UPPER CRETACEOUS SEDIMENTATION AND TECTONICS IN THE POWDER RIVER BASIN, WYOMING

Thesis for the Degree of M. S.

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ABSTRACT

UPPER CRETACEOUS SEDIMENTATION AND TECTONICS
IN THE POWDER RIVER BASIN, WYOMING

by Robert Frederick Heuser

A regional subsurface study of the stratigraphic intervals delineated by marine Upper Cretaceous bentonites in northeastern Wyoming is presented in this investigation. Large volcanic ash falls, carried by westerly winds, fell into an interior sea, later to be transformed by decomposition into time-rock units, namely bentonites.

Some 480 electric well logs and several lithologic logs were utilized to construct a series of isopach maps in order to determine the orogenic pulsations in the Powder River Basin and the surrounding positive geologic features during the early stages of the Laramide Orogeny. Eight electric log cross-sections aid in interpretations made throughout the basin.

Several of these isopached intervals show deformatory forces to be more active during some time-rock intervals rather than others. Relationships between tectonics during the Upper Cretaceous and possible oil occurrences were found to occur in several fields within the basin.

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By

Robert Frederick Heuser

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INTRODUCTION

Location and Topography of Area

The Powder River Basin is the largest intermontane basin in Wyoming and is located in the northeastern portion of the state. Figure 1 shows the major structural features surrounding the basin. The positive areas are shown by solid lines, and the basins by dashed lines. The Black Hills flank the east side of the basin, and the Big Horn Mountains, rising to heights of 13,000 feet, flank the west side. Directly to the south the Laramie Mountains rise abruptly to elevations over 10,000 feet. A northeasterly extension of the Laramies, the Hartville Uplift, separates the Powder River Basin from the Denver-Julesburg Basin. Portions of two intermontane basins, the Wind River and Shirley Basins are found about 30 miles southwest of the Powder River Basin.

The mountain ranges are composed of Paleozoic sediments and highly resistant crystalline rocks of Precambrian age that are exposed at the higher elevations. The elevations within the Powder River Basin ranges from 3,500 and 6,000 feet and decreases to the north.

LOCATION AND MAJOR STRUCTURAL FEATURES OF NORTHEASTERN WYOMING

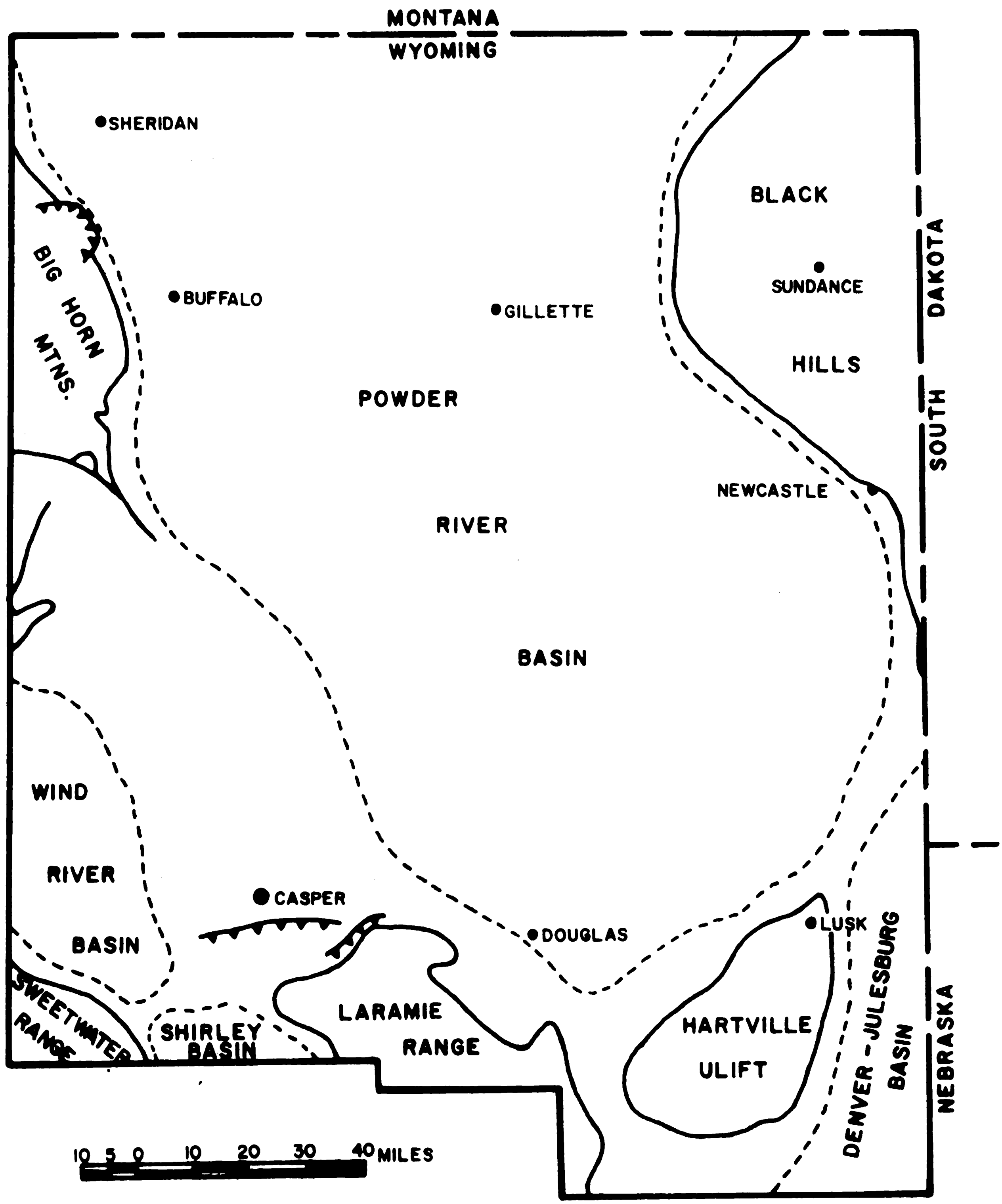


FIGURE I

Purpose

The purpose of this study is to determine the areal distribution of depocenters and positive and negative features during the marine Upper Cretaceous, in and around the Powder River Basin, Wyoming. This enables a paleogeographic setting to be constructed so that the structural history of the basin can be resolved.

Methods of Investigation

The initial step in preparing this study was to become familiar with the general stratigraphy and sedimentation of northeastern Wyoming. After a general knowledge of the area had been acquired, it was necessary to subdivide the Upper Cretaceous by utilizing a number of bentonites as subsurface time-rock units. The tops of various bentonite beds throughout the Upper Cretaceous were determined from some 480 electric logs and several lithologic logs.

Bentonites are readily distinguishable on electric logs by the positive spontaneous potential and decrease in the resistivity curve they make. Because bentonites have higher porosities than shales and their chief constituent is the clay mineral montmorillonite, they are able to absorb large quantities of water from the drilling muds and formation waters. An increase in porosity and in water content are the controlling factors in producing a negative resistivity kick on the electric logs when these bentonites are encountered.

The east side of the basin was chosen as a starting point for picking the bentonite tops for two reasons: First, since the bentonites had a westerly source, it was necessary to find which ones extended far enought to be found on the east side of the basin; and second, the western side of the basin was a shoreline facies during most of the Upper Cretaceous thus causing a random pattern of distribution of the bentonites, making them very difficult to distinguish from one another over large distances.

A log was chosen that contained the entire Upper Cretaceous section. About 15 bentonites were picked from this log, some of which were later discarded. Using this log as a key, a radiating pattern was utilized to determine which bentonites would carry regionally along the eastern flank of the basin.

In order to be certain that the same bentonites were being used on the west side of the basin, six different cross-sections were made across the basin (Plates 5 and 6). Plate 2 is an index map showing the location of the cross-sections. Two additional cross-sections were made along the east and west flanks of the basin for added assurance in correlation (Plates 3 and 4). Repeated correlations and cross correlations were needed before there was absolute certainty that the same bentonite bed was being used in each case.

The majority of bentonites picked lie beneath the Parkman sandstone and because the majority of wells in the center of the basin penetrate only as deep as the Parkman objective, there was some difficulty and time spent in making the western bentonite picks. On the east flank bentonites "C" and "D" carry extremely well as do bentonites "F" and "G" along most of the west side. Plate I shows some typical electric logs in different localities of the basin from which bentonite picks have been made.

Isopach maps were then constructed showing the depositional trends as related to the structural history of the Powder River Basin in Upper Cretaceous time.

Previous Work

A great deal of literature has been published concerning the stratigraphy, sedimentation, and regional tectonics of the Upper Cretaceous of Wyoming, but little work has been done in dividing the Upper Cretaceous into small time-rock units. Detailed studies have been made on the various formations in the area; however, these only represent approximate time units and not exact time markers as is the case with the utilization of bentonite beds.

C. S. Ross recognized the potential of volcanic beds as key horizons in stratigraphic correlations as early as 1925. Reeside (1957) worked out a broad regional study of the paleoecology of western United States Cretaceous seas.

Parker (1958) made detailed maps of various Upper Cretaceous formations and members and from this developed a tectonic picture of the Powder River Basin during Montana time. Sloss (1960) mentions that virtually all regional and inter-regional time-stratigraphic correlations are published on the basis of bio-stratigraphic evidence alone. He suggests the use of regional unconformities, time-parallel stratal units, and horizons of apparent synchroneity.

STRATIGRAPHY AND SEDIMENTATION

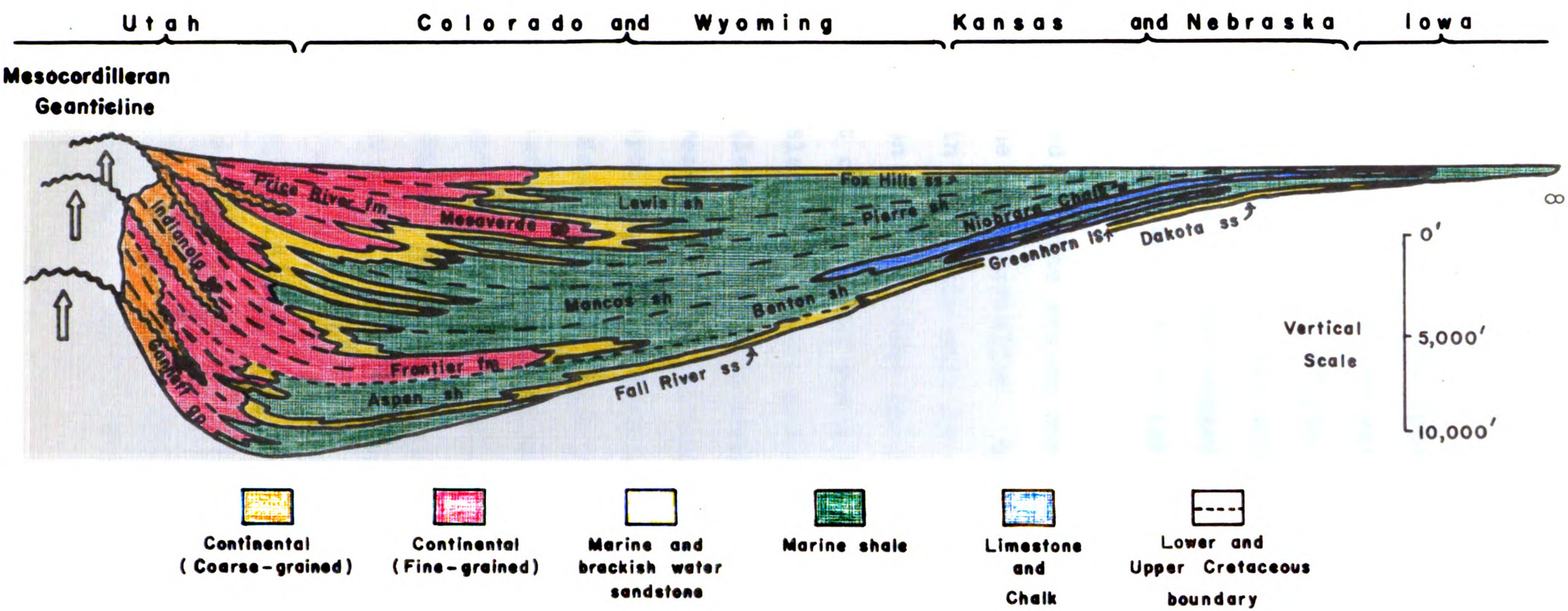
Lower Cretaceous

At the beginning of the Cretaceous period a large landmass of high mountains was present through eastern Utah and central Idaho. This landmass, called the Mesocordilleran Geanticline, was undergoing deformation. Directly to the east lay a geosyncline (Figure 2) which began receiving nonmarine, coarse, clastic sediments brought down the mountain slopes by stream action. These sediments extended eastward into Wyoming and the bordering states.

In the Powder River Basin the Lakota Formation was the first Cretaceous unit deposited. The lower portion of the formation thickens near the west flank of the Black Hills and is composed chiefly of conglomerates. The upper portion of the formation grades into lenses of sand and shale which makes it very difficult to distinguish from the overlying Fuson shale. Both the Lakota and Fuson Formations are of nonmarine origin and have been combined under a single name, the Lakota (Waage, 1958).

During the time the Fall River was being deposited, the sea began to advance from the north and south into the "Rocky Mountain" Geosyncline and did not retreat from the

STRATIGRAPHIC DIAGRAM OF CRETACEOUS DEPOSITION EAST OF THE CORDILLERAN REGION



after King, 1959

FIGURE 2

geosyncline until Fox Hills time in the Upper Cretaceous. The formation is predominantly a shallow-water, marine sandstone except around the southern end of the Black Hills where the sediments are of a terrestrial origin. The sand thickens toward the Black Hills, thus suggesting that the area was a positive feature like that of Lakota time (Crowley, 1951).

As the sea deepened, marine shales were laid down on the foreland shelf of the miogeosyncline. On the west side of the Powder River Basin the shale unit is called the Lower Thermopolis, and on the east side the Skull Creek. A large landmass northwest of the basin and a smaller landmass in the vicinity of the Black Hills were the main contributing source areas for the shales. During the middle of Thermopolis time, a small regression of the sea took place enabling sands and silts to be deposited. The Muddy sandstone and its eastern counterpart the Newcastle sandstone are interbedded with silts and shales caused by shallow water environment and shifting of the strand line due to oscillatory eustatic movement (Kohl, 1959). During this time a series of volcanoes along the Mesocordilleran Geanticline began erupting. Volcanic ash thrown high in the air was carried by westerly winds and deposited in the interior seas along with the accumulating sands and muds. Near the end of Thermopolis time the seas once again deepened and the deposition of fine, black organic clastics make up the upper portion of the Thermopolis shale formation.

At this time, the western volcanoes broke into violent explosive activity. Great quantities of ash were ejected into the atmosphere. Much of the ash fell into the sea and accumulated along with muds and was later consolidated into porcellaneous, siliceous rock known as the Mowry shale. During this same period, great quantities of tuff and agglomerates up to 1600 feet in thickness were deposited in southwestern Alberta exemplifying the extent of volcanic activity along the Mescocordilleran Geanticline. The glassy particles from each successive ash fall were decomposed to the clay mineral montmorillonite, producing beds of bentonite on the ocean floor. The top of the Mowry shale is marked by one of the most extensive bentonite beds deposited in Wyoming, the Clay Spur bentonite. The Clay Spur is readily observable on electric well logs and can be traced throughout the Powder River Basin and adjoining basins in the subsurface.

Upper Cretaceous

At the beginning of Upper Cretaceous time, the north and south embayments of the sea met in Montana and spilled eastward out of the Rocky Mountain Geosyncline onto the shelf area as far as Minnesota and Iowa. This deposition gave rise to what is now called, on the west side of the basin, the Frontier Formation and the Belle Fourche and Carlile Formations on the east side (Figure 3). Early Frontier sedimentation was similar to that of Mowry time with shales and

COLUMNAR SECTION IN NORTHEASTERN WYOMING SHOWING STRATIGRAPHIC POSITIONS OF BENTONITE BEDS

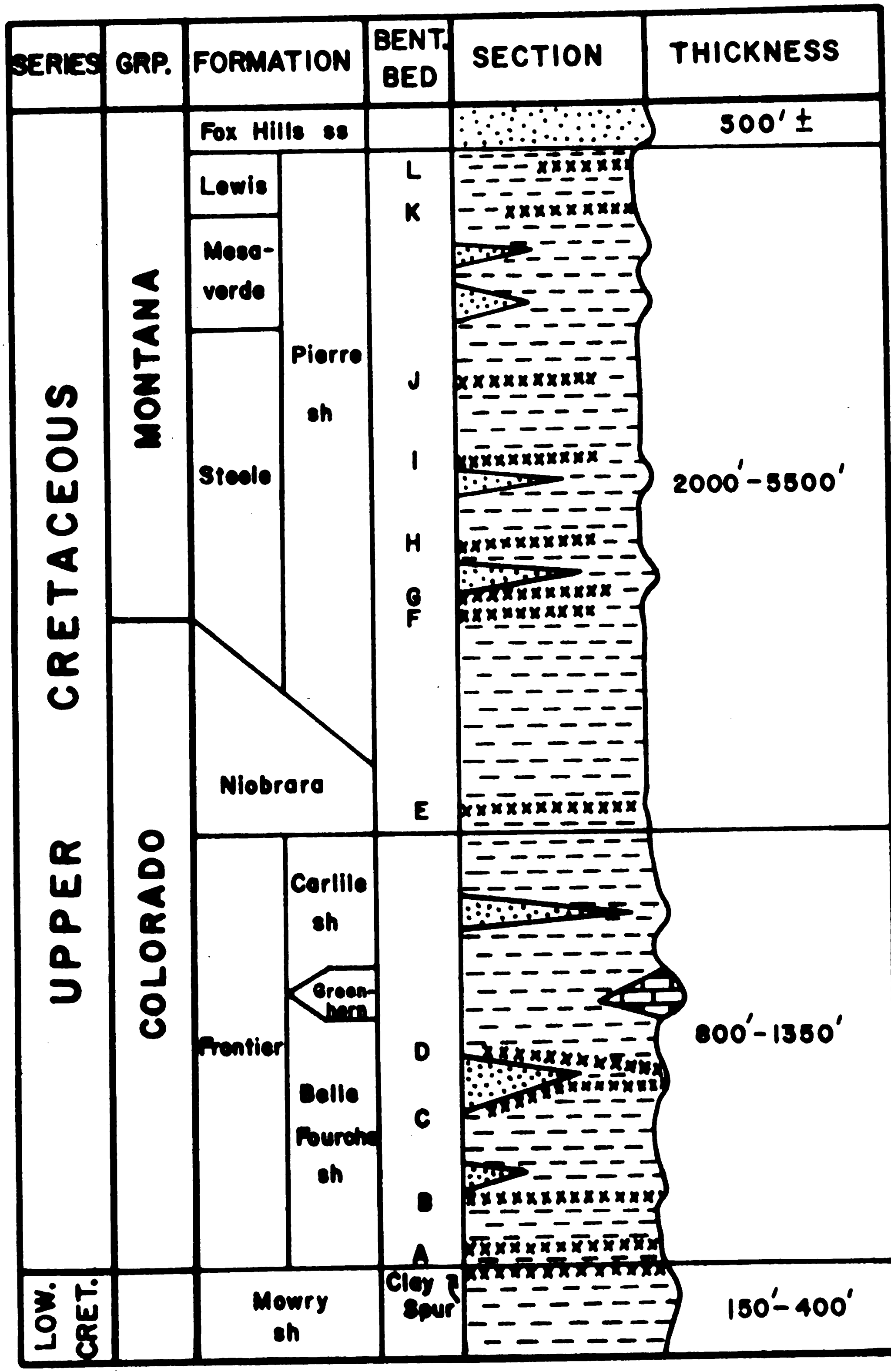


FIGURE 3

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bentonite beds being predominant. Bentonites "A" and "B" were deposited during this period (Figure 3).

Shortly thereafter renewed uplift began in the Mesocordilleran area. Streams transported deltaic sands eastward until they reached the interior sea, near what is today the western hingeline of the Powder River Basin. The first of these sands of significant importance, as to oil production, is called the Third Wall Creek sandstone member. Unstable condition involving land and sea caused an oscillating shoreline to prevail and the sands and shales became interfingered with one another; the shales being laid down with a small transgression of the sea. Two other times of rejuvenation during later Frontier time enabled two other sands to reach the sea; the Second and First Wall Creek members.

The Second Wall Creek sand lines between bentonites "C" and "D." Bentonites "C" and "D" carry very well along the eastern flank of the basin but are very difficult to trace along the western edge because of the shallow water that prevailed near the shoreline of the interior sea. Waves and currents reworked these ash falls and carried them to new locations.

The First Wall Creek, the youngest and most extensive Frontier sand, reaches across the basin and is often referred to as the Turner sand near the Black Hills. In the deeper waters to the east, shales were the predominant lithology during Frontier time. The Belle Fourche and Carlile shales are separated by the Greenhorn limestone. The limestone is best developed southwest of the Black Hills where it ranges from 175 to 240 feet thick. It grades westward into a calcareous shale which in turn grades into noncalcareous shale, then silt, and then the sand facies of the Frontier Formation. The limestone was deposited in a transgressive sea on the foreland shelf, thus indicating that the shelf area was relatively stable during Greenhorn time (Figure 2).

Above the Frontier Formation lies the Niobrara Formation. In eastern Wyoming, Kansas, and Nebraska, the formation is composed primarily of chalk. Delicate fossils remain unbroken and well preserved indicating the Niobrara sea was relatively deep and still, and an environment prevailed similar to that of Greenhorn time (Clark and Stearn, 1960). The Niobrara, like the Greenhorn, also grades westerly becoming more clastic as it approaches the Mesocordilleran Geanticline. Bentonite "E" lies near the base of the Niobrara and is found in the subsurface throughout most of the basin.

The interior sea deepened reaching its maximum extent, and thick beds of shales were laid down. This shale sequence is designated as the Pierre Formation on the eastern side of the Powder River Basin. The Pierre ranges up to several thousand feet in thickness and lies between the top of the Niobrara and the base of a marine sandstone termed the Fox

Hills. To the west the Steele shale is the lower equivalent of the Pierre Formation. Within the Steele are two interfingering sands. These sands show a rejuvenated uplift in the Cordilleran area, the last since Frontier time, are often referred to as being part of the Eagle Formation. The Shannon and Sussex sands, the latter being the younger, are thought to be 50 to 200 miles off-shore, deep water marine bars formed during Eagle time (Parker, 1958). Reeside (1957) has suggested that the seas were restricted during Eagle time and were only 200 to 400 miles wide and 1,000 to 2,000 miles long.

Two large volcanic ash falls produced bentonites "F" and "G" just before the Shannon sand made its way into the basin. Several other ash falls occurred after Shannon time and before Mesaverde time.

After a temporary shallowing of the sea during Eagle time, the sea again deepened depositing shales before it was again to undergo regression. The shallowing of the sea and a renewed westerly uplift allowed several more marine sands to make their way into the basin. In ascending order overlying the Steele shale, are the Parkman sand, an unnamed marine shale, and the Teapot sand, all of which make up the Mesaverde formation. The Parkman sand is traceable throughout most of the basin. The Parkman consists of both massive and thin-bedded marine and continental sands, coals, and thin, carbonaceous, gray shales along a transistional zone which parallels the present-day western hingeline of the basin. To the east the sands grade into marine silts and shales. The Teapot sand had a depositional pattern similar to the Parkman, but it is thinner and covered a smaller area.

The Cretaceous sea made its last advance before departing from the area during Lewis time. During this period, advance of the sea was very slow. Several minor regressions allowed the deposition of stray sands, but shallow water shales are the predominant facies depicting a littoral marine environment. The Lewis shale is merely a marine tongue of the Pierre shale. Bentonites "K" and "L" were deposited during this time, but are good marker beds only in the deeper waters along the eastern flank of the basin where deeper water allowed their preservation. The upper portions of the Lewis shale become silty and sandy.

Regression eastward and southward began at the end of Lewis time resulting in the deposition of the Fox Hills sandstone in a near-shore marine environment. The formation is composed mostly of dirty sandstones and silts and represents the last marine deposition in the basin. As the sea made its retreat toward the southeast, erratic shorelines developed; therefore, the formation transgresses time lines and becomes younger to the south. The Lance formation represents the uppermost Mesozoic strata in the basin. It is composed chiefly of continental sandstones formed following the withdrawal of the Cretaceous sea in the Powder River Basin.

The Fort Union represents the Paleocene Epoch of the Tertiary period. It is nonmarine and includes sandstones, clays, shales, and lignitic coals. Little break if any exists between the Lance and Fort Union formations. The Fort Union sediments were deposited on flood plains, and in swamps, and sloughs near sea level.

Summary

Briefly condensing the Cretaceous stratigraphy and sedimentation of the Powder River Basin will give the reader a clearer picture of the events that took place.

The opening of the Cretaceous period brought continental deposits of gravels, sands, and shales into the area occupied by the present-day basin. Both in the vicinity of the Black Hills and to the west the Cordilleran Mountains, supplied these terrestrial sediments to the area. An interior sea had been forming in the geosyncline, and by Fall River time the seas met from north and south. The sea continued to advance with periods of regression until Eagle time. During this period, volcanic activity was abundant along the Cordilleran mountains producing numerous beds of bentonite. Streams carried sands eastward into the sea to intertongue with shales caused by the oscillating shorelines. After Eagle time, regression took place with periods of transgression. Ash falls were not as common as early Upper Cretaceous time, but tongues of marine sands were abundant.

During Fox Hills time, the sea retreated to the southeast. The youngest Cretaceous formation, the Lance, was a flood plain deposit of terrestial origin. The Mesocordilleran Geanticline (Figure 2) a positive feature throughout most of the Cretaceous, was the chief source area for the clastic sediments found in the Powder River Basin.

REGIONAL TECTONICS

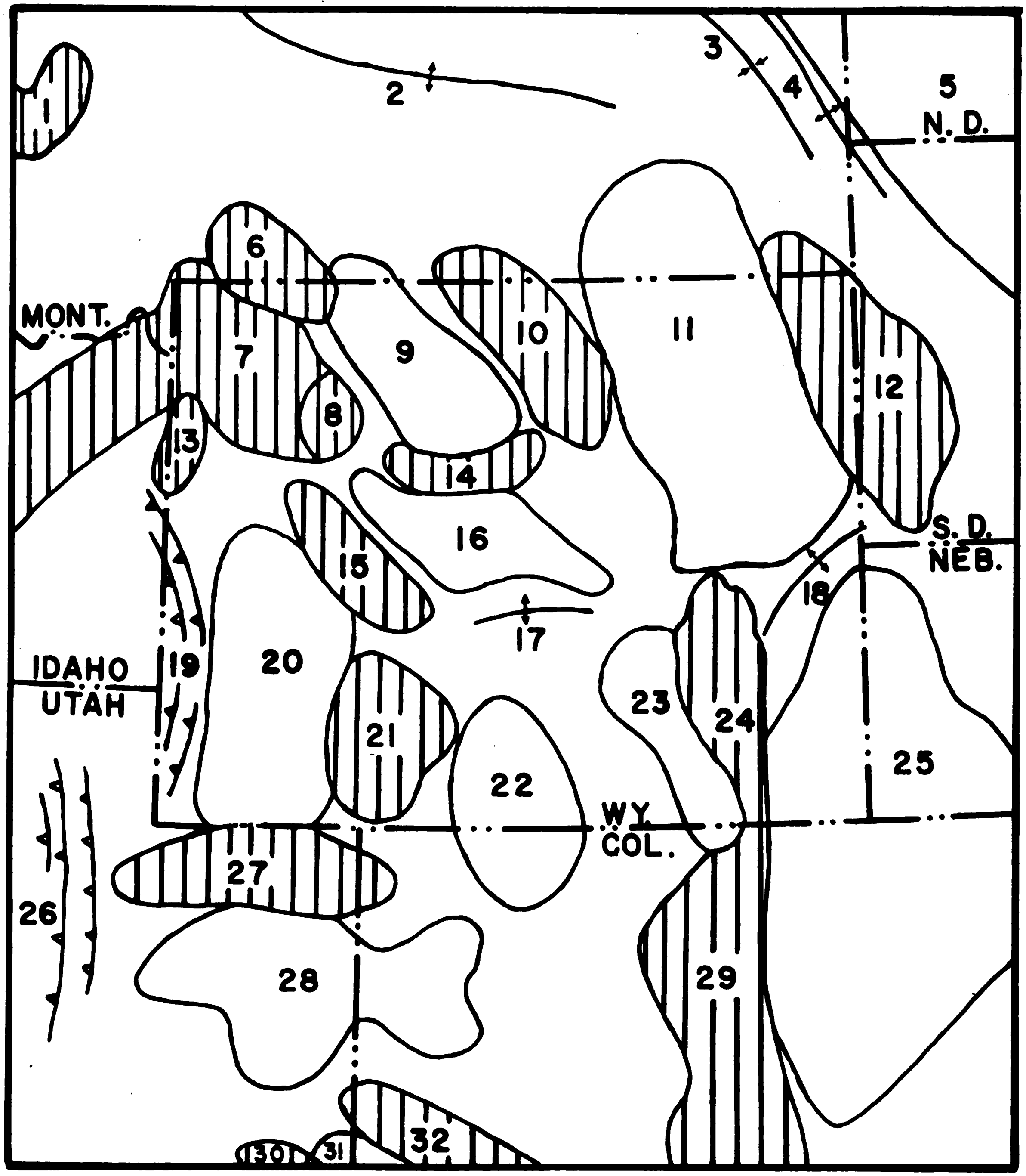
Introduction

The main tectonic features in Wyoming and its bordering states are shown in Figure 4. Two distinct trends can be recognized in the structural features. The Black Hills, Powder River Basin, Big Horn Mountains, Big Horn Basin, Wind River Mountains, all exhibit northwesterly trends between N30°W and N60°W. Southward; however, this northwesterly trend changes to a northerly trend. The other recognizable trend is from east to west, of which the Owl Creek Mountains, Wind River Basin, and Sweetwater Uplift are several good examples.

The origin of the structural trends is directly related to the basement complex. During the Precambrian Era, the crystalline rocks underwent a cooling process. Joint patterns developed from tensional stresses caused by the cooling. Tectonic forces created additional fractures and faults in the basement rocks. During the late Cretaceous, large compressional forces from the west were commencing. Fracturing and faulting of the crystalline rocks took place along planes of weakness, namely along the old joint planes. This could lead to a possible explanation as to the alignment of the tectonic features which make up the foundation of the present-day Rocky Mountains and intermontane basins produced from the "Laramide Revolution."

TECTONIC FEATURES

1. Idaho Batholith
2. Central Montana Uplift
3. Sheep Mountain Syncline
4. Cedar Creek Anticline
5. Williston Basin
6. Beartooth Mountains
7. Yellowstone Plateau
8. Absaroka Mountains
9. Big Horn Basin
10. Big Horn Mountains
11. Powder River Basin
12. Black Hills
13. Teton Mountains
14. Owl Creek Mountains
15. Wind River Mountains
16. Wind River Basin
17. Sweetwater Uplift
18. Hartville Uplift
19. Overthrust Belt
20. Green River Basin
21. Rock Springs Uplift
22. Washakie Basin
23. Laramie Basin
24. Laramie Mountains
25. Denver-Julesburg Basin
26. Wasatch Fault Zone
27. Uinta Mountains
28. Uinta Basin
29. Front Range
30. Monument Uplift
31. Paradox Basin
32. Uncompahgre Uplift



REGIONAL TECTONIC FEATURES

UPLIFTS BASINS

Scale : 1" = 80 miles

FIGURE 4

The Rocky Mountains at one time were thought to be the product of a single and intense orogeny called the Laramide Orogeny. This disturbance was thought to have occurred at the close of the Cretaceous or during the beginning of the Tertiary. Geologists have more recently discovered a succession of orogenic events through late Mesozoic and into Tertiary time. Eardley (1962) has devised the following nomenclature for the Laramide disturbances:

1. Orogenic events during Montana time--Early Laramide
2. Orogenic events during Paleocene time--Mid Laramide
3. Orogenic events during Eocene time--Late Laramide

Wyoming has been divided into three areas; western, central, and eastern, in order to show the tectonic movements in different localities of the state.

Western Wyoming

In western Wyoming, a number of thrust faults are noted (Figure 4). This deformed belt had moved eastward, and the north end moved northeastward. These thrust faults were probably formed during late Montanan or early Paleocene time (Eardley, 1962). Also during the same time, the Beartooth Range and the Wind River Range began to form (Eardley, 1962). Orogeny continued into the Paleocene creating the Unita and Rock Springs uplifts for the first time. Directly south of the newly forming Unita Range, thick sediments were accumulating indicating the beginning of the Unita Basin. The Eocene Epoch brought an acceleration of orogeny to the area.

The Wind River Range rose along high angle thrust faults, and the Uinta Mountains received their chief growth late in Eocene time. Thick sendiments were accumulating in depressions such as the Green River and Unita basins. Volcanism broke out in northwestern Wyoming in late Eocene time. The time of the main orogeny would be between the angular unconformity of the Wasatch and White River formations (Eocene-Oligocene); in other words, "Late Laramide."

Central Wyoming

Central Wyoming was tectonically active during Montana time. Eardley (1962) shows a thinning of sediments around the west side of the Big Horn Mountains and around the Owl Creek Mountains. During the Paleocene Epoch, faulting and thrusting occurred along the southern side of the Owl Creek Mountains. Sediments began filling two downward flexures, the Wind River Basin and the Big Horn Basin. The Sweetwater Uplift rose during this time. Eocene time was similar to that of the Paleocene. Mountains continued to rise and basins continued to sag, thus receiving more deposition. However, the Sweetwater Uplift underwent severe erosion in Paleocene time and was thoroughly eroded by early Eocene and then sank appreciably in late Eocene time. An unconformity between the Fort Union and Wasatch formations (Paleocene-Eocene) places the orogenic activity to be "Mid Laramide" in central Wyoming.

Eastern Wyoming

In eastern Wyoming, it is difficult to establish any particular time for orogenic deformation, however, if a probable period of orogeny is to be established, it would be between the Wasatch and White River formations (Eocene-Oligocene), giving a "Late Laramide" orogeny to the area.

Summary

Nearly horizontal thrust faults formed, along which rocks slid tens of miles eastwardly due to compressional forces from the west. This created an asymmetrical mountain and basin pattern. The mountains have a gentle slope on the west side and plunge steeply to the east. The basins are just the opposite, as one would expect. Their western flanks are the steepest. Therefore, the anticlinal axes are on the eastern side of the features and the synclinal axes on the western side of the basins. This holds true only to those features that trend north to northwest.

STRUCTURAL DEFORMATION IN AND AROUND THE POWDER RIVER BASIN

The structure of the Powder River Basin and its surrounding features formed from the Laramide Orogeny will be considered next. Plate 7 is a structure contour map contoured on the Clay Spur bentonite, from some 400 electric well logs. The dashed lines represent the approximate outcrop pattern of the Clay Spur.

The asymmetrical character of the basin is clearly shown on Plate 7. The synclinal axis is located near the west flank of the basin and runs in a northwesterly direction. The axis of the syncline plunges toward the central portion of the basin from both the northwest and southeast and the axial plane dips steeply to the southwest in the direction from which the orogenic forces originated to produce the structure of the basin. The northeast limb of the syncline has a rather uniform dip averaging about 100 feet per mile. However, the southwest limb is more complex. In the south, the general rates of dip average 500 feet per mile increasing northward to an average dip of 2,500 feet per mile.

Surrounding the basin is a distinct hingeline. The eastern and southern hingelines are more pronounced. Orogenic features are more abundant on the western side rather than along the eastern side of the basin. Because of the large contour interval (500 feet) on Plate 7, only the largest anticlinal structures are shown. Two of the closed anticlines, Kaycee Dome in T43N, R82W, and Tisdale Dome in T41N, R81W, have reached heights high enough to allow erosion to expose the Thermopolis interval.

In the southwestern portion of Plate 7, southwestern Natrona County, the eastern edge of the Wind River Basin can be seen. A complexly folded belt of closed anticlines and synclines separates the Wind River Basin from the Powder River Basin. Detectable within this folded belt is an undulating anticlinal axis trending northwest-southeast from T38N, R83W, to the Clay Spur outcrop in T34N, R82W.

East of the Laramie Range is a broad structural uplift called the Hartville Uplift. This feature trends in a northeasterly direction and separates the Powder River Basin from the Denver-Julesburg Basin. Along the flanks of the uplift, the Clay Spur outcrops because of erosion during and after the "Laramide Revolution."

The main fold axes of the intermontane basins roughly parallel those of the adjacent mountains. This is illustrated on Plate 7 as the Powder River Basin's synclinal axis parallels the anticlinal axes of the Big Horn Mountains and the Black Hills. The major structural features of the basin, as previously mentioned, formed during the Laramide Orogeny. During the orogeny, three structural trends developed in the region. The Black Hills, Powder River Basin, and the Big Horn Mountains trend in a northwesterly direction around N30°W. The second structural trend is found in the Laramie Range which lies in a northerly and northwesterly direction. The northeasterly trending Hartville Uplift, gives evidence to a third deformatory force to the area.

The structural asymmetry of the features was created by the orogenic forces originating from areas to the west acting normal to the present trends. Several large overthrusts, one located along the eastern flank of the Big Horn Mountains, and several others along the nothern boundary of the Laramie Range, add additional support that multiple deformatory forces produced the regional structure. Some deformation took place at the close of the Cretaceous around the Hartville Uplift. An angular unconformity exists between the folded and eroded pre-tertiary sediments and the relatively flat-lying Tertiary beds over them.

Looking briefly back to the late stages of the Laramide Orogeny in Wyoming, the streams drained eastward carrying sediments into the intermontane basins. The basins became so filled that the surrounding mountains were nearly submerged. Regional uplift in late Miocene or early Pliocene time caused a regime of erosion over the graded surface giving Wyoming the topography we see today (Eardley, 1962).

STRUCTURAL HISTORY OF THE POWDER RIVER BASIN DURING UPPER CRETACEOUS TIME

Twelve time-rock units, bentonites, subdivide the Upper Cretaceous into 11 segments (Plates 8-18) so an accurate account of deposition, as related to structure, can be shown and explained. The Upper Cretaceous is divided into the lower Colorado Group and the Montana Group.

Colorado Group

At the end of Mowry time (Lower Cretaceous), abundant volcanic ashes fell into an interior sea which covered the Powder River Basin locality. The bentonite bed formed during this extensive ash fall is named the Clay Spur bentonite, after outcrops found along the Clay Spur siding of the Chicago, Burlington, and Quincy Railroad (Knechtel and Patterson, 1962). The Clay Spur carries very well throughout the region and could be detected in almost every well log that penetrated this horizon.

Plate 8

Plate 8 is one of eleven isopach maps made between various bentonite units. The sedimentary unit between the Clay Spur bentonite and bentonite "A" in Plate 8 averages 50 feet in thickness. The isopached interval consists mostly of bentonitic shales. A definite increase in thickness is found on the northern flank of the Laramie Range. The Laramie Range had to be a negative feature during this time. Sedimentary thickness also increases toward the west and northwest indicating that the Big Horn Mountains were not in existence at that time. A different picture; however, exists approaching the Black Hills and the Hartville Uplift. Although it is difficult to say for certain if these features stood above sea level during this time, because erosion has since eroded the Cretaceous sediments from the crests of these features. However, these areas must have been slightly positive to cause a thinning of deposition. A thinning of sediments over a feature does not necessarily mean a rise in the sea's floor, but could merely be distant enought from any source areas not to receive as much sedimentation as the surrounding areas. Figure 5 shows a tectonic chart of the orogenic pulsations in the surrounding structural features of the basin.

Some minor orogenic effects occurred within the basin itself. In T40N, R79W, a thinning is found indicating an anticlinal bulge in the ocean floor. This is in the general vicinity of the present-day Salt Creek Anticline and the Tisdale Dome. Although well data are sparse in the center of the basin, because depths of 10,000 feet or more are necessary to encounter these horizons, the north-central portion of the basin has been contoured showing a thinning of sedimentation. There are two possible explanations of the thinning: first, if this area was a broad upwarp, one would expect less deposition over a high, but a more probable explanation is that this region was distant enought from contributing source areas.

Several wells show abnormally thick sections as compared with the surrounding wells. In T49N, R67W, Kohl (1959) noted this thickening in isopaching the Thermopolis interval, but suggested that high angle reverse faulting was the answer because of the absence of thickening higher in the section. This is partially disproven by examining the series of isopach plates made higher in the section. Reverse faults do tend to have their maximum displacements with increased depth, and this could well be a reverse fault, but slippage definitely occurred throughout Colorado time to provide a continual accumulation of thicker sediments in this area.

In central Niobrara County, a similar situation occurs along the Lance Creek fault. Thicker sediments also occur upwards in the section, but because of non-deposition of the bentonites or shallow waters destroying them, they could not be traced through Montana sediments. The southern extension of the fault in the Lance Creek area is inferred by dashed lines, but the abrupt hingeline as seen on Plate 7 in T34N, R65W, helps to support evidence as to the possible existence of a fault that may have been rejuvenated during the Laramide orogeny. There are other irregularities in the thickness of sediments, but this can be explained as merely the irregularity of the sea floor.

The last point of interest exists in the southern portion of T31N, R81W, where thicker sediments are encountered. Faulting is the probable explanation, and a fault was therefore inferred as the cause of this local thickening of sediments. The reason that these three areas have been presented is to illustrate that minor diastrophic action occurred before or during Clay Spur time and continued at least through Colorado time.

Plate 9

The separation between bentonites "A" and "B" make up the next isopached interval (see Figure 3 for stratigraphic positions of bentonites). As in Plate 8, the sediments increase in thickness upon nearing the Laramie Range and the Big Horn Mountains making these features still negative. This seems reasonable enough, because bentonite "B" lies shortly under the Third Wall Creek sandstone which made its way into the basin from about the same direction a short time later. In the extreme northwest portion of the plate, however, a definite thinning takes place as compared to the previous plate.

One of the most interesting features occurs in Weston County where the 100 foot isopach contour is broken up by thinner areas traversing it. These elongated, local highs (areas of less deposition) overlie the area of deltaic, oil-bearing Newcastle sands that were deposited in shallow marine waters west of a landmass in the vicinity of the present-day Black Hills. This can also be detected on Plate 8, though it is not as well defined because of the smaller isopach interval.

The Black Hills and the Hartville Uplift show a thinning toward them as was the case in the previous plate. Thick sediments are found in T49N, R67W; the Lance Creek area in Niobrara County, and in T31N, R81W, suggesting the continuing growth of these faults keeping up with the rate of sedimentation. If these faults did not continue to grow, the rate of sedimentation would soon fill the downward side and soon there would be an absence of a local thickening of sediments. In T29N, R82W, an abnormal amount of sediment is present. Kohl (1959) found this thickening in the Thermopolis interval and said that it was lacking upwards in the column. He was partially correct, because Plate 8 does not show any thickening whatsoever, but had he gone higher in the section, he would have found the thickening shown in Plate 9. This is an excellent example of the reoccurrence of faulting through geologic time. During the interval of Plate 8, sedimentation filled the depressed area while the fault was dormant or in nearly a dormant stage. Another fault was active during this time in T43N, R79W, and exhibits a continual growth upwards in the column. During this period some minor deformation occurred as shown by the continual growth of three faults and the appearance of two new faults.

Plate 10

In this plate bentonites "B" and "C" were used. Bentonite "B" is found shortly under the Third Wall Creek sandstone and bentonite "C" is found underlying the Second Wall Creek member. These time-rock markers, therefore, represent the period in which the Third Wall Creek was deposited during a slight shallowing of the sea. The majority of sediments came in from the Cordilleran region. This suggests that the Big Horn Mountains were submerged in order to allow the sediments to pass over this feature.

It is interesting to note that a thick tongue of silts and shales extends southeast from the Big Horn Mountains. Goodell (1962) shows a similar tongue on his isopach maps that corresponds to the 200 foot contour on this plate. The irregular shoreline during this time was the probable cause for this feature. If coareser clastics had been found around the flanks of the Big Horns, they would have suggested a possible source area for such a tongue of silts, but this was not the case.

The Laramie Range continued to remain submerged. The Hartville Uplift was again a positive feature as a thinning was detected on its eastern flank in T25N, R65W. The Black Hills, however, show the first pulsation change of the main geologic features as the sediments thicken toward it. In the extreme north portion of the plate, T57N, R68W, the sediments attain thicknesses over 300 feet. Undoubtedly, these fine clastics spread into the region of the submerged Black Hills. Since the pattern of sedimentation has changed in the east from the previous two plates, it is now difficult to ascertain a thinning over the deltaic Newcastle structures. Several thinner sections do occur as shown by the 200 foot contour, but these do not exactly overlie the trends but a similarity does exist. The center of the basin has the thinnest sediments because of its distance from the north, west, and southerly source areas.

Growth faulting continued during this time, and the previously mentioned faults continued to receive abundant sediments on their downthrown sides. The fault located in T29N, R82W, shows little increase in sedimentation as compared to the adjoining area. It probably was dormant during this time, and the sediments were continuing to fill up the large depressed area caused by the large slippage that occurred during the time of sedimentation of Plate 9.

Plate 11

The interval between bentonites "C" and "D" are illustrated in this isopach plate. On the western side of the basin, the interval is composed mostly of sands from the Second Wall Creek sand of the Frontier Formation grading eastwardly into deeper water shales. Sedimentation was generally from a westerly source, and several tongues of sand and silts are found along the western hingeline. The bentonites are readily traceable along the eastern flank of the basin, but along the western edge they are very difficult to trace regionally. A western shoreline of the interior sea prevailed through what is now the western flank of the basin. The shallow waters disturbed the depositional characteristics of a deep sea environment like that on the eastern flank of the basin, and thus caused a random distribution of the bentonites.

The Big Horn Mountains and the Laramie Range continued to remain submerged as shown by a thickening of sediments toward these features. Bentonites "C" and "D" could not be traced into the Denver-Julesburg basin, and the surrounding wells were too distant to be of any use, therefore, preventing any solution as to how the Hartville Uplift reacted during this time.

The Black Hills have again changed their pulsating nature. A marked thinning occurs in Weston County, where the two bentonites actually merged forming one thick bed of bentonite. East of where the bentonites merged, bentonite "D" could no longer be traced. Because of the regional extent of bentonites, the abruptness in the termination of this bentonite is not likely caused by nondeposition, but rather by erosion, namely sub-aqueous erosion. The Black Hills were probably just below sea level during this time and fine clactics remained in the area. This pulsation ties in with the uplifting of the Cordilleran mountains that supplied the Frontier sands at this time. During Second Wall Creek time, a minor regression of the sea prevailed, and with a small uplift in the Black Hills area allowed this feature to attain an elevation above wave base where wave action took over and destroyed the deposition of bentonite "D."

Growth faulting was not as abundant during this time and only a thickening in T49N, R67W, indicates a continuing growth of this fault.

Plate 12

Sands, silts, and shales constitute the facies interval between bentonites "D" and "E," the silts grading into shales eastwardly. Sedimentation once again rapidly thickens upon nearing the present northern flank of the Laramie Range, indicating submergence. The Big Horn Mountains make their first rise in the Upper Cretaceous during First Wall Creek time. A remarkable thinning occurs nearly parallel to the outcrop pattern, thus suggesting an upwarping feature with the same relative eastern outline as today's feature. Local uplifting and a minor regression of the interior sea placed the Big Horn's above sea level during this time. Hunter (1950) indicates local uplifting in this region because of chert pebbles and andesite porphyry pebbles found within the Frontier Formation. The chert pebbles contain fossils of Mississippian and Pennsylvanian age. On the western side of the mountains, some large andesite cobbles were found indicating transportation was from western Wyoming and Utah.

The northwestern portion of the Black Hills shows a thickening of deposition this time and a negative nature is inferred. Paralleling the Black Hills is an asymmetrical anticlinal fold, T53N, R71W, and a detailed isopach of the area would undoubtedly show the asymmetry of this feature much better with the steep side facing the Black Hills. This feature is very similar in trend and asymmetry to the Black Hills and Big Horn Mountains, which were formed later by the Laramide Orogeny, and therefore suggests early deformatory forces originating from the west. The Hartville Uplift cannot be resolved as to orogenic movements during this time or later because of the distant well coverage and lack of bentonite control.

Growth faulting was reactivated and can be found in T49N, R67W; Lance Creek area; and T42N, R80W. Orogenic disturbances were abundant throughout the basin during this time. Local highs and lows, the orogenic changes of the Big Horn Mountains and Black Hills, the formation of an asymmetrical anticlinal fold formed from westerly forces, the recurrence of faulting, and the renewed uplifting in the Cordilleran mountains enabling the First Wall Creek sand to reach the basin; are all examples of the orogenic movements that took place during this particular period of time.

Plate 13

Much sedimentation occurred between the base of the Niobrara formation and the base of the Shannon sand. This is well illustrated upon examining the cross-sections of the basin (Plates 5 and 6). The sediments thicken uniformily toward the west indicating a westerly source and subsidence. Within this interval, bentonites could only be correlated over short distances, eliminating any regional correlations. Bentonite "F" underlies the Shannon sand and carries extremely well along the southwestern hingeline of the basin. Because of the distribution of this bentonite, the orogenic activities of the Hartville Uplift and Big Horn Mountains could not be established. However, Parker (1958) noted the Hartville and Lance Creek areas to be positive during this time, but returning to a negative status throughout Montana time.

The isopach contour lines are normal to the northern flank of the Laramie Range, making this feature negative. If the contours had been diverted, this would have placed the Laramies into a positive category. It is difficulty to determine the nature of the Black Hills because of the regional thinning toward the east. Shallow marine waters may possibly have existed in the region because of the fairly abrupt termination of bentonite "F."

An anticlinal feature formed in the area of the present-day Sussex anticline in T42N, R78W, caused nearly a 200 foot sedimentary thinning over it. This feature is a northwesterly trending anticline and is parallel to the distribution pattern of the area. Sources to the southwest are indicated by the sedimentation, and forces acting normal to the anticline would have also originated in the same general area. Two of the previously mentioned faults, T49N, R67W, and T42N, R80W, continued to move. Displacement along the Lance Creek fault and the fault in T31N, R81W, could not be determined due to the areal distribution of bentonite "F." However, upon observing cross-section H-H' on Plate 6, log H-4 shows a large thickening of sediments between bentonites "E" and "K" indicating faulting continued to be active during this time of deposition.

Montana Group

Plate 14

This plate involves one of the shortest geologic time intervals of all the plates. Bentonites "F" and "G" average about 20 feet of separation between them so deformatory effects will be small during this short time period. Sediments again thicken towards the Laramie Range. The Big Horns had a positive status as the two bentonites were found nearly merging with one another upon approaching the east side of the feature. The Black Hills were undergoing submergence during this time. The northern portion of the basin remained stable, and the basin began to subside causing a thinning of sediments to the north.

The only faulting that could be interpreted was in T49N, R67W. Growth faulting may have continued during this period in many of the old faults, but the small time interval prevents these features from being shown as they might over a larger period of time. About 12 miles northeast of the town of Gillette, a northwest-southeast thin occurs. This thinning coincides with the asymmetrical anticline that was shown on Plate 12.

Plate 15

A westerly source area again contributed sediments into the region. Sediments thicken regionally to the west; although, thickening does occur near the Laramie Range. It is becoming difficult to give the geologic features surrounding the basin a positive or negative classification because of distant bentonite distribution. Sedimentation thins northward, as it also did in Plate 14.

Northeast of Gillette a sedimentary thinning again occurs over the asymmetrical anticline that first formed during the sedimentary interval which made up Plate 12. Renewed uplift of this feature caused the marine sediments to continue to thin over it. The reappearance of the Sussex anticline in T42N, R78W, occurred during the interval between bentonites "G" and "H." South of this anticline, a long north-south trending upwarped flexure occurs parallel to the present western hingeline. This flexure and the Sussex anticline are no doubt related to each other; producing a long anticlinal fold over 60 miles long.

In T42N, R80W, faulting has recurred. The well on the upthrown side has nearly 200 feet of sediments missing as compared with the downthrown. Orogenic deformation was beginning to build up during this time and preparing for the main deformation of the Laramide Revolution yet to come.

Plate 16

Mapping is becoming more restricted toward the center of the basin because of the outcropping of bentonites away from the hingelines. Bentonites "H" and "I" are the lower and upper time-rock boundaries which separate the sedimentary interval isopached on Plate 16, and the time interval includes the Sussex sand deposition. Increases in sedimentation are found nearing the Big Horn and the Laramie Range, suggesting negative positions of these structures. Sedimentation thins to the east and the north and thickens uniformily toward the southeast supporting renewed uplifting in the north.

Growth faulting continued in T42N, R80W. Over the Sussex field, T42N, R78W, a sedimentary thinning is present. This thin does not exactly overlie that of previous time, but it definitely suggests that deformation was taking place in this area with the upwarping of anticlinal features along with faulting.

In the southern portion of Plate 16, T33N, R77W, another thin section has originated. The structure corresponds to the present-day Muddy Creek field and may well be the birth of this anticlinal field during this time. A thinning is also observed over the present Glenrock field in T33N, R75W. It seems that some of the present anticlinal structures around the hingeline of the basin were beginning to form before the great deformation took place that produced the configuration of the sediments that we see today.

Plate 17

Thinning occurs along the east and west flanks and to the north. The basin must have begun its embryonic stage of development during this time, because the thickest sediments occurred in the center of the basin. Plate 16 shows basin formation beginning, but in the following plate the basin is much better defined.

The northern portion of the Black Hills may have risen very slowly with the regression of the sea and supplied a tongue of fine clastics in T46N, R68W. The Laramies were negative during this time, but deformatory forces to the south may have produced an east-west fold along the northern flank of the range. This broad fold is remarkable parallel to the thrust faults that were produced during the main orogeny.

Once again in the vicinity of the Sussex field sediments thin over 100 feet. Deformation continued in this area as nearly 100 feet of sediments accumulated on the downthrown side of the fault just west of the Sussex field.

Plate 18

The deposition of the Mesaverde formation occurred between the interval of bentonites "J" and "K." Thinning again occurs to the north, but the basin seemed to undergo a slight upwarping; the isopach contours bend southward in the center of the basin, allowing sedimentation to be somewhat greater on the flanks.

The Laramie Range remained submerged, as it had been throughout the Upper Cretaceous, and the anticlinal fold to the north continued to cause a depositional thinning, though not as great as when it originated. Deformation continued to increase in the Sussex area as four separate structures became present during this time. Faulting could well be implied to aid in the abrupt changes in deposition in the Sussex region.

Growth faulting again continued west of the Sussex area in T42N, R80W. This fault has been very active through most of the Upper Cretaceous beginning with the isopached interval in Plate 9 up through Plate 18. This illustrates that the basin was undergoing orogenic activity throughout Upper Cretaceous time, and that many features appeared and disappeared showing the unstable conditions that prevailed in the earth's crust during this period of geologic history in the Powder River Basin.

Bentonites "K" and "L" represent the last interval that was mapped. However, bentonite "L" could be traced only along the central-eastern portion of the basin because of the shallow waters that began to prevail because of the shallowing of the sea. A regional thickening of sediments toward the south was noted. A local thinning was also noted in the southern portion of T39N, R65W. A small flexure formed during the sedimentary interval which made up Plate 18, was found about two miles southwest of this thin, thus showing some deformational activity in this area. But because of the small area capable of being mapped, a plate was therefore excluded. Correlating bentonites higher in the section would be nearly an impossible task because of shallow waters and terrestrial deposition that prevailed.

Figure 5 is a tectonic chart showing how the structural features around the basin reacted during the Upper Cretaceous. This section of the study has provided a structural history of the tectonic events that took place before the "Laramide Revolution" during the marine Upper Cretaceous in the Powder River Basin, Wyoming.

TECTONIC ACTIVITY DURING UPPER CRETACEOUS TIME IN THE POWDER RIVER BASIN

SERIES	FORMATION	MESO-CORD. SOURCES	PLATE NOS.	BENT. BEDS	BIG HORN MTNS.	LARAMIE RANGE	HARTVILLE UPLIFT	BLACK HILLS
UPPER CRETACEOUS	Lewis			L–K	?	?	?	↑
	Mesa-verde		18	K–J	↓	↓	?	↓
	Steele		17	J–I	↑	↓	?	↑
	Steele		16	I–H	↓	↓	?	↑
	Steele		15	H–G	↓	↓	?	↑
	Steele		14	G–F	↑	↓	?	↓
	Steele / Niobrara		13	F–E	?	↓	* ↑	↑
	Frontier		12	E–D	↑	↓	?	↓
	Frontier		11	D–C	↓	↓	?	↑
	Frontier		10	C–B	↓	↓	↑	↓
	Frontier		9	B–A	↓	↓	↑	↑
	Frontier		8	A–C.S.	↓	↓	↑	↑

* Parker, 1958

FIGURE 5

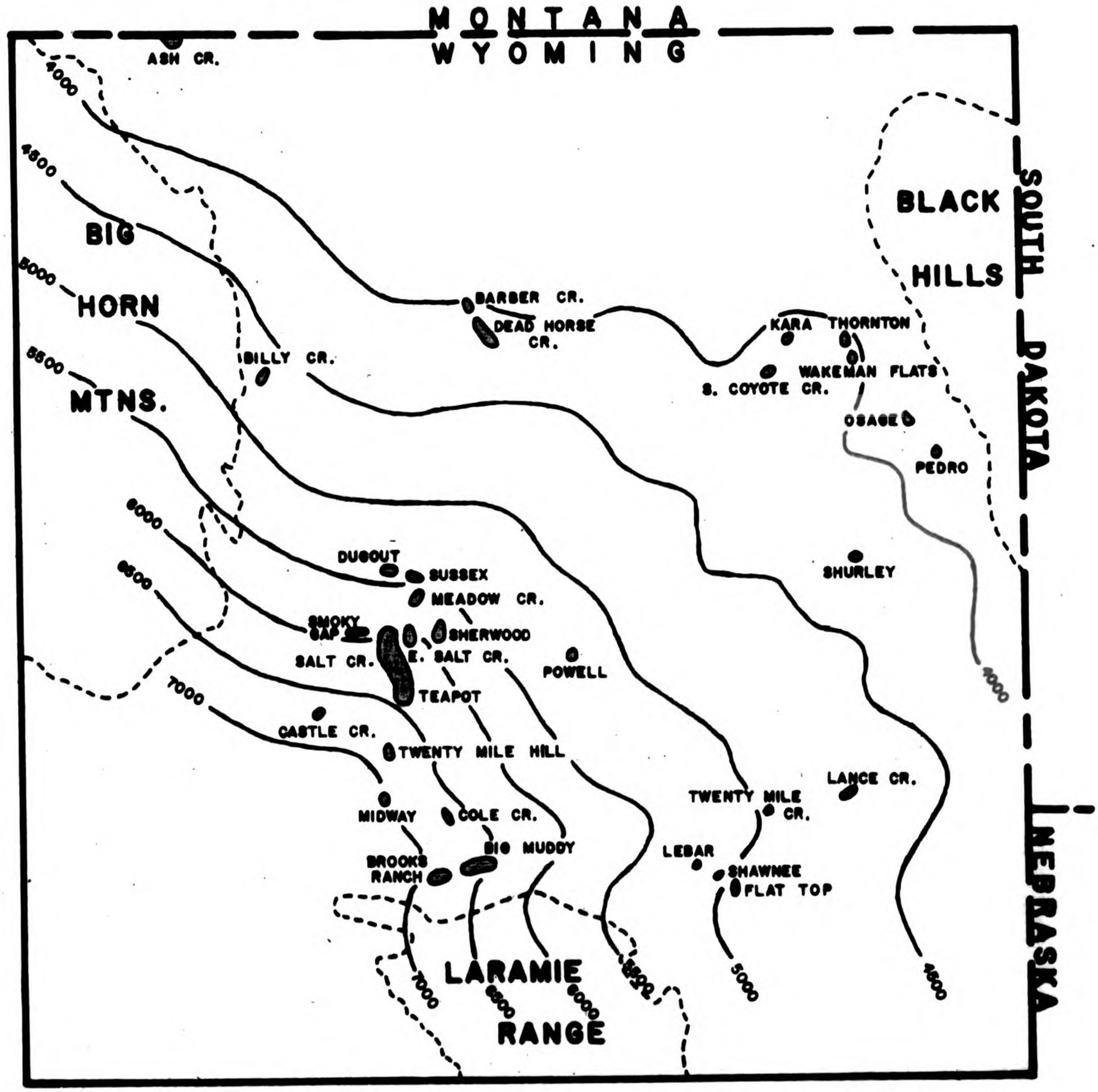
RELATIONSHIP OF UPPER CRETACEOUS TECTONICS TO POSSIBLE OIL OCCURRENCE

Strickland (1958) has devised an isopach map of the marine Upper Crataceous in the Powder River Basin and outlined the oil and gas fields producing from these rocks (Figure 6). He noted that there was no apparent relationship between the thickness of sediments and the distribution of fields; "the principal controlling factors controlling accumulation being the sand-shale quantity relationship of certain intervals, off-shore and shore line deposits of others, and Laramide structure." However, in this study the Upper Cretaceous was broken down into eleven time-rock intervals and several fields definitely show accumulation as related to Upper Cretaceous tectonics. The following fields are: Thornton, Lance Creek, Bid Muddy, Sussex, and Dugout.

Assuming that oil migration and accumulation takes place soon after deposition, then it seems reasonable that it must also be trapped early in its history or else it would have escaped from any given area. A minority of oil; however, may be generated over long periods of time after the initial amount of oil has evolved.

The Thornton field lies about 4 miles east of the fault in T49N, R67W. This field is associated with the stratigraphic nature of the Turner sand (First Wall Creek equivalent),

UPPER CRETACEOUS OIL OCCURRENCE IN THE POWDER RIVER BASIN, WY.



Isopach of Upper Cretaceous - top "Lewis" to top of "Mowry"

Contour Interval = 500 feet

(Adapted from Strickland, 1958)

FIGURE 6

and is bounded on its northwest side by a fault that is very similar to the one previously mentioned. Oil is found on the downthrown side, and the deeper waters on the low side provided the necessary conditions for the accumulation of the oil with the sand-shale facies. Faulting was noted with the beginning of the Upper Cretaceous (Plate 8) and became very common during First Wall Creek time (Plate 12).

The Lance Creek field in T35-36N, R65W, produces oil from several horizons, which includes an equivalent sand at the base of the Carlile to that of the First Wall Creek sand in other areas of the basin. Here again orogenic deformation was abundant during this time, and faulting produced a trap for the oil on the upthrown side. Shallow water conditions may have prevailed on the upthrown side causing the deposition of a sandy horizon in the Carlile shale. The actual folding of the faulted anticlinal structure occurred during pre-Oligocene time, because the White River formation (Oligocene) unconformably overlies the Lance and older beds (Emery, 1929).

The Big Muddy field is located in T33N, R76W, and the trap is associated with an anticline and permeability barriers. Both the Shannon (Plate 15) and First Wall Creek (Plate 12) are the productive zones in the Upper Cretaceous. During Shannon time, the southern portion of a north-south anticlinal fold existed over the field, and this may have caused early migration and accumulation of oil in the area (Plate 15).

Plate 16 shows an east-west fold present, thus enabling conditions to prevail for the continuation of migration and oil accumulation.

The Sussex field in T42N, R78W, is bounded on the southwestern edge by a large fault, and numerous normal faults traverse the field from southwest to northeast. The field produces from the Second (Plate 11) and First (Plate 12) Frontier sands, the Shannon sand (Plate 15), the Sussex sand (Plate 16), and the Parkman sand (Plate 18). Plate 12 is the first plate to show a thinning in the area. Plates 15 and 16 show deformation more abundant during this time, allowing faulted structural features to collect littoral sands over and around them, shortly thereafter making excellent traps for Shannon and Sussex oils. Deformation became even more abundant during Mesaverde time (Plate 18) and similar conditions, as to those mentioned above, allowed the Parkman sand to become a source of oil.

The Dugout field, located in T43N, R79-80W, produces from the Shannon sand on the downward side of the fault. Shannon sands filled into this depressed area and oil migrated up against the pre-existing fault which formed a trap. Other fields may also be related to Upper Cretaceous tectonics, but more detailed mapping would be essential to show any of these relationships.

"It is evident from the preceding discussion that although oil accumulation in the Powder River Basin is related to a sequence of past geological events occurring episodically throughout geologic history, the present accumulations are the result of relatively recent gravitational adjustments to the final structural configuration except as modified by hydrodynamic conditions" (Strickland, 1958).

CONCLUSIONS

The Cretaceous Period opened in the Powder River Basin with the deposition of coarse, continental flood plain deposits on a foreland area. The Cordilleran mountains, west of the basin, and the Black Hills, lying east of the basin, were the contributing source areas responsible for this deposition. Interior seas began to encroach into the area, and with a continuing subsidence, sea waters from north and south met in Montana.

The Upper Cretaceous seas laid down thick sequences of marine shales caused by the continuing subsidence of the area. Minor regressions of the sea occurred throughout this time allowing sands to make their way from the Cordilleran area into the basin. Regression of the sea took place with the termination of subsidence in the area, and by Lance time the seas had receded from the basin in a southeastwardly direction. The close of the Cretaceous marks the beginning of deformation that produced the basin and range systems in the Rocky Mountain states we see today. This deformation period is commonly known as the "Laramide Revolution."

As seen from the text, though, deformation in the basin began with the beginning of the Upper Cretaceous. During the deposition of the First Frontier sandstone (Plate 12), orogenic forces became very abundant throughout the basin and origins of several of the present-day oil fields were definitely associated with the tectonics during this time. Disturbances became more abundant progressing upwards in the section, and the birth of the basin itself was found to occur before Mesaverde time. Growth faulting in the basin illustrates that all the deformation did not occur at one particular time, but that a sequence of tectonic disturbances occurred throughout the Upper Cretaceous before the Laramide Orogeny.

As additional well coverage becomes available, more detailed isopachs can be made showing additional tectonic features that prevailed during this time. Sedimentary thinning over structural features may lead to new field discoveries caused by the early migration and accumulation of oils becoming trapped during the time of structural deformation. Detailed work should be done on the east side of the basin in the area of the Newcastle deltaic producing sands. As previously mentioned, the isopached bentonite intervals (Plates 8, 9, and 10) showed thins to overlie the deltaic features. Using a larger scale, complete well coverage, and picking smaller bentonite intervals, will undoubtedly delineate these fields extremely well, especially the northwest delta where little work has yet been done.

BIBLIOGRAPHY

BIBLIOGRAPHY

Clark, T. H. and Stearn, C. W. 1960. The Geological Evolution of North America. New York: The Ronald Press. Pp. 209-236.

Crowley, A. J. 1951. "Possible Lower Cretaceous Uplifting of Black Hills, Wyoming and South Dakota," Am. Assoc. of Petroleum Geologists Bull., Vol. 35, No. 1, pp. 83-90.

Eardley, A. J. 1962. Structural Geology of North America. New York: Harper & Row. Pp. 293-301, 327-350, and 361-388.

Emery, W. B. 1929. "Lance Creek Oil and Gas Field, Niobrara County, Wyoming," Structure of Typical American Oil Fields, Am. Assoc. of Petroleum Geologist, Vol. 2, pp. 604-613.

Faulkner, G. L. 1956. "Subsurface Stratigraphy of the Pre-Niobrara Formations Along the Western Margin of the Powder River Basin, Wyoming," Wyoming Stratigraphy, Wyoming Geol. Assoc., Part I, pp. 39-49

Goodell, H. G. 1962. "The Stratigraphy and Petrology of the Frontier Formation of Wyoming," Wyoming Geol. Assoc. Guidebook, 17th Ann. Field Conf., pp. 173-210.

Gries, J. P. 1962. "Lower Cretaceous Stratigraphy of South Dakota and the Eastern Edge of the Powder River Basin," Wyoming Geol. Assoc. Guidebook, 17th Ann. Field Conf. pp. 163-172.

Haun, J. D. 1958. "Early Upper Cretaceous Stratigraphy, Powder River Basin, Wyoming," Wyoming Geol. Assoc. Guidebook, 13th Ann. Field Conf., pp. 84-89.

Hunter, L. D. 1950. "Evidence of Uplift in the Big Horn Mountains During Upper Cretaceous Time," Geol. Soc. of America Bull., (Abs.), Vol. 61, No. 12, Part 2, p. 1554.

King, P. B. 1959. The Evolution of North America. Princeton, New Jersey: Princeton University Press. Pp. 108-131.

Knechtel, M. M. and Patterson, S. H. 1962. "Bentonite Deposits of the Northern Black Hills District Wyoming, Montana, and South Dakota," U. S. Geol. Survey Bull. 1082-M.

Kohl, K. W. 1959. "Regional Study of the Muddy Sandstone of Northeastern Wyoming." Unpublished Master's thesis, Michigan State University.

Love, J. D. 1953. "Periods of Folding and Faulting in Wyoming During Late Cretaceous and Tertiary Times," Am. Assoc. of Petroleum Geologists Bull. (Abs.), Vol. 37, No. 11, pp. 26-13-2614.

Parker, J. M. 1958. "Stratigraphy of the Shannon Member of the Eagle Formation and Its Relationship to Other Units in the Montana Group in the Powder River Basin, Wyoming and Montana," Wyoming Geol. Assoc. Guidebook, 13th Ann. Field Conf., pp. 90-102.

Reeside, J. B. 1957. "Paleoecology of the Cretaceous Seas of the Western Interior of the United States,"Geol. Soc. of America Memoir 67, Vol. 2, pp. 505-537.

Ross, C. S. 1925. "Beds of Volcanic Material As Key Horizons," Am. Assoc. of Petroleum Geologists Bull., Vol. 9, No. 2, pp. 341-343.

Sloss, L. L. 1960. "Interregional Time-Stratigraphic Correlation," Geol. Soc. of America Bull., (Abs.), Vol. 71, Part 2, p. 1976.

Strickland, J. W. 1958. "Habitat of Oil in the Powder River Basin," Wyoming Geol. Assoc. Guidebook, 13th Ann. Field Conf., pp. 132-147.

Waage, K. M. 1958. "Regional Aspects of Inyan Kara Stratigraphy, Wyoming," Wyoming Geol. Assoc. Guidebook, 13th Ann. Field Conf., pp. 76-76.

APPENDIX

CROSS-SECTION A--A'

Index No.	Company	Well	Location
A-1	Shell	Buszkiewie #1	20-58N-84W
A-2	E. M. & W. Drlg.	Sheridan #1	18-57N-84W
A-3	Perl Smith	Legerski #1	36-57N-85W
A-4	Shell	Demple #1	22-55N-85W
A-5	G. L. Reasor	Tarbet #1	4-51N-83W
A-6	Conoco	Unit #1	24-50N-82W
A-7	B. F. Allison Drlg. Co.	Tomberlin-State #1	16-48N-82W
A-8	British American	Case B-1	4-47N-82W
A-9	British American	Gov't.-Case #2	9-47N-82W
A-10	Pure	C. A. Case #1	15-47N-82W
A-11	Petroleum Inc.	Gov't.-Cole #1	17-46N-82W
A-12	Carter	Gov't. #1	28-46N-82W
A-13	Texaco	Gov't.-McGee (NCT-1) #1	23-45N-82W
A-14	Pan American	North Fork Unit 11	19-44N-81W
A-15	Argo Oil Co.	Gov't.-Manke #1	32-44N-81W
A-16	Byard Bennett	Beebe #1	24-43N-81W
A-17	Texaco	Gov't.-Schulte (NCT-2) #1	34-43N-80W
A-18	Husky	Gallop #1	31-43N-79W
A-19	Conoco	Sussex Unit #168	12-42N-79W
A-20	Conoco	Sussex Unit #37	16-42N-78W
A-21	Bill Tomberlin	Bill Taylor #1	19-42N-77W
A-22	Conoco	W. P. Irvine #1	18-41N-77W
A-23	Summit Oil	Gov't. 21-1	21-41N-77W
A-24	Stanolind O. & G. Co.	Unit #1	3-40N-77W
A-25	Calco	Gov't.-Pearson #1	22-40N-77W
A-26	Hiawatha	Gov't.-Pearson #1	21-39N-77W
A-27	Trigood Oil Co.	Gov't.-English #1	6-38N-77W
A-28	Trigood Oil Co.	Gov't.-Dohrey #1	20-38N-77W
A-29	Amerada	Unit #17	8-37N-77W
A-30	Amerada	U.S.A.-Richie #1	27-37N-77W
A-31	Brinkerhoff Drlg. Co.	Gov't. #1	21-36N-77W
A-32	Mobil	F-21-4-g	4-35N-77W
A-33	K. D. Owen	Rudegan Fee #1	25-35N-77W
A-34	Phillips Petr.	Cole #2	17-34N-76W
A-35	Phillips Petr.	Brimmer #1	31-34N-75W
A-36	J. D. Sprecker	L. A. M. #1	15-33N-75W
A-37	Bennett & Steele	Bixby Carey #1	20-33N-74W
A-38	Ryan Oil	Green Valley Sheep Co. #1	31-33N-73W
A-39	Curry-Calstar	Chamberlain #3	8-32N-73W
A-40	Kirby Petr.	Jenkins #1	13-32N-72½W
A-41	Texaco	Gov't.-Van Arsdale #1	18-32N-71W
A-42	Bob Phillips	Nauman #1	2-31N-71W
A-43	Colo. O & G.	Rodeman #1	18-31N-70W
A-44	Sanford & Rounds-Raymond Oil	Gov't. #1	31-31N-70W

CROSS-SECTION B--B'

Index No.	Company	Well	Location
B-1	Davis Oil Co.	Federal-Rogers #1	28-58N-71W
B-2	Pure	Olmstead #1	12-57N-72W
B-3	R. G. Steele	Gov't.-Olmstead Crk. #1	19-57N-71W
B-4	Jeff Hawks	Gov't. #1-1584	1-56N-72W
B-5	Jeff Hawks	Gov't.-Kennedy #1-17	17-56N-71W
B-6	Davis Oil Co.	Allison #1	11-55N-71W
B-7	Piedomnt Oil	T. P. Gov't. #1	26-54N-71W
B-8	Rio Oil	Federal-Dolley #1	7-53N-71W
B-9	Conoco	Unit #9	9-52N-71W
B-10	Trigood Oil Co.	Gov't.-Munoz #1	19-51N-70W
B-11	Davis Oil Co.	Talley #1	20-49N-69W
B-12	Kewanee Oil	Normal #1	14-48N-69W
B-13	C. Brazell	Norman-Jessen #1	12-47N-69W
B-14	Nat. Co-op.	Gov't. #1	2-46N-68W
B-15	Staurco Oil Co., Inc.	Gov't. #1	1-45N-68W
B-16	Anschutz Drlg.	Gov't. #3	20-45N-67W
B-17	Davis Oil Co.	Federal-Todd #1	17-44N-67W
B-18	True & Brown-R.H.Fulton	Kirgis #1	15-43N-67W
B-19	J. D. Sprecker	Fields #1	11-42N-67W
B-20	J. D. Sprecker	Gov't.-Lynch #1	22-42N-67W
B-21	Voss Oil	Gov't.-Connor #1	2-41N-67W
B-22	Dakamont Expl.	Gov't. #6	21-41N-67W
B-23	T. W. Eggleston	Gov't. #1	5-40N-67W
B-24	M. K. M. Expl.	Gov't.-Snyder #1	25-40N-67W
B-25	Gt. Basins Petr.	State #11-16	16-39N-66W
B-26	M.K.M. Expl.	Gov't.-Shepard #1	7-38N-65W
B-27	Reserve Drlg. Co.	Gov't. #1	4-37N-64W
B-28	Halbert-Jennings	Courie #1	33-37N-64W
B-29	Tidewater Oil Co.	#84-11 Bright Unit	11-36N-64W
B-30	Conoco	ELCU #B-12	26-36N-64W
B-31	Conoco	Hallbrook #1	12-35N-64W
B-32	Conoco	Martin-Lavin #1	26-35N-64W
B-33	Conoco	Gov't. #1	1-34N-64W
B-34	Conoco	Arnold #1	35-33N-62W

CROSS-SECTION A--C'

Index No.	Company	Well	Location
A-1	Shell	Buszkiewie #1	30-58N-84W
C-1	Signal	Barbula-Turley #1	19-58N-83W
C-2	Shell	Gov't.-Wamsley #1	13-57N-83W
C-3	Un. Oil of Cal.	Gov't. #1	23-57N-82W
C-4	Am. Liberty Oil	Stanolind-Gov't.#1	34-57N-80W
C-5	Shell	Clear Creek #1	11-57N-78W
C-6	Amour Prop.	Kendrick-Armoue #1	12-57N-76W
C-7	E. M. Davis	Doss #1	3-57N-73W
C-8	Davis Oil Co.	Hunter #1	11-57N-72W
B-1	Davis Oil Co.	Federal-Rogers #1	28-58N-71W
C-9	R. G. Steele	Gov't. #1	29-58N-70W
C-10	Amerada	A. M. Starr #1	32-58N-68W
C-11	Amerada	Black Hill Unie #1	1-57N-68W
C-12	Amerada	Prickly Pear Creek Unit #2	6-57N-66W

CROSS-SECTION D--D'

Index No.	Company	Well	Location
A-6	Conoco	Unit #1	24-50N-82W
D-1	British American	Gov't.-Wilson #1	21-50N-80W
D-2	Pure	Unit #1	20-48N-76W
D-3	Calco	Gov't.-Davis #4	30-49N-75W
D-4	Falcon-Seaboard Drlg.Co.	Throne-Rhodes #1	20-49N-73W
D-5	Gulf	George Wolf Estate #1	27-49N-71W
B-11	Davis Oil	Talley #1	20-49N-69W
D-6	Mule Creek oil Co.	Burrows #1	18-49N-68W
D-7	Texaco	Robinson #1	9-49N-67W
D-8	A. L. Schlaikjer	Barton Bros. #1	31-50N-66W

CROSS-SECTION E--E'

Index No.	Company	Well	Location
E-1	Stanolind O. & G. Co.	Brock #1	24-45N-83W
A-13	Texaco	Gov't.-McGee (NCT-1) #1	23-45N-82W
E-2	Amerada	Pheasant #1	18-45N-80W
E-3	Amerada	Smith Cut #1	10-44N-79W
E-4	Davis Oil Co.	Lauby #1	35-45N-75W
E-5	Lion Oil Co.	Christman #1	32-45N-74W
E-6	Skelly	W. L. Cook #1	8-45N-73W
E-7	Shell	Wright #1	11-45N-72W
E-8	Colo. O. & G.	Gov't.-Four Horse #1	27-46N-69W
E-9	Trigood Oil Co.	Gov't.-Montgomery #1	17-46N-68W
B-14	Nat. Co-op.	Gov't. #1	2-46N-68W
E-10	Tex. Pacific Coal & Oil	Gov't. "A" #1	26-47N-67W
E-11	Delta Cont. Oil Co.	D. Nolan #1	24-47N-66W
E-12	Trigood Oil Co.	Jessee #1-C	34-47N-65W

CROSS-SECTION F--F'

Index No.	Company	Well	Location
F-1	Norris Oil	#88-25	25-40N-81W
F-2	Stanolind O. & G. Co.	#12-26 T.P.N.W.	26-40N-79W
F-3	George & Wrather & Crude Oil	Gov't. #1	11-40N-78W
A-24	Stanolind O. & G. Co.	Unit #1	3-40N-77W
F-4	Un. Oil & Brazos	Moore Sheep Co. #1	4-40N-76W
F-5	El Paso Nat. Gas Co.	Ross Unit #1	10-40N-75W
F-6	Un. Oil of Cal.	Unit #1	29-40N-73W
F-7	Properties, Inc.	State #1	22-40N-72W
F-8	Gulf	Gov't.-Teckla #1	10-41N-70W
F-9	A. B. Cobb & Sup. Oil Co.	Unit #1	5-40N-68W
B-23	T. W. Eggleston	Gov't. #1	5-40N-67W
F-10	E. L. Suagee	Gov't. #2	9-40N-66W
F-11	Brazell & Wrather Oil Co.	Gaskill #1-A	9-40N-65W
F-12	British American	Moore #1	7-40N-62W
F-13	Black Hills Drlg. Co.	Sedgwick #1	21-40N-61W

CROSS-SECTION G--G'

Index No.	Company	Well	Location
G-1	Pure	N. Casper Creek #1	36-37N-82W
G-2	M.K.M. Expl.	Roach #1	25-37N-80W
G-3	Carter Oil Co.	Gov't.-Anderson-McCleod #1	33-37N-78W
G-4	Amerada	Unit #1	30-37N-77W
A-30	Amerada	U.S.A.-Richie #1	27-37N-77W
G-5	Humble	Gov't.-Garret #1	26-37N-76W
G-6	Phillips Petr.	Werner Unit #1	20-37N-75W
G-7	Davis Oil Co.	Reeves #1	10-37N-70W
G-8	El Paso Nat. Gas Co.	Fee-Ketelsen	5-37N-68W
G-9	Martex Oil & Gas	Bible #1	17-37N-67W
G-10	Ohio Oil Co.	J. Umphrey #1	17-38N-66W
G-11	Gt. Basins Petr.	Gov't. #14-7	7-38N-65W
G-12	Gt. Basins Petr.	Gov't. #11-12	12-38N-64W
G-13	Carter Oil Co.	Pfister #1	14-38N-63W

CROSS-SECTION H--H'

Index No.	Company	Well	Location
A-43	Colo. O. & G.	Rhodeman #1	18-31N-70W
H-1	Calco	G. E. Carimin #1	15-31N-70W
H-2	Dickey Oil Co.	Gov't. #1	27-32N-69W
H-3	Carter Oil Co.	Cole-C-120 #1	19-33N-68W
H-4	J. M. Huber Corp.	State-Barnes #1	36-34N-67W
H-5	Atlantic Ref. Co.	Sam Joss B #1	20-34N-66W
H-6	McAlester Fuel	State #1-A	4-34N-65W
B-32	Conoco	Martin-Lavin #1	26-35N-64W
H-7	Buck Creek Oil	Unit #2	21-36N-61W
H-8	Buck Creek Oil	Unit #5	6-36N-60W