GEOLOGY OF THE SPENCE-KANE AREA, BIG HORN COUNTY, WYOMING

BY

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THESIS

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GEOLOGY OF THE SPENCE-KANE AREA, BIG HORN COUNTY, WYOMING

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The Spence-Kane area includes about 350 square miles in Big Horn County, Wyoming, on the northeastern side of the Bighorn Basin. The climate is arid, vegetation is sparse, and rock exposures are on the whole excellent. Rocks present in the area range in age from Precambrian to Recent and represent all systems except the Silurian. A section from the Mississippian to the Recent is exposed within the area, the older rocks are known from records of deep wells drilled in the area. The exposed section of sedimentary rocks has an aggregate thickness of about 13,200 feet. The Paleozoic rocks are dominantly marine and average about 3050 feet in thickness. The Mesozoic rocks are both marine and non-marine in origin and have an average thickness of about 8250 feet. The Cenozoic rocks are continental in origin and are about 3700 feet in thickness. The stratigraphy of formations ranging in age from Cambrian to Eocene is discussed in detail and measured sections of many of the units are presented. Fossil collections from various formations are included within the text. Correlated surface and subsurface sections of many of the formations are illustrated by means of plates. A geologic and structure contour map, with cross sections, and a generalized columnar section illustrate the outcrop pattern, structure, and lithologic sequence of the formations. A number of sandstone dikes are found within the area and their relations to the surrounding formations are described. A number of terraces are found

along the major streams and pediment surfaces slope away from the mountain front.

The structure of the area is dominated by two large asymmetrical anticlines, the Sheep Mountain anticline and Little Sheep Mountain anticline, which are prominent topographic features as well. The general structural trend is northwest-southeast. The central part of the area consists of a series of minor folds generally parallel to this regional trend. To the west of this central belt, the rocks dip westward, generally in toward the central part of the Bighorn Basin, while on the eastern margin, the rocks dip westward along the gentle limb of an asymmetrical syncline and rise to the flanks of the Bighorn Mountains. There are twelve anticlinal folds, wholly or partly within the Spence-Kane area. These structures and their relations to the adjoining synclines are described.

Faults within the area are practically all high angle faults that trend northeast-southwest, perpendicular to the general structural trend within the area. Most of these faults are found along the limbs and at the nose of the Little Sheep Mountain anticline, and appear to be tensional in origin. A belt of parallel faults in the southwestern part of T. 55 N., R. 95 W., is related to a larger belt to the northwest associated with the Garland and Byron anticlines. A low angle reverse fault is present along the east flank of Little Sheep Mountain. The Sheep Mountain anticline has few faults associated with it, but sandstone dikes are common about the flanks, which are not found about the Little Sheep Mountain structure. Several of the anticlines are distinctly asymmetrical. Cross sections illustrate the asymmetry of folds and their relationships to one another.

There are three small oil fields within the area. These fields, and oil and gas tests of other anticlines within the area are discussed. Coal, bentonite, clay, gypsum, construction materials, uranium, and iron ore deposits within the area are described and evaluated.

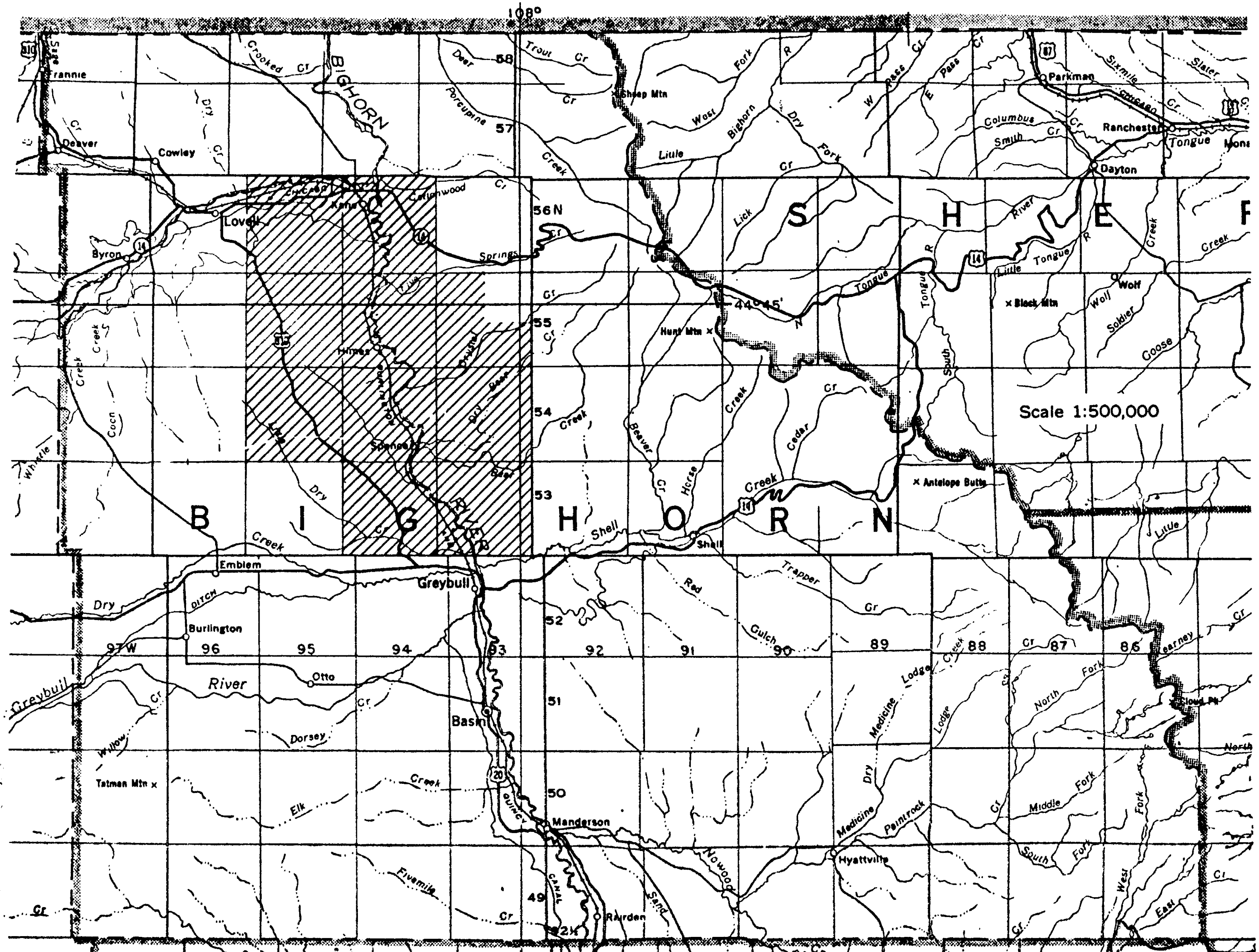
INTRODUCTION

Location and extent of area. The Spence-Kane area is located in the central part of Big Horn County, Wyoming, and covers approximately 350 square miles. The area lies north of the town of Greybull and east of the town of Lovell. The location of the area with respect to the state of Wyoming is shown by the index map on Plate I. Figure A, shows the location of the area with respect to major drainage, highways, towns, land net and latitude and longitude lines within Big Horn County.

The area mapped includes 9 3/4 townships on the northeast side of the Bighorn Basin. The area has a maximum length of 24 miles, and a maximum width of 18 miles. The 108th meridian lies just to the west of the eastern boundary. The Bighorn and Shoshone Rivers join near the northern boundary of the area.

Purpose and scope of report. This project was undertaken by the U.S. Geological Survey as a part of the program for geologic mapping and structural investigations by the Mineral Classification Branch in connection with administration of the mineral leasing laws and classification of public and semi-public lands as to their mineral character.

The primary purpose of the present study was to gather basic geologic and structural data to aid in evaluation of commercial oil and gas possibilities, as well as mineral resources of the mapped area. Two known oil fields were present at the time of initiation of the project. A third field, the Alkali anticline field, was discovered while mapping was in progress. The report includes a geologic and structure map and sections



Index map of Big Horn County showing location of the SPENCE-KANE AREA

Figure A

of the Spence-Kane area and emphasizes the stratigraphic and structural relations of the exposed rocks.

Previous geologic investigations. Various parts of the Bighorn Basin were traversed by the early surveys of the western territories. Eldridge (1894) presented a geologic map and report on northwestern Wyoming following a reconnaissance, primarily of the Bighorn Basin, for coal resources. His route of travel covered the area east of Little Sheep Mountain (Five Springs Ridge) from Five Springs Creek, north to the Shoshone (Stinking Water) River. A general description of the stratigraphy, structure and economic geology of part of northwestern Wyoming is included within the report. Darton, in 1904, established many of the stratigraphic units in use today in the vicinity of the Bighorn Mountains and correlated these units with their equivalents in the Black Hills and Front Range of the Rocky Mountains. In 1906 Darton published the results of his studies of the Bighorn Mountains. His accompanying geologic map extends into the eastern part of the Spence-Kane area and shows the geology of the area to the east of Sheep Mountain. A general description of the stratigraphy and structure of the Spence-Kane area is included with the report on the Bighorn Mountains.

Fisher (1906) presented the first fairly comprehensive treatment of the Bighorn Basin area. Along with his geologic map of the basin, he presents structure sections across the basin, and a generalized columnar section for both the east and west sides of the basin.

Washburne (1907) described the coal fields of the northeastern part of the Bighorn Basin. The report by Hewett and Lupton (1917) on anticlines in the southern part of the Bighorn Basin includes only the southeast end of the Sheep Mountain anticline and the structure was not treated in detail. Lee (1927) discusses the general succession of rocks in the vicinity of Kane, Wyoming, and the region north of Greybull on the east flank of the Sheep Mountain anticline.

Brainerd and Keyte (1927) measured a section from the base of the Amsden formation up into the Chugwater formation in the vicinity of Stucco and described fossils collected there. Branson (1939) revisited this locality and remeasured the Amsden-Tensleep portion of the section and also described fossils collected there. Andrews, Pierce and Eargle (1947) have published a geologic map of the Bighorn Basin showing terrace deposits and physiographic features. Also in 1947, Pierce, Andrews, and Keroher published a structure contour map drawn on the top of the Frontier formation for the Bighorn Basin. Zapp (1956) has used this earlier map as a base for presenting a structure contour map of the basin, drawn on the top of the Tensleep sandstone. Pierce (1948) has published a detailed geologic map of the Basin-Greybull area, immediately to the southeast of the Spence-Kane area. Hunter (1952), Agatson (1954), and Imlay (1956) have measured and described several of the sedimentary units within the Spence-Kane area. Other papers dealing with the geology of surrounding areas within the Bighorn Basin or treating regional topics are mentioned at appropriate places within the text.

Field work and map compilation. The field investigations, which form the basis for this report, were conducted from July through October of 1956 and May to September of 1957. There is no adequate topographic coverage of the area to date. The 30 minute Bald Mountain quadrangle, surveyed in 1898, overlaps the easternmost boundary of the area by less than 1 square mile.

Contact prints of vertical aerial photographs with a scale of about 1:20,000 were used as a base for plotting all map data. The prints were obtained from the Commodity Stabilization Service, U. S. Department of Agriculture, Salt Lake City, Utah, from flights flown in August and September of 1954. Approximately 200 9" by 9" contact prints were used.

The base net was compiled from the township plats of the U. S. Bureau of Land Management. Most of the resurveys of these townships were made in the period from 1900 to 1910, and the quarter and section corners marked by notched stones. Several corners have recently been marked with brass caps, apparently by the Big Horn County surveyor. One-hundred and forty-eight quarter and section corners were relocated by the writer in the field and marked on the aerial photographs to insure the positions of the land lines for horizontal control.

All planimetric detail and geologic data were transferred from the aerial photographs by means of a radial line plot and the Kail Radial Planimetric Plotter. The relocated quarter and section corners were used to establish horizontal control during map compilation. The final map was prepared by reduction from the compilation scale of 1:20,000, to a scale of 1:31,680, by use of the Saltzman projector.

Vertical control was established by altimetry. A Wallace and Tiernan surveying altimeter, type FA-181, was used. A part of the U. S.

Coast and Geodetic Survey level line between Green River, Wyoming, and Laurel, Montana, follows U. S. Highway 310 along the western part of the area, and is marked by a series of bench marks. These bench marks were used as primary control for the survey, and a series of secondary control points were established at road intersections by altimetry. A correction curve was made daily to lessen the effects of diurnal variations in pressure. Each apparent elevation was then adjusted by means of the correction curve. Elevations were not recorded during periods of unstable weather conditions. Approximately 1000 stations were occupied at various geologic contacts to obtain altitudes for structure contouring.

Stratigraphic sections were measured by use of the Brunton compass, with corrections applied for the inclination of beds following the method of Hewett (1920). More detailed sections, or thin units, were measured by use of a tape.

GEOGRAPHY

Surface features. The Spence-Kane area is situated on the northeast side of the Bighorn Basin. The Bighorn Basin is one of several large intermontane basins in Wyoming. The Bighorn Mountains bound the basin just to the east of the Spence-Kane area and the Pryor Mountains form the boundary just to the north. The basin is elliptical in outline, and is both a structural and topographic basin. Sedimentary rocks underlying the central part of the basin are brought to the surface along its borders adjacent to the surrounding mountain ranges, and a series of generally, northwest-southeast-trending folds rim the basin in this exposed border zone. Eocene and later deposits mask the structure of the central part of the basin.

The Spence-Kane area occupies a position between the central part of the basin and the Bighorn Mountains. Vegetation is sparse and exposures are, on the whole, excellent. Steep dips are common over much of the area and resistant units form a series of hogbacks or cuestas. Elevations in the area range from 3900 to slightly over 5000 feet above sea level. The most prominent topographic features in the area are the ridges of the Sheep Mountain and Little Sheep Mountain anticlines, (Figures 1 and 2) which rise about 1000 feet above the surrounding area. These two anticlinal ridges both trend approximately northwest-southeast, and nearly overlap one another in an en echelon manner. A number of smaller structures associated with the Sheep Mountain and Little Sheep Mountain anticlines are also expressed topographically. Darton (1906) and Fisher (1906) refer to this general area as the "Sheep Mountain Uplift".

FIGURE 1. - SHEEP MOUNTAIN ANTICLINE
Looking south from sec. 17, T. 54 N., R. 94 W.

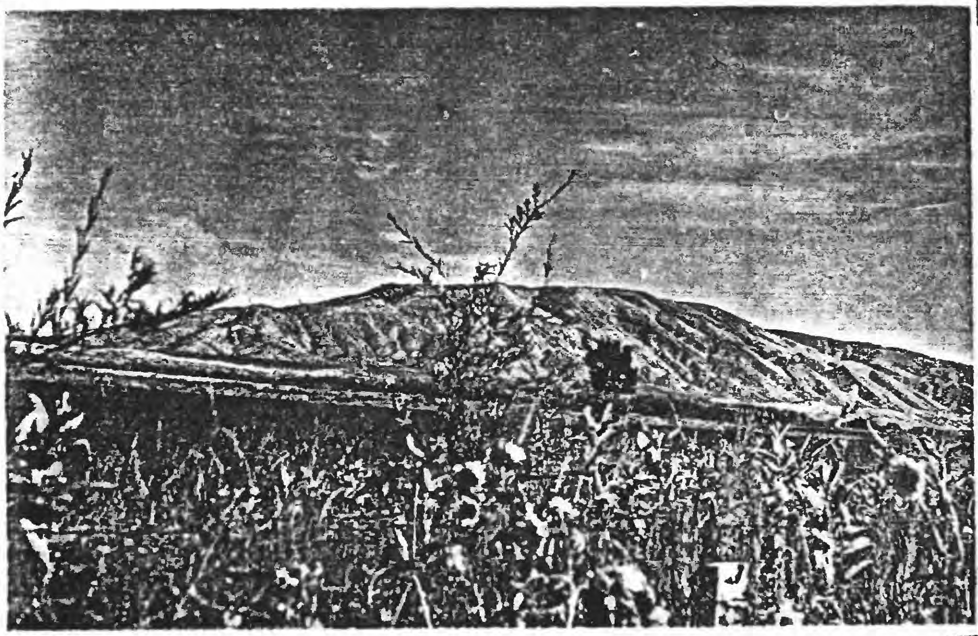


FIGURE 2. - LITTLE SHEEP MOUNTAIN ANTICLINE
Looking west from sec. 17, T. 56 N., R. 95 W.

The Bighorn River, the principal stream in the area, flows northward and has cut a deep canyon through both the Sheep Mountain and Little Sheep Mountain structures. The only other large stream in the area, the Shoshone River, flows eastward, near the northern boundary of the area and joins the Bighorn River. Stream terraces are found along the major stream courses, particularly along those of the Shoshone, Bighorn, and Dry Creek. Interstream benches are well displayed in the extreme northeast corner of the mapped area, where they slope away from the mountain front, with fragmentary patches farther away from the mountain front.

Drainage and water supply. The only perennial streams in the area are the Bighorn and Shoshone Rivers and Shell and Crystal Creeks. Shell Creek crosses the area only at the extreme southeast corner. The Bighorn River is the master stream and all other perennial streams in the area flow into it. Cottonwood Creek, Willow Creek, Five Springs Creek, Dry Bear Creek, and Bear Creek are all intermittent streams that flow into the Bighorn from the east, as do Crystal Creek and Shell Creek. Little Dry Creek is the only important intermittent stream entering the Bighorn from the west. Sand Draw, an intermittent stream, enters the Shoshone River from the south. The Shoshone River joins the Bighorn just northeast of Kane within the mapped area.

Water from the Bighorn River is pumped and used for irrigation by ranches in the region south of Kane. Water from Crystal Creek is used for irrigation purposes by the ranch in sec. 33, T. 55 N., R. 93 W.

A number of small earth dams and reservoirs are found throughout the area. With the exception of reservoirs near Crystal Creek, they contain water only intermittently.

A network of canals and ditches carry irrigation water on either side of State Highway 14 parallel to the course of the Shoshone River. This broad area of terrace and alluvium is extensively farmed from Lovell east to the vicinity of Kane. The easternmost edge of one of the two small Lovell Lakes on either side of U. S. Highway 310, lies within the mapped area. The only gaging station within the area is located on the Bighorn River just above its junction with the Shoshone River. Stream discharge data from this gaging station are summarized in Table I.

Climate and vegetation. Average annual precipitation in the Spence-Kane area is less than 10 inches, and the climate is semiarid to arid. About half of the annual precipitation falls during the months of April, May, June, and July. Seasonal variations in temperature are large within this general area. Temperatures as high as 111° F. and as low as -51° F. have been recorded at Lovell over a length of record of 24 years. Climatological data from U. S. Weather Bureau stations in Big Horn County, near Spence-Kane area, are summarized in Table II.

Vegetation is sparse throughout the greater part of the Spence-Kane area, and the region is one of the most barren in Wyoming (Figures 3 and 4). Desert shrub, salt bush, greasewood, sagebrush and some small cacti are found over large parts of the area. Juniper is found on the higher slopes of Sheep and Little Sheep Mountains and also, in places, along the outcrop of the Greybull sandstone. Trees, mainly cottonwoods, are

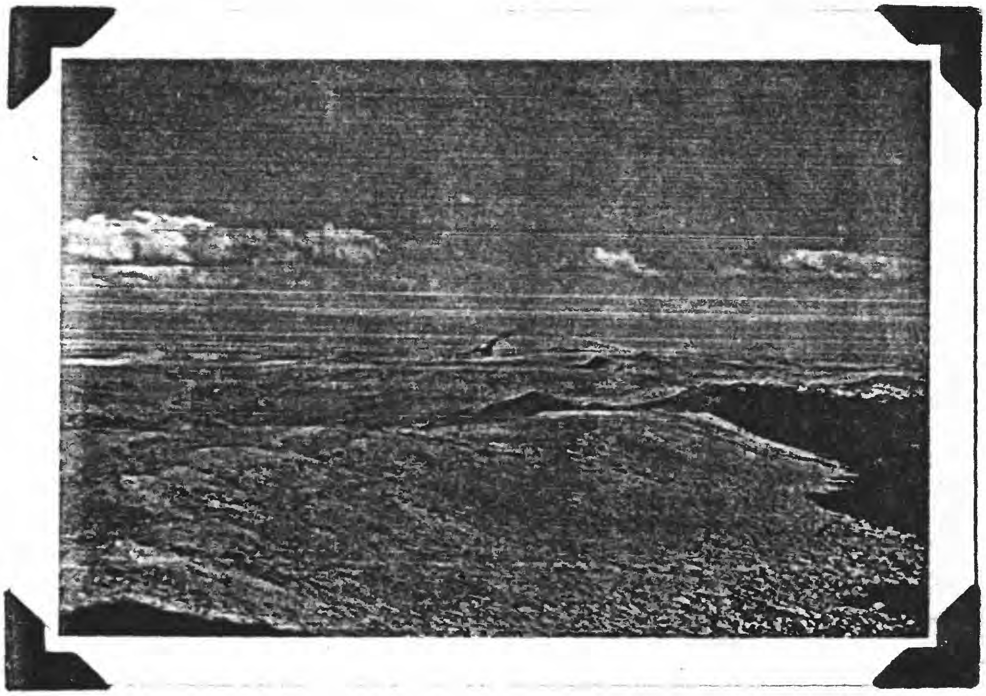


FIGURE 3. - SHEEP MOUNTAIN ANTICLINE IN THE DISTANCE - GOOSE EGG-ALKALI ANTICLINE IN FOREGROUND. Shows general character of vegetation and rock exposures in Spence-Kane area.

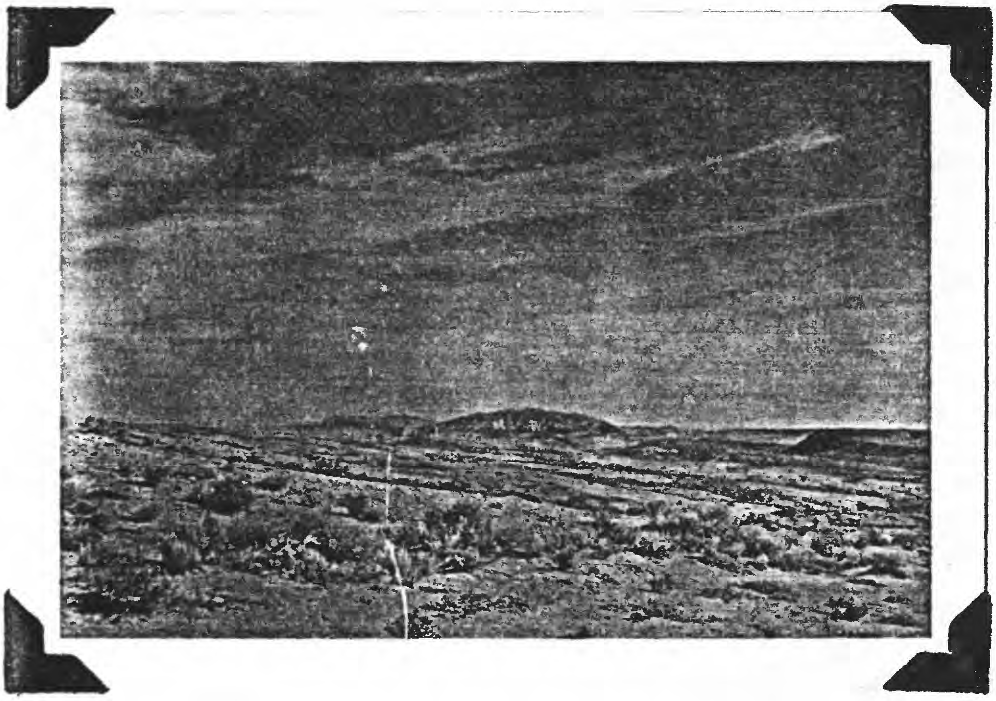


FIGURE 4. - SHEEP MOUNTAIN ANTICLINE
Note Bighorn River Canyon about in the middle of the anticline.

restricted to areas adjacent to the major drainage courses. Grass is sparse throughout the area, except along the streams and on the irrigated lands adjacent to State Highway 14 from Lovell to Kane. Small meadows adjacent to the perennial streams yield small hay crops.

An experimental area for the study of the poisonous weed, halogeton, is maintained in the southern half of T. 54 N., R. 95 W. Halogeton contains la - amounts of the oxalates of sodium and potassium and precipitates calcium out of the blood of stock grazing on the weed. This results in changes in the body fluids, causing muscular spasms and eventually death to sheep particularly. Halogeton infestation covers large areas in the northern part of the Bighorn Basin.

Accessibility, settlement and industry. There are two paved highways within the Spence-Kane area. U. S. Highway 310 crosses the area near its western boundary, connecting Greybull and Lovell. The Alkali anticline oil field and the Lovell Substation of the U. S. Bureau of Reclamation for Missouri River Basin Power are located adjacent to this highway. There are no ranches or other human dwellings along this entire stretch of highway, within the Spence-Kane area. State Highway 14 crosses the northern part of the area connecting Lovell with areas in the Bighorn Mountains. The only bridge available for automobile travel across the Bighorn River within the Spence-Kane area is along State Highway 14. Improved, unpaved roads connect Spence and Himes with U. S. Highway 310 and Kane with State Highway 14. An improved, unpaved road exists between State Highway 14 and the Deschene Ranch - Crystal Creek area - thence south along the east flanks of the Crystal Creek and Sheep Mountain anticlines to the vicinity of Shell Creek, and eventually connects with U. S. Highway 14 just east of the bridge over the Bighorn River at Greybull. An improved, unpaved road also connects U. S. Highway 310 with the Wyoben bentonite pit and the processing plant at Stucco. Other small stretches of unpaved, improved roads exist that lead mainly to oil well sites, or are maintained for hauling bentonite. Most of the other roads are unimproved jeep and geophysical trails.

The Chicago Burlington and Quincy Railroad connects Greybull and Lovell, and passes through both Sheep and Little Sheep Mountain canyons. Stucco, Spence, Himes, and Kane, the only settlements within the area, are all located along the railroad track. Stucco and Spence have been abandoned. Oil from the Spence Dome oil field is, in part, shipped by rail from Spence. The Wyoben bentonite processing plant is located at Stucco, and ships by rail from that point. Himes has a population of 11 according to the 1950 census. Kane, which has a population of 30, according to the 1950 census, is made up of a number of small ranches. The train delivers freight and mail at Kane. The majority of ranches and homes within the area are found on either side of State Highway 14. A few ranches are located along Crystal Creek and near the mouth of Five Springs Creek.

The Greybull Airport, which is serviced by Frontier Airlines, is located on a terrace along the southern border of the area, and the north end of the flight strip extends into the Spence-Kane area. A landing strip in the SW 1/4 sec. 16, T. 56 N., R. 95 W., is used by small planes employed in crop dusting.

Outside of the small ranches and farms mentioned above, industry within the Spence-Kane area is mainly restricted to extraction of oil, bentonite, and clay. One of the largest bentonite processing plants in the country, operated by the Magnet Cove Barium Corporation, is located just south of the mapped area. Some of the bentonite for this plant is obtained from pits within the Spence-Kane area. The Wyoben Bentonite Company of Greybull, Wyoming, operates a processing plant at Stucco, and has worked several pits within the Spence-Kane area.

The Lovell Clay Products Company of Lovell, Wyoming, obtains clay from a pit within the Spence-Kane area.

Two families were living at the Spence Dome oil field and maintaining production activities there. The Alkali anticline field was being actively developed during the summer of 1957.

STRATIGRAPHY

General Features

Rocks present in the Spence-Kane area range in age from Precambrian to Recent and represent all systems, except the Silurian. Rocks exposed within the Spence-Kane area range in age from Mississippian to Recent; the older rocks are known only by the records of deep wells drilled within the area. These older rocks outcrop, nearby, in the Bighorn Mountains, just to the east of the mapped area.

Plate I shows the outcrop of formations exposed in the Spence-Kane area, and Plate II summarizes the general lithologic characteristics and thickness of each formation present. This generalized columnar section also shows the location within the section of fossil collections described below, and position of unconformities within the section. The composite thicknesses shown for the exposed portion of the section combine the results of measured surface sections and analysis of records of wells drilled in the area. Thicknesses of the unexposed portion of the section are based solely on well records.

In general, rock exposures, within the Spence-Kane area, are excellent. The sedimentary rocks have an aggregate thickness of about 15,000 feet, of which 13,200 feet are exposed within the area, while the lower 1800 feet of section does not reach the surface.

The Paleozoic rocks are dominantly marine in origin and have an average thickness of about 3050 feet. The exposed Paleozoic section begins approximately 30 feet above the base of the Madison limestone, and outcrops are restricted areally to the Sheep Mountain and Little Sheep Mountain structures, with a few small stream cuts at Spence Dome exposing the top of the Phosphoria equivalent. Mesozoic rocks are both marine and non-marine in origin. They have an averager thickness of about 8250 feet, and are exposed over the greater part of the Spence-Kane area. The Cenozoic rocks are continental in origin and have an average thickness of approximately 3700 feet. Only the basal part of the Eocene rocks are exposed in the area. The Cenozoic rocks, in contrast with the underlying rocks, are poorly exposed for the most part. Areally, the Cenozoic rocks are restricted to the southwestern part of the mapped area.

Detailed surface sections were measured of the exposed Paleozoic and Mesozoic rocks, with the exception of the exposed part of the Madison limestone. The Cenozoic rocks were not measured in detail.

ROCKS NOT EXPOSED

Cambrian, Ordovician and Devonian rocks are known to be present in the Spence-Kane area through well records. The basal part of the Madison limestone of Mississippian age is not exposed within the area mapped. A relatively few of the wells drilled in the Spence-Kane area, have penetrated the unexposed portion of the section present. Table III is a compilation of wells drilled in the Spence-Kane area, and among the data presented is a column showing the lowest formation reached. Of 98 wells drilled for oil and gas, only 8 are known to have penetrated formations that are not exposed at the surface within the Spence-Kane area. Only two of these wells are known to have penetrated the entire unexposed sedimentary section. There has not been any oil or gas production from these older rocks, in the Spence-Kane area, to date.

The Cambrian rocks are divided into three units: the Flathead sandstone and Gros Ventre formation, both of Middle Cambrian age, and the Gallatin limestone, which is Late Cambrian in age.

The Flathead sandstone overlies Precambrian granite and gneiss and represents the initial deposit of an eastward transgressing sea. The Flynn, McMahon, Parker, No. 1 Great Western Sugar Co. well in SW 1/4 sec. 35, T. 54 N., R. 94 W., penetrated 123 feet of Flathead sandstone. Stipp (1947) has shown a total thickness of 174 feet of Flathead sandstone penetrated by the Prairie Oil and Gas Co. No. 1 Govt. well drilled in NE 1/4 sec. 35, T. 56 N., R. 95 W.

The sandstone is predominantly white to gray, medium- to coarse-grained and quartzitic. The basal part of the formation is conglomeratic and contains feldspar fragments and quartz pebbles.

The Gros Ventre formation overlies the Flathead sandstone. Five hundred and ten feet of the formation was penetrated by the Flynn, McMahon, Parker, No. 1 Great Western Sugar Co. well, as determined from the electric log of the well. The formation consists of white to gray, glauconitic sandstone interbedded with green shale and a few thin sandy limestone beds.

The Gallatin limestone overlies the Gros Ventre formation. Electric log correlation shows 565 feet of Gallatin limestone penetrated by the Flynn, McMahon, Parker, No. 1 Great Western Sugar Co. well. The formation consists of gray, sandy, glauconitic limestone interbedded with gray to green shales. Edgewise limestone conglomerate is found near the top. The total Gros Ventre-Gallatin interval, as determined from the Flynn, McMahon, Parker, No. 1 Great Western Sugar Co. well, is 1075 feet. Stipp (1947) has recorded a total interval of 1200 feet for the Gros Ventre and Gallatin, undivided, as penetrated by the Prairie Oil and Gas Co. No. 1 Govt. well in NE 1/4 sec. 35, T. 56 N., R. 95 W.

Ordovician rocks are represented by the Bighorn dolomite, which unconformably overlies the Gallatin limestone. The formation consists of white to tan dolomite and dolomitic limestone. Electric log correlation shows 411 feet of Bighorn dolomite to have been penetrated by the Flynn, McMahon, Parker, No. 1 Great Western Sugar Co. well. The exact age of the Bighorn dolomite is still open to question.

Charles A. Sandberg of the U. S. Geological Survey picked the electric log correlation points for the top of the Ordovician and Devonian sections. The use of the formation name Duperow for the Devonian section was established by Sandberg and Hammond (in press). The subsurface Duperow formation consists of sandy, glauconitic shale, shaly dolomite and dolomite, and is equivalent to part of the type Jefferson formation of western Montana. The sequence of lithologies is shown on the generalized columnar section (Plate II). One hundred and eighty feet of Devonian section was penetrated by the Flynn, McMahon, Parker, No. 1 Great Western Sugar Co. well. The Duperow formation is believed to be Late Devonian in age and is unconformably overlain by the Madison limestone and unconformably overlies the Bighorn dolomite. Blackstone and McGrew (1954) have reported the occurrence of a channel deposit correlated with the Lower Devonian Beartooth Butte formation at Cottonwood Canyon, sec. 34, T. 57 N., R. 93 W., just to the northeast of the mapped area.

ROCKS EXPOSED

Paleozoic Rocks

Madison limestone. The Madison limestone, of Mississippian age, is the oldest formation exposed in the Spence-Kane area. The most complete exposure is located in the Bighorn River Canyon through the Sheep Mountain anticline, sec. 35, T. 54 N., R. 94 W., where approximately 750 feet of the upper part of the formation is exposed along the axis of the anticline, in a nearly vertical wall on either side of the canyon (Figure 5). The Bighorn River Canyon across the Little Sheep Mountain anticline, in sec. 17, T. 55 N., R. 94 W., exposes only a small section of the formation on either side of the river along the axis of the anticline. The Madison limestone is also exposed in a number of heart-shaped patches along the east limb of the Little Sheep Mountain anticline, by intermittent streams which have cut down through the overlying formations. Similar exposures are found along both limbs of the Sheep Mountain anticline. No detailed measurements of the exposed part of the Madison limestone were made. Analysis of well records in the area indicates an average thickness of about 780 feet for the formation. The formation consists of gray and cream to brown limestone and dolomite. The upper contact is unconformable with the overlying Amsden formation. In places, thin pockets of red shale fill irregularities along this surface, and the limestone beds are stained a red color.

In most places the basal Amsden sandstone fills irregularities along this contact. Denson and Morrissey (1952) have discussed the stratigraphy and lithology of the Madison of the Bighorn Basin and have shown that this

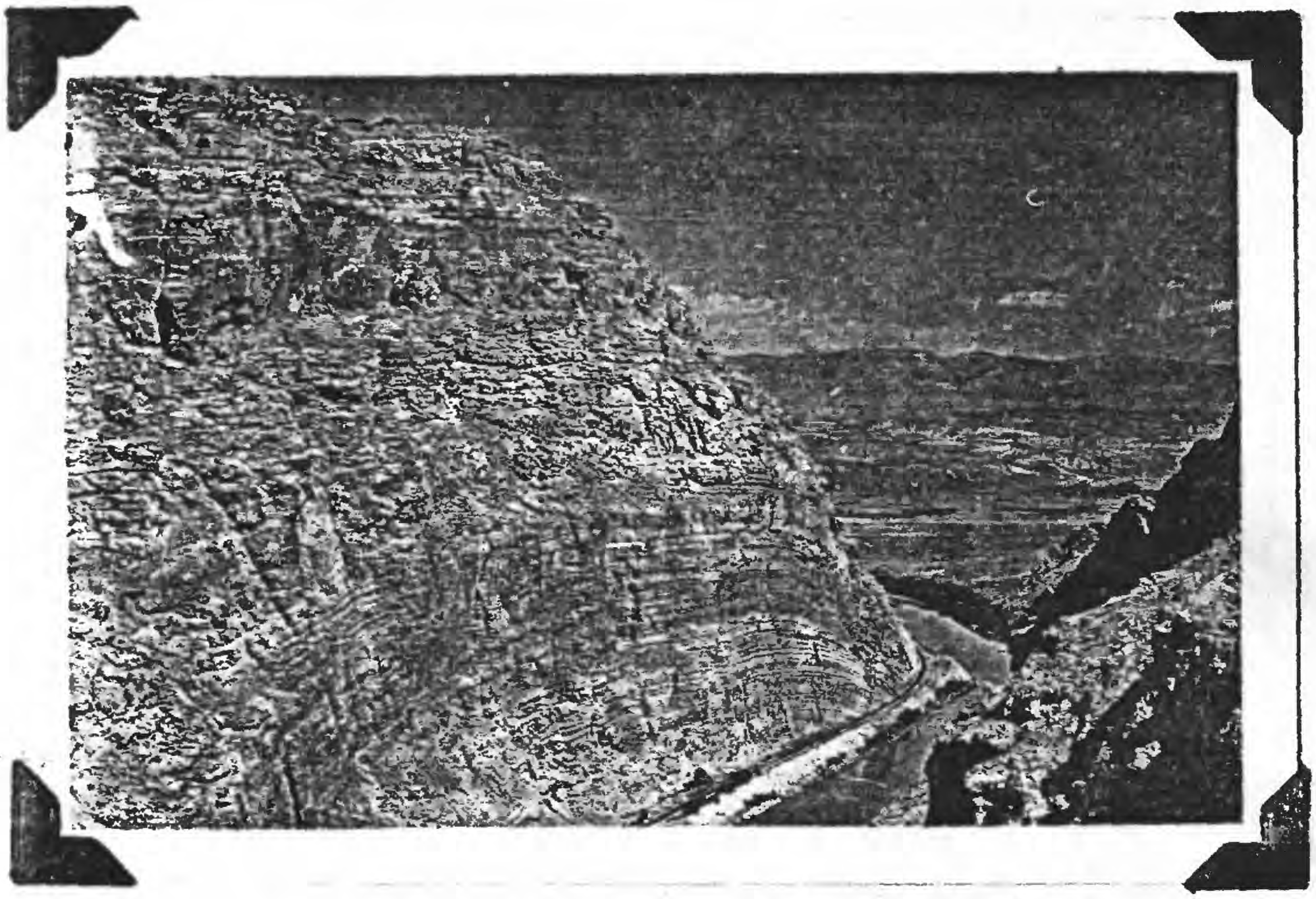


FIGURE 5. - MADISON LIMESTONE EXPOSED IN BIGHORN RIVER CANYON THROUGH SHEEP MOUNTAIN ANTICLINE

View looking eastward through canyon. Bighorn Mountains in background. Note C. B. & Q. railroad track on north side of river.

carbonate sequence can be subdivided into several units on the basis of insoluble residues.

Amsden formation. Outcrops of the Amsden formation are restricted to the Sheep Mountain and Little Sheep Mountain structures, where they occur along the axis of the anticline, or as heart-shaped patches on the limbs of the anticlines near the crest. A complete section of the Amsden is well exposed in the Bighorn River Canyon through both Sheep Mountain and Little Sheep Mountain anticlines.

Darton (1904) named the Amsden formation from exposures on Amsden Creek, a branch of the Tongue River, west of Dayton, on the northeast side of the Bighorn Mountains. The Amsden formation averages about 170 feet in thickness in the Spence-Kane area, as determined from measured surface and subsurface sections. The general sequence of lithologies of the formation is shown in Plate II.

The base of the Amsden formation is easily recognized by the change from gray limestone of the Madison to the basal Amsden sandstone, or thin red shale filling irregularities on this erosional surface. The Amsden formation is made up of three major units within the area: the Darwin sandstone at the base, a middle red shale unit, and an upper carbonate sequence. Plate III shows correlation of surface and subsurface sections of the Amsden formation within the area, illustrating changes in lithology and thickness of the formation and of its major units. Agatson (1954) shows isopachous maps of the Amsden formation and of these three subdivisions of the Amsden covering the general area of north-central Wyoming.

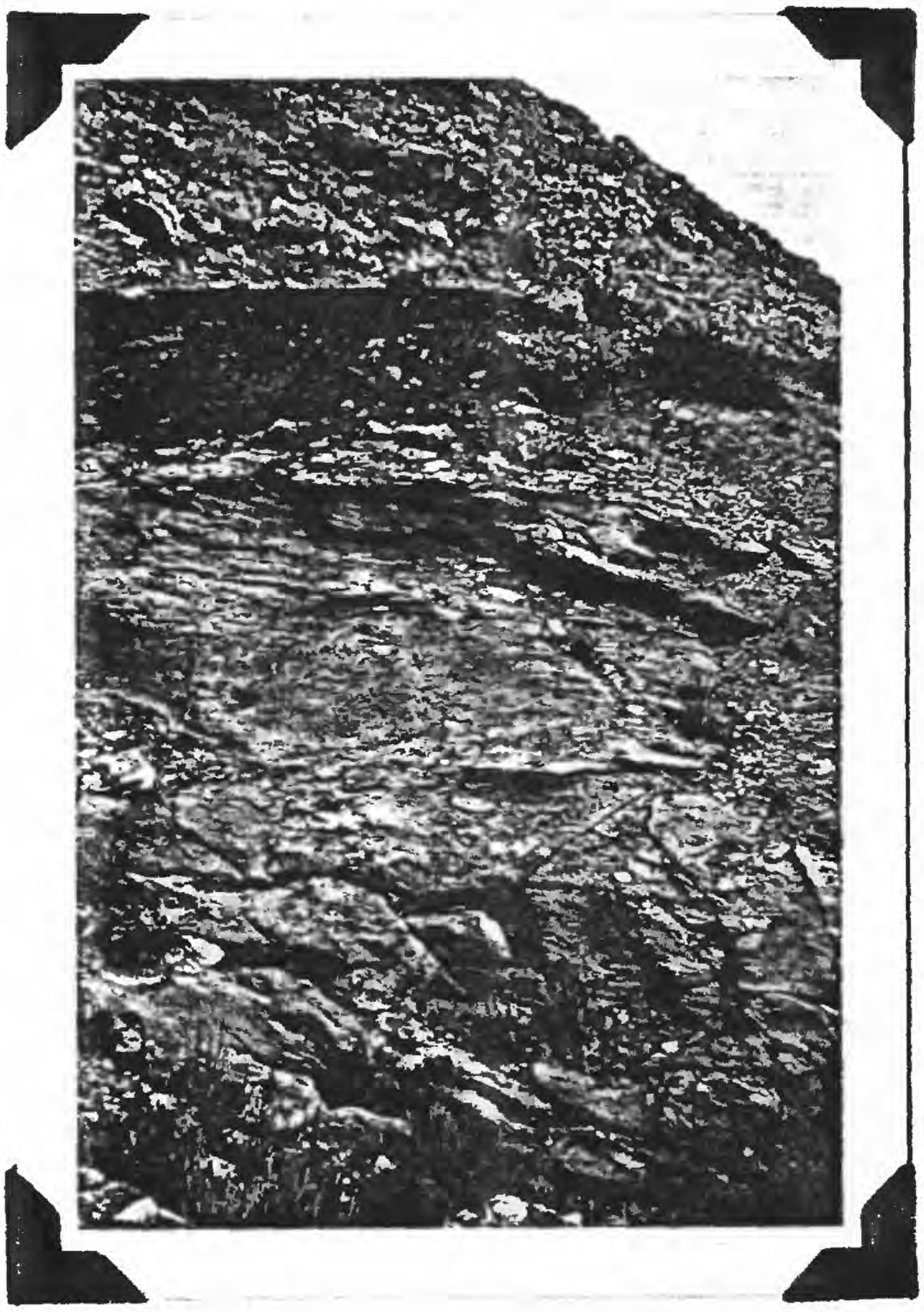


FIGURE 6. - DARWIN SANDSTONE MEMBER, EXPOSED AT BIGHORN RIVER CANYON THROUGH LITTLE SHEEP MOUNTAIN ANTICLINE.

Note dark red shale above the sandstone.

The Darwin sandstone (Figure 6) is generally a light gray, fine- to medium-grained, friable sandstone. In places, the sandstone is salmon to pink in color, with red shale below it and with some green shale interbeds. Locally the sandstone is crossbedded. The thickness of the Darwin sandstone, within the area, is quite variable, as shown on Plate III, due to the uneven erosional surface on which it was deposited. Agatson (1954) gives the results of sieve analysis of two samples of the Darwin sandstone from both Sheep Mountain and Little Sheep Mountain anticlines.

Overlying the Darwin sandstone is a sequence of red, silty shale. The shale is generally sandy at the base with many yellow-brown to tan shale beds. Thin beds of green shale and thin limestone partings are also common in this sequence. Thin gypsum veinlets were also found in places within the red shales. About two-thirds of the way up from the base of the red shale sequence, are a number of thin, lenticular, yellow-brown bands of pisolitic limonite and hematite (Figure 7). Thin seams of hematite are also found in this part of the section. Individual pisolites are generally closely packed and range upwards to about two-tenths of an inch in diameter. The matrix is red shale. Limonitic staining gives these bands a yellow-brown color, and they stand out readily against the red shale in fresh cuts. The bands are not laterally persistent and undergo rapid changes in thickness. They probably represent bog-type deposits. A maximum of about 4 feet of this pisolitic material is present at the Bighorn River Canyon through Sheep Mountain anticline, where it was observed to vary greatly in thickness.

Branson (1937) reported the presence of these "buckshot" iron ore beds in the vicinity of Stucco north of Greybull, and also noted that hematitic red shale beds were present near the base of the Amsden (Sacajawea) in the southern part of the Wind River Range.

Wanless (1955) reports the presence of similar bands of "buckshot" iron ore from the Hoback Canyon region of southwestern Wyoming.

Overlying the red shale sequence is an upper carbonate sequence. At the base of the upper carbonate sequence, is a thick, massive, ledge-forming unit of dolomite and dolomitic limestone, which is persistent throughout the area and an excellent marker bed. This unit characteristically forms a cliff above the weaker shales below. The unit is also characterized by irregular shaped pods of gray and purple chert, thin green shale partings, and is exceptionally hard. Overlying this unit is a sequence of green shale and siltstone, gray to tan, cherty dolomite and dolomitic limestone and thin lenticular beds of gray, fine-grained sandstone.

The top of the Amsden is placed at the top of the cherty, carbonate sequence marked by purplish shale or siltstone or the base of the first persistent sandstone. This boundary is apparently conformable and the top of the Amsden is generally marked by the sequence of purple-colored units, mostly fissile, purple shale, although purple siltstone and purplish dolomite have also been noted. These purplish units, however, are not persistent throughout the area. At the east end of the Bighorn River Canyon across Little Sheep Mountain, these purple units are locally absent, while on the west end, on the opposite limb of the anticline, the purple-colored units can be easily seen in cuts along the railroad track.

Pierce (1948) in the Basin-Greybull area directly to the southeast mapped the top of the Amsden above a section of fissile purplish shale. To the north, in the Bighorn Canyon-Hardin area, of Montana and Wyoming, Richards (1955) found that the Amsden formation was gradational, by interfingering, into the overlying Tensleep formation. Agatson (1954), after a regional study of the Tensleep and Amsden formations, concluded that the top of the Amsden should be placed above the massive, cherty carbonates and below the first sandstones of the Tensleep, regardless of their thickness. The Amsden-Tensleep contact is the most difficult to pick within the area. Surface sections measured in the area indicate a relatively constant thickness for the formation, yet thicknesses logged by wells drilled in the area are quite variable.

Stipp (1947) noted variations in thickness from the logs of wells drilled in the Bighorn Basin and stated that the variation might be due in part to the difficulty in placing the Tensleep-Amsden contact. Mills (1956) has discussed the difficulties in correlating the Amsden solely by use of electric logs, and suggests that sample logs are necessary in defining the limits of the Amsden.

Branson (1939) stated that the Tensleep sandstone of Darton was inseparable from the Amsden formation, in that the lithologic boundary is not recognizable in many places and the faunas are not distinct from those of the Amsden below. His proposed terminology would limit the Amsden formation to the Mississippian (?) part of the Amsden section, which he had previously (1937) named the Sacajawea formation. The entire Pennsylvanian section would then be placed in the overlying Tensleep formation.

Branson (1939) measured a section of the Amsden-Tensleep interval in the vicinity of Stucco. He divided the section into the Sacajawea formation overlain by the Tensleep formation, and placed the top of the Sacajawea formation at the top of the red shale sequence. Branson's Sacajawea formation, in the Spence-Kane area, thus includes the Darwin sandstone member and overlying red shale sequence to the base of the massive, ledge-forming dolomitic limestone at the base of the upper carbonate sequence. Branson did not report any fossils from this section. Brainerd and Keyte (1927) had previously measured a section at this same locality, which included the Amsden-Tensleep interval. They reported on the presence of fossils (Zone A) from the Amsden. Inspection of their section shows, however, that these fossils actually came from a point above the Tensleep-Amsden contact as mapped in the Spence-Kane area.

Although Branson's proposals appear to have merit, in that the Amsden-Tensleep contact is difficult to establish, and in cases even appears to be gradational in this general area, his redefinition of the limits of Darton's Tensleep and use of the Sacajawea formation have not been widely accepted. There are several objections to the use of Branson's terminology within the Spence-Kane area. The thickness of the Sacajawea in this area would be such that it could only be shown at rather large map scales. Also, there is no fossil evidence from the Spence-Kane area to determine how much, if any, of the Amsden section is Mississippian in age. Richards (1955) has reported that fusulinids collected and identified by L. G. Henbest in the Bighorn Canyon-Hardin area to the north indicate that at least the upper two-thirds of the Amsden there is of Pennsylvanian age. No fossils were found in the lower third of the formation.

Since the major unconformity is at the top of the Madison limestone, it would be most logical to place the Mississippian-Pennsylvanian boundary at that point, on the basis of physical evidence alone. However, since there is no faunal evidence as to the age of the lower part of the Amsden, the possibility exists that these beds are of Late Mississippian age and that the unconformity does not coincide with the systemic boundary.

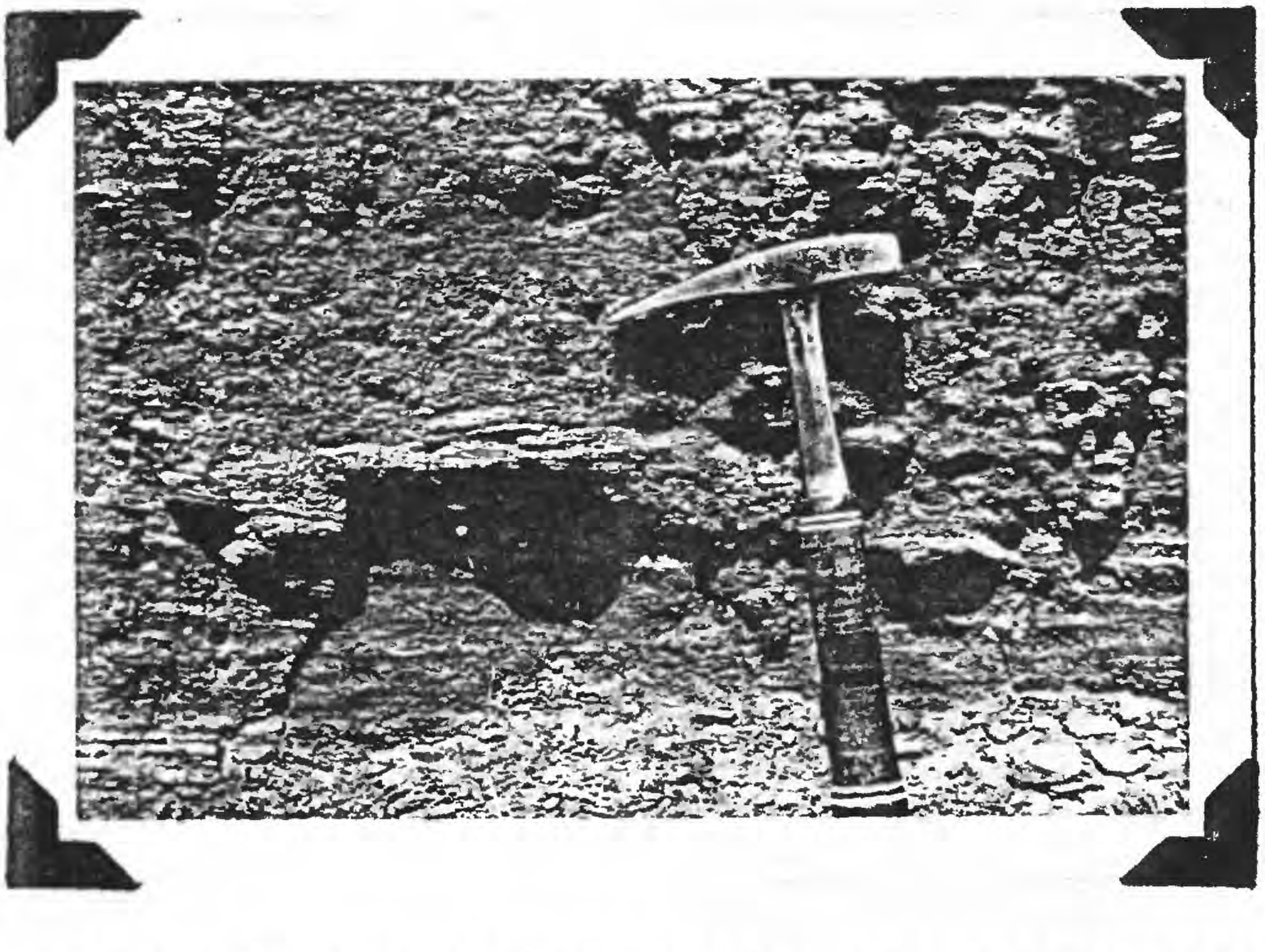


FIGURE 7. - THIN LENSING BANDS OF PISOLITIC IRON ORE IN RED SHALES OF AMSDEN FORMATION.

Section exposed at Bighorn River Canyon through Little Sheep Mountain anticline. Bands are stained yellow, and individual pisolites can be seen.

Section of Amsden formation:
Measured in NE 1/4 sec. 17, T. 53 N., R. 93 W.

Tensleep formation.

Amsden formation:	Feet
19. Shale, purple, fissile, poorly exposed; 8" green siltstone at base of unit and purple siltstone at top	3.3
18. Dolomite, greenish-gray, dense, massive, cherty	2.0
17. Shale, purplish, poorly exposed	6.7
16. Shale, green; few thin, tan dolomites in center of unit	6.7
15. Siltstone, pale green, sandy; dense, gray, cherty dolomite at top of unit	1.0
14. Shale, green, silty; 8" gray, dolomitic limestone in center of unit	3.3
13. Dolomitic limestone, dense, massive; prominent ledge former throughout region; contains large pods of gray chert	13.4
12. Shale, green, silty	3.3
11. Shale, red to maroon, hard, silty	30.1
10. Shale, maroon, hard, with thin bands of tan shale and lensing bands of pisolitic iron ore	16.7
9. Shale, maroon with purplish cast, blocky, silty	5.3
8. Shale, maroon to red, silty, blocky; few thin, green shale beds	40.1
7. Limestone, gray, sandy, stained deep red; forms blocky ledge; resistant unit; interbedded with thin, red, shale	6.7
6. Shale, and siltstone, pale green; few thin, red, shale interbeds	3.3
5. Sandstone, gray, soft, friable, medium-grained, crossbedded; some limonitic staining; weathered surfaces have pimply nodes	16.7
4. Shale, green, silty	0.5
3. Shale, red, silty	6.7
2. Sandstone, gray, soft, friable, medium-grained, stained pink in places	4.3
1. Sandstone, red, and hard, red, shale	0-3
Total Amsden formation	171.6

Madison limestone

Section of Amsden formation:
Measured in NE 1/4 sec. 17, T. 55 N., R. 94 W.

Tensleep formation.	Feet
Amsden formation:	
19. Shale, green	1.0
18. Dolomitic limestone, gray, creamy-white on weathered surface, dense crystalline	0.4
17. Chert, gray, dense, bedded	1.0
16. Shale, green	1.0
15. Dolomite, gray, white weathered surface, dense	0.5
14. Shale, green	0.5
13. Dolomite, gray, white to brown weathered surface, dense	0.5
12. Shale, green; lenses of white gypsum and thin, tan, dense dolomite beds	2.0
11. Dolomitic limestone, gray, weathers creamy-white, dense; several very thin green shale and siltstone partings	7.8
10. Shale, brilliant blue-green; thin, creamy-white, dense dolomitic limestone partings	2.0
9. Dolomitic limestone, gray, creamy-white, dense	0.4
8. Siltstone, pale green	0.4
7. Shale, green	0.7
6. Siltstone, pale green, sandy; $1\frac{1}{2}$" gray chert at top	0.5
5. Shale, green	1.0
4. Dolomitic limestone, gray, weathers brown, dense, massive; cliff-former; many pods of blue-black chert throughout, and thin, green shale and siltstone partings	31.0
3. Shale, green	3.0
2. Shale, red, with sandy shale beds; several yellow-brown limonitic shale beds and thin, lenticular bands of pisolitic "buckshot" iron ore beds	81.0
1. Sandstone, light gray, stained in places, fine-grained, locally crossbedded. Red shale and sandstone fills irregular surface on Madison limestone. Darwin sandstone member	37.0
Total Amsden formation	171.7

Madison limestone

Burk (1954) and Shaw and Bell (1955) have recently reviewed the problem of the age of the Amsden in the Wind River Mountains, where Mississippian fossils have been reported from the lower part of the formation.

<u>Tensleep sandstone</u>. The Tensleep sandstone outcrops along the axis of the Sheep Mountain and Little Sheep Mountain anticlines. In places, the massive sandstone and thin chert bed at the top of the formation forms resistant dip slopes near the crest of the anticlines.

Darton (1904) named the Tensleep sandstone for a sheet sandstone with extensive exposures in the walls of the lower canyon of Tensleep Creek, just east of Tensleep, Wyoming, in the eastern Bighorn Basin.

The Tensleep sandstone averages about 105 feet in thickness in the Spence-Kane area, as determined by measured surface sections and the record of wells drilled in the area, most of which test the Tensleep. The thickness recorded for the Tensleep, like that of the Amsden, depends on the boundary selected between the two, and since the contact is gradational in some cases, quite variable thickness data result. Zapp (1956) shows isopachs of the Tensleep sandstone within the Bighorn Basin. Agatson (1954) also shows an isopachous map of the Tensleep sandstone in the northern part of Wyoming. The Spence-Kane area and the general region to the southwest lie at or near the 100 foot thickness line and show the thinnest section of Tensleep in the Bighorn Basin. The formation thickens both to the northwest and southeast of the area. According to Mills (1956) the thinnest interval, on the east side of the basin, is 108 feet in the Alkali anticline area. Plate II shows a generalized section of the Tensleep sandstone for the Spence-Kane area, while Plate III shows the thickness and variation in lithology of sections within the area. No attempt is made to correlate beds within the formation due to the lithologic variation of thin beds with relatively short horizontal distances.

Sandstone is the dominant lithology in the upper two-thirds of the section. The sandstones are generally white to tan, medium- to fine-grained and massive. The sandstones are locally pink and dark gray in color, and have pimply nodes on weathered surfaces. Sandstone beds near the top of the formation are commonly crossbedded and contain thin lenticular beds of gray to varicolored chert. The lower third of the formation shows great variation in lithology and consists of dolomitic limestone, dolomite and limestone alternating with green shale. The dolomites are generally sandy and can be observed to grade laterally into sandstone within relatively short distances at the section exposed in the Bighorn River Canyon through Little Sheep Mountain. Thin beds of sandstone interrupt the general alternation of carbonates with green shale.

Several diastems were noted in the basal part of the Tensleep in this same section (Figure 8). Mills (1956) states that although the Tensleep-Amsden contact is generally considered to be conformable in the Bighorn Basin, minor unconformities in the base of the Tensleep have been reported from several localities.

Throughout the Spence-Kane area, the upper contact is marked by a lithologic change from the white to tan, crossbedded sandstones with lenticular chert beds to the basal redbeds of the overlying Permian sequence. There is an erosional unconformity at the top of the Tensleep sandstone, which accounts for some of the variation in thickness of the formation within the area. Richards (1955) has reported the presence of this unconformity in the Bighorn River Canyon-Hardin area of Montana and Wyoming, due north of the mapped area. Pierce (1948) reported an unconformity at the top of the Tensleep in the Basin-Greybull area to the southeast, and (1947) has collected fusulinids from near the top of the Tensleep just below the erosional unconformity at the Paton Ranch locality at Shell Creek Canyon.

Agatson (1954) has discussed the nature of the unconformity and shown that the Tensleep thins to the north in this general area, due to regional truncation, and that variations in thickness of the Tensleep are due to the topography of the erosion surface. He compared isopachs of the overlying Permian strata, which also thins regionally to the north due to transgressive overlap, with those of the Tensleep interval and found that after allowing for the regional thinning of the strata to the north, that the total interval for the Phosphoria and Tensleep remained relatively constant, while the interval for either formation alone differed quite markedly. He concluded that topographically high areas along the erosional surface show relatively thin intervals for the Phosphoria and thick intervals for the Tensleep, while topographically low areas would show relatively thick intervals for the Phosphoria, and thin intervals for the Tensleep. This would account for variations in thickness of the two formations, other than that due to the regional southward thickening.

Brainerd and Keyte (1927) and Branson (1939) have measured sections in the vicinity of Stucco, at Sheep Mountain, and collected and described fossils from the Tensleep at this locality.

Brainerd and Keyte describe fossils from two zones, A and B, within the formation. Collections from Zone B, were made from a chert zone at the top of the Tensleep sandstone and included bryozoans, crinoid stems, gastropods, brachiopods, and a trilobite. They concluded that the fauna indicated a position in the Mid-Continent section between the Fort Scott and upper part of the Kansas City. The collection from Zone A appears to have been made from the basal portion of the Tensleep, although they have placed the zone within the Amsden. They identified several brachiopods from this zone and concluded that they were Pennsylvanian in age but not distinctive enough to place it accurately. Branson (1939) remeasured the Tensleep-Amsden interval at this same locality and lists fossils identified from two chert beds near the top of the Tensleep formation. The high percentage of carbonates and shale in this section was one of the reasons advanced by Branson in determining that the Tensleep sandstone of Darton is not a satisfactory formational unit, since sandstone is not the dominant rock in this section. Branson, however, has included the upper carbonate sequence of the Amsden within his definition of the Tensleep and called the lower red shale sequence and Darwin sandstone member the Sacajawea formation. This terminology does not tend to preserve the original lithologic description of the Tensleep sandstone.

Agatson (1954) measured a detailed section of the Tensleep sandstone at Little Sheep Mountain and noted the marked lithologic changes there, which he concluded were not cyclothemic.

The writer collected foraminifera from a lenticular, banded chert bed at the top of the Tensleep sandstone, and base of the Permian redbeds, in SE 1/4 sec. 17, T. 53 N., R. 93 W., on the west flank of the Sheep Mountain anticline. The chert bed is believed to be the equivalent of Zone B of Brainerd and Keyte and the uppermost fossiliferous chert bed of Branson. The fossils were identified by L. G. Henbest of the U. S. Geological Survey as follows:

U. S. G. S. collection f-12389

Climacammina magna Roth and Skinner
Endothyra sp.
Bradyina sp.
Globivalvulina (?) sp.
Monotaxis sp.
Fusulina sp. aff. *F. rockymontana* Roth and Skinner
Fusulina sp.
Wedekindellina euthysepta (Henbest)

According to Henbest,

> "This is a McCoy-Tensleep-Quadrant type of fauna which characterizes a part of the lower half of the Des Moines epoch of the Mid-Continent region."

Thus, the top of the Tensleep sandstone in this area would be of Middle Pennsylvanian age. Henbest (1954) discusses the generic content and stratigraphic significance of similar collections of Foraminifera from both the Tensleep sandstone and Amsden formation in Montana and Wyoming.

FIGURE 8. - DIASTEM IN BASAL PART OF TENSLEEP SANDSTONE.

SW 1/4 sec. 9, T. 55 N., R. 94 W. Note irregular contact between white-weathering dolomite above and sandstone below.

Section of Tensleep formation:
Measured in NE 1/4 sec. 17, T. 53 N., R. 93 W.

Goose Egg formation.	
Tensleep formation:	Feet
22. Sandstone, gray, fine-grained, crossbedded, cherty at top----	13.4
21. Shale, tan and green, sandy----------------------------------	2.0
20. Sandstone, fine- to medium-grained, gray, crossbedded------	23.4
19. Sandstone, weak with yellowish-green shale; poorly exposed---	3.3
18. Sandstone, weak, gray, cherty at base; poorly exposed--------	6.7
17. Sandstone, gray, poorly consolidated with interbedded green and tan shale ---	8.7
16. Sandstone, gray, friable, fine-grained, forms dip slope-------	16.7
15. Shale, green and tan--	2.7
14. Dolomitic limestone, gray-------------------------------------	1.0
13. Shale, green and tan--	2.0
12. Dolomitic limestone, gray-------------------------------------	1.0
11. Sandstone, gray with greenish cast, fine-grained-------------	10.0
10. Dolomitic limestone, gray, dense resistant unit--------------	1.0
9. Shale, green---	1.3
8. Dolomitic limestone, gray, cherty------------------------------	1.0
7. Shale, green---	1.0
6. Sandstone, gray, fine- to medium-grained, crossbedded, resistant---	4.0
5. Dolomitic limestone, cherty, gray; chert is black and gray and in both bands and pods----------------------------------	2.0
4. Shale, green---	1.5
3. Dolomitic limestone, gray, dense, cherty, poorly exposed----	2.0
2. Shale and siltstone, green, poorly exposed-------------------	5.3
1. Sandstone, gray, fine- to medium-grained, weathers pale gray--	1.0
Total Tensleep formation	111.0
Amsden formation	

Section of Tensleep formation:

Measured in SW 1/4 SW 1/4 sec. 9, T. 55 N., R. 94 W.

Goose Egg formation.

Tensleep formation:	Feet
58. Sandstone, light gray, fine-grained, silty	3.0
57. Chert, gray, bedded	0.3
56. Sandstone, light gray, dense, calcareous cement, fine-grained	0.6
55. Chert, gray, bedded	0.7
54. Sandstone, light gray, fine-grained, dense	2.3
53. Sandstone, medium-to fine-grained, calcareous; weathers light brown; thin lenses of chert	5.3
52. Shale and siltstone, green	1.1
51. Sandstone, gray, fine- to medium-grained, friable, calcareous, dense, weathers brown	6.5
50. Shale and siltstone, green	2.0
49. Sandstone, gray, fine- to medium-grained, calcareous, weathers brown	11.4
48. Shale, green	0.5
47. Sandstone, gray, fine- to medium-grained, well sorted quartz grains, calcareous cement, weathers brown	1.7
46. Shale and siltstone, pale green, dense	0.7
45. Dolomitic limestone, gray, weathers white; vugs filled with asphaltic residue	0.7
44. Sandstone, gray, pimply surface, fine-grained	3.2
43. Dolomitic limestone, gray, weathers white, dense; grades laterally into sandstone	0.3
42. Sandstone, light gray, fine-grained, calcareous, pimply surface	6.0
41. Siltstone, green	1.2
40. Chert, black to gray	0.3
39. Dolomite, gray, sandy, dense	0.6
38. Shale, green	0.1
37. Dolomite, gray, weathers white, dense	0.8
36. Sandstone, light gray, calcareous, fine-grained; cuts out dolomite unit above it; asphaltic residue and oil staining	5.5
35. Dolomitic limestone, gray, dense, sandy, weathers white	0.4
34. Shale, green, sandy	1.0
33. Dolomite, gray, weathers white, dense	0.5
32. Sandstone, gray, fine-grained, calcareous	2.1
31. Dolomite, gray, dense, weathers white; alternates with green shale; unit poorly exposed	5.5
30. Siltstone, green-gray to tan, calcareous	2.0
29. Dolomitic limestone, gray, sandy, weathers white	1.1
28. Limestone, gray; many vugs stained with oil and lined with secondary calcite crystals	1.0

27.	Dolomite, buff, sandy; thin green sandy shale partings	1.4
26.	Shale, green, sandy	1.2
25.	Sandstone, light gray, fine-grained, dense, tan to flesh colored weathered surface, calcareous	3.5
24.	Shale, green, sandy	0.3
23.	Limestone, gray, microcrystalline, dense; weathers white	0.8
22.	Shale, green	0.1
21.	Limestone, gray, microcrystalline, dense; weathers white	1.4
20.	Dolomitic limestone, gray, sandy, weathers light gray, cherty at base	1.1
19.	Green shale and gray chert nodules	0.4
18.	Dolomitic limestone, gray microcrystalline, dense, weathers white to tan	1.6
17.	Shale and siltstone, pale green	1.1
16.	Dolomite, gray, dense, weathers white	0.5
15.	Sandstone, greenish-gray, fine-grained, silty; grades upward into poorly consolidated sandy zone with oil stains and thin cherty bed of pale green shale	1.1
14.	Shale, green, with thin gray, dolomite, which weathers white	1.5
13.	Dolomite, gray, dense, weathers tan	0.7
12.	Sandstone, and siltstone, with thin, green, shaly zones, greenish cast, upper contact irregular, oil stains	2.1
11.	Chert, gray to white, cavernous, with vugs lined with calcite crystals and stained with asphaltic residue	0.8
10.	Dolomitic limestone, gray, dense	0.6
9.	Shale, green, with thin, gray dolomite partings	1.5
8.	Chert, blue-gray, with many cavities and vugs lined with quartz and calcite crystals and stained black by an asphaltic residue	0.6
7.	Shale, green	1.0
6.	Dolomite, gray, dense, weathers white	0.7
5.	Shale, gray	0.4
4.	Dolomite, gray, weathers white, dense	1.5
3.	Shale, green	0.4
2.	Dolomitic limestone, gray, weathers tan, dense; cherty at base	1.0
1.	Sandstone, gray, weathers flesh colored, fine-grained, cross-bedded; massive, resistant	2.0
	Total Tensleep formation	97.7

Amsden formation

Paleozoic and Mesozoic Rocks

Goose Egg formation of Burk and Thomas, 1956. (Includes Tongues of Park City formation.) Above the Tensleep sandstone is a sequence of redbeds, evaporites, chert and carbonates of Permo-Triassic age. In the Spence-Kane area, these rocks represent the border or intertongued zone between a marine carbonate facies to the west and an evaporite or redbed facies to the east.

The history of the nomenclature applied to these rocks is complex. Darton (1906b, p. 17) applied the name Embar to,

> "a prominent series of limestone and chert beds lying between the Tensleep sandstone and the Chugwater redbeds."

The formation was described by Darton from exposures on the flanks of the Owl Creek Mountains at the southern end of the Bighorn Basin. Blackwelder (1911) and (1918) used the names Park City formation for the lower part of Darton's Embar and Dinwoody for the upper part, although Lee (1927) maintains that Darton did not intend to include beds equivalent to the Dinwoody within his original definition of the Embar formation. Condit (1916) traced the marine sequence of Darton eastward from the Owl Creek and Wind River Mountains to the Bighorn Mountains, into an evaporite sequence, and noted several distinct facies. He believed that there was a gradation from a marine facies to the west, through a transitional facies, to a shallow-water facies to the east, but as Tourtelot (1952) has pointed out, his illustration of these relationships shows an intertonguing rather than gradational relationship. Condit (pp. 263-264) noted the following changes in the Dinwoody from west to east: a change from

> "pale-green to white clay and shaly limestone weathering brown and containing obscure pelecypod shells" in the Wind River Mountains, to "gypseous greenish or brownish shale devoid of fossils, toward the east", while, "farther east the beds become increasingly gypseous and assume a lithology that can only with difficulty be distinguished from that of the Chugwater."

Condit summarized changes in the Park City beds eastward from the Owl Creek and Wind River Mountains as follows, (p. 264):

> "(1) Increasing thickness;
> (2) lithologic changes, including thinning of limestone beds and an increasing amount of shale almost entirely of red color;
> (3) the appearance of beds of massive white sediment-free gypsum in all but the basal portion;
> (4) the gradual eastward disappearance of marine fossils except in the basal beds of the formation;
> (5) the increasing prevalence of calcareous conglomerates at the principal limestone horizons;
> (6) the disappearance of concentrated beds of phosphate rock."

According to Condit, the nodular chert of the upper part of the Park City beds was the only unit of the Park City and Dinwoody in common with their equivalents in the Bighorn Mountains. He reported that a similar relationship existed between the marine facies of the Wind River Mountains and redbeds sequence of the Rattlesnake Hills.

The use of the name Park City formation, which was defined by Boutwell (1907), was later abandoned in the literature, of this general area, and replaced by the term Phosphoria formation. The Phosphoria formation, defined by Richards and Mansfield (1912), as used in this general area, constitutes the lower part of Darton's Embar, and was used in this manner by Lee in 1927. Oil company geologists, in particular, have used the

Dinwoody (Triassic) Phosphoria (Permian) terminology for this interval. The U. S. Geological Survey officially abandoned use of the term Embar in 1934 and Thomas (1934), at that time, suggested that this interval be designated the

"intertongued phase of Phosphoria and Dinwoody age."

Lee (1927) and Branson (1930) believed that the Phosphoria and Dinwoody formations were older than the evaporite sequence to the east. It remained for Thomas (1934), working on the south side of the Wind River Mountains, to demonstrate that tongues of the Phosphoria and Dinwoody formations could be traced eastward into the redbed sequence. He named (1934 and 1948) several of the eastward-extending carbonate tongues and westward-extending tongues of the evaporite or redbed facies. Recently, Tourtelot (1952) was able to extend a part of Thomas' nomenclature from the Rattlesnake Hills, into the southeast margin of the Bighorn Basin. He recognized the Ervay tongue, Minnekahta dolomite, Opeche shale and Little Medicine tongue.

In 1941 Pierce and Andrews recommended that the term Embar be used instead of Phosphoria in the Bighorn Basin. Their reason for doing so is contained within their following statement (1941, p. 110):

> "The beds in the Bighorn Basin formerly called Embar are assigned in this report to the Phosphoria. Additional work, subsequent to the writing of this report, has led to doubt concerning the advisability of using Phosphoria here because the rocks differ decidedly in lithology from the Phosphoria of the typical area and because the term Embar is so well established in local usage. Although it is impracticable to change the text and illustrations of this report, each of the writers in subsequent reports on the Bighorn Basin will assign to the Embar the rocks referred to the Phosphoria in this report."

Thus, the term Embar was again used in the vicinity of the Bighorn Basin, along with Phosphoria and Dinwoody terminology. The term, however, was now apparently restricted to beds of Phosphoria age (Permian). Pierce (1948) and Richards (1955) have used the term Embar in reports and maps on the Basin-Greybull area to the southeast, and Bighorn Canyon-Hardin area to the north respectively.

McKelvey, et al. (1956, p. 2840) following an extensive study of the stratigraphy of the Phosphoria and Park City formations and their partial correlatives in the western phosphate field, concluded that:

> "with respect to the Embar problem, it seems unwise to use both the names Embar and Park City for rocks that have essentially the same lithologic character and are physically continuous. The name Park City is and always has been in good standing in central and eastern Utah, where the section is mainly carbonate rock and it was once used for the dominantly carbonate rock section of central Wyoming by Blackwelder (1918, p. 423) and others. Thus, it seems desirable to use that term in preference to Embar, which has been abandoned officially once (Thomas, 1934, p. 1670; Wilmarth, 1938, p. 683) and has been used in several different senses by different workers."

McKelvey, et al. (1956, p. 2835) also state that:

> "Weed's Teton formation and Darton's Embar formation are considered obsolete and the Geological Survey has abandoned them."

In this report they restore the name Park City to carbonate rocks in western Wyoming that have been assigned to the Phosphoria. They would restrict the name Phosphoria to rocks of their chert-mudstone-phosphorite facies.

Burk and Thomas (1956) have applied the name Goose Egg formation to the redbed bacies of the Phosphoria and Dinwoody formations. The formation was named (p. 4) for:

> "a sequence of interbedded red to ocher shales and siltstones, thin limestones, gypsums, and limestone breccias typically exposed near the Goose Egg Post Office in central Wyoming, from which the name is derived."

The writers state that the named tongues of the Phosphoria and Dinwoody may be treated as members of the Goose Egg formation.

In the Spence-Kane area there are excellent surface sections of the Permo-Triassic along the flanks of both the Sheep Mountain and Little Sheep Mountain anticlines, and the uppermost part of the section is also exposed at Spence dome. A generalized lithologic sequence is shown on Plate II, and Plate IV illustrates changes in thickness and lithology of sections within the area. The term Goose Egg formation, of Burk and Thomas, 1956, is here applied to the Permo-Triassic section in the Spence-Kane area. The Phosphoria and Dinwoody equivalents can be recognized in the field and are indicated on both the generalized and detailed sections so that the section may be correlated more easily with terminology used in the past especially in reference to oil company records. The major carbonates are assigned to the Park City rather than Phosphoria in accordance with the restoration of that name by McKelvey, et al. (1956).

The Goose Egg formation rests unconformably on the Tensleep sandstone. The nature of the unconformity was discussed under the previous section. The Tensleep-Goose Egg contact is easily recognized and is typically represented by red shale siltstone and sandstone of the Permian resting unconformably on the white to tan sandstone and lenticular chert beds at the top of the Tensleep (Figures 9 and 11). The upper contact is placed at the top of a sequence of greenish-gray shale and siltstone with thin dolomite and gypsum beds near the top, and the base of the redbeds of the Chugwater (Figures 10 and 12). This upper contact appears to be conformable.

The lower part of the Phosphoria equivalent of the Goose Egg formation consists of a sequence of redbeds and gypsum or anhydrite interbedded with thin carbonates. Interfingering of the marine and evaporite facies takes place in this part of the section. The redbeds are predominantly shale and siltstone with some sandstone especially near the base of the formation. In many places these beds are yellow to tan in color and grade laterally into red-colored beds. The gypsum beds are characteristically white and massive. The carbonates are usually crinkly, banded, and platy dolomitic limestones. More detailed studies may possibly show that they are correlatives of the Minnekahta and Forelle members of the Goose Egg formation, and that the redbeds at the base of the section are representatives of the Opeche shale. These carbonates are here designated as undifferentiated tongues of the Park City formation. Two distinct chert zones were found within this lower sequence and are best seen on the west flank of Sheep Mountain. Both chert zones overlie dolomitic limestone units.

The upper part of the Phosphoria equivalent is a thick carbonate sequence, "the Embar lime of the oil geologist", which is tentatively correlated with the Ervay tongue of the Park City formation, principally on the basis of stratigraphic position. The unit consists of gray, dolomitic

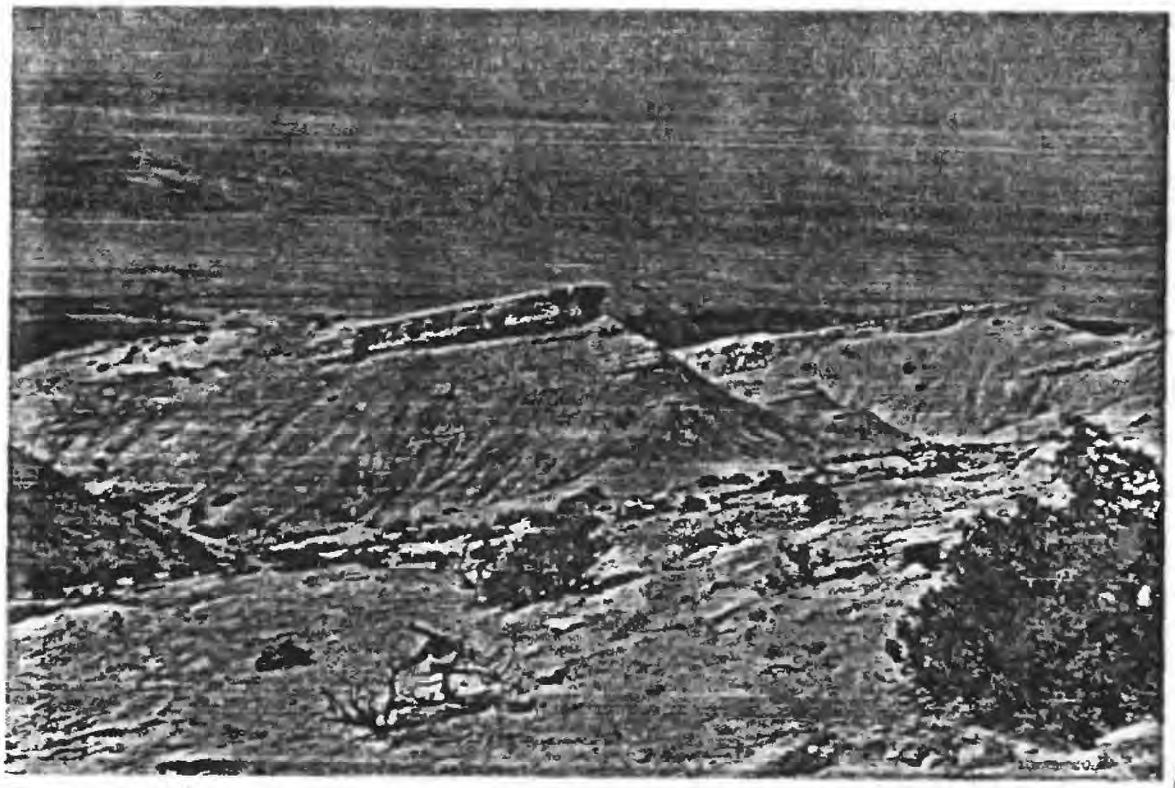


FIGURE 9. - TENSLEEP-GOOSE EGG CONTACT-AT BASE OF RED SHALES.

White Tensleep sandstone in foreground. Note resistant dolomitic limestones within redbeds. West flank Sheep Mountain anticline. SE 1/4 sec. 17. T. 53 N., R. 93 W.

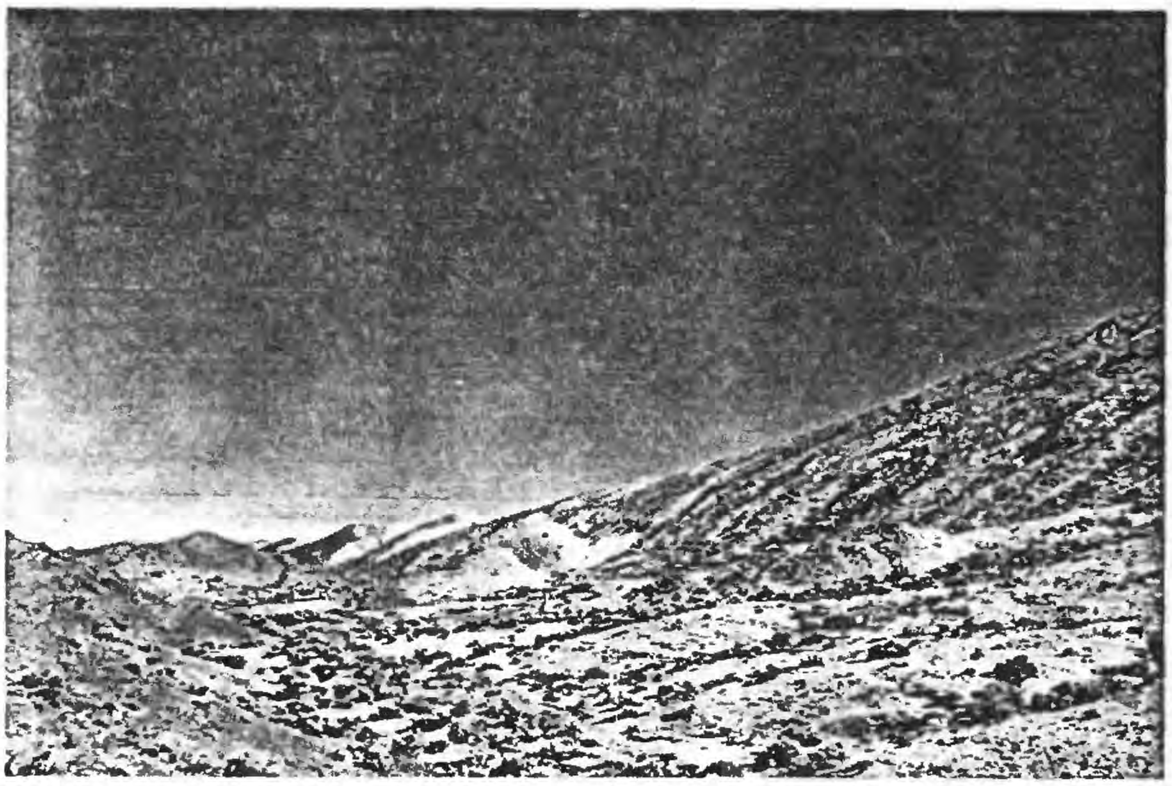


FIGURE 10. - GOOSE EGG-CHUGWATER CONTACT-AT BASE OF REDBEDS

Phosphoria equivalent forms steep slope on right - Dinwoody equivalent, largely concealed, is the pale green shales above to the base of the Chugwater redbeds. Looking north on west flank of the Little Sheep Mountain anticline.

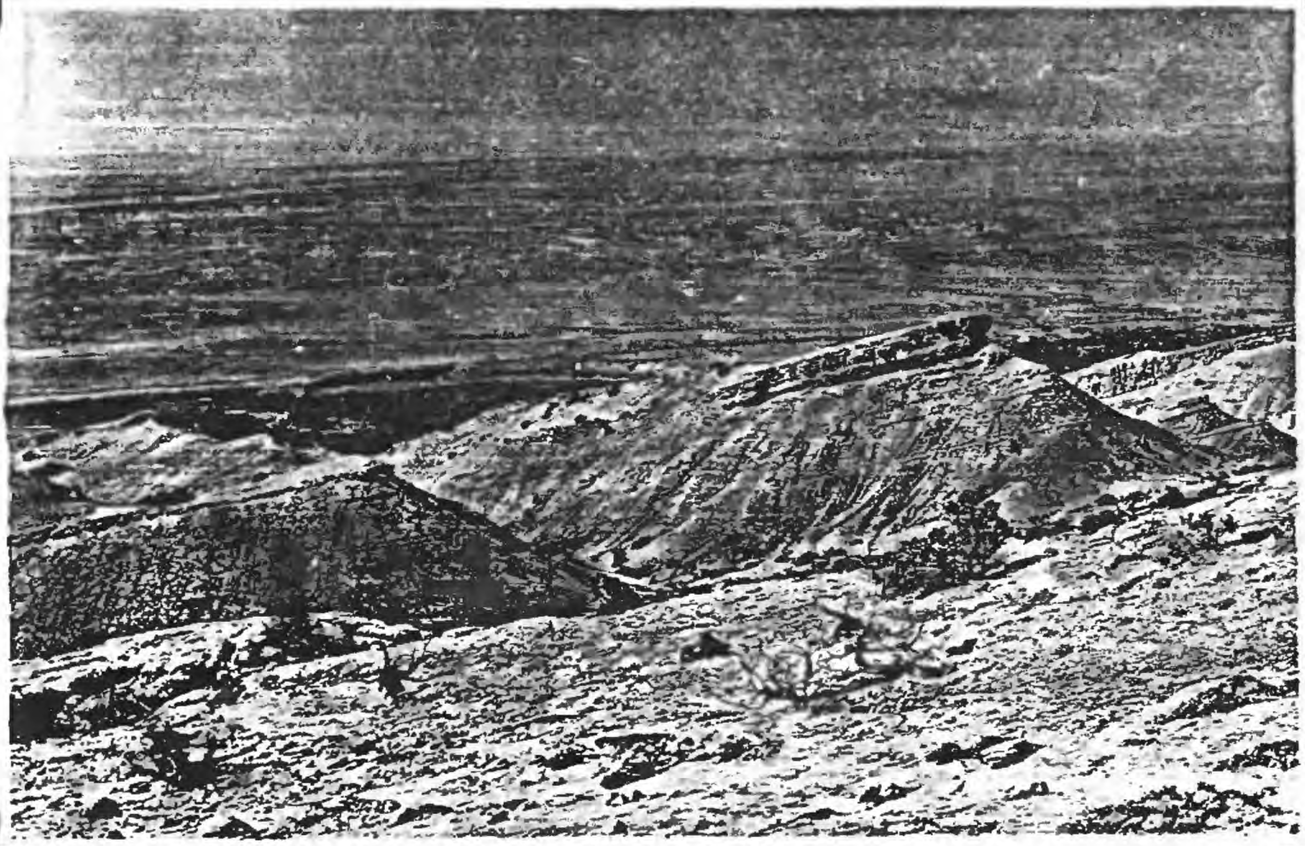


FIGURE 11. - TENSLEEP-GOOSE EGG CONTACT AT BASE OF RED SHALES

As in Figure 9, note Bighorn River at base of dip slope on west flank Sheep Mountain anticline.

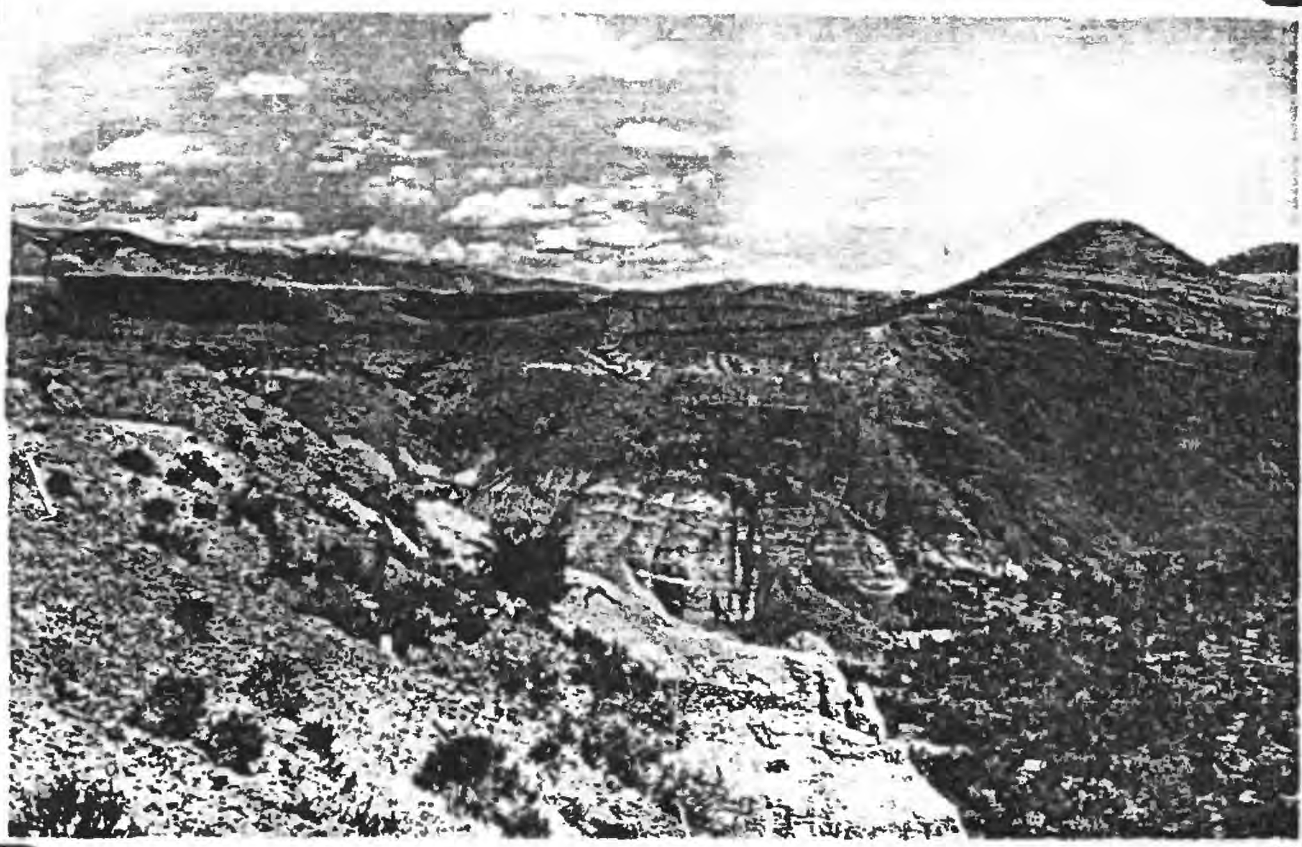


FIGURE 12. GOOSE EGG-CHUGWATER CONTACT

Exposed in cut in terrace gravels near Bighorn River - SE 1/4 sec. 21, T. 55 N., R. 94 W. Contact is at top of light pale-green shale of Dinwoody equivalent and base of dark red Chugwater redbeds.

limestone and dolomite, that is commonly cherty, and maintains a relatively constant thickness throughout the area. It forms the long, resistant, dip slopes of both Sheep Mountain and Little Sheep Mountain anticlines. Fossils were found about 12 feet below the top of this unit at two localities; one in sec. 8, T. 55 N., R. 94 W., and the other in sec. 21, T. 53 N., R. 93 W. The fossils were poorly preserved in each case, and individual fossils were not useful for correlation purposes. J. B. Reeside and E. L. Yochelson of the U. S. Geological Survey made the following identifications from these collections:

Bellerophontoid gastropods
Pelecypod similar to Myophoria
Pelecypod possible with pectenoid affinities
Scaphopod probably Plagioglypta

> They reported that, "the identification of the formation as Goose Egg is not incompatible with the fossil evidence (basing this on the abundance of bellerophontaceans); but additional, better specimens are needed before the question of a possible Triassic age can be conclusively ruled out."

The Phosphoria equivalent averages about 220 feet in thickness within the Spence-Kane area and is placed in the Permian.

Overlying this thick carbonate section is the Dinwoody equivalent or Triassic portion of the Goose Egg. The Dinwoody outcrops at the top of Spence dome and along the flanks of Sheep Mountain and Little Sheep Mountain, at the base of steep dip slopes of the Ervay tongue of the Park City formation (Figure 10). Small stream cuts at Spence dome just expose the upper part of the Ervay tongue. The unit consists of green to greenish-gray and greenish-yellow shales and siltstones commonly cut by small white gypsum veinlets. Near the top of this sequence there are usually several beds of massive gypsum and gray dolomite that may be equivalent to the Little Medicine tongue of the Dinwoody equivalent. The unit is easily distinguished from the redbeds of the overlying Chugwater formation and is about 50 feet in thickness throughout the area. The unit is too thin to distinguish at ordinary mapping scales within the area, because with the exception of the outcrop at Spence dome, the section dips rather steeply throughout the area of exposure. No fossils were found in this part of the section, but its stratigraphic position correlates it with sections known to be of Triassic age.

The Sheep Mountain and Little Sheep Mountain structures bring to the surface exposures of the Permo-Triassic rocks, which to the west are deeply buried in the center of the Bighorn Basin. Unfortunately, the exposures parallel facies boundaries, but they do afford the opportunity for surface investigation of this interesting part of the section. Condit (1916) measured four sections illustrating the lithology of the Embar and its gradation into redbeds and evaporites in the Bighorn Mountains. One of these sections was measured at the south end of the Sheep Mountain anticline, which Condit used to represent his "transitional facies". Concerning this section, Condit said (p. 267),

> "In the Sheep Mountain region, the fossiliferous limestones of the upper two-thirds of the formation show that deposition for the most part took place in sea water. A little below the middle, however, persistent beds of gypsum alternate with the fossiliferous limestones, indicating intermittent restrictions of the sea and concentration of the water, which temporarily favored precipitation. The fine-textured, arenaceous even-bedded red shales of the lower

> part denote deposition for the most part at or a little below
> sea level."

Plate IV shows the relations of both surface and subsurface sections within the Spence-Kane area. The "intertongued" interval below the Ervay tongue thins considerably, from south to north, across the area, due to transgressive overlap onto the unconformity at the top of the Tensleep sandstone. Sections 1, 2, and 6 of Plate IV, which lie slightly to the east of the other sections illustrated, show a larger percentage of redbeds in this lower "intertongued" interval, even though the distance of separation is small, suggesting that facies changes are rather rapid in this interval. Also noteworthy, is the reported presence of phosphate oolites in the lower part of this interval in the section penetrated by the Sohio Petroleum Company's No. 4 Alkali Anticline Unit Well in SW 1/4 sec. 29, T. 55 N., R. 95 W. This may represent an eastward extension of a thin phosphorite unit farther west. Pierce and Andrews (1941) have recorded phosphate near the base of the Phosphoria formation in the region south of Cody, in Park County, Wyoming, directly to the west on the other side of the Bighorn Basin. Tourtelot (1952) has pointed out the need for investigation of these facies boundaries in an east-west direction along the eastern part of the Bighorn Basin.

Section of Goose Egg formation:

Measured in SE 1/4 sec. 17, and NE 1/4 sec. 20, T. 53 N., R. 93 W.

Chugwater formation.	
Goose Egg formation:	Feet
Dinwoody equivalent	
34. Shale and siltstone, dark green; interbedded with thin, white gypsum beds	19.8
33. Gypsum, white, granular	1.5
32. Shale and siltstone, dark green	4.5
31. Gypsum, white, granular	1.7
30. Siltstone, dark green	5.3
29. Gypsum, white, bedded, granular	2.5
28. Siltstone, shaly, dark green; cut by numerous gypsum veinlets and bands with several thin beds of gypsum	39.6
Phosphoria equivalent	
27. Dolomitic limestone, gray, vuggy, with fossiliferous zone at base; thin cherty dolomite beds at top of unit	9.9
26. Dolomitic limestone, pale gray, dense, vuggy; weathers light gray to near white, very resistant unit and forms dip slopes of Sheep Mountain. Few thin, cherty zones	79.4
25. Siltstone, green to tan and yellow-brown, sandy in places, poorly exposed	9.0
24. Nodular chert, blue-gray and dolomitic limestone; chert covers surface	5.0
23. Dolomitic limestone, gray, sandy near base, vuggy, vugs lined with calcite crystals, nodules of blue-gray chert	9.0
22. Shale, dark green, sandy to silty	4.0
21. Dolomitic limestone, white-gray, dense	2.5
20. Shale, green, silty	1.5
19. Gypsum, white, granular, soft	0.8
18. Shale, red, silty; and siltstone, red; thin gypsum lenses	9.9
17. Gypsum, white, massive	5.5
16. Dolomitic limestone, gray, vuggy	0.5
15. Shale, green	0.5
14. Shale, red, silty; few white gypsum stringers	5.5
13. Chert, blue-gray, bedded; thin zone purple chert at top and thin interbeds of gray dolomite	4.0
12. Dolomitic limestone, gray, medium crystalline; forms resistant capping unit on salmon-red colored units below; weathers light gray to white	6.0

11. Shale, green	2.0
10. Shale, maroon	2.0
9. Shale, red, hard, silty; becoming sandy near top	6.0
8. Dolomitic limestone; banded green and gray where fresh, pink to buff where weathered	2.0
7. Shale, red, fissile, silty; few thin beds of green shale	25.2
6. Dolomitic limestone, banded	1.5
5. Shale, red, silty, grades to green at top	10.1
4. Limestone, sandy	2.0
3. Shale, red, silty	11.1
2. Sandstone, red, medium-grained	5.0
1. Shale, red; few thin green shale, siltstone and yellow-brown shale beds	20.1

Total Goose Egg formation	314.9
Total Dinwoody equivalent	74.9
Total Phosphoria equivalent	240.0

Tensleep formation

Section of Goose Egg formation:
Measured in SW 1/4 SW 1/4 sec. 9, T. 55 N., R. 94 W.

Chugwater formation.
Goose Egg formation:

	Feet
Dinwoody equivalent. (not measured)	
Phosphoria equivalent:	
15. Dolomitic limestone, gray, crystalline, vuggy, thick-bedded; oil residue in lower part; fossils found 8' below top; Ervay tongue of Park City formation	99.3
14. Siltstone, green-yellow to tan, thin sandy zones; includes nodular and bedded chert poorly exposed through 8' of section. Chert is gray and weathers white, shaly near top	30.0
13. Dolomitic limestone, gray, vuggy; some white-weathering, gray, nodular chert and sandy dolomite	8.0
12. Shale and sandstone, greenish-yellow to tan, poorly exposed	52.0
11. Dolomitic limestone, gray, crinkly banding, finely-crystalline, cliff-forming, massive in lower part, upper 2' is thin-bedded	9.0
10. Shale and siltstone, green, sandy at base	4.5
9. Shale, red, sandy at base, nodular; grades vertically and horizontally into green and tan shales	5.0
8. Limestone, gray, lithographic, platy; thin red shale partings	0.9
7. Shale, red, silty; sandy at base and top; thin, pale green shale partings	47.0
6. Dolomitic limestone, gray, crinkly banding, finely-crystalline; some thin, white gypsum veinlets	0.5
5. Sandstone and siltstone, yellowish-green; grades laterally into red, silty shale	4.0
4. Dolomitic limestone, gray, sandy, crinkled surfaces which give unit a banded appearance on a weathered surface	1.2
3. Shale, red, silty, fissile near top	11.0
2. Shale, red, fissile; thin, pale green shale beds near top	10.5
1. Sandstone, tan to yellow-green, stained red; with tan, and red shaly zones; sandstone is medium- to coarse-grained	11.0
Total Phosphoria formation	293.9

Tensleep formation

Section of Goose Egg formation:
Measured in NE 1/4 sec. 28, T. 56 N., R. 95 W.

	Feet
Chugwater formation.	
Goose Egg formation:	
Dinwoody equivalent:	
17. Gypsum, white, massive, banded	7.0
16. Shale and siltstone, green with cross-cutting, white, gypsum veinlets	3.0
15. Gypsum, white	0.8
14. Dolomite, gray, dense, jointed, banded; thin, green shale partings and gypsum veinlets	1.2
13. Shale, green, sandy; cross-cutting gypsum veinlets	2.0
12. Gypsum, white, massive	0.5
11. Siltstone and shale, green, cut by numerous gypsum veinlets	34.0
Phosphoria equivalent:	
10. Dolomitic limestone, gray, vuggy, cherty in places. Ervay tongue of Park City formation	80.0
9. Siltstone and sandy shale, yellowish-green to greenish-gray; traces of nodular chert found; unit largely covered by slope wash	19.0
8. Dolomitic limestone, dark gray, finely-crystalline, vuggy, jointed, forms cliff, weathers pale gray	11.5
7. Shale, sandy, red and tan; grades upward into dull, yellowish-green, sandy shale and siltstone with chert zones and thick gypsum beds; unit poorly exposed	30.0
6. Gypsum, white	4.0
5. Dolomitic limestone, dark gray, finely-crystalline, weathers light gray, banded; thin-bedded at top; cliff-former; overlain by poorly exposed, yellowish-green shale and siltstone	11.0
4. Shale, red, fissile	15.6
3. Gypsum, white, massive, forms ledge	1.3
2. Dolomitic limestone, light gray to pink, banded, platy	0.3
1. Shale, sandy, and siltstone; sandy zone at basal 10' is greenish-yellow in color while upper shale and siltstone is red	33.3
Total Goose Egg formation	254.5
Total Dinwoody equivalent	48.5
Total Phosphoria equivalent	206.0
Tensleep formation	

Mesozoic Rocks

Chugwater formation. The Chugwater formation was named by Darton (1904) for the extensive series of redbeds found along the base of the Bighorn Mountains. He derived the name from Chugwater Creek in the vicinity of Iron Mountain, Wyoming. Darton's original definition included strata from the top of the Tensleep sandstone to the base of the Sundance formation. In 1906, Darton separated the Embar formation from the basal part of the Chugwater, and Love (1939 and 1945) distinguished the Gypsum Spring formation from the upper part of this formation. The formation is placed in the Triassic on the basis of regional relationships and plant and vertebrate remains.

In the Spence-Kane area, the Chugwater formation appears to conformably overlie the Goose Egg formation and is unconformably overlain by the Gypsum Spring formation. The formation is exposed over a large area, on the flanks of the Sheep Mountain and Little Sheep Mountain anticlines and Spence dome (Figure 13). The exposure of the formation in the extreme northeast corner of the mapped area represents its outcrop at the base of the Bighorn Mountains.

Within the mapped area, the formation averages about 600 feet in thickness, and consists of red shale, siltstone, and sandstone. Thin gypsum beds are present near the base of the formation, and gypsum veinlets are found throughout the section. Green mottling is common throughout the formation. A few thin, dark, dolomite beds, apparently lenticular, are present. Sandstone units are generally more prevalent near the top of the formation. The formation is easily recognized as the redbeds contrast sharply with the predominantly green units of the underlying Dinwoody equivalent, and the top of the formation is marked by the base of the massive gypsum of the Gypsum Spring formation (Figure 14). This upper contact appears to be sharp at the outcrop, but is known to be regionally unconformable. The redbeds in the overlying Gypsum Spring formation have a distinctly lighter red appearance on their weathered surface than do those of the Chugwater redbeds and are easily distinguished on the outcrop.

Plate II shows the general sequence of lithologies present, and Plate V illustrates surface and subsurface sections within the area. The formation thins noticeably, within the area, as shown by Plate V, and ranges in thickness from about 600 feet in the south to 500 feet in the north. The thinning results from a progressive loss of the upper part of the section in a northerly direction due to truncation by the regional unconformity at the base of the Gypsum Spring formation. Only the Red Peak member of the Chugwater of the southern part of the Bighorn basin is believed to be present in the Spence-Kane area. No evidence for the presence of the Alcova limestone was found.

Part of the Chugwater formation is bleached to a pale green color in the vicinity of a small reverse fault on the east side of the Little Sheep Mountain anticline, where the beds are tightly compressed and crumpled. A pale green, weathered band also appears in the Chugwater along the axis of the Sheep Mountain anticline in sec. 22, T. 53 N., R. 93 W. Moulton (1926) has noted several occurrences of bleached Chugwater redbeds along the crest of minor folds on the flanks of the Bighorn Mountains in southern

Montana. He attributed the bleaching to the reduction of ferric oxide by hydrogen sulphide associated with the migration of oil through fractures near the crest of the anticlines. He suggested that the petroleum in anticlines whose crests are marked by bleached redbeds may have escaped unless the reservoir existed at considerable depth. No asphaltic residue or oil stain was noted within the greenish-white band at the Sheep Mountain anticline.

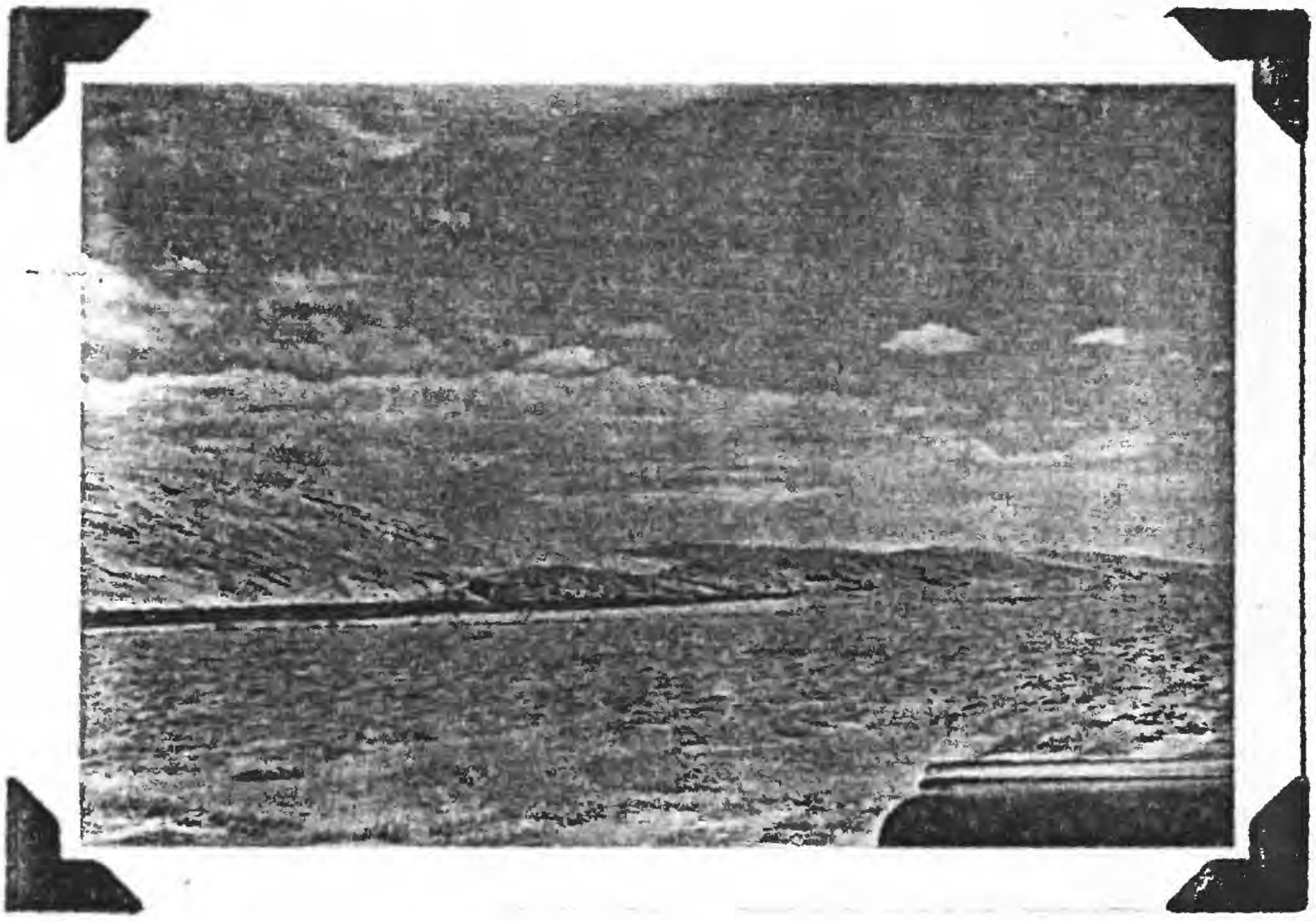


FIGURE 13. - CHUGWATER REDBEDS ON WEST FLANK SHEEP MOUNTAIN ANTICLINE

White, resistant, slopes on left are Ervay tongue of Park City formation. Terrace gravels in foreground.

Section of Chugwater formation:
Measured in S½ sec. 22, T. 53 N., R. 93 W.

Gypsum Spring formation.

Chugwater formation:	Feet
5. Sandstone, red, medium- to fine-grained, with red siltstone and shale; resistant units near base	406.7
4. Shale, green, gypsiferous; two thin red sandy shale beds and a thin black dolomitic limestone bed; forms green-white weathering band in midst of red Chugwater	12.9
3. Interbedded shale, siltstone, and fine-grained sandstone, red	61.5
2. Sandstone, medium- to fine-grained; cut by numerous gypsum veinlets ½" or less in thickness	30.3
1. Shale and siltstone, red; few thin green shale and gypsum beds less than 4" thick	90.9
Total Chugwater formation	602.3

Goose Egg formation.

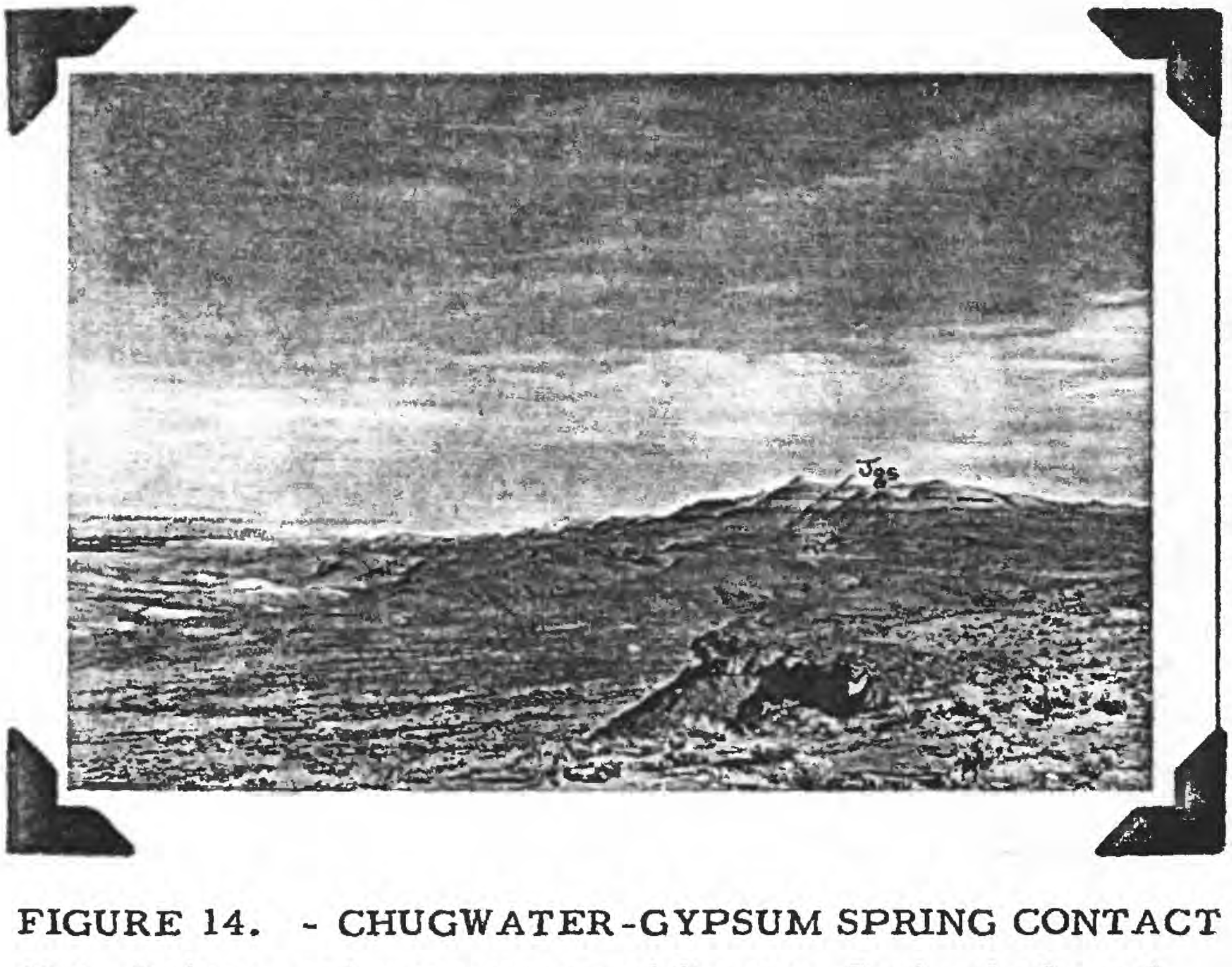


FIGURE 14. - CHUGWATER-GYPSUM SPRING CONTACT

Note lighter-red appearance of Gypsum Spring beds and massive gypsum forming cliff at base. Looking southeastward from SE 1/4 sec. 10, T. 55 N., R. 95 W.

Section of Chugwater formation:
Measured in $N\frac{1}{2}$ sec. 28, T. 56 N., R. 95 W.

Gypsum Spring formation.	
Chugwater formation:	Feet
5. Shale and siltstone, red	231.8
4. Sandstone, red, fine-grained, rounded grains, some beds ripple marked; thin red shale and siltstone interbeds	109.2
3. Siltstone and shale, red; thin green siltstone beds and irregular green shaly bleached zones	79.2
2. Sandstone, red, fine- to medium-grained; thin gypsum veinlets	8.8
1. Siltstone and sandy shale, red; thin gypsum veinlets and green shale beds	74.8
Total Chugwater formation	503.8
Goose Egg formation.	

Gypsum Spring formation. The strata comprising the Gypsum Spring were distinguished from beds in the underlying Chugwater by Love (1939) at Red Creek, near Dubois, Wyoming, and the unit was officially classed as a formation following the work of Love and others (1945).

In the Spence-Kane area the formation outcrops along the flanks of the Sheep Mountain and Little Sheep Mountain anticlines and Spence dome, and also along the crest of the Crystal Creek anticline and Rose dome. The formation also outcrops in the extreme northeast corner of the mapped area, near the base of the Bighorn Mountains.

The base of the formation is marked by a thick, massive, white gypsum bed (Figure 15). In the subsurface, anhydrite is commonly reported rather than gypsum. The lower contact at the base of this gypsum unit and top of the Chugwater redbeds appears sharp in exposures, but regionally is known to be unconformable. The top of the formation was placed at the contact between red-brown shales and pale greenish-gray shales just below the basal Sundance limestone or sandstone. This contact is easily mapped in the area, since the basal Sundance sandstone or limestone forms small ledges that are easily traced on aerial photographs, and the color contact between the red-brown and greenish-gray shales is conspicuous in the field.

Three members are easily distinguished from surface exposures. The lower member consists of the massive gypsum bed at the base overlain by redbeds. Thin interbeds of red-brown and green shale are common within the massive gypsum, and thin gray dolomitic limestone interbeds were observed at several points. The gypsum appears to have been leached near its base at several localities and has a brecciated appearance, with red shale and siltstone enclosing gypsum and dolomite fragments. In general, however, the gypsum forms a resistant unit throughout the area and caps small hills and slopes at several points within the area, notably at the south end of Sheep Mountain anticline and on the east flank of Spence dome. The overlying redbeds consist of red-brown to maroon shales and siltstones with thin green shale interbeds and thin lenticular beds of white gypsum.

The middle member consists of dolomitic limestone, limestone, redbeds and thin gypsum beds. The carbonates are the most characteristic lithology of the middle member, and consist of thin, platy, dense, white-weathering, dolomitic limestones and a relatively thick, gray, limestone unit which forms conspicuous dip slopes throughout the area. Several thin maroon and pale-green shale beds with thin lenses of white gypsum separate the carbonates.

The upper member consists predominantly of red-brown and pale green shales and siltstones with thin lenses of white gypsum. Thin vari-colored dolomitic limestones, in the middle of this unit, make very colorful outcrops throughout the area and are particularly well shown along the crest of Rose dome where they outcrop over a broad area (Figure 16). The colors range from white to purplish and pink. Nodular chalcedony, apparently irregular in distribution is found in the lower part of the unit, while thin banded cherts are common near the top.

Imlay (1956) has made a detailed study, over a number of years, of the stratigraphy of marine rocks of Middle and Late Jurassic age exposed in the Bighorn Basin, Pryor Mountains and northern Bighorn Mountains of Wyoming and Montana. He presents (p. 569) the results of measured sections in the vicinity of Little Sheep Mountain and Spence dome and correlates them with sections both to the north and south of the Spence-Kane area. Imlay has divided the three members described above into 8 units and correlated these with similar units in the Piper formation of the Pryor Mountains and northern Bighorn Mountains of Montana.

Through regional studies, the top of the Gypsum Spring formation is believed to represent an erosional unconformity on the east side of the Bighorn Basin, as there is a progressive loss of the upper part of the formation from north to south within this general area. The unconformity is not readily apparent at individual outcrops within the Spence-Kane area. Imlay (1956, pp. 579-580) has summarized the evidence for this unconformity.

The formation averages about 200 feet in thickness in the Spence-Kane area. Plate II shows the general lithologic sequence, and Plate VI illustrates surface and subsurface sections within the area, and demonstrates the general thinning from north to south.

Imlay (1956, pp. 580-581) has identified several fossils from the Gypsum Spring of this area and dates the formation as Middle Jurassic in age.

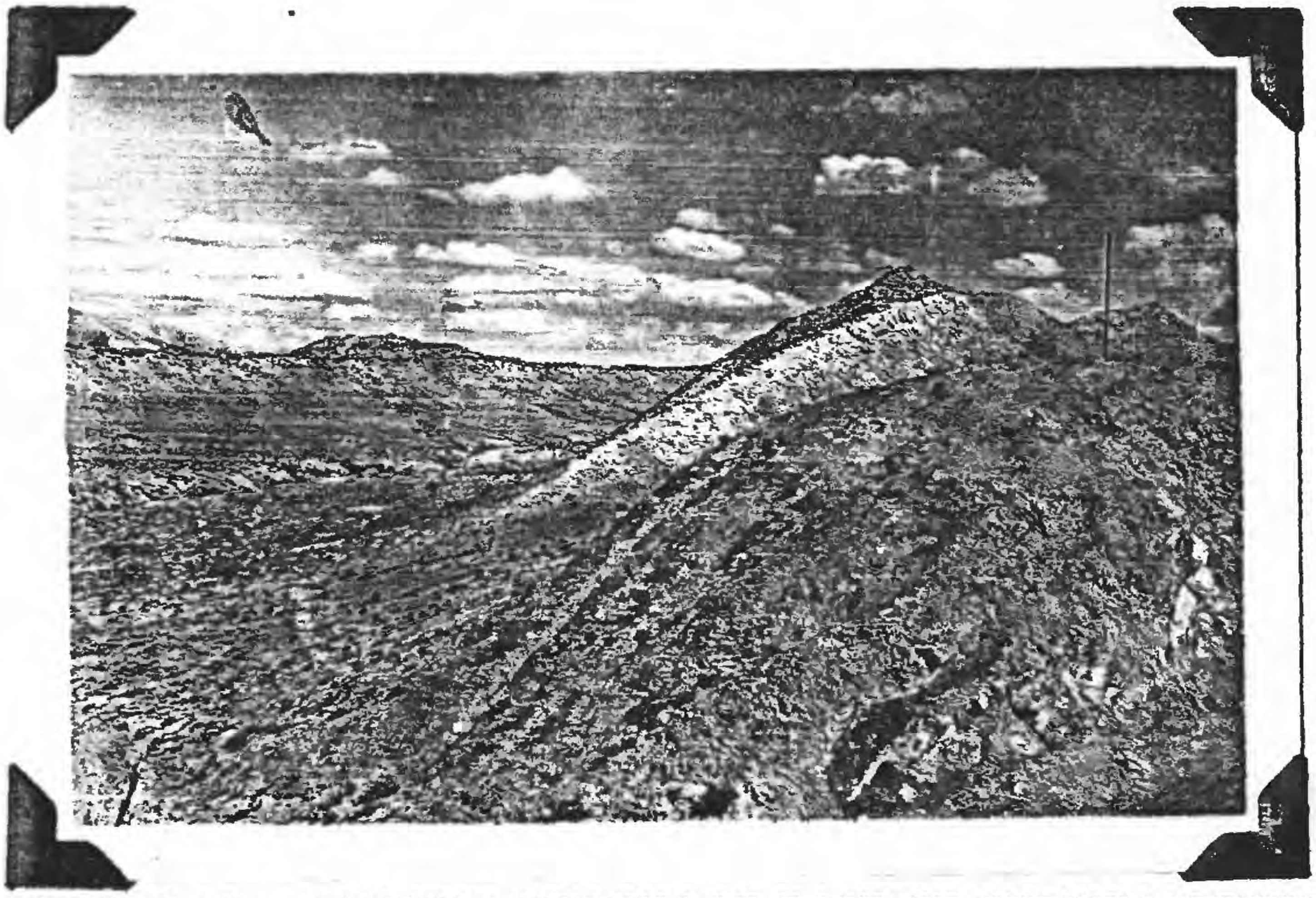


FIGURE 15. - MASSIVE GYPSUM AT BASE OF GYPSUM SPRING FORMATION.

Note typical weathered surface of gypsum exposed in lower right foreground.

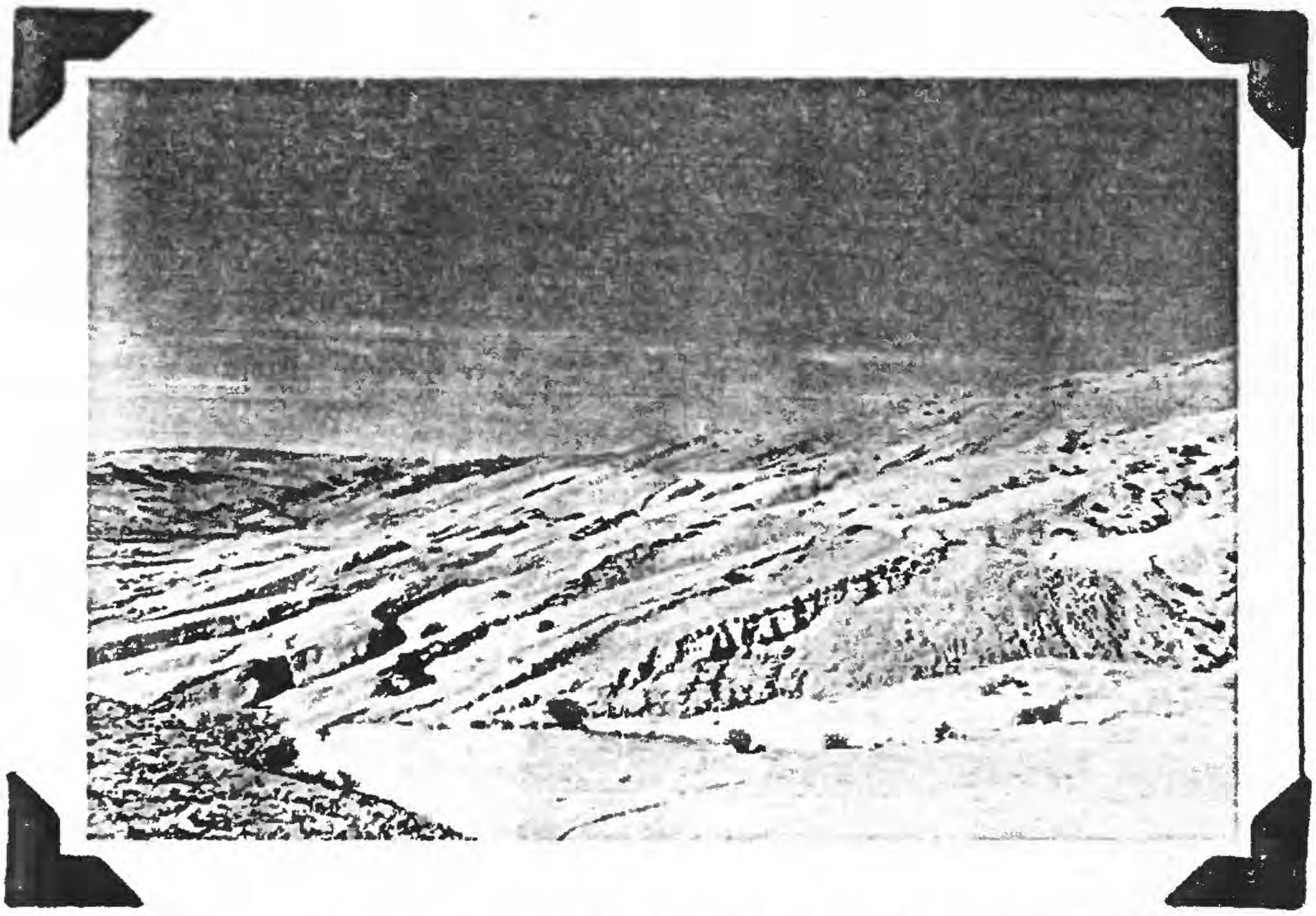


FIGURE 16. - THIN VARICOLORED DOLOMITIC LIMESTONE BEDS IN UPPER PART GYPSUM SPRING FORMATION

West flank Little Sheep Mountain anticline.

Section of Gypsum Spring formation:
Measured in W$\frac{1}{2}$ sec. 3, T. 55 N., R. 95 W.

Sundance formation.

Gypsum Spring formation:	Feet
22. Shale, maroon to red-brown; thin blue-green shale and siltstone partings ----------	39.2
21. Dolomitic limestone, gray, platy; thin bed of banded chert at top. Lenticular white gypsum at base ----------	3.0
20. Siltstone, maroon and green, with thin lensing gypsum beds- -	23.5
19. Gypsum, white, massive----------	1.0
18. Dolomitic limestone, white, pink, purplish; dense, platy, thin-bedded; nodular chalcedony irregular in distribution -	19.6
17. Shale, maroon, and gray-green, and maroon siltstone-------	1.8
16. Gypsum, white, massive ----------	2.0
15. Shale, green----------	0.5
14. Dolomitic limestone, pale gray, dense, weathers white, platy----------	1.5
13. Siltstone and shale, maroon and pale green, with several thin, poorly exposed gypsum beds----------	14.7
12. Limestone, gray, finely-crystalline, resistant; forms dip slopes over entire area----------	29.4
11. Shale, green----------	0.5
10. Siltstone, maroon and pale green, calcareous; thin, white, gypsum beds----------	8.5
9. Dolomitic limestone, pale gray, weathers white, platy, shaly -	0.5
8. Shale, pale green----------	0.2
7. Dolomitic limestone, gray, dense, microcrystalline, blocky -	0.9
6. Shale, maroon with thin beds of gray-green shale ----------	4.0
5. Gypsum, white, massive----------	0.6
4. Shale, maroon, with thin gray-green beds; thin gypsum beds less than 1 foot in thickness in middle of unit ----------	18.2
3. Gypsum, white, massive----------	1.0
2. Shale, maroon, blocky, with thin gray-green beds ----------	17.6
1. Gypsum, white, massive, banded; thin interbeds of maroon to red-brown shale----------	53.9
Total Gypsum Spring formation	242.1

Chugwater formation.

Sundance formation. The Sundance formation was named by Darton (1899). There are extensive exposures of the formation along the flanks of the Sheep Mountain, Little Sheep Mountain, and Crystal Creek anticlines and Spence and Rose domes.

The Gypsum Spring-Sundance contact is discussed in the preceeding section. Imlay (1956) has divided the Sundance formation into an "Upper Sundance" formation and a "Lower Sundance" formation along the eastern and southern margins of the Bighorn Basin. He correlates the "Lower Sundance" formation with the Rierdon formation and the "Upper Sundance" formation with the Swift formation of Montana. The Sundance was mapped as a single formation within the Spence-Kane area, but two major subdivisions, "Upper Sundance" and "Lower Sundance", were readily recognizable in the field and are indicated on Plate II, which shows the general sequence of lithologies within the area, and on Plate VI which illustrates surface and subsurface sections.

The Sundance formation averages about 370 feet in thickness in the Spence-Kane area; about 210 feet of this section is represented by the "Upper Sundance" while the lower 160 feet is placed in the "Lower Sundance". Imlay (1956, p. 588) found that the "Lower Sundance" increased in thickness from 144 feet at the north end of Little Sheep Mountain, to 167 feet at the southeast end of Sheep Mountain.

Three units are readily recognizable within the "Lower Sundance". Imlay has named these units, the lower oolitic sandstone or limestone member, the medial shale member and the upper sandstone member.

The lower oolitic unit consists of oolitic sandstone, sandy limestone and limestone in several thin ledge-forming beds that are interbedded with gray-green siltstone and shale (Figure 17). The oolitic beds are usually fossiliferous and the units form a resistant ledge above about 4 feet of gray-green shale, through most of the area. These oolitic beds vary in lithology, in that in places they are composed wholly of either limestone or sandstone, but generally they consist of sandy limestone beds. Fossils were collected from a blocky, sandy limestone coquina, 30 feet above the base of the Sundance formation in SE 1/4 sec. 15, T. 55 N., R. 95 W., and identified by R. W. Imlay of the U. S. Geological Survey as follows:

U. S. G. S. Mes. Loc. 26716

Ostrea strigilecula	White
Astarte morion	Crickmay
Lyosoma powelli	White

In the report on the above collection, Imlay stated:

> "The fossils from Unit No. 6 contain the gastropod Lyosoma powelli White and Astarte morion Crickmay, which according to my knowledge, do not range above the basal member of the Lower Sundance formation (Imlay, 1956, A.A.P.G. Bull. V. 40, p. 591), but do occur in older beds (e.g. (1) Cody area, Wyo., (2) Red Dome in Pryor Mountains, Mont.). I have not found them in the Gypsum Spring formation along the east side of the Bighorn Basin."

Overlying the lower oolitic unit is the medial shale unit, which consists of gray-green shale that becomes sandy near the top. Throughout the area, the surface of this shale is commonly littered with Gryphaea shells. A collection of fossils obtained from this unit in SE 1/4 sec. 15,

T. 55 N., R. 95 W., was sent to R. W. Imlay of the U. S. Geological Survey, who made the following identifications:

U. S. G. S. Mes. Loc. 26719

Gryphaea nebrascensis Meek and Hayden
Pleuromya sp.

In regard to this collection, Imlay noted:

> "Collection J1 contains an abundance of Gryphaea nebrascensis Meek and Hayden. This species appears abruptly in great abundance at the top of the lower member of the Lower Sundance formation, becomes less common upward, and is rare in the Upper Sundance formation. It occurs in greatest abundance in calcareous siltstone and shale and occurs rarely in sandy sediments where the genus Ostrea is apt to be common. Apparently Gryphaea thrived in deeper waters than Ostrea."

The upper unit of the "Lower Sundance" consists of gray, papery limestone which splits into extremely large thin sheets and fine- to medium-grained calcareous, glauconitic sandstones which are commonly crossbedded. The unit is quite variable, but forms ledges throughout the area. Inthe north half of the area, papery limestones, with some sandstone at the top are the dominant lithology. In the south half of the area, cross-bedded, calcareous sandstone and sandy limestone become the dominant lithology (Figure 18). Imlay (1956, pp. 589-591) has discussed the regional variations in lithology of this unit, and presents evidence for a disconformity between the "Upper Sundance" and "Lower Sundance". He assigns the "Lower Sundance" to the Late Jurassic (Callovian) and presents fossil evidence gathered from the east and south margins of the Bighorn Basin.

The "Upper Sundance" is composed of two distinct units within this general area; a lower shale member, and an upper sandstone member. The contact between the two units, however, is gradational.

The lower shale member consists of gray-green shale with thin lenticular sandstone beds, and there is a gradation upwards through sandy shale to sandstone. This unit, in the field, can be easily identified by the large number of belemnites and oyster shells found along the outcrop. Some of these fossils were collected from this unit in SE 1/4 sec. 15, T. 55 N., R. 95 W., and sent to R. W. Imlay, of the U. S. Geological Survey, who made the following identifications:

U. S. G. S. Mes. Loc. 26720

Pachyteuthis "densus"	(Meek and Hayden)
Ostrea engelmanni	Meek

The writer placed the base of the upper sandstone member at the base of thin calcareous coquina beds, at the top of the shale sequence just described. Two of these beds were found in a section measured at the south end of the area, while only one of these coquina beds was present in the north (Plate VI). Fossils from this coquina bed in SE 1/4 sec. 15, T. 55 N., R. 95 W., were collected 99 feet below the top of the Sundance formation and sent to R. W. Imlay of the U. S. Geological Survey, who made the following identifications:

U. S. G. S. Mes. Loc. 26718

Camptonectes bellistriatus Meek and Hayden
Astarte sp.

Above the coquina bed is a thin section of sandy, gray-green shales followed by the sandstones of the upper part of the Sundance. The sandstone

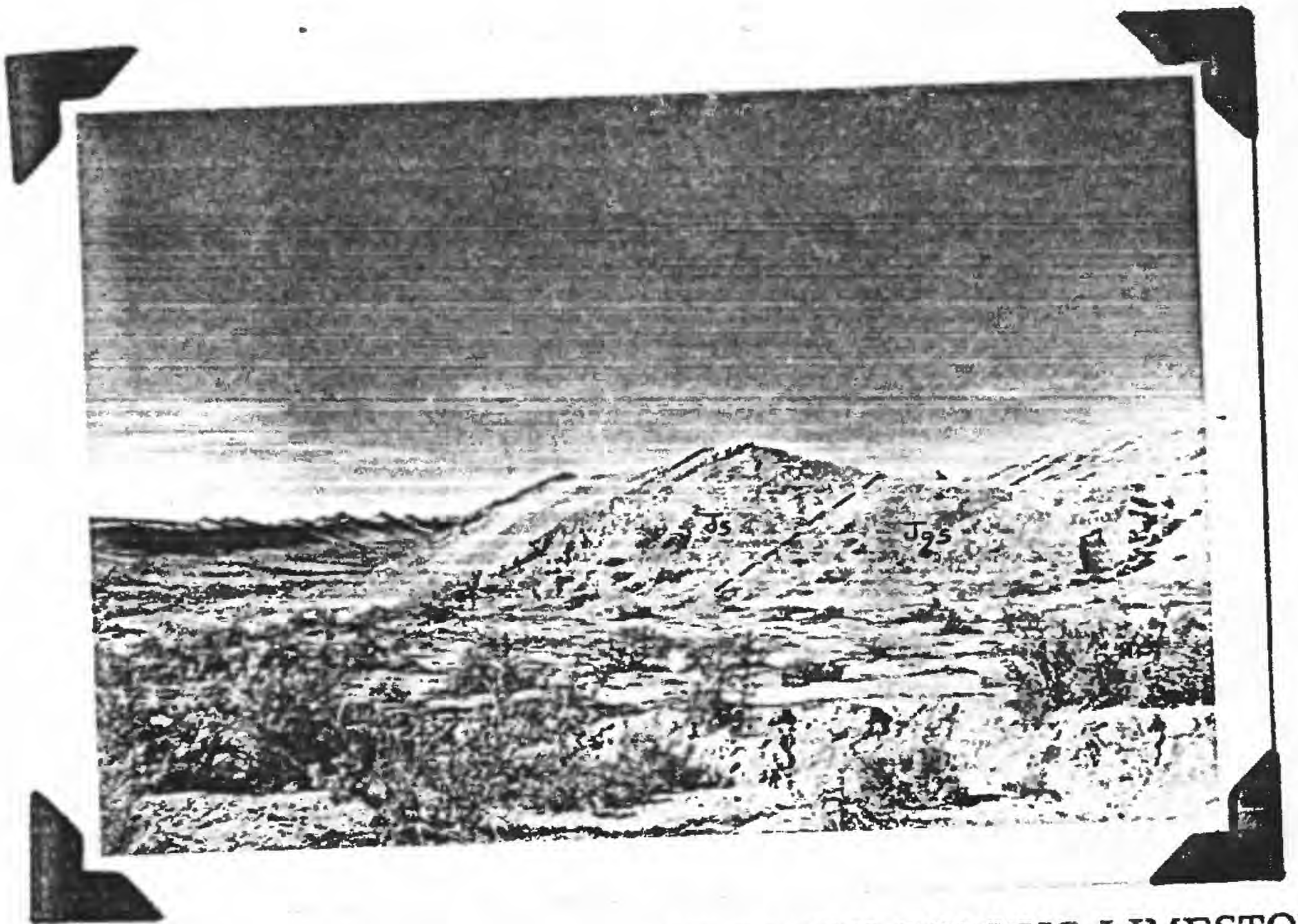


FIGURE 17. - LEDGE-FORMING SANDY OOLITIC LIMESTONES OF BASAL SUNDANCE FORMATION

Note several thin ledges above Gypsum Spring (Jgs)-Sundance (Js) contact. West flank Spence dome.

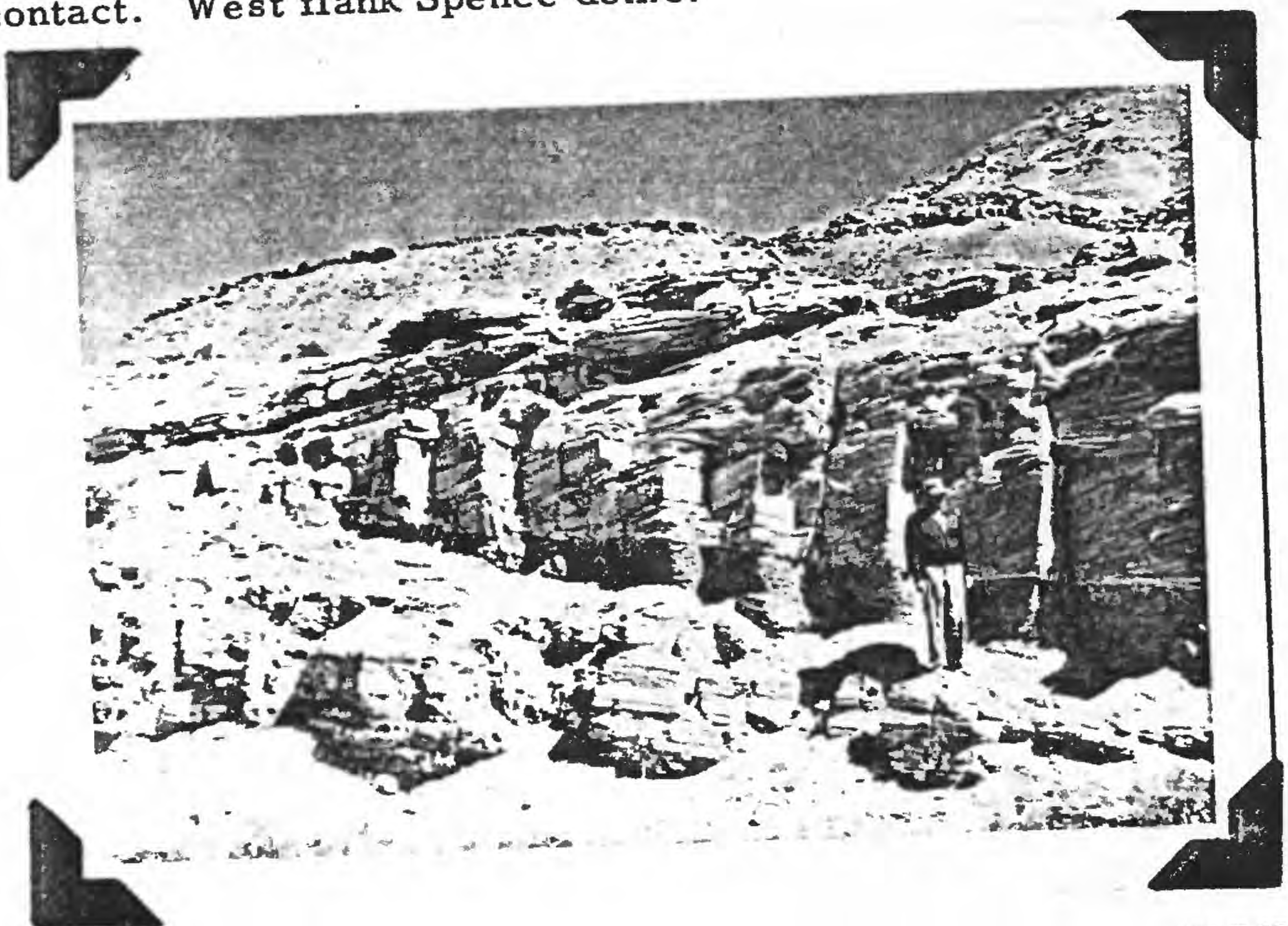


FIGURE 18. - LEDGE-FORMING CROSSBEDDED CALCAREOUS SANDSTONE AND SANDY LIMESTONE UNIT AT TOP OF "LOWER SUNDANCE"

East flank Crystal Creek anticline. NE 1/4 sec. 8, T. 54 N., R. 93 W.

beds consist of medium- to coarse-grained sandstone that is calcareous, glauconitic and locally crossbedded. Thin-bedded resistant units, that weather brown, alternate with massive, less resistant sandstone. Fossil fragments are commonly seen in the upper sandstone units. The upper sandstones of the formation form a series of distinct ledges over much of the area and help to distinguish the top of the Sundance from the overlying Morrison formation (Figure 19).

An ammonite was found by the writer on the east flank of Little Sheep Mountain in NW 1/4 sec. 22, T. 56 N., R. 95 W., in glauconitic sandstone, 20 feet below the top of the Sundance formation. The fossil was sent to R. W. Imlay of the U. S. Geological Survey, who made the following identification:

U. S. G. S. Mes. Loc. 26717

Goliathiceras (*Pachycardioceras*)
cf. *G. russelli* (Reeside)

Imlay made the following remark concerning this collection:

> "The presence of a cardioceratid ammonite, *Goliathiceras* in collection JsSM2 only 20 feet below the top of the Sundance formation is interesting because the genus in Europe is not known above the lower Oxfordian zone of *Cardioceras cordatum*. Its presence so near the top of the Sundance formation indicates that part of the Morrison formation in the Bighorn Basin is of late Oxfordian age. A similar age for the basal part of the Morrison in the Wind River Basin is suggested likewise by the presence of the ammonite *Cardioceras* only 25 feet below the top of the Sundance formation (Imlay, 1956, p. 598) at Horse Creek. By contrast in Montana the Morrison formation does not appear to be older than Kimmeridgian at its base (Imlay, 1956, p. 595), which suggests that continental deposition (Morrison formation) took place in the area of the Wind River and Bighorn Basins during middle to late Oxfordian time while marine deposition was taking place in Montana."

Section of Sundance formation:
Measured in NW 1/4 sec. 10, T. 55 N., R. 95 W.

Cloverly and Morrison formations.	Feet
Sundance formation:	
"Upper Sundance"	
20. Sandstone, gray-green, medium- to coarse-grained, calcareous, resistant; forms dip slopes; thin-bedded, resistant beds alternate with thick, massive, less resistant sandstone; locally glauconitic	55.2
19. Sandstone, gray-green, fine-grained, with glauconite in discrete grains, interval largely covered by slope wash	36.8
18. Shale, gray-green, sandy	6.6
17. Limestone, gray, coquinoid, largely shell fragments	1.3
16. Shale, gray-green to olive-green, abundant fossils in upper part, poorly exposed	99.6
15. Sandstone, gray, medium-grained, calcareous; not continuous laterally	1.0
14. Shale, gray-green to olive-green	4.7
13. Sandstone, gray, calcareous, medium- to coarse-grained, large glauconite grains, grades upward to white-weathering, platy limestone at top	2.3
"Lower Sundance"	
12. Limestone, gray, weathers white, lithographic, papery, splits into extremely thin sheets	32.9
11. Shale, gray-green, sandy	98.7
10. Limestone, gray, sandy, coquinoid	1.5
9. Shale, gray-green	1.7
8. Limestone, gray, sandy, oolitic	1.5
7. Shale, gray-green	1.0
6. Limestone, gray, sandy, oolitic, coquinoid, blocky	0.7
5. Shale, gray-green, sandy, poorly exposed	18.0
4. Limestone, gray, shaly at base, grades upward to blocky, oolitic, sandy, limestone; forms resistant ledge	2.3
3. Shale and siltstone, gray-green	5.0
2. Limestone, gray, shaly, weathers white to light gray	1.2
1. Siltstone and shale, gray-green	3.7
Total Sundance formation	375.7

Total "Upper Sundance"	207.5
Total "Lower Sundance"	168.2

Gypsum Spring formation.

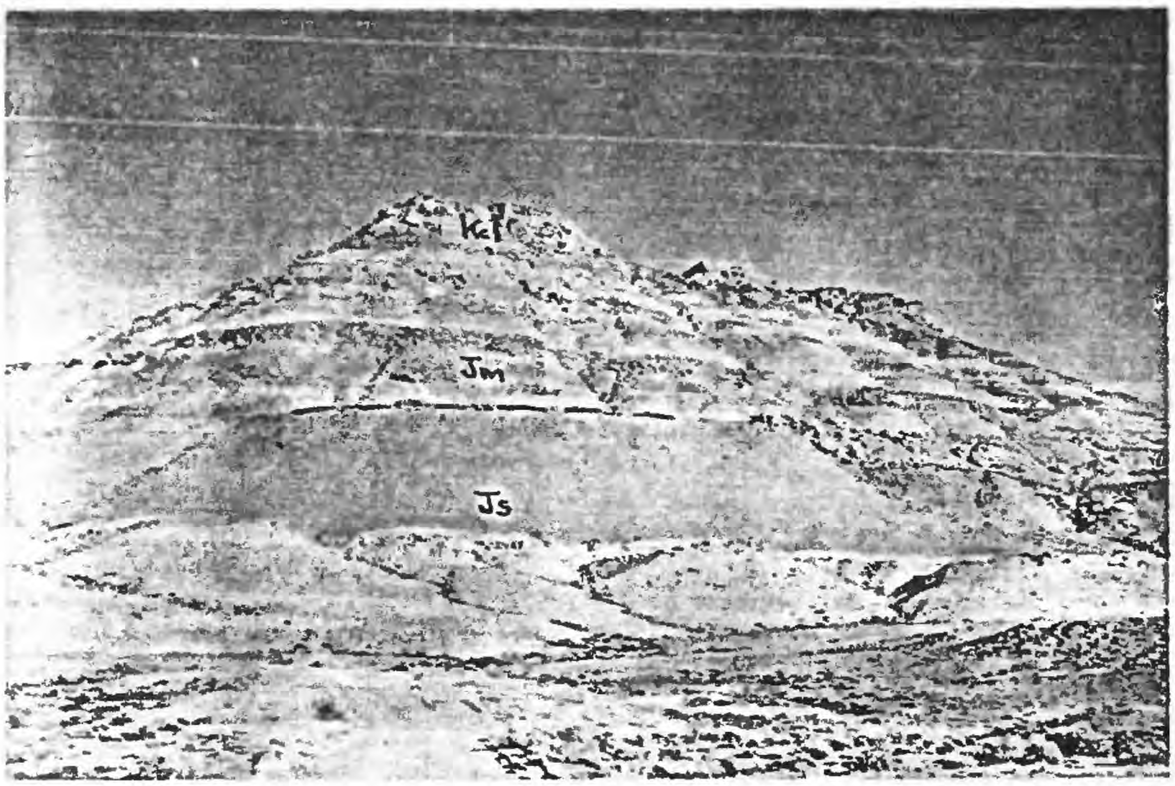


FIGURE 19. - GENERAL VIEW OF SUNDANCE (Js)-MORRISON (Jm) CONTACT

Note white unit near base, at top of "Lower Sundance", and Cloverly (Kcl) sandstones at top.

Morrison and Cloverly formations undivided. The Morrison formation was originally described from exposures near Morrison, Colorado. The lower contact of the formation with the underlying Sundance formation is generally marked by pale green and maroon shales of the Morrison formation above the ledge-forming, glauconitic sandstones of the Sundance formation. In places, however, lenticular sandstone units within the continental Morrison are found to overlie the uppermost sandstone beds of the marine Sundance formation. In such cases differentiation of the formations is based on the less-resistant character of the Morrison sandstones and the lack of glauconite in contrast with the resistant, glauconitic sandstones at the top of the Sundance formation.

The top of the Morrison formation and base of the overlying Cloverly formation presents a distinct problem over much of the Bighorn Basin. The congflomerates, conglomeratic sandstone, and massive coarse-grained sandstone, which define the base of the Cloverly formation are lenticular, and over much of the area no consistent basis for subdivision of these two formations is known. Such is the case in the Spence-Kane area, where the problem is complicated by the presence of lenticular conglomeratic sandstones, and the general development of sandstones in the Morrison formation that could be confused with basal Cloverly beds. Also in the absence of conglomerate or sandstone, the critical part of the section, as regards placement of this contact, consists largely of varicolored shale beds.

For these reasons the two formations are mapped as a single unit in the Spence-Kane area.

Darton (1904) named the Cloverly formation from the old post office at Cloverly, Wyoming on the northeast side of the Bighorn Basin. The original description was scanty and Darton (1906a, pp. 50-53) amplified the description of the formation and stated that it was believed to represent the Lakota sandstone, Fuson formation, and Dakota sandstone of the Black Hills It is noteworthy that Darton's basal Cloverly beds were either coarse-grained sandstone or conglomerate. The remainder of the formation, as defined, consisted of varicolored clays with thin sandstones at the top. Above the Cloverly formation, at the base of the Colorado formation, in the region west of Cloverly, Wyoming, Darton noted about 100 feet of dark gray to black shales with layers of thin brown sandstone weathering to a rusty color, which he designated the "rusty series". These beds are now known as the "rusty beds".

Lupton (1916, p. 168) correlated the Greybull "sand" with the upper sandstones of Darton's type section at Cloverly, Wyoming, and hence placed the base of the Thermopolis at the top of the Greybull sandstone. Stratigraphers since have placed the top of the Cloverly at the top of the Greybull sandstone in some publications, while others have included the "rusty beds" within the Cloverly formation. Richards (1955, p. 45) has pointed out that placing the "rusty beds" at the top of the Cloverly formation constitutes a redefinition of Darton's Cloverly, but that such a revision is justifiable when the Greybull sandstone is not readily separated from the overlying "rusty beds". Richards (1955) mapped the "rusty beds" within the Cloverly formation in the Bighorn Canyon-Hardin area of Montana and Wyoming, north of the Spence-Kane area, as did Pierce (1948) in the Greybull-Basin area of Wyoming, directly to the southeast. This practice was also followed in the Spence-Kane area, where there is no sharp separation between the Greybull sandstone member and the overlying "rusty beds".

The Morrison and Cloverly formations, undivided, have extensive exposures within the Spence-Kane area, (Plate I). Plate II shows a generalized section of the formations within this area, and Plate VII illustrates surface and subsurface sections. The lower part of the Morrison formation consists mainly of pale green, gray-green and maroon shales interbedded with fine- to medium-grained sandstones, that are commonly crossbedded. Fragments of dinosaur bones were found in several of these sandstone beds. The upper beds of the Morrison consist of varicolored clays and shales. The colors range from deep blue-gray through purple to lilac, maroon and green, and present a very colorful sequence, (Figure 20). Hard, brown-weathering, nodular limestone occurs in layers throughout this sequence. The nodular limestone layers form bands of broken rubble along the weaker shale beds. Their distribution within the formation appears to be erratic, but they are especially prominent within the purplish or lilac colored shales in the upper part of this sequence. Pierce and Andrews (1941) placed the base of the Cloverly formation, in the vicinity of the South Sunshine anticline, above a sequence of lilac-colored limestone and shale. Large dinosaur bones were found in varicolored shale exposures of the upper part of the Morrison formation in the vicinity of Crystal Creek (Figure 21).

Above this sequence there is a section of somber shales that range in color from deep blue-gray to maroon and gray, commonly with a ledge-forming sandstone at the base. A few layers of brown-weathering nodular limestone also occur in these beds. Overlying these beds is the Greybull sandstone member of the Cloverly formation. The member forms conspicuous dip slopes and caps steep cliffs cut into the underlying, weaker shales, (Figure 20). The sandstone is white to buff, commonly mottled pink and yellow, medium-grained, resistant, and frequently is crossbedded and ripple-marked. The sandstone varies in thickness throughout the area, and grades into shale, siltstone, and sandstone laterally within relatively short distances. Locally the unit thickens to a maximum of about 90 feet and forms large massive cliffs. The sandstone has an average thickness of about 50 feet in this area.

Overlying the Greybull sandstone, there is an alternation of buff to gray sandstone that weathers brown and brown weathering siltstones with gray to dark gray shale. Thin ironstone beds within the sequence add to the rusty-weathering appearance of these "rusty beds". The beds represent a gradational sequence between the Greybull sandstone below and the dark gray to black Thermopolis shale above, and the amount of shale increases from base to top. The "rusty beds" average about 85 feet in thickness within the area.

The Cloverly-Thermopolis contact was placed at the top of the last persistent sandstone within this gradational sequence. This practice placed thin sandstone stringers within the base of the overlying Thermopolis shale.

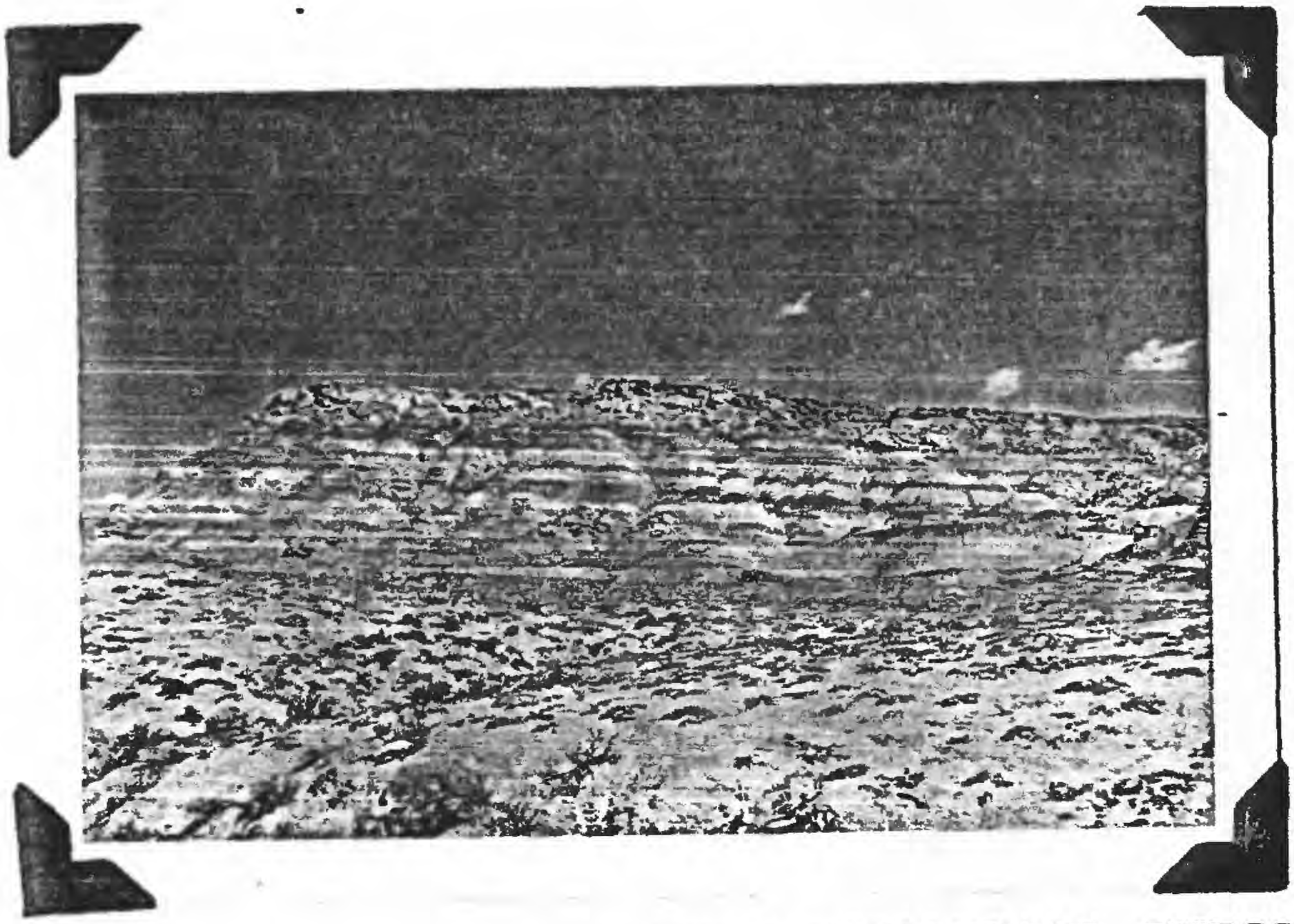


FIGURE 20. - MORRISON-CLOVERLY FORMATIONS, EXPOSED JUST SOUTH OF CRYSTAL CREEK

Greybull sandstone forms cap at top. East flank Crystal Creek anticline.

FIGURE 21. - DINOSAUR BONES FROM MORRISON FORMATION

The Morrison formation is Late Jurassic in age, while the Cloverly formation is Early Cretaceous. The combined interval of the two formations, within this area, averages about 620 feet and appears to be remarkably uniform in thickness for beds of continental origin.

A number of small pelecypods were found in the basal part of the "rusty beds" in SE 1/4 sec. 17, T. 54 N., R. 94 W. W. A. Cobban, of the U. S. Geological Survey, identified the collection as follows:

U. S. G. S. Mes. Loc. D1289

Pelecypod:

Hadrodon sp.

Remarks: "This fresh-water clam was described by Yen from the Morrison formation (USGS Prof. Paper 233-B), and at the time of Yen's work (1952) the genus was not known above the Jurassic. Dr. Reeside, who examined a cast of your fossil, remarked that he has seen a specimen or two from the Cloverly formation. Your specimen is the posterior half of a more elongated species than any described by Yen. It is probably a new species."

Similar fossils collected from the "rusty beds" on the west flank of the Little Sheep Mountain anticline in SW1/4 sec. 21, T. 56 N., R. 95 W., were also identified by W. A. Cobban, who rendered the following report:

U. S. G. S. Mes. Loc. D1428

Pelecypod:

"Unio" sp.

Remarks: "These fragments suggest a fresh-water pelecypod but none are complete enough for positive generic assignment."

Section of Cloverly and Morrison formations:
Measured in $S\frac{1}{2}$ sec. 15, T. 55 N., R. 95 W.

	Feet
Thermopolis shale.	
Cloverly and Morrison formations (undivided):	
18. Sandstone, gray, weathers brown, and thin-bedded brown stone; alternating with dark gray shale. Thin iron-stone beds near base	106.0
17. Sandstone, white to buff, medium-grained, mottled pink and yellow, ripple-marked	1.5
16. Sandstone, white to buff, medium-grained, interbedded with gray shale in thin beds	13.8
15. Sandstone, white to buff, medium-grained, noncalcareous, mottled red and yellow, crossbedded, ripple-marked, resistant	57.0
14. Sandstone, gray, nonresistant, poorly exposed; grades upward into overlying unit	58.0
13. Shale, gray to purplish, poorly exposed	23.0
12. Shale, gray and maroon; severl zones of nodular, finely-crystalline limestone, which forms rubble on slopes	73.6
11. Shale, varicolored; deep blue-gray, purple, maroon and gray	36.0
10. Sandstone, white, weathers gray to brown, fine-grained, ledge-former	2.0
9. Shale, gray-green and pale green at base, grades upward to varicolored shales, primarily red and purplish, at top. Nodular, finely-crystalline limestone found throughout unit	111.2
8. Shale, gray-green; two thin brown-weathering, gray, fine-grained, sandstone beds, one in middle of unit, other at top of unit	19.4
7. Sandstone, light gray, weathers buff, fine- to medium-grained, noncalcareous, massive, crossbedded, friable, contains dinosaur bone fragments	17.1
6. Shale, gray-green, few thin sandy zones	17.1
5. Sandstone, gray, fine-grained, subrounded grains, weathers brown	1.5
4. Shale, gray-green, with thin interbeds of gray, fine-grained, calcareous, sandstone, which weathers brown	7.6
3. Shale, varicolored; maroon, red, pale-green, and gray-green	23.0
2. Sandstone, gray, fine-grained, calcareous, crossbedded, subrounded grains, poorly exposed	7.6
1. Shale, pale green and red with thin sandy zones; unit poorly exposed	72.0
Total Cloverly and Morrison formations	647.4
Sundance formation	

<u>Thermopolis shale.</u> Lupton (1916, p. 168) named the Thermopolis shale after exposures near the town of Thermopolis, Wyoming. He described the formation from sections obtained in drill holes near Basin, Wyoming, as predominantly dark shale with one or more lenticular sandstone beds.

The Thermopolis shale has extensive areas of exposure within the Spence-Kane area, where it forms large strike valleys between escarpments of the resistant Mowry shales and the sandstones of the "rusty beds" and Greybull sandstone member of the Cloverly formation.

The Thermopolis shale, as mapped in the Spence-Kane area includes the strata between the top of the "rusty beds" and the base of the Mowry shale. Both the upper and lower contacts are gradational. The formation consists of three distinct units, within the area; a lower black shale unit, the Muddy sandstone member, and an upper black shale unit (Figure 22).

The base of the formation contains thin beds and laminae of fine-grained, buff sandstone. A prominent zone of dahllite concretions is present within the lower 30 feet of the formation and provides a useful marker in areas of thin cover (Figure 23). These concretions are spherical in shape and their weathered surface has been referred to as having a "cauliflower" appearance. They average about 1 inch in diameter and are buff to light gray on their weathered surfaces. The center of the concretion is dark in color and surrounded by radiating fibers. McConnell (1935) has described the mineralogy of these concretions. Darton (1906a, p. 55) and Fisher (1906, p. 29) noted the presence of these "globular concretions" during their early investigations. The remainder of this lower unit

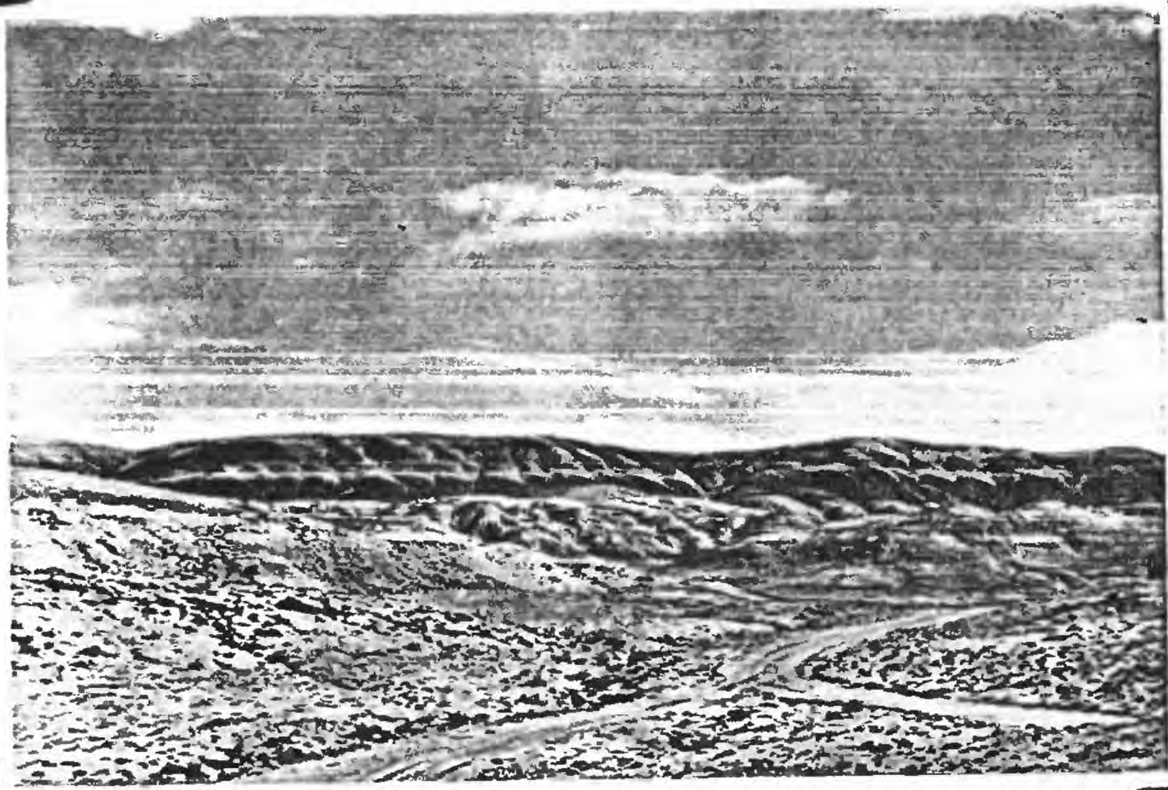


FIGURE 22. - THERMOPOLIS SHALE CAPPED BY TERRACE GRAVELS

Note white band made by Muddy sandstone. East flank Crystal Creek anticline.

FIGURE 23. - DAHLLITE CONCRETIONS FROM BASAL PART OF THERMOPOLIS SHALE

Note: Top row consists of concretions split through center.

consists of dark gray to black shale.

The Muddy sandstone member, where it is well exposed, forms a distinct white band, within the dark shales above and below, and is easily recognized on aerial photographs (Figure 22). The sandstone occurs about 200 feet above the base of the formation and consists of light gray, fine- to medium-grained sandstone, that has thin bentonitic shale interbeds. The lower contact with the underlying shale is sharp, but the upper contact grades into dark gray shale. The unit is nonresistant on the whole, and in general is poorly exposed. In many sections it is not possible to determine if the sandstone is present due to its lenticular nature, as there is often quite a lot of cover in the middle portion of the valleys underlain by the Thermopolis shale. It averages about 25 feet in thickness and thins from south to north within the area.

The upper unit consists of dark gray to black shale with many thin bentonite beds averaging 1 foot in thickness throughout the section. On weathered surfaces, the bentonite beds form darker-weathered bands within the shale sequence, and have the typical "popcorn" structure at the surface. The upper, weathered bentonite is white, hard, and has a conchoidal fracture; the fresh material at depth is olive-green in color, waxy, and soft. Seven of these bentonite beds were present in the Thermopolis shale above the Muddy sandstone in a section measured in N$\frac{1}{2}$ sec. 14, T. 53 N., R. 94 W., while five were noted within the same interval in a section measured in NW 1/4 sec. 15, T. 55 N., R. 94 W.

The contact between the Thermopolis and Mowry shales is gradational. Within the Spence-Kane area the contact was placed at the base of a series of brown-weathering, calcareous concretions that mark the transition from black shale to siliceous shale. These concretions are locally absent within the area, and in a few places there are several zones of these concretions near the base, but over the greater part of the area, there is a single concretionary zone. The zone occurs just below a small break in slope, at the base of the Mowry escarpment, and can be identified easily by its very prominent cone-in-cone structure (Figure 24).

The Thermopolis shale is of Early Cretaceous age and averages about 500 feet in thickness. Plate II shows a generalized section of the formation for the Spence-Kane area, while Plate VIII illustrates surface and subsurface sections. The formation thins from south to north within the mapped area.

Mowry shale. Darton (1904, p. 400) named the "Mowrie" beds from Mowrie Creek northwest of Buffalo, Wyoming. The Mowry shale overlies the Thermopolis shale and underlies the Frontier formation.

In the Spence-Kane area, the Mowry shale forms escarpments (Figure 25), over most of the area of outcrop, which is shown on Plate I. The formation averages 330 feet in thickness. Plate II shows a generalized section of the formation in this area, and Plate VIII illustrates surface and subsurface sections.

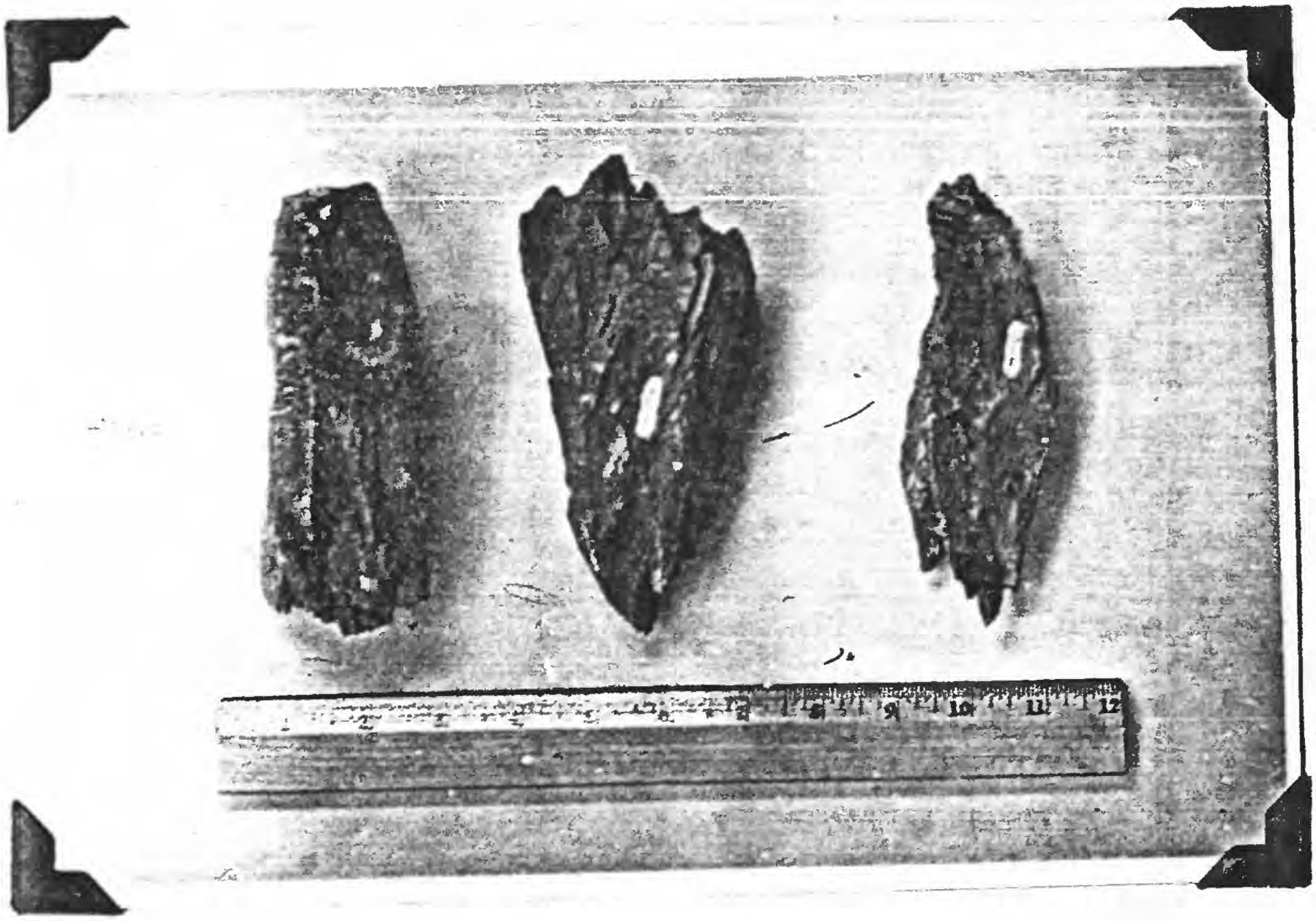


Figure 24. - CONE-IN-CONE STRUCTURE IN CONCRETIONS AT BASE OF MOWRY SHALE

Section of Thermopolis shale:

Measured in N½ sec. 14, T. 53 N., R. 94 W.

Mowry shale.

Thermopolis shale:	Feet
20. Shale, black; few very thin bentonitic beds	55.5
19. Bentonite, popcorn structure at surface	0.7
18. Shale, black	27.6
17. Bentonite; poorly exposed	0.3
16. Shale, black	25.6
15. Bentonite, olive-green, waxy, soft, in fresh material; white, hard, conchoidal fracture, with popcorn structure on weathered surface; dark-weathering bentonitic beds in Thermopolis stand out in contrast to gray weathered surfaces of the Thermopolis shale	1.0
14. Shale, black, fissile	93.9
13. Bentonite, olive-green, blocky; forms dark weathered band at surface; popcorn structure on weathered surface	0.8
12. Shale, black, fissile	75.6
11. Bentonite, shaly	0.9
10. Shale, black	3.8
9. Bentonite, shaly	0.9
8. Shale, black	5.0
7. Bentonite, shaly	1.0
6. Shale, black-gray; with interlaminated fine-grained gray sandstone	5.5
5. Sandstone, gray, medium- to fine-grained; bentonitic in part, nonresistant. Muddy sandstone member	18.1
4. Shale, black, silty, fissile	81.4
3. Shale, black, poorly exposed	117.5
2. Shale, black, fissile; thin, brown-weathering sandy zones near base; lower 5' has abundant dahllite concretions weathering out of the shale	54.2
1. Shale, black, silty; few thin, fine-grained, buff sandstone beds near base	22.6
Total Thermopolis shale	591.9

Cloverly and Morrison formations.

The formation consists predominantly of shale and siltstone, that is siliceous and weathers to a characteristic silver-gray or bluish-white color. The base of the Mowry is difficult to select in the subsurface due to the gradational nature of the contact and in many areas, the base of the Mowry is now placed at the base of the Muddy sandstone. In the Spence-Kane area, the lower contact was mapped at the base of the calcareous concretion zone with prominent cone-in-cone structure, as discussed in the preceding section (Figure 24). Directly above this concretionary zone, the weathered shales have a typical bluish-white color. In fresh cuts, however, the shales are dark gray to black or brown, and fissile. Brown shales are common at the base of the Mowry in the southern part of the mapped area, while in the northern part, the shale is predominantly dark gray to black throughout. Fish scale impressions are characteristic of the formation, and while they are common throughout these beds, they appear to be especially abundant in the softer shales of the lower section of the Mowry. In addition to fish scale impressions, the only other fossil remains observed were fragments of fish bones.

The shales and siltstones are progressively more siliceous higher in the section, and become very hard and platy, and break with a subconchoidal fracture. At the upper part of the typical Mowry scarp, thin, quartzitic, very fine-grained sandstone beds and siltstone beds form dip slopes (Figure 26). At the foot of the dip slope formed by these resistant beds is the Clay Spur bentonite bed, which averages 5 feet in thickness within this area. Thinner bentonite beds are found throughout the underlying section of the Mowry shale in great abundance, interbedded with the shales and siltstones. The bentonite beds range in thickness from less than an inch to the 5 foot Clay Spur bed. The bentonite beds are hard, white to buff, with a conchoidal fracture and "popcorn" structure at the weathered surface. Fresh cuts reveal an olive-green, soft, clay that feels waxy. Rubey (1929) has correlated the high silica content of the Mowry shales and the abundant bentonite beds within the section with derivation from volcanic ash. He also pointed out, that in general, the Mowry shale is hardest just below the bentonite beds and not silicified above the last and thickest bentonite bed, (Clay Spur bentonite in Spence-Kane area). These hard siliceous beds are commonly found in the Spence-Kane area directly beneath bentonite beds, even though the remainder of the immediate section is not siliceous in character, as in the overlying Frontier formation. Bentonites in the Frontier have, characteristically, a very hard, silicified shale directly beneath the bentonite, which forms a distinct ledge. Grim (1953, pp. 362-364) suggests that excess silica, resulting during the formation of bentonite from volcanic ash is probably the source of the free silica in these hard siliceous beds beneath the bentonite.

Above the Clay Spur bentonite there are dark gray and brown, slightly siliceous shales, which grade vertically into black fissile shale with laminae and thin beds of typical Frontier-type sandstone. The top of the Mowry shale was mapped at the top of the dark gray and brown, slightly siliceous shales, which occur at the base of a small scarp held up by the basal Frontier sandstone. This contact was easily traced in the

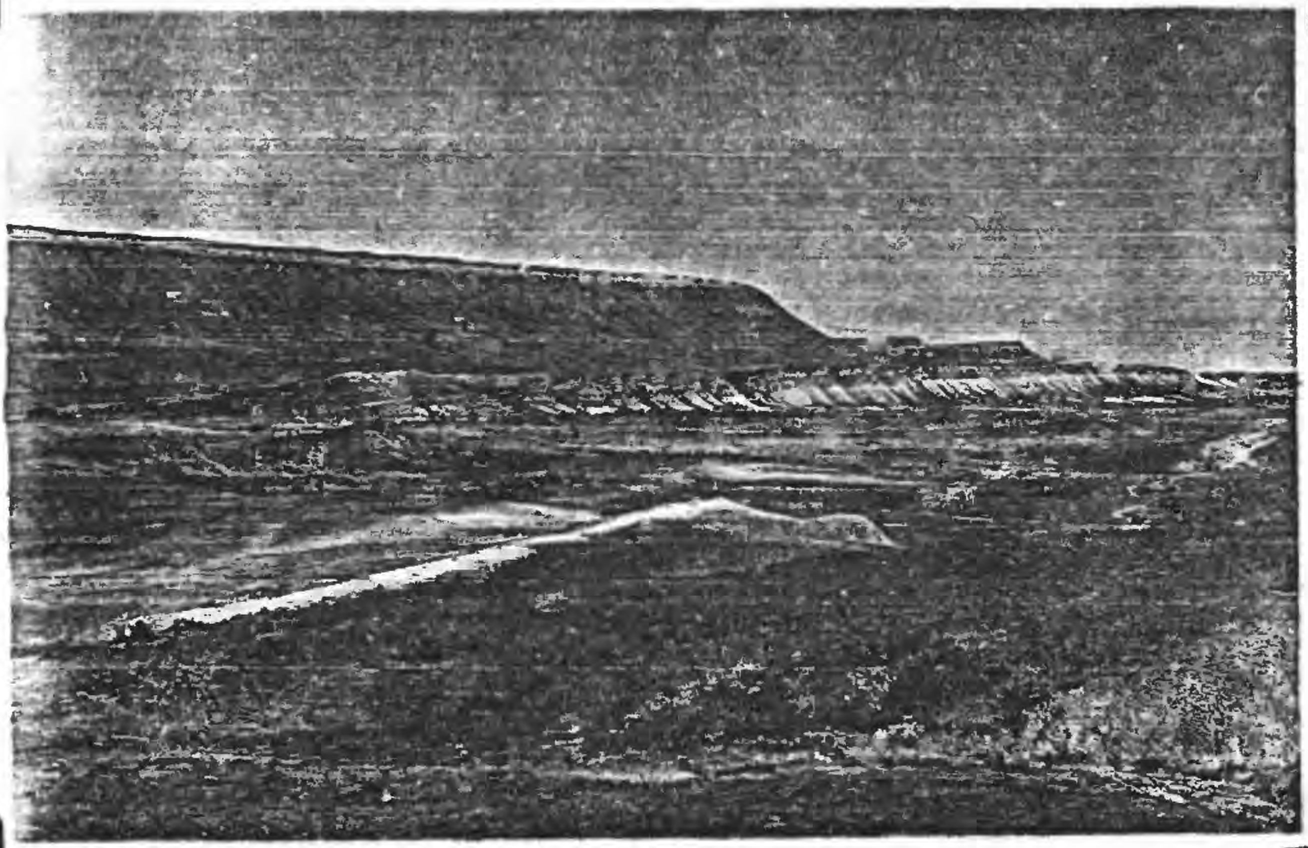


FIGURE 25. - MOWRY ESCARPMENT, EAST FLANK SHEEP MOUNTAIN ANTICLINE

Cloverly sandstones form small scarp in center of picture, while Mowry shale forms high scarp at left background, with valley between underlain by Thermopolis shales.

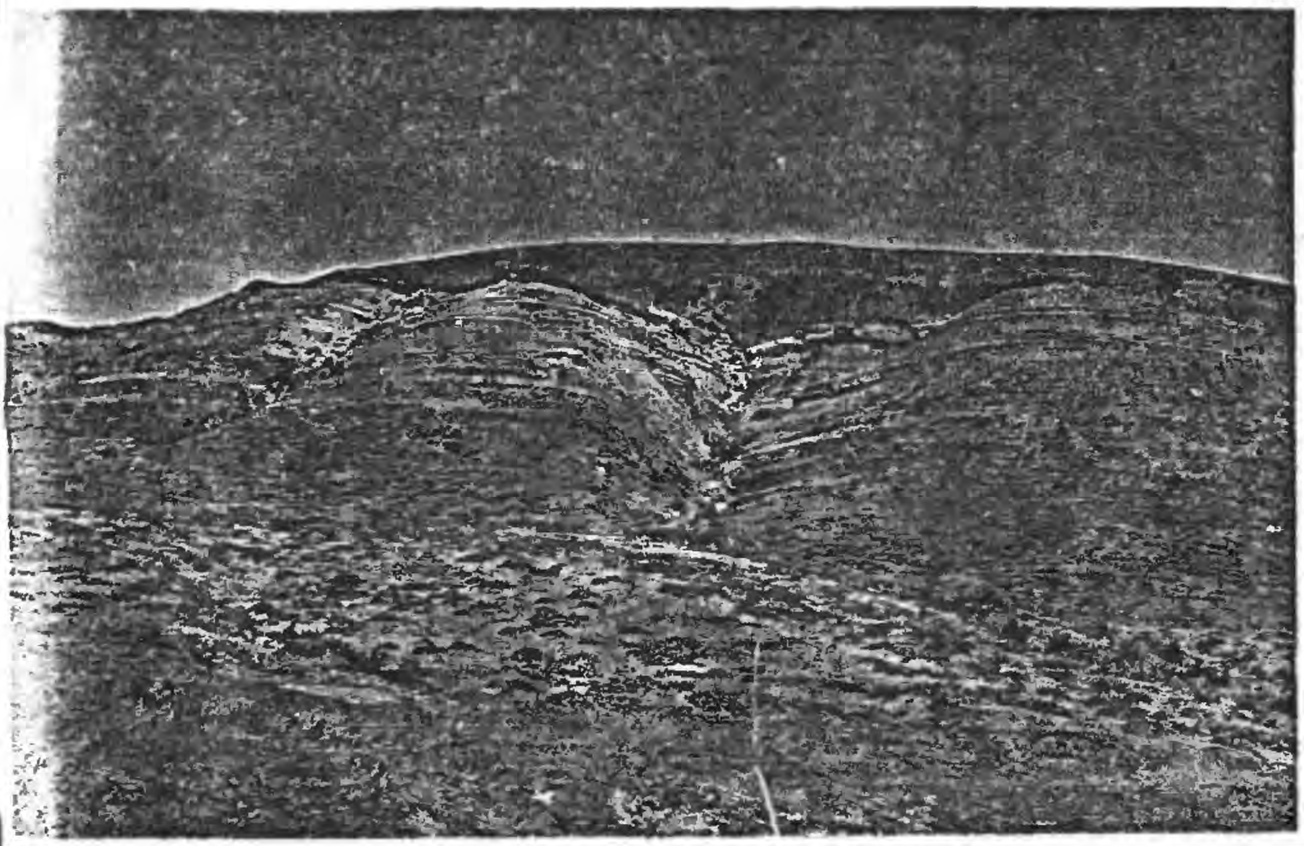


FIGURE 26. - DIP SLOPE NEAR TOP OF MOWRY SHALE FORMED BY SANDSTONE AND SILTSTONE BEDS

Mowry-Frontier contact is found near base of higher ridge in background.

field, and on aerial photographs, over most of the area, where this scarp is present. Cobban and Reeside (1951, p. 1892) assign an Early Cretaceous age to the Mowry shale.

The Mowry shale is cut by a number of sandstone dikes within this area (Figure 27). Fisher (1906, p. 30) noted the presence of small sandstone dikes a short distance west of Sheep Mountain. The areal distribution of these dikes is shown on Plate I. A similar occurrence of sandstone dikes, associated with minor folds adjacent to a major uplift, has been reported by Russell (1927) and sandstone dikes appear to be common in this part of the section in widespread areas of the Rocky Mountains. The largest concentration of these dikes is found at the nosing of the Mowry shale at the Sheep Mountain anticline in sections 1, 11, and 12, T. 54 N., R. 95 W., and at the nose of the small, sharp syncline just to the east. The sandstone dikes transect the Mowry shale in all cases, but in several instances the "dikes" were traced into the top of the underlying Thermopolis shale and up into the basal part of the overlying Frontier formation (Figure 28).

The dikes are bounded by straight walls, at the surface, and for the most part are vertical or dip at very slight angles to the vertical. They often occur in sets, with offsets and overlapping of small segments along the dike sets. The longest exposure of such a dike set is near Crystal Creek in sections 3 and 4, T. 54 N., R. 93 W., and sections 34 and 35, T. 55 N., R. 93 W., where it may be followed over a distance of about two miles. This dike set parallels a fault directly to the south as shown on Plate I. In the NE 1/4 sec. 4, T. 54 N., R. 93 W., a small road used for bentonite exploration was bulldozed across this dike set and the exposure at this point reveals that these "dikes" do not persist at depth. The sandstone dikes appear to have all the characteristics of a channel filling. The sandstone truncates the Mowry shale on either side with no evidence of displacement. This was the only point found where the bottom of these sandstone "dikes" could be observed (Figures 29 and 30).

The sandstone in these "dikes" is variable in composition, ranging from fine- to medium-grained, buff sandstone to fine-grained, siliceous, gray sandstone. Individual grains are angular to subangular. The thickness of the dikes also varies from 4 feet to less than a foot often along the same dike, within relatively short distances. Several of the "dikes" have slickensides and polished surfaces along their walls. The slickensides observed all were oriented perpendicular to the bedding planes of the surrounding shales.

Several of the sandstone dikes, on the west flank of Sheep Mountain were found to contain black chert pebbles. These black chert pebbles are common in the Peay sandstone of the overlying Frontier formation, but are not known from the Mowry or older formations in this area. The presence of these black chert pebbles in the sandstone of these dikes suggests that the Peay sandstone may have been the source of sand for the dikes, the sand being forced down into fissures. In most cases, however, the sandstone dikes appear to terminate well below the base of the Peay sandstone. The black chert pebbles are thought to be derived from the Tensleep

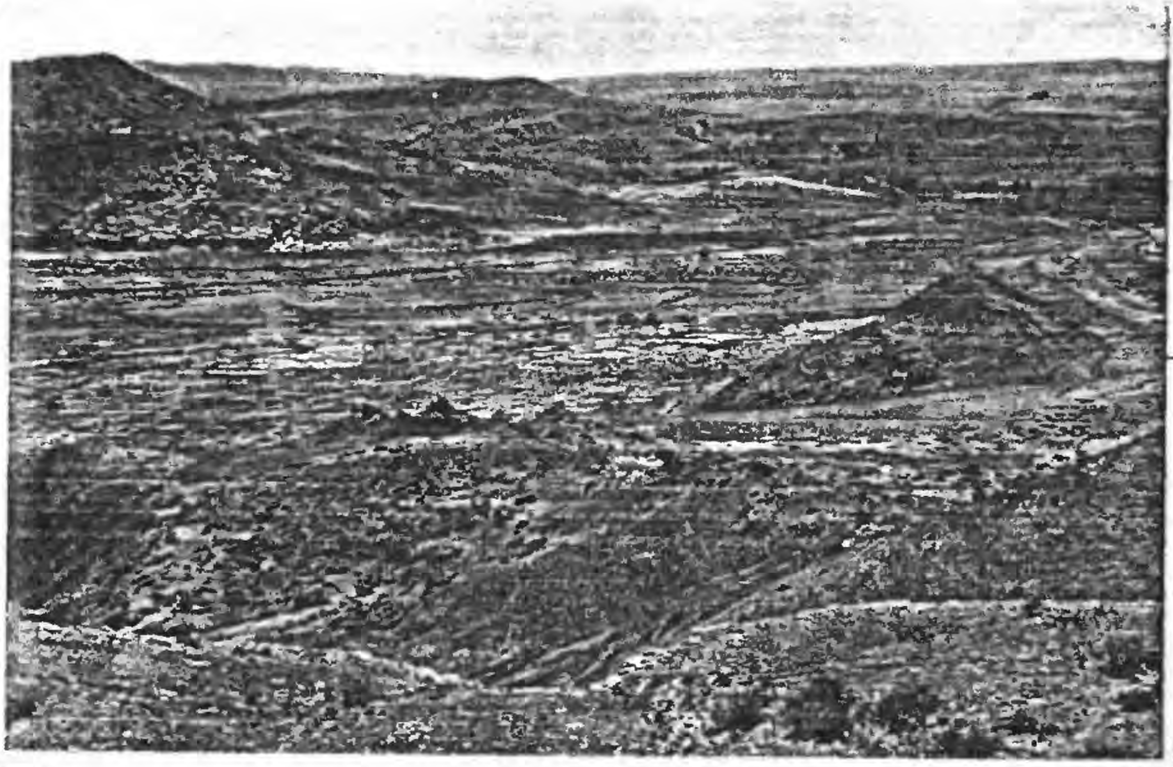


FIGURE 27. - SANDSTONE DIKE TRANSECTING MOWRY SHALE

Forms small ridge in center foreground. Crystal Creek anticline in center, background.

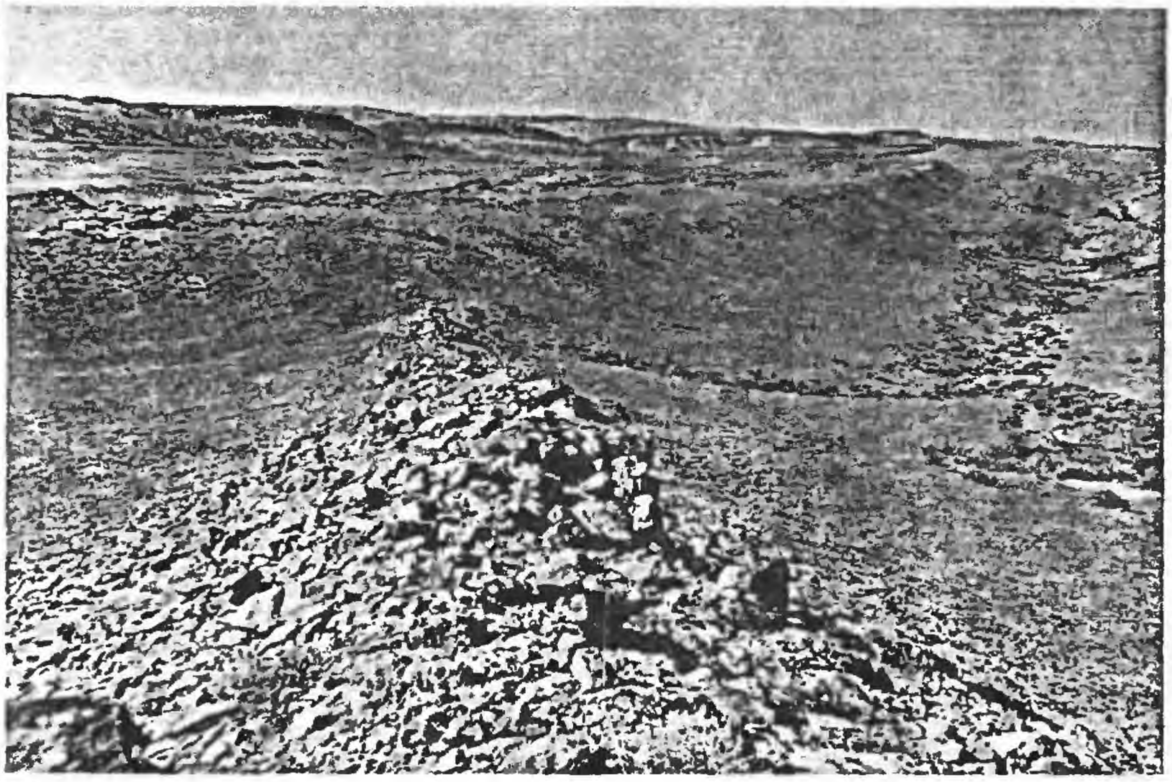


FIGURE 28. - SANDSTONE DIKE EXTENDING TO BASE OF FRONTIER FORMATION

Mowry-Frontier contact is at base of low scarp with Peay sandstone member of Frontier formation at top.

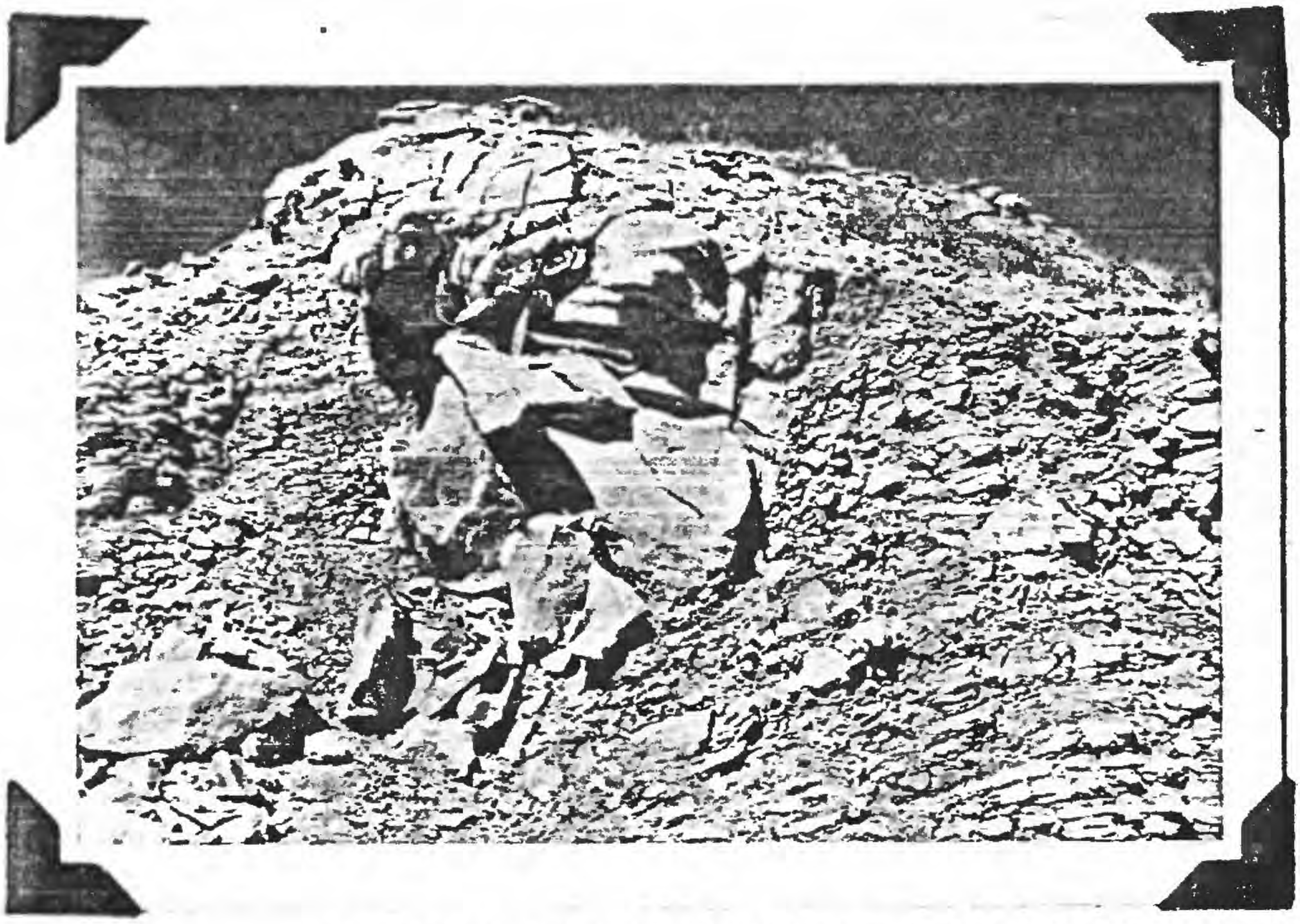


FIGURE 29. - CHANNEL-TYPE BOTTOM TO SANDSTONE DIKE
NE 1/4 sec. 4, T. 54 N., R. 93 W. Note warping of surrounding Mowry Shales.

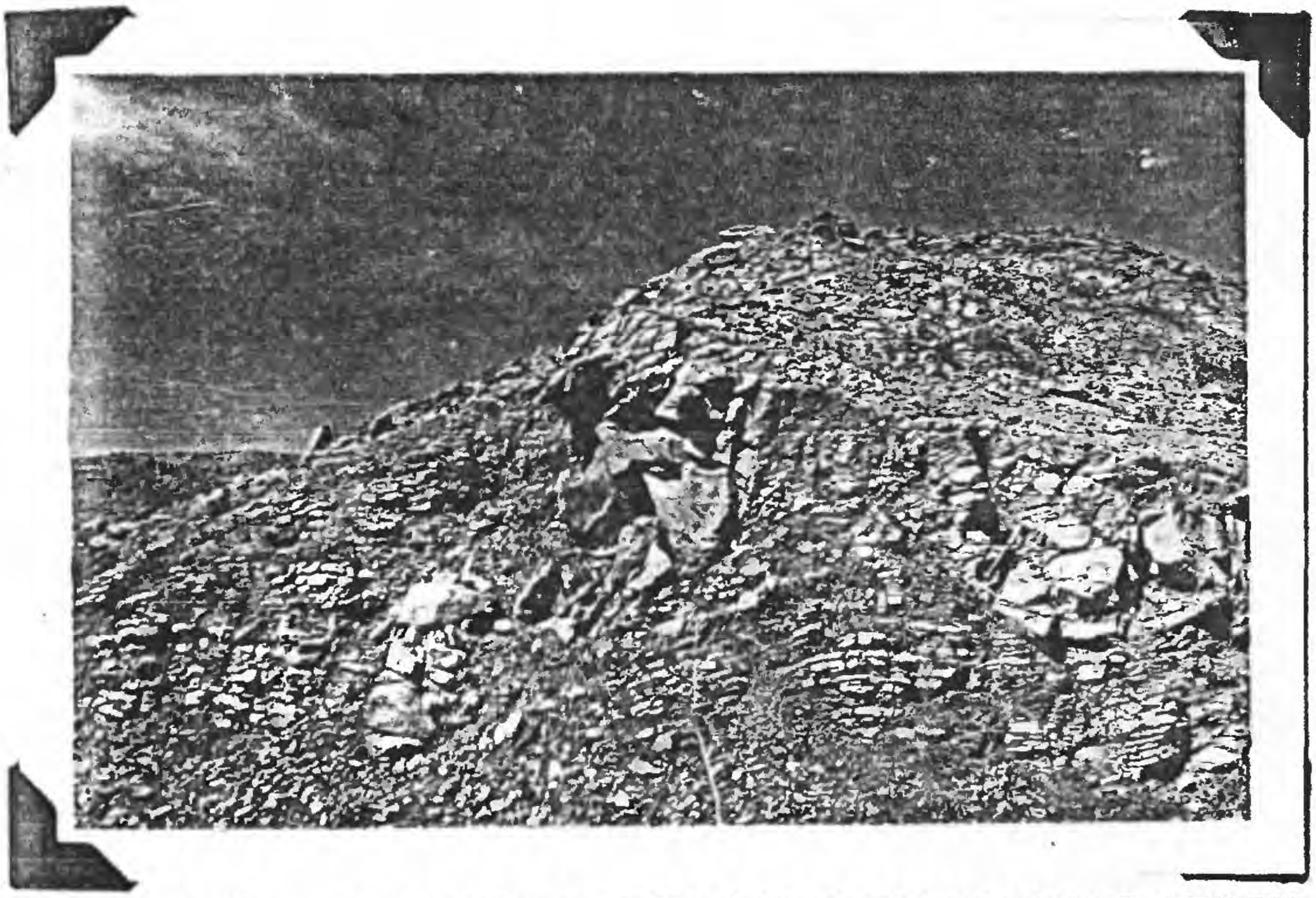


FIGURE 30. - SANDSTONE DIKE SET NEAR CRYSTAL CREEK WITH CHANNEL-TYPE BOTTOMS

Same locality as Figure 29.

sandstone as the fusulinid, Fusulina sp., has been reported within them (Pierce, 1948). The sand for the "dikes" could have been derived from this same source, prior to deposition of the Peay sandstone by the filling of fissures that were open to the surface, and subjected to scour accounting for the channel-type bottom of the dike set near Crystal Creek. Fissures of this type may have resulted in connection with earthquake activity associated with folding, faulting or with the volcanism that resulted in such large amounts of volcanic ash during this part of geologic time. The parallelism of the dike set near Crystal Creek with the fault to the south suggests a possible genetic relationship between the two. Also several faults, where they cross the Lance formation in the area west of the Alkali anticline oil field, have gouge zones composed of slabby sandstones that resemble sandstone dikes except that there are no well defined walls to the sandstone masses. Russell (1927) noted similar sandstone masses along faults in the Fox Hills, Lance and White River formations of South Dakota. He also noted that the sandstone dikes about the Black Hills were associated with sharp minor folds rather than the main uplift, and suggested that the dikes owe their origin to stresses produced by tension set up during the formation of these minor folds. As he pointed out, the dikes, however, are about as common at the synclines as they are at the anticlines, where tension is supposedly more marked. It is noteworthy that both the sandstone dikes and faults in the Spence-Kane area, trend northeast- southwest and that they are both essentially perpendicular to the axes of the folds.

None of the dikes could be followed far below the Mowry-Thermopolis contact, which would rule out the possibility of the sand having been derived from the Muddy sandstone member and forced upward into fissures due to the weight of the overlying rocks. Whether the fissures are related to folding, faulting, or earthquake activity associated with volcanism, remains in doubt. The presence of Frontier-type sandstone, and black chert pebbles, along with the channel-type bottom of the dike set at Crystal Creek, suggests that these sandstone dikes represent filling of fissures that were open to the surface and subjected to scour, sometime between deposition of the Clay Spur bed of the Mowry shale and deposition of the Peay sandstone member of the Frontier formation.

Section of Mowry shale:
Measured in NW 1/4 sec. 14, T. 53 N., R. 94 W.

Frontier formation.	
Mowry shale:	Feet
18. Shale, brown to black, fissile; with few thin, hard, platy siltstone beds----------------------------------	56.7
17. Bentonite, olive green, waxy, in fresh cuts; white, with conchoidal fracture at surface; popcorn structure on weathered surface, poorly exposed, at foot of long dip slope. Clay spur bentonite equivalent--	5.0
16. Sandstone, blue gray, fine-grained and siltstone; massive resistant unit; forms dip slope at top of ridges of resistant Mowry----------------------------------	3.0
15. Shale and siltstone, hard platy, siliceous, with few very thin bentonite beds--------------------------------	12.2
14. Shale and Siltstone, siliceous, hard platy; with 4" bentonite at top of unit--	14.2
13. Siltstone and shale, siliceous, hard platy; with two bentonites, the lowermost is 3" thick and is 2' below the top of the unit; the uppermost is 2" thick and is 8" below the top of the unit------------------------------	7.1
12. Bentonite---	0.5
11. Shale, brown and gray, hard, platy--------------------	4.1
10. Bentonite---	1.1
9. Shale and siltstone, gray and brown, hard, siliceous, platy; siltstone weathers light blue and rusty colors-----	24.3
8. Bentonite--	2.5
7. Shale, hard brown fissile; 10" bentonite at top of unit ------	91.7
6. Shale, hard brown; 3" bentonite at top of unit--------------	3.0
5. Bentonite, poorly exposed----------------------------	1.0
4. Shale, blue-gray, hard; brown siliceous shale with a few thin sandy zones--------------------------------------	45.9
3. Shale, blue-gray and brown; with 3" bentonite at top of unit--	9.3
2. Shale, brown and blue-gray; abundant fish-scale impressions; 6" bentonite at top of unit---------------	20.9
1. Shale, brown, hard, fissile; abundant fish scales; rusty-brown, calcareous, concretionary zone with good cone-in-cone structure. Weathers pale blue-gray to white. 3" bentonite at top of unit------------------	25.0
Total Mowry shale	327.5

Thermopolis shale

Frontier formation. Knight (1902, p. 721) named the Frontier formation for exposures two miles north of Kemmerer, Wyoming, at the small town of Frontier, Wyoming. The formation, is about 2000 feet thick at its type locality. Cobban and Reeside (1952, p. 1914) have shown that ordinarily one of three sandstone units forms the top of the Frontier formation, and that the sandstone units at the top of the formation pass eastward into shale from the type locality. The age of the upper sandstone of the Frontier thus differs, depending on which sandstone unit is locally present.

In the Spence-Kane area, the Torchlight sandstone is the upper member of the formation and corresponds to the older of the three sandstone units generally forming the top of the formation. The only other major sandstone unit within the section of the Frontier of this area, is the Peay sandstone member, near the base of the formation. The Peay and Torchlight sandstones were originally defined as sandstone A and B, respectively, by Washburne (1908). Much later, (1915), Hintze applied the names Peay and Torchlight from the Greybull-Basin area, to these sandstones. Lupton (1916, pp. 169-171) extended the use of the name Frontier to this general area and included the Torchlight and Peay sandstones as members.

In the Spence-Kane area, the Frontier formation has large areas of outcrop (Plate I), especially on the flanks of the Goose Egg-Alkali anticline and along the gentle eastern limb of the broad syncline along the eastern border of the area. The formation ranges in thickness from about 550 to 600 feet in the Spence-Kane area.

The Mowry-Frontier contact was discussed in the preceding section.

The contact between the Frontier formation and the overlying Cody shale was mapped at the top of the Torchlight sandstone member and the base of a light gray-weathering band of shale, characteristically devoid of vegetation, which was easily discernible, both in the field and on aerial photographs.

A typical section of the Frontier formation is shown on Plate II. In the field, an attempt was made to correlate units within the Frontier with those described by Pierce (1948), since the formation was originally extended to the Bighorn Basin in the Basin-Greybull area, and both the Peay and Torchlight sandstones were named from localities there.

The basal beds of the formation in the Spence-Kane area consist of dark gray to black fissile shale, which grades upward through shale with thin laminae and beds of Frontier-type sandstone with "salt and pepper" texture, to sandstone and interbedded shale at the base of the Peay sandstone member (Figure 31). This interval is usually poorly exposed due to slope wash on the face of the scarp.

The Peay sandstone member is about 50 feet above the base of the Frontier formation and averages about 70 feet in thickness, as mapped within this area. The sandstone is white-gray, locally glauconitic with a slight greenish cast, medium-grained, and massive with some thin-bedded units. Approximately the upper 6 feet of the sandstone is conglomeratic, and there is black chert pebble conglomerate at the top. The chert pebbles weather black, but when broken, on fresh surfaces they are light gray in color. Pierce (1948) reported the fusulinid Fusulina sp. from these chert pebbles. Hunter (1952), who made a detailed study of the Frontier along the eastern margin of the Bighorn Basin, reported finding a variety of Pennsylvanian fossils in these chert pebbles and thought that they were derived from the Tensleep sandstone. He identified lighter-colored chert pebbles as typical Madison chert.

Above the Peay sandstone there is about 30 feet of interlaminated black shale and fine-grained gray sandstone, commonly with red-brown weathering sandstone concretions. Overlying this unit is a hard, silicified, shale and siltstone bed which underlies a thick persistent bentonite bed. The silicified bed is extremely resistant and hard and the less resistant bentonite above has often been eroded to a lower topographic position than this underlying ledge-former (Figure 32). This is especially noticeable where dips are relatively steep. The probable origin of the underlying siliceous bed and the bentonite was discussed in the preceding section.

The bentonite bed is persistent, and is mined extensively throughout the area. The bentonite averages about 10 feet in thickness and appears to thicken and thin erratically within the area, possibly due to flowage. This bentonite bed is here called the Stucco bentonite bed from exposures within the Frontier formation in the vicinity of Stucco, Wyoming, west of the Wyoben bentonite processing plant. The bed is tentatively correlated with the Soap Creek bentonite bed of the Bighorn Canyon-Hardin area of Montana and Wyoming (Richards, 1955, and Knechtel and Patterson, 1952, 1956). Richards (1955, p. 49) mapped the top of the Frontier formation at the top of the Soap Creek bentonite bed in the Bighorn Canyon-Hardin area where the formation consists predominantly of sandy shale and bentonite.

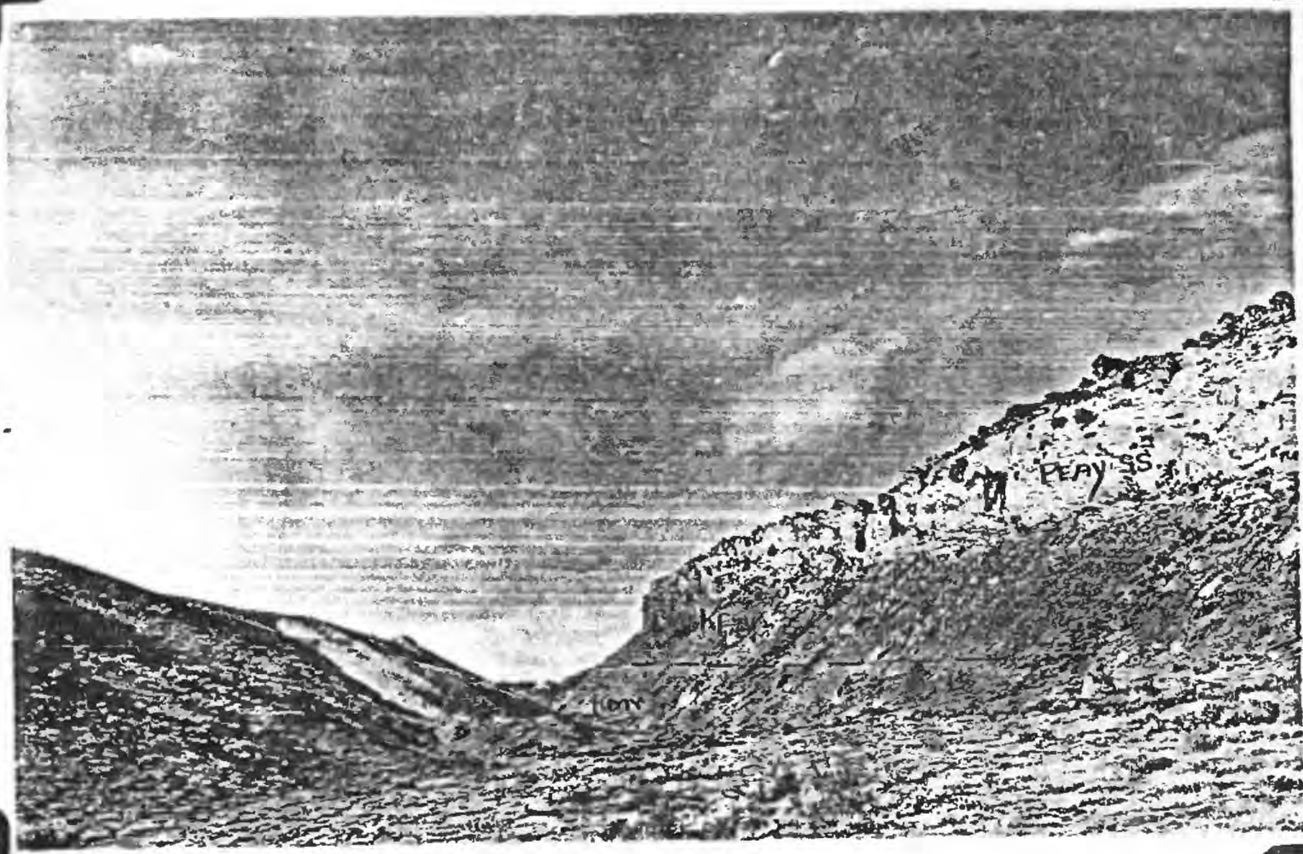


FIGURE 31. - PEAY SANDSTONE ABOVE MOWRY-FRONTIER CONTACT

Note characteristic dip slope in Mowry shale. East flank Alkali anticline. SE 1/4 sec. 3, T. 54 N., R. 95 W.

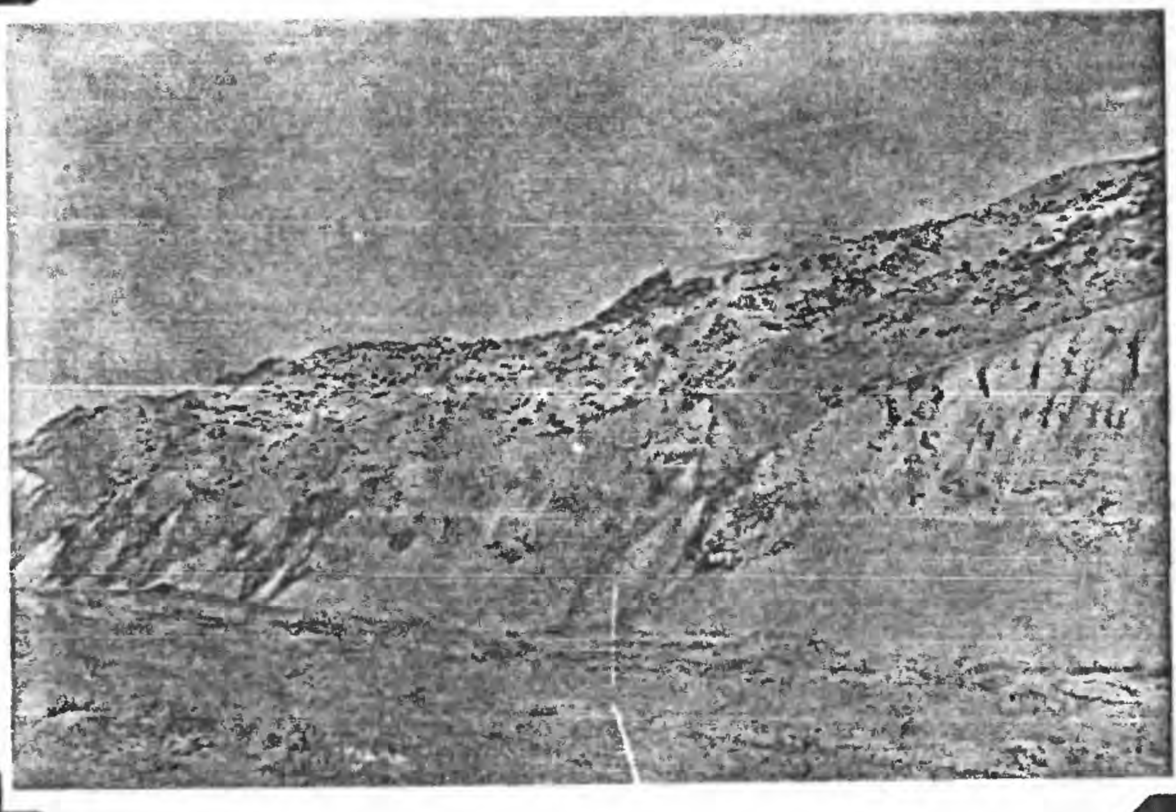


FIGURE 32. - SILICIFIED, LEDGE-FORMING SILTSTONE BELOW STUCCO BENTONITE BED

Bentonite (light-colored) on dark colored silicified bed. Peay sandstone forms ridge. NW 1/4 sec. 14, T. 53 N., R. 94 W.

Knechtel and Patterson (1956, pp. 15-20) assigned the beds formerly placed in the Frontier, in the Hardin area, to the Belle Fourche member of the Cody shale, and place the Soap Creek bentonite in about the middle of the Belle Fourche member. The bentonite of the Stucco bed is olive-green to yellowish-green with a waxy consistency when fresh, while the weathered surface material is white to buff, hard, and breaks with a conchoidal fracture (Figure 33).

Above the Stucco bentonite bed, is a sequence of interlaminated fine-grained gray sandstone and dark gray shale; the amount of sandstone increases upwards and the top of the unit is overlain by medium-grained, gray sandstone with typical "salt and pepper" texture. This sandstone is not persistent throughout the area. At the top, the sandstone is conglomeratic with a black chert pebble conglomerate, composed of ellipsoidal, black-weathering chert pebbles and a few light-colored chert pebbles. This sandstone is about 10 feet thick in exposures on the east flank of Alkali anticline. Above this sandstone unit, the section consists of interlaminated, dark gray, silty shale and fine-grained sandstone at the base, which grades upward to fine-grained, gray sandstone. A bentonite bed six feet in thickness overlies this unit in the exposures on the east limb of Alkali anticline. This bentonite bed is usually not well exposed over most of the region due to the surrounding shaly section, but appears to be thinner at other localities within the area.

The section above this upper bentonite bed is predominantly sandstone. The bentonite is directly overlain by fine- to medium-grained, gray sandstone with thin, dark gray shale laminae, which grades upward to medium- to coarse-grained, friable, nonresistant, gray sandstone with prominent conglomeratic zone at the top. The upper conglomeratic zone contains large chert pebbles and pebbles and cobbles of andesite porphyry concentrated in a thin zone at the top (Figure 34). The cobbles are as large as six inches in their longest dimension. The cobbles and pebbles are rounded and ellipsoidal in outline. They are gray to greenish-gray in color with large, euhedral feldspar crystals. These andesite porphyry pebbles and cobbles make an excellent stratigraphic marker within this area. The sandstones below this conglomeratic zone represent the Torchlight sandstone of Lupton (1916, p. 170), however, Pierce (1948) placed the Torchlight sandstone above this conglomeratic zone during the mapping of the Basin-Greybull area, and this practice was followed in the Spence-Kane area also.

The Torchlight sandstone, above the conglomeratic zone, consists of light gray to buff, fine- to medium-grained, sandstone, with thin laminae of dark shale. Large red- brown-weathering sandstone concretions are found within the middle of the unit. Unlike the Peay sandstone member, the Torchlight sandstone is nonresistant over most of the area, and good exposures of this interval are not common.

Cobban and Reeside (1952, p. 1957) suggest, on the basis of occurrence of ammonites, that the top of the Frontier formation varies in age due to interfingering with the Cody shale. They place the age of the Torchlight sandstone, in this general vicinity, as pre-Carlile (Cenomanian). The Frontier formation is placed within the Upper Cretaceous series.

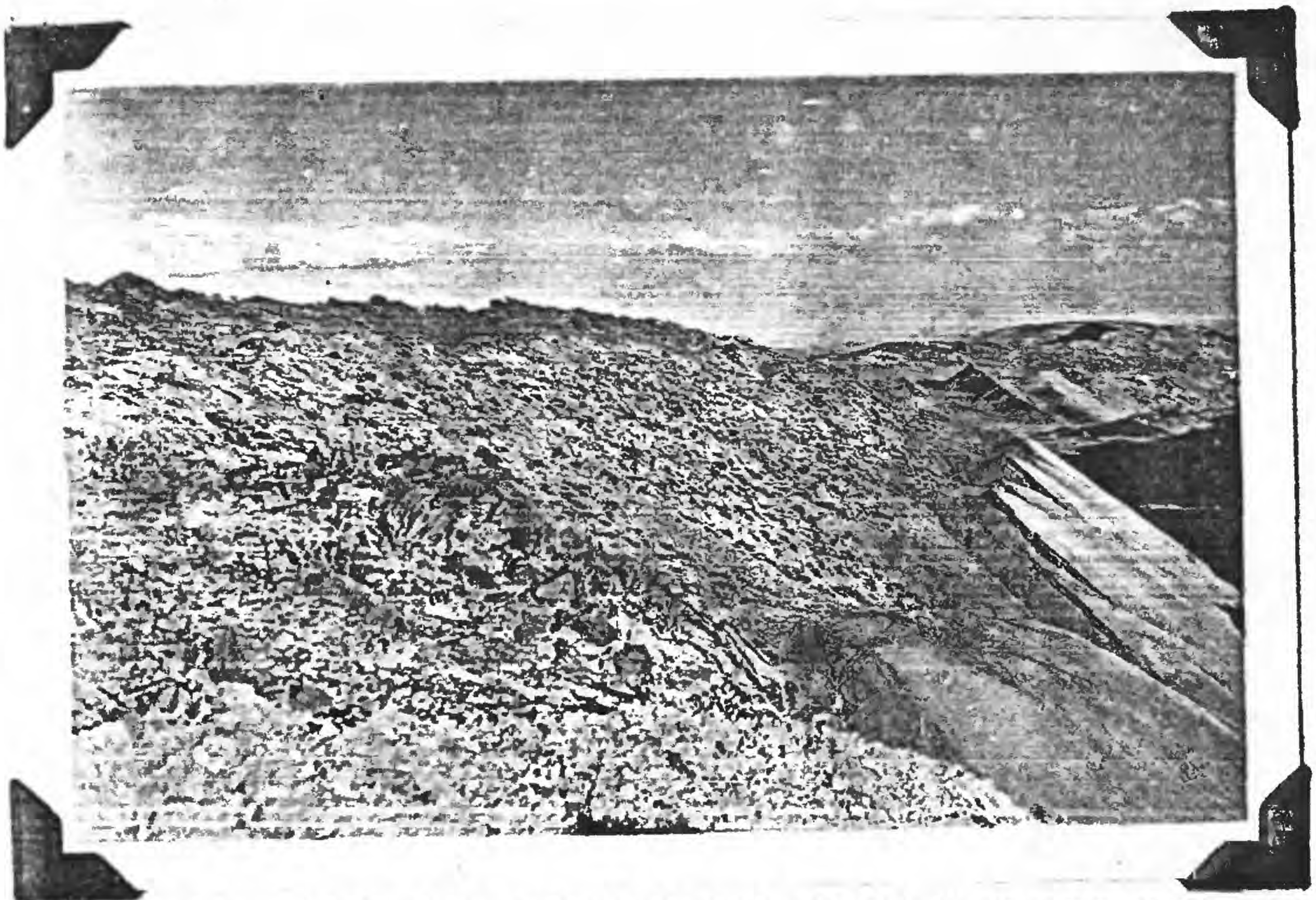


FIGURE 33. - STUCCO BENTONITE BED ON WEST FLANK GOOSE EGG-ALKALI ANTICLINE

Bentonite at right overlying ledge-forming silicified bed. Peay sandstone at left. Looking south from C sec. 33, T. 55 N., R. 95 W.

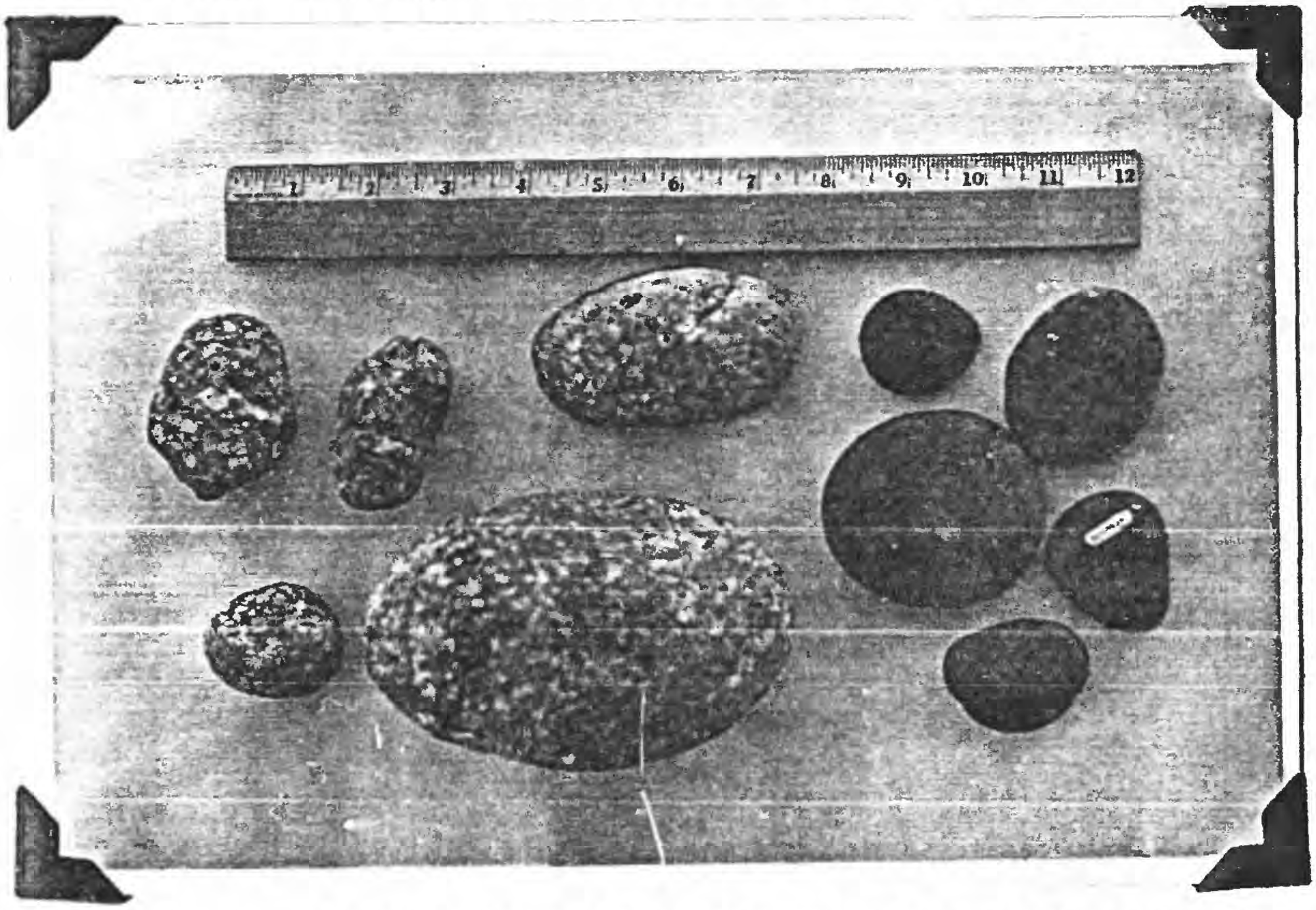


FIGURE 34. - BLACK CHERT PEBBLES AND PEBBLES AND COBBLES OF ANDESITE PORPHYRY FROM UPPER CONGLOMERATE OF FRONTIER FORMATION

Black chert on right - andesite porphyry at left.

Section of Frontier formation:
Measured in NW 1/4 sec. 3, T. 54 N., R. 95 W.

Cody shale.

Frontier formation:	Feet
22. Sandstone, light gray, medium- to fine-grained, nonresistant; with thin laminae of gray-black shale throughout. Large red-brown sandstone concretions found in middle of unit. Few black chert pebbles throughout	80
21. Shale, dark gray to black, with laminae of fine- to medium-grained, gray sandstone	2
20. Sandstone, gray, medium- to coarse-grained, friable, nonresistant. Top of unit is conglomerate with black chert pebbles and andesite porphyry pebbles and cobbles, which are concentrated in the upper 1' of this unit	32
19. Sandstone, gray, fine- to medium-grained; with thin black to dark gray shale laminae which are bentonitic	43
18. Sandstone, bluish-gray, fine- to medium-grained; locally forms resistant units	16
17. Shale, dark gray, fissile	7
16. Sandstone, buff, medium-grained, "salt and pepper" texture, forms resistant unit, buff color contrasts with gray sandstone below	2
15. Sandstone, gray, fine-grained, resistant; shaly and hard siltstone with blocky fracture above bentonite	29
14. Bentonite, white to greenish-olive color on fresh exposure	6.3
13. Sandstone, gray, hard, shaly, fine-grained	5
12. Shale, black to gray, silty, with thin laminae of sandstone, fine-grained, nonresistant. Shale dominant at base of unit; sandstone at top. Zone of red-brown, sandy, ironstone concretions 5' below top of unit	53
11. Sandstone, gray, medium-grained, "salt and pepper" texture; with 4' of black-gray shale overlain by black chert pebble conglomerate and conglomeratic sandstone. Few light gray and tan, chert pebbles. Resistant unit	12
10. Sandstone, gray, fine-grained, with black-gray shale interbedded in thin laminae. Sandstone and shale are present in equal amounts at base of unit, with sandstone predominant at top of unit	29
9. Shale, black to dark gray, fissile; with thin laminae of fine-grained gray sandstone	48
8. Shale, black to dark gray, fissile, silty	33
7. Bentonite, olive-green, soft, and waxy when fresh; white, with conchoidal fracture, hard when altered; popcorn or coral-like structure on weathered surface. Top of unit is poorly exposed. Stucco bentonite bed	7

6. Siltstone, gray, hard, blocky, sandy, forms resistant ledge directly below bentonite and is underlain by 2' of hard gray shale --	3
5. Interlaminated black shale and fine-grained, gray sandstone; with a few red-brown sandstone concretions-----	39
4. Sandstone, white-gray, with few beds weathering dark brown, massive with few thin-bedded units. Forms resistant dip slopes characterized by light-weathering upper sandstone. Upper 6' is conglomeratic sandstone and black chert pebble conglomerate with chert pebbles up to 3"in diameter. Peay sandstone member ---------------	72
3. Sandstone, gray, nonresistant; with interlaminated black shale--	27
2. Shale, black, fissile; interlaminated fine-grained, sandstone; shale dominant at base becoming progressively sandier toward top of unit---	36
1. Shale, black, fissile, nonresistant; at base of scarp held up by dip slope of Peay sandstone------------------------------	18
Total Frontier formation	599.3

Mowry shale.

Cody shale. The Cody shale was named by Lupton (1916, p. 171) for the town of Cody, Wyoming, on the west side of the Bighorn Basin. He described the shale from the vicinity of Basin, Wyoming, as being 3,360 feet thick. The formation is about 2230 feet thick in the Spence-Kane area. Plate II illustrates a generalized section of the formation.

The Cody shale, in the Spence-Kane area, is exposed along the axis of the broad syncline on the eastern border of the area in secs. 1 and 12, T. 53 N., R. 93 W., and on the east side of Little Sheep Mountain. Small exposures are found along the axis of the syncline between the Goose Egg-Alkali anticline and Rose dome and the Sheep Mountain anticline (Plate I). A complete section of the Cody shale is exposed along or adjacent to U. S. Highway 310, and for the greater part of its route across the area, the highway is on Cody shale. The Cody shale generally forms a broad valley between the underlying Frontier sandstones to the east, and overlying Mesaverde sandstones to the west, along this route.

The Frontier-Cody contact was discussed in the previous section. The lower part of the formation consists of light to dark gray, calcareous shale with zones of spherical, calcareous, septarian concretions, which form small ledges. A few thin sandstone and sandy shale beds are commonly found in the lower part of the Cody but the section is predominantly gray shale. A persistent zone of ledge-forming calcareous concretions is present about 80 feet above the base of the formation. While these concretions are commonly fossiliferous throughout the Cody section, the lowermost ledge-forming zones of concretions are barren.

Septarian veins of yellow to white calcite are common in most of the concretions, which often break open along these veins, and the fossils weather out and are abundant on the slopes below the concretion ledges. Calcareous, septarian, concretions are especially numerous between 150 and 250 feet above the base of the Cody shale, and they are quite fossiliferous. All fossil locations are indicated with respect to a generalized columnar section of the area on Plate II.

The following fossils were collected by the writer from these concretions in the lower part of the Cody shale and identified, as follows, by W. A. Cobban of the U. S. Geological Survey:

U.S.G.S. Mes. Loc. D1429
(From 150 feet above base of Cody shale, SE 1/4 sec. 24, T. 56 N., R. 95 W.)

Cephalopod (ammonite):
Metoicoceras sp.

(*Metoicoceras* sp. was also identified from collections about 200 feet above the base of the Cody shale at the following locations: S$\frac{1}{2}$ sec. 32, T. 56 N., R. 95 W., and NW 1/4 sec. 30, T. 56 N., R. 94 W. The pelecypod, *Inoceramus pictus* Sowerby, was identified from a collection about 200 feet above the base of the Cody shale at SE 1/4 sec. 24, T. 56 N., R. 95 W.)

U.S.G.S. Mes. Loc. D1431
(From 200 feet above base of Cody shale in W$\frac{1}{2}$ sec. 19, T. 54 N., R. 94 W.)

Cephalopod:
Metoicoceras sp.

U.S.G.S. Mes. Loc. D1430
(From 228 feet above base of Cody shale in SW 1/4 sec. 32, T. 56 N., R. 94 W.)

Pelecypod:
Gryphaea n. sp.

Cephalopods (ammonites):
Metoicoceras muelleri Cobban
Dunveganoceras albertense (Warren)

Remarks: This is the youngest of the *Dunveganoceras* zones. The ammonites show a correlation with the Mosby sandstone member of the Colorado shale of central Montana and with the upper part of the Hartland shale member of the Greenhorn formation of the central Great Plains. For illustrations of these ammonites see Prof. Paper 243-D (Cenomanian ammonite fauna from the Mosby sandstone of central Montana).

Cobban's summary of these collections follows:

"Lots $KcSM_6$, $KcSM_{11}$, and $KcSM_{13}$, contain fragments of *Metoicoceras*, an ammonite of Greenhorn age (late Cenomanian-early Turonian). The fragments are too small for specific determination. Lot Kc_2 is of considerable interest in that it is the first record of the *Dunveganoceras albertense* fauna in the Bighorn Basin."

Above this section is a sequence of gray to dark gray shale with thin calcareous sandstone beds that locally develop cone-in-cone structure and thin ironstone concretionary zones. At the top of this sequence there are zones of calcareous, red-brown weathering, septarian concretions and thin sandstones. The following fossils were collected from these concretions and identified by W. A. Cobban of the U. S. Geological Survey as follows:

U.S.G.S. Mes. Loc. D1288

(From 875 feet above base of Cody shale in N$\frac{1}{2}$ sec. 15, T. 54 N., R. 95 W.)

Pelecypods:

Nucula sp.
Inoceramus n. sp.
Ostrea congesta Conrad
Parmicorbula n. sp.

Gastropods:

Turritella sp.
Tessarolax sp.

Cephalopods (ammonites):

Baculites asper Morton
Baculites codyensis Reeside
Clioscaphites? sp.

Remarks: The undescribed species of Inoceramus has been found only in rocks of late Niobrara age. The collection is probably from the zone of Clioscaphites vermiformis (Meek and Hayden). See "Correlation of the Cretaceous formations of the western interior of the United States," Geol. Soc. America Bull., v. 63, Oct. 1952.

U.S.G.S. Mes. Loc. D1432

(From 960 feet above base of Cody shale in N$\frac{1}{2}$N$\frac{1}{2}$ sec. 29, T. 55 N., R. 95 W.)

Pelecypods:

Nemodon sp.
Periploma sp.
Legumen sp.
Parmicorbula? sp.

Gastropod:

Turritella sp.

Cephalopod (ammonite):

Baculites codyensis Reeside

Remarks: The ammonite indicates a correlation with some part of the Smoky Hill chalky shale member of the Niobrara formation of the central Great Plains.

Above this section is approximately 930 feet of dark gray shale, generally poorly exposed, with a few spherical septarian concretions. Overlying this sequence is a prominent ledge-forming, buff to olive-drab, thin-bedded, sandstone with many calcareous, septarian concretions which are highly fossiliferous.

The following fossil collections were made from this unit by the writer and identified by W. A. Cobban, of the U. S. Geological Survey, as follows:

U.S.G.S. Mes. Loc. D1433
(From 1940 feet above the base of the Cody shale in NE 1/4 NW1/4 sec. 29, T. 55 N., R. 95 W.)

Pelecypod:
Inoceramus cf. I. proximus Tuomey

Cephalopods:
Nautiloid:
Eutrephoceras alcesense Reeside

Ammonites:
Scaphites aquilaensis Reeside
Baculites haresi Reeside

Remarks: The cephalopods are guides to rocks equivalent in age to the Eagle sandstone of Montana.

U.S.G.S. Mes. Loc. D1434
(From 1950 feet above base of Cody shale - same locality as D1433 above)

Pelecypods:
Nemodon aff. N. martindalensis Stephenson
Inoceramus aff. I. subcompressus Meek & Hayden
Gryphaea n. sp.
Anomia subquadrata Stanton
Terebrimya selliforma (Meek & Hayden)

Gastropod:
Gyrodes sp.
Cylichna sp.

Cephalopods:
Nautiloid:
Eutrephoceras alcesense Reeside

Ammonites:
Placenticeras meeki Boehm
Scaphites hippocrepis (DeKay)
Scaphites aquilaensis Reeside
Baculites haresi Reeside

This section is followed by approximately 175 feet of gray shale with several thin bentonite beds near the base. The bentonite beds are deeply weathered but make darker bands in the surrounding gray shales, and gypsum and calcite crystals are found along the outcrop of these beds. The bentonite beds are poorly exposed, and appear to be about one foot in thickness.

Above this section, throughout the north half of the mapped area, is a poorly consolidated, massive, buff to olive-drab sandstone averaging about 30 feet in thicknèss. This sandstone is poorly resistant and generally has a greenish cast due to the presence of glauconite in discrete grains, but buff-colored sandstone with no clauconite has also been observed at this horizon. Gray shale interbeds in the sandstone were seen in some cuts. It is possible that the sandstone unit is composed of several lenticular sandstone beds. In the south half of the area the interval in which this sandstone occurs is covered by loam developed on the Cody shale, but glauconitic sandstone is exposed in the cut along Little Dry Creek near the southern border of the area in approximately the same stratigraphic position as the unit to the north. Pierce and Andrews (1941, pp. 127-128) found similar glauconitic sandstones in the upper part of the Cody shale. No fossils were found in this sandstone although it was examined quite carefully with the hope of possibly correlating it with the Shannon sandstone member of the Cody shale.

Overlying this sandstone unit is approximately 70 feet of gray sandy shale with several thin, deeply weathered, bentonite beds averaging about one foot in thickness.

The top of the Cody shale was placed at the beginning of an alternating sequence of sandy, gray shale and buff to gray, fine-grained sandstone representing a gradation from the underlying marine shales to the massive, nonmarine sandstones of the overlying Mesaverde formation.

Haas (1949) and Fox (1954) have reported the presence of the Dunveganoceras fauna from the basal Cody shale and upper sandstone of the Frontier formation from the vicinity of Greybull, Wyoming, directly south of the mapped area. Fox (1954) also measured 388 feet of the basal Cody shale at Greybull dome, southeast of Greybull, and describes foraminifera collected from this section. He recognized assemblages similar to those of the Greenhorn, Carlile and Niobrara formations of the Great Plains within this section.

Section of Cody shale:
Measured in NW 1/4 NW 1/4 sec. 28, and N½ sec. 29, T. 55 N., R. 95 W.

Mesaverde formation.

Cody shale:	Feet
22. Shale, gray, poorly exposed	40.0
21. Bentonite; light yellow weathered zone at surface, where a deep gumbo has formed; poorly exposed	1.5
20. Shale, gray, sandy, poorly exposed	8.0
19. Bentonite; yellowish weathered gumbo at surface; forms a dark weathering band in the Cody shale; selenite gypsum and calcite crystals along the surface outcrop	1.5
18. Shale, gray, silty	20.0
17. Sandstone, olive drab to buff, fine- to medium-grained, glauconitic, poorly consolidated; withthin dark-brown weathering, resistant layers of gray sandstone with a "salt and pepper" texture. Many tubular-shaped markings	28.0
16. Shale, gray; with few thin sandy shale and sandstone beds near top of unit. Zone of calcareous concretions at top of unit	172.0
15. Bentonite; weathered to deep gumbo; poorly exposed	1.0
14. Shale, gray	7.0
13. Bentonite, yellowish-green; makes dark weathered band in gray shale, with gypsum and calcite crystals along the surface outcrop	1.5
12. Sandstone, buff to olive drab, thin-bedded, concretionary; with broad zone of fossiliferous, calcareous, concretions which are spherical and septarian; forms ledge in gray shale sequence	52.0
11. Shale, dark gray, poorly exposed	592.0
10. Shale, dark gray, noncalcareous; with some calcareous, septarian, spherical, barren concretions	70.3
9. Shale, dark gray, noncalcareous	273.8
8. Shale, dark gray, calcareous; with many thin sandy, calcareous concretionary zones, some of which are fossiliferous	53.3
7. Shale, dark gray, noncalcareous; with thin calcareous zones 2 inches or less in thickness with good cone-in-cone structure at the top	430.5
6. Shale, gray, sandy; with very thin sandy zones less than 1 inch thick throughout the upper half of the unit	94.3
5. Shale, gray, noncalcareous	82.1
4. Shale, gray, calcareous; with large, spherical, calcareous concretions cut by septarian veins of yellow-white calcite; concretions split up into rubble along these septarian veins. Occurrence of these concretions in the shale appears to be sporadic	123.1

3. Shale, gray, calcareous; with thin, calcareous, concretionary zones which frequently have well developed cone-in-cone structure	102.5
2. Concretions, dark gray, calcareous, weathers brown, barren, ledge-forming	3.0
1. Shale, gray, calcareous; forms distinct band devoid of vegetation	77.9
Total Cody shale	2235.3

Frontier formation.

Mesaverde formation. The Mesaverde formation of the Spence-Kane area is exposed in a northwest-southeast trending band along the western margin of the mapped area. The formation consists predominantly of massive sandstones, which form escarpments above the more easily eroded Cody shale to the east, and valley-forming units of the lower part of the Meeteetse formation to the west. Measured sections at several points within the area, indicate an average thickness of about 1,250 feet for the formation. A generalized section of the formation is shown on Plate II.

The basal part of the Mesaverde consists of an alternating sequence of sandy, gray shale, and thin, gray to buff, fine-grained sandstone, which is locally crossbedded. The shale is similar to that in the underlying Cody and this unit undoubtedly represents a transitional sequence. At the top of this unit, in SE 1/4 sec. 32, T. 55 N., R. 95 W., a conglomeratic sandstone with black chert pebbles up to $\frac{1}{2}$ inch in diameter occurs. The sandstone is medium-grained and glauconitic. The unit is apparently lenticular as it was not found in other sections of the Mesaverde formation measured at other localities within the area. The black chert pebbles are similar to those found in some of the sandstone dikes described previously, and in the conglomerates of the Frontier formation. Pierce and Andrews (1941, p. 128) have reported a chert-pebble conglomerate in "greensand" 1,175 feet above the base of the Cody shale in the vicinity of the Pitchfork anticline on the western side of the Bighorn Basin. They placed the Cody-Mesaverde contact, however, at the base of the lowest massive sandstone of the Mesaverde formation and probably included the alternating shale and sandstone, described here, within the Cody shale.

Above this sequence, there is about 100 feet of dark gray, sandy shale with thin interbeds of fine-grained, gray sandstone, which grades upwards into about 70 feet of alternating sandstone and shale, with sandstone predominant.

Overlying this unit, is approximately 110 feet of fine- to medium-grained, gray to buff, massive sandstone, which is resistant near the top and forms a distinct scarp. About 50 feet of alternating fine-grained, gray to buff sandstone and sandy, gray shale overlie this unit.

Above this sequence, there is about 350 feet of fine-grained, buff sandstone with thin interbeds of gray shale. The uppermost 45 feet of this section consists of medium-grained, massive, buff sandstone, that is resistant and forms distinct ledges.

Overlying this resistant sandstone is about 140 feet of alternating gray shale, and fine-grained, light-gray sandstone beds, with many brown, carbonaceous shale beds up to 7 feet in thickness.

Above this relatively weak unit is about 150 feet of fine- to medium-grained, massive and resistant sandstone, which forms distinct scarps over the area. Large dinosaur bone fragments are common within this sandstone unit. The upper part of this sandstone unit contains many red-brown, ironstone concretions and these upper sandstones are mottled a distinctive red-brown color (Figure 35). The overlying units in the basal part of the Meeteetse formation are poorly resistant and commonly form broad valleys adjacent to the upper massive sandstones of the Mesaverde

FIGURE 35. - MESAVERDE-MEETEETSE CONTACT
Section along Little Dry Creek, SE 1/4 sec. 36, T. 53 N., R. 94 W.
Note concretions and reddish-brown cast of upper Mesaverde sandstones.

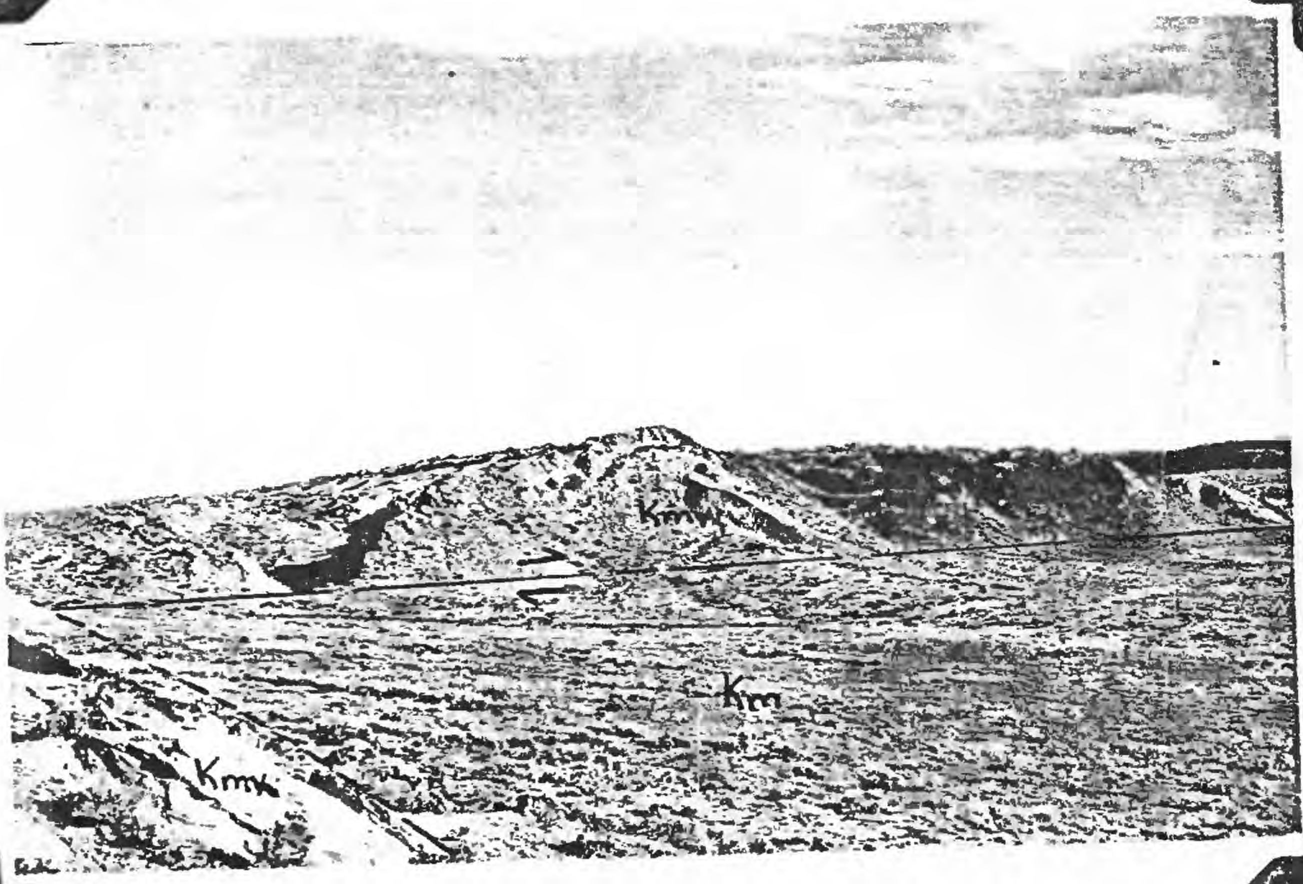


FIGURE 36. - FAULT OFFSETTING UPPER MESAVERDE SANDSTONES
Looking south, near center sec. 32, T. 55 N., R. 95 W. Note valley forming sequence in lower part of Meeteetse formation in foreground. Contact shown by short dashed lines, fault by long dashed lines.

formation (Figure 36).

Exact correlation of the Mesaverde of this area with sections to the south, is not known. The upper massive sandstones here probably represent only the Parkman sandstone member of sections farther south in Wyoming.

Section of Mesaverde formation:
Measured in SE 1/4 sec. 32, T. 55 N., R. 95 W., and NE 1/4 sec. 5, T. 54 N., R. 95 W.

Meeteetse formation.
Mesaverde formation:

	Feet
47. Sandstone, light gray, medium- to fine-grained, weathers buff; contains many small ironstone concretions near the top of unit which is mottled red-brown; massive; dinosaur bone fragments common; forms scarp	139.5
46. Shale, gray, sandy	3.0
45. Shale, brown, carbonaceous	2.0
44. Shale, gray, sandy; with thin interbeds of fine-grained, gray, sandstone	5.5
43. Shale, brown, carbonaceous	0.5
42. Shale, gray, sandy	1.5
41. Shale, brown, carbonaceous	1.0
40. Sandstone, buff, fine-grained, friable, nonresistant	21.7
39. Shale, brown, carbonaceous	1.5
38. Sandstone, gray, weathers light gray, fine-grained	9.3
37. Shale, brown, carbonaceous	7.2
36. Sandstone, buff, fine-grained, nonresistant; with thin zones of ironstone concretions	12.4
35. Shale, brown, carbonaceous; weathers light gray	6.1
34. Shale, gray, sandy	2.0
33. Sandstone, light gray, fine-grained, weathers white to gray	7.2
32. Shale, gray, sandy	2.0
31. Sandstone, light gray, fine-grained, resistant	3.1
30. Shale, gray	3.1
29. Sandstone, buff, fine-grained, nonresistant	3.1
28. Sandstone, light gray, weathers buff, fine-grained, resistant	4.1
27. Shale, gray, sandy	3.1
26. Shale, brown, carbonaceous	1.5
25. Shale, gray, sandy	12.3
24. Sandstone, buff, medium-grained, subangular grains, massive	46.2
23. Sandstone, buff, fine-grained; with thin interbeds of gray shale; poorly exposed	303.8
22. Shale, gray, sandy	9.3
21. Sandstone, buff, fine-grained, thin-bedded	1.0
20. Shale, gray, sandy	3.1
19. Sandstone, buff, fine-grained, massive	4.1
18. Sandstone, buff, fine-grained; alternating with gray sandy shale	31.0

17. Sandstone, gray to buff, medium-grained, massive, resistant	37.5
16. Sandstone, gray to buff, fine-grained	63.4
15. Sandstone, gray, fine-grained; aternating with thin, gray, sandy shale beds	63.4
14. Shale, dark gray, sandy; with few thin beds of fine-grained, gray, sandstone	105.4
13. Sandstone, gray, medium-grained; with angular quartz and disseminated glauconite grains; conglomeratic with black chert pebbles up to $\frac{1}{2}$ inch in diameter; conglomerate appears to be lenticular	1.0
12. Sandstone, gray, fine-grained; with a few resistant beds; interbedded with gray, sandy shale	14.5
11. Sandstone, gray and buff, fine-grained, nonresistant; with a few resistant beds and gray sandy shale beds	80.6
10. Shale, gray, sandy	24.8
9. Sandstone, gray, fine-grained, friable; with thin gray shale beds in middle of unit; upper part of unit weathers brown and is resistant	12.5
8. Sandstone, buff to gray, fine-grained; alternating with thin beds of light gray, sandy shale	80.6
7. Shale, dark gray, fissile at base; grades upward to light gray, sandy shale	12.4
6. Shale, gray, sandy, and sandstone, buff; fine-grained at base; grades upward to fine-grained, gray, resistant sandstone	24.8
5. Sandstone, buff to gray, fine-grained, alternating with dark gray, sandy shale and a few thin beds of light gray shale	49.6
4. Sandstone, light gray to buff, fine-grained, subrounded grains, thin-bedded with a few massive beds, locally crossbedded; alternating with sandy, gray shale	9.0
3. Shale, gray, sandy; with thin, gray, fine-grained sandstone interbeds	21.7
2. Sandstone, buff, fine-grained, thin-bedded; alternating with gray, sandy shale	6.2
1. Sandstone, gray and buff, fine-grained	3.1
Total Mesaverde formation	1261.7

Cody shale.

Meeteetse formation. The Meeteetse formation was named by Hewett (1914, pp. 102-103) from the town of Meeteetse, Wyoming in the southwest part of the Bighorn Basin. According to Hewett, the most characteristic features of the formation are the presence of carbonaceous shale and coal beds and the lack of induration of the beds. Hewett observed that silicified wood was common in the lower 600 feet. His section on the Shoshone River totals 1,110 feet.

In the Spence-Kane area, the Meeteetse formation outcrops in a northwest-southeast trending band along the western margin of the mapped area (Plate I). Exposures in the south half of its area of outcrop are poor with the exception of the section exposed along Little Dry Creek near the southern edge of the area. There are, however, excellent exposures in the northern half of the area. The formation averages about 900 feet in thickness within the Spence-Kane area, and consists of poorly consolidated sandstone and shale, and carbonaceous shale, siltstone, and bentonite in the lower 470 feet, while the upper 430 feet consists of persistent, well indurated sandstones with interbedded shale. Plate II shows a generalized section of the formation and the sequence of lithologies.

The base of the Meeteetse formation is easily distinguished by the general lack of induration of the beds, above the massive sandstones of the Mesaverde which have a reddish-brown cast due to the many ironstone concretions concentrated in these uppermost beds (Figure 35).

Approximately the lower half of the formation makes up a broad valley-forming sequence, which is divided by a resistant, lenticular sandstone at some localities, into two broad valleys.

The lower valley-forming sequence consists of unconsolidated sand and poorly consolidated gray to buff sandstone, that is locally crossbedded. Petrified wood is common in this section. The sandstone is interbedded with gray shale and brown carbonaceous shale and gray, carbonaceous siltstone with partially coalified plant remains. Thin shaly bentonite beds are also found within this lower sequence. The carbonaceous shales throughout the Meeteetse formation are very tough, blocky and resistant beds in general. They often form ledges in the surrounding weaker sandstones and shales (Figure 37).

Locally, within the area, a gray sandstone, crossbedded in places, forms a resistant ridge and divides the section into a lower and upper valley. The upper valley forming sequence consists of gray shale and siltstone and hard, brown carbonaceous shale and siltstone, with thin coalified zones and plant impressions. There are many thin bentonite beds and poorly consolidated, light gray to buff sandstone beds interbedded with these units. The bentonite beds are quite numerous within the broad valley-forming sequence but are generally thin and often shaly. They weather to a darker gray than the surrounding lighter-colored beds and have the prominent "popcorn" structure along the outcrop. The outcrop is often also marked by a reddish-brown limonitic staining and the presence of plates of selenite gypsum and calcite crystals (Figure 38). The bentonite often forms a small ledge above the poorly consolidated units below. The upper part of this sequence is usually found in the face of a distinct scarp

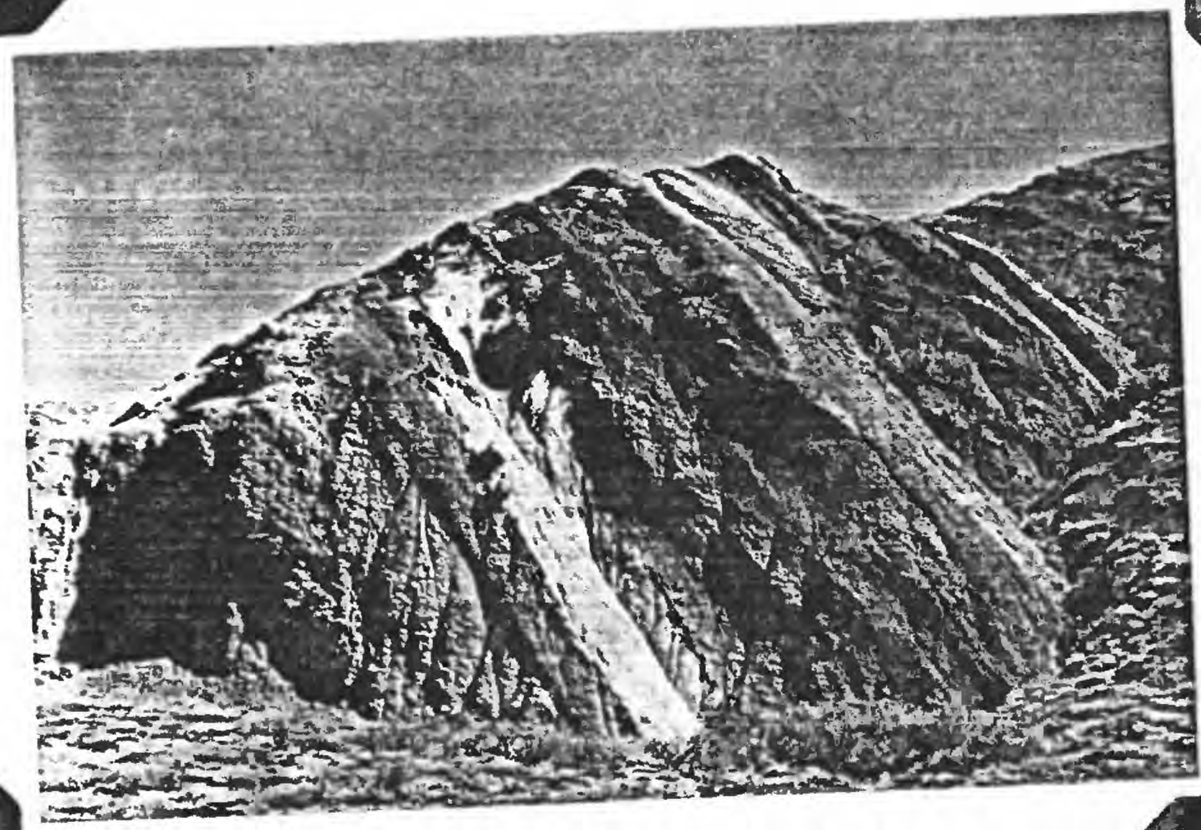


FIGURE 37. - HARD, LEDGE-FORMING, CARBONACEOUS SHALE BEDS WITHIN MEETEETSE FORMATION

Section exposed along Little Dry Creek. Carbonaceous shale forms dark brown ledges in surrounding weaker sandstones and shales.

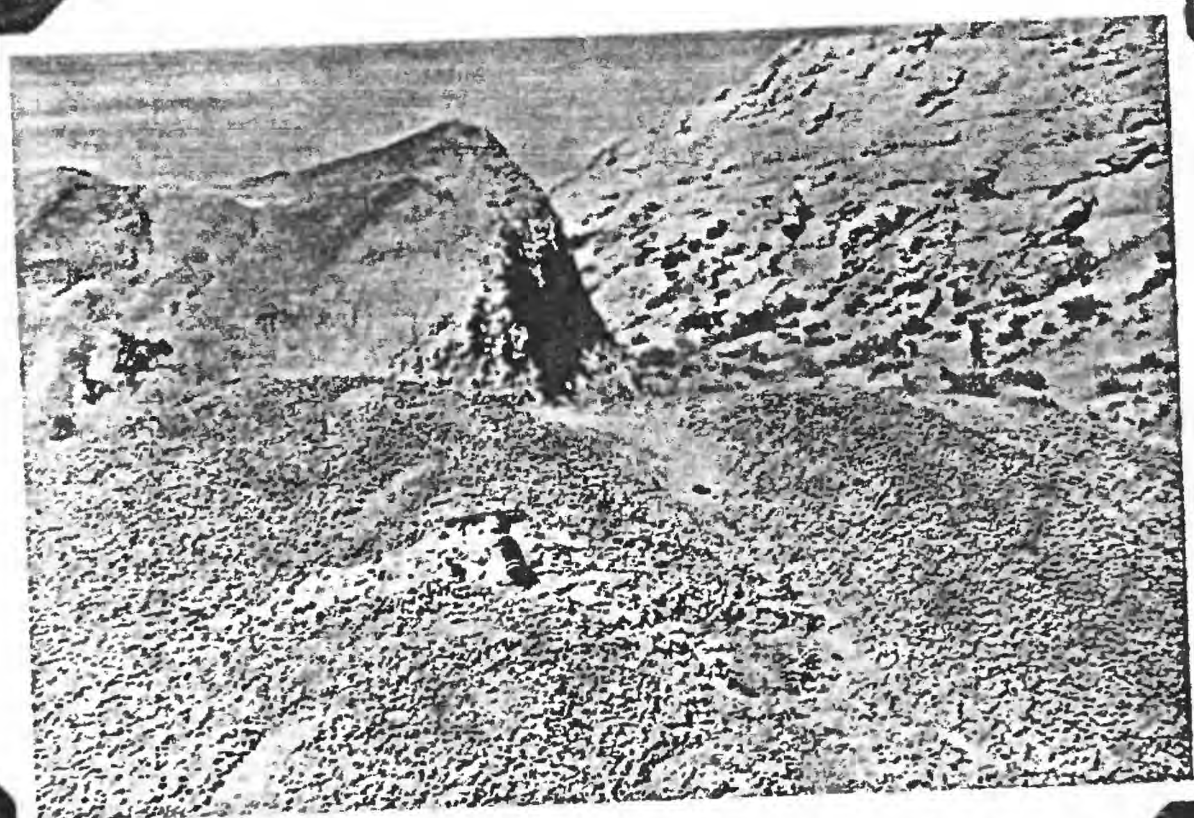


FIGURE 38. - BENTONITE BEDS IN MEETEETSE FORMATION
SW 1/4 SW 1/4 sec. 29, T. 55 N., R. 95 W. Note small ledges formed by bentonite, and "popcorn" structure and limonitic staining along outcrop. Resistant sandstone in upper right divides broad valley-forming sequence into two parts.

held up by the prominent indurated sandstones of the upper Meeteetse. Hard carbonaceous shales are especially prominent at the top of this sequence and form a series of small ledges in the face of the scarp and give a distinct banded appearance to this section. Thin coaly seams are often found associated with the carbonaceous shale beds.

Overlying the broad valley-forming sequence is a series of persistent gray, calcareous, ledge-forming sandstones with thin interbeds of gray shale. The sandstones are commonly resistant at their top and weather dark brown. This gives the unit a distinct banded appearance both in the field and on aerial photographs. Spherical, brown-weathering sandstone concretions are common in the upper sandstone beds. This unit is approximately 360 feet thick and apparently marine. The sandstone beds have many peculiar bedding plane markings in places. Some of these definitely appear to be impressions of Halymenites which is believed to represent near-shore conditions of deposition. W. A. Cobban, of the U. S. Geological Survey, identified a Halymenites cast on a bedding plane in this unit while examining the section with the writer. Higher in this sequence of sandstones, the writer collected the following fossils which were identified by W. A. Cobban, as follows:

U.S.G.S. Mes. Loc. D1435
(From upper part of Meeteetse formation in
SE 1/4 SE 1/4 sec. 30, T. 55 N., R. 95 W.)

Pelecypod:
Veniella? sp.

Cephalopod (ammonite):
Acanthoscaphites sp.

Remarks: These are marine fossils. The ammonite is common in the Bearpaw shale of Montana.

Overlying this sequence is about 30 feet of fine-grained, buff sandstone that is nonresistant, which is overlain by about 45 feet of white-weathering sandstone with thin brown carbonaceous shale and gray shale interbeds near the base and top. This white-weathering sandstone is commonly nonresistant and fluted. The top of the Meeteetse formation was placed at the top of this white sandstone and the base of a massive, resistant, buff sandstone directly overlying it (Figure 39).

FIGURE 39. - MEETEETSE-LANCE CONTACT MARKED BY WHITE SANDSTONE NE 1/4 NW 1/4 sec. 5, T. 54 N., R. 95 W.

Note buff sandstone, at base of Lance formation, directly above white sandstone.

Approximately, the lower half of the formation is very similar in lithology to the Meeteetse formation at its type locality on the western side of the Bighorn Basin (Hewett, 1914, pp. 102-103 and 1926, pp. 22-26). Sections of the Meeteetse measured by Pierce and Andrews (1941, pp. 132-133) also correspond, lithologically, with the lower part of the Meeteetse formation of this general area. The upper part of the formation, as mapped, however, is not similar in lithology to the Meeteetse of the type section.

According to Downs (1952, p. 30) the Meeteetse formation is the non-marine equivalent of the Bearpaw shale. The presence of marine fossils, and totally different lithologic aspect of the sandstones overlying the thick section of carbonaceous shales, and weak valley-forming units of the lower part of the Meeteetse, as mapped, suggest that these beds are correlative with the Lennep sandstone of central southern Montana (Wilmarth, 1938, p. 1169). The Lennep sandstone, which consists of dark-colored sandstone and interbedded shale, overlies the Bearpaw shale and underlies the Lance formation. The Lennep sandstone is believed to be correlative with the Fox Hills sandstone of areas to east and south. The presence of <u>Halymenites</u> strengthens this correlation in that it is common in the Fox Hills sandstone, though it is not diagnostic of it according to Brown (1939, pp. 253-254). The upper white sandstone is possibly correlative with the Colgate sandstone member of the top of the Fox Hills sandstone, as redefined by Thom and Dobbin (1924). Dobbin and Reeside (1929, p. 11) have discussed the occurrence of this sandstone with respect to criteria for separation of the Fox Hills and Lance formations, in eastern Montana, western North and South Dakota, and northeastern Wyoming.

It is suggested here that the Meeteetse formation, as mapped, actually represents two distinct formations. The lower sequence of non-marine, poorly consolidated sediments, with prominent carbonaceous shale and bentonite beds, probably represents the Meeteetse formation of the type area in the southwestern part of the Bighorn Basin. The upper part of the Meeteetse formation, as mapped, consisting of sandstones and thin alternating shale beds, with a prominent white sandstone at the top, is probably correlative, in part, with the Lennep and Fox Hills sandstones. These beds are shown to be marine, at least in part, by fossils collected in the area. They also differ in lithology and degree of induration with the Meeteetse of the type locality. This problem deserves regional studies of these beds to determine their true correlations.

Section of Meeteetse formation:
Measured in SW 1/4 SW 1/4 sec. 29, and NE 1/4 NE 1/4 sec. 31,
T. 55 N., R. 95 W.

Lance formation.
Meeteetse formation:

	Feet
88. Sandstone, light gray, weathers white, fluted, medium grained, subangular to subrounded quartz grains; few thin brown, carbonaceous and gray shale partings	45.1
87. Sandstone, buff, fine grained, noncalcareous, nonresistant, poorly consolidated; weak valley former	32.8
86. Sandstone, buff to gray, massive; poorly resistant with a few resistant ledges and large brown weathering sandstone concretions	36.9
85. Shale, gray	4.1
84. Sandstone, gray, fine grained, nonresistant; with a few thin gray shale beds	23.5
83. Shale, gray, sandy	11.2
82. Sandstone, buff to gray, noncalcareous, fine grained; alternating with resistant, brown-weathering, gray, calcareous, fine grained sandstone	90.2
81. Sandstone, gray, fine grained calcareous, resistant; weathers brown	1.2
80. Sandstone, gray, fine grained, nonresistant, poorly exposed	27.6
79. Sandstone, gray, fine grained, weathers brown; forms ledge	0.4
78. Sandstone, gray to buff, fine grained, poorly consolidated; with few thin gray shale beds	29.7
77. Sandstone, fine grained, gray, calcareous; weathers brown; forms ledge	0.5
76. Sandstone, gray, fine grained, nonresistant, noncalcareous; few gray shale interbeds	14.3
75. Sandstone, gray, fine grained; forms ledge	0.5
74. Sandstone, gray, fine grained, nonresistant; with few thin beds of gray shale	11.2
73. Sandstone, gray, fine grained; weathers brown; forms ledge	0.5
72. Sandstone, gray, fine grained, nonresistant; with thin gray shale interbeds	31.0
71. Sandstone, gray, fine grained, calcareous; weathers brown; forms ledge	0.6
70. Sandstone, gray, fine grained, nonresistant; with thin alternating beds of gray shale	17.4
69. Sandstone, gray, fine grained, calcareous; weathers dark brown; resistant;forms ledge	1.5
68. Shale, dark gray, sandy; poorly exposed; alternating with nonresistant, fine grained, gray sandstone	5.1

67. Sandstone, gray, fine grained, calcareous; weathers dark brown; subrounded grains; resistant, forms ledge	1.2
66. Shale, gray, sandy; alternating with nonresistant, fine grained, gray sandstone; unit poorly exposed	12.8
65. Sandstone; base of sequence of resistant and laterally persistent, brown-weathering, ledge-forming, calcareous, fine-grained, gray, sandstone beds which commonly have tubular molds and other markings on their bedding plane surfaces	0.4
64. Sandstone, gray, fine-grained, nonresistant; with thin alternating beds of gray shale	41.0
63. Sandstone, light gray, medium to fine-grained, subrounded grains, massive, crossbedded	27.0
62. Shale, brown, carbonaceous, silty; siltstone, brown to dark gray, carbonaceous	10.5
61. Shale, gray, sandy	3.5
60. Shale, brown, carbonaceous, silty; with gradation locally into gray, carbonaceous siltstone, resistant	18.0
59. Sandstone, gray to buff, fine-grained, nonresistant, poorly consolidated, poorly exposed	19.0
58. Shale, brown, carbonaceous, hard	4.0
57. Siltstone, carbonaceous, bentonitic	5.0
56. Bentonite, pale green with included brown carbonaceous matter; popcorn structure on weathered surface and selenite gypsum crystals along outcrop	0.5
55. Sandstone, gray, fine-grained, nonresistant; alternating with hard, dense, dark gray to brown, carbonaceous siltstone that contains plant material, in part coalified	30.0
54. Shale, brown, carbonaceous	1.6
53. Shale, gray, sandy; grades upward to fine-grained, gray sandstone	3.5
52. Shale, brown, carbonaceous, hard	1.5
51. Shale, gray, sandy	3.0
50. Sandstone, gray, fine-grained; grades upward to dark gray, carbonaceous siltstone	5.0
49. Shale, brown, carbonaceous, hard	3.0
48. Siltstone, gray, carbonaceous; with few thin, gray, sandy beds	10.2
47. Shale, brown, carbonaceous	1.4
46. Siltstone, dark gray, carbonaceous, dense, hard	1.8
45. Bentonite, white to greenish gray, conchoidal fracture, shaly; popcorn structure on weathered surface and selenite gypsum crystals along outcrop	0.3
44. Siltstone, dark gray; with some carbonaceous material, which is in part coalified	0.8
43. Bentonite, gray-green to white, impure, shaly, conchoidal fracture; popcorn structure on weathered surface and selenite gypsum crystals along outcrop	0.6

42. Sandstone, gray, fine-grained; grades upward to dark gray siltstone	2.0
41. Bentonite, gray, shaly; popcorn structure on weathered surface	0.5
40. Siltstone, gray, carbonaceous; visible plant fragments	3.0
39. Bentonite, greenish-gray, weathers light gray, conchoidal fracture; popcorn structure on weathered surfaces	1.5
38. Sandstone, light gray, fine-grained, carbonaceous, and gray carbonaceous siltstone with plant fragments	24.2
37. Sandstone, gray, fine-grained; alternating with coaly, carbonaceous shale	8.2
36. Shale, gray, and sandy siltstone, which grade vertically into brown carbonaceous shale	4.1
35. Sandstone, gray, fine-grained; alternating with gray, carbonaceous siltstone	12.3
34. Shale, brown, carbonaceous; in part coalified	3.1
33. Sandstone, gray, medium-grained, nonresistant, poorly consolidated, poorly exposed	7.6
32. Sandstone, gray, medium-grained, subangular grains, noncalcareous, poorly cemented, friable; forms ridge in middle of broad valley forming sequence; massive; locally crossbedded	40.2
31. Shale, gray	1.0
30. Sandstone, gray to buff, medium- to coarse-grained; weathers light gray	46.1
29. Shale, gray, sandy	7.1
28. Shale, brown, carbonaceous, and gray, carbonaceous siltstone	1.0
27. Sandstone, gray, fine-grained, poorly exposed	5.1
26. Shale, carbonaceous, hard, brown, blocky; with thin coalified seams	1.2
25. Sandstone, gray, fine- to medium-grained; with thin gray shale interbeds	18.4
24. Sandstone, gray, fine-grained; large blocks of petrified wood near base; nonresistant; with few thin, hard, brown resistant beds. Large brown-weathering, barren, spherical, sandstone concretions up to three feet in diameter at top of unit	11.2
23. Shale, brown, carbonaceous, coaly	1.1
22. Siltstone, gray, carbonaceous; grades upward into fine-grained, gray, carbonaceous sandstone at top	3.0
21. Shale, brown, carbonaceous, blocky	1.6
20. Shale, gray-green, sandy	1.4
19. Shale, brown, carbonaceous, poorly exposed	0.8
18. Sandstone, gray, medium-grained, noncalcareous; with partly coalified plant remains; nonresistant	3.1
17. Shale, brown, carbonaceous, hard, blocky; plant fragments in part coalified	1.5

16. Siltstone, gray; with abundant, partly coalified plant remains	2.0
15. Bentonite, gray-green, carbonaceous; and bentonitic, carbonaceous, sandstone and siltstone	4.1
14. Sandstone, gray, medium-grained, nonresistant; and gray, carbonaceous siltstone; with partly coalified plant remains	8.2
13. Sandstone, gray, medium- to coarse-grained, subangular grains; many thin beds of carbonaceous material, in part coalified	31.0
12. Sandstone, dark brown with ironstone concretions	0.7
11. Shale, gray-green, sandy	0.5
10. Siltstone, gray, dense; with disseminated carbonaceous material, in part coalified	2.3
9. Sandstone, gray, fine-grained, nonresistant; with many small plant and root-like carbonaceous traces	6.1
8. Shale, brown, carbonaceous, hard; with abundant plant and root impressions, partially coalified	2.3
7. Sandstone, gray to buff, medium-grained, nonresistant	18.2
6. Shale, brown, carbonaceous; poorly exposed	1.0
5. Shale, gray-green; sandstone, gray, medium-grained, carbonaceous, nonresistant	5.1
4. Shale, brown, carbonaceous	1.0
3. Sandstone, gray, medium-grained, poorly consolidated to unconsolidated, massive, locally crossbedded; with few thin gray shale interbeds and carbonaceous lenses; valley-forming unit	20.5
2. Shale, brown, carbonaceous, hard	0.5
1. Sandstone, gray, medium-grained, angular to subangular grains, crossbedded, massive, calcareous; in part unconsolidated sand remainder is but poorly consolidated; thin gray shale interbeds; with a few thin, brown lenticular, carbonaceous shale beds	20.5
Total Meeteetse formation	925.2

Mesaverde formation.

Lance formation. The Lance formation, like the underlying beds assigned to the Meeteetse, is poorly exposed in the southern part of the area, where it is covered in large part by windblown sand. There are good exposures of this section along the south side of Little Dry Creek and in the northern part of the area.

The base of the formation consists of massive, medium-grained, buff sandstone, which overlies the white sandstone unit of the underlying section (Figure 39). The remainder of the formation consists of alternating, sandy, gray shale and massive buff sandstones. The sandstone units are lenticular, and commonly, large brown sandstone concretions weather from them (Figure 40). The sandstones are locally crossbedded. Gray-green shale is common in the section, particularly near the top of the formation, along with thin brown carbonaceous shale beds. Fragments of dinosaur bones are found throughout the formation, but appear to be especially numerous near the top.

The top of the Lance formation and the base of the overlying Fort Union formation was placed at the base of the first thin coal below a cliff-forming white sandstone in the basal Fort Union. Dinosaur bone fragments aid in placing this contact as they may be found below the thin coals at the base of the Fort Union formation, but they are not found above them.

The Lance-Fort Union contact is believed to be unconformable. Hewett and Lupton (1917, p. 26, Plate VI, B) have described an angular unconformity between the Lance and Fort Union formations on Dry Creek, just to the south of the mapped area. A similar section is exposed, in this area, along the south side of Little Dry Creek in sec. 36, T. 53 N., R. 94 W., (Figure 41). This section along Dry Creek, was visited by George H. Horn and the writer, who concluded that the angular relationship was within the basal part of the Fort Union formation as mapped in this area. Similar conditions exist at the section exposed along Little Dry Creek. The angular relationship, itself appears sharp from a distance, but close examination of this part of the section reveals a more gradual change in dip, and the possibility exists that this relationship is due to lensing sandstone units and a rapid change in dip basinward. Unfortunately the beds involved are capped by thick terrace gravels and could not be traced out horizontally, to help prove or disprove the angular relationship.

The Lance formation was not measured in detail, but sections in the area indicate a thickness of about 600 feet for the formation.

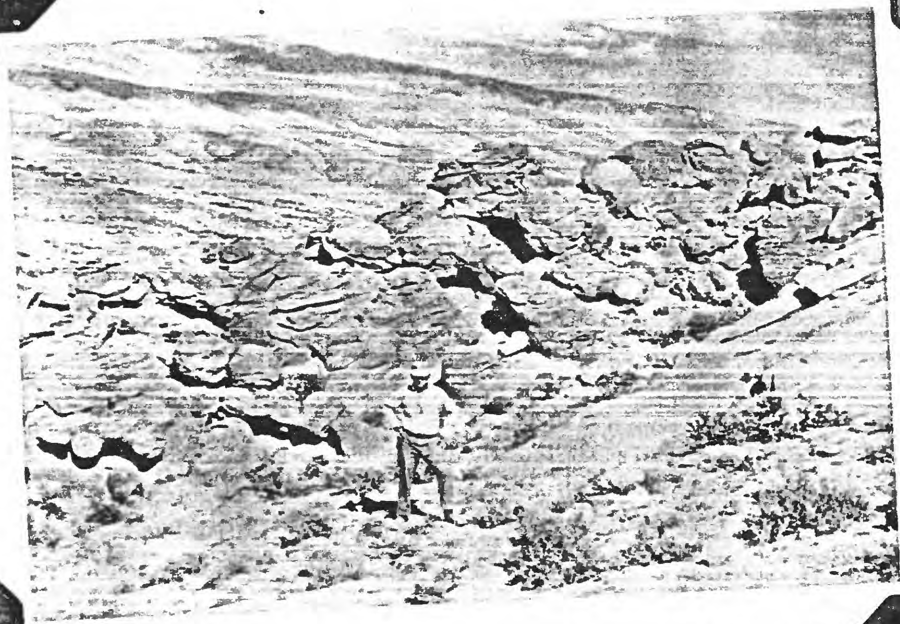


FIGURE 40. - LARGE SANDSTONE CONCRETIONS IN LANCE FORMATION

Looking east, SW 1/4 sec. 36, T. 53 N., R. 94 W.

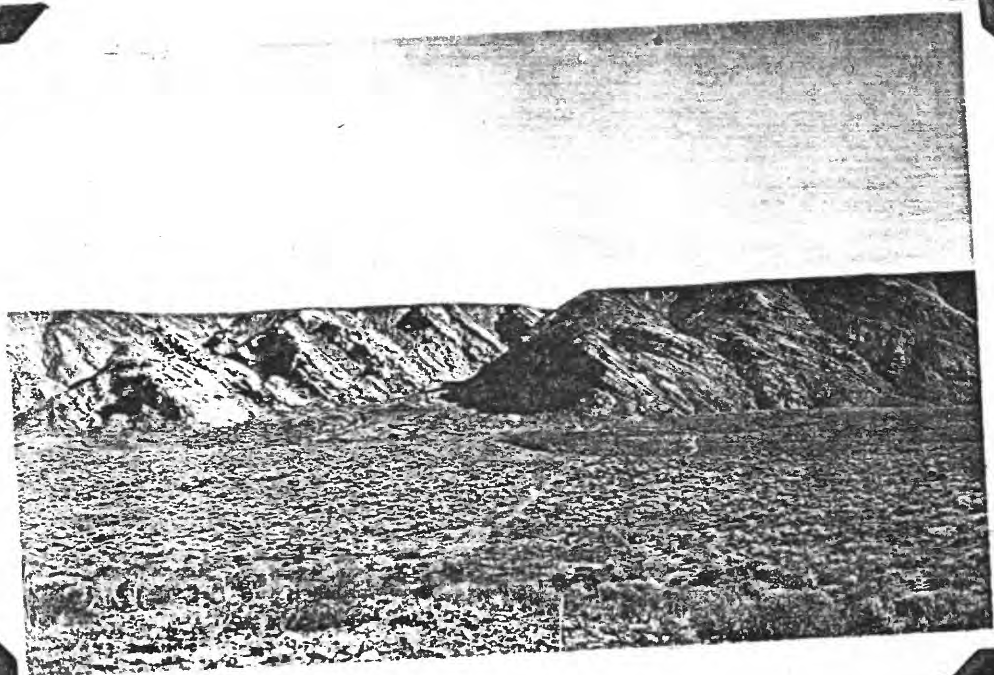


FIGURE 41. - LANCE-FORT UNION CONTACT

At base of scarp on right side of re-entrant in section. Top of section capped by terrace gravels. Section south of Little Dry Creek, sec. 36, T. 53 N., R. 94 W. Note seemingly angular relationship of beds to the right of the contact.

Section of Lance formation:
Measured in $N\frac{1}{2}$ sec. 16, T. 54 N., R. 95 W.

Fort Union formation.

Lance formation:	Feet
11. Sandstone, gray, fine-grained, friable	23.0
10. Shale, gray-green, dinosaur bone fragments	2.8
9. Sandstone, buff, massive; with large spherical sandstone concretions	59.6
8. Sandstone, buff to light gray, weathers brown; locally crossbedded; thin interbeds of green-gray, and carbonaceous shale at top of unit	286.8
7. Sandstone, buff, medium-grained, massive	22.7
6. Sandstone, buff, medium-grained, massive; thin interbeds of gray, sandy shale	107.9
5. Shale, gray to gray-green, poorly exposed	15.1
4. Sandstone, buff, medium-grained; interbedded with gray, sandy shale	56.8
3. Sandstone, buff, medium-grained, weathers brown; large brown-weathering, spherical sandstone concretions	8.5
2. Shale, gray, sandy	11.4
1. Sandstone, buff, medium-grained, massive	21.0
Total Lance formation	615.6

Meeteetse formation

Cenozoic Rocks

Fort Union formation. The Fort Union formation underlies a large area in the southwestern part of the Spence-Kane area. The formation is poorly exposed throughout its greater part, and no detailed sections of the formation were measured.

The formation consists of several thin coal beds less than one foot thick at the base, interbedded with brown, carbonaceous shale, gray-green shale, and buff to gray sandstone. Massive white-weathering, light gray sandstone is interbedded with thin coal beds and shale near the top of this section, and these sandstones form a distinct scarp over much of the area (Figure 42). Locally these sandstones are conglomeratic, and individual units appear to be highly lenticular. Jepsen (1930, p. 478) has described a similar, scarp-forming, sandstone unit in the basal part of this section in Park County, Wyoming, which he has designated the Puerco sandstone. In the Spence-Kane area, this basal section of the Fort Union is about 160 feet in thickness.

This lower section is overlain by about 300 feet of light gray sandstone with thin interbeds of gray shale. This section is well exposed over most of the area, and the beds generally have relatively steep dips.

The overlying section is poorly exposed over most of the area, and the dip of the beds appears to decrease rapidly basinward. This upper section consists primarily of gray shale and brown carbonaceous shales with relatively thin lenticular sandstone beds. Small, orange-brown ironstone concretions are common in the shale. In places the shale is bentonitic, but none of the beds were traced out. Gray, sandstone beds are locally prominent near the top of the formation.

No consistent basis for separation of the lower sandstone units from the overlying shale unit was found. These lower sandstones are probably equivalent, in part, to the Tullock sandstone member of the Fort Union formation. Jepsen (1940) and Jepsen and Van Houten (1947) have used the name Polecat Bench formation for rocks overlying the Lance and underlying the Willwood. They discuss the nomenclature, stratigraphic correlations, and mammalian fauna of the formation, within the Bighorn Basin and adjacent areas.

Section of basal part of Fort Union formation:
Measured in: SW 1/4 sec. 36, T. 53 N., R. 94 W.

	Feet
Sandstone, light gray, medium grained; with thin interbeds of gray shale--	294.0
Sandstone, light gray, medium grained, subangular, quartz grains; weathers white; massive, forms scarp-------------	58.0
Shale, gray, with thin sandy beds; several thin coal seams 3/4" to 3" in thickness----------------------------------	36.0
Sandstone, buff to gray, medium grained, massive, resistant; forms scarp---	30.0
Shale, gray-green, with brown carbonaceous shale and several thin coal seams less than 1/4" thick near the base; with several thick brown, carbonaceous shale and carbonaceous siltstone beds above the coaly zone-----------------------	53.0
Total basal part of Fort Union formation	471.0

Lance formation.

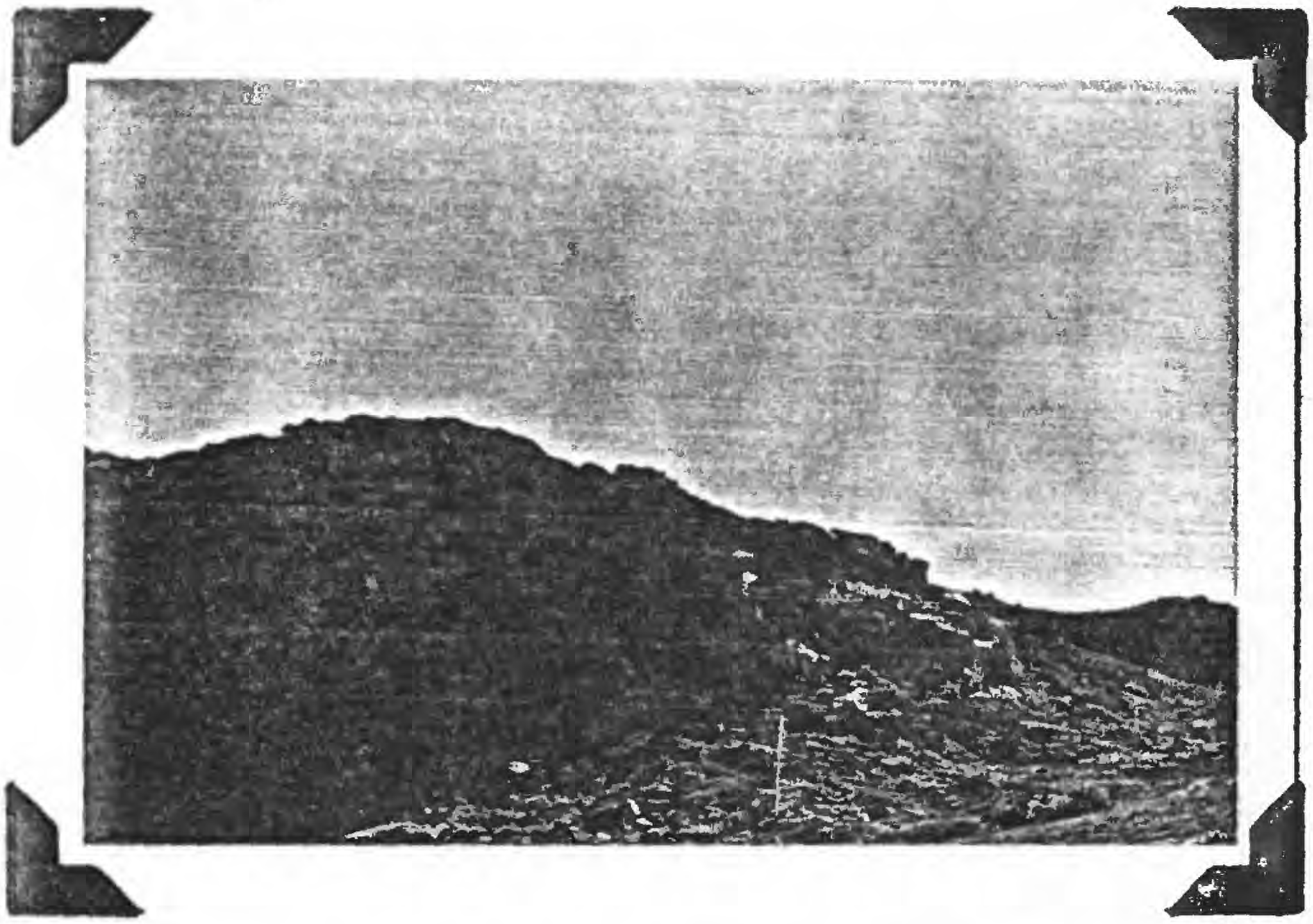


FIGURE 42. - THIN COAL BEDS AT BASE OF FORT UNION FORMATION

Lance-Fort Union contact is at base of scarp. SW 1/4 sec. 36, T. 53 N., R. 94 W.

Willwood formation. The term "Willwood" was proposed by Van Houten (1944, p. 176) for the red-banded strata of the Bighorn Basin that overlie the Fort Union formation and underlie the Tatman formation. These beds were previously assigned to the Wasatch formation. According to Van Houten (1944, p. 175) significant differences between the Wasatch of the type area and that of the Bighorn Basin led to this revision in the nomenclature.

Only the lower part of the formation is exposed in the Spence-Kane area, where it consists of red and gray-banded shales, varicolored shales and thin light gray sandstone beds. Exposures of the formation are poor and badland topography common. The contact between the Willwood and underlying Fort Union formation is locally unconformable along the margin of the Bighorn Basin. No evidence was obtained in the Spence-Kane area regarding the nature of this contact.

Van Houten (1944 and 1948) has discussed the stratigraphy, paleontology and origin of these sediments in this general area.

Terraces, undifferentiated bench surfaces, and alluvium. Surficial deposits in the Spence-Kane area consist mainly of terraces, pediment surfaces, and alluvium. The terrace gravels are found along the Bighorn and Shoshone Rivers and along the south side of Little Dry Creek (Figure 41). With the exception of the extensive terrace along the Shoshone River near the northwestern border of the area, the terraces are largely fragmentary and continuous tracing for correlation purposes is not possible. The less reliable method, of correlation based on the height of the terrace above present stream level, has been used by Andrews, Pierce and Eargle

(1947) who have mapped terrace deposits and physiographic features in the Bighorn Basin. They were able to distinguish eight different levels along the Bighorn River.

The terrace along the Shoshone River is correlated with the Cody terrace, as defined by Pierce and Andrews (1941, p. 156) as the highest and most extensive of a series of small benches about 100 to 160 feet above the Shoshone River. The other discontinuous terraces within the area have not been differentiated. The terraces are usually capped by well rounded pebbles, cobbles, and boulders. Mackin (1937, pp. 837-839) has analyzed the lithology of Bighorn River gravels above the junction with the Shoshone River and found that they are made up of approximately 45 percent Paleozoic sedimentary pebbles, 40 per cent Tertiary volcanic pebbles, and 15 percent of Precambrian crystalline pebbles. Fossils have not been found in these terraces. Pierce and Andrews (1941, p. 158) have traced the Cody terrace beneath a Wisconsin terminal moraine, and thus place the age as older than the Wisconsin stage of the Pleistocene Epoch. Andrews, Pierce and Eargle (1947) have placed all the terrace and undifferentiated bench surfaces within the Spence-Kane area in the Quaternary.

A number of undifferentiated interstream benches are found within the area. These surfaces are usually veneered with gravels, sand or silt and merge into terrace deposits toward the main stream courses and grade into pediment surfaces toward the mountain front. Most of these surfaces consist of isolated fragments, that occur at more than one level, and no attempt has been made to differentiate them. Several well defined pediment surfaces can be seen in the extreme northeastern part of the mapped area in the vicinity of Cottonwood Creek and Willow Creek (Figure 43). These surfaces bevel the Thermopolis shale, and slope away from the Bighorn Mountains toward the Bighorn River. These pediment surfaces occur at two distinct levels.

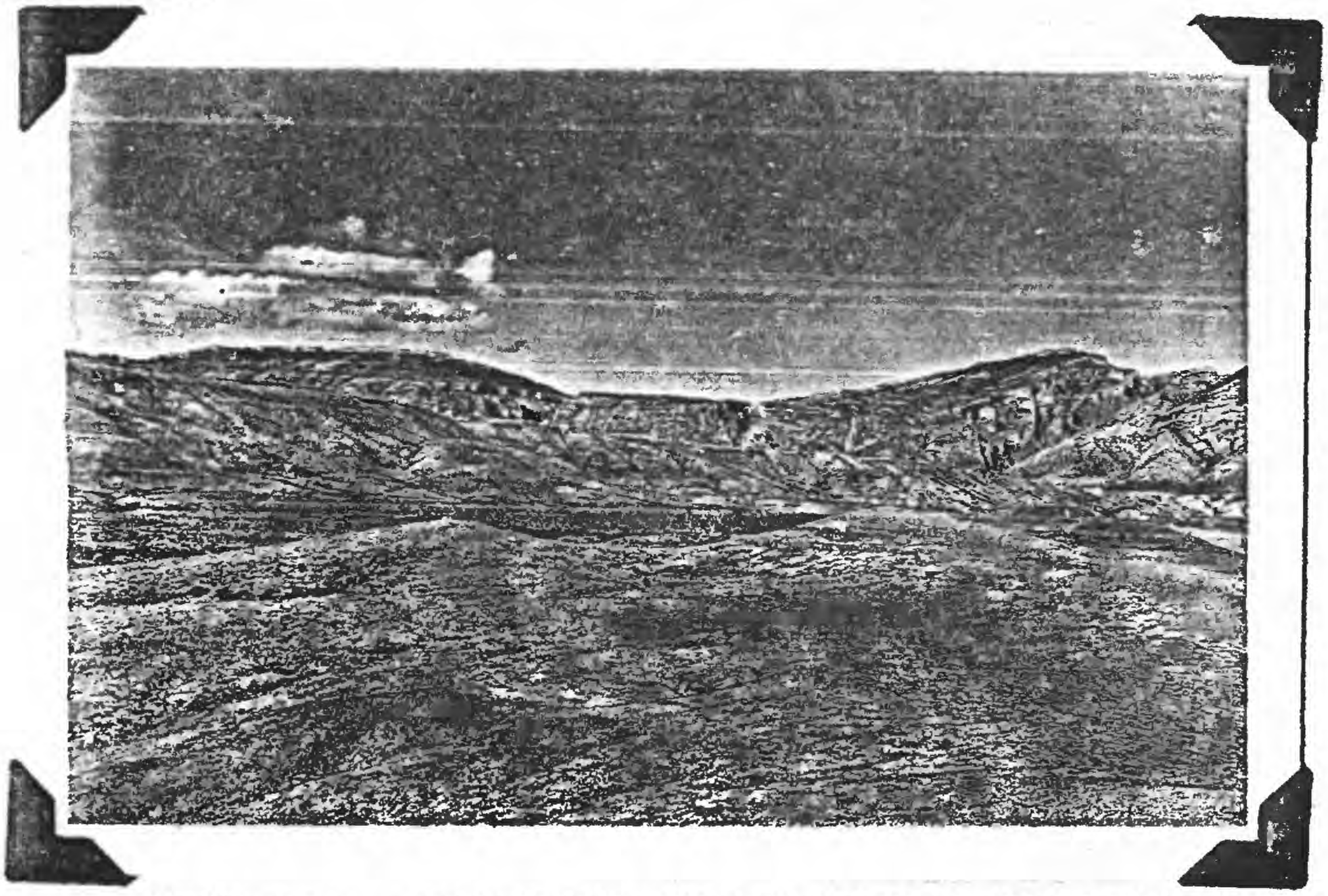


FIGURE 43. - PEDIMENT SURFACE BEVELING THERMOPOLIS SHALE

Cottonwood Canyon in Bighorn Mountains in background. Pediment slopes away from Bighorn Mountains toward Bighorn River.

Alluvium is present along the larger stream beds and was mapped where it was continuous, and of sufficient width to be shown at the map compilation scale. The alluvium, as mapped, includes some lower intermediate benches adjacent to present stream levels. The alluvial plain of the Bighorn River is widest near its junction with the Shoshone River because of the nonresistant character of the underlying Thermopolis shale. At the

Sheep Mountain and Little Sheep Mountain anticlines, where the Bighorn River is superimposed across these structures, the alluvial plain is restricted to a few isolated patches, too small to show, due to the resistant nature of the Paleozoic rocks exposed in the canyons. Where there were sufficient exposures to map the bedrock, and the overlying surficial deposits were thin, the bedrock was shown as the surface rock on the geologic map.

STRUCTURE

General Features

The Spence-Kane area is bordered on the east by the western flank of the Bighorn Mountains, and on the west by the central part of the Bighorn Basin. The area occupies the border zone between these two major structural units. The general structural trend within this area is northwest-southeast. The central part of the area consists of a series of minor folds generally parallel to this regional trend. This central area was referred to by Darton (1906a) and Fisher (1906) as the "Sheep Mountain Uplift". Faults in the area generally trend northeast-southwest, perpendicular to the regional trend. To the east of this central folded belt, the rocks dip westward along the gentle limb of an asymmetrical syncline and rise to the flanks of the Bighorn Mountains. To the west of this belt of minor folds, the rocks dip westward into the Bighorn Basin proper. Geologic cross sections (Plate IX) show the general structural relationships across this belt of minor folds. Axes of the folds, as well as structure contours drawn on the top of the Tensleep sandstone at an interval of 500 feet, are shown on Plate I.

Method of structure contouring. Subsurface data were used for primary control in drawing the structure contours, however, most of the wells drilled in this area (Table 3) are concentrated in the three small oil fields. It was necessary, therefore, to rely in large part upon surface elevations and dips in order to project contours on the top of the Tensleep sandstone, which is only exposed along the axis of the Sheep Mountain and Little Sheep Mountain anticlines.

About 1000 elevations, established by altimetry, were obtained at formation contacts throughout the area. Since the only level line in the area is near the western border it was necessary to establish a series of secondary control points based on altimetry, so that travel time to points of known elevation could be reduced. Although this method does not insure a high degree of accuracy for vertical control, the elevations obtained are more than satisfactory for contouring on a 500 foot interval, in an area where dips in general are relatively steep.

A greater possible source of error lies in the calculation of depth to the datum. Where the surface dip and normal stratigraphic interval are used to convert altitudes to the common datum, two important assumptions are made: (1) that the surface dip continues unchanged at depth, (2) that the normal stratigraphic thickness of the beds involved remains constant, i.e. folding is of the parallel type.

Rubey (1926) has analyzed this problem in relation to incompetent beds where folding is probably more nearly of the similar type than of the parallel or concentric type. He concluded that the vertical distance to datum, for these beds, is more accurately determined by making no correction for dip, and using the normal stratigraphic interval. In the Spence-Kane area, incompetent units are represented by thick sequences like the Cody and Thermopolis shales. On the east flank of the Sheep Mountain and Little Sheep Mountain anticlines, there appears to be a marked thinning of the Chugwater formation and several of the higher formations on the steep limbs of these anticlines (Plate IX).

Two depth to datum calculations were made for each surface altitude obtained at a formation contact. The first calculation employed only the normal stratigraphic thickness with no correction for dip. The second calculation was obtained by multiplying the secant of the angle of dip by the normal stratigraphic interval to obtain the vertical distance to datum. This calculation assumes that the surface dip continues unchanged with depth. The true depth to the datum probably lies part way between the two extremes that these figures represent, since the cross sections indicate that the dip does become more gentle with depth, but that the amount of dip is not entirely negligible. Where dips are relatively gentle the two calculations are in very close agreement, but diverge rapidly for steeper dips. Subsurface data and cross sections provided a series of control points for checking the accuracy of these figures. Generally, the calculation employing no correction for dip was found to be more nearly in agreement with these check points, except in the case of very steep dips.

Faults within the area are believed to diminish with depth and are not known to have affected the Tensleep sandstone, and the structure contours were drawn on this assumption. The surface axes of the folds are shown on Plate I and since the Tensleep sandstone outcrops near the axis of the two markedly asymmetrical anticlines, Sheep Mountain and Little Sheep Mountain, the trace of the axes on the top of the Tensleep should be close to that of the surface axes of these structures. For other anticlines in the area, the contours were drawn assuming that the axial planes of these folds were vertical.

Contours are not shown west of the Lance-Fort Union contact, due to the lack of subsurface data, and contacts from which depth to datum calculations could be made. There is apparently a rapid decrease in dip basinward in this general vicinity which may be due to the presence of an angular unconformity at or near the Lance-Fort Union contact. This problem was discussed in connection with the stratigraphy of this section. Furthermore, it seems possible that an anticlinal axis, trending northwest-southeast, may extend beneath the overlapping Willwood formation, which masks the underlying structure, to a point slightly to the southwest of the southwest corner of T. 54 N., R. 95 W., (Osterwald and Dean, 1958) Andrews, Pierce and Eargle, 1947). This appears likely, since the Sinclair Oil and Gas Co. No. 1 Government well in NE 1/4 sec. 1, T. 53 N., R. 96 W., places the elevation of the top of the Tensleep sandstone at about -8750 feet. This would require a reversal in dip in the general area to the east, beneath the Willwood overlap. Lack of knowledge concerning the possibility of structures in this vicinity, was another reason for not extending the structure contours across this area.

Folds. Plate I shows 12 anticlines wholly or partly within the Spence-Kane area. Nine of these structures have formal names, while three of the anticlines are not named and are of very short extent. From west to east across the area these named anticlinal structures are the Byron anticline, Lovell dome, Goose Egg-Alkali anticline, Sheep Mountain anticline, Rose dome, Spence dome, Little Sheep Mountain anticline, Crystal Creek anticline and Shell dome.

The Byron anticline which is well developed to the west of this area, appears to extend into the Spence-Kane area in the N$\frac{1}{2}$ sec. 30, T. 55 N., R. 95 W. There is a prominent nosing in the Mesaverde sandstones in the NE 1/4 of this section which could not be traced to the southeast of the northeast-southwest trending fault that cuts across the section. There is a gentle reversal of dip along the axis farther to the west. There is also field evidence for an extension of the bordering Byron syncline into the area in the S$\frac{1}{2}$ sec. 19, T. 55 N., R. 95 W. There is a slight reversal of dip along the surface axis which is shown on Plate I.

The Hiawatha Oil and Gas Co. No. 1-19 Govt. well, drilled in the SE 1/4 sec. 19, T. 55 N., R. 95 W., in 1957, places the top of the Tensleep sandstone at approximately -3640 feet. Examination of the electric log of this well reveals no faulting of sufficient magnitude to account for the low structural position of the Tensleep in this well. An extension of the Byron syncline would account for the low structural position of this well. Extension of these two structures into this area would also account for the nosing in secs. 29, 30, and 32, T. 55 N., R. 95 W., and the oil field there which has been called the Alkali anticline field.

Lovell done is believed to extend into the Spence-Kane area in the SW 1/4 sec. 17, T. 56 N., R. 95 W. The surface here is covered by alluvium but the structure is defined farther to the northwest. The Ajax Oil Co. No. 1 Burnham well in Lot 99, T. 56 N., R. 95 W., tested the

Tensleep on this structure and it was dry.

The Goose Egg-Alkali anticline extends northwestward from about the NE 1/4 sec. 32, T. 54 N., R. 94 W., to the NE 1/4 sec. 28, T. 55 N., R. 95 W. A slight structural saddle in the NE 1/4 sec. 3, T. 54 N., R. 95 W., separates the Goose Egg structure to the northwest from the Alkali structure to the southeast. The Peay sandstone member of the Frontier formation forms resistant ridges along the flanks of the anticline, which stand out in relief above the more easily eroded units above, and outlines the anticline. The Mowry shale forms an inner escarpment about the two structural highs. The Thermopolis shale, which is the oldest formation exposed along the anticline, outlines these two structural highs. Dips along the east flank of the structure are slightly steeper than those on the west flank in the vicinity of secs. 3 and 11, T. 54 N., R. 95 W. In general, however, there is no marked asymmetry to the fold. Both the Goose Egg and Alkali parts of the structure have been tested at or near the crest and no commercial amounts of oil or gas were found. Commercial oil wells in secs. 29 and 32, T. 55 N., R. 95 W., have been referred to as the Alkali anticline field, but the accumulations do not appear to be controlled by this structure. The surface faults, to the west of these producing wells are not known to affect the Paleozoic rocks. These faults appear to die out to the east in the Cody shale. In the subsurface these faults may die out with depth in the relatively incompetent Cody shales and only cut the more competent beds. If such is the case, the same deformational forces that produced these surface faults may have also produced an entirely different fault pattern, at depth, cutting the relatively competent units in the Phosphoria equivalent of the Goose Egg formation, Tensleep sandstone and Darwin sandstone member of the Amsden formation which contain commercial quantities of oil and gas in this field. Richards (1955, p. 77) has suggested such a relationship between surface faults in the Ninemile area to the north and structure at depth. On the basis of surface work alone, however, the oil accumulation appears to be controlled by a plunging nose, along an extension of the Byron anticline into this area. On the east flank of the Goose-Egg-Alkali anticline a synclinal trough parallels the anticlinal axis as far northwestward as the W$\frac{1}{2}$ sec. 34, T. 55 N., R. 95 W. At this point a small anticline to the northeast, entirely within the Mowry shale at the surface, separates this synclinal axis from another northwest-southeast trending syncline which parallels the Goose Egg part of the structure.

The Sheep Mountain anticline is the most prominent structure in the area. The thick carbonates at the top of the Phosphoria equivalent of the Goose Egg formation, here correlated with the Ervay tongue of the Park City formation, form resistant dip slopes and outline the imposing topographic feature known as Sheep Mountain. The anticline extends from the SE 1/4 sec. 2, T. 54 N., R. 95 W., southeastward to the SW 1/4 sec. 35, T. 53 N., R. 93 W., where it continues on to the south beyond the limits of the mapped area. The anticline is markedly asymmetrical, the steep limb lying to the east or mountainward side, while the gentle limb is on the west or basinward side. The strata along the east flank dip at very high angles, often approaching the vertical. Large "flatirons" have been cut in the steeply dipping Amsden, Tensleep and Phosphoria beds along most of the eastern flank (Figures 44 and 45). The oldest formation exposed is the Madison limestone. This formation is exposed along the axis of the anticline in the Bighorn River Canyon (Figure 5) and at other places near or at the crest of the anticline, where the overlying formations have been stripped away exposing heart-shaped patches or elongate exposures of the upper part of the formation. The intermittent streams, which have carved the heart-shaped patches on the flanks, have cut small canyons in the upper part of the Madison, notably in the N$\frac{1}{2}$ sec. 7, T. 53 N., R. 93 W., where the axis of the anticline is well exposed on the north wall of one of these cuts. A number of hogbacks are formed by resistant strata on the flanks of the anticline (Figure 46). The anticline, in plan view, has a "cigar-shaped" outline as defined by the resistant carbonates of the Ervay tongue of the Park City formation which form the prominent topographic ridge (Figures 47 and 48). This outline is broken by a small anticline which also is expressed topographically by these resistant carbonates, forming a prong outward from the main anticline and extending northward from the N$\frac{1}{2}$ sec. 3, T. 53 N., R. 94 W., to the S$\frac{1}{2}$ sec. 27, T. 54 N., R. 94 W., where it appears to intersect the main axis of the Sheep Mountain anticline. There are two structural highs along the axis of the main anticline as shown by closure of the 5000 foot contour. The northernmost of these two structural highs appears to be related to the intersection of these two folds. Several synclinal troughs separate the Sheep Mountain

FIGURE 44. - STEEPLY DIPPING BEDS ON EAST FLANK SHEEP MOUNTAIN ANTICLINE

View looking southward. "Rusty beds" of Cloverly formation near synclinal axis in foreground.

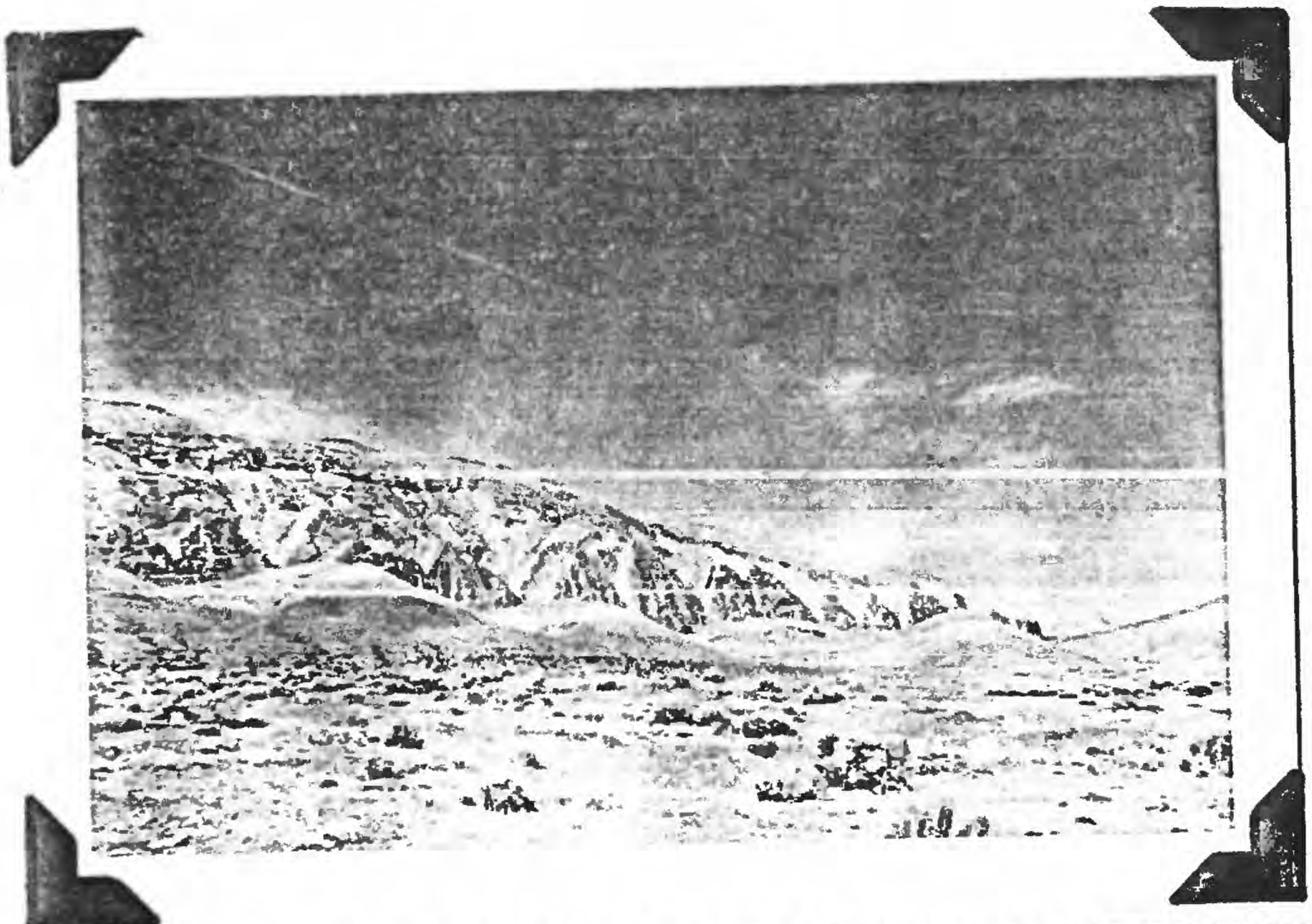


FIGURE 45. - EAST FLANK SHEEP MOUNTAIN ANTICLINE

View looking westward. Anticlinal axis is just to the east of the topographic crest here. Synclinal axis lies to the west of the redbeds in the foreground.

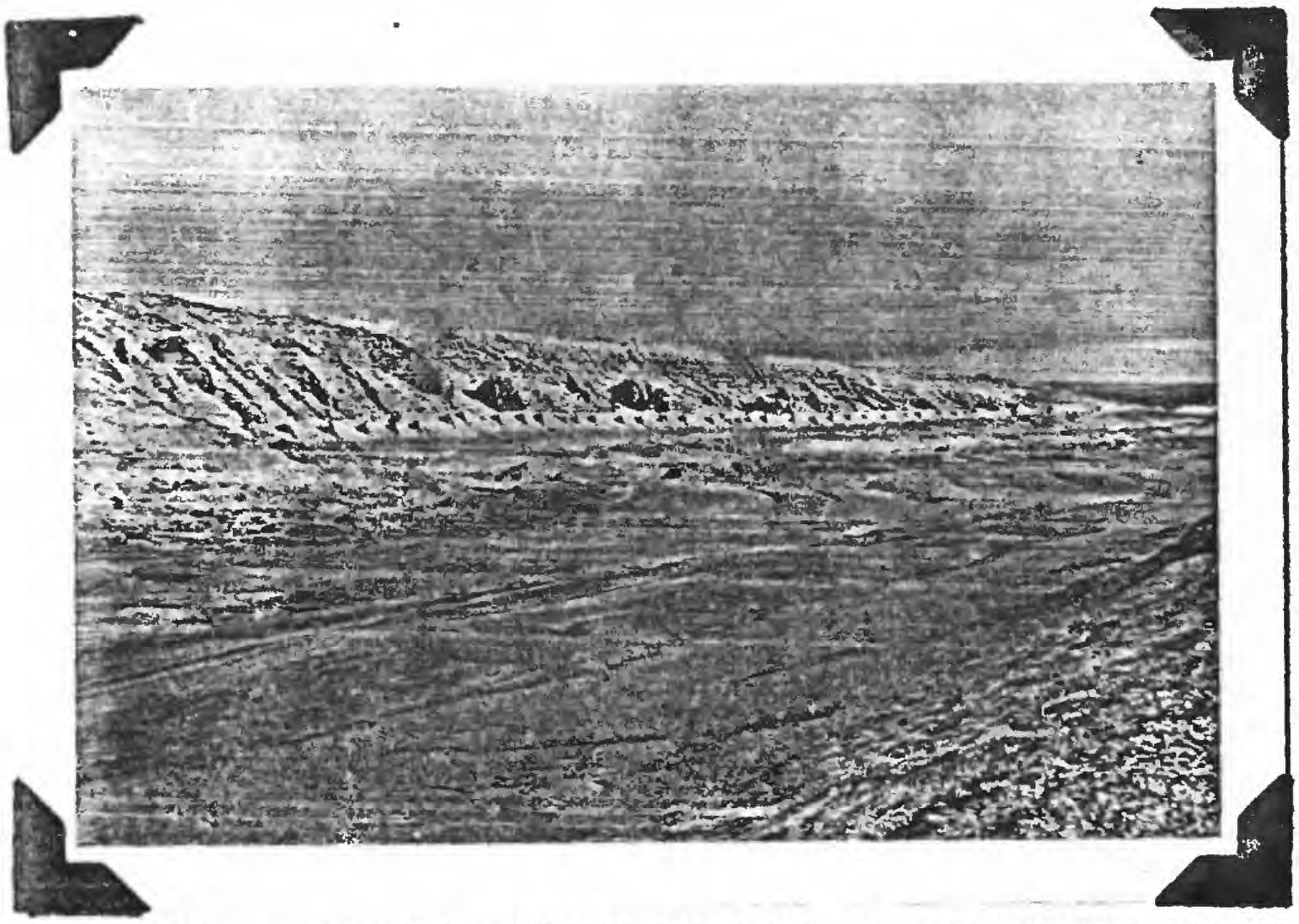


FIGURE 46. - VIEW OF WEST FLANK OF SHEEP MOUNTAIN ANTICLINE. Mowry escarpment in lower right with strike-valley in Thermopolis shale below. Greybull sandstone hogback prominent in upper left. White flatirons in distance are of Gypsum Spring limestone. Phosphoria equivalent of Goose Egg formation forms topographic ridge.

FIGURE 47. - NOSE OF SHEEP MOUNTAIN ANTICLINE IN $N\frac{1}{2}$ SEC. 20 AND $S\frac{1}{2}$ SEC. 17, T. 54 N., R. 94 W. View looking west. Note plunge of anticline and ridge made by carbonates of Ervay tongue of Park City formation.

anticlinal axis from Rose dome, Spence dome, Crystal Creek anticline and Shell dome to the north and east. Two synclinal troughs (Figure 49) that plunge to the north and separate the northern end of the Sheep Mountain anticline from anticlinal structures to the east are separated, where their axes overlap, by a small anticline entirely within the upper part of the Cloverly formation in the NW 1/4 sec. 17, T. 54 N., R. 94 W., (Figure 50). Farther to the southeast, a synclinal trough separates the Sheep Mountain and Crystal Creek anticlines, and the Thermopolis shale occupies the deepest part of the trough. Farther to the southeast, the Sheep Mountain structure is bordered on the east by a broad syncline that extends to the foot of the Bighorn Mountains.

Rose dome, which has been referred to as Red dome in some cases in the past, is located in sec. 35, T. 55 N., R. 95 W. The crest of the structure exposes the varicolored dolomitic limestone beds in the upper part of the Gypsum Spring formation (Figure 51). The oolitic limestones of the basal part of the Sundance formation form a rimrock about the greater part of the dome. A small structural high is shown by closure of the 3500 foot contour in C sec. 35, T. 55 N., R. 95 W.

The Spence structure, is an elongate dome, whose axis extends southeasterly from the S$\frac{1}{2}$ sec. 31, T. 55 N., R. 94 W., to about the SW 1/4 sec. 23, T. 54 N., R. 94 W. The Dinwoody equivalent of the Goose Egg formation, consisting of green, gypsiferous shales and siltstone, is exposed at the structural high along the dome, in secs. 4, 5, 8, and 9, T. 54 N., R. 94 W., (Figure 52). A few cuts expose the top of

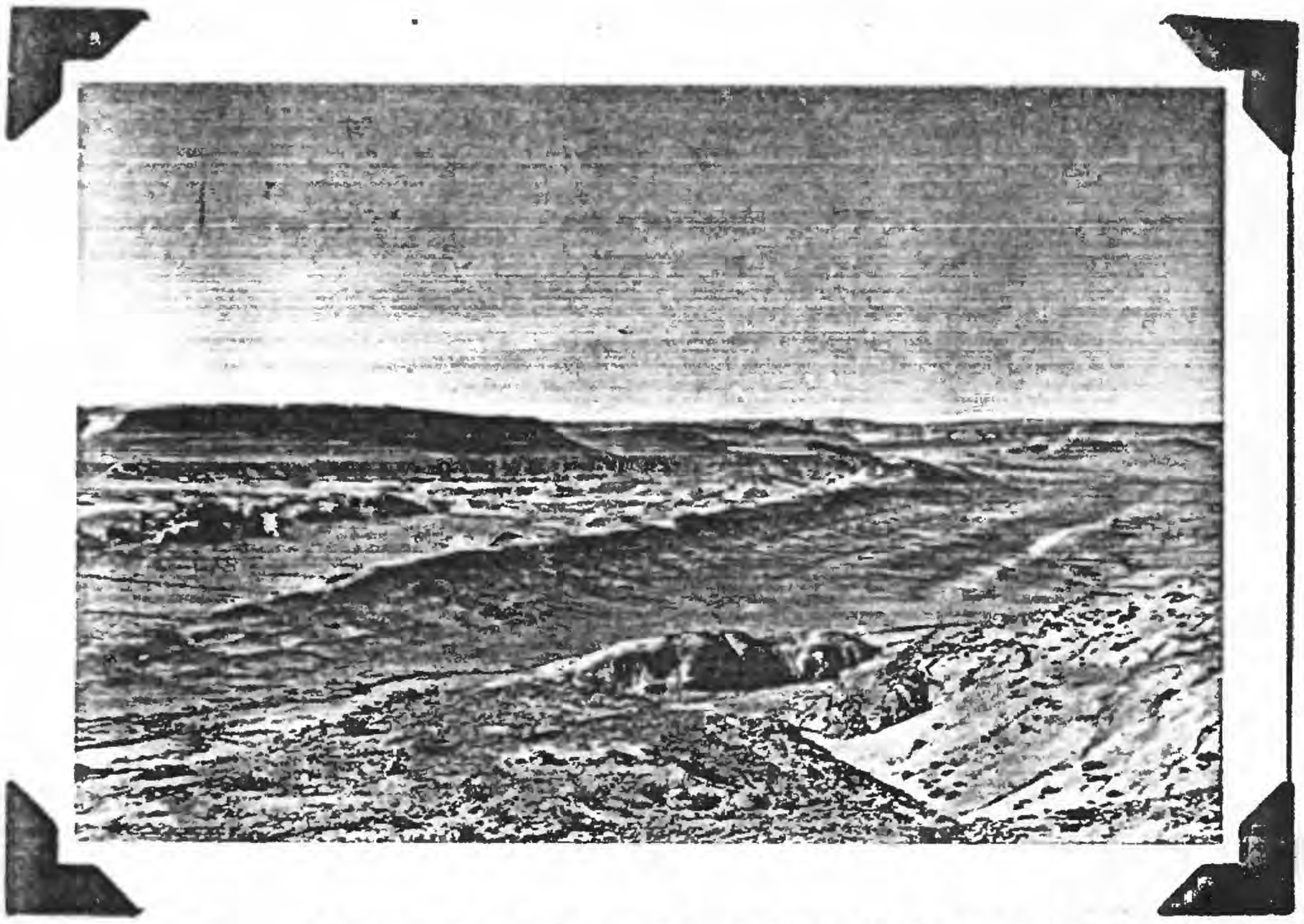


FIGURE 48. - NOSE OF SHEEP MOUNTAIN ANTICLINE
Cloverly sandstones form prominent nose in center of picture. Thermopolis shale with white band representing Muddy sandstone at right. Mowry escarpment in the distance. Sandstones at top of Sundance form resistant ridges at left.

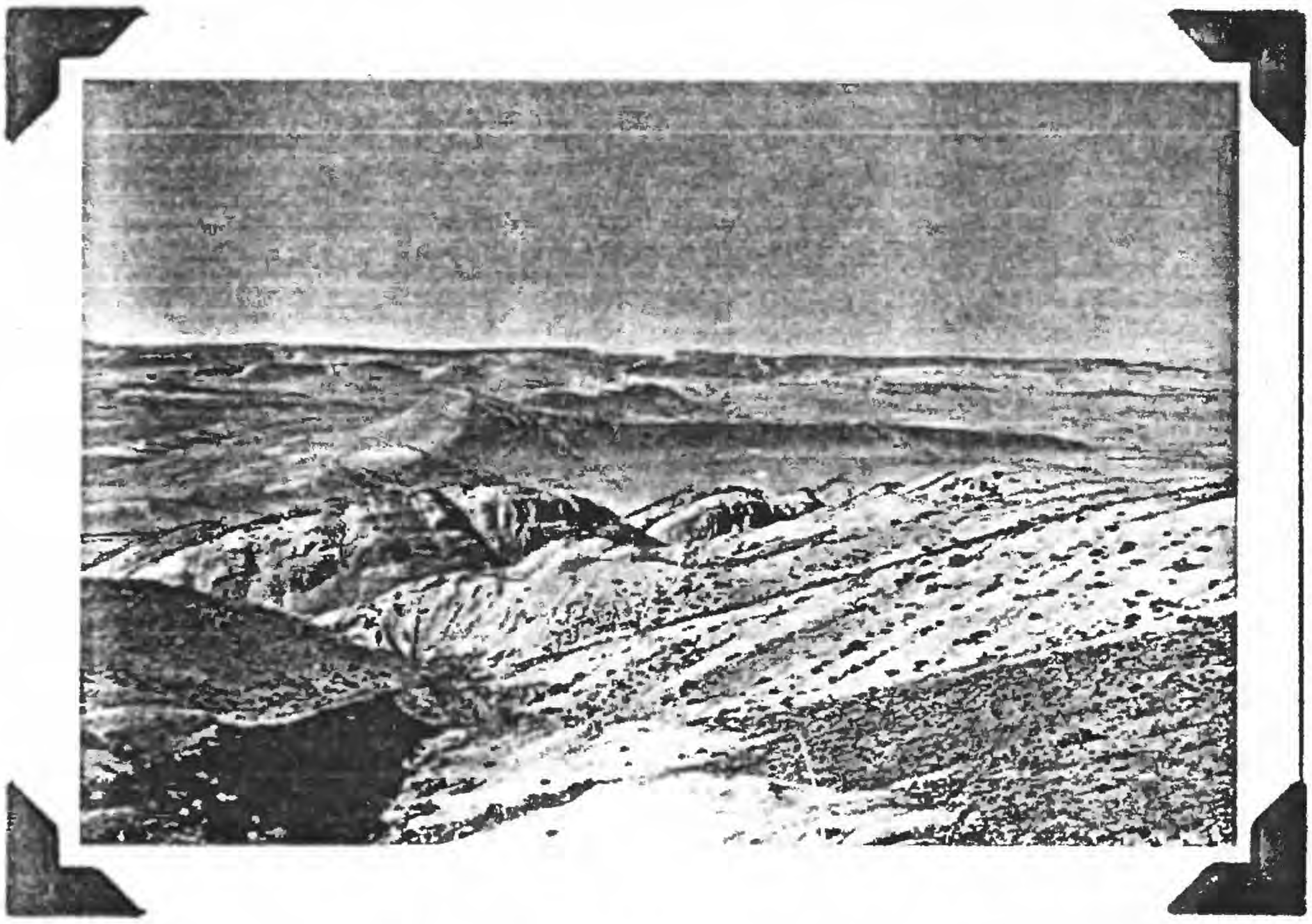


FIGURE 49. - SYNCLINAL TROUGH EXPRESSED BY MOWRY ESCARPMENT. Mowry escarpment forms v at axis of syncline plunging northward, in general vicinity of sec. 7, T. 54 N., R. 94 W.

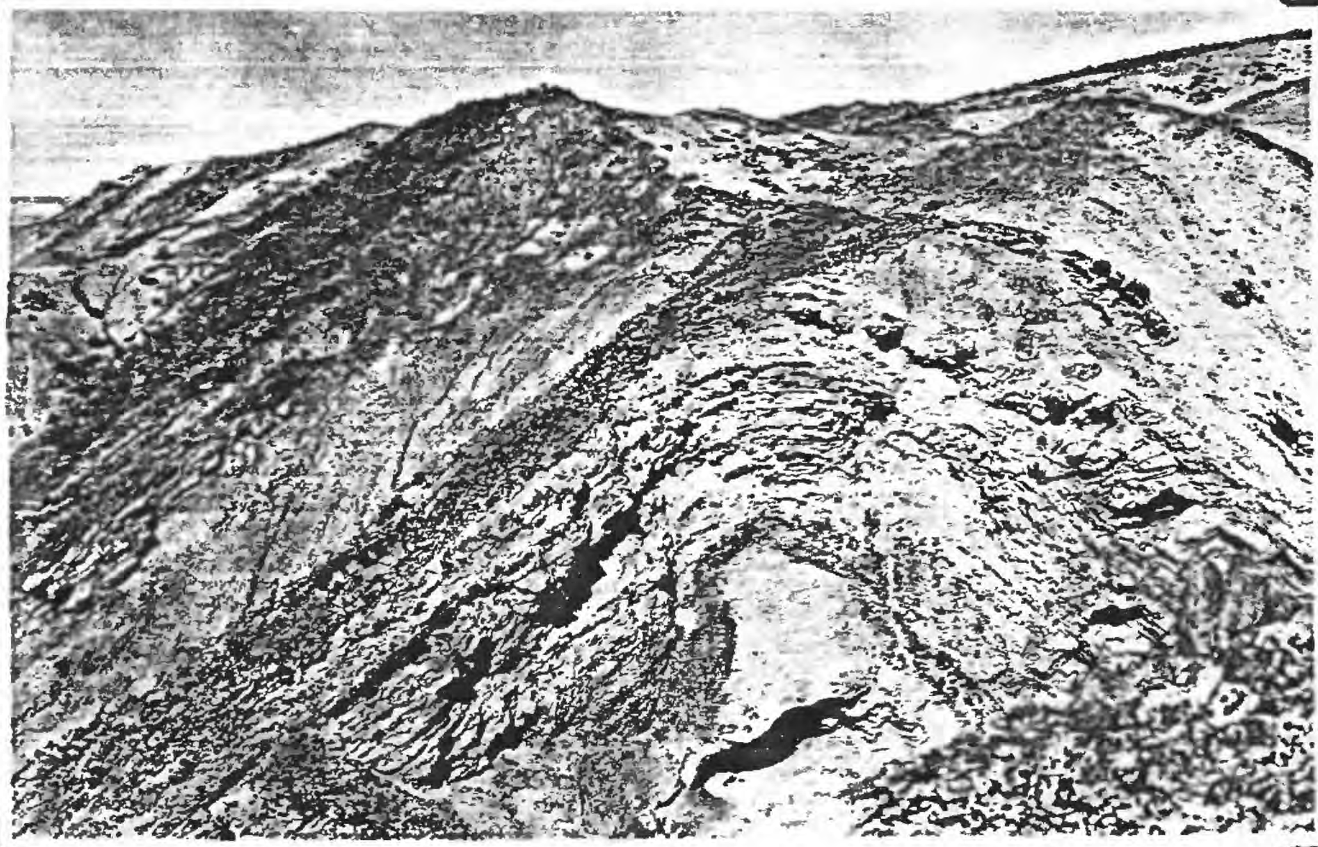


FIGURE 50. - SMALL ANTICLINE IN CLOVERLY FORMATION

In NW 1/4 sec. 17, T. 54 N., R. 94 W.

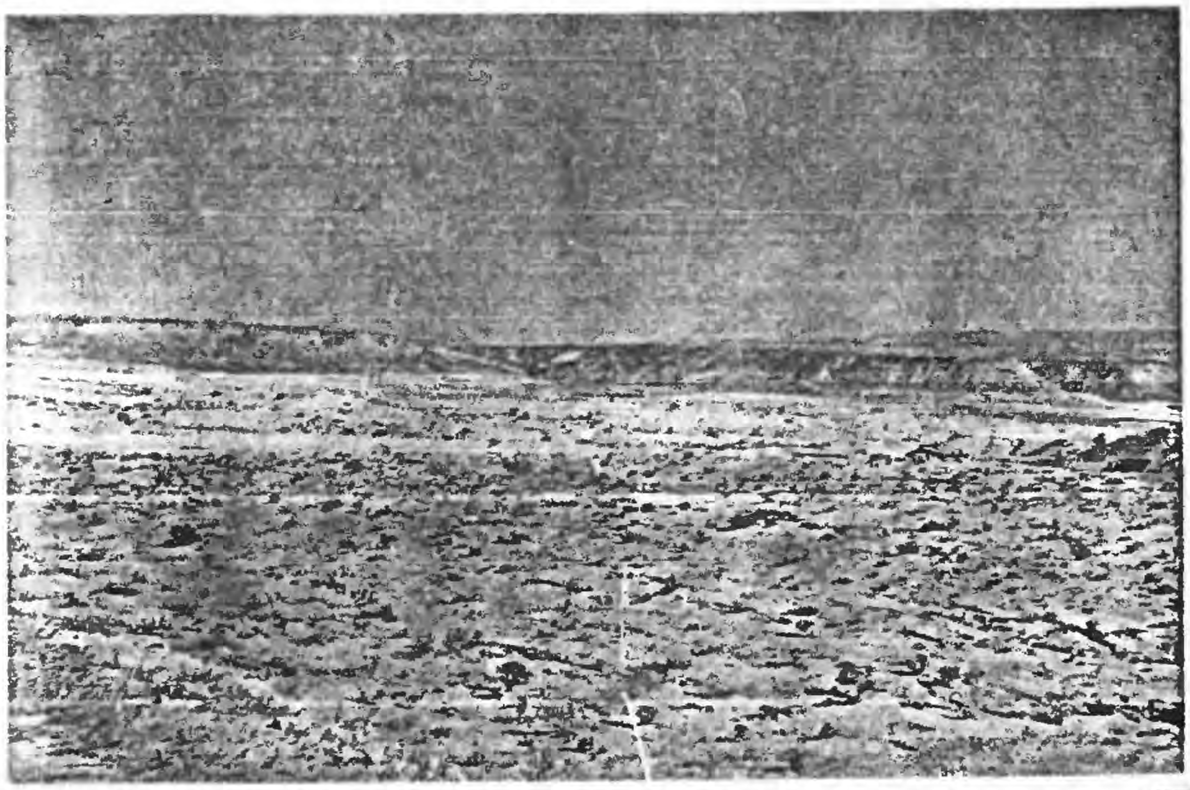


FIGURE 51. - VARICOLORED DOLOMITIC LIMESTONE OF GYPSUM SPRING FORMATION AT CREST OF ROSE DOME

"Oolitic" limestone of basal Sundance forms rimrock in background.

the Phosphoria equivalent at the south end of this structural high. There is a sharp nose in the Gypsum Spring formation in $S\frac{1}{2}$ sec. 31, T. 55 N., R. 94 W., while farther to the south, the axis is concealed by terrace deposits and alluvium along the Bighorn River. A number of shallow wells have been drilled to the Madison limestone at the structural high, where a small oil field is located. A shallow syncline separates the Rose dome-Spence dome trend from the Little Sheep Mountain structure to the northeast.

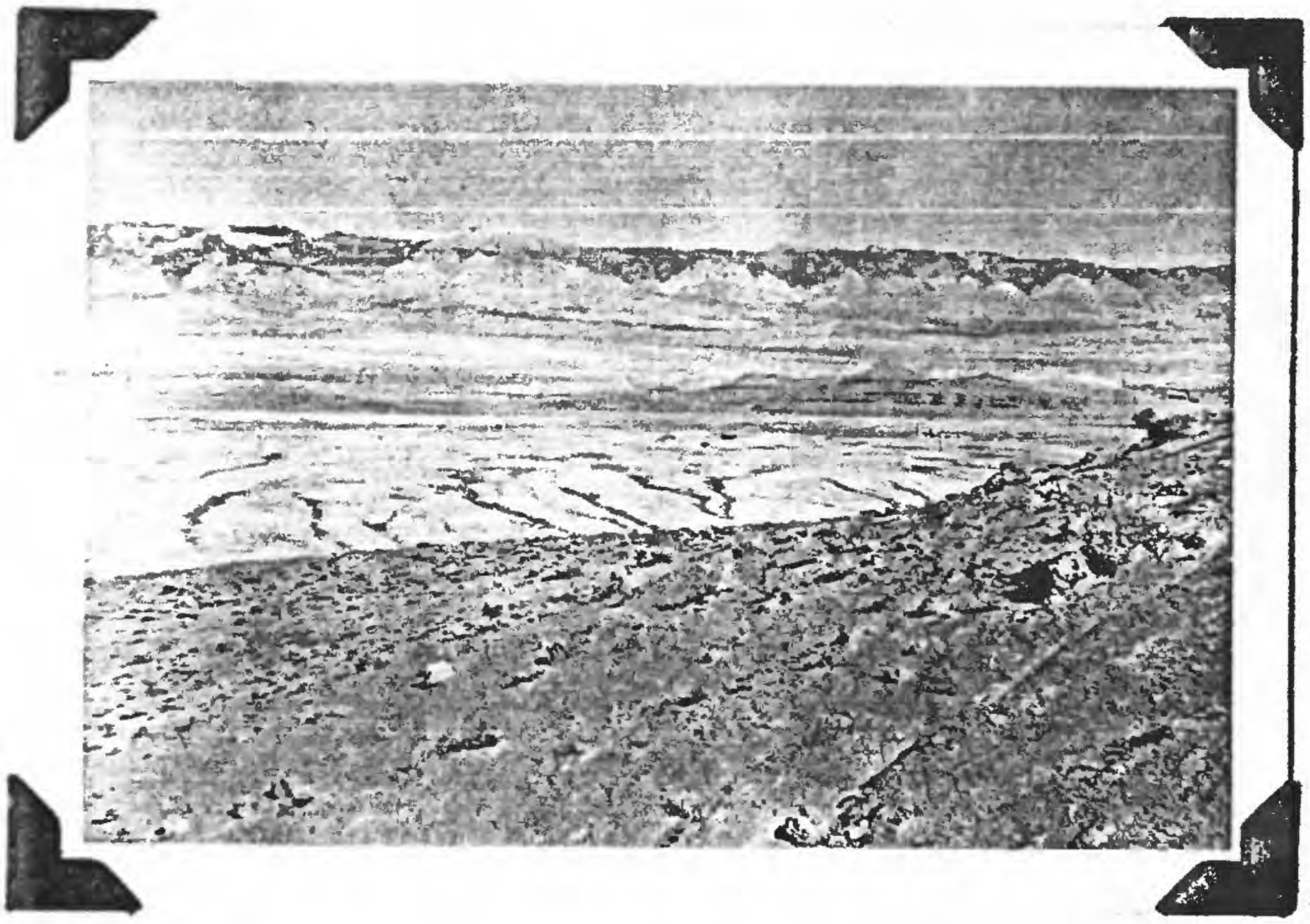


FIGURE 52. - SPENCE DOME

Pale green exposure is Dinwoody equivalent of Goose Egg formation exposed at structural high along dome. Chugwater and Gypsum Spring redbeds can be seen on both east and west flanks of structure. Bighorn Mountains in background.

The Little Sheep Mountain anticline extends southeastward from about the N$\frac{1}{2}$ sec. 16, T. 56 N., R. 95 W., where its relations to the north are obscured by terrace gravels and alluvium, to the southeastern part of T. 55 N., R. 94 W., where it is separated by a structural saddle from the Crystal Creek anticline. This structure is similar in all major respects to the Sheep Mountain anticline. The carbonates of the Ervay tongue of the Park City formation form resistant dip slopes giving rise to the topographic feature known as Little Sheep Mountain. This anticline is also distinctly asymmetrical with its gentle limb on the west or basinward side and the steep limb on the east or mountainward side. The fold is not as sharp as that of the Sheep Mountain anticline in that the western limb is gentler. The 4500 foot contour outlines the structural high of the anticline, which extends from about the NE 1/4 sec. 21, T. 56 N., R. 95 W., to approximately the SW 1/4 sec. 6, T. 55 N., R. 94 W. The Madison limestone is the oldest formation exposed along the anticline. The Bighorn River canyon through the southern end of the structure exposes only the uppermost part of the Madison along the axis of the anticline. Heart-shaped patches of Madison limestone are also exposed just to the east of the surface axis of the structure, where intermittent streams have removed the overlying formations. The Amsden and Tensleep formations are also exposed in a number of small canyons cut through the overlying Permian rocks as well as on the flanks of the structure. Unlike the Sheep Mountain anticline, a number of small cross-faults cut the strata on the limbs of Little Sheep Mountain anticline. The Little Sheep Mountain anticline is bordered on the east by a large asymmetrical syncline, whose gentle eastern limb rises gradually to the foot of the Bighorn Mountains.

The Crystal Creek anticline is separated from the Little Sheep Mountain anticline by a structural saddle in sec. 31, T. 55 N., R. 93 W., and a shift in the direction of the axis from northwest-southeast to essentially a north-south trend. Two separate closures are present along this axis as shown by the 3000 foot contour, with a structural saddle between them in sec. 18, T. 54 N., R. 93 W. The anticline extends from sec. 31, T. 55 N., R. 93 W., south to about the C sec. 5, T. 53 N., R. 93 W. The Gypsum Spring formation outcrops at the crest of the anticline at the two structural highs. The oldest formation exposed, the Chugwater formation, is found at the cut across the northern end of the anticline, along the south side of Crystal Creek. This anticline is asymmetrical and quite distinct from others in this general vicinity in that the steeper limb is on the west or basinward side, while the gentler limb is on the east or mountainward side. This anticline is bordered on the west by a continuation of the Little Sheep Mountain syncline, which extends to the foot of the Bighorn Mountains.

The axis of Shell dome, a small structural high, just extends into the SE 1/4 sec. 25, T. 53 N., R. 93 W. The crest of this dome lies to the southeast, outside the area. This dome is separated from the Sheep Mountain anticline by a small synclinal trough which trends northwest-southeast across sec. 36, T. 53 N., R. 93 W.

Faults. Faults within the Spence-Kane area are practically all high angle faults trending northeast-southwest perpendicular to the general trend of the structure within the area. The majority of these faults are found along the west flank of the Little Sheep Mountain anticline. They appear to be cross faults and flank faults of tensional origin, developed as a result of folding. A number of faults near the north end of Little Sheep mountain appear to be related to the plunge of the fold. In the southwestern part of T. 55 N., R. 95 W., a belt of parallel faults appears to be part of a larger belt extending to the northwest across the Garland and Byron structures. These faults appear to die out to the northeast in the Cody shale, and could not be extended to the faults with a similar trend that lie just to the northeast on the flank of the Little Sheep Mountain anticline. Many of the faults in the area appear to affect only the more competent beds and to die out in thick shale sequences like the Cody and Thermopolis, although several faults are known to offset the Thermopolis shale. As was mentioned previously, these surface faults are not known to affect the Paleozoic formations, but it is possible that an entirely different fault pattern could have been generated in the deeper competent beds, by the same forces that produced the surface faults. A low-angle reverse fault in vicinity of the southwestern corner of T. 56 N., R. 94 W., locally cuts out the Chugwater formation. The extent of this fault along the strike is unknown due to slope wash which conceals its exact relations. The strata along the east limb of the Little Sheep Mountain anticline in the vicinity of this fault are locally overturned, and thinned, and the Chugwater redbeds are bleached pale green, in part. The Sheep Mountain anticline is unusual in that there are few faults associated with it in contrast with Little Sheep Mountain anticline. Adjustment to folding was apparently largely by slippage and flowage. On the other hand, sandstone dikes are common along the flanks of the Sheep Mountain anticline but appear to be absent along the flanks of the Little Sheep Mountain anticline.

Asymmetry of folds. Sheep Mountain anticline, Little Sheep Mountain anticline and Little Sheep Mountain syncline, the major folds within the Spence-Kane area are distinctly asymmetrical, the anticlines having their steep limb to the east, while that of the syncline is on the west. Goose Egg-Alkali anticline appears to be nearly symmetrical, while Crystal Creek anticline is slightly asymmetrical, with the steep limb to the west. Cross sections (Plate IX) were drawn through the larger anticlines and synclines and show the general structural relationships. Hewett and Lupton (1917, p. 34) noted in their regional study of anticlines in the southern part of the Bighorn Basin, that the anticlines and domes were generally asymmetrical, and that on the eastern side of the Bighorn Basin the gentler limb was nearest the center of the basin, while the steeper limb was toward the Bighorn Mountains.

Sheep Mountain and Little Sheep Mountain anticlines are striking examples of asymmetrical anticlines along the eastern side of the Bighorn Basin. As shown on Plate IX, the axial planes of these folds are probably slightly curved surfaces, although they may be warped in actuality, inclined toward the gentler limb of the anticline. Both folds appear to increase in closure and sharpen with depth. The crestal plane of these folds, appears to be offset, slightly, in the direction of the gentler limb, from the axial plane of these folds as indicated by the cross sections and structure contours. The location of this crestal plane, rather than the axial plane, is of prime importance in locating wells to test the structurally highest points on these anticlines.

These folds as well as others in the area were formed by compressional forces during the Laramide orogeny. Fanshawe (1952, pp. 19-21) has summarized the genesis and tectonic history of the Bighorn Basin. The formation of the asymmetrical anticlines, so common in the Bighorn Basin, and their characteristic direction of asymmetry are explained by a concept called "Basin Mechanics" originally developed by W. T. Thom, Jr. According to Fanshawe (1939, p. 1484) this concept applies to

> "formation of near-surface thrusts and superjacent asymmetric folds in consequence of the flexing into basin form of massive, competent, rock units either devoid of bedding planes or lacking enough bedding to permit easy and well distributed bedding-gliding of successively higher layers toward the rims as a basin depression developed in consequence of general regional compression."

According to this concept flexing of the basement rocks may result in adjustment by formation of high angle or ramp thrusts. Many of the asymmetric anticlines around the Bighorn Basin margin are thought to be surface reflections of high angle thrusts in the Precambrian basement rocks, although it seems likely that this process could result in the formation of asymmetric anticlines without rupturing of the basement rocks. It is possible that a ramp thrust is present in the Precambrian rocks underlying the Sheep Mountain and Little Sheep Mountain anticlines.

ECONOMIC GEOLOGY

Oil and gas. About 98 wells have been drilled for oil and gas within the Spence-Kane area. There is no record available for some of the older locations. Table 3 is a list of the wells that are numbered on the geologic map, giving the name, location, date drilling ceased or well was abandoned, lowest formation reached, and remarks, where appropriate, for each of these wells. The majority of these wells were drilled at Spence dome, along the northern part of the Crystal Creek anticline, and in the southwestern part of T. 55 N., R. 95 W., which are the three oil producing fields within the Spence-Kane area (Figure 53).

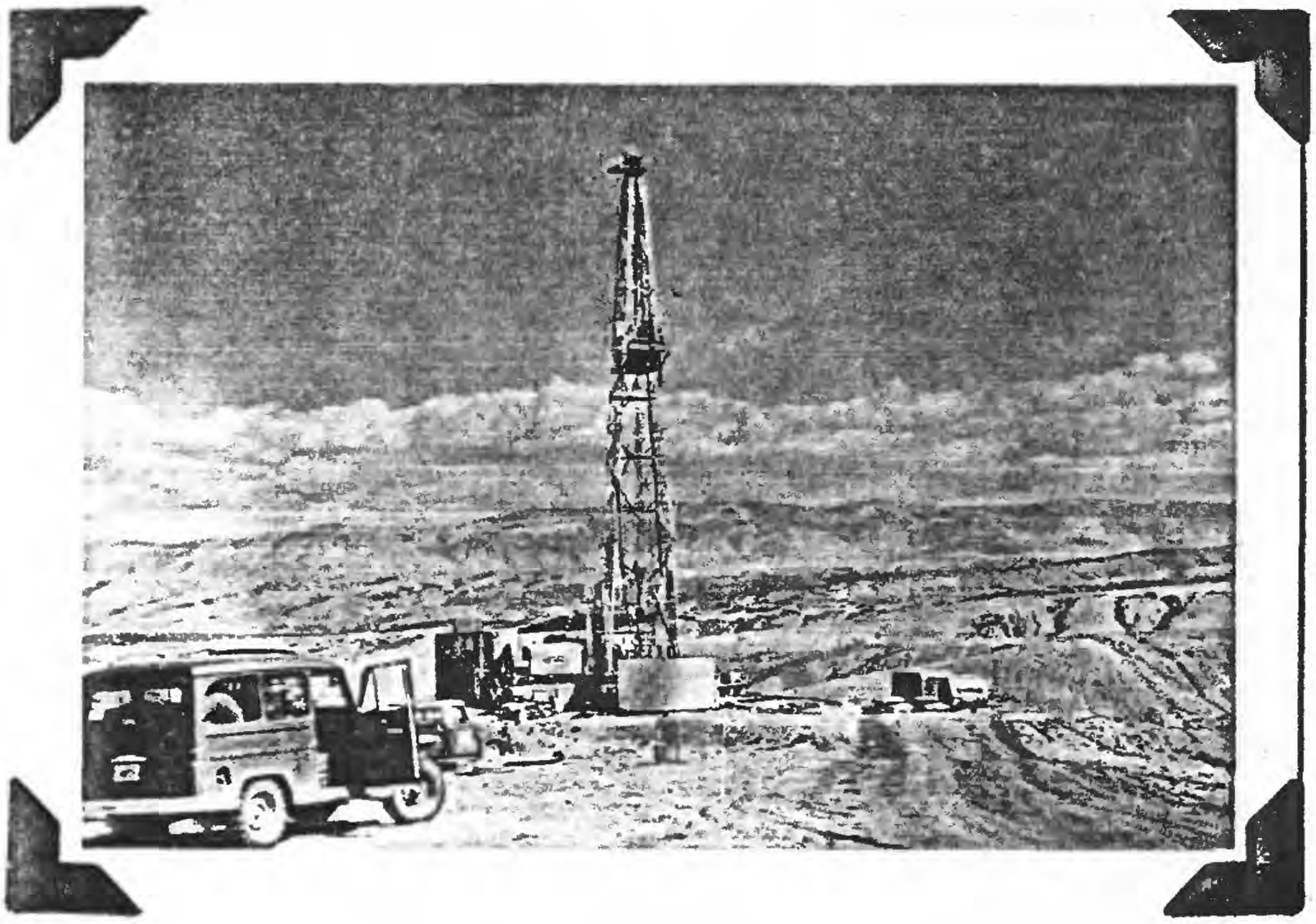


FIGURE 53. - DRILLING OIL WELL AT ALKALI ANTICLINE FIELD

The extension of the Byron anticline into the N$\frac{1}{2}$ sec. 30, T. 55 N., R. 95 W., indicates that the nose to the southeast is possibly related to this structure, rather than the Goose Egg-Alkali anticline. This relationship was discussed under the section on structure. The Alkali anticline field, located in secs. 29, and 32, T. 55 N., R. 95 W., was discovered on May 8, 1957, by completion of the Sohio Pet. Co. No. 3 Unit well in the NE 1/4 sec. 32, T. 55 N., R. 95 W. The well had an initial production of 170 barrels of 21.2^{o} A.P.I. gravity oil a day from the Tensleep sandstone, and later the well was recompleted in the "Phosphoria equivalent" for an additional initial production of 70 barrels a day of 25.3^{o} A.P.I. gravity oil. Two additional oil wells have been dually completed in the Tensleep and "Phosphoria equivalent" to the north of the discovery well in sec. 29, T. 55 N., R. 95 W. One of these wells discovered oil in the Darwin sandstone member of the Amsden formation, although it has not been produced. An attempt to extend the field to the south in the NW 1/4 sec. 15, T. 54 N., R. 95 W., resulted in a dry hole. If the extension of the Byron anticline, based on surface data, actually controls oil accumulation in this general vicinity, the most favorable area for oil production would be in the N$\frac{1}{2}$ sec. 30, and W$\frac{1}{2}$ sec. 29, T. 55 N., R. 95 W.

Lovell dome was discussed under the section on structure. The two wells drilled on this structure have been unsuccessful.

The Goose Egg structural high along the Goose Egg-Alkali anticline, has been tested by three dry holes drilled in sec. 33, T. 55 N., R. 95 W. The deepest test, the Yale Oil Corp. No. 1 Govt. in the NE 1/4 sec. 33, T. 55 N., R. 95 W., reached the Madison limestone, for a total depth of 3525 feet, and reported an oil show.

About 8 wells have been drilled at or near the crest of the Alkali portion of the structure. All of these wells were unsuccessful. The Mule Creek Oil Co. No. 2 Unit well in SW 1/4 sec. 11, T. 54 N., R. 95 W., reached the Madison limestone, for a total depth of 3012 feet and reported an oil show in the "Amsden sand".

The Sheep Mountain anticline has been tested for oil and gas by three wells drilled near the axis of the structure. These wells were unsuccessful and did not report either a show of oil or gas.

The deepest test on this structure, the Flynn, McMahon, Parker, et al., No. 1 Great Western Sugar Co. well in SW 1/4 sec. 35, T. 54 N., R. 94 W., reached Precambrian, for a total depth of 2605 feet. The other two wells were both drilled in sec. 17, T. 53 N., R. 93 W. The Shell Oil Co. No. 1 Govt. well reached the Cambrian, for a total depth of 1422 feet, while the Sheep Mountain Oil Corp. No. 1 Govt. well is reported to have reached the Madison limestone at 600 feet. These wells were drilled on the gentle limb of the anticline. The lowest producing formation in the Spence-Kane area to date, the Madison limestone, is exposed along the axis of the anticline and at the Bighorn River Canyon through the anticline. The anticline is thus not considered to be a good prospect for oil discoveries.

Rose dome (Figure 51) has been tested by two dry holes drilled near the crest, near the center of sec. 35, T. 55 N., R. 95 W. The Red Dome Oil Co. No. 1,Govt. well in SE 1/4 sec. 35, T. 55 N., R. 95 W., reached the Madison limestone, for a total depth of 1212 feet and reported a show of oil. The Mule Creek Oil Co. No. 1, Govt. well in the SW 1/4 of this same section, reached the Madison limestone, for a total depth of 1660 feet.

Spence dome is the site of a small oil field located on the top of the dome in secs. 4, 5, 8, and 9, T. 54 N., R. 94 W., (Figure 52). There are 10 producing oil wells on the structure, to date, and a large number of shallow, dry holes have been drilled in this vicinity. The main production is from the Madison limestone, which is exposed at the surface on Sheep Mountain anticline only about 2 miles to the south. The producing horizon is shallow and averages about 500 feet in depth below the surface. The first well drilled at Spence dome is believed to be the Mo., Neb., Wyo. Develop. and Mining Co. Placer claim, in the SE 1/4 sec. 4, T. 54 N., R. 94 W., drilled in 1904, which reported a show of oil from the Embar. Recently, in 1957, the Western Giant-Oil Inc., No. 10-x, Govt. well, in the SW 1/4 sec. 4, T. 54 N., R. 94 W., discovered oil in the Darwin sandstone member of the Amsden formation, adding a new productive horizon in this field. The field is reported to have produced 8896 barrels of oil in 1956, and to have had a cumulative production of 39,915 barrels of oil prior to 1956.

The Little Sheep Mountain anticline, like Sheep Mountain anticline, has not produced oil or gas to date. Several wells drilled at or near the crest of the structure were unsuccessful. The Prairie Oil and Gas Co. No. 1, Govt. well, in the NE 1/4 sec. 35, T. 56 N., R. 95 W., reached

Precambrian, for a total depth of 3035 feet. The A.C. Oil Co. No. 1, Govt. well, in the SE 1/4 sec. 21, T. 56 N., R. 95 W., reached the Bighorn dolomite, for a total depth of 1400 feet and reported a show of oil in the Devonian. Asphaltic residue and oil staining were observed within the section of the Tensleep sandstone exposed in the Bighorn River canyon through Little Sheep Mountain. The town of Lovell drilled a well for water at the nose of the Little Sheep Mountain anticline in the SE 1/4 sec. 16, T. 56 N., R. 95 W., which was also unsuccessful.

Numerous attempts have been made to establish commercial production of oil at the Crystal Creek anticline since 1919. To date the structure is not yet a commercial field. Several wells have produced small quantities of oil, and many of the wells have had good oil shows, in the Tensleep sandstone, Darwin sandstone member of the Amsden formation, and in the Madison limestone. The latest attempt, was the V. Ziegler No. 1, Govt. well, in the NE 1/4 sec. 7, T. 54 N., R. 93 W., which reached the Madison limestone, for a total depth of 1335 feet. This well discovered oil in the Amsden formation, but is temporarily suspended at present.

The crest of Shell dome has been tested by dry holes at the crest of the structure, outside the limits of this area.

Coal. Thin coal beds, less than 1 foot in thickness, are found in the basal section of the Fort Union formation (Figure 42). The thickness of these beds combined with the steep dip of this section throughout the area, rules out the possibility of commercial use. Coal beds of sufficient thickness for commercial use may be present higher in the section of the Fort Union formation that is largely concealed by wind-blown sand. Coal was not observed in the Willwood section exposed in this area, nor in the Lance formation. Thick carbonaceous shale beds are present throughout the lower half of the Meeteetse formation and thin coal seams and partially coalified plant material is common in this section, but no workable deposits were found. The Mesaverde formation contains thick carbonaceous shale beds near the top (Plate II), but coal was not observed in this formation or in the underlying formations exposed in this area.

Bentonite. Bentonite, within the area, typically has a "popcorn" or "coral-like" weathered surface. The bentonite near the surface is hard, blocky, and breaks with a conchoidal fracture and usually is white to buff in color (Figure 54). The unweathered bentonite, however, is usually green to greenish-yellow, and soft with a waxy consistency. Commonly, the surface outcrop is marked by the presence of reddish-brown limonitic staining and selenite gypsum plates and calcite crystals. The bentonite often forms a low ridge in the more easily weathered shales.

Bentonite occurs in the upper part of the Thermopolis shale, throughout the Mowry shale, and in the Frontier, Cody, and Meeteetse formations of the Spence-Kane area. Bentonitic shale was observed in the Morrison formation and the Fort Union formation. The general relations of these beds and their thickness and distribution was discussed under the section on stratigraphy.

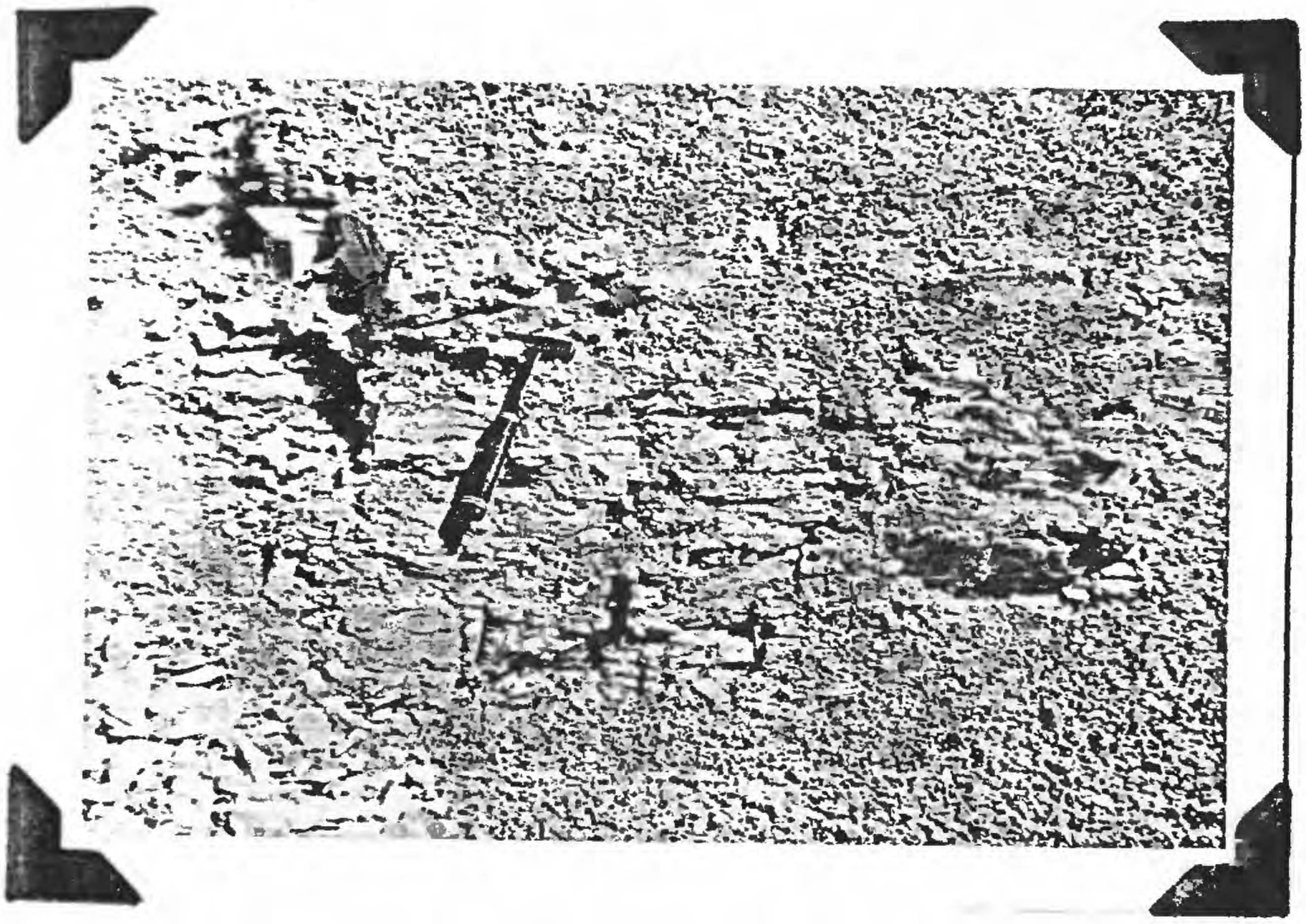


FIGURE 54. - TYPICAL WEATHERED SURFACE OF BENTONITE BED

Note "popcorn" or "coral-like" weathered surface and white, blocky, bentonite.

There are about 6 beds of bentonite averaging 1 foot in thickness in the upper part of the Thermopolis shale, above the Muddy sandstone member. Bentonite beds are found throughout the Mowry shale. The beds range in thickness from less than an inch to the Clay Spur bentonite bed at the base of the dip slope of the Mowry escarpment, which averages about 5 feet in thickness in this area. Measured sections of the Thermopolis and Mowry shales illustrate the abundance of these beds within these two formations, and their position within the section.

Commercial production of bentonite in the Spence-Kane area is, at present, restricted to bentonite beds in the Frontier formation. Two thick bentonite beds are present in this formation. The Stucco bentonite bed averages about 10 feet in thickness in this area. This persistent bed is about 30 feet above the top of the Peay sandstone member and is tentatively correlated with the Soap Creek bentonite bed of areas to the north. This bentonite bed has been stripped extensively within the area. On the east limb of Alkali anticline, a bentonite bed, 6 feet thick, is exposed below the Torchlight sandstone member. This bed appears to be thinner in other sections within the area.

Several bentonite beds averaging about 1 foot in thickness are found in the upper part of the Cody shale. These beds are deeply weathered and their true thickness is difficult to determine. The measured section of the Cody shale shows the position of these beds within the section, and the lithology of the section above and below.

Bentonite beds in the Meeteetse formation (Figure 38) are found in the lower half of the formation, as mapped in the Spence-Kane area. These bentonite beds are shaly and impure for the most part and average less than one foot in thickness. A detailed measured section of the Meeteetse formation shows the distribution of these bentonite beds within the section.

Two companies, the Wyoben Bentonite Company, and Magnet Cove Barium Corporation, produce bentonite from pits within the Spence-Kane area. At least one other large company was engaged in active exploration in the area during the course of the mapping. The Wyoben Bentonite Co. maintains offices at Greybull, Wyoming, and has a processing mill at the Stucco siding in sec. 11, T. 53. N., R. 94 W. Currently, they are actively developing the pit in sec. 24, T. 54 N., R. 95 W., (Figure 55).

The bentonite is hauled by truck to the mill, and shipped by freight after processing. The Magnet Cove Barium Corporation operates one of the world's largest bentonite processing plants just beyond the southern border of the mapped area, north of Greybull. Stripping operations were centered in the northeastern part of T. 53 N., R. 93 W., along the western limb of the syncline (Figure 56). These operating pits, like those of the Wyoben Co., are in the Frontier formation. The bentonite is also hauled to the mill by trucks, and shipped by rail after processing. The product is marketed under the trade name of Magcogel for use as a drilling mud and for stopping water seepage in ponds, reservoirs, dams and earthen structures. Another product is marketed as Yellowstone Foundry Bentonite for use as a bond in molding sands. The bentonite has a multitude of other uses, such as use in ceramic products, as a filtering agent, for de-inking newsprint, etc. Heathman (1939) has reviewed the history of production of bentonite in Wyoming.

Over much of the Spence-Kane area, the thick bentonite beds in the Frontier and Mowry dip steeply and only a relatively small amount of the bentonite can be stripped by surface pits. The most promising area for bentonite production is along the broad syncline at the eastern margin of the area. There are extensive outcrops of both the Frontier and Mowry along the syncline and the dip of the formations is low, averaging about 5^{o} on the broad, gentle eastern limb, which should allow extensive surface stripping operations.

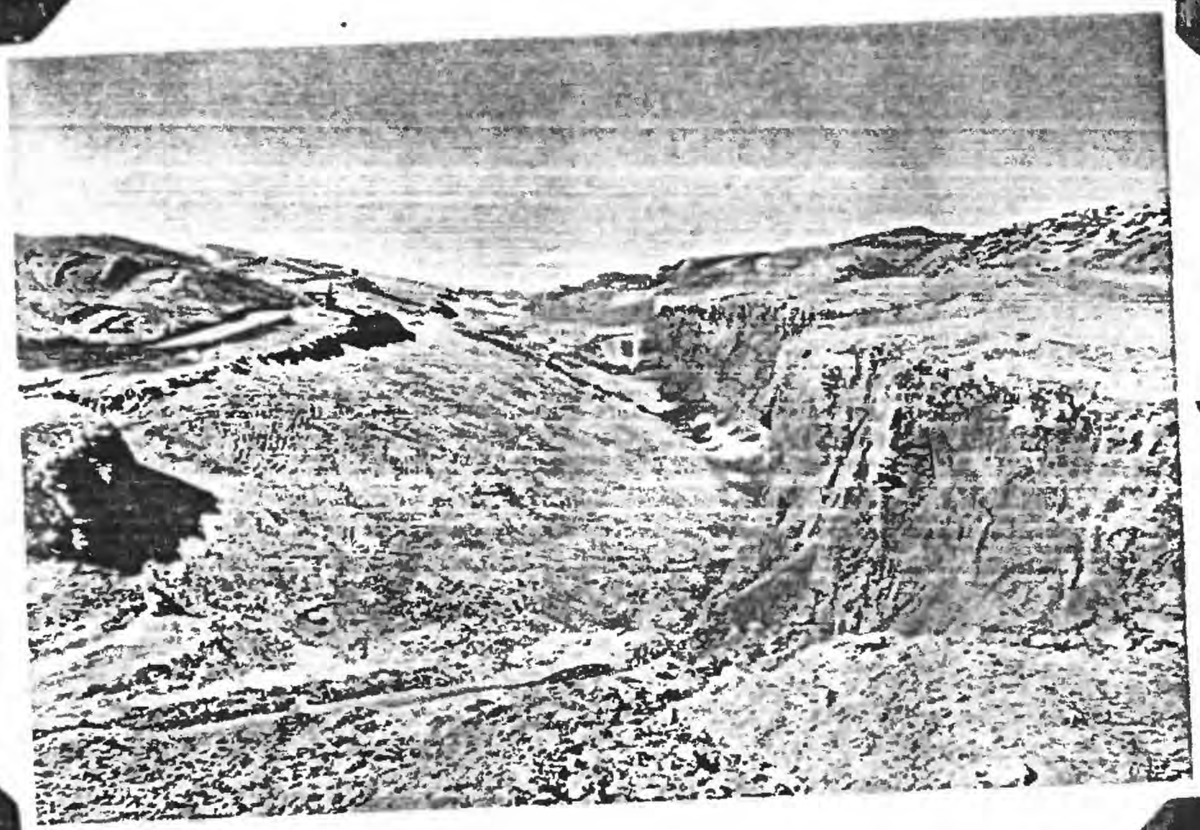


FIGURE 55. - WYOBEN CO. BENTONITE PIT IN SEC. 24, T. 54 N., R. 95 W.

View looking north, on east flank Alkali anticline.

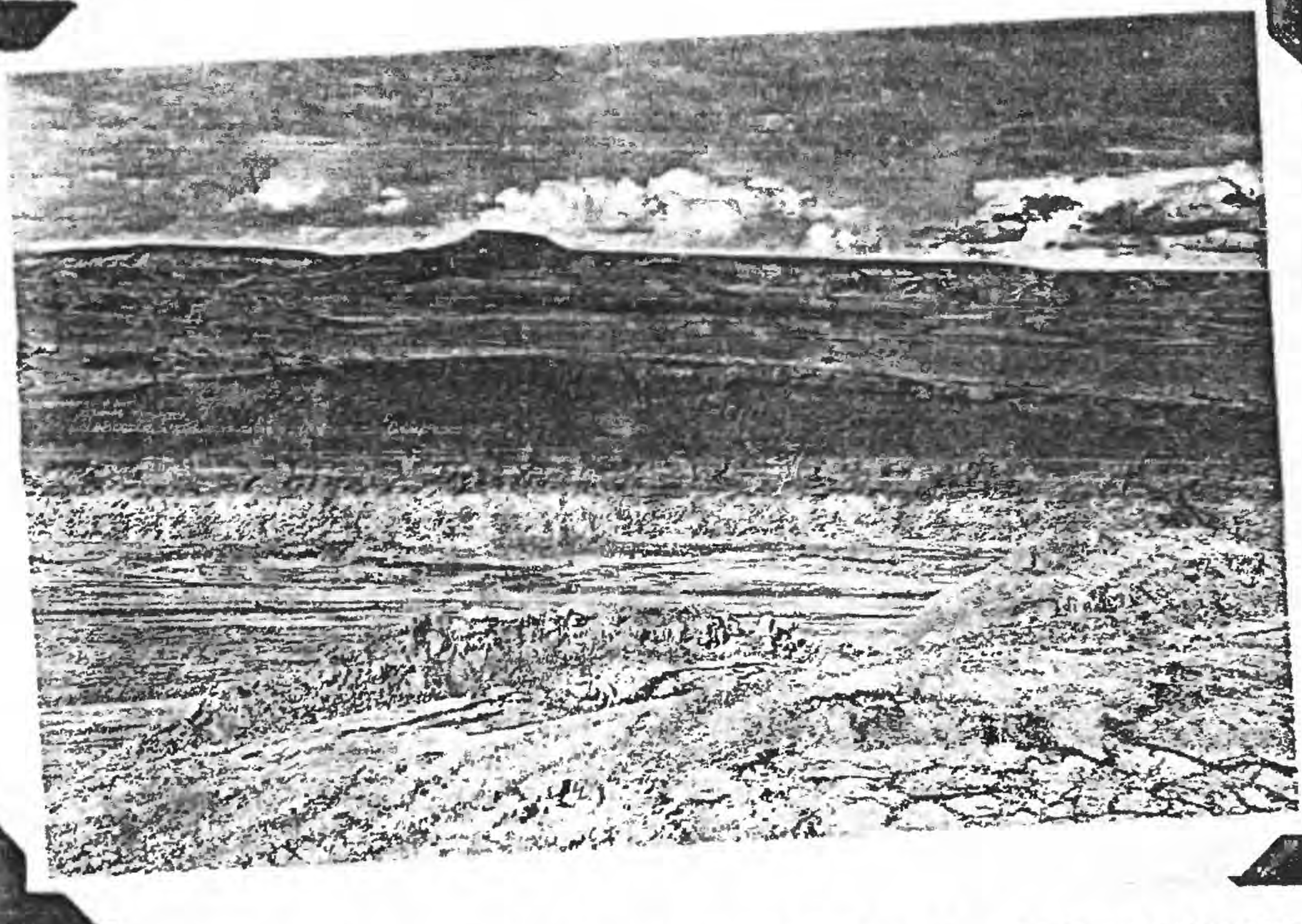


FIGURE 56. - MAGNET COVE BARIUM CORP. BENTONITE PIT

In sec. 13, T. 53 N., R. 93 W., view looking east.

Clay. The Lovell Clay Products Company operates a pit in the NE 1/4 sec. 20, T. 56 N., R. 95 W. The clay is derived from the Cloverly formation and hauled by truck to the company's plant in the town of Lovell. There, it is used in the manufacture of structural clay products.

Gypsum. There are extensive thick deposits of gypsum in the Goose Egg formation, and the Gypsum Spring formation. The stratigraphic relations of these beds was discussed earlier under the section on stratigraphy. The most promising bed is the massive gypsum unit at the base of the Gypsum Spring formation (Figures 14 and 15). This unit is about 50 feet thick and well exposed over most of the area of outcrop. The gypsum is snow-white in fresh cuts, and appears to be exceptionally pure. Thin red and green shale partings, however, are found separating individual beds of gypsum within this unit and probably would detract from its usefulness as a commercial source of gypsum due to difficulty in separation. There are tremendous reserves of gypsum within the area. A small pit in the SE 1/4 sec. 11, T. 53 N., R. 94 W., was mined in the past, for use in making stucco blocks (Figure 57).

Construction materials. Thick gravel deposits cap many of the terraces and pediment surfaces within the area, and are used in surfacing unpaved roads. A section of U. S. Highway 310 in T. 53 N., R 94 W., was being rebuilt and straightened, and terrace gravels were being utilized from the SE 1/4 sec. 34, T. 53 N., R. 94 W.

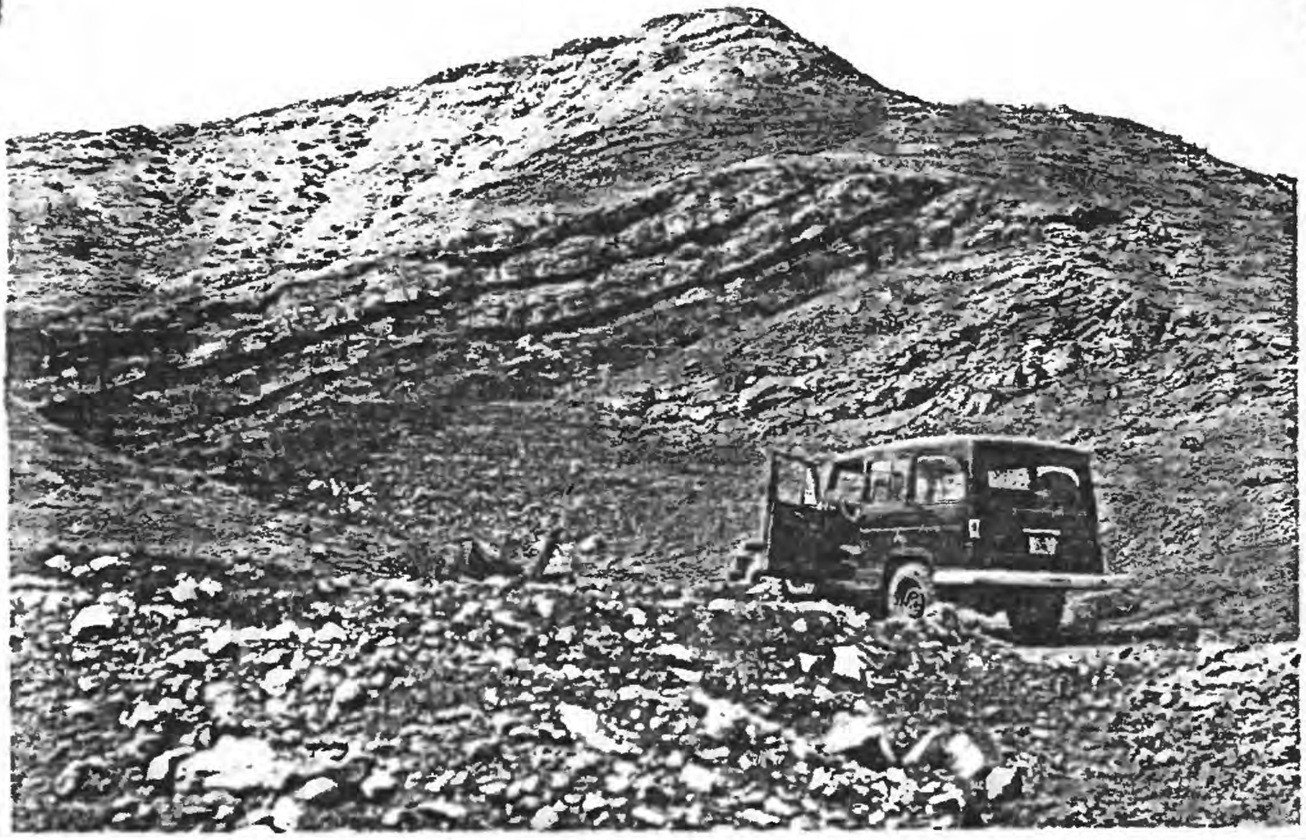


FIGURE 57. - PIT IN MASSIVE GYPSUM UNIT AT BASE OF GYPSUM SPRING FORMATION

SE 1/4 sec. 11, T. 53 N., R. 94 W. Note shale partings between more resistant gypsum beds.

Limestone quarries in the Madison limestone in the Bighorn River canyons through Little Sheep Mountain and Sheep Mountain, appear to have been used primarily as a source of crushed rock for railroad ballast along the C.B.&Q. railroad track, although some of this rock may have been used in the sugar beet factory in Lovell. One of the quarries is located in the NE 1/4 sec. 17, T. 55 N., R. 94 W., and two quarries are located in sec. 35, T. 54 N., R. 94 W.

Uranium. There is no commercial production of uranium to date within the area. The Cloverly and Morrison formations have been staked at many places within the area. Dinosaur bones in the Morrison formation (Figure 21) appear to commonly contain uranium. The Greybull sandstone member, is often mottled red and yellow, and has been staked quite often. Finnell and Parrish (1958) have shown three localities in this area from which chemical assays of 0.01 per cent or more uranium or uranium minerals have been obtained. These locations are all in the Cloverly and Morrison formations. The three localities are: (1) sec. 4, (?) T. 55 N., R. 95 W.; (2) sec. 1, T. 54 N., R. 95 W., and sec. 6, T. 54 N., R. 94 W.; (3) sec. 3, T. 53 N., R. 94 W. A small mine in sec. 1, T. 54 N., R 95 W., is called the Marvel Uranium Mine. Production of this mine is unknown.

Iron ore. The pisolitic "buckshot" iron ore in the red shale sequence of the Amsden formation has been described in the section on stratigraphy (Figure 7). The ore consists of pisolites in a matrix of red shale arranged in lenticular bands. A maximum of 4 feet of this ore is present in the section exposed in the Bighorn River canyon through Sheep Mountain. Chemical analysis for iron indicates that this material would make a very good ore.

The lenticular nature of the deposits and the steep dips and thick overburden generally associated with the exposures, appear to rule out any possibility of commercial exploitation of these deposits.

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VITA

Robert Lester Rioux was born in Natick, Massachusetts, on June 11, 1927. He graduated from Raymond High School, Raymond, New Hampshire in June, 1945. The next four years were spent in the U. S. Navy. Upon return from military service, he entered the University of New Hampshire, Durham, New Hampshire, in October 1949, and graduated in June, 1953, with a B.A. degree in geology. He entered the Graduate College of the University of Illinois, Urbana, Illinois, in July, 1953, attending the geology summer field camp near Durango, Colorado. In the fall of 1954, he received a University of Illinois Fellowship for graduate work in geology. During the scholastic year of 1954-1955, he held a half-time graduate assistantship in the geology department. He received the M.S. degree in geology in February, 1955. The title of the M.S. thesis was "A Study of Topography on a Granitic Terrain", prepared under the supervision of Dr. C. A. Chapman, of the Geology department. He was the recipient of the Shell Fellowship for one year of graduate study for the scholastic year 1955-1956. In June, 1956, he left the University of Illinois to join the U. S. Geological Survey and undertake a project that would serve as a thesis, completed in absentia. He had previously worked for the U. S. Geological Survey during the summer months of 1954 and 1955, in Washington, D. C. and in the field in Wyoming and Colorado. Membership in professional societies includes the American Association of Petroleum Geologists, and the Geological Society of America. He is also a member of the Society of Sigma Xi, Phi Kappa Phi, and Phi Beta Kappa.