregory Member is noncalcareous, is lighter colored, and is more frothy weathering and apparently more bentonitic than shale in the lower part of the member. The lighter color and the bentonitic character of the upper part of the Gregory have not been previously emphasized (compare White River-Chamberlain sections, pl. 1).

The Gregory Member thins southeastward from its maximum thickness of about 150 feet in the White River-Chamberlain area (pl. 2) to about 40 feet at a point 2 miles south of the bridge constructed in 1963 across the Missouri River due west of Platte; the thinning occurs mainly in the lower, calcareous part of the Gregory.

As noted by all previous geologists in the area, manganiferous nodules are extremely abundant in the bentonitic facies of the DeGrey Member (Oacoma zone, Searight, 1937)—so abundant that the black-weathering nodules commonly form a black band on Pierre outcrops when seen from a distance. Previously, manganiferous nodules were reported only from this interval. However, during the present study, apparently similar nodules were found in less abundance in the upper part of the Gregory Member (pls. 1 and 2).

WHEELER BRIDGE–FORT RANDALL AREA

At Wheeler Bridge the lower part of the Pierre Shale was below the water level of Fort Randall Reservoir when visited for the present study in 1957, 1959, and 1963. Consequently, recognition of units described by Searight (1937) and Gries and Rothrock (1941) is somewhat indirect, and the basis of recognition must be discussed.

The section observed in October 1963 (pl. 1, col. *F*) had at its base 20 feet of marlstone that contained scattered sand grains, shale pebbles, and shale lenses in its lower half. The 46-foot-thick interval above this thick marl was composed of highly bentonitic shale containing several thin bentonite beds and fairly abundant black-weathering manganiferous concretions in both its middle and lower parts. In this 46-foot interval, marls were not conspicuous; but 30½–32 feet above the base of the interval, an inconspicuous 1½-foot-thick bed of very calcareous shale pinched out along the outcrop. This calcareous lens is at about the same horizon and of about the same thickness as the Crow Creek zone of Gries and Rothrock (1941, p. 11, 31) in their Wheeler Bridge section (pl. 1, col. *E*, this report), but the sandy base they mentioned was not seen. Except for this calcareous lens, the entire 46-foot interval appears to lithologically represent the bentonitic facies of the DeGrey (Oacoma zone, Searight, 1937). It is the same thickness as the Oacoma zone measured by Searight at Wheeler Bridge (pl. 1, col. *D*). It is also about the same thickness as the combined interval of the shale zone of the Gregory Member, the Crow Creek zone, and the Oacoma zone of the Sully measured by Gries and Rothrock (pl. 1, col. *E*, this report). The shale beds overlying the 46-foot interval (not shown on pl. 1) contain numerous rusty-weathering siderite nodules typical of the Verendrye Member. The thick marlstone at water level in the Wheeler Bridge section (pl. 1, col. *F*), therefore, appears to be the same as Searight's (1937, pl. 1, col. *D*, this report) marl of the "upper Gregory" and Gries and Rothrock's (pl. 1, col. *E*) basal marl zone of the Gregory Member. The 20-foot thickness of the Crow Creek Member measured (pl. 1, col. *F*) is nearly twice that measured for previous studies; however, it was measured, not at the original Wheeler Bridge locality (at the south end of the bridge), but about half a mile farther east (near the South Wheeler Recreation Area boat landing), where the marl extended a maximum distance above water level. The marl apparently varies considerably in thickness and in elevation in the Wheeler Bridge area.

At Wheeler Bridge, the base of the Crow Creek Member was below water level at all times during the present study. However, splits of samples were obtained from D. R. Crandell, who, before the reservoir was filled, had sampled the sandy basal part of a marlstone unit at the Wheeler Bridge section for his study of the Crow Creek Member (Crandell, 1952, p. 1758). Crandell's samples, besides being conspicuously sandy, contained numerous shale pebbles (pl. 1, col. *G*). Also, Crandell (oral commun., 1963) found the sandy basal part of his sampled marl to be 30 inches thick and the total thickness of the unit to be about 10 feet. Therefore, Crandell's Crow Creek samples could not have been from the thin marl at Wheeler Bridge that was designated as Crow Creek by Gries and Rothrock (pl. 1, col. *E*); his samples could only be from the thick, lower marl at the base of Gries and Rothrock's Gregory Member.

The entire thickness of a sandy-based marl was above water level just south of the mouth of Whetstone Creek (pl. 2) 4 miles northwest of Wheeler Bridge. The section measured in October 1963 consisted, in ascending order above water level, of:

1. About 20 feet of light-gray shale, without conspicuous fissility or abundant fish remains, that was undoubtedly in place locally but that in most places was covered by rubble and heterogeneous masses of tilted to nearly horizontal shale and sandy marl slumped from above. At one or two places the light-gray shale was clearly cut by nearly vertical sandy carbonate dikes.
2. Six feet of marl; the sandy crossbedded rippled lower part contains remarkably abundant shale fragments and along the outcrop ranges in thickness from 2 feet to almost the entire 6-foot thickness of the unit.

3. Sixteen feet of bentonitic noncalcareous claystone that contains many manganiferous nodules.

Thus, both Crandell's marl samples from Wheeler Bridge and the marl at Whetstone Creek contain abundant shale pebbles, such as were described by Searight (1937) from the base of his "upper Gregory marl" and by Gries and Rothrock (1941) from the marl zone at the base of their Gregory Member. Gries and Rothrock (1941) did not mention such shale pebbles in their Crow Creek zone at Wheeler Bridge, and Gries (1942, p. 14–15) specifically commented on the rarity of shale pebbles in the Crow Creek. Thus, the Crow Creek Member of this study at Whetstone Creek (pl. 2) and at Wheeler Bridge (pl 2; pl. 1, col. *F*), the marl sampled by Crandell at Wheeler Bridge (pl. 1, col. *G*), the marl at Wheeler Bridge called "upper Gregory" by Searight (pl. 1, col. *D*), and the marl unit at the base of Gries and Rothrock's Gregory Member at Wheeler Bridge (pl. 1, col. *E*) are all the same. At Whetstone Creek, the 20-foot-thick shale just above water level (pl. 2) must be a considerably thickened equivalent of the upper part of the "lower Gregory" of Searight (1937) and the upper part of the Sharon Springs of Searight (in Moxon and others, 1939) and Gries and Rothrock (1941) at Wheeler Bridge (pl. 1).

The entire lower part of the Pierre Shale is well exposed along Fort Randall Creek (pl. 2) about 10 miles southeast of Wheeler Bridge. The section appears to be similar in thickness and lithologic detail to the Gregory type section at Wheeler Bridge as reported by Searight (1937; pl. 1, col. *D*, this report). Of particular significance at Fort Randall Creek is the 6-foot-thick unit just below the sandy-based marl of the Crow Creek Member and above the "trash"-nodule layer. It is in a position similar to that of Gries and Rothrock's upper part of the Sharon Springs Member at Wheeler Bridge (pl. 1, col. *E*) and is composed of soft frothy-weathering shale that grades from medium dark gray in its basal part to light olive gray at its top. The shale thus appears more similar in color and composition to the bentonitic shale in the upper part of the Gregory at Whetstone Creek and farther northwest (pl. 2) than to the dark-gray nonbentonitic shale characteristic of the upper part of the Sharon Springs. Another noteworthy feature of the section at Fort Randall Creek is the thin unit of calcareous nonsandy shale that grades both up and down into noncalcareous bentonitic shale of the DeGrey Member, just as at Wheeler Bridge, but apparently occurs at a slightly lower stratigraphic position.

SOUTHEAST AREA

Southeast of Fort Randall Dam the interval between the Niobrara Formation and the Crow Creek Member of the Pierre Shale thickens to about 60 feet at Rising Hail and then thins markedly to about 35 feet at the Wagner section and to 3–12 feet at sections between Verdel and Yankton (pl. 2). The lower part of this interval generally is composed of hard bituminous fish-scale shale that contains a few bentonite beds and is generally typical of the lower part of the Sharon Springs. The upper part of the shale is commonly softer than the lower part and locally contains small white phosphate nodules; its topmost part commonly is lightest colored, as can be seen at the Fort Randall Creek section. A distinct layer of phosphate nodules and gypsum separating the lower, hard shale from the upper, soft shale, however, was not seen southeast of Fort Randall.

Southeast of Fort Randall Dam the Crow Creek Member (pl. 2) is marlstone whose thickness is 3 feet at Rising Hail and Wagner, 8 feet at Verdel, 7 feet at Niobrara, 8½ feet at Devils Nest, and 4 feet at Tabor, Crofton, and Yankton. The basal contact is sharp. At every outcrop seen the lower part of the member is conspicuously sandy and generally contains shale pebbles. This is the marl unit that from 1942 to 1961 was commonly called the Gregory marl in southeastern South Dakota and adjacent Nebraska (fig. 1b; pl. 1, cols. *I*, *J*, and *K*). The phosphatic nodules from the sandy basal part of this marl unit mentioned by Simpson (1960, p. 34) were found at the Yankton Quarry, Tabor, and Crofton sections (pl. 2). Unlike the phosphatic nodules in the underlying shale, those in the sandy layer have smooth, highly polished outer surfaces.

In the area southeast of Fort Randall, a second conspicuous marlstone unit 4–8 feet thick commonly occurs 25–40 feet above the lower sandy marl. This marl was seen at Yankton, Wagner, and at all the Nebraska localities (pl. 2). An 8-foot-thick calcareous shale bed 25–33 feet above the lower sandy marl at Rising Hail may also represent the upper marl. This is the marl called Crow Creek by Simpson (1960; pl. 1, col. *J*, this report) and by most other geologists who have worked in this area. Locally, one or two thinner beds of marlstone or calcareous shale occur in the bentonitic shale between the two most conspicuous marl units. At the Tabor locality (pl. 2), so many thin beds of marlstone and calcareous shale occur that it is difficult to estimate which may be the equivalent of the Crow Creek of Simpson. None of the upper marl beds are conspicuously sandy. The shales between the marl beds appear bentonitic and contain numerous thin bentonite beds (pl. 2, Tabor and Yankton Quarry), features characteristic of the bentonitic facies of the DeGrey but not of most of the Gregory Member.

Thus, several lithologic features—especially the sandy character of the lower marlstone unit southeast of Wheeler Bridge—suggested that this lower marlstone, rather than the higher, nonsandy marlstone, is correlative with the Crow Creek Member northwest of Wheeler Bridge (fig. 1*A*). Mineralogic data for the marlstone and the adjacent shales support this interpretation.

LABORATORY DETERMINATION OF COMPOSITION OF ROCKS

Compositional data for the marlstone in the lower part of the Pierre Shale are arranged in table 1 by localities from northwest to southeast along the Missouri River (index map on pl. 2). At most localities, two samples were taken from each marlstone unit—one from the upper main part and one from the basal few inches of the unit. Data for these upper and lower samples are shown in table 1 to the left and right of slash marks, respectively. Where samples are from two separate units—for example, the Gregory marl beds at Landing Creek—the data are tabulated in separate columns without slash marks.

The proportions of the different clay minerals were determined by X-ray diffraction methods described elsewhere (Schultz, 1964). The total amount of calcite and dolomite was determined by weight loss of 5 grams of sample after treatment in 1*N* HCl; relative proportions of calcite and dolomite were determined by X-ray diffraction. Particle-size data were determined by separation of the $>50\ \mu$ fraction from the acid-treated and disaggregated sample by elutriation, weighing, and correction under the binocular microscope for the clay particles that did not disaggregate. Clay-aggregate particles were dominant from some samples, but most coarse separates were composed predominantly of quartz grains and contained minor amounts of feldspar, biotite, black chert, siliceous foraminifera shells, and clay aggregates. Quartz grains range from rounded and frosted to angular and clear; subangular to subrounded clear quartz grains are most common. In table 1, the different methods of presenting data—in parts per 10, percent, or tenths of percent—reflect the probable accuracy of the data.

Mineralogic data for samples from the lower part of the Pierre Shale, other than samples from marlstone units, will be presented in another report. The aspects of the composition of the marlstone units, as well as of the associated shales, that are significant to the correlation of these units are summarized in figure 2.

NORTHWEST AREA

Sand and silt larger than 50 μ is found in all of the the Crow Creek samples and commonly composes 5–10 percent and rarely as much as 20 percent of the lower part of the Crow Creek Member. In the Gregory Member, sand and silt is much less abundant in the marls; where it is found it does not exceed a few tenths of a percent of the sample and is of small maximum grain size. The laboratory measurements thus confirm field observations—that the Gregory marls are much less sandy than the Crow Creek marl.

Montmorillonite is less abundant in the shales of the Sharon Springs Member and in the shales and calcareous rocks in the lower part of the Gregory Member than in stratigraphically higher rocks. In the lower strata, montmorillonite makes up generally less than two-tenths of the clay-mineral fraction, whereas in rocks in the upper part of the Gregory, the Crow Creek, and the DeGrey Members it commonly makes up three-tenths to more than half of the clay-mineral fraction.

Kaolinite occurs in largest amounts in rocks below the DeGrey Member—commonly one-tenth or more of the clay-mineral fraction. Chlorite, if present, is a very minor component. Rocks in the DeGrey and Verendrye Members contain approximately equal trace amounts of both kaolinite and chlorite.

Dolomite and calcite both occur in the Crow Creek Member. The main part of the marlstone unit commonly contains about 5 percent dolomite, and the lower sandy part, 15–35 percent. In contrast, marlstones and calcareous shales in the Gregory Member generally contain no dolomite, only calcite. Exceptions are Gregory samples from Bull and Landing Creeks, which contained a calcian dolomite but not dolomite of ideal composition such as occurs in the Crow Creek Member. The calcian dolomite seems to be related to recrystallization of the soft marl beds into hard dense carbonate rock.

Rhodochrosite and siderite are both characteristic minerals in the black-weathering iron-manganese nodules that are conspicuous in the bentonitic facies of the DeGrey Member (Oacoma zone, Searight, 1937). Most other ironstone concretions in the Pierre Shale contain only siderite. However, although not as abundant as in the DeGrey Member, similar rhodochrosite-bearing nodules were found in the upper part of the Gregory Member at Chamberlain, Landing Creek, Platte Bridge, and Whetstone Creek (pl. 2).

Feldspars differ in relative abundance above and below the Crow Creek Member. Below the Crow Creek the dominant feldspar is a potassium variety; above, a plagioclase variety.

SOUTHEAST AREA

Southeast of Wheeler Bridge a sequence of compositional changes similar to those northwest of the bridge occurs in the lower part of the Pierre (fig. 2).

Sand and silt larger than 50 μ is conspicuously abundant in the Crow Creek Member southeast of Wheeler Bridge. Sand and silt make up generally 10–15 percent of the member's basal part, and in one sample from near Fort Randall, 50 percent (table 1). Such coarse grains are generally less abundant above the basal part of the member. The distribution of sandy material is thus similar to that in the Crow Creek at Wheeler Bridge, Whetstone Creek, and farther northwest (fig. 2, pl. 2, and table 1). In contrast, most samples from higher marlstone beds at and southeast of Wheeler Bridge contain either no sand grains larger than 50 μ or less than 0.1 percent such grains. One sample from an upper marlstone near Verdel contains 1.4 percent grains larger than 50 μ, and quartz grains as much as one-fifth millimeter in diameter were found in an upper marlstone at Wagner. Thus, though the upper marlstones are not completely devoid of sandy grains, they are notably less sandy than the Crow Creek, particularly in their lower part.

TABLE 1.—*Composition of marlstone units in the lower*

[Sample localities listed from northwest to southeast, see index map on pl. 2. Data for slash marks, respectively; Tr, 1–2 percent; +, present

	Oahe Dam (core)	Fort Pierre	Big Bend[1]	Lower Brule	Fort Thompson (core)	Crow Creek	Chamberlain	Oacoma	White River	Bull Creek	Elm Creek
											Marlstone beds above
CLAY MINERALS [3]											
Montmorillonite	--	--	--	--	--	--	--	--	--	--	--
Mixed-layer clay	--	--	--	--	--	--	--	--	--	--	--
Illite	--	--	--	--	--	--	--	--	--	--	--
Chlorite	--	--	--	--	--	--	--	--	--	--	--
Kaolinite	--	--	--	--	--	--	--	--	--	--	--
CARBONATE MINERALS [4]											
Calcite	--	--	--	--	--	--	--	--	--	--	--
Dolomite	--	--	--	--	--	--	--	--	--	--	--
INSOLUBLE RESIDUE >50μ											
Percent of sample	--	--	--	--	--	--	--	--	--	--	--
Maximum size mm	--	--	--	--	--	--	--	--	--	--	--
											Crow Creek Member
CLAY MINERALS [3]											
Montmorillonite	4/5	5½/6½	8	4½/6	4/4½	4½/5½	4/7½	4½/6	--	3/3½	3/7½
Mixed-layer clay	5/4½	3½/2½	1½	4½/1	4/4	3½/3½	4/½	4/2	--	5/4	5½/1
Illite	½/½	½/1	½	½/½	1½/1	1/½	1/1½	1/1½	--	1/1½	½/½
Chlorite	Tr/0	0/Tr	0	0/Tr	Tr/Tr	Tr/0	0/0	Tr/0	--	Tr/0	Tr/0
Kaolinite	Tr/0	Tr/Tr	0	½/2	½/½	½/½	1/1½	½/½	--	½/1	1/1
CARBONATE MINERALS [4]											
Calcite	35/26	40/25	33	35/25	35/45	38/31	44/32	45/30	--	50/33	45/25
Dolomite	3/27	4/20	36	5/30	5/15	7/21	5/36	5/30	--	5/30	9/25
INSOLUBLE RESIDUE>50μ											
Percent of sample	0.6/5.6	0.7/4.7	20.1	0.2/12.0	0.1/5.9	1.1/19.7	0.2/24.2	1.2/13.9	--	0.6/9.9	.4/24.4
Maximum mm	.07/.1	.07/.1	.2	.1/.07	.1/.2	.1/.2	.05/.2	.07/.1	--	.1/.1	.07/.1
											Marlstone units in the
CLAY MINERALS [3]											
Montmorillonite	--	--	--	--	2	½/1	1½/2	0	1/½	½	0/0
Mixed-layer clay	--	--	--	--	4½	5/5	5/4½	6½	5½/6	6	6/5½
Illite	--	--	--	--	2	2½/2	1½/1½	2	2/1½	1½	1½/1½
Chlorite	--	--	--	--	½	½/Tr	½/½	Tr	0/Tr	½	0/0
Kaolinite	--	--	--	--	1	1½/1½	1½/1½	1½	1½/2	1½	2½/3
CARBONATE MINERALS [4]											
Calcite	--	--	--	--	35	50/36	50/58	30	40/35	25	60/65
Dolomite	--	--	--	--	0	0/0	0/0	0	0/0	[6]15	0/0
INSOLUBLE RESIDUE>50μ											
Percent of sample	--	--	--	--	+	+/.08	0/0.2	+	0/0	0	0.1/0
Maximum mm	--	--	--	--	0.07	0.05/.05	−/.1	0.05	--	--	.1/−

[1] Entire 2-ft bed is sandy.
[2] Data for lower part of the marlstone unit are averages from 4 of Crandell's (1952, p. 1758) samples from 2½-ft-thick basal sandy part.
[3] Parts per 10 of total clay minerals.

Maximum grain size of material in the Crow Creek of this report is greatest in the Niobrara-Yankton area and generally decreases northwestward. The largest grain measured (2 mm in diameter), was found at the locality near Crofton (index map on pl. 2); the next largest grains (1.5 mm) were from Yankton, Tabor, and Devils Nest. Thus, the southeastward increase in maximum grain size noted by Crandell (1952) in the Crow Creek Member as far as Wheeler Bridge seems to continue in the Crow Creek of this report southeastward to the limit of outcrop along the Missouri River.

Along the Missouri River the lower part of the Crow Creek Member does differ in appearance and composition. Northwest of Iona (index map on pl. 2) the sandy basal part of the Crow Creek Member averages about 60 percent carbonate minerals, 20 percent clay minerals, and 5–10 percent quartz grains larger than 50 μ; southeast of Wheeler Bridge, the sandy, basal part of the Crow Creek averages about 35 percent carbonate minerals, 35 percent clay minerals, and 10–20 percent quartz grains larger than 50 μ. Northwest of Iona the layer is commonly indurated and stands out as a ledge or occurs as hard slabs of calcite-cemented sandstone strewn on the weathered outcrop. To the south-

part of the Pierre Shale, Missouri River area

samples from upper and lower parts of individual units indicated to left and right of
in amounts less than 0.1 percent of total sample]

Iona	Landing Creek		Platte Bridge	Whetstone Creek	Wheeler Bridge [2]	Fort Randall Creek	Rising Hail		Wagner	Verdel	Verdigre	Niobrara	Devils Nest	Tabor		Crofton	Yankton Quarry
the Crow Creek Member																	
----------	----------		----------	----------	4½/4½	3½	4½	5	6/8	3½/6½	2½/5½	----------	5½/6	7/5	5	6/8	4/4½
----------	----------		----------	----------	4/4	5	4	3	2½/1	4½/2	4½/2	----------	2½/2½	2/3½	3½	2/1	4/3½
----------	----------		----------	----------	1½/1	1½	1½	2	1/1	1/1	2/2	----------	1½/1	1/1	1	1/1	1½/1
----------	----------		----------	----------	Tr/Tr	0	Tr	Tr	Tr/Tr	½/Tr	Tr/0	----------	Tr/0	0/Tr	Tr	½/Tr	Tr/½
----------	----------		----------	----------	Tr/Tr	Tr	Tr	Tr	Tr/Tr	½/Tr	1/½	----------	Tr/½	Tr/Tr	Tr	½/Tr	½/½
----------	----------		----------	----------	13/13	12	17	20	26/30	[5]82/50	[5]87/40	----------	31/39	46/8	35	36/50	47/28
----------	----------		----------	----------	0/0	0	0	0	0/0	0/0	0/0	----------	0/0	0/0	0	0/0	0/0
----------	----------		----------	----------	0.1/0.2	0	0	0	+/+	1.4/+	+/+	----------	+/0	0.2/0.4	0	+/+	0/+
----------	----------		----------	----------	.2/.2	----------	------	-----	0.2/0.07	0.1/0.07	0.1/0.2	----------	0.1/	.04/.05	------	0.2/0.2	–/0.1
of this report																	
3/5	3/4½		3½/8	2½/4	2½/4	3½/7	3½/7½		6/6	5/9	----------	4½/8½	4/8	3½/7		5/8	4/8
4/3	4½/3½		3/½	5/3½	4/3½	4/2	4/1½		2/3	3½/0	----------	3½/½	3½/½	5/2		3/1½	3½/½
1½/½	1/½		2/1	1/1½	2/1½	1½/½	1/½		1/½	1/½	----------	1/½	1½/1	1/½		1½/½	1½/1
Tr/Tr	0/Tr		Tr/0	0/0	0/0	0/0	0/0		0/0	0/0	----------	0/0	0/0	Tr/0		Tr/0	0/0
1/1	1½/1		1/½	1/1	1½/1	1/½	1/½		1/½	½/½	----------	1/½	1/½	½/½		½/Tr	1/½
45/27	45/28		44/23	49/38	50/38	25/0	48/0		40/34	53/18	----------	52/29	55/19	56/25		50/10	57/21
9/12	3/10		5/9	6/12	3/19	45/10	8/0		8/8	3/10	----------	8/4	5/15	9/16		12/20	8/15
3.0/5.7	.6/11.9		.3/13.8	1.3/10.8	.4/17.5	3.2/50.4	8.3/5.2		3.8/9.2	3.7/16.7	----------	2.5/20.4	4.6/13.3	7.0/9.9		4.2/16.6	7.5/14.5
.1/.2	.2/.5		.1/.5	.1/1.0	.2/.7	.2/.7	.3/.5		.2/.3	.3/.3	----------	.2/1.0	.5/1.5	.5/1.5		.3/2.0	.5/1.5
Gregory Member of this report																	
0	0	0	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
7½	5½	5½	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
1½	2	2	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
0	Tr	Tr	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
1	2½	2½	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
2	56	10	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
0	0	[6]68	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
0	0.1	0.1	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------
----------	.07	.1	----------	----------	----------	----------	----------		----------	----------	----------	----------	----------	----------		----------	----------

[4] Percent of sample.
[5] Magnesian calcite.
[6] Calcian dolomite.

east the sand and silt are in a soft clayey matrix, and the less resistant sandy layer is much less conspicuous. The different appearance of the sandy layer is further emphasized by the much greater abundance of shale pebbles to the southeast. These differences may in part explain why the similarity in sandiness of the Crow Creek Member in the Chamberlain area and in the Wheeler Bridge–Yankton area has not been generally recognized.

Montmorillonite is abundant in the Crow Creek Member of this report, in all the other higher marlstone units in the lower part of the Pierre, in the shale between the marlstone units, and in the shale just below the Crow Creek Member of this report in the area southeast of Wheeler Bridge (fig. 2). Thus, none of the marl units are mineralogically and lithologically equivalent to the montmorillonite-poor calcareous lower part of the Gregory of the northeast area (fig. 2). In the southeast area the fissile shale of the Sharon Springs at the base of the Pierre contains a generally low but somewhat variable amount of montmorillonite—0–2½ parts montmorillonite per 10 parts clay. Thus, though the montmorillonite content of some samples is higher than is characteristic of the Sharon Springs or the lower part of the Gregory to the northwest, the montmorillonite content is generally more similar to that in these lower beds than to that in the upper part of the Gregory, the Crow Creek, or the DeGrey Members.

Kaolinite and chlorite abundance above and below the Crow Creek Member southwest of Wheeler Bridge is similar to that above and below the Crow Creek northwest of Wheeler Bridge—trace amounts of both minerals above and relatively large amounts of kaolinite and little or no chlorite below.

Dolomite is present only in the Crow Creek Member of this report. It is not present in marlstone units previously designated as Crow Creek, in other thin marl beds, or in the shales between the marls. Calcite is the only carbonate mineral found in any of the upper marlstone units; the magnesian calcite from hard lenses in the marlstone at Verdel and Verdigre, like the mixed carbonates from the Gregory at Bull Creek and Landing Creek (table 1), seems to be related to recrystallization of the soft marl beds.

Feldspar is almost exclusively a potassium variety in and especially below the Crow Creek Member of this report. Above, plagioclase is the dominant variety. Northwest of Wheeler this change in feldspar content also occurs in or just below the Crow Creek Member (fig. 2).

Manganiferous concretions having a separate rhodochrosite phase are considerably less abundant southeast of Wheeler Bridge than to the northwest. At Wheeler Bridge such concretions are fairly conspicuous, but they become progressively less abundant southeastward from Fort Randall to Rising Hail and, beyond, to the Wagner section. In the Niobrara-Yankton area they are rare, indeed; only one was found near Niobrara. Iron-manganese concretions reported by Simpson (1960, p. 35) at Yankton (pl. 1, col. *J*) were not found in this study. All the manganiferous nodules southeast of Wheeler Bridge, including those reported by Simpson, occur in the interval just above the Crow Creek Member of this report, in shale that is interpreted as the bentonitic facies of the DeGrey Member (fig. 1*A*).

The abundance of manganese concretions in the DeGrey is at its maximum near Chamberlain and it decreases to the southeast; the decrease in abundance of manganiferous concretions southeastward from Wheeler Bridge noted in the preceding paragraph seems to be a continuation of this trend within the DeGrey Member. This trend is apparently paralleled by the abundance of rhodochrosite-bearing concretions in the Gregory Member, wherein concretions decrease from moderately abundant northwest of Wheeler Bridge to absent southeast of Wheeler Bridge.

FOSSIL EVIDENCE FOR CORRELATIONS

Megafossils generally are scarce in the lower part of the Pierre Shale along the Missouri River. The following fossils, found in the Gregory Member of this report at Big Bend Dam and at the Chamberlain and Bull Creek localities (pl. 2), were identified by W. A. Cobban:

Pelecypods:
- *Nucula obsoletistriata* Meek & Hayden
- *Inoceramus sublaevis* Hall & Meek
- *Inoceramus* aff. *I. proximus* Tuomey
- *Pteria* sp.
- *Ostrea inornata* Meek & Hayden

Cephalopods:
- *Anaklinoceras mortoni* (Hall & Meek)
- *Oxybeloceras crassum* (Whitfield)
- *Anapachydiscus complexus* (Hall & Meek)
- *Baculites gregoryensis* Cobban
- *Baculites scotti* Cobban

Gastropods:
- *Trachytriton vinculum* (Hall & Meek)
- *Drepanochilus* sp.
- *Polinices*? sp.

The megafossils are of no direct aid to correlation of beds along the Missouri River because no such fossils have been found southeast of the general Chamberlain-White River area. They are here recorded to complete the record for the Gregory Member because it will be redefined herein and because the baculites will be used later in this paper to help interpret lithologic changes along the Missouri River in terms of local or regional changes in depositional conditions.

Searight's (1938) microfossil studies are the only published fossil data that may have a bearing on correlation of the marl beds in the lower part of the Pierre along the Missouri River. He described a distinctive microfauna in shale just above the Crow Creek (called the Gregory zone by Searight (1938); pl. 1, cols. *A*, *D*, and *H*) at Fort Pierre, Rosebud Bridge (Wheeler Bridge), and Yankton; and he mentioned (p. 137) that this fauna is different from the microfauna below the Crow Creek (his Gregory zone). Although details of the differences between the microfaunas have not been published, observations of the microfauna summarized in 1938 would indicate that the sandy marls along the Missouri are a single correlative unit, as originally interpreted by Searight (1937) and as advocated in this report, and that they are not two different units as was believed from 1941 to 1961 (fig. 1*B*).

DIFFERENT CORRELATIONS AS RELATED TO ROCK COMPOSITION

Correlation of the Crow Creek Member as advocated in this report (fig. 1*A*) is consistent with all available compositional evidence. In all areas along the Missouri River:

1. Conspicuous amounts of sand, silt, shale pebbles, and dolomite, and the basal unconformity are associated with the same marl unit.
2. Changes in montmorillonite content and in proportions of kaolinite and chlorite and of potassium and plagioclase feldspar occur at the same stratigraphic horizons.
3. Rhodochrosite-bearing nodules occur mainly in the DeGrey Member (Oacoma zone, Searight, 1937) and less commonly in the upper part of the Gregory Member; their abundance decreases southeastward in both members.

If previous correlations of the marl units had been correct (fig. 1*B*), the sandy-based dolomitic marlstone units would not be equivalent, and the mineralogical changes would necessarily occur at different horizons along the Missouri River. Also, rhodochrosite nodules would occur at Whetstone Creek in beds that would have been called the upper part of the Sharon Springs Member by Gries and Rothrock in 1941, and the greatest abundance of these concretions would be in the DeGrey Member northwest of Wheeler Bridge and in the Gregory Member at and southwest of Wheeler Bridge. Some of these nonequivalent features are difficult to explain, especially the distribution of montmorillonite.

DISTRIBUTION OF MONTMORILLONITE

Previous correlations of these units (fig. 1*B*) result in the equivalence of a montmorillonite-rich Gregory Member in the Yankton–Wheeler Bridge area and a mostly montmorillonite-poor Gregory Member in the Chamberlain area. The compositional contrast between these two units is about as great as any contrast within the normally uniform Pierre Shale of the northern Great Plains area. Such a difference in composition in supposedly equivalent rocks might occur if the Gregory rocks in the Chamberlain and Wheeler Bridge areas were derived from different source areas or if originally similar sediments were altered after deposition under conditions that differed markedly in the two areas. As explained in the following paragraphs, neither explanation seems to apply, and the mineralogically different sediments therefore cannot be equivalent.

The Pierre Shale was deposited in a north-trending basin several hundred miles wide that extended from Canada at least as far as New Mexico (Tourtelot, 1962, fig. 1). The eastern shore is not preserved, but because it apparently was low, it contributed little detritus to the basin. Almost all the sediments in the Pierre Shale in the northern conterminous United States, including large amounts of altered volcanic material, came from the west side of the basin. On the east side of the basin, in what is now the Missouri River area, the Pierre Shale is composed almost entirely of fine-grained material, owing to the wide expanse of water across which nearly all the sediment was transported. The scarcity of montmorillonite in the Pierre Shale in rocks below the upper part of the Gregory of the Chamberlain area is recognizable in the Pierre Shale throughout a large part of the northern Great Plains. The scarcity is recognized in the Black Hills area (Tourtelot and others, 1960, p. B449), and preliminary data on marine shales deposited near the west margin of the Pierre sea in north-central Wyoming and central Montana indicate that this small content of montmorillonite in the lower part persists across the basin. The upward increase in montmorillonite content seemingly is the result of an increase in the amount of volcanic material introduced into the west side of the basin. This increase in volcanic material affected the composition of sediments at about the same time throughout much of the basin, and the increased amount of volcanic material seemingly could not have arrived at considerably different times at localities only a few tens of miles apart on the east side of the basin. Thus the montmorillonite-rich Gregory of the Yankton area could not have been deposited while montmorillonite-poor Gregory was still being deposited to the northwest

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in the Chamberlain area even closer to the western source area (fig. 2).

Mechanisms, other than different source areas, that have been used to explain changes in montmorillonite content of rocks elsewhere also do not seem to apply to the Pierre Shale along the Missouri River. Gradual decrease in montmorillonite content with depth of burial between about 4,000 and 10,000 feet, as suggested by Powers (1959) and Burst (1959) for gulf-coast sediments of Tertiary age, does not seem to apply, because the Pierre rocks in question probably have been buried at depths of only a few thousand feet; even if burial was somewhat greater, the rocks are nearly flat-lying, so that the depth cannot have been greatly different in areas northwest and southeast of Wheeler Bridge. Furthermore, the very abrupt vertical change in mineralogy in the Pierre (fig. 2, pl. 2) contrasts with the gradual change in montmorillonite content over several thousand feet in the gulf-coast Tertiary sediments. Diagenetic alteration of montmorillonite in a marine environment (Whitehouse and McCarter, 1958; Powers, 1957; Johns and Grim, 1958; Milne and Earley, 1958; Weaver, 1959) also seems improbable as a cause of the differences, because all Pierre rocks in question on the east flank of the Pierre basin were deposited in a marine environment and there seems to be no reason to believe that the thick montmorillonite-poor sequence of Gregory rocks at Chamberlain was exposed to marine conditions any longer than the much thinner and more montmorillonitic rocks in the Wheeler Bridge-Yankton area—if anything, the opposite seems more probable.

The vertical change in the amount of montmorillonite in the lower part of the Pierre along the Missouri River seemingly can be explained only if the change represents a virtually contemporaneous time horizon. Thus, the Crow Creek Member of the Chamberlain area can be equivalent to only the lower thick sandy-based marl between Wheeler Bridge and Yankton, as originally correlated by Searight (1937) and as advocated in this report (figs. 1*A* and 2).

SYNTHESIS EXPLAINING COMPOSITIONAL FEATURES

The hypothesis that best explains compositional features of the marlstones and associated shales in the lower part of the Pierre seems to be as follows. Shallowing of the sea began during early Gregory time and caused increased circulation of oxygenated bottom waters terminating preservation of the abundant organic material such as that characteristic of the Sharon Springs Member. Shallowing was accompanied by a rise in water temperature, which, as explained by Crandell (1952) for the Crow Creek Member, caused a decrease in carbon dioxide content. This resulted in an increase in pH, a more favorable environment for preservation of calcite shells of marine organisms that at other times were resorbed by the sea water, and local development of calcareous shale and thin marl beds.

Shallow-water marine and even continental conditions also were prevalent in other parts of the Pierre basin during early Gregory time. *Baculites gregoryensis* and *Baculites scotti*, found in the lower and middle calcareous parts of the Gregory Member near Chamberlain, also occur in the middle and upper parts, respectively, of the Red Bird Silty Member of the Pierre on the southeast flank of the Black Hills (Gill and Cobban, 1962, p. B23). The Red Bird Silty Member, in turn, is a time equivalent of the Judith River Formation of Montana, the Parkman Sandstone Member of the Mesaverde Formation of Wyoming, and the Hygiene Sandstone Member of the Pierre Shale in Colorado. The Red Bird thus represents the maximum recognizable esastward extent of these partly nonmarine and partly nearshore marine tongues that extend in from the west margin of the basin. *Baculites gregoryensis* has also been found in marlstone beds in the Gregory Member of the Pierre Shale in eastern North Dakota (Gill and Cobban, 1965). Thus, the shallowing that produced the carbonate-rich rocks on the east margin of the basin in the Dakotas must have extended across the basin, but the east margin nevertheless was sufficiently far from the western sources that it did not receive coarse material from them. The east shore remained low-lying and still furnished no significant amount of material to the basin.

During the latter part of *Baculites scotti* time, transgression and deepening of the Pierre sea began anew (Gill and Cobban, 1965), and increasing amounts of volcanic material entered the basin from the west and spread fairly rapidly across the basin. In the Missouri River area, these two changes are reflected in the carbonate-free and montmorillonite-rich shale in the upper part of the Gregory Member (fig. 2, pl. 2).

The marlstone of the Crow Creek, unlike that of the Gregory, does not seem to be related to basinwide shallowing of the Pierre sea. No equivalent carbonate-rich or silty beds indicative of shallowing are known in the Black Hills area. No basal sandy unit such as characterizes the Crow Creek is found below any of the marlstone beds in eastern North Dakota. The shallowing that produced the Crow Creek Member must have been a local event caused by uplift in east-central South Dakota, as was suggested by Crandell (1952, p. 1764). Erosion of sandy materials from the nearby eastern uplifted area would account for the sandstone at the base of the Crow Creek, as contrasted with absence of sand in the Gregory marls which are related to regional shallowing. Further, water depths in east-central South Dakota must have been even shallower during early Crow Creek time than during early Gregory time, as judged from the disconformity produced by submarine erosion prior to Crow Creek deposition. However, submarine erosion was not great in most areas, because the upper bentonitic part of the Gregory seems to be essentially continuous from Chamberlain to Yankton (pl. 2). The maximum amount of submarine erosion that can be reasonably inferred is 10–15 feet near the Wheeler Bridge and Whetstone Creek localities (pls. 1, 2). Near Wheeler Bridge (pl. 1) the 10- to 20-foot thickness of Crow Creek may represent a channel filling, the channel having cut out all but a few feet of the soft bentonitic shale of the upper part of the Gregory (pl. 1, cols. *D* and *E*). Only a few miles away at the Whetstone Creek locality (pl. 2), which is apparently a channel flank area, at least 20 feet of soft shale in the upper part of the Gregory Member occurs below a much thinner Crow Creek marl. Part of the apparently contorted and jumbled bedding seen in the Gregory at Whetstone Creek could be the result of slumping on the side of the channel. The exceptional abundance of shale pebbles in the Crow Creek near Wheeler Bridge may also reflect considerable erosion in this area. Channel cutting through the upper part of the Gregory into the montmorillonite-poor shale below, in the vicinity of Wheeler Bridge, could account for the exceptionally low montmorillonite content of several Crow Creek samples taken here from the thickest part of the unit (table 1). Several shale pebbles taken at this locality are montmorillonite poor and are typical of the type of shale below the upper part of the Gregory.

Shale pebbles eroded from the sea bottom and rounded and polished phosphate nodules, eroded with the shale and rolled about the sea bottom by wave action or currents, were deposited in the basal part of the Crow Creek along with coarse sand, transported from the uplifted eastern area, and locally derived shell fragments. Calcite in the shell material that accumulated in the exceptionally shallow and warm waters would have contained exceptionally large amounts of magnesium (Chave, 1954)—possibly as much as 10–20 percent MgO. This magnesium, perhaps with magnesium diffusing from the sea water into the coarse and porous basal part of the Crow Creek sediment, seems to have converted some of the calcite to dolomite. As the waters deepened beyond wave base, movement and deposition of coarse particles ceased; and except for a small amount of dolomite still being formed, the fine carbonate mud deposited was indistinguishable from other marl muds that now compose beds in the lower part of the Pierre Shale.

The continued deepening and cooling of the sea water during sedimentation of most of the DeGrey and Verendrye Members generally prevented carbonate deposition. Near the eastern edge of the Pierre basin between Wheeler Bridge and Yankton, however, shallow-water conditions conducive to carbonate preservation persisted intermittently longer than they did elsewhere and resulted in deposition in the DeGrey and Verendrye Members of nonsandy and nondolomitic marls similar to those in the Gergory Member.

STRATIGRAPHIC NOMENCLATURE

The correlation of the Crow Creek Member along the Missouri River indicated in this report (figs. 1*A*, 2; pls. 1, 2) results in an anomalous situation in formal nomenclature. Of Searight's (1937) original Gregory Member at its type section at Wheeler Bridge (pl. 1, col. *D*), the lower part has been reassigned by both Searight (1938; in Moxon and others, 1939) and Gries and Rothrock (1941; pl. 1, col. *E*, of this report) to the Sharon Springs Member, and the upper part has been shown to be the same as the Crow Creek as named and defined at its type locality by Gries and Rothrock (1941). Thus, there appears to be no Gregory Member left at its type section. This apparently would call for a new name for the more than 100 feet of rocks in the Chamberlain area (pl. 1, cols. *B* and *C*), which has been called Gregory in many publications.

Strict application of the rule of priority would retain the name Gregory for the thick marlstone at its type locality (Searight, 1938), but would result in abandonment of the name Crow Creek (Gries and Rothrock, 1941), and would still require a change in application of the Gregory Member in the Chamberlain area. Several considerations indicate that priority should not be the decisive factor in this particular situation. Article 11*b* of the stratigraphic code (Am. Comm. Strat. Nomenclature, 1961) does provide for preservation of well-established names lacking priority. The name Crow Creek has been widely used since it was first proposed, whereas Searight's name Gregory zone of the Sully Member has not. Therefore, changing the name back to Gregory would cause much confusion in the literature.

If Searight's treatment of his "upper Gregory marl" is reapplied, the same probably should be done for his "lower Gregory." When Searight (1938; in Moxon and others, 1939) extended use of the name Sharon Springs from Kansas into South Dakota, he clearly intended to include the entire "lower Gregory" of the 1937 classification in his Sharon Springs Member—all of the approximately 150 feet of strata in the Chamberlain area now called Sharon Springs and Gregory Members (pl. 1). By so doing, Searight included nonbituminous shale, calcareous shale, marl, thin limestones, and bentonitic claystone—rock types different from the bituminous fish-scale shale typical of the Sharon Springs Member. Their inclusion seems inconsistent with the fact that lithologic similarity was one basis for extending use of the name Sharon Springs into South Dakota. This inconsistency seems to have been a major consideration in the redefinition of the Gregory Member by Gries and Rothrock (1941). A further consideration is that these rocks are not of the same age as the Sharon Springs elsewhere; the two baculites previously listed from the Gregory Member of Gries and Rothrock (pl. 1, col. *B*) in the Chamberlain area, *Baculites gregoryensis* and *Baculites scotti*, occur in the southern Black Hills in the Red Bird Silty Member of the Pierre Shale 1,264–1,765 feet above the Sharon Springs Member (Gill and Cobban, 1965).

The most useful course of action seems to be to again redefine the Gregory Member at its type locality to agree with the current nomenclature of the Chamberlain area (pl. 1, this report). Gries and Rothrock's (1941) thin shale unit at Wheeler Bridge, designated by them as the upper part of the Sharon Springs Member (pl. 1, col. *E*), does not seem to be the same as their "upper Sharon Springs" in the Chamberlain area (pl. 1, col. *B*). Near Chamberlain the shale in their "upper Sharon Springs" is composed of medium- to dark-gray bituminous shale that is not highly bentonitic. The unit at Wheeler was not seen for this study, but only 4 miles away, at Whetstone Creek (pl. 2), the shale below the Crow Creek is light olive gray, nonbituminous, and fairly bentonitic and contains some manganiferous nodules (pl. 2)—features that indicate equivalence with the upper part of the Gregory rather than with the upper part of the Sharon Springs of the Chamberlain area. The shale in this interval at Fort Randall Creek (pl. 2), except for the darker color in its lower part, is of a similar type. Proximity of Whetstone and Fort Randall Creeks to Wheeler Bridge suggests that at least the upper part of the current Gregory Member of the Chamberlain area must be partly equivalent to the 5-foot-thick shale unit at Wheeler Bridge designated by Searight (1937) as the upper part of the lower part of his original Gregory Member, a conclusion that Searight (1937, p. 20) implied. Therefore, the Gregory Member is herein redefined at Wheeler Bridge, the type locality of the member, to include rocks in the upper part of the "lower Gregory" of Searight (1937, p. 14, unit 40). At least a few feet of original Gregory Member is thereby retained at the type section, and a considerable thickness of the member is present in other parts of eastern Gregory County, from which the member takes its name (pl. 2). The name thus can be used for equivalent rocks such as those currently designated at Gregory in the Chamberlain area.

The name Crow Creek Member is retained for the sandy-based marl unit as defined at its type locality on Crow Creek north of Chamberlain and for all laterally equivalent units. Thus, in the area northwest of Wheeler Bridge (about which there are several publications), the current nomenclature is retained unchanged. Regarding the Yankton–Wheeler Bridge area of southeastern South Dakota where member designations must be shifted, published maps and reports are few, and the units involved are so thin that they generally have not been differentiated on the maps. Thus, the proposed redefinition of the Gregory Member will cause a minimum of change and confusion in the literature.

The extent of the Gregory Member southeast of Gregory County is problematical. In this area the Pierre Shale beneath the Crow Creek Member almost everywhere comprises two parts: an upper part composed of softer, highly montmorillonitic shale that is commonly a lighter gray at its top than at its bottom; and a lower part composed of fairly hard fissile shale containing fish scales and having a low to moderate montmorillonite content. The lower part generally is lithologically and mineralogically like the Sharon Springs, which it has been called in the past. The upper part is similar mineralogically and lithologically to the upper part of the Gregory Member of the Chamberlain area (fig. 2, pl. 2) and differs only by being darker gray in its lower part. The troublesome aspect of these two designations is that rocks equivalent to the montmorillonite-poor upper part of the Sharon Springs and the lower calcareous part of the Gregory of the Chamberlain area are absent and there is no indication of a depositional break, such as a disconformity or "trash"-nodule layer (fig. 2, pl. 2). Perhaps the Sharon Springs is younger southeastward from Platte Bridge, so that in the Yankton area the bituminous fish-scale shale is a lateral time equivalent of part of the Gregory of the Chamberlain area. This time equivalency would explain both the absence of a depositional break and the somewhat higher-than-normal montmorillonite content of some Sharon Springs samples from the Yankton area (fig. 2). Southeastward lateral gradation of Gregory into Sharon Springs could also explain some of their reciprocal thickness relations—thick Gregory and thin Sharon Springs at Platte Bridge (pl. 2); thin Gregory and thick Sharon Springs in the Wheeler Bridge–Fort Randall area. However, if such lateral gradation occurs, the "trash"-nodule layers of the two areas cannot be contemporaneous. The question also arises as to whether the bentonite beds at the top of the Sharon Springs at Tabor or Yankton (pl. 2) actually are equivalents of some of the numerous bentonites in the lower part of the Sharon Springs farther northwest, as they have generally been considered, or whether they are equivalent to some of the bentonites in the upper part of the Gregory. Regardless of its time equivalence, the montmorillonitic shale above the typical shale of the Sharon Springs southeast of Gregory County seems lithologically more closely related to the upper part of the Gregory Member than to the Sharon Springs, and it therefore is designated as Gregory (pl. 2).

The type section of the Gregory Member at Wheeler Bridge is now submerged at normal water level by Fort Randall Reservoir. Therefore, the section near the mouth of Landing Creek (pl. 2) is designated as a principal reference section for the Gregory Member; there the member is well exposed, is fairly thick, and is in Gregory County, from which the unit takes its name. In the area northwest of Gregory County, where the member attains its maximum thickness, the Chamberlain section (pl. 1, col. *C*) is a typical, complete, and reasonably well exposed reference locality. The Fort Randall Creek locality (pl. 2) is a well-exposed section that is apparently almost identical with the Wheeler Bridge type section, but the Gregory Member, as herein redefined, is very thin. A section almost identical with that along Fort Randall Creek and equally well exposed and on public land is that described by Kepferle (1959, pl. 50, sec. 25) in SW¼ sec. 13, T. 95 N., R. 65 W., Charles Mix County, about a mile below Fort Randall Dam on the east side of the Missouri River.

MEASURED SECTIONS

Landing Creek section. In and above a large slump scar southwest of the mouth of Landing Creek; NW¼ sec. 25, T. 100 N., R. 72 W., Gregory County, S. Dak. Principal reference section of the Gregory Member

[Section measured May 27, 1963, by L. G. Schultz; water level of Fort Randall Reservoir, 1,350 ft elev]

	Feet
Pierre Shale (part):	
DeGrey Member (bentonitic facies; part):	
12. Shale, medium-gray, noncalcareous; bentonitic with numerous thin bentonite beds and layers of black-weathering manganiferous nodules throughout; weathers to bare "frothy" slope strewn with nodule fragments	45.0
Pierre Shale (part)—Continued	
Crow Creek Member:	
11. Marlstone, yellowish-gray; top 0.3 ft stained brown; lower 0.5 ft conspicuously sandy and containing rare shale flakes; overlying 2 ft slightly sandy; forms vertical cliff at top of slump scar; light-colored layer elsewhere	9.8
Gregory Member:	
10. Shale, mostly medium-gray, light gray at top; noncalcareous, weathers slightly frothy, particularly in upper part; poorly exposed except in slump scar; numerous layers of tabular rusty siderite nodules 0.2 ft by 0.5 ft, manganiferous in the upper part; rare small phosphate nodules; bentonite beds 0.15 ft thick at 29.3 ft above base, 0.1 ft thick at 30.5 ft, 0.2 ft at 31.7 ft, and 0.03 ft thick at 48.7 ft	49.8
9. Marlstone, yellowish-gray; grades into shale above and below; forms light-colored layer	.4
8. Shale, medium-dark-gray, partly calcareous; jarosite on cracks of noncalcareous parts	5.0
7. Marlstone, similar to unit 9	.7
6. Shale, light-olive-gray, partly calcareous	2.5
5. Limestone, light-gray; in two layers separated by 0.3-ft shale parting; forms a conspicuous ledge; blocks of limestone litter slope below	2.1
Total Gregory Member	60.5
Sharon Springs Member (upper part):	
4. Shale, medium-dark-gray, soft, noncalcareous; abundant jarosite on fractures; slightly fissile, no fish scales; locally, top 1 ft is light-gray highly apatitic shale with white and yellow blebs of sulfate minerals	7.5
Sharon Springs Member (lower part; part):	
3. Phosphatic nodules, 0.2 ft by 0.5 ft, encrusted with gypsum in a yellow earthy matrix	.6
2. Shale, brownish-gray, fissile; abundant fish scales; jarosite and gypsum on bedding planes; 0.1-ft ashy bentonite layer 2 ft below top	8.0
Reservoir water level.	
Total Sharon Springs Member measured	16.1
Total Pierre Shale measured	131.4

[Kepferle's (1959, pl. 50, loc. 23) section of the Sharon Springs Member, measured 1 mile north of the mouth of Landing Creek before the reservoir was filled, shows, in ascending order above the Niobrara Formation: 36 ft of black shale equivalent to the lower part of the Sharon Springs and similar to unit 2; a zone of "ferruginous" nodules equivalent to phosphatic nodules in unit 3; 6 ft of gray shale equivalent to the upper part of the Sharon Springs and similar to unit 4; and a thin sandstone layer overlain by a marl bed at the base of the Gregory Member and equivalent to unit 5. No sandy layer could be found at the base of the Gregory Member during this study, however, either at Kepferle's section or at the principal reference section.]

Chamberlain section. In and above first big roadcut north of U. S. Highway 16 at the west end of highway bridge across the Missouri River at Chamberlain; NW¼NE¼ sec. 17, T. 104 N., R. 71 W., Lyman County, S. Dak.

[Section measured Aug. 7, 1957, by L. G. Schultz]

	Feet
Gravel, not measured.	
Pierre Shale (part):	
DeGrey Member (bentonitic facies; part):	
9. Shale, medium-gray, flaky; weathers to "frothy" gumbo surface; contains some black limy manganiferous concretions	18.0
Crow Creek Member:	
8. Marlstone, light-gray; weathers to smooth tan slope. Basal 1 ft is fine-grained ledge-forming slabby sandstone. Unit slumped, measurement inexact	5.0
Gregory Member:	
7. Shale, light-olive-gray; breaks into plates; weathers to deep tough gumbo surface; few scattered black-weathering concretions; a 0.1 ft bentonite bed dug out in lower part, others may be concealed	42.0
6. Shale, light-gray, mostly limy; hackly fracture; weathers to thin brownish-gray soil; three thin ferruginous marlstone zones in basal 3 ft, and 1-ft marlstone bed 14 ft above base; numerous rusty flat siderite concretions 13–18 ft above base; scattered pyrite nodules, some with red hematitic weathered surfaces, and some phosphatic nodules with pyrite cores; numerous pelecypod and baculite shell fragments, particularly in lower part of unit	39.0
5. Shale, medium-gray; noncalcareous except for transition zones at top and bottom; five zones of 0.2- by 0.5–1-ft rusty siderite concretions in top top 18 ft; few pyrite nodules on surface may be float from above	32.0
4. Shale and marlstone, interbedded. Two 0.8-ft marlstone beds at top and bottom, separated by 1.4 ft of dark shale; marlstones weather to light bands on outcrop; abundant fragments of *Inoceramus* in marl beds	3.0
Total Gregory Member	116.0
Sharon Springs Member (upper part):	
3. Shale, dark-gray; abundant yellow jarosite on cracks; well bedded, but not as fissile as unit below; bentonite beds 0.1 ft thick at 7.5 ft above base, 0.5 ft thick at 10 ft, and 0.05 ft thick at 11.5 ft; scattered oval 0.1- by 0.3-ft phosphatic nodules, some with pyrite cores	15.0
Sharon Springs Member (lower part):	
2. Shale, black, fissile; abundant fish scales, abundant jarosite; black sooty pyrite blebs 0.5 in. across in lower part; weathers to bare, black ridge; 0.3 ft bentonite bed 1 ft above base; top 0.1 ft composed of very hard shale with numerous bone fragments and sparse 0.1- by 0.2-ft gypsum-encrusted phosphatic nodules	8.5
Total Sharon Springs Members	23.5
Total Pierre Shale measured	162.5
Niobrara Formation (part):	
1. Chalk, medium-gray; weathers buff; 35 ft exposed above highway, and about 40 ft exposed between highway and Fort Randall Reservoir water level	75.0

Fort Randall Creek section. Cut bank on the south side of Fort Randall Creek, about 1 mile south of Fort Randall Dam in SW¼NE¼ sec. 19, T. 95 N., R. 65 W., Gregory County, S. Dak.

[Section measured June 18, 1959, by L. G. Schultz]

	Feet
Pierre Shale (part):	
DeGrey Member (bentonitic facies; part):	
8. Shale, medium-gray, bentonitic; bentonite beds 0.1–0.2 ft thick; some biotite at 1, 1.5, 10, 15, 17, 20.5, and 21.5 ft above base; light-brownish-gray calcareous shale bed 17–18 ft above base; scattered black-weathering manganiferous nodules enclosing *Inoceramus* shell fragments	28.0
Crow Creek Member:	
7. Marlstone, silty; forms buff ledge; basal 0.1 ft very sandy, contains shale pebbles, rusty patches	6.0
Gregory Member:	
6. Shale; light olive gray at top grading down to medium dark gray at bottom; bentonitic; 0.1-ft bentonite beds 2 and 4 ft above the base; scattered 0.1- by 0.2-ft gypsum-encrusted phosphatic nodules	6.0
Sharon Springs Member:	
5. Phosphatic nodules encrusted with gypsum; marks break in slope between soft light-colored shales without fish scales above and hard bituminous buttress-weathering shale with fish scales below	.2
4. Shale, medium-dark-gray, fissile; abundant fish scales; weathers to light-gray steep, buttresslike slope; 0.1-ft yellow bentonite beds at 1.5, 3.5, 18, and 32 ft above base	35.0
3. Bentonite and shale; 0.8-ft bentonite at top and 0.5-ft bentonite at bottom, both with thin shale partings, separated by 0.7 ft of shale similar to that of unit 4	2.0
2. Shale, very fissile; black with abundant yellow jarosite on cracks; abundant fish scales and bones; two thin bentonite beds near base; lower 0.1 ft very rusty	3.5
Total Sharon Springs Member	40.7
Total Pierre Shale measured	80.7
Niobrara Formation (part):	
1. Chalk, buff, to creek level	13.0

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