An Isopach Map and a Discussion of the Permian in Wyoming and Adjacent Areas

Willard Leskela

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AN ISOPACH MAP AND A DISCUSSION OF THE
PERMIAN IN WYOMING AND ADJACENT AREAS

by
Willard Leskela

A Thesis
Submitted to the Department of Geology
in partial fulfillment of the
requirements for the degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
May, 1948
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INTRODUCTION

The accelerated post-war demand for petroleum products with resultant high prices and dwindling reserves has spurred producers to an extensive search for new fields and for additional production in known fields. Exploration and discovery is dependent on the collection and correlation of vast amounts of data both in the field and that found in literature.

The thickness of strata is but one of the many aids to the geologist, and it enters into the determination of depths to which drilling must be carried to reach a possible oil-bearing horizon. With advance knowledge as to the thickness of a formation, correlation of well cores is simplified.

Thus, the writer has undertaken, as an undergraduate thesis, the construction of an isopach map of Permian strata in Wyoming and adjacent areas. To the writer's knowledge such a map does not exist in present literature.

Information for this thesis was collected from various publications, textbooks and well logs found in the library and the geology department of the Montana School of Mines.

The writer wishes to express his thanks and appreciation to Dr. Eugene S. Perry and various members of his staff
Index Map

1. Williston Basin
2. Cedar Creek Anticline
3. Yellowstone Park
4. Big Horn Basin
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8. Hartville Uplift
9. Laramie Range
10. Rocky Mountains
11. Red Mountain
12. Medicine Bow Mountains
13. Owl Creek Mountains
14. Wind River Basin
15. Wind River Mountains
16. Green River Basin
17. Uinta Mountains
18. Uinta Basin

14. Rattlesnake Hills
PERMIAN STRATIGRAPHY

Distribution

The Permian beds in Wyoming and adjacent areas constitute Marine deposits to the west, and essentially red beds with marine tongues to the east of a line from the Utah-Colo
orado boundary northeast through central Wyoming and thence northwestward to a point east of Helena, Montana, as shown by Plate 2. The Phosphoria formation to the west of this line, though not of great thickness, maintains a fair degree of uniformity, and occurs in northeastern Utah, southeastern Idaho, southwestern Montana and adjacent areas in western Wyoming. East of this line red beds predominate with tongued limestones deposited during transgressions of the Phosphoria sea. In ascending order they are named the Minnekahta, Forelle and Ervay tongues. They differ from each other in areal distribution and their limits are not too well known. The intercalated limestones, sandstones and red shales constitute the limy red-bed "Embar" of central Wyoming.

The northern boundary of the Embar occurs in south-cen
tral Montana approximately 70 miles from the Wyoming border. From this area the margin swings northeast across eastern Montana and into North Dakota, crossing the state line in the vicinity of Sidney, Montana. Here the lowermost shale is correlated with the Opeche of the Black Hill region with an
Map showing outline of the Phosphoria sea with areas of Phosphoria, Embar and Minnekahta-Opeche formations.

EXPLANATION

Outline of Phosphoria sea

Outline of existing Permian beds

Phosphoria

Embar

Minnekahta and Opeche
overlying limestone known as the Minnekahta. The eastern margin is defined by a line cutting across southwestern North Dakota and entering South Dakota in the vicinity of McIntosh, Corson County. From here the line continues southeastward to approximately 20 miles east of Pierre, South Dakota.

The Opechee shale and the Minnekahta limestone are typically exposed in the Black Hills and are recognized in the Hartville uplift to the south. In the Laramie Range beds that appear the same, although not exactly equivalent, are named the Satanka shale and the Forelle limestone. The red beds continue south into Colorado on both the east and west sides of the Ancestral Rockies in central Colorado, and also eastward into Nebraska.

Stratigraphic Nomenclature and Correlation

The Phosphoria formation was named from Phosphoria Gulch, a small stream that joins Georgetown Canyon near Meade Park, Bear Lake County, Idaho. Here the formation is typically exposed and consists of approximately 450 feet of limestone, massive cherts, shales and phosphatic rocks. The formation contains two distinct lithologic units. The upper unit, which consists of massive limestones and cherts, is called the Rex chert member, from Rex Peak in the Crawford Mountains, Rich County, Utah. The lower unit comprises the phosphatic shales, with which are included beds of limestone which may be fetid in places.

Equivalent lithologic members of the Phosphoria formation
are known to extend northward from northeastern Utah, where it is correlated with the upper Park City formation, through eastern Idaho to southwestern Montana and into adjacent areas in western Wyoming. The Phosphoria formation thins eastward to approximately 300 feet in western Wyoming where the same name is applied to a formation comprising cherty limestones and dolomites, phosphatic shales, and thin sandstone and chert beds. As in Idaho, the upper part of the formation (Rex chert) consists of almost pure chert beds with some cherty limestone. As usual, the phosphatic member is near the base, and within this portion there are several distinct layers of phosphate rock and phosphatic shale separated by clay, shale and limestone.

In the Wind River Mountains to the east, the Phosphoria, correlated with the type Phosphoria of southeastern Idaho, ranges in thickness from 200 to 300 feet, and consists of alternating beds of shales, limestones of different sorts, and unusual rock types, such as bedded chert and phosphate rock. In the Owl Creek Mountains the formation retains its typical lithologic character, but is considerably thinner.

Limestone and sandstone tongues extend east and south from the Phosphoria in the Wind River and Owl Creek Mountains, and interfinger with red shales. East and south the red shales become thicker, while the Phosphoria tongues become thinner and less conspicuous.

The upper limestone unit of the Phosphoria of the Wind River and Owl Creek Mountains has been named the Ervay
Tongue. It may be found at a number of places in central Wyoming, but its eastern and southern limits are not well known. According to Thomas (15, page 124) its horizon lies well in the Spearfish formation in the Hartville uplift, and for this reason a good portion of the Spearfish is considered of Phosphoria age. The exact position of this horizon has not been defined. Therefore, the writer is considering only the Opechee shale and the Minnekahta limestone as being of Phosphoria age.

The next lower tongue from the Phosphoria is the Forelle limestone which can be traced south to correlate with the crinkly limestone (Lykins) of Colorado. The Forelle may be discriminated over a wide area, but its northeastern and eastern limits have not been worked out.

The lowermost tongue of the Phosphoria is more widely distributed than the others. Thomas (27) in 1934, traced this tongue south to the Laramie basin, and at the time he named it the Sybille tongue. More recently (15, page 124) he concluded that this tongue extends to the Black Hills where it is known as the Minnekahta limestone. Thus, he has dropped the term Sybille and applied the name Minnekahta.

In the Laramie Basin the lower part of the Satanka shale, red-beds, separates the Minnekahta from the underlying Casper, (Pennsylvanian). In the Black Hills area the term Opechee shale is applied to beds equivalent to the lower Satanka. The upper Satanka separates the Minnekahta
Diagram illustrating general relations of stratigraphic units discussed in text. Geographic locations of sections shown on index map (Plate 1).
from the overlying Forelle.

The Minnekahta limestone and Opechee shale then cover the eastern portion of the area under consideration, namely southeastern Montana, southwestern North Dakota, western South Dakota and eastern Wyoming.

PALEOGEOGRAPHY
Permian Seas

A rather large enclosed sea, in which the cherts, the black, gray, and green shales, and the phosphate rock, which characterize the typical phosphoria, covered much of northern Utah, western Wyoming, the extreme western part of Montana and all of Idaho, extending north into British Columbia,(Plate 2). The sea was possibly connected to the central Pacific by way of northern California and Nevada, and with the northern Pacific and Arctic by way of British Columbia and Alaska. Because of the occurrence of a few species of Phosphoria fossils in the Permian of western Texas, it has been postulated that at some time there was a connection between the Phosphoria sea and the Permian sea of Texas by the way of Utah and New Mexico. Although geologists have contributed toward its understanding, its exact nature remains more or less obscure.

During earlier Phosphoria time the sea was distinctly separated from the mid-continent Permian sea by a province in which red beds (Opechee and Satanka) were deposited. Oscillatory movements of the Phosphoria sea with marginal mi-
gration to the northeast and southeast resulted in deposition of the limestones of the Minnekahta, Forelle and Ervay tongues. The transgression to the southeast may have been of such an extent during Forelle time as to connect the Phosphoria sea with the mid-continent sea.

Phosphoria time was terminated after the final transgression during Ervay time, which was of limited areal extent, by the withdrawal of the Phosphoria sea from the continent.

Depositional Environments

The location of positive areas that supplied land-derived materials during Phosphoria time are not definitely known. The Phosphoria sea, as previously noted, was in all probability an elongate hook-shaped body of water, that entered either from the north through British Columbia, or from the southwest through northern California, and overlay in part the Pacific element, Cascadia, on the west.

To the east, in the region that now comprises Wyoming, Colorado and Arizona, a less persistent land area, the Rocky Mountain element, is recognized as having existed.

These two elements, the Pacific element on the west and the north-south land barrier to the east, may have supplied the terrigenous material now preserved in the Phosphoria formation.

P. B. King says (16, page 89), "During Permian time an embayment from the Gulf of Mexico extended inland through Mexico into western Texas, where it divided into two branches,
one of which reached northeast into the Mid-Continent region beyond Nebraska, and the other penetrated the Cordilleran region of New Mexico, Arizona and Utah.

Thomas (27, page 1692) believes that the region east of Wyoming lying between these two embayments seems to be a logical source of supply for some of the material of the sediments of Phosphoria age in southeastern Wyoming, although the source does not seem adequate. He also notes that the increase in the amount of clastic material from west to east across Wyoming seems to indicate that some of the material came from east of Wyoming.

Red-beds to the south and east of the phosphate bearing areas indicates marginal seas, either in the form of playas or broad shallow lagoons with interrupted connections to the Phosphoria sea. Into these shallow basins residual red soils were deposited, which indicates an environment in which oxidation dominated over reduction. Limestone interbedded with the red beds indicates that the lands, from which sediments might have been derived, were relatively distant, or so low that little waste from the lands mingled with the debris of the calcareous organisms. The presence of cherts in nodules or minor bands indicates that siliceous organisms also inhibited the sea and that silica as well as lime was supplied in solution from bordering lands.

The presence of sandy or quartzitic beds within the Phosphoria formation, as in southwestern Montana, indicates
that such a district was near the shore of the sea or possibly that the neighboring land was high enough or steep enough to furnish clastic material.

Dr. Eugene S. Perry * has noted a conglomeratic phase in the Phosphoria formation near Three Forks, Montana, indicating proximity to a shore line with a land mass lying to the north or northeast of this area.

The mode of origin of the phosphatic oolites is not clearly understood, and many hypotheses have been advanced toward its explanation. Mansfield (18, page 366) contributes the following outline:

"The phosphatic oolites, were probably formed directly by biochemical and physical agencies from phosphatic solutions or colloids on the sea bottom. This material represents a slow gathering and concentration of phosphatic debris under conditions which largely excluded oxygen from the deeper waters and were thus unfavorable for forms of life that ordinarily inhabit the sea bottom and prevent the accumulation of organic debris. These conditions were induced by the considerable separation of the waters of the Phosphoria sea from the ocean and by the restriction in the circulation of its waters caused by this separation and by supposedly smaller temperature differences which then existed between high and low latitudes. Generally cool temperatures with some climatic oscillations prevailed during the time of deposition of the phosphate. These

* personal communication
conditions tended to favor the growth of plant and animal life in the shallower waters, while at the same time they reduced the activities of denitrifying bacteria, which curtail plant life and thus hinder the growth of animals dependent upon plants. Reduction of the activities of denitrifying bacteria may also have curtailed the precipitation of calcium carbonate, thus favoring the concentration of phosphatic solutions from which oolites might be formed. There was sufficient time for the postulated slow formation of the extensive phosphate deposits now found."

In general, oolites are considered to be a shallow-water type of deposition. Calcareous oolite is now being formed on the shallow southern floor of Great Salt Lake.

STRUCTURAL GEOLOGY

Since the time of deposition of the Phosphoria formation of Idaho, Montana, Wyoming and Utah, other sediments have accumulated so that many thousands of feet of subsequent strata have overlain them. The originally flat-lying sediments were then tilted, folded and broken by deformation of the earth's crust. Uplift of the land or recession of the sea has subjected these disturbed rocks to erosive forces so that large portions of the more elevated parts have been removed, and the truncated edges of the strata are now exposed at the surface, although often covered by material from overlying formations.
The folding and faulting started in the west and moved eastward. Thus, areas in Utah, Idaho, western Montana and western Wyoming were effected more so by folding and thrust faulting than areas to the east, where the folds are simple anticlines, domes and synclines.

The exposures of the Phosphoria formation in the western part of the area under consideration are traceable with difficulty, whereas to the east exposures are found at the truncated edges of uplifts such as the Laramie, Big Horn and Medicine Bow ranges and the Black Hills. Intervening basins, such as the Powder River, Wind River, Hanna and Laramie, contain the Permian beds overlain by thousands of feet of later accumulations.

No attempt is made here to note the presence or absence of the Phosphoria in specific localities throughout the region or to note the lithologic changes in detail. Instead, the following pages contain a general description for a few localities which the writer thinks are typical.

LITHOLOGY AND CHARACTERISTIC FOSSILS

Park City of Utah

Exposures of the Park City formation in the Uinta Mountains of Utah are divided by Schultz (25, page 46-53) into four parts, the second and third of which are correlated with the Phosphoria of southeastern Idaho. He describes the upper member, assigned to Phosphoria, as a cherty limestone,
variable in detail but prominent and easily recognized. It consists of massive, gray to cream-colored limestone 20 to 25 feet thick, underlain by gray to greenish dark chert in a matrix of shale. Certain parts are highly fossiliferous and contain abundant specimens of *Leioclema*, *Derbya*, *Spiriferina pulchra* and *Lingulidiscina utahensis*.

The phosphatic shale is made up of black and green fissile shale, 40 to 50 feet thick, and beds of limestone, sandstone, chert and phosphate ranging in thickness from a few inches to several feet. Some limy beds of phosphate contain an abundance of fossils. In addition to Bryozoans there are numerous comminuted fossil fragments, glauconite, and scattered foramaniferal shells. The Phosphoria ranges in thickness from approximately 600 feet near Park City to 70 feet near the Utah-Colorado border.

**Phosphoria of Southeastern Idaho**

**Phosphatic shale member:**

The lower part, or the phosphatic shale member, of the Phosphoria formation overlies the Wells formation of Pennsylvanian age. It is characterized by 75 to 180 feet of yellowish to brown phosphatic sandstone, dark brown to black phosphatic shales, beds of brown or black fetid limestone, and one to three economically valuable beds of phosphate rock. The phosphate rock is gray, brown or black with fine to coarse oolitic texture. The ovules or oolites are rounded grains that are built up in roughly concentric
structure and range in size from extremely minute specks to bodies half an inch or more in diameter. When the rock is freshly broken a strong fetid odor is given off, like that of crude petroleum, and it is exceedingly penetrating. The strength of the odor is not indicative of the relative phosphatic content. Weathered fragments or pieces of float develop a characteristic bluish-white "bloom" and commonly white reticulate markings. The thicker and generally richer beds of phosphate rock occur at or near the base, and range in thickness from 4 to 7 feet. The other valuable beds are thinner and occur near the top and the middle.

The Phosphoria shows considerable variation in lithology between the northern and southern parts of southeastern Idaho. In southern Idaho the phosphatic shale member contains about 75 percent shale, 17 percent oolitic phosphate rock and 8 percent limestone, while in the northern portion the percent of shale and phosphate rock decreases to about one half the amounts shown above, and the limestone increases in percentage. Also, much more sandstone appears to the north.

The phosphate rock itself is practically nonfossiliferous, although a few discinoids and bone fragments have been found. The beds that accompany the phosphate rock, however, yield a richer fauna. The following list has been selected by Girty (12) as characteristic of the phosphatic shales.

Lingula carbonaria (?)
Lingulidiscina missouriensis
Chonetes ostiolatus
Productus geniculatus
Productus eucharis
Rex chert member:

The Rex chert is the conspicuous part of the Phosphoria formation. Because of its superior hardness it stands out as strong cliffs and ledges, whereas the weakness of the phosphatic shales commonly cause them to weather into gullies and depressions. The lower 50 to 75 feet of this member is composed of massive chert, which microscopically consists of cryptocrystalline quartz with tiny scattered fragments of the same material. The color of the chert is dark gray or black, but in places purplish, flesh tints or even white has been observed.

Above the chert are massive beds of limestone so crowded with fossils, especially Productus, that the name "upper Productus limestone" has been applied. Frequently found in the limestone are the following fossils as reported by Girty (18, page 79).

Productus multistriatus
Productus subhorridus
Spirifer aff. S. cameratus
Spiriferina pulchra
Composita subtilita var.

The cherty member is generally nonfossiliferous, but locally it contains sponge spicules, discinoids and casts of crinoid stems.
The Rex chert member shows a considerable range in thickness, from 110 to 550 feet, as well as a variation in lithology. Northward the limestone becomes absent, and the chert becomes largely a dark, flinty shale, though usually some beds of massive chert are also present. Still further north, approaching southwestern Montana, the Rex chert member is largely quartzite.

The Rex chert member in southeastern Idaho is overlain disconformably by the Woodside shale of Triassic age.

Phosphoria of southwestern Montana

The Quadrant of Pennsylvanian age is overlain by 100 to 250 feet of dark-gray cherty quartzite layers, and ropy masses of nodular chert and shale, with one or more beds of phosphate rock. The sequence is regarded as equivalent to part of the Park City formation of Utah, and more nearly equivalent to the Phosphoria formation of Idaho. The line of division between the Quadrant and Phosphoria is commonly marked by a few inches of conglomerate and a non-persistent bed of phosphate rock. It is suspected that these beds denote an unconformity. The overlying rock is a dark-gray cherty quartzite with scattered phosphorite granules, differing chiefly in color from the purer quartzitic sandstone below, which is pinkish-gray crossbedded and intercalated with argillaceous creamy limestone.

The Phosphoria is notably siliceous being either cherty or quartzitic almost throughout. In Yellowstone Park and to the west along and near the Idaho state line, the irregular layer of phosphate rock at the base is made up of frag-
ments of phosphatized shells of the brachiopod *Lingulidiscina utahensis*, together with fossil bones. In some places the phosphatic material appears as a resinous brown substance forming a cement for the sandstone. At 30 to 60 feet above the base of the Phosphoria occur other phosphatic beds consisting of one or more layers of gray to black oolitic phosphorite, and perhaps a few feet of dark shale overlain by chert either in thin wavy layers or as nodular masses mixed in an irregular manner with brownish quartzite. The upper most beds of the Phosphoria contain poorly preserved brachiopod shells and fish bones, probably of Permian age.

North of the Idaho-Montana border the Phosphoria is overlain unconformably by Triassic strata.

**Phosphoria of Western Wyoming**

In this area strata 300 to 500 feet thick, lying between the Tensleep sandstone (Pennsylvanian) below and the Dinwoody shale (Triassic) above, are designated the Phosphoria. It is correlated with the upper Park City of northeastern Utah and the Phosphoria of Idaho and southwestern Montana. In the Wind River and Owl Creek mountains the strata contain phosphate rock; and according to Condit (8, page 11) the upper part is divisible into three rather distinct members, namely the *bryozoan-bearing limestone*, the phosphate shale and the lower bryozoan-bearing limestone, with an underlying lower part.

The upper bryozoan-bearing limestone is variable in
in detail, but is a prominent easily recognized member. It consists generally of massive gray to cream-colored limestone 30 to 60 feet thick, underlain by greenish nodular chert in a matrix of shale. It has abundant large specimens of the bryozoan *Leioclema* and the brachiopods *Plicatod derbya* and *Spiriferina pulchra*.

The phosphatic shale member consists of sepia brown to nearly black shale, 20 to 40 feet thick, and more or less cherty in the upper portion. It is for the most part notably fissile, and has bands of limestone and oolitic phosphate. Fossils are rare but the following have been identified from material collected in the principal bed of phosphate at the base of the shale.

Nucula  
Pleurotomaria  
Productus nevadensis  
Productus subhorridus

The lower bryozoan-bearing limestone is a little above the middle of the formation. It is gray to brown, and becomes distinctly darker and more phosphatic toward the top. This limestone contains abundant fossils, the most prominent being *Leioclema* and *Spiriferina pulchra*. Also plentiful in a few places is *Chonetes aff. C. geinitzianus*.

The lowest division of the Phosphoria, although more variable than the other members, generally consists of two shaly zones, each underlain by beds of dolomite, sandstone and chert. The shales are yellow to green, and the lower shale contains much chert in the form of then greenish laminae. About 50 feet above the Tensleep sandstone is a
massive gray limestone ledge, beneath which is a phosphate bed filled with the disk shaped shells of Lingulidiscina utahensis.

Embar of Central Wyoming

As previously noted, the red-bed Embar of central Wyoming constitutes intercalated limestones, sandstones and red shales. Tongues of limestone and sandstone extend east and south from the Phosphoria of the Wind River and Owl Creek mountains, and interfinger with the red shales of Chugwater (Triassic).

Literature concerning the Embar is not too plentiful, and the lateral extent, as well as the lithologic character of the various tongues, has not been too well defined in existing publications. The problem requires more investigation, but in the light of present knowledge the following is presented.

The marine fossil, Plicatoderbya, is found as a conspicuous element in the upper limestone unit of the Phosphoria in the Wind River and Owl Creek mountains. The same fossil is found in exposures of limestone above several hundred feet of red beds west of Casper, Wyoming in the Rattlesnake Hills, and also at a number of places in central Wyoming. This limestone is then about the age of the top of the Phosphoria, and has been named the Ervay tongue. Its limits are not exactly known.

The next lower tongue of the Phosphoria, known as the
Forelle limestone, is of marine origin, and in places carries poorly preserved pelecypods and gastropods. It has a crinkly structure and on this basis it can be discriminated over a wide area, although its eastern and northeastern limits have not been worked out. It has been traced southeast to the Laramie Basin, and correlated with the crinkly limestone of Colorado. The intervening red-beds, between the Ervay and Forelle tongues, differ considerably in the details of their lithology from place to place.

The lowermost tongue of the Phosphoria is of greater areal extent than are the others. Its correlation from place to place is based on its position above the red beds separating it from the Tensleep sandstone, and also upon peculiar geodal structures common to it. The abundance of an elongate scaphopod, *Plagioclopta*, also serves for correlation, however the range of this genus is not restricted to this tongue. The Minnekahta to the east has been correlated with this lowermost tongue. Its southernmost limits are uncertain.

The red-beds between the Forelle and the Minnekahta are simply red shales and siltstones. These represent the upper part of the Satanka shale of the Laramie Basin, the lower part of which separates the Minnekahta and the underlying Tensleep. These red-beds are considered equivalent to the Opechee shale to the east.
Embar of South-central Montana

The Embar here consists of yellowish-brown sandstone, siltstone, dolomite and limestone with some red and greenish-gray limestone. The entire unit is non-resistant, and reaches a thickness of 80 feet.

The following section, measured by Hendricks and Rogers (11, page 78), occurs approximately 60 miles west-southwest of Billings, Montana.

<table>
<thead>
<tr>
<th>Embar formation:</th>
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</thead>
<tbody>
<tr>
<td>Limestone, light gray, dolomitic, very sandy, many thin clay partings.</td>
</tr>
<tr>
<td>Dolomite, white, finely crystalline, massive, middle part weathers porous.</td>
</tr>
<tr>
<td>Dolomite, light gray, finely crystalline, thin bedded layers 1 to 2 inches thick.</td>
</tr>
<tr>
<td>Siltstone, yellow, sandy; layer of green fissile shale 4 inches thick at top of unit.</td>
</tr>
<tr>
<td>Siltstone, red, calcareous, sandy, chippy.</td>
</tr>
<tr>
<td>Sandstone, yellow with green tint, friable, medium grained; conglomeratic zones with pebbles of red chert.</td>
</tr>
</tbody>
</table>

Total thickness... 79

Another section measured by Hadley and Rogers (11, page 80) approximately 60 miles east of the section noted above, is notably thinner, but lithologically similar. The two beds of dolomite are missing in this section.

Minnekahta and Opeche

In the Black Hills, where the Permian is typically exposed, occur the Opeche shale and the Minnekahta limestone. The Minnekahta is overlain by the Spearfish of Triassic age, while the Opeche is underlain by the Casper sandstone of Pennsylvanian age.

The Opeche shale consists of a thin series of irregular,
red and purple, soft clay shales, 60 to 150 feet thick. In places there is a basal sandstone or conglomerate. Gypsum often makes up an appreciable part of the formation. Above it the Minnekahta consists of 30 to 50 feet of purplish, crinkly limestone. It is thin-bedded and close-textured, and makes a prominent outcrop. The fauna of the Minnekahta is sparse and is molluscan in nature. None of the typical Phosphoria brachiopods were able to exist in the environment in which the Minnekahta was deposited, perhaps because of too warm, too shallow or too saline water.

ECONOMIC GEOLOGY
Phosphate
Phosphate rock deposits occurring in the Phosphoria formation or its equivalents are irregularly distributed over an area of about 100,000 square miles. The western phosphate region includes adjoining parts of Montana, Idaho, Wyoming and Utah. The northwestern limit is defined by the Garrison and Phillipsburg fields southeast of Missoula, Montana. North of this area the Phosphoria formation has been removed by erosion.

The phosphate beds exhibit a considerable range in thickness and purity, containing approximately 35 to 80 percent tricalcium phosphate known as "bone phosphate of lime" or b.p.l. The beds differ in thickness from a few inches to as much as 8 feet. The phosphate deposits of Montana average approximately 55 percent tricalcium phos-
phate although the grade differs from place to place. In Wyoming the average is somewhat lower, about 40 percent, while in southeastern Idaho and northern Utah the average approaches 70 percent b.p.l.

The 1940 estimate (19) of reserves of phosphate rock in the western states amounts to approximately 13,300,000,000 tons, of which 5,700,000,000 tons occur in Idaho, 1,740,000,000 tons in Utah, 400,000,000 tons in Montana and 115,700,000 tons in Wyoming. Production in the western states amounts to approximately 800,000 tons per year. Two thirds of the phosphate rock produced is used in the manufacture of superphosphates for fertilizer. Other uses are in safety matches, medicines, cements, photography, ceramics and as supplement for livestock feed.

Petroleum

Bartram (2, page 870-873) states that oil in the Embar limestone occurs in porous dolomite, chert beds and in a few places in thin sandstones. He also shows that there is no porosity at the top of the Embar formation of central and north-central Wyoming, and that in every field there is 25 to 125 feet of dry barren limestone overlying the oil or water reservoir. The barren limestone is green, and in some places contains glauconite. Beneath it are coarse chert beds in a matrix of shaly limestone, dolomite, and calcareous shale which is the producing horizon. Lower in the Embar some porous dolomite or sandy limestones occur, and yield some oil or water; but they are not commercially
important. In the lower part the limestones are dense and tight with much more shale.

Oil has not been found in the Embar of Montana, but in north-central Wyoming the Embar carries a heavy black oil in many fields, which probably could be produced in large amounts. In the past the expense of refining has been rather high, and the market price has been low. The Warm Springs, Grass Creek, Oregon Basin and Elk Basin fields of the Big Horn Basin produce black, heavy oil from the Embar. Heavy oil also occurs in the Black Mountain anticline, and in the Sunshine and Maverick Springs fields. Near Lander in central Wyoming the Embar is found at a depth of 900 feet and is said to contain black oil. To the writer's knowledge, the Embar is barren in south-central and eastern Wyoming, and the Dakotas.

ISOPACH MAP

Discussion

In the compilation of the isopach map lines of equal thickness of the Permian strata are drawn at 100 foot intervals and shown in heavy black, with the intermediate lighter lines drawn to indicate 50 foot intervals. In areas where dashed lines occur, information is lacking as to thickness and limits. The map is so constructed that no provision is made for the absence of deposits in certain areas as in the truncated uplifts. Lines are drawn across these areas as though there had been no uplift and no erosion.
The map shows an area of greatest thicknesses extending from northern Utah and southeastern Idaho, east to central Wyoming and then east southeast to Nebraska. To the north of this area deposits become thinner in Idaho, southern Montana, northern Wyoming, and the eastern parts of the Dakotas. South of the area of greatest thicknesses the deposits also become thinner, with the zero line surrounding the ancient Colorado land mass in north-central Colorado.

The foregoing then supports the conclusion that the basin of greatest accumulation occurred in the Cordilleran geosyncline with an intermediate basin in central Wyoming possibly connecting the Phosphoria sea with the Mid-Continent Permian sea by way of Nebraska. The zero line in north-central Colorado can be postulated as approximating a shore line surrounding the Colorado land mass.

The thicknesses shown in southwestern Montana and adjacent parts of Wyoming and Idaho are less than those to the south. Although this area may have been part of the geosyncline occupied by the Phosphoria sea, the decrease in thickness can be accounted for by the approach to a shore line to the northeast and by pre-Ellis erosion having removed parts of the Phosphoria formation in this area.

**SUMMARY**

Permian strata in adjacent parts of Utah, Idaho, Montana and Wyoming, known as the Phosphoria formation, were deposited in a more or less enclosed sea occupying the Cord-
The Phosphoria sea entered by way of British Columbia from the north or by way of California and Nevada from the southwest. Limestone tongues were deposited with marginal migrations of the Phosphoria sea eastward. These tongues were intercalated with continental red-beds. The limestones thin to the east and south while the red-beds thicken. During Forelle time the transgression reached the Mid-Continent Permian sea by way of Nebraska. Permian deposits in the eastern part of the region constitute the Minnekahta limestone and the underlying Opechee shale, which occur in eastern Wyoming and adjacent parts of Montana and the Dakotas. The isopach map was constructed as an aid to those engaged in drilling through Permian strata and as an aid in correlation of strata. Extensive reserves of phosphate rock occur in the Phosphoria formation of Utah, Idaho, Montana and Wyoming. The Embar of central Wyoming is a producer of heavy black oil.
BIBLIOGRAPHY

The bibliography contains the more important sources from which material has been taken for discussion in the text. Thicknesses for the isopach map of Permian strata have been taken from many sources other than those listed.


19. , Economic Geology.


ISOPACH MAP OF PERMIAN STRATA IN WYOMING AND ADJACENT AREAS

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