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Stanley D. Whiteford Jr.
Northwestern University

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Regional Aspects of the Muddy Formation in the Wind River Basin, Wyoming¹

STANLEY D. WHITFORD, JR.²

Abstract. The Lower Cretaceous Muddy Formation can be recognized almost everywhere in the Wind River Basin. The Formation consists primarily of quartzose and chert bearing sandstones and siltstones, carbonaceous sandstones and siltstones, fine-grained conglomerates, black and gray shales, and brown lignitic shales. The sandstone bodies within the Formation are extremely local and lenticular in nature and are irregularly distributed. These lenses appear to represent both individual and coalescing bar, channel, and deltaic deposits. The Muddy Formation is believed to be a poorly developed eastward extending tongue of the Bear River Formation occupying the same stratigraphic position as the Newcastle Sandstone which is believed to be a westward extending tongue of the Dakota Group of eastern Nebraska. The vertical sequence of lithologic varieties, sedimentary structures, and wide-spread evidence of diastems and local angular unconformity suggest that the sediments of the Muddy Formation were deposited in the shallow shoaling waters of an eastward regressing and subsequently westward transgressing Early Cretaceous sea. Evidence indicates that most of the sediments were deposited in a transitional environment, some are certainly of marine origin, and some may represent fluvial conditions.

INTRODUCTION

The Lower Cretaceous Muddy Formation, formerly called the Muddy Sandstone, occurs throughout most of central and eastern Wyoming and can be recognized in parts of southern Montana and northern Colorado. It consists of a number of lenticular bodies of sandstone, and associated siltstones, and silty shales, all occupying approximately the same stratigraphic position within the black, fissile, Thermopolis Shale. Originally the Muddy Sandstone was considered a member of the Thermopolis Shale due to the great similarity of the black shale above and below the sandstones (Lupton, 1916). In many localities the Muddy consists of only one unit of sandstone. Elsewhere several sandstones are present, each of which normally is separated by shale ranging from 1 to 10 feet in thickness. The lenticular and locally discontinuous nature of the Muddy Sandstone makes it difficult to define in formal stratigraphic terms; however, the regional persistence of this pattern makes it extremely desirable to define the unit with as much rigor as possible. For this reason

¹ Part of a dissertation for the degree of Master of Science completed at Northwestern University, Evanston, Illinois in 1959.

² Peoples Gas Light and Coke Company, Chicago, Illinois.

the term "Muddy Formation" is preferred to "Muddy Sandstone."

When the Muddy Sandstone is recognized as a formation the Thermopolis Shale is defined to include all rocks between the top of the Greybull Sandstone and the base of the lowermost Muddy sandstone unit. In addition, the base of the Mowry Shale is extended downward to the top of the uppermost sandstone in the Muddy, and the black fissile shale overlying the Muddy Sandstone is included in the Mowry. Paull (1957) advocated the retention of the original definition of the Mowry to include only the siliceous shale and proposes the term Shell Creek Shale for the black fissile unit between the top of the Muddy Sandstone and the base of the Mowry Shale (Fig. 1).

	Westernmost Wyoming	Big Horn Basin	Wind River Basin		Northeastern Wyoming	Southeastern Wyoming
			West	East		
Upper Cretaceous	Aspen	Mowry	Mowry	Mowry	Mowry	Huntsman Sh.
Lower Cretaceous	Bear River Fm.	Shell Creek Sh.	Shell Creek Sh.	Shell Creek Sh.	Netsy	Newcastle Sh.
		Muddy Ss.	Muddy Ss.	Muddy Ss.	Newcastle Ss.	Newcastle Ss. "J"
		Thermopolis Sh.	Thermopolis Sh.	Thermopolis Sh.	Skull Creek Sh.	Skull Creek Sh.
	"Rusty beds"-Greybull interval	"Rusty beds"-Greybull interval	Fall River Ss.	Inyan Kara Group	Fall River Ss.	Fall River Ss.
	unnamed variegated beds	unnamed variegated beds	Fuson Sh.		Fuson Sh.	Fuson Sh.
	Gonnelt Gp.	Pryor Cgl.	quartz crystal ss zone	Lakota Cgl.	Lakota Cgl.	Lakota Cgl.
Upper Jurassic	Morrison	Morrison	Morrison	Morrison	Morrison	

Figure 1. Stratigraphic Correlation Chart of Lower Cretaceous Rocks in Wyoming.

Identification of the Muddy Formation is dependent on the presence or absence of sandstone or siltstone. Locally, these sandstones may be small lenticular bodies completely isolated from one another by black shale. They may be found overlapping one another or may appear to be interconnected laterally by some thin sandstone or sandy shale zone. If only one such body is present in any given locality, it is the sole representative of the Formation. If, however, more than one is present, the Formation then includes all rock units between the base of the lowermost sandstone or siltstone and the top of the uppermost unit. The Muddy Formation appears to be represented almost everywhere by at least a thin brown silty shale zone. In the few localities where the Formation cannot be recognized it must be considered absent. At these points it is impossible to make the distinction between the Thermopolis and Shell Creek Shales, and

the thickness of each can be estimated only on the basis of regional information.

DESCRIPTIVE GEOLOGY

In the Wind River Basin the Muddy Formation ranges up to 150 feet in thickness, but is absent locally. Rarely is it entirely absent or is the maximum thickness present, and in most places the Formation is 10 to 40 feet thick. Individual sandstones within the Muddy Formation range from a few inches to about 120 feet in thickness; most of them, however, do not exceed 20 or 30 feet.

Lithologic Varieties

Until recently, no type section had ever been specified for the Muddy Formation. Paull (1957) suggests the designation of a surface section in the southeastern part of the Big Horn Basin to be used in this capacity. The value of employing this type section as representative of the stratigraphic sequence in the Wind River Basin seems questionable due to the extensive local variability in almost all aspects of the Formation. The lithology is extremely diverse when details of composition and mixture or gradation are considered. For this reason rather than to describe a type locality the writer prefers to consider the Muddy Formation in the Wind River Basin as represented by six general rock types appearing in a variety of sequences. These rock types are summarized below.

Sandstones and siltstones. The bulk of the Muddy Formation is composed of quartzose, medium to fine-grained sandstones and siltstones. A trace to a few percent of chert grains is almost always present in the sandstones, but the siltstones are invariably devoid of detrital chert. A few percent of microcline, sanidine, or plagioclase feldspar may also be present.

In a number of samples the volume of detrital chert is high and, together with fragments of shale and phyllite, makes up about 50 percent of the rock. These rocks containing such fragments tend to be poorly sorted, and contain a greater amount of matrix material, than those whose detrital fraction is almost entirely quartz. Their main distinction, however, is the high content of detrital chert.

Many of the sandstones contain some calcite. Usually calcite is present as cement and in some cases is so prevalent that glistening crystal faces appear on the surface of the sandstone. These faces are formed by growth of large calcite crystals within the matrix resulting in a poikilitic texture. In some places calcareous sandstone occurs only at the top of any particular unit and grades downward into non-calcareous beds. At Tisdale (locality 12, Fig. 2) and Kidd Ranch (locality 10) a thin sand-

stone occurs which is extremely calcareous throughout and is characterized by a deep maroon color.

The sandstones and siltstones display a variety of bedding. Some are massive or thickly bedded; each bed has a thickness of several feet. Many display thin, even or wavy bedding and are platy, whereas others are very finely laminated. Although

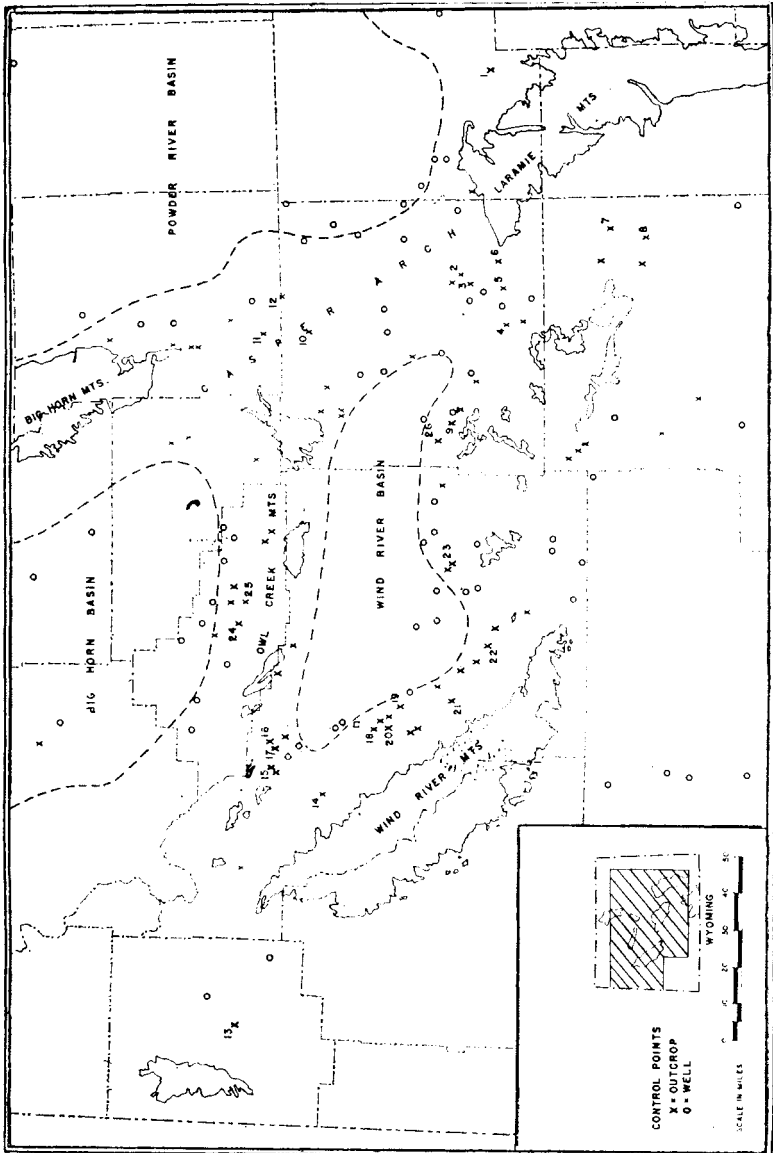


Figure 2 Location Map.

the massive units tend to be composed of the coarser sand sizes and the finely laminated rocks of silt size particles there seems to be no direct correlation between bedding and particle size. Some of the siltstones and fine-grained sandstones contain alternating light and dark colored laminae which gives the rock a banded appearance. Many of the massive and thickly bedded units display well-developed cross bedding. The length of the transverse beds ranges from several inches to several feet, and the degree and direction of dip are extremely variable both vertically and laterally within the Muddy Formation as a whole. Well-developed current and oscillation ripple marks also are common features in most of the above mentioned rocks.

Carbonaceous sandstones and siltstones. Carbonaceous sandstones and siltstones are prevalent in the Muddy Formation. They are similar in lithology to those previously described but contain varying amounts of carbonized material. This material occurs in several forms and is distributed in several patterns. In some cases minute flecks of what appears to be carbonized plant material are randomly distributed through a sandstone or siltstone. In other cases large pieces of carbonized wood and fossil leaf imprints may be similarly distributed. Such fragments range from 1 to 8 inches in length and may be 2 inches in width. In some rocks they are oriented parallel to the bedding and form an extremely thin mat. Black carbonaceous material frequently occurs as discontinuous undulate laminae in sandstones and siltstones which themselves display wavy bedding. Often these laminae bend around small included pods of massive quartzose sandstone ranging from $\frac{1}{2}$ to 3 feet in length. A few of the sandstones and siltstones contain a black carbonaceous paste occurring in minute pores or vugs. This material may be partly oxidized liquid hydrocarbon.

Fine-grained conglomerate. Two types of fine-grained conglomerate occur rarely in the Muddy Formation of the Wind River Basin. One of these is composed mainly of rounded and angular fragments of fossil bone, rock, black chert, plagioclase, potash feldspar, and a small amount of quartz. At some localities phosphatic nodules are present. These fragments and nodules range from 3 to 6 mm. in diameter, whereas the matrix consists of silt-size quartz and chert grains, and clay. This type of conglomerate can be seen at Conant Creek (locality 23) in the southern part of the Basin, at Dry Creek (locality 15) in the northwestern corner of the Basin, and also Mud Creek west of Thermopolis at the southern margin of the Big Horn Basin. At each of these localities the conglomerate occurs in well defined discontinuous beds up to several inches thick. Such beds usually are found within thicker sandstone and siltstone units.

Another type of conglomerate can be seen in outcrop at several localities along the western margin of the Wind River Basin. This rock is texturally similar to the fine-grained conglomerate mentioned above, but the coarse detrital fraction is composed almost entirely of light colored chert grains, a few rock fragments, and a minor amount of quartz. White clay pellets frequently are present. Feldspar and bone fragments are entirely absent. The matrix consists of chert and what appears to be a tuffaceous material. This conglomerate usually occurs in thin beds and stringers which are not as well defined as the type first described, and which grade both laterally and vertically into the surrounding sandstone. The beds of conglomerate normally occur near the base of the thickest sandstone unit at each locality.

Black and gray shales. Much of the shale in the Muddy Formation ranges from black to light gray in color. The black shale normally is waxy, extremely fissile, and is identical to the Thermopolis Shale below, and the Shell Creek Shale above, the Muddy. Variations in the color of the shale may be attributed to several factors such as degree of weathering, presence of bentonitic material, or presence of varying amounts of silt-size quartz. These shales may be 10 to 20 feet thick but more commonly occur as thin beds and laminae. Shale stringers frequently are interbedded with sandstone and siltstone. Lateral interfingering relationships have not been established with certainty, but they probably occur locally.

Brown lignitic shale. Dark brown shale is a common rock type in the Muddy Formation. In some places such shale is fissile and appears to be a silty zone in the surrounding black or gray shale. Frequently, however, brown shale is intimately associated with lignite or carbonaceous shale and is composed of partly carbonized plant remains. A pure lignite occurs locally within the Muddy along East Difficulty Creek near Medicine Bow (locality 8). It is dark brown in color and contains a great many fragments of yellow resinous material which appears to be amber. Although the rock appears coaly the original form of much of the plant material has been preserved. For classification purposes this type of rock appears to fall midway between a brown silty shale and a lignite and is herein referred to as brown lignitic shale.

Bentonite. Bentonite beds are fairly abundant in most of the Cretaceous rocks of the Rocky Mountains. Thin beds of bentonite occur within the Muddy Formation, but they are rare and seem to be limited in their distribution. Normally the bentonite beds are associated with shale, but in a few places they occur within thinly bedded siltstones.

Lithologic Relationships

Lithologic changes within the Muddy Formation in the Wind River Basin are extremely rapid both vertically and laterally. The order of magnitude of the lateral changes appears to range from those observed within one outcrop (several hundred feet or less) to others noted over a distance of no more than 2 to 3 miles. Regionally, the Formation as a whole does not seem to display any major interfingering relationships with surrounding black shale. However, units within the Formation do show these relationships, and local facies changes appear to involve any or all of the lithologic types previously described. At Maverick Springs (locality 16) two thin sandstone units which are separated by 5 feet of shale can be seen to grade laterally into dark gray shale. The lower unit "pinches out" in an easterly direction, whereas the upper unit disappears westward. Both of these facies changes occur within a distance of several hundred yards. Similar lateral gradations can be observed at Sage Creek (locality 19) and elsewhere throughout the Basin.

Vertical changes in lithology may be gradational or extremely abrupt. Most of the sharp contacts are limited to the coarser clastics, with siltstone and shale normally grading into one another. However, there are many exceptions to this pattern.

Fossil Content

With the exception of plant remains and vertical borings of marine organisms, fossils are exceedingly rare and sparsely distributed in the Muddy Formation.

The remains of vertebrate fauna were seen in only four places, mainly along Mud Creek west of Thermopolis, along Dry Creek (locality 15), a section just west of Crowheart Butte (locality 14), and at Conant Creek (locality 23). These localities are along the north and west margins of the Basin. In each case the remains occur as partly rounded bone fragments within thin beds of fine-grained conglomerate. Only two or three of these conglomeratic beds occur within each outcrop, usually within or between thicker sandstone units, but the fossil fragments are extremely abundant in each bed. The faunal suite identified from these fragments is essentially identical to that from the Muddy Formation of the Big Horn Basin as described by Paull (1957). The remains include shark spines and teeth, fragments of the carapace of a turtle, crocodile teeth, and vertebrae from a bowfin or dogfish. The detrital character of the fragments together with the apparent mixture of essentially marine, transitional or swamp, and non-marine faunas suggest allochthonous accumulation.

The only semblance of an invertebrate fauna that the writer

could find in the Muddy Formation consists of vertical tube-like structures less than 1 cm. in diameter and 5 to 15 cm. in length. These are common features in many of the sandstones and siltstones and appear to be sporadically distributed in local groups throughout the Wind River Basin. They most frequently occur in thinly bedded calcareous sandstones. The tubes are composed of the same material as the enclosing rock but due to differential weathering they are readily distinguished in outcrop. They are almost always straight and are perpendicular to the bedding, each tube transecting several beds in the thinly laminated rocks. The diameter of each tube is fairly constant throughout its length with a slight rounding and narrowing of the lower end being noticeable in many instances. Termination of the upper end of the tube normally occurs on a bedding plane; whereas the lower termination may lie between two bedding planes.

The tubular structures are almost certainly of organic origin and very closely resemble the burrows of certain modern phoronids as described by Shrock and Twenhofel (1953).

It is assumed by the writer that the vertical tubes in the Muddy Formation represent the burrows of some type of marine or brackish water organism. Regardless of the specific origin or characteristics of this organism its mere presence in the geologic record is some indication of the environment of deposition of the enclosing sediments. Preservation of these tubes required quiet water conditions during and immediately after their formation, at least until the tubes could be buried sufficiently to prevent reworking of the sediment by wave or current action. The necessary conditions would exist most likely in an estuary, a lagoon behind a barrier beach, or off shore in water deep enough so that bottom sediments would be below wave base. A deltaic environment, when not subjected to extensive wave and current action, might also be conducive to the preservation of this type of structure. It is conceivable that such burrows might be preserved occasionally in a beach, or offshore bar environment provided that the rate of burial is rapid enough. It must be remembered that the sediment of the host rock could have been deposited under any of the above conditions and may have undergone a great deal of reworking before the burrows were formed. The environmental restrictions mentioned above can be rigorously applied only to the sediments immediately overlying the host rock. Frequently vertical burrows are found to originate along bedding planes within thinly and evenly bedded sandstones of the Muddy Formation. In this case the distribution of the burrows and nature of the bedding infer a quiet water environment for the host rock as well.

Plant remains are by far the most abundant type of fossil

found in the Muddy Formation of the Wind River Basin. Carbonized fragments of leaves, stems and bits of wood occur locally throughout the area in all types of sandstone, siltstone, and brown shale. Less frequently they occur in the black or gray shales. Local concentrations of plant remains commonly occur as thin discontinuous beds of lignite. The floral assemblage appears to be dominated by conifers. Several species have been tentatively identified by the writer as *Sequoia gracillima* (Lsq.) Newberry, *Abietites cretacea* Newberry, and *Nageiopsis longifolia*. Leaves of dicotyledonous plants and trees also are present. Although not identified specifically, many of these closely resemble ancient species of sassafras, poplars, and willows.

Sedimentary Structures

Concretions of various kinds are a major type of sedimentary structure in the Muddy Formation. Most often they are associated with shale in which they may be randomly distributed or occur in thin uniform layers or beds. The most predominant type of concretionary material is ironstone which is found as round masses or thin discontinuous beds and lenses. The spherical forms are often slightly flattened parallel to the bedding, range from a few inches to several feet in diameter, and are common throughout the Thermopolis and Shell Creek Shales. In several localities a zone of spherical, calcareous, septarian concretions occurs in the Thermopolis Shale just below the base of the lowest sandstone in the Muddy. At other localities a distinctive zone of septarian concretions, composed of aragonite, occurs in a similar stratigraphic position. The occurrence of phosphatic concretions associated with bone and chert conglomerate has been mentioned earlier.

Conceivably some of the more distinctive concretion zones might be of value in correlating units within the Muddy on a local basis, providing, however, the continuity of these zones could be established. The author was unable to find any zones that displayed regional continuity. With more surface data, however, it might be possible to establish overlap relationships between concretion zones and thus extend their use to regional stratigraphic correlation.

Cone-in-cone is another common feature of silty beds within the shales of the Muddy. Rare occurrences of folded and contorted bedding on a very small scale have been observed in some sandstones. Doubtless these structures were formed sometime prior to lithification of the sand. Extensive slump structure and contorted bedding have also been observed in the Fall River Sandstone which underlies the Thermopolis Shale in the eastern part of the Wind River Basin (Curry, 1954). In this For-

mation slump structures are more extensive than in the overlying Muddy.

Local Unconformities

Much evidence is to be found indicating numerous local unconformities and diastems within the Muddy Formation. Criteria for recognition of unconformities described by Krumbein (1942) can be seen in outcrops of the Muddy together with other features indicative of unconformable relationships between strata.

Channeling and scour and fill structures are the most distinctive and widespread of these features in the Muddy of the Wind River Basin. Small scour and fill structures are most common, occurring almost everywhere in the Basin. At locality 9 along Wallace Creek a channel 40 feet wide and 5 feet deep has been scoured into thinly bedded medium-grained sandstone in the upper part of the Muddy. The channel fill is shaly siltstone. Several similar scour and fill structures may occur at various horizons within a single outcrop. Their vertical distribution does not appear to be limited, and the channels may cut into any of the rock types present. In many cases the fill consists of fine-grained sandstone, siltstone, and shaly material, the thinly bedded nature of which is evident in some of the larger channels. In others the fill is massive and in some cases cross-bedded.

Occurrence of large channels is less frequent yet widespread. Gudim (1956) describes one of these channels in the Muddy Formation in the Lost Soldier area. This channel is 100 feet deep and has eroded deeply into the Thermopolis Shale. The base of the channel is close to the top of the "Dakota Sandstone." Another large channel can be seen near Alcova at locality 4. Here the upper sandstone unit of the Muddy thickens at its base, truncates the lower shales and siltstones, and cuts into the top of the Thermopolis Shale. The channel is several hundred yards wide and 20 feet deep. These are minimum dimensions for only part of the structure is exposed. The channel fill consists of a basal silty shale overlain by thinly bedded fine-grained sandstones several of which display torrential cross bedding. Curry (1954) describes a well-developed sinuous channel within the Muddy Formation at South Glenrock along the Casper Arch. This channel trends north and south, ranges from $\frac{1}{2}$ to $1\frac{1}{2}$ miles wide, and 100 feet deep at its maximum. The deep parts of the channel are filled with shale, siltstone, and fine sandstone.

Such channels may or may not be indicative of significant time breaks during deposition of the Muddy sediments. They do, however, represent either subaerial or shallow water submarine erosion locally. According to Krumbein and Sloss (1951) bone

and tooth conglomerates which often are associated with phosphatic pellets are indicative of "...at least a submarine diastem if not subaerial exposure." As mentioned earlier, this phenomenon occurs in the Muddy Formation at several of the localities visited.

A basal conglomerate is usually good evidence for an unconformity and often is thought to indicate former subaerial erosion. The fine-grained chert pebble conglomerate occurring in the Muddy Formation along the western margin of the Wind River Basin is not necessarily limited to the base of the Formation as a whole; however, it almost always occurs at the base of an individual sandstone unit and grades upward into that unit. The base of the conglomerate usually is sharply defined. The underlying unit may be either shale, siltstone or sandstone. In the latter case the lithology, bedding and structure are markedly different from those in the overlying sandstone into which the conglomerate grades. There is little doubt that the occurrence of this conglomerate at the base of the Muddy Formation indicates at least a local erosional disconformity. The writer also believes that many of the conglomerates occurring at other horizons within the Formation represent similar relationships.

Although no single unconformity or series of unconformities within the Muddy has yet been traced over any large area in the Wind River Basin, it appears significant that evidence of the type described above can be seen in practically every outcrop. Paull (1957) describes similar features in the Muddy Formation of the Big Horn Basin. Certainly some of these features represent only local erosion and non-deposition that occurred during very short periods of time. However, their extremely common and widespread occurrence indicates that collectively they represent a regional interruption during deposition of the Formation.

Shapes of Sandstone Bodies

The sandstone units in the Muddy Formation of the Wind River Basin are lenticular in shape as are equivalent units in the Big Horn Basin and the Black Hill region (Grace, 1952). The areal extent of these lenses is difficult to determine in the absence of closely spaced control points. Most of them, however, cover an area of less than a few square miles. An indication of the lenticularity and discontinuous nature of the sandstones is given by the typical outcrop pattern. Frequently the units of the Muddy crop out along the strike in a series of short low ridges of pod-like form which are formed by the thicker and more resistant zones of sandstone. The areas between the ridges normally are topographically level, due to the paucity or absence of sand-

stone, and form a part of the gently-sloping valleys between the prominent and continuous ridges of the Fall River or Grey-bull Sandstones and the Mowry Shale.

Although any one outcrop gives only a two-dimensional view of the lenses or thickened zones of sandstone, continuous outcrops show these lenses to be distributed in several different ways. Some of the smaller lenses are entirely surrounded by black shale of the Thermopolis and Shell Creek Shales. Others appear to be only local thickened zones of sandstone within the thin and more extensive sandstone and silty shales of the Muddy. It is probable that the latter units also frequently constitute thin lenses covering a larger area and are completely enclosed by black shale.

Local thickening may occur at the top or bottom of the thin more continuous units mentioned above. Many of the lenses thicken downwards at the expense of the underlying units and have narrow bases convex downwards, and probably represent filled channels as described earlier. Other sand bodies, however, appear to thicken at the top or at both top and bottom with respect to the thin surrounding units. There is some question as to whether these thickened units are filled channels or whether they represent beach or offshore bar deposits. According to Bass et al (1954) a sand bar has a wide flat base and a narrow convex top and usually dips gently seaward. The top of a sand bar may, however, be flattened due to subsequent erosion. It seems fairly certain that many of these local thick zones of sandstone in the Muddy Formation represent beach or offshore-bar deposits of this type. This interpretation implies that the sandstone bodies in question have an elongate shape. Minor elongation parallel to the strike is frequently observed in outcrop; however, this has little bearing on the actual direction of elongation of the bar or channel. The direction of elongation can be determined only by using several control points to find the maximum and minimum areal dimensions.

Some of the bar-like sandstone lenses with tops that are convex upward actually may be channels whose shapes have been distorted by differential compaction. Also, relatively structureless sandstone bodies representing a facies change from the surrounding shale may assume a lenticular shape with rounded top and bottom caused by differential compaction. Bedding relationships between the sandstone and adjacent shale and siltstone units often serve to distinguish between channel fill, bar deposits, and other types of lenticular sand accumulation.

Not uncommonly all types of local sandstone lenses are intimately associated with, or superimposed upon, one another

within the Muddy Formation. Channels may be found cutting into older subjacent channel or bar deposits. Many of the smaller lenses appear to coalesce both vertically and laterally. The writer believes that this same type of relationship is present between the larger sandstone lenses of the Muddy Formation, although this cannot be demonstrated at this time. There seems to be no limit to the range of distribution of these local lenticular sandstones within the Muddy Formation.

STRATIGRAPHY

Lower Cretaceous rocks in Wyoming are characterized by thin discontinuous sandstones, shales, and conglomerates which were deposited under stable shelf conditions. Westward these rocks essentially maintain their lithologic characteristics but thicken tremendously as the area of major crustal downwarping in westernmost Wyoming and southeastern Idaho is approached. They represent an overall transition from dominantly non-marine deposition at the end of Jurassic time to dominantly marine conditions at the beginning of Late Cretaceous time. Specific regional correlation of these rocks has been in a state of flux for some time. This has been due mainly to the lack of adequate marker horizons, the discontinuous nature of individual units, and the lack of good paleontologic control.

Despite the localized distribution of units within the Muddy, the Formation itself is extremely persistent throughout the Wind River Basin. In only a few localities is it poorly defined. At Conant Creek (locality 23) it is represented by 11 feet of silty shale bounded at both the top and bottom by sandstone less than 2 feet thick. At the Kidd Ranch and along Willow Creek (localities 10 and 11) the Formation cannot be recognized with certainty. However, at the first mentioned of these localities a maroon colored sandstone 3 feet thick occupies the same stratigraphic position as the Muddy Formation does elsewhere. At the second of these localities several closely spaced siltstones, each less than 1 foot thick, identify the stratigraphic position of the Muddy.

The Thermopolis Shale contains numerous thin silty zones which some workers claim might be confused with units of the Muddy Formation. These siltstones are rarely well-developed in the Wind River Basin and in all but those few localities mentioned above they are readily distinguished from even the most poorly developed units of the Muddy. In westernmost Wyoming, however, the Muddy Formation loses its identity due to the numerous well-developed sandstones throughout the rocks of Early Cretaceous age in that area.

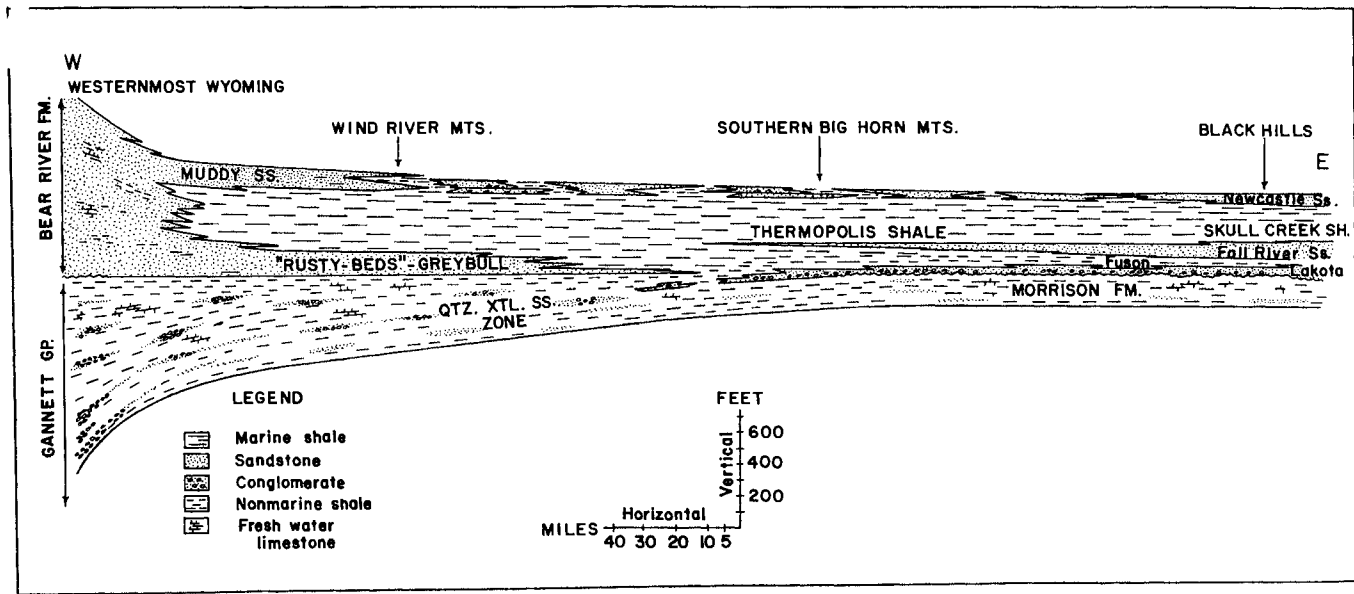
In the Wind River Basin the Muddy Formation is readily recognized in the subsurface and is invariably identified by 2 or

3 distinctive high peaks on the resistivity curves of electric logs. The corresponding portions of the S.P. curve vary radically and may display peaks, valleys, or no deviation whatsoever depending on the local permeability and fluid content of the units in the Formation. The fact that the characteristics of the resistivity curves and especially the S.P. curve vary rapidly over short distances is another indication of the extremely local distribution and lenticular nature of the individual units within the Formation.

According to Wanless (1955) the Muddy Formation of central Wyoming is stratigraphically equivalent to a part of the Bear River Formation of western Wyoming but lies above the Greybull Sandstone. The relationship of the Muddy and its equivalents in the southern and southwestern part of the state is poorly understood. Gudim (1956) states that the Thermopolis Shale thins gradually southward through the Washakie Basin until it no longer can be recognized in the southern part, and the Muddy Formation appears to merge with the "Dakota Sandstone." A similar relationship occurs in the southwestern part of the Green River Basin where the Muddy can be tenuously correlated with the upper part of the Dakota (?) Sandstone of northern Utah. According to Burk (1957) the Dakota (?) Sandstone is stratigraphically equivalent to the Bear River Formation.

Curtis (1951) discusses the possibility of an unconformity at the base of the Mowry Shale in southwestern Wyoming and infers that the Muddy is absent due to erosion rather than merging with the "Dakota Sandstone." Even if this were true the pre-erosion relationship might well have been that mentioned above, with the line of mergence occurring somewhere south of the present limit of the Thermopolis Shale.

The Newcastle Sandstone of the Black Hills region has long been considered the stratigraphic equivalent of the Muddy Formation in central Wyoming. It is believed to be a tongue of the Dakota Sandstone of eastern Nebraska extending westward into Wyoming and occurring above the Fall River Sandstone. Both the Newcastle and Muddy Formations occupy the same stratigraphic position relative to the surrounding units; however, it has not been demonstrated that they are exactly time equivalent nor stratigraphically continuous with one another. McCrae (1957) states that the "J" or Cruise Sandstone of western Nebraska and eastern Colorado is equivalent to both the Newcastle and Muddy Sandstones. Although the relationship of the "J" Sandstone with the Newcastle is fairly well established, the exact relationship between the Muddy Formation on the one hand and the Newcastle and "J" Sandstones on the other has not been demonstrated.



It is herein proposed that the relationship between the Muddy Formation and the Newcastle and "J" Sandstones is similar to the relationship between the "Rusty beds"—Greybull interval and the Fall River Sandstone (Fig. 3). In this case the Muddy would represent a tongue of the upper part of the Bear River Formation extending eastward into central Wyoming, and the Newcastle and "J" Sandstones would represent a tongue or tongues of the Dakota Group extending westward into eastern and southeastern Wyoming respectively. Whether these tongues of sandstone were deposited concurrently or consecutively is not known.

As stated earlier, identification of the Muddy Formation depends on the presence of sandstone or silty zones at the top of the Thermopolis Shale or base of the Shell Creek. These occur at almost every locality within the Wind River Basin. Consequently the Formation as a whole can be traced regionally. However, as described previously, individual units within the Formation are extremely thin and discontinuous and at best can be traced over very short distances. The vertical sequence of these units varies greatly from place to place. At any one locality any combination of the previously described rock types may occur in any vertical sequence. Some lithologic types may be absent. This would be expected in a formation such as the Muddy in which individual units are thin, facies changes are rapid, and many local diastems and channel structures occur. Nevertheless there does appear to be a general stratigraphic sequence that commonly occurs in the Muddy in the Wind River Basin. The sequence, with many exceptions, consists of a basal sandstone or sandy units, a middle shale unit, and an upper sandy unit. The sequence can be seen in outcrop but is displayed best by the resistivity curves of electric logs. Although it is believed that this pattern may have regional significance, exceptions appear to be too numerous to warrant any attempt at regional correlation of the subdivisions.

ENVIRONMENT OF DEPOSITION

Local Environments

The lithology, structures, and stratigraphy of the Muddy Formation indicate that a number of local environments were involved during its deposition. These are designated by three main categories: marine, transitional, and non-marine.

Despite their sparse marine fauna the black shales of the Thermopolis and Shell Creek Formations and the Mowry Shale are considered to be marine in origin by most workers (Curry, 1954, Burk, 1957, and Rubey, 1928). The high organic content of the shales indicates euxinic or restricted conditions, and it is diffi-

cult to determine whether they were deposited offshore in a shallow epicontinental sea or are lagoonal in origin. It is believed that both environments are represented but that most of the shales were deposited offshore.

The shapes of some of the sandstone bodies in the Muddy Formation, although seen in only two dimensions, indicate that they may be beach or bar deposits. According to Moore and Shepard (1955) the greatest concentration of coarse sand along the present western coast of the Gulf of Mexico is found in the barrier beach deposits. Here the size grade of much of the coarse fraction is in the order of 0.5 to 1 mm. Practically none of the coarse fraction of the Muddy Formation is this large in diameter, a feature which may be a function of source; but some of the cleaner lenticular sandstone bodies contain detrital material which is coarser than that occurring in adjacent rocks. Examples occur in the upper sandstone of the Muddy Formation exposed near Lander (locality 21), and the lower sandstone unit at Hall Creek (locality 22). Although barrier beach deposits may be represented in the Muddy Formation, they seem to be poorly developed and very limited in distribution.

Most of the sediments in the Muddy Formation appear to have been deposited in a transitional environment; i.e. between open marine conditions seaward from a beach or strand line and non-marine continental conditions which were completely unaffected by the sea. The lignite, lignitic shale, thinly laminated fine-grained sandstones and siltstones, phoronid tubes, and thin interbedded shales are indicative of deposits accumulated in a lagoon or swamp environment. The presence of a mixed marine and non-marine fauna at Mud Creek and Conant Creek also are indicative of a transitional environment.

The deltaic environment is considered transitional. Scruton (1955) describes the sediments of the eastern Mississippi delta as being characterized by fragments of wood, plant material buried in place, mixtures of fine-grained sand, silt, and clay, many small lenses of these materials, and a paucity or complete absence of incorporated fauna. All of these characteristics are widely exhibited in the Muddy Formation. Also the diversity of cut and fill structures and cross-bedding in the Muddy Formation might well be expected in a deltaic environment because of the multiplicity of current action and the presence of a constantly shifting distributary system.

True non-marine sediments are difficult to identify in the Muddy Formation and appear to be poorly developed. Some of the lignites and lignitic shales are almost surely of continental origin. Also, some of the channel deposits might have a fluvial ori-

gin, but as yet this cannot be demonstrated. Certainly the presence of fragments of non-marine vertebrates, even though they occur in allochthonous accumulation, and the overall lack of any fauna in the Formation, are good indications of the proximity of a subaerial environment.

Regional Environment

As previously stated there seem to be no significant areal limits to the types of environments that occurred during deposition of the Muddy Formation. It appears that transitional, marine, and non-marine environments each occurred throughout central Wyoming at some time during deposition of the Formation.

Also, there seems to be an increase in rocks of non-marine character westward in the Wind River Basin and an increase in rocks of marine character eastward in the vicinity of the Casper Arch. These characteristics in addition to the prevailing stratigraphic sequence within the Muddy Formation and the generally accepted marine origin of the shales surrounding the Formation suggest that the sediments of the Muddy Formation represent an influx of coarser clastic material into the shallow Early Cretaceous seaway in which the Thermopolis Shale was deposited. The extensive tectonic stability in Wyoming at the time of deposition suggests that this influx of sediment slowly filled the seaway and caused an eastward regression of the strand line. Regression was in turn followed by a rapid westward transgression of the sea and consequently a return to marine conditions under which the Shell Creek Shale was deposited. The discontinuous nature of the sandstones within the Muddy indicates that this strand line was poorly defined, very irregular, and contained numerous re-entrants.

The regression may have been caused by a more rapid influx of sediment from a westerly direction into the shallow Early Cretaceous epicontinental sea. This may have been accompanied by gentle tectonic subsidence of the shelf area; if so, the rate of sedimentation must have exceeded the rate of subsidence. As the sea was filled the strand line gradually migrated eastward. The topography, during the time of deposition, might well have resembled that of the present Gulf Coast even though the tectonic settings are not comparable. Migration of the strand line would seem to have been accompanied by shoal areas and sand bar development seaward, development of deltas, lagoons and swamps landward, and finally subaerial conditions.

It is believed that regression was comparatively slow and was interrupted by numerous minor transgressions. Thus most of the sediments of the Muddy would have been deposited during the regression eastward. According to such an interpretation the re-

gression was terminated by a reduction in the supply of sediment and/or introduction of tectonic instability in the shelf area. This was followed by a rapid westward transgression bringing with it the marine conditions which were to prevail into Late Cretaceous time.

The interpretation set forth above explains the many overlapping relationships of local lenticular sandstone units within the Muddy Formation. It also explains the heterogeneity of vertical sequence. At any time during the depositional cycle transporting agents could erode previously deposited sediments and redistribute them. This condition together with the fact that very little sediment was involved in the total deposition of the Muddy Formation, explains the extreme discontinuity of individual rock units and the incompleteness of the sedimentary record.

CONCLUSION

The Muddy Formation appears to be a poorly developed and discontinuous sandstone tongue in an area of only slight subsidence which received a small amount of sediment (Fig. 3). This tongue of sandstone is thought to extend westward to its origin in the upper part of the Bear River Formation and eastward to its termination in the vicinity of the Powder River Basin.

Most workers in the past have considered the Newcastle Sandstone to be stratigraphically continuous with, or equivalent to, the Muddy Formation. However, at several places in the Powder River Basin the Newcastle Sandstone as correlated from the east overlies the Muddy Formation as correlated from the west. It is possible, therefore, that the Newcastle Sandstone is a tongue similar to the Muddy but originating in the Dakota Group of eastern Nebraska and extending westward to the vicinity of the Powder River Basin. The formation in question would represent two distinct stratigraphic units, different source areas, and different directions of transgression and regression. Whether the two formations show a slight regional overlap relationship or whether they were deposited concurrently is unknown.

More quantitative and regional data is needed to test this interpretation.

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