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THE PHOSPHORIA FORMATION OF THE
NORTHEASTERN BIG HORN BASIN, WYOMING

BY

WILLIAM A. BEATTY

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, GEOLOGY MAJOR

Rolla, Missouri

1957

Approved by - A.C. Spreng
Associate Professor of Geology

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INTRODUCTION

Purpose and Scope. -- The Phosphoria formation of the northern Rocky Mountains of the United States has received considerable attention from geologists because of its important reserves of phosphate and petroleum. In the Big Horn Basin of Wyoming, however, still more work is needed to compile the information necessary for a complete understanding of the facies changes exhibited by this formation.

The purpose of this paper is two-fold: first, to present a description of the lithology and the paleontology of the Phosphoria formation in the northeastern part of the Big Horn Basin, and secondly to show the stratigraphic relationship of the facies present in the outcrop sections to each other and to those in adjacent area. The author hopes this study will aid in the understanding of the complex Permo-Triassic problems existing in this region.

Procedure of Study. -- During the summer of 1956, a general survey of the thesis area was made after which ten outcrops were selected to be studied in detail. The lithologic units of these exposures were described in detail and sampled. The thicknesses were measured by the author and his field assistant with a 100 foot tape and a hand level. After returning to the campus of the Missouri School of Mines and Metallurgy, the samples were examined under the binocular microscope for their major mineral constituents, and tested for the presence of phosphate.

The phosphate test used was devised by Oakes (1938, pp. 456-457). Thin sections were prepared from selected samples for petrographic study. The literature applicable to the problem was reviewed. The information thus obtained was incorporated into this paper during the scholastic year of 1956-1957.

Acknowledgements. -- The author wishes to express his appreciation to Professor A. C. Spreng who acted as adviser on the thesis and also supervised the field and laboratory work. The Sinclair Oil and Gas Company supplied well samples, well records, maps, transportation and aided financially by employing the author during the period of field work. The following personnel of the Casper, Wyoming Division Office contributed recommendations; G. J. Gudim, T. Ross, L. Johnson and C. Tenny. Charles Wood, also of the Sinclair Oil and Gas Company, assisted the author with the field work. Professors O. R. Grawe, D. I. Frizzell and G. C. Amstutz aided in the lithologic, paleontologic, and photographic parts of the study respectively.

GEOGRAPHY

Location. -- The area under discussion is located in Big Horn County, Wyoming, encompassing approximately 600 square miles of the northeastern Big Horn Basin. It is bounded on the south by U. S. Highway 14, on the west by U. S. Highway 310, on the north by Wyoming Highway 14 and on the east by the west flank of the Big Horn Mountains. Fig. 1 is a location map showing the exact location of the thesis area.

Culture. -- Except for minor unpaved roads built by oil and mining companies the only major routes of communication are those mentioned previously which circumscribe the area. Accessibility to outcrops along the flanks of the Big Horn Mountains is possible only in a four-wheel drive vehicle, on horseback or on foot.

Three towns are situated within the area and are located along the outer boundary. They are Lovell, Greybull and Shell. The largest is Lovell with a population of approximately 2,508. The population of the area is centered primarily in towns although a portion resides on nearby ranches.

The arid climate restricts the cultivation to strips along the streams. The major agricultural products are sugar beets and vegetables. Both cattle and sheep ranches are common throughout the area. Sheep herders graze their flocks on the upper slopes of the Big Horn Mountains during the summer months and return each fall to valleys for the long cold winters. The cattle herds remain in the lowland country all year long. The cowboy represents an important phase of Wyoming life. In fact, his silhouette adorns their automobile license plates as the state symbol. The oil companies and the Magcobar Company provide a source of employment in the Greybull area. The latter is one of the

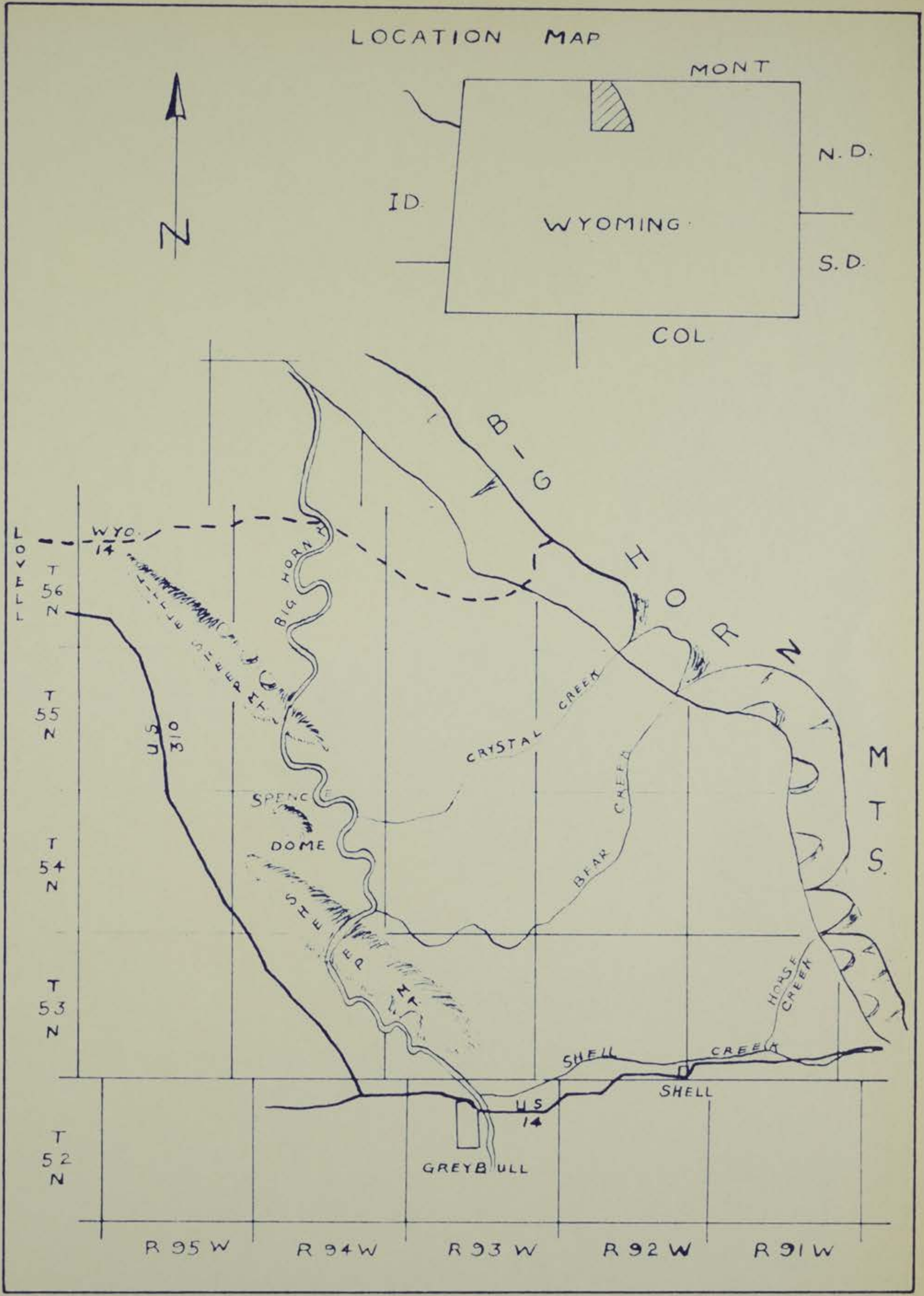

LOCATION MAP
MONT
N.D.
ID.
WYOMING
S.D.
COL
N
LOVELL
WYO. 14
T 56 N
T 55 N
T 54 N
T 53 N
T 52 N
U.S. 310
BIG HORN R.
LITTLE SHEEP MT.
SPENCE DOME
SHEEP MT.
CRYSTAL CREEK
BEAR CREEK
BIG HORN MTS.
HORSE CREEK
SHELL CREEK
SHELL
U.S. 14
GREYBULL
R 95 W
R 94 W
R 93 W
R 92 W
R 91 W

FIG. 1

country's largest producers of bentonite clay for use in drilling muds. Another important source of income for the residents of this region is derived from the tourist trade. Both U. S. Highway 14 and Wyoming Highway are popular routes for tourists traveling from the central and eastern U. S. to Yellowstone National Park and other scenic areas in the northwestern part of this country during the summer months.

PHYSIOGRAPHY

Regional Setting. -- The Big Horn Basin is situated in the northeastern portion of the Middle Rocky Mountain Physiographic Province (Fenneman, 1931, p. 166). This basin is an elliptical shaped depression open to the north, but is bounded on the east by the Big Horn Mountains, on the south by the Owl Creek, Bridger, and Shoshone Mountains, and on the west by the Absaroka Mountains. Structurally it is a northwest - southeast trending syncline approximately 150 miles long and 100 miles wide. Subordinate anticlinal and synclinal structures within the basin parallel the major synclinal axis. The strata present range from Cambrain to Tertiary in age.

The thesis area comprises the northeastern portion of the Big Horn Basin. The oldest formation exposed within this area is the Madison Limestone (Mississippian), while the youngest is the Cody Shale (Upper Cretaceous).

Topography and Drainage. -- The most prominent topographic feature of the area is the Big Horn Mountains, an outlying part of the Middle Rocky Mountains, which rise approximately 1500 feet above the basin to an average elevation of 9,000 feet. The highest point is appropriately called Cloud Peak, which has an elevation of 13,163 feet. The Big Horn Mountains consist of Paleozoic and Mesozoic rocks lying on a granitic core folded to form a monocline, the west limb of which is the Big Horn Basin. The Madison Limestone (Mississippian) forms the dip slope of the west flank of the mountains. Steep sided "V" shaped valleys break this linear structure with steeply dipping flatirons of Tensleep sandstone (Pennsylvanian) and Phosphoria formation (Permian) lining the basin wall. Plate 1 shows the west flank of the Big Horn Mountains and the flatiron structures. In the region north of Shell Creek Canyon, the west flank of the Big Horn Mountains slopes steeply (60°) to the west, while just to the south the average slope is moderate (20°). This reflects the effect of underlying structure on the topography as the slopes parallel the dip of the underlying beds, illustrating the more intense folding which took place north of the canyon. Faults are prevalent throughout the basin area.

The Big Horn Basin possesses the characters of a region in the mature stage of erosional development. Erosion has accented the structure of the region by removing the softer material producing cuestas from the more resistant rock. Sheep and Little Sheep Mountains are the only major topographical features within the basin. Both are asymmetrical, doubly plunging anticlines with a maximum relief of approximately 400 feet.

The primary drainage of the region is the Big Horn River which flows into the Yellowstone River in Montana and ultimately into the Missouri River. The Big Horn River enters the Big Horn Basin through a canyon 2,350 feet deep in the Owl Creek Mountains and leaves via a 2,000 feet deep canyon in the northern tip of the Big Horn Mountains in Montana. As this river crosses both ranges, it can be inferred that it is a superimposed stream developed on an erosion surface which was initially higher than the ranges now present. Two major tributaries, the Greybull and Shoshone Rivers, drain the western half of the basin and join the Big Horn River at Greybull and Lovell, respectively. The eastern part is drained by streams which originate on the flanks of the Big Horn Mountains and flow west to join the Big Horn. Shell Creek, Horse Creek and Crystal Creek are examples in the latter drainage area. Many of these small streams are intermittent due to the low rainfall.

The major streams form a dendritic drainage pattern.

HISTORY OF THE TERM "PHOSPHORIA"

The Permian strata of the Big Horn Basin area of Wyoming were first described and napped as a separate unit by Darton (1906). He recognized that the limestone, shale, and phosphate rocks along the northern flanks of the Owl Creek Mountains were distinct from the overlying red Chugwater formation (Triassic) and the underlying Tensleep sandstone (Pennsylvanian). To this interval he gave the name Embar formation.

Blackwelder (1911) later subdivided the Embar formation of Darton into two parts. For the upper portion which is composed of greenish gray shales, thin bedded sandstones, and light gray dolomites, he proposed the name Dinwoody formation. He considered the Dinwoody formation to be lower Triassic in age and equivalent to the Woodside shale of southeastern Idaho. He later (1918) correlated the dolomites, phosphate beds, and shale sequence which comprise the lower portion of the Embar with the Park City formation (Permain) of Utah. Boutwell (1907) named the latter formation for the Park City mining district in Utah. He considered it to be Pennsylvanian in age because of the presence of <u>Bellerophon</u> and <u>Orbiculoidea</u>.

Subsequently, in 1912, Richards and Mansfield suggested the name Phosphoria be applied to the upper phosphate beds of the Park City formation in northeastern Utah. Since that time, the name Phosphoria formation has been used by geologists for the Permain strata of Wyoming along with the term Embar.

Since the Dinwoody formation and the Phosphoria formation are considered to belong to different systems, Thomas (1934) proposed that these names should replace the term Embar. Thus, the term Embar was discarded by the U. S. Geological Survey as obsolete, (Wilmarth, 1938). At present, however, this term is still in current usage in both the oil industry and the U. S. Geological Survey as exemplified by Richards (1955) and Pierce (1948).

The usage of several terms for the same strata coupled with a lack of complete understanding of the Permo-Triassic relationships has resulted in a rather confusing nomenclature. The author is of the opinion the strata under discussion should be named the Embar Group. The subsequent division, Phosphoria, Park City, Freezeout tongue and other local names would still be valid in their respective areas. The employment of such a nomenclature is very applicable to the thesis area for several reasons. First, the term Phosphoria implies a lithologic type which is not present in the eastern Big Horn Basin. Likewise, the name, Park City, carries the connotation of a particular lithologic sequence which is not duplicated here. Secondly, the Phosphoria formation is comprised of carbonate, evaporite,detrital, and chert units some of which are named, while others are not. The basal Permian of this area is the Opeche formation which is a separate unit and not a tongue of the Chugwater formation as are the other red clastic units. Lastly, the reader must be aware that if the Dinwoody formation is to be included, as it has commonly been, then a systemic boundary will be crossed. This formation is not present in the thesis area, unless the gypsum and siltstone beds which overlay the Ervay tongue are considered to be equivalent to it. McCue (1953) was of the opinion that such was the case in the southeastern part of the Big Horn Basin. Before any single name can be applied to the Permo-Triassic interval of the northeastern Big Horn Basin, the above requirements must be considered. The term then must include all the units present.

Because of the specific lithology present, a new formational name might well be applied to the Permo-Triassic units of this area, however, for the sake of simplicity and in view of the regional stratigraphy involved, this interval will be referred to us the Phosphoria formation in this paper. Fig. 2 illustrates the evolution of the Phosphoria formation nomenclature.

EVOLUTION OF PHOSPHORIA FORMATION NOMENCLATURE

<table>
<tr><th colspan="2">UTAH & SOUTHEASTERN IDAHO</th><th colspan="5">WIND RIVER & OWL CREEK MOUNTAINS, WYOMING</th></tr>
<tr><th>BOUTWELL 1907</th><th>RICHARDS & MANSFIELD 1912</th><th>DARTON 1908</th><th>BLACKWELDER 1918</th><th>CONDIT 1924</th><th>THOMAS 1934</th><th>McKELVEY 1956</th></tr>
<tr><td></td><td></td><td rowspan="2">EMBAR</td><td>DINWOODY</td><td colspan="2">DINWOODY</td><td>DINWOODY</td></tr>
<tr><td rowspan="2">PARK CITY</td><td>PHOSPHORIA</td><td>PARK CITY</td><td colspan="2">PHOSPHORIA</td><td>PHOSPHORIA</td></tr>
<tr><td>PARK CITY</td><td colspan="5"></td></tr>
</table>

FIG. 2

STRATIGRAPHY

Phosphoria Formation. -- The Phosphoria formation in the Big Horn Basin is a unit of considerable lithologic variation. Carbonate members extend as tongues from the west to interfinger with shallow water clastic tongues projecting from the east. Thomas, in 1934, was the first to differentiate the Upper Permian strata of the southern Big Horn Basin and to visualize this relationship. Fig. 6 illustrates this intertonguing relationship. The age of the carbonates has been established as Permian; however, the clastic red bed members are considered to be tongues of the lower portion of the Chugwater formation (Permo-Triassic). The evidence for the ages of these strata will be reviewed in a following section of this paper.

The following is a brief discussion of the members comprising the stratigraphic sequence of the Phosphoria formation in the southern Big Horn Basin from oldest to youngest. A table of the stratigraphic nomenclature of Wyoming and South Dakota showing the formational names used in this discussion is given in Fig. 3.

The oldest and most recently recognized member of the Phosphoria formation is the Nowood tongue. McCue (1953) described this tongue from outcrops in the southern portion of the Big Horn Basin. It is a light to grayish orange limestone and dolomite which is locally sandy and clayey and also contains a considerable amount of nodular chert. This member lies unconformably on the Tensleep formation. The upper boundary has received post depositional erosion which McCue (1953) and Tourtelot (1952) think represents a major unconformity between the Nowood tongue of the Phosphoria formation and the overlying Opeche formation.

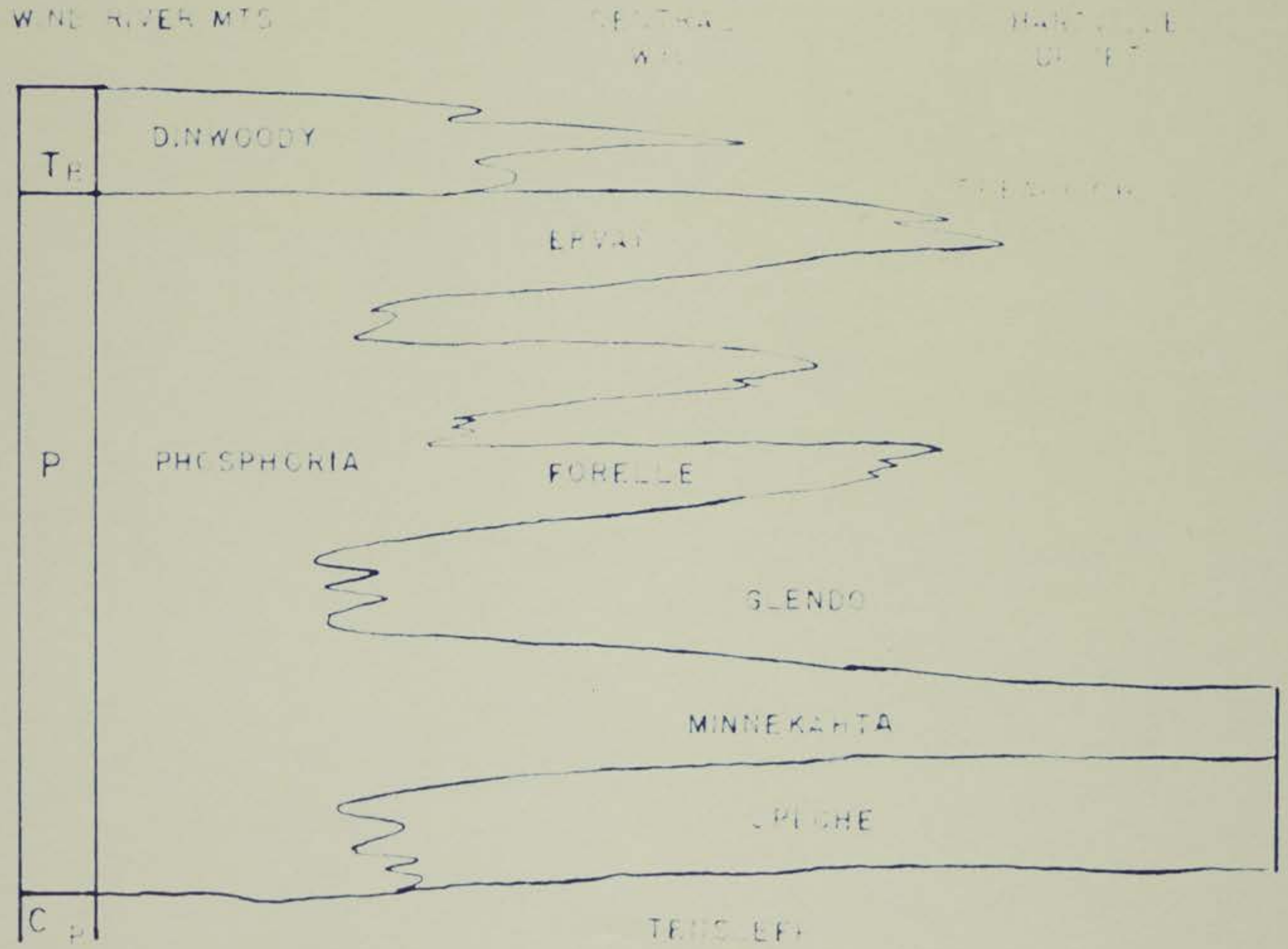
STRATIGRAPHIC NOMENCLATURE CHART

<table>
<tr><td rowspan="2"></td><td colspan="4">WYOMING</td><td rowspan="2">SOUTH DAKOTA
BLACK HILLS</td></tr>
<tr><td colspan="2">BIG HORN BASIN</td><td colspan="2">WIND RIVER BASIN</td></tr>
<tr><td rowspan="3">TRIASSIC</td><td colspan="2" rowspan="3">CHUGWATER</td><td rowspan="3">CHUGWATER</td><td>POPO AGIE</td><td rowspan="3">SPEARFISH</td></tr>
<tr><td>ALCOVA</td></tr>
<tr><td>RED PEAK</td></tr>
<tr><td rowspan="2">PERMIAN</td><td rowspan="2">EMBAR</td><td rowspan="2">PHOSPHORIA</td><td rowspan="2">EMBAR</td><td>DINWOODY</td><td>MINNEKAHTA</td></tr>
<tr><td>PHOSPHORIA</td><td>OPECHE</td></tr>
<tr><td>PENNSYLVANIAN</td><td colspan="2">TENSLEEP</td><td colspan="2">TENSLEEP</td><td>MINNELUSA</td></tr>
</table>

FIG. 3

PHOSPHORIA FORMATION FACIES DIAGRAM

AFTER THOMAS (1949) p 20



In the Black Hills, the Permain is comparatively thin and is represented by two lithologic units; a red bed sequence, the Opeche formation (Darton, 1901) and the youngest carbonate member of the Phosphoria formation, the Minnekahta tongue. The Opeche formation overlies the Minnelusa sandstone (Pennsylvanian) and is composed of red to dark purplish shales and sandy shales. The average thickness is 90 to 100 feet. This formation may be an eastward extension of the lower part of the Spearfish formation (Permo-Triassic) of South Dakota, but at present it is considered to be a separate unit. If the former is true, then the Opeche is, of course, a tongue of the Spearfish and should be redesignated as such. The Minnekahta tongue of the Phosphoria formation was also first described by Darton (1901) in the Black Hills. This unit is a thin (50 feet), homogeneous, light purple limestone which forms an escarpment over the less resistant Opeche formation in many localities. Not recognizing this unit in central Wyoming, Thomas (1934) named it the Sybille tongue of the Phosphoria formation. This latter name is not valid and, although originally recognized by the U. S. Geological Survey, is no longer in use.

While working in southern Wyoming, in 1908, Darton found the lower Phosphoria to be composed of 223 feet of red shales containing interbeds of gypsum. To this unit he gave the name Satanka Shale, at the same time suggesting that it might possibly be the basal portion of the Chugwater formation. Later, Thomas in 1934, verified this and renamed it the Satanka shale tongue of the Chugwater formation. If the Minnekahta tongue is present in an area, the red bed interval between it and the overlying carbonate members is called the Glendo tongue of the Phosphoria formation as named by Condra, Reed and Scherer (1940, p. 40).

The next youngest tongue of the Phosphoria formation is the Forelle tongue. It was originally described and designated a formation by Darton in 1908, and redesignated as a tongue of the Phosphoria in 1934 by Thomas. Lithologically it is a gray, thick bedded limestone with a thickness of 4 to 20 feet.

Overlying the Forelle limestone tongue in Wyoming from the Laramie Basin to the Freezeout Mountains is a 110 feet thick sequence of red shales which contain lenticular beds of gypsum, limestone, and breccia. Thomas (1934) called this unit the Freezeout tongue of the Chugwater formation. It occupies the interval between the top of the Forelle tongue of the Phosphoria formation and the bottom of the Little Medicine tongue of the Dinwoody formation (Triassic): thus by definition the Freezeout tongue is restricted to localities where the [illegible] can be positively identified.

In the Wind [illegible]

[illegible]

youngest tongue of the Phosphoria formation designated the Ervay tongue by Thomas (1934). It is a thin unit (16 feet thick) composed of sandy limestone containing chert beds and calcite geodes.

If the above nomemclature is used and both upper carbonate members of the Phosphoria formation are present, the red shale interval between the Ervay and Forelle tongues is left without a name. In the eastern Big Horn Basin, this situation does occur and is complicated by the presence of well developed chert and carbonate tongues of the Phosphoria in the center of the red beds.

In summary, the Phosphoria formation thins eastward and consists of three or four carbonate tongues which interfinger with the red clastic tongues of the Chugwater formation which thickens toward the east. The basal Permain is represented by the Nowood member of the Phosphoria formation.

Phosphoria Formation Exposures in the Thesis Area. -- The ten outcrops studied in detail are located along the perimeter of the area under discussion, as shown in the Outcrop Location Map, Fig. 4. The first to be examined are located at the water gaps in Sheep and Little Sheep Mountain cut by the Big Horn River. Since the eastern flanks of these exposures are more readily accessible, they were chosen for study. Here the Phosphoria formation forms the dip slope on both limbs of the anticlinal structures and is well exposed, although the upper boundary has been eroded away. Plates 2 and 3 show the eastern limb of the Little Sheep Mountain anticline.

Another section was measured three miles north of the Big Horn River cut in Little Sheep Mountain, where the Permain is exposed in a series of flatirons along the eastern flank. Erosion has produced a linear breach in the anticline which exposes the Phosphoria and Tensleep formations.

Situated between the above structures is another smaller doubly plunging anticline named Spence Dome. The upper Phosphoria formation and the Phosphoria - Chugwater contact are well exposed at this location. Plates 4 and 5 show the upper units of the Phosphoria formation, but not the contact.

The last outcrop studied in the western part of the thesis area is a flatiron of Phosphoria located on the western tip of the southern nose of Sheep Mountain. This excellent exposure illustrated in Plate 6 will be employed as a reference section in this paper.

Two sections were studied in detail near Shell, Wyoming. Both are located west of Shell close to the flanks of the Big Horn Mountains. One is one-half mile north of U. S. Highway 14 near the mouth of Shell Creek Canyon. The other is situated approximately two miles south of Shell, just south of what is locally called Black Mountain road. Here the

OUTCROP LOCATION MAP

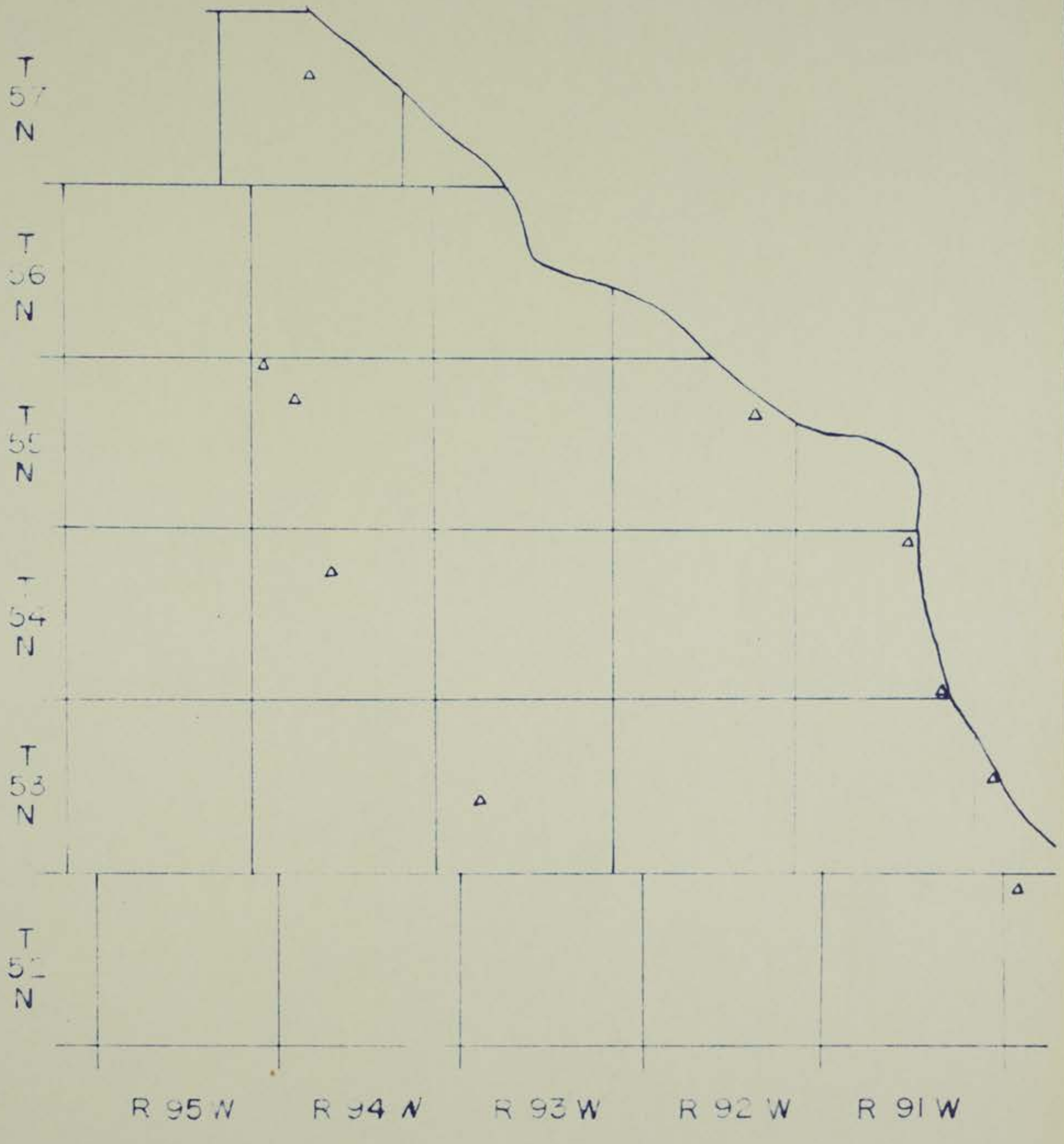


FIG. 4

flanks of the Big Horn Mountains have a moderate slope and dip in comparison to those north of Shell Creek Canyon.

The remaining outcrops are located along the western flank of the Big Horn Mountains between Shell and Lovell. The Phosphoria occurs here as steeply dipping flatirons and good exposures are difficult to find. Sections were measured where Horse, Beaver, and Bear Creeks egress from the mountain flank. Additional ouctrops of the Phosphoria were studied at Cottonwood Canyon, along Wyoming Highway 14 approximately 24 miles from Lovell, and the last outcrop was located in a canyon cut in the northern tip of the Big Horn Mountains. Plate 8 shows the Beaver Creek outcrop. An outcrop location map is shown in Fig. 4.

Reference Section. -- For the sake of convenience, the detailed outcrop sections will be discussed by lithologic units in a stratigraphic sequence from oldest to youngest in a geographical order beginning with the southern Sheep Mountain exposure. This outcrop is located on the western slope of the southern nose of Sheep Mountain anticline approximately three miles north of Greybull. Along this slope are a series of flatirons composed of the Phosphoria formation which have been left standing while other adjacent parts of the slope were eroded away. The The upper part is exposed further south along the anticline where the Phosphoria dips under the Chugwater.

Although this section is not the thickest, it was chosen as a standard with which to compare other outcrops as it most nearly examplifies the typical lithology of the Phosphoria formation. Because of the extreme variation it is impossible to select any single outcrop which possesses all the lithologic units, however, this section is a median between two general types of lithologic sequences which exist in the area.

Unit No. 1, the oldest unit present overlies the Tensleep sandstone (Pennsylvanian). In the reference section, this unit consists of 55 feet of massive sandstone, red in color except the lower 10 feet which are green in color. Quartz grains comprise 95 per cent of the rock. The remainder is calcium carbonate cement. The size distribution of the quartz particles is as follows: 15 per cent coarse sand, 70 per cent very fine sand, and 15 per cent coarse silt. The coarse sand size particles possess high sphericity and moderate roundness, while the smaller detritals exhibit moderate sphericity and low roundness. The calcium carbonate cements the grains which are covered with a ferruginous coating that imparts a red color to the entire rock.

This unit is differentiated from the underlying Tensleep sandstone by its red color, smaller detrital size, and an unconformity which separates the two.

The only good exposure of the Phosphoria - Tensleep contact is located at the north Shell outcrop. Directly overlying the Tensleep formation are four thin beds. The lowest is a sandy, gray-green very finely crystalline dolomite six inches thick. Above this bed are two and one half feet of massive gray siltstone. Overlying this siltstone is a six inch bed of sandstone identical with the Tensleep sandstone. The top bed is composed of gray massive siltstone.

Unit No. 1 is found to occur along the southern and western margins of the thesis area. It is present in the Sheep and Little Sheep Mountain and Shell outcrops except where concealed at the Sheep Mountain Cut and at Spence Dome.

North of the reference section at Little Sheep Mountain the detrital size decreases to silt and clay, the former being dominant. At the Big Horn River Cut where the Phosphoria is sharply folded, the red siltstones become nodular and grade laterally into mustard colored nodular shales and siltstones. Several very finely crystalline limestone interbeds are present near the top. At the outcrop north of Shell, only nodular siltstones are present. Gypsum in the form of satin spar fills the fractures in the upper twelve feet of this unit, south of Shell, the unit is represented by sandstone as at the reference section.

Although primarily a clastic unit, Unit No. 1 has one important carbonate subunit, which might be considered a separate unit. It occurs only in the vicinity of Shell, Wyoming. South of Shell, it consists of two feet of very light gray, very finely crystalline dolomite 30 per cent of which is made up of coarse silt size quartz grains overlain by three feet of light purple, very finely crystalline dolomite. It is very thin bedded, one half to one inch thick beds. In the section north of Shell, this subunit is two feet and six inches thick and is composed of only the silty dolomite.

The basal unit of the Permo-Triassic interval in the area under discussion is an extension of the Glendo tongue of the Chugwater formation. This tongue is believed to be the Glendo equivalent as it is composed of a lithology corresponding to that found in the south-eastern part of the Big Horn Basin as described by McCue (1953). It is overlain by a carbonate bed which resembles the Forelle tongue of the Phosphoria formation. The subunit no. 1A is considered to be a northern tip of the Minnekahta tongue. Where this latter unit is present, the detrital material underlying this bed would be the upper part of the Opeche formation.

The Glendo tongue of the Chugwater formation, the Minnekahta tongue of the Phosphoria formation, and the Opeche formation are absent in the western and northern parts of the thesis area due to off lap of the Permain seas.

Overlying the clastic unit no. 1 is a thin carbonate stratum which grades laterally into an evaporite and will be referred to as unit no. 2. It outcrops in the area near Shell and along Little Sheep Mountain in addition to the reference section. The lower Phosphoria formation is not sufficiently exposed on Sheep Mountain and Spence Dome to determine its presence. Lithologically this unit is a light gray, very finely crystalline, porous dolomite which is stained a light pink in the reference outcrop. The bedding is massive, but it weathers into thin beds. At the Little Sheep Mountain cut the porosity has decreased greatly. The fresh color here is still a light gray, but changes to a light brown northward along the anticline. It is also gypsiferous with gypsum filling the fractures.

At the section north of Shell, the unit has thinned to two feet of grayish purple, laminated dolomite sandwiched between two massive beds of white, powdery gypsum. South of Shell this unit is represented by approximately fourteen feet of gypsum.

Unit No. 2 is believed to be the eastern and northern extension of the Forelle tongue of the Phosphoria formation. This unit is well developed in the western part of the thesis area, but thins toward the western flanks of the Big Horn Mountains and where it changes lithologic character.

The thick interval which overlies the Forelle tongue basically consists of three distinct parts, a carbonate and chert stratum between sequences of gypsum and siltstone. Together these beds comprise the unnamed interval between the Forelle and the Ervay tongues of the Phosphoria formation.

The lower portion of this interval, that below the carbonate and chert beds is designated unit no. 3. At the reference section, it is composed of 38 feet of massive siltstone in which are present several thin, light gray dolomite interbeds. The upper ten feet are green in color while the remainder is dark red. East of the reference outcrop, this unit consists of approximately 40 to 53 feet of red siltstone with veinlets of gypsum filling the fractures. In the Little Sheep Mountain cut this unit is represented by 27 feet of white, powdery, massive gypsum. Along the flanks of the Big Horn Mountains unit no. 3 was found only in the Lovell outcrop where it is a gypsum bed. Since this unit is not very resistant, it is generally concealed by its own talus and debris from younger units.

The overlying two units could be considered as one; however, the lithologic differences suggest a separation. Unit no. 4 is a dolomite and a persistent ridge former and can be traced from the southeastern to the northeastern part of the Big Horn Basin, (McCue, 1938, p. 19). In the latter part of the basin, it occurs in all the sections in which the central portion of the Phosphoria is exposed except in the Lovell section. Lithologically this unit is a light gray, finely crystalline, clayey dolomite which is slightly porous in the reference section. Throughout the region the thin bedding is characteristic as are the other properties except for the fresh color which often varies to shades of gray and brown. The thickness is also uniform, with an average of ten feet.

Overlying this carbonate, but a part of the same ledge forming sequence is the bed of blue-black nodular chert. This chert forms a separate distinct bed in the reference outcrop and all other outcrops except in the Shell area where it appears to be interbedded with the upper part of unit no. 4. The thickness decreases toward the north and east from three feet at the southern tip of Sheep Mountain to less than three inches along the eastern edge of the basin.

Above this ledge former is unit no. 6 which is similar to unit no. 3. It consists of approximately fifteen to forty-five feet of red, calcareous, massive to nodular shale and white, powdery gypsum. Gypsum veinlets are common in the shale. The only well developed gypsum beds occur along the southern border of the thesis area. Like the underlying units, no. 6 has a generally uniform thickness. The average is 30 feet.

As previously mentioned, units 3, 4, 5 and 6 comprise an unnamed interval. The name Freezeout tongue of the Chugwater formation has not been employed for this interval because of the presence of the overlying Ervay tongue of the Phosphoria formation.

In the thesis area, the Ervay tongue is composed of three carbonate units separated by a chert bed and a shale sequence. Not all of these units are present throughout the area.

The oldest unit of this tongue is a dense, light gray dolomite. This dolomite, unit no. 7, was found to occur in the Sheep Mountain and Shell outcrops. The thickness increases toward the east from three to nine feet. The porosity of this ledge former varies from low to high.

As unit no. 8 is the shale interval between unit no. 7 and the upper portion of the Ervay tongue, it can be distinguished as a separate unit only where no. 7 is present. Unit no. 8 consists of a greenish gray, massive, calcareous siltstone in the reference section, but is predominately red in all other outcrops. The thickness varies from five to ten feet.

The upper and more massive portion of the Ervay tongue is comprised by units no. 9 and 11 in the reference section, but in some localities a thin chert bed, unit no. 10, separates the two.

Unit no. 9 is a light gray, massive, finely crystalline dolomite. The pores of this dolomite are not filled with asphalt as are those in the other carbonate beds of this member. In the southern part of the thesis area, blue-black chert occurs as very thin beds or small nodules in the upper portion. This chert is considered to be a distinct unit no. 10 in most localities. Although absent along the flanks of the Big Horn Mountains it is well developed at Spence Dome and Little Sheep Mountain. When present it occurs approximately ten feet below the top of the Ervay tongue.

The next unit, no. 11, is the youngest carbonate member of the Phosphoria formation. It is one of the most resistant stratum of the formation and is a persistent ledge former. The dip slopes of Sheep and Little Sheep Mountain anticlines are formed by this carbonate. The series of flatirons along the flanks of the Big Horn Mountains are capped by this unit of the Phosphoria formation.

Unit no. 11 is also the only fossiliferous unit of the formation in this area. Fossils were found only in the upper six feet of dolomite in the Sheep and Little Sheep Mountain outcrops.

In outcrop section, this unit appears as a light gray to light brown dolomite which weathers medium gray with a rough potmarked surface. It is composed of brecciated dolomite and oolites which range in size from one fifteenth to two millimeters in diameter. The average is approximately one fourth of a millimeter. The centers of the oolites are angular fragments of dolomite. The number of concentric rings is generally few, the average being three with a maximum of six. The oolites have an ellipsoidal shape with the length of the long axis usually one and one-half times the short axis. Particles over one millimeter are multi-nuclear. Plates 10 and 11 are microphotographs of two oolitic samples. The oolites are cemented with dolomite, but the interstitial pore space is filled with very finely crystalline calcite. In many samples asphaltic material stains the dolomite brown or black. All samples of this unit were found to yield a positive reaction to the phosphate test, although the intensity varied.

The thickness of this unit varies from an average of five feet along the western margin of the thesis area and near Shell to over 40 feet along the flanks of the Big Horn Mountains.

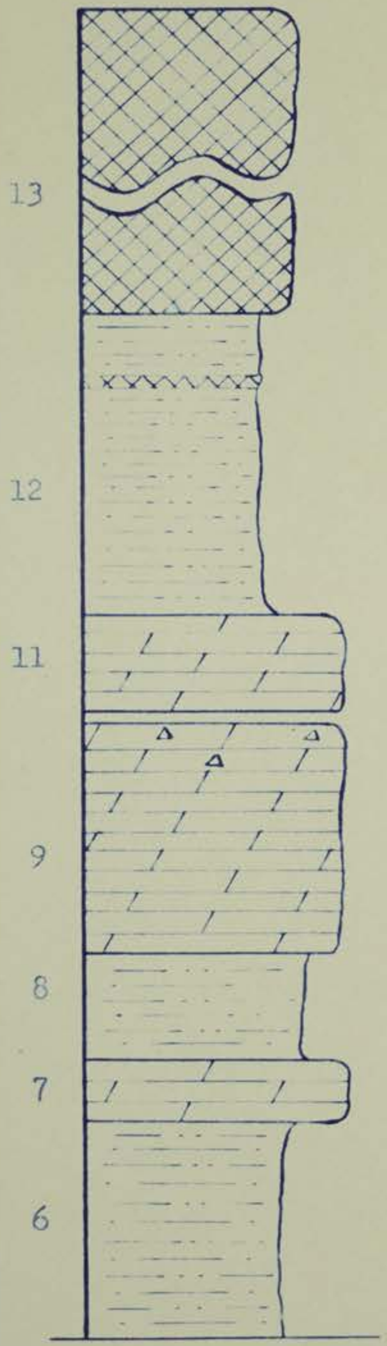
Overlying the carbonate portion of the Ervay tongue are two more units which may be considered as a part of the Phosphoria formation or as a tongue of the Chugwater formation. The first of these units, No. 12, is a nodular gray-green siltstone with satin spar filling the fractures to produce a network of white veinlets. The nodules range in size from one to eight inches in diameter. The gypsum veinlets are from one half to two inches thick and exhibit a well developed fibrous structure. This unit is found only at Spence Dome and at the reference section. The thicknesses of these two outcrops are 25 and 27 feet respectively. Plate No. 4 illustrates this and the overlying unit no. 13.

Unit no. 13 is the uppermost and youngest unit. It is a white, finely granular, massive gypsum bed. The measured thickness is 20 feet; however, the total original thickness may have been greater but has been reduced by erosion. This gypsum bed occurs along the flanks of Sheep and Little Sheep Mountains, at Spence Dome and at the two localities near Shell. The maximum thickness of 40 feet was recorded at Shell.

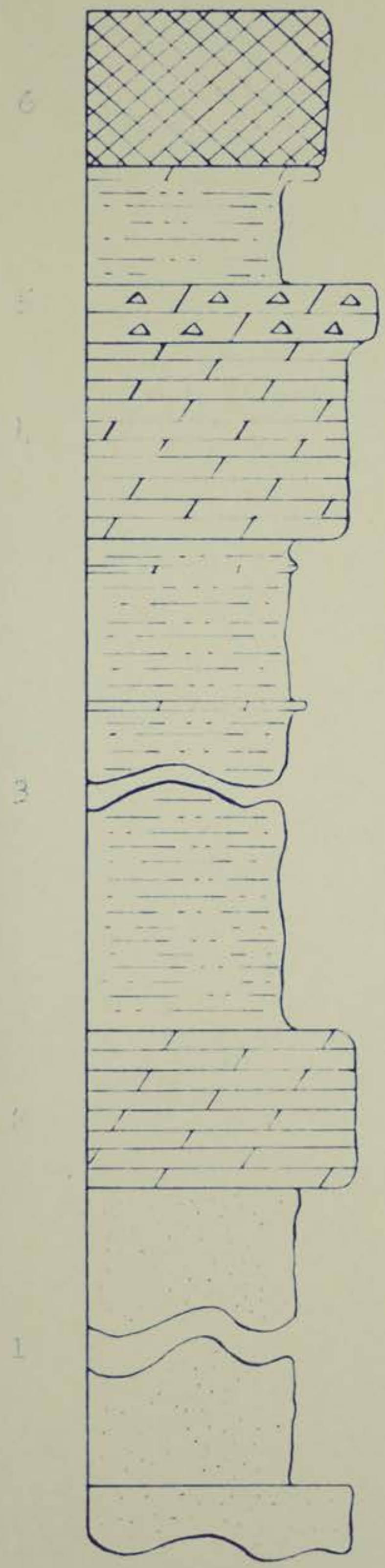
The Chugwater formation lies comformably upon the uppermost gypsum bed of the Phosphoria formation. This contact is not exposed in the area under discussion except where the upper units of the Phosphoria are present as in the Shell area and at the reference section.

Southern Sheep Mountain Section

Location: T53N, R93W, Sec. 20, NE¼
Phosphoria formation forms a flat-iron along the west slope of the southern tip at Sheep Mountain
(Reference Section)
Upper boundary concealed



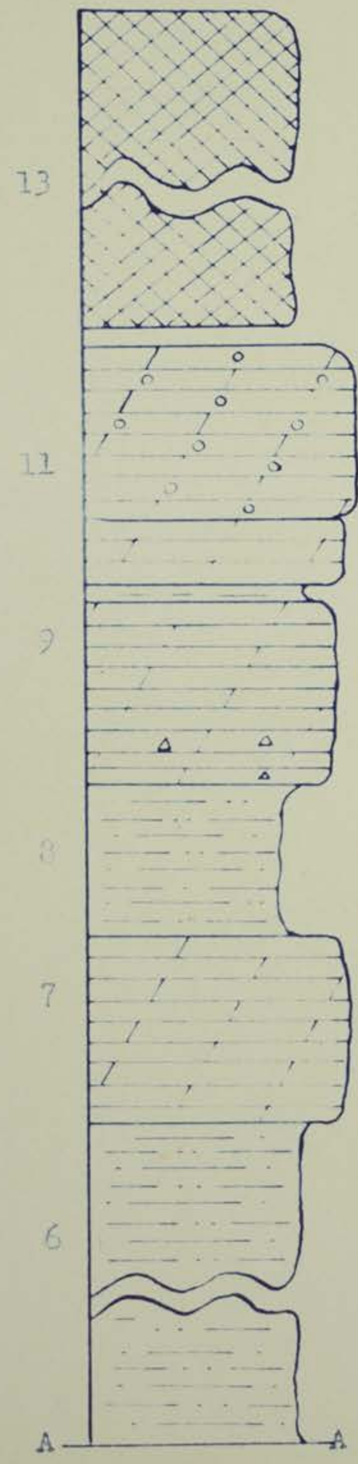
Feet	Inches	
20	0	Gypsum, white, stained red, powdery, massive
25	0	Siltstone, gray-green, weathers same, nodular (1-8 inches in diameter), gypsum veinlets fill fractures (1/2 - 2 inches thick)
5	0	Dolomite, medium gray, weathers tan to gray, finely crystalline, dolitic (1 mm. in diameter), massive, very porous.
		Contact concealed
16	7	Dolomite, light gray, weathers very light gray, very finely crystalline, massive, calcite geodes (1/2 - 5 inches); interbedded chert, upper 3 feet, nodular (1-6 inches in diameter)
5	6	Siltstone, gray-green, weathers same, massive, calcareous
3	0	Dolomite, light gray, weathers same, massive, very finely crystalline, calcareous, very porous
10	8	Siltstone, red, upper 2 feet mustard, weathers same, nodular (1-5 inches in diameter), gypsum veinlets (1/4 - 4 inches thick), fill fractures



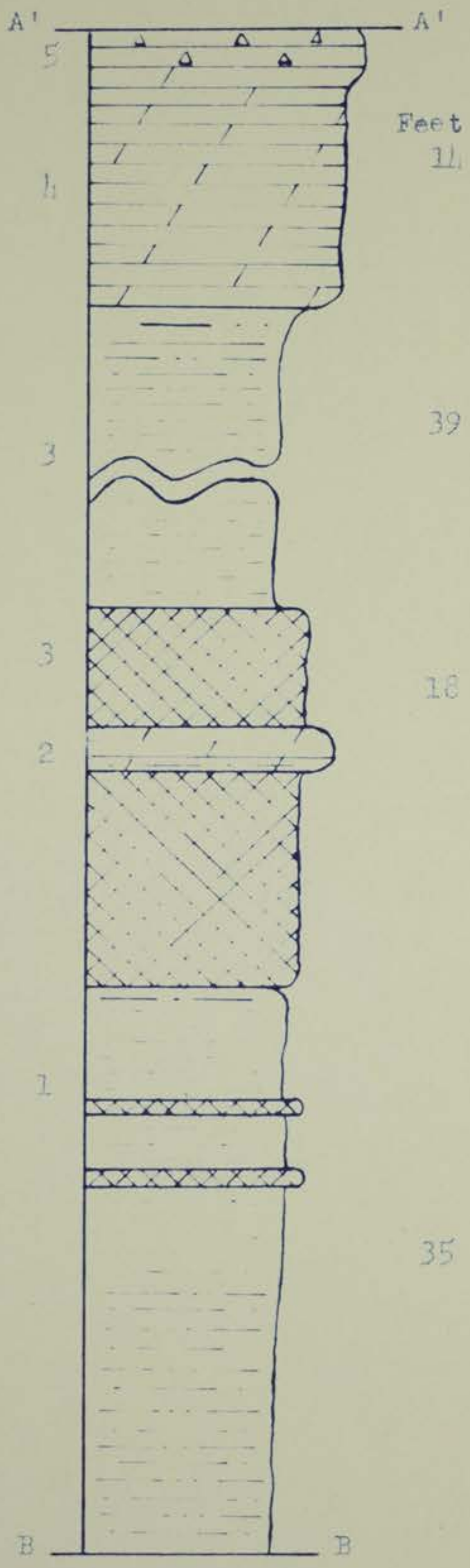
8	0	Gypsum, white, stained red, powdery, massive
6	4	Siltstone, red, weathers red, massive; bed of limestone, medium grey fresh, weathers very light gray, 6 inches thick, overlies siltstone.
3	0	Chert, blue-black, nodular
10	0	Dolomite, light gray, weathers same, very finely crystalline, clayey, massive, upper 4 feet thin bedded (4 inches), slightly porous
38	0	Siltstone, red, upper 10 feet green, weathers same, massive; interbeds of dolomite, in upper 10 feet, 6 inches thick, light gray, weathers medium gray
[illegible]	0	Dolomite, light gray, weathers pink, very finely crystalline, massive, weathers into thin beds
[illegible]	[illegible]	Sandstone, red, lower 10 feet green, weathers same, sandy, massive, calcareous
		Tensleep sandstone

North Shell Section

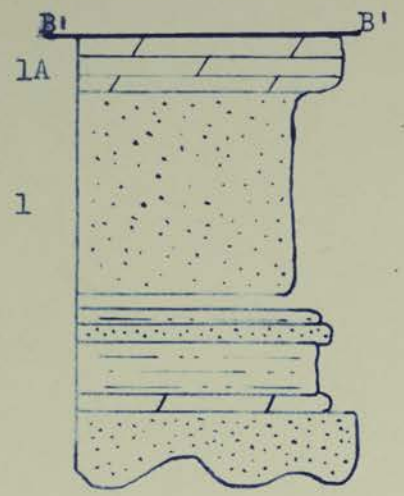
Location: T53N, R90W, Sec. 8, SE$\frac{1}{4}$. West flank of Big Horn Mountains, near mouth of Shell Creek Canyon; 3 miles east of Shell, Wyoming; approximately $\frac{1}{4}$ mile north of U.S. Highway 14.



Feet	Inches	
10	0	Gypsum, white, stained red, powdery, massive
		Concealed
8	0	Dolomite, light gray to tan, weathers very light gray, finely crystalline, oolitic (1 mm. in diameter), thin bedded (3-6 inches), porous
12	3	Dolomite, very light gray, upper 3 feet dark gray, weathers light gray, very fine crystalline, calcareous, thin bedded (1 - 3 inches); interbed of shale, 1 feet 5 inches thick, 3 feet from top, lime green, weathers same, calcareous; interbeds of chert in lower 3 feet, brown
7	0	Siltstone, red, small green areas, massive, calcareous
9	0	Dolomite, light gray to medium gray, weathers medium gray, finely crystalline, clayey, porous
23	0	Siltstone, red, weathers into chips, massive, calcareous



Feet	Inches	
14	0	Dolomite, light to medium gray, weathers medium gray, very finely crystalline, clayey, very thin bedded (1 - 3 inches thick), upper 3 feet, interbeds of chert, blue-black, nodular (1-4 inches in diameter)
39	6	Siltstone, red, weathers red, nodular (1-6 inches in diameter), massive, gypsum veinlets fill fractures (1-2 inches thick)
18	0	Gypsum, white, stained red, massive, powdery; interbeds of dolomite, medium gray, weathers light purple, very finely crystalline, 8 1/2 inches thick; underlain by siltstone, red, 3 1/2 inches thick, interbeds occur 6 feet 6 inches below top
35	0	Siltstone, red, weathers red, nodular (3 inches - 1 foot in diameter), calcareous

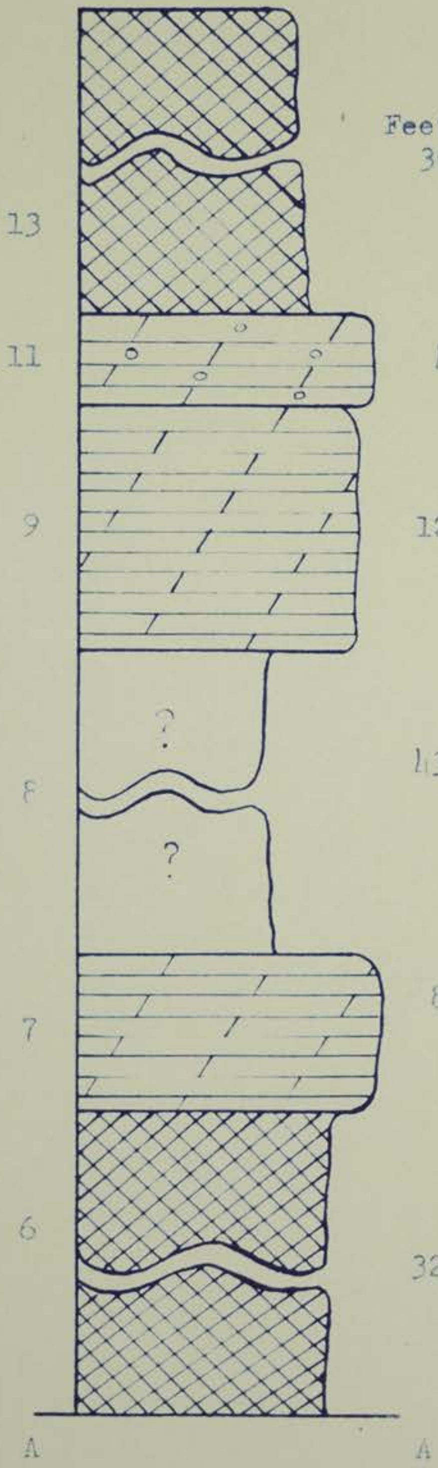


2	4	Dolomite, light gray to purple, weathers same, finely crystalline, quartz grains, very fine sand size, 30 per cent of rock
10	0	Sandstone, red, weathers red, very fine grained, massive; interbeds at bottom, Interbeds at bottom, Siltstone, gray-green, massive, 6 inches Sandstone, gray, very fine sand, 6 inches Siltstone, gray, massive, 2 feet 6 inches Dolomite, gray-green, very finely crystalline, 6 inches

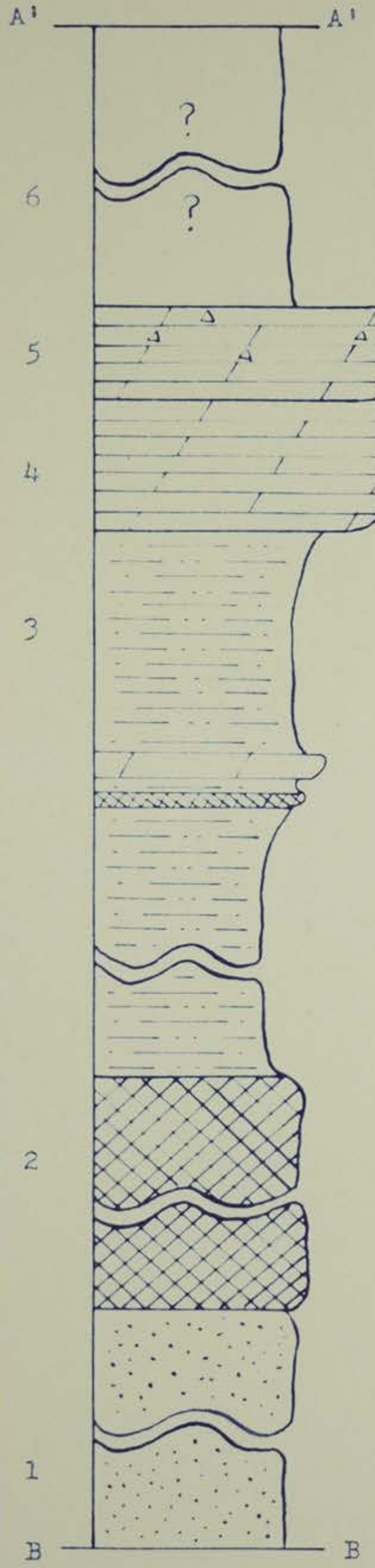
Tensleep formation

South Shell Outcrop

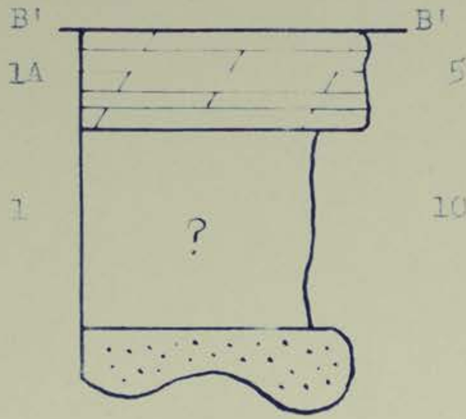
Location: T52N, R90W, Sec. 6, two miles south of Shell, Wyoming, along flank of Big Horn Mountains



Feet	Inches	
		Upper boundary eroded
30	0	Gypsum, white, weathers same, massive, powdery
4	6	Dolomite, brownish gray, weathers medium gray, oolitic (1 mm.) medium bedded (8 inches - 2 feet thick), porous
12	0	Dolomite, medium gray, weathers same, finely crystalline, thin bedded (3 - 8 inches thick), porous
43	0	Concealed, red siltstone float
8	0	Dolomite, light gray, weathers medium gray, very finely crystalline, calcareous
32	0	Gypsum, white, stained red, massive, powdery



4		Concealed, red color
5	0	Dolomite, light gray, weathers same, very fine crystalline, massive; interbeds of chert, purple, very thin bedded (1 inch thick)
7	0	Dolomite, tan-gray, weathers light gray, fine crystalline, clayey
53	7	Siltstone, red, weathers same, upper 12 feet massive, below interbeds siltstone nodular, gypsum veinlets fill fractures; interbeds 12 feet 3 inches below top, limestone light gray, weathers very light gray, very finely crystalline, 2 feet thick, underlain by 1 foot bed of red siltstone and 1 foot thick white gypsum, massive, powdery
19	4	Gypsum, white, stained red, massive, powdery
45	0	Sandstone, red, very fine sand size, massive



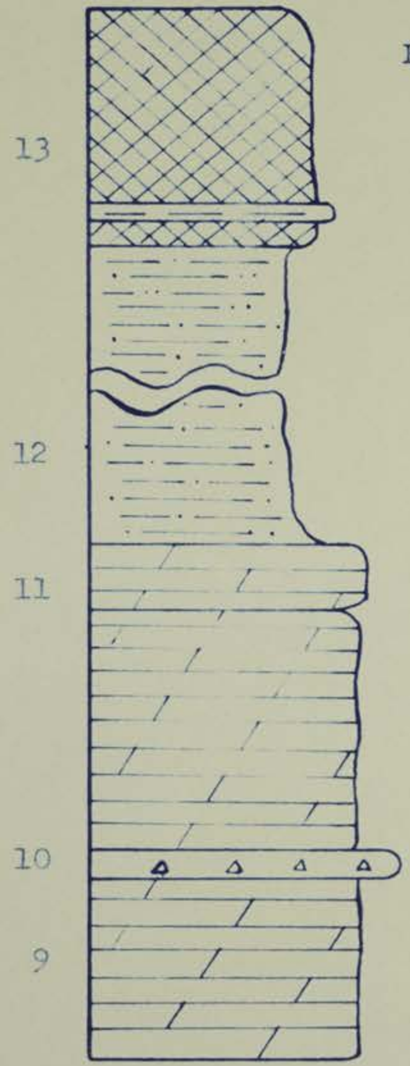
1A	5 0	Dolomite, medium gray, weathers darker gray, massive, finely crystalline, sandy, porous
1	10 0	Concealed

Tensleep formation

Spence Dome Section

Location: T54N, R94W, Sec. 9, SW 1/4, NE 1/4
Phosphoria formation forms crest of anticline, 1/4 mile east of flank of Sheep Mountain

Upper boundary eroded or concealed

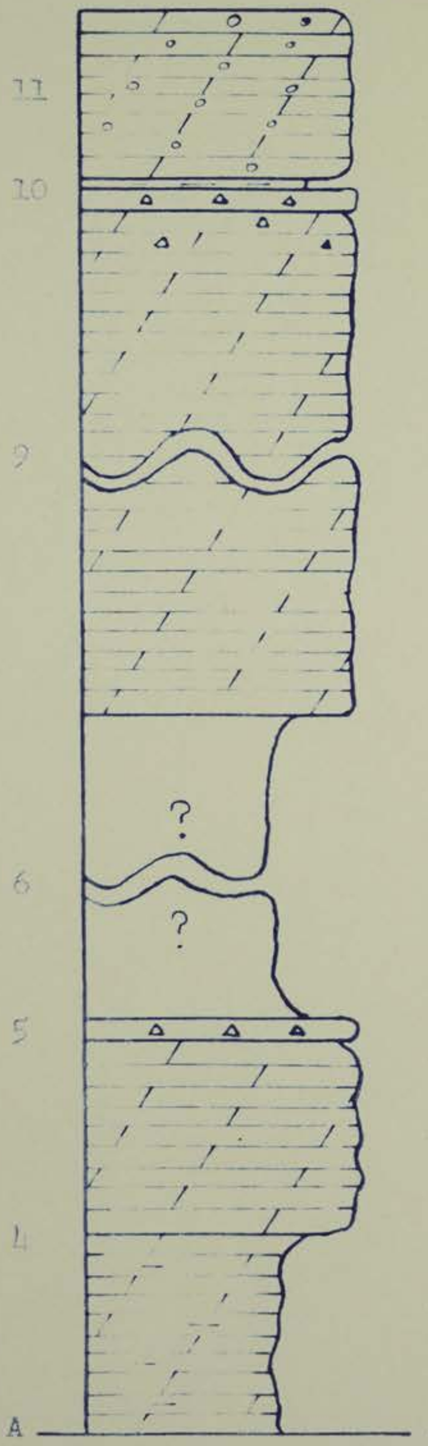


Feet	Inches	
10	0	Gypsum, white, stained brown, powdery, massive, basal 3 feet very thin bedded (1/16 - 2 inches); Interbed of shale, green-gray, weathers same, very thin bedded 6 inches thick, 2 feet from base
27	6	Siltstone, gray-green, weathers same, nodular, gypsum veinlets fill fractures
3	0	Dolomite, light gray, weathers tan to medium gray, massive, finely crystalline, oolitic, (1 mm. in diameter), porous
12	0	Dolomite, medium gray to light brown, basal 4 feet gree-gray, very finely crystalline, thin bedded (3-8 inches), massive, asphalt in pores and vugs
1	0	Chert, blue-black, stained brown, massive
8	9	Dolomite, gray to light brown, basal 4 feet chocolate brown, weathers same, massive, calcite geodes in upper 4 feet, interbedded chert nodules in upper 2 feet, blue-black.

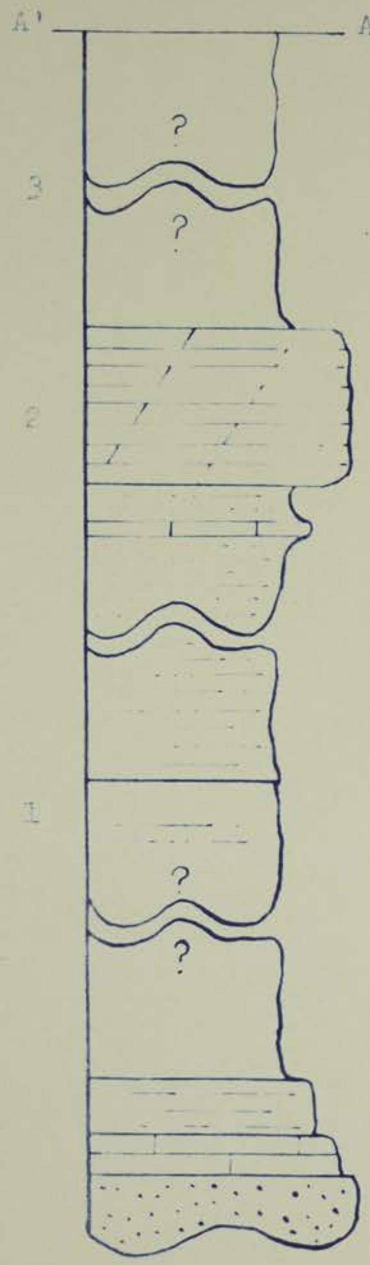
Lower boundary concealed

Little Sheep Mountain - Big Horn River Cut

Location: T55N, R94W, Sec. 8, SE 1/4
North side of east limb of anticline
Phosphoria formation forms dip slope



Feet	Inches	
		Upper boundary eroded
8	11	Dolomite, medium to very dark gray, weathers medium gray, finely crystalline, brecciated, oolitic (1 mm. in diameter), thin bedded (10 inches to 2 feet), porous, asphalt fills pores and fractures, calcite geodes (2 inches)
0	6	Shale, gray, weathers green and brown
1	3	Dolomite, very light gray, weathers same, interbedded with chert, blue-gray, thin bedded, (1-8 inches)
18	3	Dolomite, medium gray to chocolate, weathers medium gray, massive, oolitic (1 mm. in diameter), brecciated in part, finely crystalline, very porous, calcite geodes, chert, gray-blue, nodular (1-2 inches in diameter), in upper 5 feet, asphalt fills pores and fractures
30	0	Concealed
1	6	Shale, gray, weathers gray, chert, blue-gray, nodular
9	6	Dolomite, light gray, weathers same, finely crystalline, clayey, massive, slightly porous
12	0	Dolomite, light gray, weathers same, very finely crystalline, very clayey, calcareous, poorly consolidated

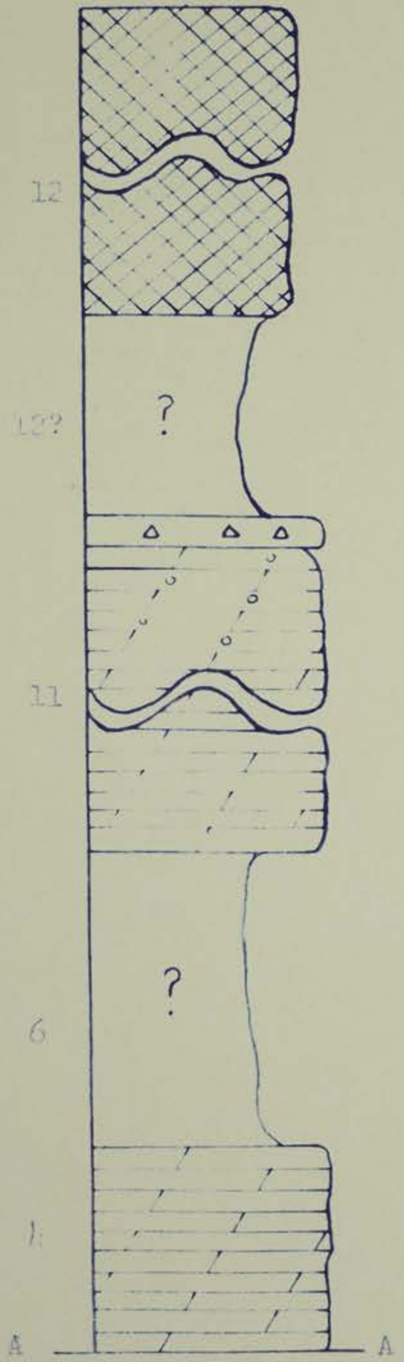


26	3	Concealed, red siltstone float
7	9	Dolomite, light gray, weathers same with potmarked surface, very finely crystalline, very porous, calcite geodes in lower 3 feet
19	11	Siltstone, red, weathers red, nodular (1-8 inches in diameter), calcareous, grades into mustard colored siltstones toward west, Upper 2 feet green gray; interbeds of limestone, very light gray, weathers same, very finely crystalline
20	0	Concealed, red siltstone float
2	7	Shale, red, weathers red, massive, calcareous
2	0	Limestone, green-gray, weathers same with potmarked surface, very finely crystalline, porous

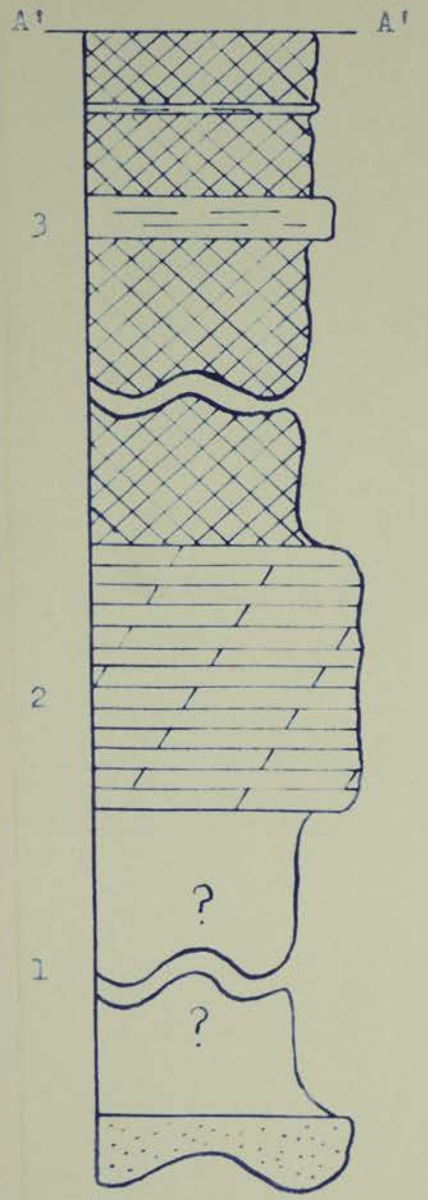
Tensleep formation

East Flank of Little Sheep Mountain

Location: T55N, R94W, Sec. 6, S 1/2
Phosphoria formation forms dip slope



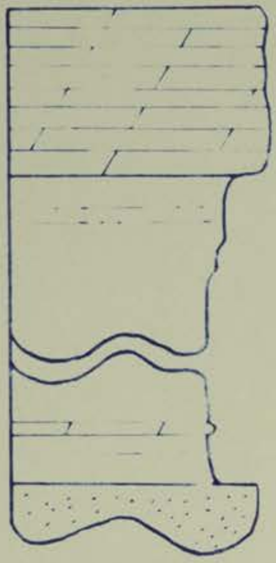
Feet	Inches	
25	0	Gypsum, white, stained red, massive, powdery
10	0	Eroded or concealed by talus
1	3	Chert, dark blue-gray
60	2	Dolomite, light gray to tan-gray, weathers medium gray, with rough surface, oolitic (1 mm. in diameter), brecciated in part, porous, massive, vertical fractures, Chert light to blue-gray, nodular (1-8 inches in diameter, in upper 5 feet and 5 feet zone, 30 feet from top
20	0	Concealed
8	11	Dolomite, light gray, weathers same, fine crystalline, Chert, blue-gray, nodular (1-2 inches in diameter), upper 3 feet



7	9	Gypsum, white, weathers white into thin beds, powdery, massive; interbeds of shale, red and green, weathers same, calcareous, 6 inches thick
2	8	Siltstone, red, weathers same into chips, calcareous
27	3	Gypsum, white, stained red, massive, powdery
8	6	Dolomite, light gray to tan fresh, weathers light gray, very finely crystalline, very thin bedded (1-3 inches), gypsum fills fractures, upper 2 feet
55	0	Concealed, red siltstone and shale float
		Tensleep formation

Horse Creek Section

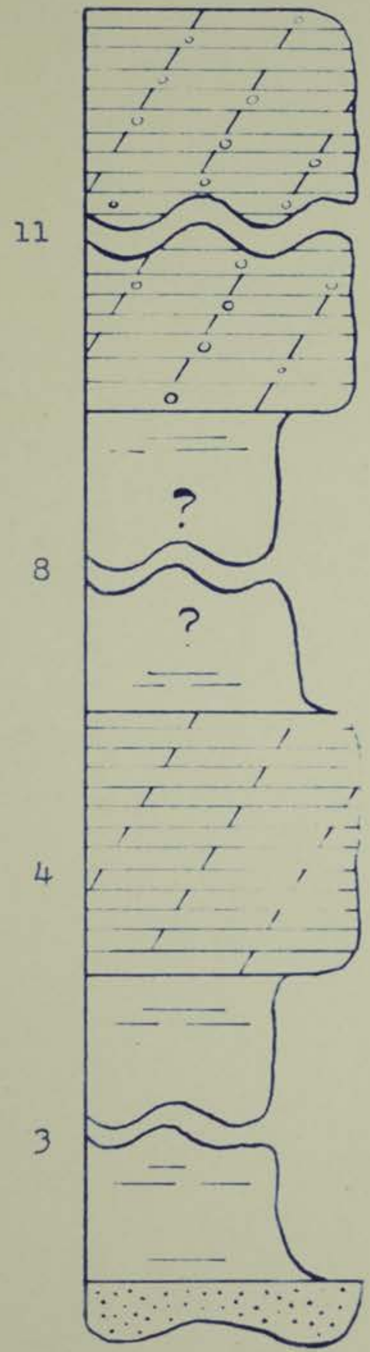
Location: T54N, R91W, Sec. 36, SW 1/4



Feet	Inches	
		Concealed by talus
8	0.	Dolomite, light gray, weathers same, very finely crystalline, thin bedded (4-10 inches), slightly porous
70	0	Concealed by talus, red siltstone float; interbed of dolomite, pink, weathers same, very finely crystalline, 1 foot thick, 15 feet from base
		Tensleep formation

Bear Creek Section

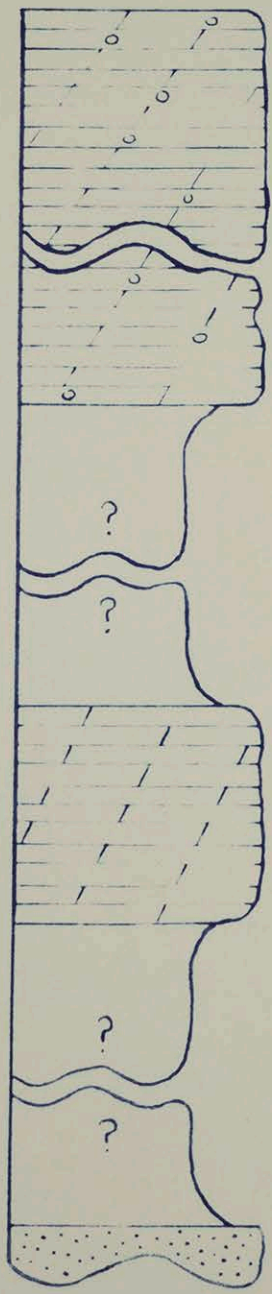
Location: T55N, R92W, Sec. 14, C
Along flank of Big Horn Mountains
Phosphoria formation forms minor
flatiron



Feet	Inches	
58	4	Dolomite, very light gray, weather light gray, finely crystalline, brecciated, lightly oolitic, calcite and quartz geodes (1-2 inches in diameter), porous, lower 9 feet low porosity
14	8	Concealed by talus, red shale float
13	0	Dolomite, very light gray, weathers light gray, finely crystalline, thin bedded (2 inches to 3 feet)
65	6	Concealed, red siltstone float
		Tensleep formation

Beaver Creek Section

Location: T54N, R91W, Sec. 3, NW 1/4
West flank of Big Horn Mountains
Phosphoria formation forms flat-iron



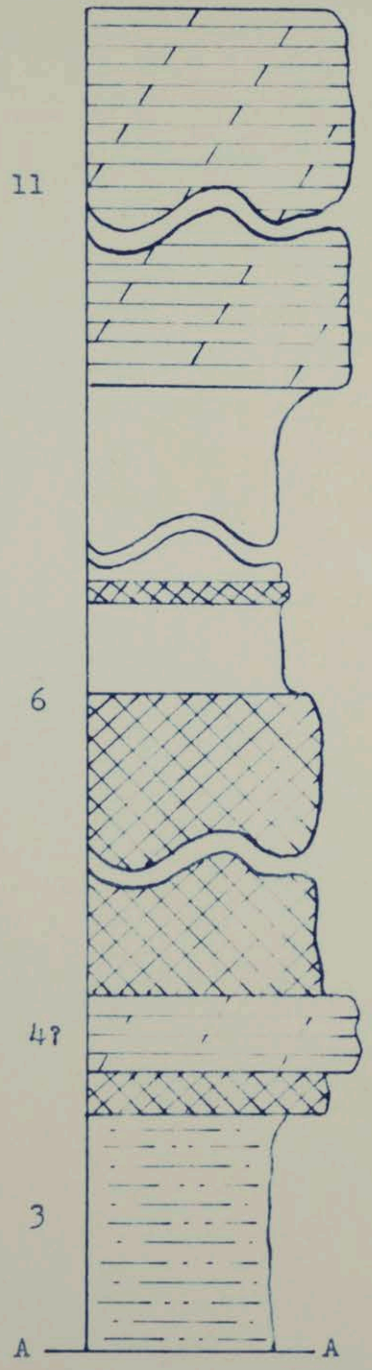
Upper boundary eroded

	Feet	Inches	
11	70	5	Dolomite, very light gray to tan, weathers light gray, very finely crystalline, massive, calcite geodes (1 inch in diameter), slightly oolitic, brecciated, clayey
6	25	10	Shale, red, weathers red, massive, nodular (1-6 inches in diameter), lower 10 feet concealed
4	11	0	Dolomite, light gray, weathers same, stained red in places, finely crystalline, clayey, thin bedded (2-8 inches), slightly porous
3	51	8	Siltstone, red weathers red, massive, nodular (1-8 inches in diameter), lower 20 feet concealed, upper 2 feet green

Tensleep formation

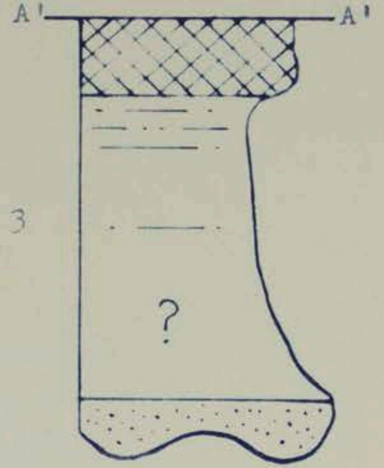
North Lovell Section

Location: T57N, R94W, Sec. 16, NE¼, 6 miles northeast of Lovell, Wyoming. Phosphoria formation forms dip slope of west flank of Big Horn Mountains



Upper boundary eroded

Feet	Inches	
71	6	Dolomite, very light to light gray, weathers same with pot-marked surface, stained tan in places, finely crystalline, brecciated, oolitic (1 mm.), medium bedded (6 inches to 5 feet) porosity varies, asphalt fills pores, calcite geodes in upper 15 feet
55	6	Concealed, red siltstone float; interbed of gypsum, white, stained red, powdery, 3 feet thick, 38 feet from top
24	2	Gypsum, white, weathers white, powdery, massive
4	0	Limestone, tan-gray, weathers tan, finely crystalline, massive, porous
14	2	Siltstone, red, weathers red, massive, calcareous, partially concealed, gypsum, white, stained red, powdery, massive, 2 feet thick bed at top



3 6	Gypsum, white, stained red, powdery. massive
15 10	Concealed, red in color, upper 2 feet, siltstone, green-gray, weathers same, massive, calcareous
	Tensleep formation

AGE AND PALEONTOLOGY

In Idaho and western Wyoming where the Phosphoria formation contains commercially important phosphate reserves, extensive research has been done on the stratigraphy and paleontology. Unfortunately, much of the early work was of a general nature with little or no emphasis placed on the stratigraphic positions of the fossils within the formation.

As early as 1910, Girty studied the paleontology of the lower Phosphoria near the intersection of Idaho, Utah and Wyoming and concluded that it was of Late Pennsylvanian age. Later in 1927, he revised his work and changed his concept of the age to Lower Permian. E. B. Branson (1916) considered the lower Phosphoria formation of the Wind River Mountains of Wyoming to be Pennsylvanian in age. His astute observation that the fauna from the lower and upper Phosphoria were different set the stage for later and more detailed studies of the paleontology.

In 1930, C. C. Branson examined the Phosphoria formation of the Wind River and Owl Creek Mountains in Wyoming and subdivided it into five members each of which contained a characteristic fauna. These members were named; the Lower Chert, the Lower Phosphate, the Pustula, the Hustedia, and the Top Limestone member. He verified the conclusions of E. B. Branson, and considered the Upper Phosphoria to be Lower Permain in age. He also stated that the lower part of the formation graded into the upper part without a lithologic break of any kind, thus it crossed the Pennsylvanian-Permian systemic boundary.

Almost simultaneously with Branson's investigation in 1930, King suggested that strata resembling the Phosphoria formation in lithology and fauna were underlain by the Kaibab formation in the San Rafael Swell area of Utah. The Kaibab formation is of Middle Permian age. Baker and Williams (1940) confirmed this by correlating, at least in part, the fauna of the lower limestone of the Park City formation of Utah with that in the Kaibab. They considered the basal Park City formation to be lower Middle Permian (Leonardian) in age.

A study of the cephalopods found in the middle and upper Phosphoria formation in Idaho and Wyoming by Miller and Cline (1934) indicated the parts of the formation studied were Middle Permian in age and probably correlative with the Word formation in Texas.

Later in 1942, Frenzel and Mundorf examined the basal portion of the Phosphoria near Three Forks, Montana and concluded it was of Wolfcampian age by the identification of fusulinids. The basal Permian of this region directly overlies the Quadrant formation of the Des Moines group or Middle Pennsylvanian age.

The carbonate members of the Phosphoria formation of the northeastern part of the Big Horn Basin are non-fossiliferous except for the youngest tongue. At the Big Horn River cuts in Sheep and Little

Sheep Mountains, poorly preserved fossils were found in the upper six feet of the Ervay tongue of the Phosphoria. The following fossils were identified:

1. *Fenestella* sp.
2. *Schizodus phosphoriensis* C. Branson
3. *Nuculana* sp.
4. *Naticopsis tayloriana* Girty (?)
5. *Plagioglypta* sp.
6. ?*Coelogasteroceras thomasi* Miller and Cline

The most abundant genera are *Schizodus* and (?) *Coelogasteroceras*. Other outcrops were diligently searched, especially those along the flanks of the Big Horn Mountains, but no additional fossils were discovered. Thin sections and hand samples were carefully scrutinized for micro-fossils without success.

The faunal assemblage collected from the upper carbonate member of the Phosphoria formation in the thesis area is present throughout the Big Horn Basin at the same stratigraphic horizon. *Schizodus* and *Naticopsis* were reported by C. Branson (1930) as indicative of his Top Limestone member. Miller and Cline (1934) described *Coelogasteroceras* from the same horizon in the Rattlesnake Mountains of Wyoming. While studying the Phosphoria in the southeastern Big Horn Basin, McCue (1953) found *Schizodus*, *Naticopsis*, and *Nuculana* to be present in the Ervay tongue. By comparing the fauna of the thesis area with that found by other workers, the upper carbonate member of the Phosphoria formation is considered to be the equivalent of and a northern extension of the Ervay tongue. This is supporting evidence for the conclusion reached employing only lithologic properties.

CORRELATION

Thesis Area -- One of the more difficult problems encountered by the author in this study was the correlation of the lithologic units comprising the Phosphoria formation within the thesis area. All of the outcrop sections were studied in detail before any attempt was made. Similarities in color and crystallinity tend to make the carbonates appear identical in the field. The oolitic and brecciated texture of unit no. 11 was not discovered until the samples were cut and examined under the microscope. The chert beds like the paleontological evidence were too restricted to be of great aid. The red bed and gypsum tongues change lithologic character laterally and vertically and thus could not be used. Since the carbonate members are persistent ledge formers, they were found to be the most useful. By careful observation of such properties as crystallinity, color, porosity, presence of asphalt, texture, etc. of each sample taken from the carbonate units, it became possible to trace certain units throughout the area. The most easily recognized units were the oolitic and brecciated dolomite of unit no. 11 or the upper portion of the Ervay tongue and the chert beds where present.

In the area under discussion, all units of the Permo-Triassic interval are present except the Nowood member. The Minnekahta tongue of the Phosphoria formation and underlying Opeche formation occur only as very thin strata in the outcrops near Shell, Wyoming.

The Forelle tongue is present only along the southern and western edges of the area. It has a relatively uniform thickness of approximately eight feet. The very light gray and tan dolomite grades into a gypsum facies in the southeastern corner.

The unnamed chert-carbonate like the Ervay tongue occurs in all parts of the northeastern Big Horn Basin; however, the chert beds tend to be discontinuous along the northern flanks of the Big Horn Mountains. The clayey light gray dolomite is uniform in character and thickness.

The most diagnostic unit of the sequence is the youngest stratum of the Ervay tongue. In all outcrops, it is an oolitic, brecciated, porous dolomite. The textural characteristics cannot be determined in most hand specimens without the aid of a binocular microscope and often only then if the sample has been cut with a diamond saw. In thin sections, these features are quite obvious. In contrast to other units, its thickness increases in the northeastern part of the area.

The lower units of this member are light gray to chocolate in color, finely crystalline, and possess a high porosity. The presence of calcite geodes and asphalt filled vugs and fractures is also helpful. The chert bed so well developed at the Spence Dome outcrop is absent to the east.

The tongues of the Chugwater formation vary in thickness and lithologic character from sandstones, siltstones, and shales to massive gypsum beds. In the southern part of the area, these tongues are thicker, of coarser detrital size, and contain more evaporite beds than in the northern part.

The differences in total thicknesses measured at the different localities may be due to the amount and character of the deposit present in each section, but the topographic relief of the Tensleep formation erosion surface upon which the Phosphoria formation was deposited must also be considered. A quantitative evaluation of this latter factor is difficult to determine in this area as the subsurface control is not close enough.

Fig. 5 is a correlation diagram showing the relationships of the tongues of the Phosphoria and Chugwater formation in the thesis area.

The Phosphoria formation is 415 feet thick at the type section, Phosphoria Gulch, Idaho. To the east in the Big Horn Basin, it thins to approximately 200 feet. The formation continues to thin in total thickness in the Black Hills of South Dakota, although the Minnekahta tongue and the Opeche formation thicken. The interfingering Chugwater formation increases in thickness from western Wyoming to the Dakotas. The Tensleep formation, on the other hand, like the Phosphoria formation thins from west to east in Wyoming.

McCue (1953) after extensive field work was able to trace the tongues of the Permo-Triassic sequence described by Darton and Thomas from the Wind River Mountains along the southern and eastern margins of the Big Horn Basin as far north as Tensleep, Wyoming, by the use of paleontological and lithological evidence.

This author has been able to correlate the units described by McCue with those in the northeastern part of the basin by lithologic characteristics. The paleontology of the Ervay tongue is also found to be similar.

CORRELATION DIAGRAM

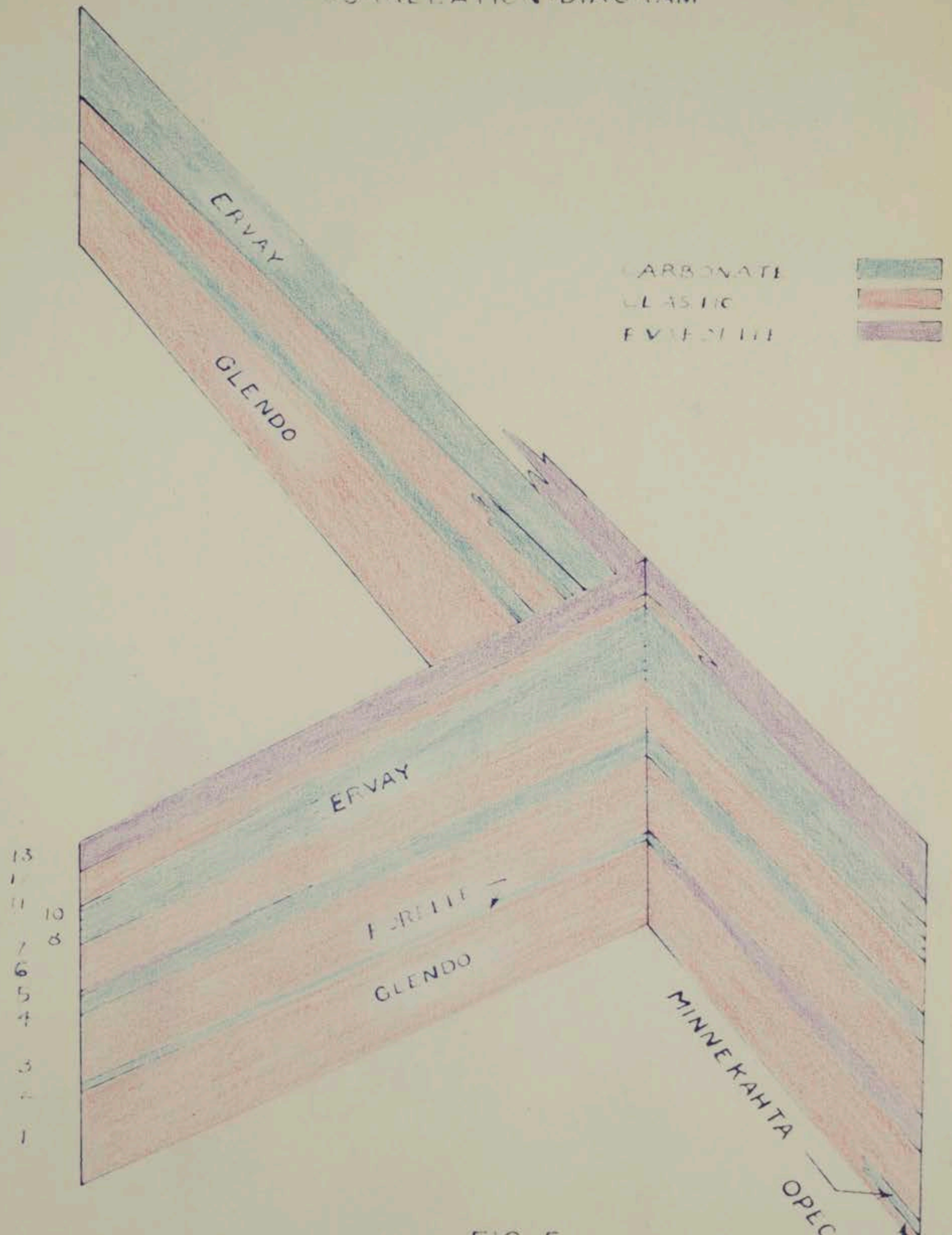


FIG. 5

ENVIRONMENT OF DEPOSITION

The Permian history of the Big Horn Basin is exceedingly complex and its reconstruction involves the consideration of many factors, many of which have no quantitative measure. The available evidence concerning this problem can be derived from three sources: the carbonate beds, the paleontology, and the clastic and evaporite beds.

The carbonate units, the first to be considered, are composed of very fine to finely crystalline dolomite with two major variations; the oolitic and brecciated unit of the Ervay tongue and the sandy dolomite which comprises the Minnekahta tongue. The presence of angular silt size particles in the latter member would suggest that it was deposited in an aqueous environment in which the water was so shallow that the wave action stirred up detritals from the basin floor. Simultaneous deposition of detritals and carbonates is not considered to be likely as the grains are not coated with the carbonate material. The detritals from the Minnekahta tongue cannot be distinguished from those of the underlying Opeche sandstone, although the average grain size of the former is slightly smaller. This would also be anticipated as the wave action would move the smaller particles first.

The brecciated nature of the upper unit of the Ervay tongue is unusual in that the dolomite particles show an extreme range in grain size and possess high angularity and low sphericity indicating that they have not been reworked or abraided. The long axes of the particles parallel the bedding plane for the most part. No sorting or packing is observed. In some thin sections, the grains resemble a jig-saw puzzle. The evidence suggests that the dolomite was brecciated in place after lithification, perhaps during the orogeny which produced the present regional structures.

Very little is known about the origin of oolites in nature; however, modern oolites appear to form in a shallow water marine environment (Thorp, 1939). The nuclei of the spherules in this area are composed of small angular pieces of dolomite which may be particles from an underlying brecciated dolomite.

The carbonate tongues of the Phosphoria formation exhibit a general decrease in thickness to the north and east with the exception of the upper unit of the Ervay tongue which increases in thickness. The shore line of the basin of deposition would be then to the east and north of the thesis area.

The limited fauna present further supports the hypothesis of a shallow basin of deposition. It is composed of pelecypods, gastropods, and scaphopods, all of which are or may be benthonic forms. Modern decendents of <u>Nuculana</u> and <u>Naticopsis</u> are found in shallow marine seas. Scaphopods live at a variety of depths ranging from 2 to 2400 meters and thus are not diagnostic.

So far the evidence has indicated a shallow marine environment; however, the red beds may represent a terrestial phase of deposition. The red color of these detritals as shown previously is due to an iron oxide coating on the grains, which is considered to be the product of an oxidizing environment. The grains received their coating during or after deposition. If coated prior to deposition, abrasion would have removed it during transportation. Dehydration of an iron compound in the reduced state would change primary yellows and browns to red, thus the color may have been altered after deposition. Since an oxidizing environment is also an acid one, plus the fact that marine waters are generally basic, the presence of red beds is considered to be the product of a terrestrial type of deposition. However, this concept could also be challenged.

The association of evaporite beds with the detrital material can imply a basin so shallow that local areas became isolated into individual basins which deposited the gypsum as they dried up. The variable and scattered occurence of gypsum beds in the thesis area could be also interpreted to mean deposition in an unstable shelf area.

In general, all three modes of evidence considered above suggest that the Phosphoria formation of the Big Horn Basin was deposited in a shallow marine environment. If the area in which the seas deposited the carbonate beds was a shelf area, only minor oscillations of the sea level without a change in the amount of detrital material would be sufficient to produce the interfingering relationships existing in this region. Since the origin of red beds has not been definitely proved to be the product of terrestrial deposition, this objection cannot be considered valid, although it is not to be overlooked.

ECONOMIC GEOLOGY

Phosphate, petroleum, sulphur, uranium, gypsum and vanadium are products of economic importance which can be produced from the Phosphoria formation.

In Idaho, phosphate has been produced commercially, although the present production is rather small compared to the large reserves available. The phosphate occurs mostly as collophane and francolite in oolitic and pisolitic forms. It is primarily concentrated in the lower and upper phosphate members. Only the younger member is present in the Big Horn Basin; however, it is of no commercial value because of the low concentration of phosphate.

One of the most important commercial products of this formation is the petroleum. The first producing well in the Big Horn Basin was situated on the Warm Springs anticline near Thermopolis, Wyoming. Since that time, 1927, many more wells have been "brought in" from the Phosphoria formation. The Greybull dome when operating produced from the Phosphoria.

The Worland field produces hydrogen sulphide bearing gas from the Phosphoria. Elemental sulphur is extracted from the gas which is further refined for domestic use. Plate no. 12 shows the sulphur storage area at Worland, Wyoming.

The high vanadium concentration known to be present in western Wyoming, southeastern Idaho, and northeastern Utah has not been tested for in the thesis area.

Uranium prospectors have staked extensive claims on the surface sections of the Phosphoria formation, but no commercial production has yet been established.

Gypsum comprises an appreciable amount of this formation and thus could be a future source of this mineral.

From an economic viewpoint, the Phosphoria formation has only two products, phsophate and petroleum, which have been produced in commercial quantities.

CONCLUSIONS

The Phosphoria formation of the northeastern Big Horn Basin overlies the Tensleep formation unconformably and grades conformably upward into the Chugwater formation. It is composed of a series of carbonate beds interfingered with red clastic and gypsum strata. For the purpose of this study, the Phosphoria formation was subdivided into units on the basis of major lithologic divisions. Minor subdivisions were not considered separately as the lithology of the main units often changes laterally. The units were numbered from 1 to 13, with the latter being the youngest. Unit no. 1 is a red bed interval composed of a massive sandstone which ranges from very fine sand size to medium silt. A thin sandy dolomite bed (1A) outcrops ten feet from the base of the sandstone in the southeastern corner of the thesis area. When unit 1A is present, the underlying lithology is indistinguishable from the overlying unit. Unit no. 1 is the basal Phosphoria throughout this area. Overlying this sandstone is a light gray, clayey, finely crystalline dolomite, called unit no. 2. It is 8 feet thick in the southwestern part of the area and grades laterally into an evaporite strata in the east. Units 3 and 6 are red siltstone beds between which is sandwiched a chert and dolomite strata, units no. 5 and 4 respectively. Unit no. 3 varies from 25 to 40 feet thick, while no. 6 is approximately 25 feet thick throughout. The latter unit is shale in some localities and both contain gypsum beds locally. Unit no. 4 is a 10 to 15 feet thick bed of very light gray, finely crystalline dolomite which like the overlying chert bed is a persistant ledge former. Unit 5 is a blue-gray nodular chert bed which pinches out to the north and east. Its maximum thickness is 3 feet. Overlying unit 6 is a porous, light gray, finely crystalline, thin bedded, dolomite present only in the southern part of the area. It is 3 to 10 feet thick. Between unit no 7 and the younger carbonates is a thin, 5 feet thick, red, calcareous shale bed called unit no. 8. The next three units occur together as a persistent ledge former. No. 9 is a medium gray to chocolate, finely crystalline, massive dolomite approximately 8 feet thick. Overlying this unit is a thin blue-gray nodular, chert bed, unit no. 10, and a light to dark gray, oolitic, brecciated finely crystalline dolomite. The latter dolomite is referred to as unit no. 11 and is one of the most diagnostic units of the formation. It varies in thickness from 5 to 60 feet. Unit no. 12 is a green-gray siltstone in which gypsum veinlets fill the fracture forming a net-like pattern This unit is 25 feet thick and like the overlying unit it outcrops only in the southern part of the area where the Phosphoria formation has a shallow dip. The youngest unit is no. 13 which consists of 20 to 40 feet of massive gypsum.

When tracing units from one section to another, the carbonate and chert beds were found to be most useful as they are persistent ledge formers and thus always exposed even where talus covered part of the outcrop. The most diagnostic unit was the oolitic and brecciated dolomite of unit no. 11 which can be found throughout the entire area. The other carbonates standout from the other dolomites and limestones in the stratigraphic section because of their light gray color and fine crystallinity, but often they resemble each other making identification difficult if only a small portion of the formation is exposed.

The paleontologic evidence was very limited and consisted of only megafossils. The fauna was composed of pelecypods, gastropods, and scaphopods. Branson (1930), McCue (1957), and others reported a similar assemblage from the youngest carbonate unit in the southern part of the Big Horn Basin, thus a direct correlation was established.

By comparing the lithologic characteristics of the units in the thesis area and comparing these with those described in other parts of the region, supplimented by paleontologic evidence, the following correlation was developed:

Unit no.	13	Unnamed interval, possibly Dinwoody formation equivalent
	12	
	11	
	10	
	9	Ervay tongue of the Phosphoria formation
	8	
	7	Unnamed tongue of the Chugwater formation
	6	
	5	Unnamed interval of Phosphoria formation
	4	
	3	Unnamed tongue of the Chugwater formation
	2	Forelle tongue of the Phosphoria formation
	1	Glendo tongue of the Chugwater formation
	1A	Minnekahta tongue of the Phosphoria formation
		Opeche formation

Fig. 5 is a correlation diagram which illustrates the above relationships.

The carbonate tongues in the area under discussion are considered to be extensions of those described by Thomas (1934) and Darton (1906b) in the Owl Creek Mountains. The Opeche formation, the Minnekahta and Forelle tongues of the Phosphoria formation pinch out in this area, while the Nowood member is absent. The total thickness of this formation decreases from a maximum of approximately 259 feet in the southern part to a minimum of 160 feet along the northern flanks of the Big Horn Mountains. All members of the formation thin in this direction except the Ervay tongue (only unit no. 11) which thickens.

The environment of deposition is thought to have been a shelf covered by a shallow marine sea which oscillated across the area. This conclusion was arrived at after considering the environment of deposition of modern oolitic carbonates, the paleontologic evidence, and possible origins of the red beds with their associated gypsum beds.

In many parts of the Big Horn Basin, petroleum has been produced from the Phosphoria formation; however, in the area under discussion no commercial production has been established although several holes have been drilled on anticlinal structures. The phosphate concentration is too low to enable profitable mining of the product.

The carbonate tongues of the Phosphoria formation have been described principally from field evidence supplemented with minor amounts of information obtained from thin sections. A complete petrographic study of each unit of these carbonate members throughout the Big Horn Basin would yield valuable information about the type, origin and nature of [illegible].

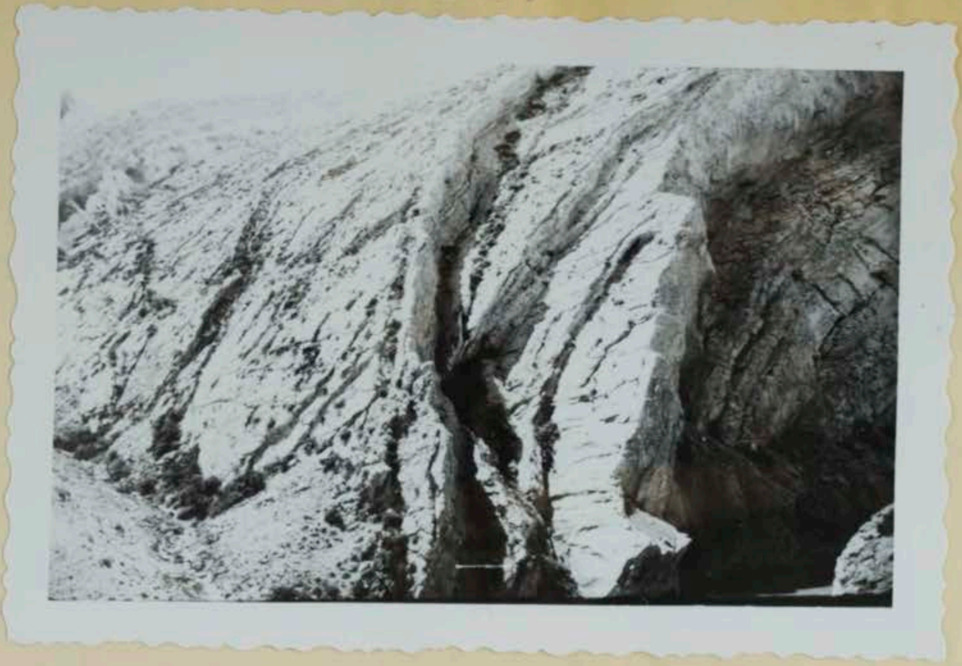
Plate 1

View of west flank of the Big Horn Mountains looking north from Shell, Wyoming. Notice the well developed flatiron structures.

Plate 2

Phosphoria formation (Pp) forms the dip slope of Sheep Mountain anticline at the Big Horn River cut.

Plate 3



Ervay tongue of the Phosphoria formation at the Big Horn River cut in Little Sheep Mountain.

Plate 4

Units 12 and 13 of the Phosphoria formation (?) at Spence Dome.

Plate 5

Ervay tongue of Phosphoria formation at Spence Dome.

Plate 6

Reference outcrop at the southern tip of Sheep Mountain.

Plate 7

View of flatirons along the west slope of Sheep Mountain looking south toward Greybull, Wyoming. The meanders in the Big Horn River are shown here.

Plate 8

Phosphoria formation outcrop, Beaver Creek Section.

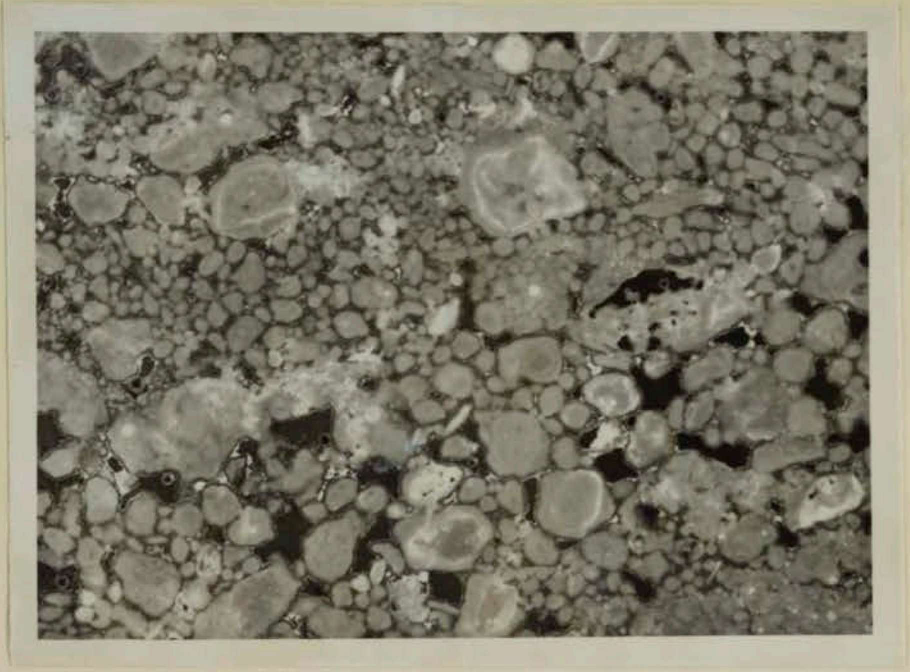
Plate 9

Phosphoria formation outcrop northeast of Shell, Wyoming. Notice how the carbonate ledges stand out in relief.

Plate 10

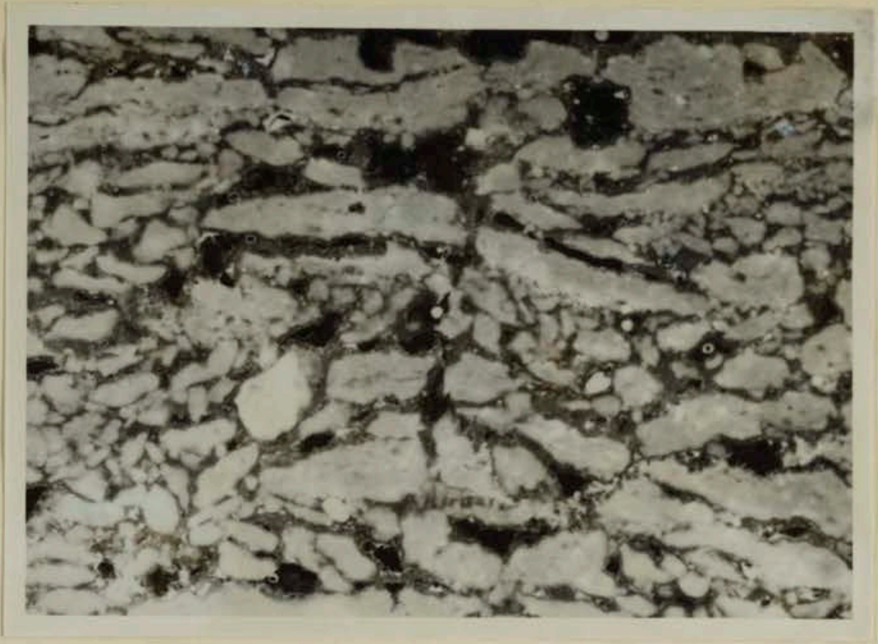
Sulphur storage at Worland, Wyoming.

Plate 11.



Above is a photograph of a sample from unit no. 11 (Ervay tongue) which illustrates the oolitic texture of this unit. It was produced directly by using the thin section as a negative. Note the wide range of particle size and the low number of concentric bands in the spherules. The lack of sorting is also apparent.

Plate 12



This is a photograph of a brecciated sample of unit no. 11 (Ervay tongue) which illustrates this texture. The particles are orientated with the long axis parallel to the bedding plane. They possess high angularity and low sphericity.

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VITA

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