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Areal Geology of the Post-Paleozoic Surface of the Northwest Plains

William M. Broderick

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OF

THE NORTHWEST PLAINS

By

William M. Brodrick

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements of the Degree of
Bachelor of Science in Geological Engineering

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INTRODUCTION

Realizing the increasing importance of sub-surface geology especially in the petroleum field, the writer undertook this problem at the suggestion of Dr. E. S. Perry and Dr. L. L. Sloss of the Geology Department of Montana School of Mines.

This paper was written as partial fulfillment for the Degree of Bachelor of Science in Geological Engineering. The material was gathered during the school year 1939-1940, and the report written and maps drawn in April of 1940.

Probably most of the area included in this report has been examined to some extent by oil geologists, and most, if not all, of the important domes have been discovered and surveyed thoroughly. In parts of the area, the bedrock is covered by glacial drift or alluvium material, but it is reasonable to believe that no new domal structure will be found. This means that surface examination alone will be insufficient in locating new oil fields, so future prospecting will be dependent, to a great extent, on studies of sub-surface stratigraphy.

With this thought in mind, the report was written and the map drawn hoping that they would reveal, with a fair degree of accuracy, the relative positions of different formations prior to the laying down of the Mesozoic sediments. It was also hoped that a basin, dome, or other favorable oil structure might be brought to light, and since the depletion of shallow zones in many oil producing localities has caused deep drilling into pre-Mesozoic rocks to come into prominence, a map of this sort may be of some value.

The writer wishes to acknowledge the assistance of Dr. E. S. Perry and Dr. L. L. Sloss of the Geology Department of Montana School of Mines, under whose supervision this paper was written. Their many helpful suggestions, assistance in correlating the information, and help in drawing the final map, greatly benefited this report.

GENERAL GEOLOGY OF THE NORTHWEST PLAINS

Structure

The greater part of this area is characterized by flat or rolling plains, underlain by a thick succession of Tertiary, Cretaceous, Carboniferous, and older strata. Occasional isolated areas of mountain uplifts are scattered throughout the area, especially in Montana and Wyoming. The origin of these may be one of three different types of structure. Some were caused by intrusion of igneous rocks into sedimentary beds, others caused by the extrusion of lavas on a nearly level surface, and a third may be due to large asymmetrical folds. These have formed many ideal oil structures, some producing oil and gas, while others are entirely lacking in them. It has been noticed that the structures that contain petroleum are complexly faulted; the displacement of which in many cases does not exceed over 20 to 50 feet, but in some cases may be 100 feet or more. Dr. Perry* believes that the intensive artesian circulation in this area flushed the oil and gas from the structures except those that were faulted, and that these faults displaced the beds in such a manner as to seal the channel of circulating ground-water and stopped the circulation in that area.

The Rocky Mountains, which border the area on the west, covering Idaho, western Montana and western Wyoming, are a continuous succession of compressed folds, great overthrust faults, and widespread igneous intrusions and extrusions. Wide flat intermontane valleys are common, filled in many cases with sediments of lake origin.

Stratigraphy

The size of the area concerned in this report made it necessary to draw up a correlation chart for the different formations. Different names have been given to the same strata in different localities, so it was essential that equivalent beds be correlated in order to make a clearer understanding of the stratigraphy of this area. (See Plate I.) A description of only the strata exposed at the surface of post-Paleozoic time will be made.

The Madison Formation.--The Madison limestone (Mississippian age) ranges from 800 to 2,000 feet in thickness. It was named from outcrops in the Madison river valley, south of Three Forks, Montana. In this area the limestone is light to dark gray in the upper por-

*Oral Communication.

PLATE I

CORRELATION CHART OF FORMATIONS IN THE ROCKY MOUNTAINS AND NORTHWEST PLAINS

Age	Wasatch Mountains Utah	Black Hills Area So. Dakota	Wind River Canyon Wyoming	Yellowstone Park Wyoming	Three Forks Montana	Little Belt Mountains Montana	Little Rocky Mountains Montana	Williston No. Dakota	Alberta Canada
Jurassic	Morrison Twin Creek Nugget	Morrison Sundance	Morrison Sundance	Morrison Ellis	Morrison Ellis	Morrison Ellis	Ellis	Morrison Sundance	Fernie
Triassic	Ankareh Thaynes Woodside	Spearfish	Chugwater	Spearfish	Chugwater			Spearfish	Spray River
Permian	Park City	Minnekahta Opeche	Phosphoria	phosphoria	phosphoria			Minnekahta Opeche	
Pennsylvanian	Weber	Minnelusa	Tensleep Upper Amsden	Quadrant Upper Amsden	Quadrant Upper Amsden	Upper Amsden		Upper Amsden	Rocky Mountain
Mississippian	Brazer Madison	Lower Amsden Pahasapa Englewood	Lower Amsden Madison	Lower Amsden Madison	Lower Amsden Big Snowy Madison	Lower Amsden Big Snowy Madison	Madison	Lower Amsden Big Snowy Madison	Rundle Banff
Devonian	Three Forks Jefferson			Three Forks Jefferson	Three Forks Jefferson	Three Forks Jefferson	Three Forks Jefferson	Devonian	Minnewanka

tions, and commonly more crystalline and massive than the lower part. Frequently chert nodules are present along the bedding planes. The middle and lower part of the formation are usually finer grained and contain thin clay seams, and in some places are sandy. The lower portions also contain beds of black limestone and bands of dark chert. Fossils are scarce in much of the formation, although locally a few beds are highly fossiliferous. The Madison is equivalent in part to the Pahasapa formation in the Black Hills area.

The Madison is an important formation in connection with the oil industry. Its upper portion is a reservoir rock in the Kevin-Sunburst field, Montana, and also the Turner valley field, Alberta, Canada. In many fields it is the "floor" to which drilling is planned.

The Big Snowy Group.--That group of strata that occurs between the Madison and Amsden of central Montana has been designated the Big Snowy group of Mississippian age, because of its extensive distribution and excellent exposure in the Big Snowy Mountains of Montana.

The beds occur over an area of approximately 20,000 square miles and obtains a maximum thickness of nearly 1,600 feet. Until recent work by Scott,* this group of sediments together with the Amsden formation, which lies above it, erroneously had been called the Quadrant.

The upper 500 feet, called the Heath formation, consists of black petroliferous shale with sandstone lenses. The middle portion of the formation consists of approximately 600 feet of gray to green shales

*Scott, H. W., Some carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. of Geol., Vol. 43, Part II, pp. 1011-1032, 1935.

intercalated with thin oolitic and fossiliferous limestone.

The Devil's Basin field of Montana is the only locality where commercial amounts of oil or gas have been found in the Big Snowy formation. The Heath is an excellent source rock and the Kibby and Heath sandstones would make good reservoir rocks.

The Amsden Formation.--The Amsden formation received its name from its exposures along a branch of the Tongue River near Dayton, Wyoming. It was originally considered Pennsylvanian in age, but later it was shown to be Mississippian in part.

In south-central Montana and north-central Wyoming the formation consists of two zones, a lower red magnesian shale and an upper limestone layer. The lower zone has an average thickness of about 100 feet. Near Gardiner, Montana, it is 130 feet thick and decreases in thickness northward until it is only 25 feet thick just north of Three Forks, Montana.

The limestone member is blue-gray, thinly bedded, and averages 160 feet in thickness in central Montana. This member also has a decreasing lateral gradation from the south to the north, and in conjunction with this, the limestone becomes arenaceous and pink in color in the basal part.

The Quadrant-Tensleep Formation.--In southern Montana and the Yellowstone Park area, the Quadrant formation, which is Pennsylvanian in age, consists of white, yellowish, and pink beds of quartzite. The quartzite is generally compact, occurs in beds from 4 to 25 feet in thickness, and in certain localities is intercalated with drab saccharoidal limestone. The total thickness averages 400 feet in the Gallatin range.

On the basis of stratigraphic, lithologic and faunal evidence, the Quadrant of Montana has been correlated with the Rocky Mountain quartzite of Alberta, Canada, the Tensleep formation of Wyoming, and the Minnelusa of the Black Hills area. The Tensleep is a buff- to cream-colored sandstone, 75 to 100 feet in thickness, not particularly hard, and somewhat calcareous in places. It is an important reservoir rock in the Big Horn basin of southern Montana and northern Wyoming and is one of the chief producers in other Wyoming fields. The Minnelusa formation is from 350 to 600 feet thick and consists of white to brownish sandstones in massive beds. Local beds of limestone, mostly thin, are included in the middle of the formation.

The Phosphoria-Embar Formation.--The Phosphoria, which is Permian in age, consists of 100 to 250 feet of dark gray cherty quartzite, layers of nodular chert and shale, with one or more beds of phosphate rock. In some places the phosphate material appears as a resinous brown substance, forming a cement for the brown sandstone, but in general the phosphatic material is oolitic or pisolitic. 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 phosphate.

In the Black Hills region the Minnekahta limestone and the Opeche shale are equivalent to the Phosphoria. The limestone has a purple tinge from which the old name "purple limestone" was derived. The shales are red in color and occur in thin beds.

The Phosphoria is also equivalent to the Embar formation of Wyoming where it yields oil and some gas, and the Park City formation of the Wasatch Mountains of Utah.

The Chugwater-Spearfish Formation.--The Chugwater formation (Triassic age) was named from its exposures along Chugwater Creek in southeastern Wyoming. It is composed mostly of bright to dark red sandy shales and sandstone. The brilliant red contrasts sharply with the browns and grays of the associated strata, and can be readily traced by its flaming outcrops and soils. Near the top of the bed, pure granular gypsum forms a bed 5 to 40 feet thick and small gypsum veinlets are abundant near the bottom. It is an important formation in the Black Hills region where it is known as the Spearfish. In the Wasatch Mountains of Utah, the Triassic is composed of 1,100 feet of red shales (Woodside) at the base; next above, a two-parted sandy calcareous formation (Thaynes limestone) 1,200 feet thick, and at the top, a red shale (Ankareh) 1,100 feet thick, all of which may be correlated with the Chugwater and Spearfish.

PROCEDURE

Source of Information

The nature of this paper made it necessary for the writer to gather all the information from already published material, and no field work was attempted.

Logs of oil, gas, and water wells were one of the main sources of data. These were obtained from the United States Geological Survey publications, various state publications, American Association of Petroleum Geologists' bulletins, and other sources. Logs of the Turner Valley oil fields in Alberta, Canada, were obtained from "Schedule of Wells Drilled for Oil and Gas to 1938" by F. K. Beach, published by the Department of Lands and Mines of the Province of Alberta, Canada.

Another source of information was from measured geologic sections in different areas, especially in the mountainous regions where the older formations were exposed. In addition to the above mentioned publications, sections were obtained from the Journal of Geology, American Journal of Science, Canadian Geological Survey memoirs, and other publications.

Valuable information was also obtained by personal communication with Dr. E. S. Perry and Dr. L. L. Sloss, whose field work in recent years made it possible to interpret the information gathered with a greater degree of accuracy than could have been done without their assistance.

Methods of Assembling It

Since a map of the areal geology of the pre-Mesozoic surface was to be the ultimate objective of this undertaking, it was necessary to plot all information on a map of the area included. Individual state maps were used as work sheets, and every locality, where suitable information was obtained, was marked on the map with a letter indicating the formation underneath the Mesozoic sediments and a numeral which served as an index to a reference sheet which contained a brief description of the formation, its thickness, and the source of information.

When all the data was plotted, the state maps were compiled into one large map of the northwest plains, and all the information was transposed onto it. The contacts between the formation were then interpreted and drawn in.

In order to give a better understanding of the structure of the beds, three cross-sections were drawn--one drawn across the area in a north to south direction and two in an east to west direction.

Difficulties

As was expected, many difficulties were encountered. Lack of information in certain localities greatly subtracted from the accuracy of the final map. Only one well log which was of any value was found in North Dakota. Little information was available in western Minnesota, and only a limited amount in Nebraska and South Dakota. Due to the oil and gas fields in Montana and Wyoming, and also the mountain uplifts, which afforded many geologic columns, a great amount of material was available in those states. Nevertheless, there were certain important localities, such as northeastern Montana, that were devoid of information. Data was lacking in southern Saskatchewan, but in southern Alberta the Turner Valley oil and gas field and other small fields, provided a useful amount of information.

There have been many wells drilled throughout this entire area, but since many were drilled for water, the greater majority of them are comparatively shallow, and did not reach pre-Mesozoic rocks. Records were found of some deep wells which extended in some cases to rocks of pre-Cambrian age, but in many instances the logs were lost, no record kept, or the logging done by the driller himself and never correlated by a geologist and were, therefore, of little use.

In the past few years, deep test holes have been sunk by several oil companies, but most of their findings are not available to the public as yet.

Misinterpretation of well logs was another source of error which had to be kept in mind. No faulty logs were found, but in some cases one was discarded because it did not seem to correlate with other logs nearby.

Several erroneous geologic columns from early work done in this area were uncovered. This is not meant to reflect on the work of the early geologists, but new evidence brought to light in recent years has altered their conclusions to some extent. These errors were pointed out by Dr. Sloss and Dr. Perry and were discarded.

MATERIAL RESULTS

The Map

The map brought out two outstanding structural features. (See Plate 3.) One of these was a large dome of pre-Jurassic age occupying north-central Montana, southeastern Alberta, and southwestern Saskatchewan. The northern and southern extent of the dome was fairly well established due to the amount of information obtained in these localities. However, the lack of data on the eastern and western side made it necessary to make certain assumptions as where to draw the contacts between the different formations. These are indicated by a broken line.

This dome is very similar to the Cincinnati arch in Ohio, which has been a good oil producer in the past. Both are composed of Paleozoic, and both are related to an adjoining basin on the east side of them. The Cincinnati arch is just west of the Appalachian basin, and the domal area in Montana and Alberta is just west of the basin near Williston, North Dakota.

East of this dome and occupying northeastern Montana, northwestern North Dakota, and southern Saskatchewan, a basin is indicated by the distribution of Paleozoic outcrops. Information was lacking in the basin area itself, but by the stratigraphic arrangement of the formations on both the west and east side, and the log of a deep test well located near Williston, North Dakota, the basin was proven. The eastern limb terminated in Minnesota and Manitoba, where the beds lapped up on the Canadian Shield.

The Cross-sections

Three cross-sections were drawn across the area. (See Plate 2.) One (section A-A') was drawn in a north-to-south direction from Saskatchewan, through central Montana, western Wyoming, and into Utah. This brought out the large domal structure referred to above, as well as the southern extent of the Big Snowy formation, which pinches out near Three Forks, Montana. It also shows the pinching out, to the north, of the Quadrant formation in the same vicinity.

Another section (section B-B') was drawn from west central Alberta, down through southern Saskatchewan to the Montana border, and thence along the International Boundary to Minnesota. This shows the relationship of the domal and basin structures.

A third section extends east and west across the area along the Montana-Wyoming border. This shows only the regular sequence of beds dipping slightly to the west, with the older Paleozoic cropping out in eastern South Dakota and western Minnesota.

Distribution of the Sediments Beneath Mesozoic Sediments

The Phosphoria-Embar-Minnekahta formation of Permian age has the most extensive outcrops of any of the strata in the area. The entire area south of the Montana-Wyoming border has Permian strata underlying Mesozoic strata, and the same condition exists over the western half of North Dakota and most of South Dakota.

The Madison limestone probably occupies the next largest area, forming a large circular pattern in Montana, Alberta, and Saskatchewan.

Forming a ring around the Madison, the Big Snowy, and the Amsden of later Mississippian age, and the Quadrant of Pennsylvanian age outcrops in this area, indicating the presence of a dome.

The greater part of the Big Snowy group was covered by the Amsden and, therefore, has only a small outcrop area in central Montana.

In the eastern part of the area, the Pennsylvanian, Mississippian, and pre-Mississippian beds are exposed at the surface.

THEORETICAL DEDUCTIONS

Geologic History of the Paleozoic Era

At the very outset of the Paleozoic era, the Cambrian seas began to encroach upon the lowlands of North America. They are seen not to be distributed over the present lowlands, but are limited to two comparatively narrow belts, which have been named the Appalachian geosyncline in eastern United States and the Cordilleran geosyncline in the western part of the United States. It is the latter one that is related to the geologic history of the area included in this report.

A great thickness of Paleozoic rock was deposited in this trough by the marine waters. From time to time the influx of water would cause the geosyncline to overflow and flood the area to the east, depositing the Paleozoic sediments in that region.

Since the formations of Ordovician, Silurian, and Devonian age were lumped together as pre-Mississippian, only a word or two will be said about their geologic history.

The Ordovician and Silurian seas did not extend very far north in the trough. The only Ordovician formation in Montana is the Big Horn dolomite in the Big Horn mountains in southern Montana and the Silurian is missing in Alberta, Montana, Idaho and northern Wyoming. The Devonian sea was more widespread than either the Ordovician or Silurian, depositing relatively thin formations in most of the area. It is, however, absent in the Black Hills and the Big Horn mountains.

During the Mississippian period, immediately following the Devonian, the entire area was submerged as far east as western Minnesota. Over 1,000 feet of limestone were deposited and are persistent throughout the area. Following this deposition, local forces caused warping of the area in Montana and Alberta forming a broad gentle dome-like uplift. Post-Madison age was given this uplift due to the fact that there was no thinning of the Madison limestone, except from erosion, in this area, but the overlying sediments all thin out as they approach the dome, and it is believed that some were never deposited on top of the dome. During middle and upper Mississippian time a large inland sea invaded Montana. It extended in an east to west direction through the central and east part of the state, and laid down 1,500 feet of sediments, which have been named the Big Snowy formation. Later-

Mississippian time brought on another widespread inundation of the sea, laying down the Amsden formation, consisting of shales and limestone.

The Pennsylvanian period began with a widespread advance of the sea, depositing marine sandstones and conglomerates, and closed with a general retreat of the seas. To the south, in Oklahoma and Arkansas, mountain uplifting closed the period. Pennsylvanian sediments are not present in the domal area in Montana, and there could be two different explanations for this. One is that it was deposited and later eroded away, exposing the underlying formation, and the second explanation is that it never was deposited in this area due to the fact that the structure was elevated to such an extent that it was not covered by the Pennsylvanian sea. This seems the more plausable, due to the fact that the Quadrant formation, Pennsylvanian age, seems to pinch out near Three Forks, Montana, indicating that it terminated on the limb of the anticline. Another reason for this belief is that the Amsden formation, upper Mississippian in age, is seen to be gradually thinning as it approaches the middle of the dome. Erosion has cut away the part where it would actually pinch out completely, and since it is not reported on the northern limb, it is evident that it was never deposited.

The geologic history during the Permian time is still indefinite. It opened up with more or less continued sedimentation from the Pennsylvanian period making the Permian-Pennsylvanian boundary very hard to distinguish. The seas covered most of the area, but it seems probable that central and northern Montana, and southern Alberta were land masses. Also Minnesota, eastern North Dakota, eastern South Dakota, and eastern Nebraska were above the level of the sea.

Inland Seas

Probably there were only three inland seas that did not originate from the Cordilleran trough in this area after Devonian time and prior to the laying down of the Jurassic sediments. One of these was the middle Mississippian sea in central Montana, which laid down the Big Snowy sediments. Recent work by Scott*, shows that the western limit of this sea was in the vicinity of Helena, Montana. It probably did not extend past Three Forks and Livingston, Montana, on the south, but on the north, it has been eroded away near Great Falls, Montana, so the northern limit of it has not been determined. Just how far east the sea extended is not known, but it extends at least to Williston, North Dakota, where 1,800 feet of Big Snowy sediments were laid down.

The Permian sea came in from the south as indicated by the increasing thickness of the beds in that direction, and in Jurassic time the sea encroached from the north, depositing the Ellis formation.

Areas of Erosion

In north-central Montana and southern Alberta a large erosion area existed at or shortly after the close of Madison time. In this area the Madison is overlain by Jurassic sediments, showing the removal of all the upper Paleozoic that may have been deposited there. Around the flanks of this domal area is more evidence of the removal of certain Paleozoic formations.

*H. W. Scott, op. cit.

During Triassic time, the entire state of Montana, except the southern and eastern part, suffered extensive erosion. This erosion period extended into middle Jurassic time.

Source of Clastics

The increasing thickness of beds to the west, and the lithological gradation of some of the formations indicate that the source of clastics was from the west. Cascadia, a high land mass bordering the Cordilleran trough in the west must have been the source.

The possibility of the domal area in Montana and Alberta furnishing sediments for the later Paleozoic rock must be considered. There is no doubt that the erosion which took place in this area supplied some of the material in the near vicinity, but the great thickness of the beds indicate that a much larger source than this was necessary for the accumulation of such a large quantity of material.

Development of Porosity in Limestone

In some oil fields, such as the Kevin-Sunburst field in Montana and the Turner Valley field in Alberta, the Madison limestone is a big producer of oil and gas.

Most limestone oil reservoirs owe their porosity to solution performed by meteoric waters. Calcium carbonate is but little soluble in pure water, but it is important in that water carries the solvents, such as carbonic acid, which is formed by the combination of water and carbon dioxide. The carbon dioxide is derived from either the atmosphere or decayed organic matter.

In order to dissolve calcium carbonate, there must be a circulation rapid enough to remove the relatively soluble calcium bicarbonate which is formed, and also to bring fresh carbonic acid in contact with the rock.

Fractures and joints are the best channel-ways for the solution to flow, and the material around these openings undergo the greatest change.

In some places the solution has gone so far as to form large caverns or caves in the limestone. These large openings are later filled by sloughing of the walls and infiltration of silts. This general process forms what is known as karst topography.

Conditions were very favorable for the development of karst topography in the domal area of Montana and Alberta. That extensive erosion period at or following the close of the Paleozoic era and extending into the middle Jurassic gave ample time for weathering processes to develop great porosity.

ECONOMIC APPLICATION

Areas for Prospection

The domal area in northern Montana, as indicated by the map, is naturally a good area for prospecting. This dome already has been examined to a considerable extent, and oil and gas is being produced on a large scale in several different fields. There is undoubtedly some parts of the area which have not be prospected thoroughly, and it seems feasible that this should be carried on, and it is probable that it is being carried on at the present time by oil companies.

Another important area for prospecting is in northeastern Montana, northwestern North Dakota, and southern Saskatchewan, where the basin structure exists. The Illinois basin, a great oil and gas producer, is somewhat similar to this. Small wrinkles or structural "highs" in the basin form excellent oil traps.

The extensive deposition active in this basinal area during the Paleozoic era, and the climatic conditions at that time should afford a favorable condition for an abundance of organic matter to live and die, and to accumulate in quantities which would result in the formation of petroleum. There are formations suitable for reservoir and cap rocks, so the chance of petroleum being present is by no means remote.

The pinching out of formations against a domal structure is a condition favorable for the accumulation of petroleum, and such conditions exist in Montana, and possibly Alberta and Saskatchewan, where the later Paleozoics pinch out against the Madison dome, as shown by the cross-sections. These areas should be worthy of prospecting.

Other structural features that might be well worth prospecting for are shore lines and possible shoe-string sands, which are important producers in many localities. The southern shore line of the Big Snowy sea is fairly well established and prospecting in this area might be advisable. An attempt to locate shore lines of the other Paleozoic seas might be made.

Geophysical prospecting for buried hills, which have in some cases formed good oil traps, might be carried on in any part of the area.

Another economic factor that should be kept in mind is the possibility of commercial deposits of salt and gypsum. Such deposits have been found by the drilling of wells, and in a few localities gypsum has been produced. Climatic conditions in the Permian and Mississippian periods were favorable for their deposition, and deposits of commercial size might be uncovered with some prospecting.

CONCLUSIONS

Due to the fact that only a minimum amount of information was available in many parts of the area, the placing of the contacts between the different formations had to be, in some cases, more or less hypothetical. However, the writer feels that the object of the study was accomplished and the final result is as accurate as may be expected. Regardless of this, he believes that what he has gained in knowledge of regional geology, sub-surface stratigraphy, and the acquaintanceship with different aspects of geology in reading the many articles used as references, that the time spent was well worth while.

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Many other points of information other than those listed here were used, but in order to simplify this index, only the diagnostic points are listed below:

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40. Geologic map of Nebraska.

41. Log of Williston well, Carter Oil Co.

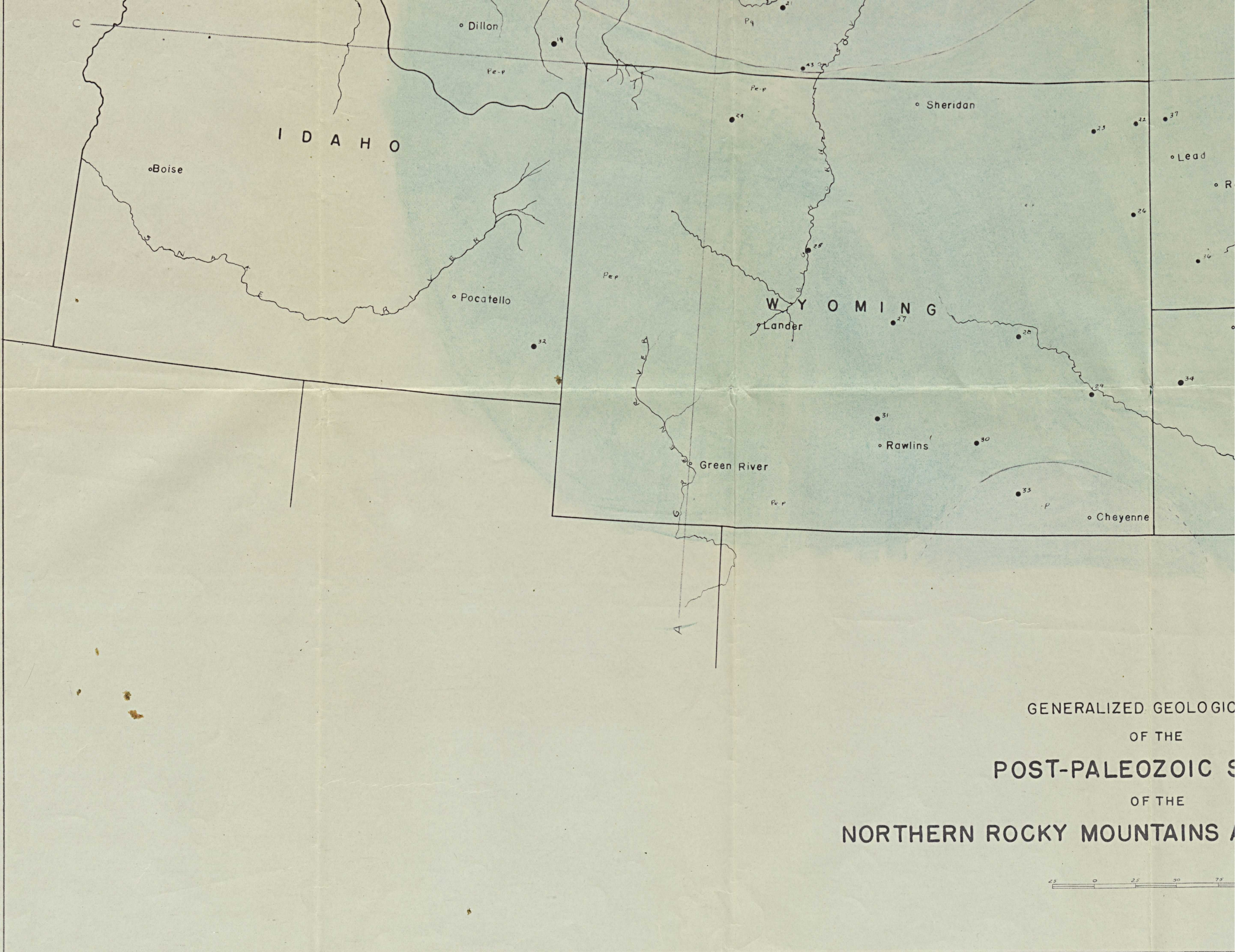
42. Geologic map of Manitoba, Canada.

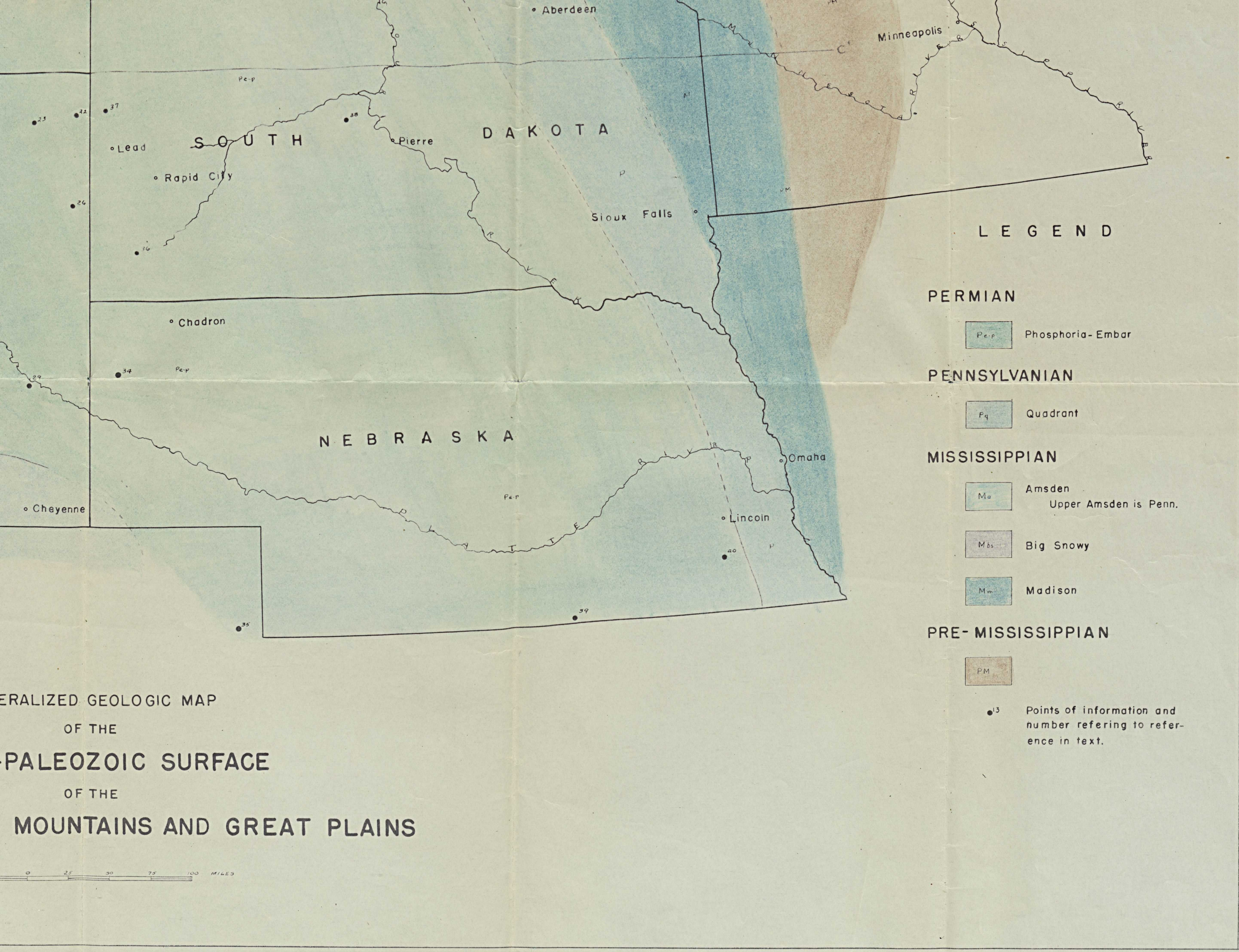
43. Sloss, L. L., Personal Communication.

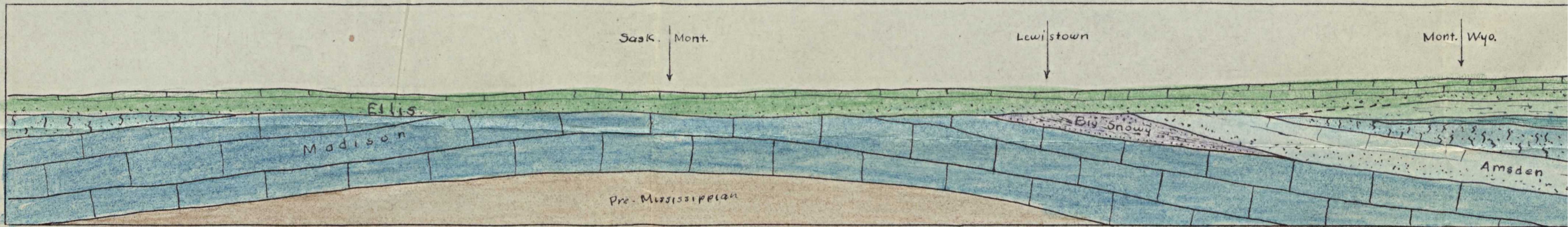
B
A'
C
Pq
Calgary
Mm
ALBERTA
SASKATCHEWAN
Cut Bank
Kalispell
Ma
Glasgow
Williston
Gt. Falls
Mbs
Lewistown
Moscow
Missoula
MONTANA
Helena
Butte
Bozeman
Billings
Baker
Pep
Dillon

PLATE 3

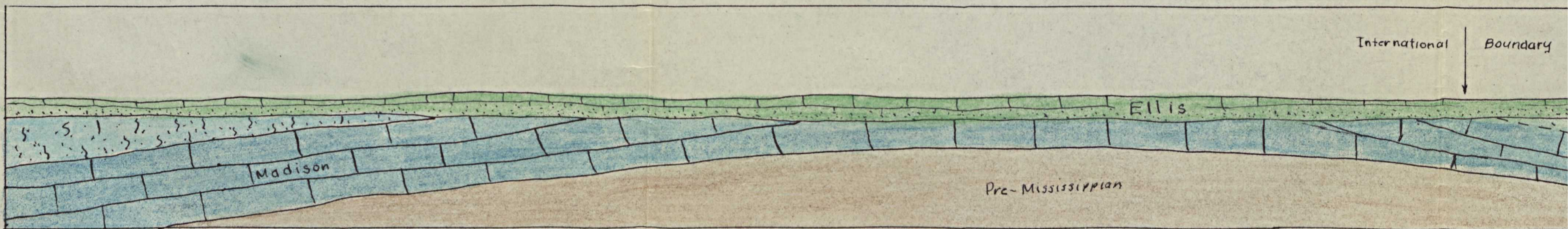

EWAN
NORTH
DAKOTA
MINNESOTA
Williston
Devil's Lake
Fargo
Bismark
Baker
Alexandria
Aberdeen
B'
PM
M
P


Dillon
IDAHO
Boise
Pocatello
Sheridan
Lead
WYOMING
Lander
Rawlins
Green River
Cheyenne
GENERALIZED GEOLOGIC
OF THE
POST-PALEOZOIC
OF THE
NORTHERN ROCKY MOUNTAINS

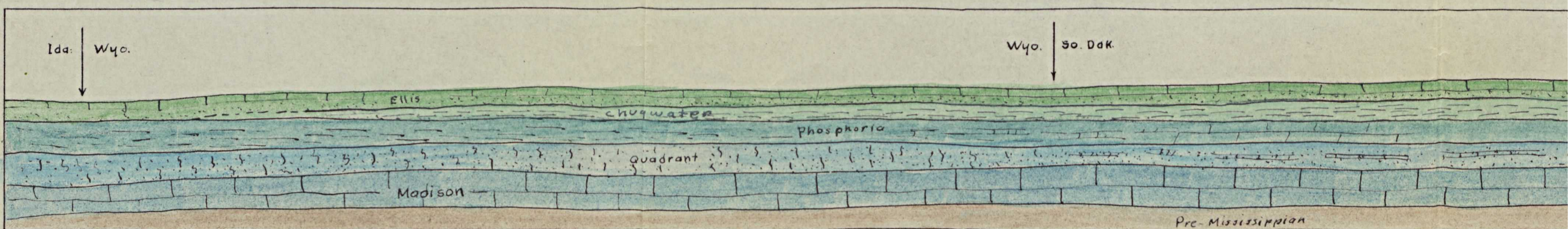

Aberdeen
Minneapolis
C'
SOUTH
DAKOTA
Lead
Rapid City
Pierre
Sioux Falls
Chadron
NEBRASKA
Omaha
Lincoln
Cheyenne
PLATTE
LEGEND
PERMIAN
Pe-p Phosphoria-Embar
PENNSYLVANIAN
Pq Quadrant
MISSISSIPPIAN
Ma Amsden
Upper Amsden is Penn.
Mbs Big Snowy
Mm Madison
PRE-MISSISSIPPIAN
PM
Points of information and number refering to reference in text.
ERALIZED GEOLOGIC MAP
OF THE
-PALEOZOIC SURFACE
OF THE
MOUNTAINS AND GREAT PLAINS
0 25 50 75 100 MILES



SECTION A-A'

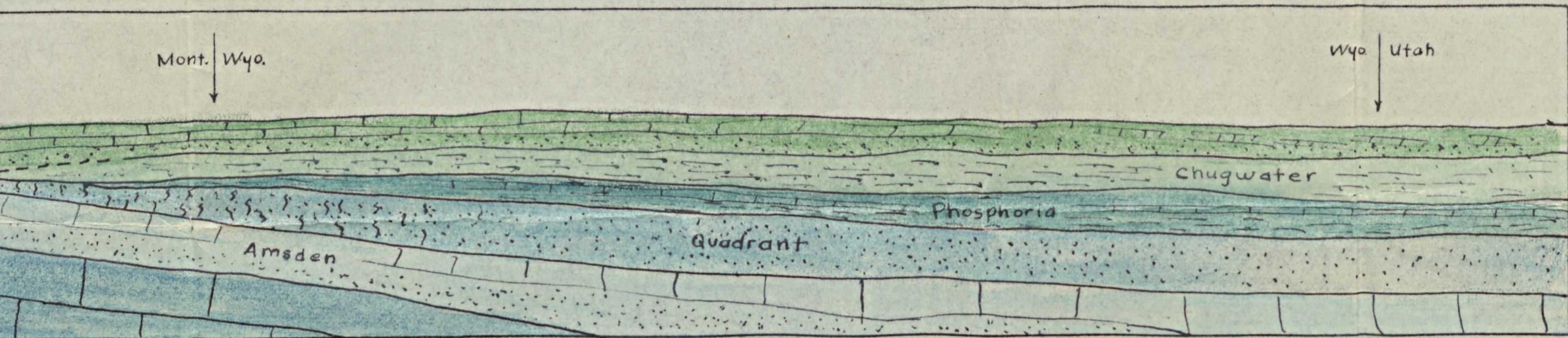


SECTION B-B'

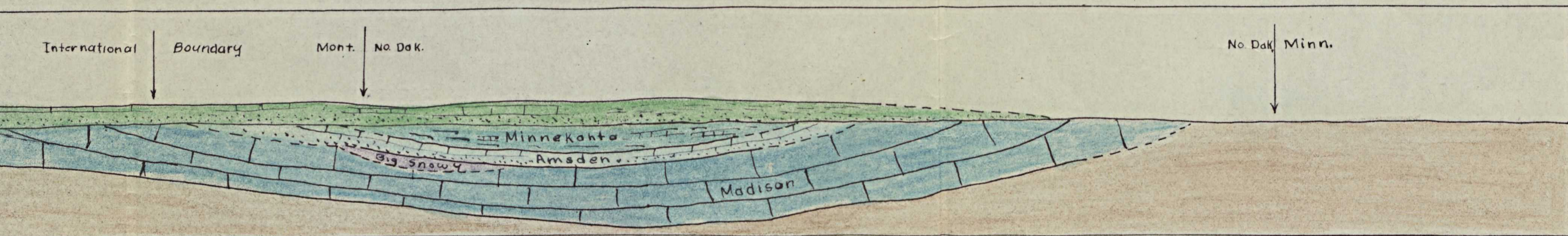


SECTION C-C'

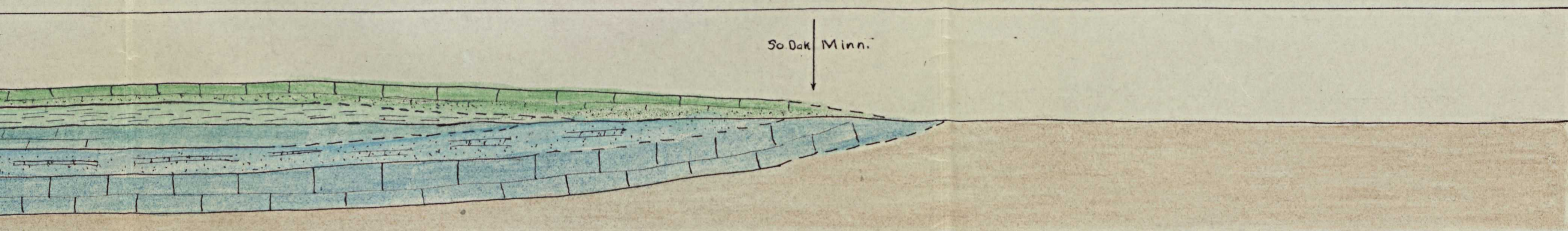
DIAGRAMMATIC GEOLOGIC



SECTION A-A'



SECTION B-B'



SECTION C-C'

GEOLOGIC CROSS-SECTIONS