THE GEOLOGICAL SURVEY OF WYOMING
HORACE D. THOMAS, State Geologist

BULLETIN NO. 44

STRATIGRAPHY
OF THE
NEWCASTLE FORMATION, BLACK HILLS REGION, WYOMING AND SOUTH DAKOTA

BY

ROBERT M. GRACE

UNIVERSITY OF WYOMING
LARAMIE, WYOMING
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GEOLOGICAL SURVEY

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ROBERT M. GRACE

ABSTRACT

The outcrop of the Newcastle formation was studied on the west, north, and east flanks of the Black Hills, and seven areas of thick development were found. The name, Newcastle sandstone, as used by previous workers, is misleading because the unit referred to comprises a shale-siltstone facies in addition to a sandstone facies. For this reason, the more inclusive name, Newcastle formation, is introduced. Two phases of the formation are discriminated, a carbonaceous one on the west and northwest flanks of the Black Hills, and a non-carbonaceous one on the east flank.

Intruded sandstone dikes and masses were found in Crook County, Wyoming, and it is believed that they were derived from the Fall River sandstone.

It is concluded that (1) the western part of the Black Hills was probably a low land area during Newcastle time; (2) this land area may have originated as a result of minor uplift; and (3) the source of the Newcastle sediments cannot be determined without the benefit of still broader regional studies.

INTRODUCTION

The Newcastle formation has been found to have a shale and siltstone facies with a distribution of equal magnitude to that of the sandstone facies. In order to avoid any misconceptions, the term, Newcastle sandstone, of previous workers, is here replaced by the more inclusive term, Newcastle formation.

The Newcastle formation is considered to be the basal unit of the Upper Cretaceous series in the Black Hills region of northeastern Wyoming and western South Dakota (Reeside, 1944). It varies in thickness from a fraction of a foot to 85 feet and consists of sandstone, siltstone, light-colored shale, bentonite, and lignite. The Newcastle formation is underlain by the Skull Creek shale and overlain by the Mowry shale.

The Newcastle is not a prominent stratigraphic unit, and thus it received little notice by geologists until it was recognized as a source of petroleum. This formation produces oil in the Skull Creek, Mush Creek, Fiddler Creek, and Osage fields in Weston County, Wyoming, and hence is important economically. It is characterized by lensing and rapid facies changes; thus a knowledge of this formation is of value in understanding the depositional environment in the Black Hills during Newcastle time. Although detailed studies of the Newcastle formation have been made in the vicinity of Osage and Newcastle (Knight, 1902; Hancock, 1920; Collier, 1922; Dobbin and Horn, 1949; Summerford, Schieck, and Hiestand, 1949), this study is the first to have been made over such a large area.

* A thesis submitted to the Department of Geology and the Graduate School of the University of Wyoming in partial fulfillment of requirements for the degree of Master of Arts.

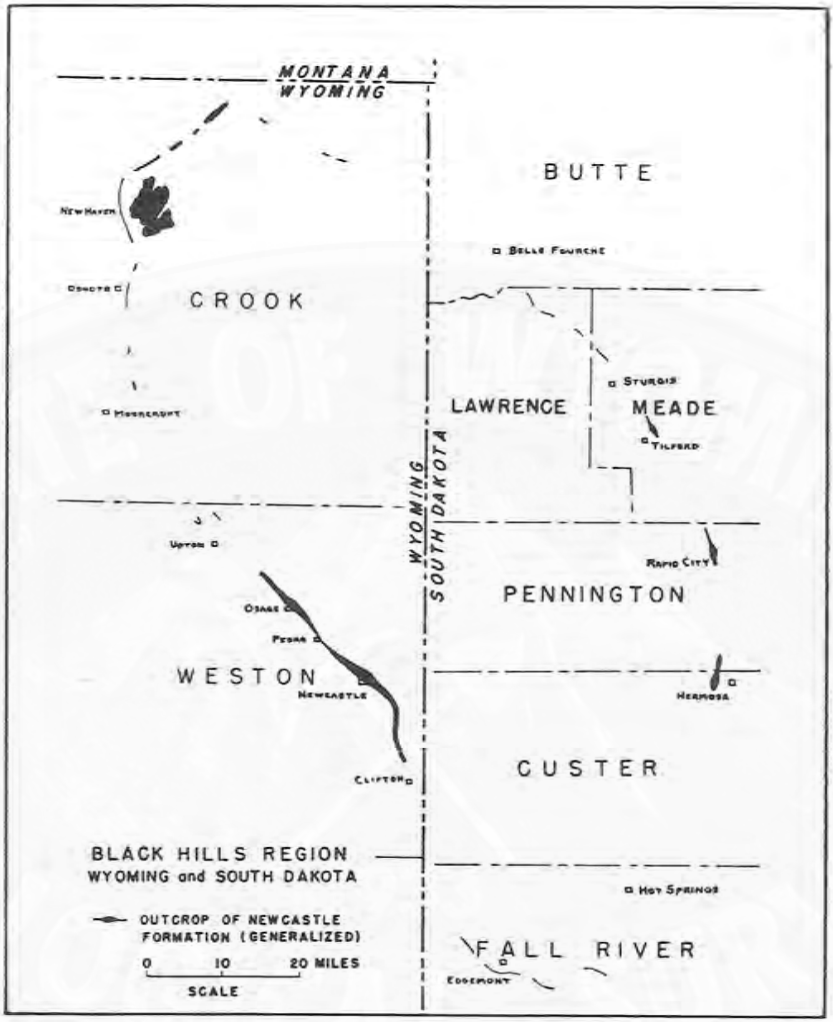

Fig. 1. Outcrop of the Newcastle formation, Black Hills region, Wyoming and South Dakota.

OUTCROP BELT

The Newcastle formation is underlain and overlain by shale, and in those few areas where the sand is well-developed, it has a prominent topographic expression. Along most of the flanks of the Black Hills, however, the Newcastle is poorly developed, and there is little or no differentiation between it and the enclosing shale. For this reason, it was necessary to conduct a diligent search of the horizon at which the Newcastle formation occurs in order to gain a reasonably accurate pattern of its distribution. The stratigraphic horizon of the Newcastle

formation was followed for a distance of 300 miles around the Black Hills uplift, and each occurrence of the formation was noted. The study began at the Wyoming-South Dakota state line near Clifton, Wyoming (Fig. 1). From this point the outcrop belt extends northwestward, passing near Newcastle, Osage, and Moorcroft, Wyoming. From the vicinity of Moorcroft, the belt extends northward and then northeastward almost to the Wyoming-Montana state line where it turns abruptly to the southeast, passing into South Dakota to Belle Fourche. Continuing southeastward, the belt extends to Sturgis, Tilford, and Rapid City, thence southward to Hermosa and Buffalo Gap. The outcrop belt was not investigated on the south flank of the Black Hills in the vicinity of Edgemont, South Dakota.

FIELD WORK

For three weeks prior to the field work well samples and electric logs from wells in the Black Hills area were examined.

Field work began July 1, 1950, and ended September 5, 1950. During the first month the Newcastle outcrops on the east, north, and northwest flanks of the Black Hills were investigated. Two sections were measured from the top of the Fall River sandstone to the top of the Greenhorn limestone; seven were measured from the top of the Fall River to the top of the Newcastle formation; and six sections of the Newcastle only were measured. During the second month a detailed study of the Newcastle formation was made on the west flank of the Black Hills in the vicinity of Osage, Pedro, Newcastle, and Clifton, in Weston County, Wyoming. Two sections were measured from the top of the Fall River to the top of the Greenhorn limestone; three were measured from the top of the Fall River to the top of the Newcastle; and 18 were measured of the Newcastle formation only (Fig. 2).

All sections were located with reference to U. S. General Land Office Survey markers by means of plane table and alidade.

Overall stratigraphic thicknesses were measured with the plane table and alidade, and the dip of the beds was calculated by establishing three points of elevation on recognizable horizons. Supplementary measurements were taken with a 200-foot steel tape. At most places the thickness of the Newcastle formation was taken by direct measurement with a six-foot folding carpenter's rule. It was found that this type of rule is a very convenient and accurate tool for obtaining direct measurement of flat-lying beds.

In order to check any discrepancies, stratigraphic thicknesses were calculated before leaving each section. In the Osage-Newcastle area, where sections were measured close together, each lithologic unit in the Newcastle formation was plotted in columnar form as it was measured so that rapid facies changes would be apparent.

Samples were taken from each lithologic unit. The lithologic descriptions made in the field were supplemented by studying the samples with a binocular microscope.

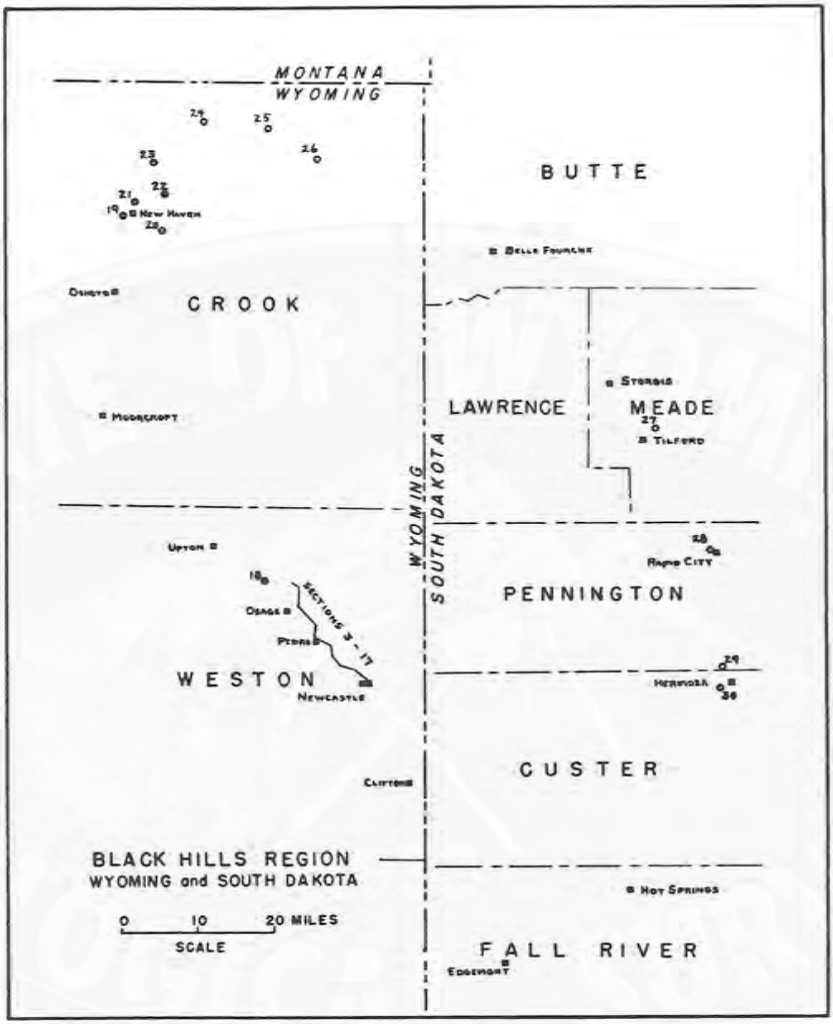

FIG. 2. Map showing location of stratigraphic sections.

ACKNOWLEDGMENTS

The field work for this investigation was made possible by the active and generous support of Stanolind Oil and Gas Company. The author wishes to thank Mr. J. C. Johnston, Mr. M. D. Hubley, and Dr. G. L. Taylor of that company for their encouragement and their interest in the problem.

Dr. S. H. Knight, Head of the Department of Geology, University of Wyoming, made available the facilities of the department; and Dr.

H. D. Thomas, thesis director, and Dr. D. L. Blackstone offered valuable criticism and suggestions in the preparation of the thesis.

Especial thanks are due Mr. Eugene G. Williams, graduate student, University of Illinois, for his assistance in the field work.

CRETACEOUS STRATIGRAPHY OF THE BLACK HILLS

The Cretaceous rocks of the Black Hills region have an average thickness of 6,000 feet and are divided into three groups, the Inyan Kara at the base, the Colorado, and the Montana above (Rubey, 1930, pp. 3-5).

The Inyan Kara group is of Lower Cretaceous age and consists predominantly of sandstone. It has a thickness of 150 to 350 feet, and except for the top 20 feet, it is considered to be of continental origin on the basis of cycads, dinosaur bones, and deposits of coal. Scanty fossil evidence found in the top 20 feet suggests that this part of the group is of marine origin (Rubey, 1930, p. 5). The Inyan Kara group is overlain by the Colorado group which has a general thickness of 1,700 feet and consists principally of marine shales but contains several poorly developed sandstones and limestones. The Colorado group is of Upper Cretaceous age except for the lowermost 200 feet. This basal unit, the Skull Creek shale, is of Lower Cretaceous age. The Colorado group is separated from the overlying Montana group by a distinct faunal change (White, 1878, pp. 21, 22, 30). The Montana group is composed of marine shales and some sandstones and has an average thickness of 4,000 feet.

NOMENCLATURE OF THE INYAN KARA AND THE COLORADO GROUPS

The division between the Lower and the Upper Cretaceous series in the Black Hills has been placed successively higher in the section since the strata involved were first described in 1880 (Newton and Jenney, pp. 169-186). The recognition by subsequent workers that older Cretaceous rocks were present resulted in several changes in the nomenclature (Table 1). Other geologists have subdivided the larger units into smaller ones, resulting in several new stratigraphic names.

The Upper Cretaceous nomenclature introduced by Meek and Hayden (1862, pp. 418-419) for rocks of that age in Nebraska was applied to the whole Cretaceous section of the Black Hills by Newton and Jenney (1880, pp. 171-175). Darton (1901, p. 526) restricted the name, Dakota, used by Newton, to include only the upper sandstone because the lower rocks had been found by Ward (1894, p. 254) to be of Lower Cretaceous age. Darton applied the new names, Fuson shale and Lakota sandstone, to the Lower Cretaceous rocks. The Dakota sandstone, as restricted by Darton, was later found to be of Lower Cretaceous age and a new name, Fall River sandstone, was introduced by Russell (1927, p. 402). Fossils found in the Skull Creek shale have shown that this unit is also of Lower Cretaceous age, and the Lower Cretaceous-Upper Cretaceous boundary is now drawn at the base of the Newcastle formation (Reeside, 1944).

NEWTON 1880	DARTON 1901	COLLIER 1922	RUBEY 1930	REESIDE 1944	CROWLEY 1951
NIOBRARA GROUP NO. 3	NIOBRARA FM	NIOBRARA SH	NIOBRARA FM	NIOBRARA FM	
FORT BENTON GROUP NO. 2	CARLILE FM (BENTON GROUP (1))	CARLILE SH (COLORADO GROUP (3))	CARLILE SH	CARLILE SH	
	GREENHORN LS (BENTON GROUP (1))	GREENHORN LS (COLORADO GROUP (3))	GREENHORN FM (COLORADO GROUP)	GREENHORN LS	
	GRANEROS SHALE (BENTON GROUP (1))	BELLE FOURCHE SH MBR (4) (GRANEROS SHALE (COLORADO GROUP (3)))	BELLE FOURCHE SH MBR (GRANEROS SHALE (COLORADO GROUP))	BELLE FOURCHE SH	BELLE FOURCHE SH (GRANEROS SH)
		MOWRY SH MBR (5) (GRANEROS SHALE (COLORADO GROUP (3)))	MOWRY SILICEOUS SH MBR (9) (GRANEROS SHALE (COLORADO GROUP))	MOWRY SH	MOWRY SH (GRANEROS SH)
		NEFSY SH MBR (6) (GRANEROS SHALE (COLORADO GROUP (3)))			
		NEWCASTLE SS MBR (7) (GRANEROS SHALE (COLORADO GROUP (3)))	NEWCASTLE SS MBR (GRANEROS SHALE (COLORADO GROUP))	NEWCASTLE SS	NEWCASTLE SS MBR (13) (SKULL CREEK SH (GRANEROS GR.))
		SKULL CREEK SH MBR (8) (GRANEROS SHALE (COLORADO GROUP (3)))	SKULL CREEK SH MBR (GRANEROS SHALE (COLORADO GROUP))	SKULL CREEK SH (12)	SKULL CREEK SH (SKULL CREEK GR.)
DAKOTA GROUP NO. 1	DAKOTA SS (2)	DAKOTA SS	FALL RIVER SS (10) (INYAN KARA GROUP (11))	FALL RIVER SS (INYAN KARA GROUP)	FALL RIVER SS (INYAN KARA GROUP)
	FUSON FM	FUSON FM	FUSON FM	FUSON SH (INYAN KARA GROUP)	FUSON SH (INYAN KARA GROUP)
	LAKOTA FM	LAKOTA SS	LAKOTA SS (INYAN KARA GROUP)	LAKOTA SS (INYAN KARA GROUP)	LAKOTA SS (INYAN KARA GROUP)

TABLE 1. Evolution of the Nomenclature of the Inyan Kara and the Colorado Groups. Heavy line indicates division between lower and upper Cretaceous. Numbers refer to explanatory notes on pages 10 to 11.

A microfauna identical with one contained in the Skull Creek shale was found in the Newcastle formation by Crowley (1951, pp. 83-84). This fauna does not seem to occur in the superjacent Mowry shale. For this reason Crowley believes that the Newcastle formation belongs more properly in the Lower Cretaceous.

Explanatory Notes Concerning Nomenclature Used in Table 1.—

(1) The Benton group was divided into three formations, and names used in southeastern Colorado were applied to the rocks in the Black Hills because of the similarity of lithology and stratigraphic position (Darton, 1901, pp. 532-533).

(2) "The sandstone series formerly designated 'the Dakota sandstone' or 'Cretaceous No. 1,' has in the last few years been found to comprise not only a formation carrying an Upper Cretaceous flora but an extensive series of Lower Cretaceous deposits as well. Accordingly, the term Dakota has been restricted to the upper sandstone, containing the Upper Cretaceous flora, while the much thicker lower series has been separated as Lower Cretaceous, and as it consists of several stratigraphic units these will here be differentiated as separate formations" (Darton, 1901, p. 526).

(3) The term, Colorado group, was introduced by King and defined by Hayden (1876, p. 45) to include the Fort Benton, Niobrara, and Fort Pierre divisions of the Cretaceous. On the basis of paleontological evidence, White (1878, pp. 21, 22, 30) restricted the Colorado group to include only Fort Benton and Niobrara.

(4) The Belle Fourche shale member was defined by Collier (1922, pp. 77, 83) as the top member of the Graneros shale. The name was taken for exposures along the Belle Fourche River, Crook County, Wyoming.

(5) The Mowry shale is a widespread Upper Cretaceous formation in Wyoming, Montana, and western South Dakota. It was originally defined by Darton (1904, pp. 399-400) from exposures on the east side of the Bighorn Mountains. On the southeastern flank of the Black Hills the Mowry shale cannot be differentiated from the superjacent and subjacent shales.

(6) The name, Nefsy shale member of Graneros shale, was used by Collier (1922, p. 82) to designate the soft dark shale of variable thickness overlying the Newcastle formation and underlying the Mowry shale.

(7) The Newcastle sandstone member of the Graneros shale was named by Hancock (1920, pp. 39, 42) for conspicuous exposure at Newcastle, Wyoming. This sandstone had been noted as an "oil sand" in earlier reports by Darton (1901, p. 532), and Knight (1902, p. 9). It probably correlates with the Muddy sandstone of other parts of Wyoming (Reeside, 1944).

(8) The Skull Creek shale member of the Graneros shale was named by Collier (1922, p. 79) for exposures along Skull Creek southeast of Osage, Wyoming.

(9) The soft shale, formerly called Nefsy, is now included in the Mowry shale (Rubey, 1930, p. 4). The non-siliceous soft shale is gradational with the superjacent siliceous hard shale.

(10) Fossil plants of Lower Cretaceous age proved that the Dakota sandstone, as restricted by Darton, is much older than the typical Dakota sandstone of eastern Nebraska. For this reason the name, Fall River sandstone, was introduced by Russell (1927, p. 402).

(11) The name, Inyan Kara group, was applied by Rubey (1930, p. 5) to the variable succession of sandstone, sandy shale, conglomerate, and siltstone which is equivalent to the Fall River sandstone, Fuson formation, and Lakota sandstone, because these units cannot always be distinguished.

(12) The Skull Creek shale was classed as Lower Cretaceous by Reeside (1944).

(13) Crowley (1951, pp. 83-84) has placed the Newcastle in the Lower Cretaceous because he found in this formation a microfauna identical to the one in the Skull Creek shale and different from the one in the Mowry shale.

STRATIGRAPHY OF THE NEWCASTLE FORMATION

EARLY INVESTIGATORS

The Newcastle formation received little notice by the early geologists in the Black Hills. Darton (1901, p. 532) first noted this formation in his description of the Graneros shale, as follows:

> In some areas it contains, near its base, a thin layer of hard sandstone which often rises in a ridge of considerable prominence. This sandstone is a noticeable feature in the vicinity of Newcastle, where it contains petroleum and has been explored as an oil sand. It there attains a thickness of 30 feet and lies 275 feet above the Dakota sandstone. To the north, in the vicinity of Pedro, it thins to less than a foot in thickness, and in the vicinity of Edgemont it disappears. In the Newcastle region it is overlain by 600 feet of black shales, constituting the remainder of the formation which here, consequently, has a total thickness of 900 ft.

In the same report Darton also described a sandstone lens west of Hermosa, South Dakota, which he correlated with the sandstone at Newcastle, Wyoming.

In 1902 Knight described the "oil sand" at Newcastle, recognizing its value as a future source of petroleum.

The sandstones known now as the Muddy and the Newcastle were correlated by Darton (1904, p. 445), who noted that:

> The sandstone in the lower portion of the Graneros appears to extend almost continuously through southeastern Wyoming, and it appears at intervals around the Black Hills, notably at Newcastle, Hermosa, and at the northern end of the uplift, but it does not appear in the Bighorns unless possibly at one locality.

The first detailed study of the Newcastle formation was made by Hancock in connection with a description of the stratigraphy and structure of the Upton-Thornton, the Mule Creek, and the Lance Creek oil fields, all of which are located in the vicinity of the Black Hills. The field work for these investigations was done in 1918 and 1919.

The name, Newcastle, was first applied by Hancock in his report on the Mule Creek oil field (1920, p. 40):

> These beds attain an unusual thickness at Newcastle and are oil bearing at that locality, so for convenience of description they are named the Newcastle sandstone member.

A shale and siltstone sequence outcropping near Osage was referred to as the Newcastle sandstone by Collier (1922, pp. 80-82). Thus he recognized that this formation is not always predominantly sandstone. It appeared to Collier, as it did to later investigators, that the Newcastle formation was deposited in shallow water near an exposed land surface.

In a description of the distribution of the Newcastle sandstone around the Black Hills, Sinclair (1926, pp. 806-807) used the term, sandstone, literally and reported only two thin sand members in the outcrop at Osage. Actually the formation has an average thickness of 50 feet at this locality, but the sequence is predominantly shale and siltstone.

The south flank of the Black Hills was not investigated by the writer, but this area has been studied by Russell (1927, p. 403), who noted evidence of both a terrestrial and a marine origin of the Newcastle formation. His description is given below:

> Just above this member [Skull Creek shale], and just below the base of the Mowry shale, is the horizon of the Newcastle sandstone. This sandstone is of two types, one of which is soft and contains fish scales and no traces of pink clays or terrestrial fossils. It is probably of marine origin. The other type is harder and is associated with light gray and pink clays, leaves and thin streaks of coal. Owing to its hardness it generally forms a prominent ridge. It contains no fish scales and is apparently chiefly of terrestrial origin. In places this phase reaches a thickness of about 30 feet.

It is not clear whether this description pertains to the Newcastle formation on the south flank of the Black Hills only, or whether it is intended to be a general description of this formation applicable to the whole Black Hills region.

The fact that the Newcastle formation is not always composed predominantly of sandstone is apparent in the description of this unit by Rubey (1928, p. 154), who stated that it is "a variable unit of sandstone, shale, lignite, bentonite, and phosphatic nodules from a few inches to 75 feet thick."

Dobbin (1947, p. 802) briefly described the lithology and the depositional environment of the Newcastle formation at Osage as follows:

> The Newcastle sandstone is a highly variable zone of discontinuous beds of sandstone, shale, sandy shale, impure lignite, and bentonite, containing both continental and marine or brackish-water fossils. Petrified wood, ripple marks, cross-bedding, and dinosaur bones also indicate its shallow water origin.

An extensive investigation of the Newcastle formation in the subsurface of the Mush Creek and Skull Creek fields was made by Summerford, Schieck, and Hiestand (1949, pp. 69-79). They concluded that the sediments were derived from remote source areas and deposited in a near-shore environment, and that the distribution of the various sand beds was accomplished by wave, current, and eddy action similar to present-day processes known to occur in the Gulf of Mexico on the continental shelf.

Crowley (1951, p. 89) postulated a possible uplift of the Black Hills during Newcastle time, as follows:

> The evidence of shallow-water deposition of the Newcastle sandstone suggests the presence of a landmass close at hand. The presence of gold identical in analysis with that found in pre-Cambrian rock in the Black Hills, together with the presence of cassiterite, suggests that the Black Hills area may have been the landmass that contributed to the sediment. Furthermore, these facts suggest that a part of the Black Hills, and particularly the Harney Peak region, may have been denuded to the pre-Cambrian at the time the Newcastle sandstone was being deposited.

The Muddy sandstone is considered to be the basal unit of the Upper Cretaceous series and is correlated with the Newcastle formation (Reeside, 1944). Crowley (1951, pp. 83-84) found the microfauna of

the Skull Creek shale in some of the shale beds of the Newcastle formation and placed the Newcastle in the Lower Cretaceous series. The results of his work indicate the need for additional study on both the age and correlation of the Muddy sandstone and the Newcastle formation.

FACIES NOMENCLATURE

The early workers in the Black Hills region thought of the Newcastle formation as discontinuous sandstone lenses. Later workers (Collier, 1922; Russell, 1927; Rubey, 1928; Dobbin, 1947) have shown that beds of many other lithologies are present. The writer's work shows that while the Newcastle formation can be discriminated as a unit, it is not always one consisting predominantly of sandstone, for in some places it is primarily a siltstone and shale sequence. The best example of the differing lithology of the Newcastle formation is found in a comparison of the outcrop at Newcastle with that near Osage (Pl. 1). At the former, the lithologic succession is predominantly sandstone, while at Osage it is primarily siltstone and shale. The areal distribution of the shale and siltstone facies of the Newcastle around the Black Hills is of the same magnitude as that of the sandstone facies.

It is the opinion of the writer that the name, Newcastle sandstone, as used by previous workers, is a misleading term. The more inclusive term, Newcastle formation, has, therefore, been used, recognizing a sandstone facies and a shale-siltstone facies. In addition, two phases are recognized, one a carbonaceous phase best developed in the Newcastle and Osage area, and the other a non-carbonaceous phase best developed on the east flank of the Black Hills.

AREAL DISTRIBUTION

The Newcastle changes laterally from a sandstone to a shale-siltstone facies. The formation is also lens-like in that its total thickness decreases in both directions along the outcrop from points of maximum thickness.

The Newcastle formation thickens into lenses in seven of the areas studied. For clarity of description these lenses are named, and in a clockwise order are as follows (Fig. 1): (1) the Newcastle lens, (2) the Osage lens, (3) the New Haven lens, (4) the Little Missouri lens, all in Wyoming; and (5) the Tilford lens, (6) the Rapid City lens, and (7) the Hermosa lens, in South Dakota.

The Newcastle lens.—In Wyoming the southern limit of the outcrop study was at Clifton, in Weston County, where the Newcastle is two feet thick and is obscured to the southeast by a cover of alluvium. Three miles north of this town, along Whoopup Creek, the thickness increases in less than one mile to 45 feet. Northward, this thickness is maintained with some variation almost to the town of Newcastle, where the formation thickens rapidly to a maximum of 85 feet. West and northwest of Newcastle, the formation is at least 60 feet thick for three miles, 30 feet thick for the next three miles, thinning to 10 feet in one additional mile.

A thickness of 10 feet is maintained for four more miles, and then the Newcastle formation again thickens into another lens east and north of Osage.

This Newcastle lens can be considered to have a lateral extent of 25 miles along the outcrop, extending from Clifton, where it is two feet thick, to Pedro, where it is 10 feet thick, reaching its maximum development at Newcastle, between these two towns. The lens is composed of thick layers of sandstone interbedded with thinner layers of shale, siltstone, and bentonite.

The Osage lens.—In contrast to the Newcastle lens, the Osage lens consists predominantly of shale and siltstone. A point in sec. 31, T. 46 N., R. 62 W., near Pedro, is arbitrarily taken as the division between the Newcastle and the Osage lenses. Northwest from this point the formation begins to thicken, and within three miles it is 40 feet thick, increasing to 70 feet in one additional mile to a point east of Osage. Northwest from this point near Osage, the Newcastle thins to 50 feet in a distance of two miles and maintains this thickness for at least five miles, beyond which the thickness could not be measured because of poor outcrops. Eleven miles northwest of the point where the outcrop is lost, however, the formation is only five feet thick where it is exposed at Thornton dome.

Between Thornton dome and the next exposure of the Newcastle to the northwest, the formation is covered. In sec. 24, T. 51 N., R. 67 W., 10 miles northeast of Moorcroft, the Newcastle formation is 27 feet thick and forms an isolated ridge of low relief. North of this outcrop the Newcastle is a thin, poorly exposed unit for 10 miles. One mile east of Oshoto, it is only three or four feet thick, consisting of thin-bedded sandstones interbedded with shale.

The New Haven lens.—For a distance of about seven miles north of Oshoto the Newcastle formation remains a thin, poorly developed, poorly exposed unit. Three miles south of New Haven, however, it has a thickness of 34 feet, and it is 44 feet thick one mile north of New Haven. The formation thins slightly to the east of New Haven and maintains a thickness of about 25 feet over an area of 20 square miles. In the vicinity of New Haven the strata are flat-lying, and the Newcastle formation caps the top of a dissected plateau. The flat-lying Newcastle formation in this area is composed almost entirely of sandstone and forms a plateau surface six miles wide in an east-west direction, and seven miles long in a north-south direction. West and northwest from the New Haven lens, the formation forms a narrow outcrop band where it dips beneath the overlying strata. Here it has a thickness of only five feet.

The Little Missouri lens.—North and northeast from the New Haven lens, the Newcastle formation thickens to form another lens on the north bank of the Little Missouri River. The outcrop of this lens extends almost to the Wyoming-Montana state line and has a lateral extent of 15 miles. The maximum development of the formation found in this lens is in sec. 16, T. 57 N., R. 65 W., where it is 80 feet thick and consists predominantly of siltstone and shale.

Area between the Little Missouri lens and Belle Fourche, South Dakota.—From the northernmost outcrop of the Little Missouri lens, near the Wyoming-Montana line, southeastward to Belle Fourche, South Dakota, a distance of 40 miles, the Newcastle formation is poorly developed or entirely absent.

Isolated outcrops of the formation lie in sec. 24, T. 57 N., R. 64 W., four miles south of the Little Missouri River. In this area the beds dip two or three degrees to the north, and erosion has sculptured the Skull Creek shale into undulating hills. The Newcastle formation caps several of these small hills and is 25 feet thick.

Within several hundred feet of these outcrops are numerous intruded sandstone dikes and masses which also cap hills of Skull Creek shale and which could easily be mistaken for the Newcastle formation. The sandstone masses are situated at the proper horizon for the Newcastle formation, but they do not lie in a plane. The proximity of these masses to outcrops of the Newcastle formation further adds to the danger of misidentification.

A second occurrence of intruded sandstone is found eight miles to the southeast in sec. 7, T. 56 N., R. 62 W. Masses of sandstone are found here, but no dikes are present. Within several hundred feet, outcrops of the Newcastle formation are found which are 25 feet thick, consisting mainly of siltstone with interbedded bentonite. No Newcastle was found east between this locality and Belle Fourche, South Dakota.

Belle Fourche area.—Four miles west of Belle Fourche, there is a dark-brown, ferruginous mass of sandstone 10 feet thick. It has no bedding and lies 50 feet below the base of the Mowry siliceous shale, which outcrops on a tree-covered ridge less than one mile to the north. Five miles northwest of this mass, a five-inch thick hard ferruginous dike was found at the same horizon. There is a large mass of sandstone five miles southeast of Belle Fourche in the N½ sec. 18, T. 8 N., R. 2 E. This sandstone, which protrudes from a Tertiary-covered hill, is 20 feet thick and lies 40 feet below the base of the Mowry siliceous shale. Lithologically the mass of sandstone is identical to the upper part of the Fall River sandstone exposed one mile to the west and is much like the Newcastle formation near Tilford, South Dakota. It is also very similar to the previously mentioned sandstone masses found in northeastern Wyoming. Russell (1927, pp. 404-405) found intruded sandstone dikes and masses at this locality and also at points a few miles south and southwest of Belle Fourche.

Southeastward from Belle Fourche to the vicinity of Sturgis, the Newcastle formation is present as a thin layer, never more than five feet thick. Its presence is difficult to discern, for it commonly underlies level grassy fields.

The Tilford lens.—Three miles northeast of Tilford, the Newcastle formation thickens to 18 feet and maintains this thickness for a distance of less than one mile along the outcrop. The lens is composed almost entirely of friable sandstone, yet it is resistant enough to form a tree-covered hill.

The Rapid City lens.—The first outcrop found southeast from Tilford is at a point three miles north of Rapid City. Here the formation is 27 feet thick, consisting primarily of shale but containing three feet of sandstone. The Newcastle formation is not exposed between this point and Rapid City. Within the city limits of Rapid City the Newcastle formation is 25 feet thick, consisting almost entirely of sandstone and forming a ridge one mile long.

The Hermosa lens.—The next exposure of the Newcastle formation begins 16 miles south of Rapid City and extends for three miles, forming a dumbbell-shaped lens 16 feet thick on the north end, half that thickness in the middle, and 54 feet thick on the south end. This lens is composed predominantly of sandstone and is located in T. 2 S., R. 8 E., near the town of Hermosa, South Dakota. For 20 miles south of Hermosa the outcrop belt of the Newcastle formation is covered by a blanket of Tertiary rocks. Twenty-five miles south-southwest from Hermosa, a section was measured from the top of the Fall River sandstone to the top of the Greenhorn limestone, but no representation of the Newcastle formation was found at the horizon where it should occur. Several sandstone beds less than one foot thick, however, were found in the lower half of the Skull Creek shale. This area was the southernmost point studied in South Dakota.

LITHOLOGY OF THE NEWCASTLE FORMATION

The Newcastle formation can be divided into two phases depending upon the presence or absence of black carbonaceous matter. The carbonaceous phase is found in Wyoming on the west and northwest flanks of the Black Hills and is best developed in the Newcastle, Osage, and Little Missouri lenses of the Newcastle formation. The non-carbonaceous phase is found in South Dakota on the east side of the Black Hills in the Tilford, Rapid City, and Hermosa lenses.

THE CARBONACEOUS PHASE

The carbonaceous material occurring in the carbonaceous phase of the Newcastle formation consists of wood fragments and leaves. The carbonized wood is found as soft black angular fragments varying in length from a fraction of an inch to 4 or 5 inches. The cell structure of the wood has been preserved and appears always to have the same box-like structure. In contrast to the usual soft carbonized wood fragments, some are found which are hard, siliceous, and rounded. The maximum length of these fragments is about three inches. The state of preservation of the siliceous wood indicates that it underwent a series of events prior to deposition different from that of the soft wood fragments, although, when present, the hard pieces occur together with the soft pieces. The hard wood fragments apparently were first carbonized and then replaced by silica. The rounding of these pieces may have been produced by stream transport, but it is possible that it was done by fire. These pieces of wood, except for their weight, closely resemble charcoal fragments in the ashes of a wood fire. Some of them are only par-

tially carbonized, and, where they weather out on the surface, could easily be mistaken for the remains of a camp fire. It is possible that these silicified fragments may be evidence of a forest fire in Cretaceous time. The few leaf imprints which were found were examined by Dr. R. W. Brown, of the United States National Museum, but because of the poor preservation of the specimens, he was unable to determine whether they represent Lower or Upper Cretaceous plants.

The carbonaceous phase is characterized by a sequence of interbedded sandstones, siltstones, shales, and bentonites.

Sandstones.—The sandstones exhibit cross-bedding on both large and small scales, but they may also be plane-bedded and massive. In the upper part of the formation, some of the bedding planes are ripple-marked. Some of the sandstones are bentonitic, and in places the top sandstone is slightly calcareous and may be of marine origin. The texture is usually very fine to fine and the grains are sub-angular to sub-rounded. The grains in some of the beds have been enlarged by secondary growths of quartz, the crystal faces of which impart a sparkly appearance to the sandstone. Accessories found are mica, black grains, and pink and smoky quartz. The mica is clear with sharp edges showing no alteration. The black grains, probably magnetite, are hard and have smooth surfaces. When weathered, they stain the surrounding quartz grains brown. The size of the colored quartz grains is the same as that of the clear quartz grains.

In the sandstones, the carbonaceous matter is found on the bedding planes or disseminated through the sandstone. The long pieces of carbonized wood are not always parallel to the bedding but lie at all angles, suggesting rapid burial. In the sandstones which exhibit large-scale cross-bedding the carbonaceous material is mainly concentrated in the lower part of each bed.

Siltstones.—Siltstone is found predominantly in Wyoming on the west side of the Black Hills and is most conspicuous in the Osage lens, where it is hard, argillaceous, and massive, forming the basal 10 to 15 feet of the Newcastle formation. The siltstones contain the same accessory minerals as those found in the sandstones. Thin beds of siltstone interbedded with sandy shales are present in the upper part of the formation. Carbonaceous material is found disseminated in the siltstones but not as abundantly as in the sandstones. Lateral gradation of the siltstone into sandstones or into carbonaceous shales was noted, particularly in the Osage lens.

Shales.—Beds of shale form a prominent part of the lithologic sequence of the carbonaceous phase of the Newcastle formation. Some of the shale beds have thicknesses as great as 10 feet and, because of their lighter color, are distinct from the Skull Creek and Mowry shales. Many of the shales of the Newcastle formation are bentonitic and silty. In addition to the light-colored shales, there are jet-black and dark-brown carbonaceous shales described by some geologists as sub-lignite. The black carbonaceous shales are generally hard and dry and sometimes

bentonitic. Small pieces of clear amber and paper-thin layers of coal were found in these shales in the Newcastle and Osage lenses. In almost every outcrop of the carbonaceous phase of the Newcastle formation, a black carbonaceous shale was found subjacent to a pure bentonite. In the Osage and Newcastle lenses, some of the beds of black carbonaceous shale can be traced laterally into a non-carbonaceous shale or else into a siltstone or a sandstone.

Bentonite.—The beds of bentonite in the carbonaceous phase of the Newcastle formation vary in thickness from a fraction of an inch to five feet. At the outcrop the bentonite is generally cream-colored or very light-yellow and green. A differential thermal analysis of 20 samples of bentonite collected from the Newcastle and Osage lenses was made by Stanolind Oil and Gas Company. The three-foot bentonite near the top of the Newcastle formation in these two lenses contains from 95 to 100 percent bentonite, the remainder being kaolin. The thermal curves are almost identical for all of the beds of bentonite sampled. On these curves there are two conspicuous "breaks," one between 175° and 210°C, the other between 700° and 730°C. A minor "break" occurs at 940°C.

THE NON-CARBONACEOUS PHASE

The non-carbonaceous phase is developed only in the Tilford, Rapid City, and Hermosa lenses. There is carbonaceous matter in the top three feet of the Hermosa lens, and there are impressions of wood fragments in some of the sandstone beds of the Hermosa and Rapid City lenses, but in comparison to the carbonaceous phase, the amount of carbonaceous matter is negligible. The three lenses in South Dakota comprising the non-carbonaceous phase consist almost entirely of sandstone, the shale and siltstone present occurring only in the top few feet.

Sandstones.—The sandstones of the non-carbonaceous phase are very similar to those of the carbonaceous phase, but a few differences should be noted. The sandstone beds are of medium thickness, and the cross-bedding is always on a small scale. The sorting of the grains is generally good with very little interstitial clay and silt. These grains have a matt surface and are commonly more rounded than those of the carbonaceous phase. Mica is present in the Tilford lens, at the north, in about the same quantity as in those sandstones of the Newcastle formation in Wyoming. Southward, mica becomes less conspicuous and is absent or rare in the Hermosa lens. Dark grains and colored quartz, however, are rare in the Tilford lens but increase in abundance to the south.

Siltstones, shales, and bentonite.—The only shales and siltstones present in the lenses of the non-carbonaceous phase occur as thin beds at the top of the Newcastle formation. Lithologically these shales and siltstones are the same as those found in Wyoming. The only bentonite found in the non-carbonaceous phase occurs at the base of the Hermosa lens. This bentonite is identical to that found in lenses of the carbonaceous phase.

INTRUDED SANDSTONE DIKES AND MASSES

A study of the intruded sandstone dikes and masses in the Black Hills region was not a part of the writer's problem; however, their peculiar association with the Newcastle formation is of interest.

Most of the dikes and masses found are in sec. 24, T. 57 N., R. 64 W., and in sec. 7, T. 56 N., R. 62 W., in Crook County, Wyoming. Others were found a few miles south of Belle Fourche, South Dakota.

The dikes vary in thickness from a fraction of an inch to 10 feet. Most of them are nearly vertical, but a few approach the horizontal. Vertical slickensides are common on the outer surfaces, probably indicating movement subsequent to the emplacement of the dikes. The sandstone masses range in thickness from 10 to 20 feet and have a length and width two to three times that amount. The original size of these masses probably has been reduced by erosion, for they cap small hills cut into the subjacent Skull Creek shale. The masses exhibit some bedding, but this feature is poorly developed and is not parallel to the regional dip. No feeders, or pipes, were found leading to the masses, but dikes are usually present within a hundred feet of them.

Russell (1927, pp. 402-408) studied the intruded sandstone dikes and masses in South Dakota and noted that they occur most abundantly on the north and south flanks of the the Black Hills. He reported that the sandstone forming the dikes was derived from a marine sandstone in the Mowry, because this sandstone and the intruded sandstone are lithologically similar and both contain fish scales and bone fragments. The intruded sandstone dikes and masses in Crook County are lithologically similar to the Fall River sandstone and to the sandstone in the Newcastle formation. They do not contain organic matter, and the sandstone in the Mowry is poorly developed in this area. There is very little sandstone in the Newcastle formation in Crook County in the region where the intruded dikes and masses are found. It is believed, therefore, that the intruded sandstone in Crook County was derived from the Fall River sandstone.

THE DEPOSITIONAL ENVIRONMENT OF THE NEWCASTLE FORMATION

EXISTENCE OF AN ISLAND IN THE BLACK HILLS AREA

The writer believes that the Newcastle formation was deposited near the shore of a small island in the Cretaceous sea. Several previous workers (Collier, 1922; Dobbin, 1947; Summerford, Schieck, and Hiestand, 1949) have referred to a nearby land area to explain the carbonaceous matter and shallow water features found in the Newcastle formation. These writers, however, did not delineate the areal extent and location of this land area, perhaps because they were concerned only with the Newcastle formation in the vicinity of Newcastle. The writer studied the Newcastle formation over a large area and found evidence of a near-shore environment not only around Newcastle but also along the entire western and northwestern flanks of the Black Hills. Shallow water features were found in the Newcastle formation on the east flank, but the

almost total lack of carbonaceous matter suggests that the landmass lay closer to the present west flank and comprised an area much smaller than that of the Black Hills. The only previous worker to delimit a landmass was Crowley (1951), who postulated an uplift in the eastern part of the Black Hills during Newcastle time. He described gold found in the Newcastle formation which is identical with gold from the pre-Cambrian rocks in the Harney Peak region of the Black Hills.

The fine texture of the sandstone in the Newcastle formation almost precludes the possibility of an island of any appreciable relief, especially relief sufficient to expose the pre-Cambrian, as Crowley postulated. Every indication points to a land area that was low and swampy and covered with vegetation. The island was not necessarily the source of the sands of the Newcastle formation, but some of the finer sediments may have been derived from it.

EXPLANATIONS FOR THE ISLAND'S ORIGIN

There are at least three possible explanations for the origin of the island that seems to have existed during Newcastle time.

Lowering of sea level.—The Skull Creek shale, like its equivalent, the Thermopolis shale, is a widespread unit with little variation in thickness. This shale could have been deposited throughout the Black Hills area, and, following this, a lowering of sea level might then have exposed as an island any irregularity that existed on the top of the Skull Creek shale.

Incomplete Submergence.—A continental environment existed in the Black Hills area during Inyan Kara time. A part of this area may have had enough topographic relief to persist as land until complete transgression of the sea submerged the area at the end of Newcastle time. The change from the continental environment of the Inyan Kara group to the marine environment of the Skull Creek shale is suggested by the marine nature of the upper 20 feet of the Inyan Kara. This top 20 feet is flaggy and ripple-marked and is probably reworked material.

Minor Uplift.—The Black Hills were formed during the Laramide orogeny, which began near the close of the Cretaceous. It seems likely that slight upwarping may have taken place at the beginning of Upper Cretaceous time.

The sandstone dikes on the flanks of the Black Hills may be taken as evidence of minor uplift just before or soon after the beginning of Upper Cretaceous time. The sandstone dikes could have been emplaced much later, but the sands from which the dikes were derived would have been most easily intruded into cracks and fissures before the source sand was indurated. The position of the dikes, for the most part on the north and south ends of the Black Hills, is related to the long axis of the uplift.

The presence of gold in the Newcastle formation typical of a pre-Cambrian area in the Black Hills is difficult to explain. The texture of the Newcastle formation does not suggest that there was an uplift of sufficient magnitude to expose the pre-Cambrian rocks, but if minor up-

lift occurred, the gold might have been derived from the Lakota sandstone, in which formation the metal is present (Stone, 1912, pp. 63-64). No analysis has been made to determine whether gold in the Lakota is related to pre-Cambrian lodes in the Black Hills.

Thinning of the Upper Cretaceous formations toward the center of the Black Hills cannot be observed because of the magnitude of the uplift during the Laramide orogeny and because of the accompanying and continuing erosion. The Upper Cretaceous formations, consisting for the most part of soft shales, dip gently away from the Black Hills and are now exposed only on the outermost flanks. The uplift during Newcastle time could have been slight, so that the area where the Upper Cretaceous strata are now exposed would not have been involved.

Conclusions.—The writer has postulated the existence in the Black Hills area during Newcastle time of an island that was the source of the carbonaceous matter in the Newcastle formation. No evidence was found to indicate that the Newcastle sediments were derived either from the island or from a distant source. If this island existed, however, it may have contributed at least some of the finer sediments.

The lenticularity and rapid facies changes of the Newcastle formation may reflect off-shore bars and brackish-water lagoons formed in the shallow water surrounding the island.

The origin of the land area remains a matter of speculation. The writer found no evidence in support of the idea that the land area resulted from a lowering of sea level or from incomplete submergence. Of the three hypotheses presented, the most tenable one would involve minor uplift. This theory would explain the occurrence of gold in the Newcastle formation and the peculiar sandstone dikes and masses on the flanks of the Black Hills. The fact that the island was formed in a region involved in later uplift adds to the support of this hypothesis.

SUMMARY AND CONCLUSIONS

The outcrop of the Newcastle formation was studied on the west, north, and east flanks of the Black Hills, and seven areas of thick development were found. The name, Newcastle sandstone, as used by previous workers, is misleading because the unit referred to contains a shale-siltstone facies in addition to a sandstone facies. For this reason, the more inclusive name, Newcastle formation, is introduced. Two phases of the formation are discriminated, a carbonaceous one on the west and northwest flanks of the Black Hills, and a non-carbonaceous one on the east flank.

Intruded sandstone dikes and masses were found in Crook County, Wyoming, and it is believed that they were derived from the Fall River sandstone.

It is concluded that (1) the western part of the Black Hills was probably a low land area during Newcastle time; (2) this land area may have originated as a result of minor uplift; and (3) the source of the Newcastle sediments cannot be determined without the benefit of still broader regional studies.

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APPENDIX

DETAILED STRATIGRAPHIC SECTIONS

SECTION 3

(NE¼ sec. 28, T. 45 N., R. 61 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
Contact, Mowry shale and Newcastle formation.		
		NEWCASTLE FORMATION
17	5.5	Sandstone, white, weathers light-brown, medium-bedded, hard; grains, very fine to fine, sub-angular to sub-rounded, matt-surfaced, sorting fair to good; pink and smoky quartz, black grains present; upper four feet, sorting good; lower foot, grain size slightly larger, sorting fair.
16	11.0	Bentonite and bentonitic clay, variegated yellow, pale-blue and green, well-bedded; lower part pure bentonite.
15	1.1	Shale, black, silty, hard, very carbonaceous.
14	2.6	Sandstone, light-gray, hard, argillaceous, poorly bedded; grains, very fine, sub-angular, sorting poor; mica present; lower foot contains silt and some black carbonaceous matter.
13	5.0	Shale, black to gray, carbonaceous; several thin siltstones near top.
12	5.0	Sandstone, light-brown, thin- to thick-bedded, hard; grains, very fine, sub-angular, sorting poor to fair; mica, pink quartz, black grains present; top foot, sorting poor, argillaceous, with some carbonaceous matter; lower four feet, sorting fair with oil staining.
11	1.7	Shale, gray, hard, bentonitic; coarse-textured; at top, several very thin sandstones, grains very fine.
10	0.1	Bentonite, white to light-gray, compact; weathered mica abundant on bedding.
9	1.7	Shale, black, hard and dry, very carbonaceous, slightly bentonitic; yellow coating on bedding planes.
8	5.75	Sandstone, light-gray to light-brown, cross-bedded; grains, very fine, sub-angular to sub-rounded, sorting poor to fair; mica, pink and smoky quartz, black grains present; top four feet, sorting poor, argillaceous, silty, grains sub-angular to sub-rounded, oil staining in part; carbonaceous in top and bottom foot.
7	2.5	Shale, light-gray, well-bedded, very bentonitic; fine-textured; one-eighth inch yellow bentonite in middle.
6	9.75	Sandstone, gray to light-yellow, argillaceous, hard, irregularly bedded with interbeds of siltstone; grains, very fine, sub-angular, sorting poor.
5	8.0	Sandstone, light-gray to light-yellow, well-bedded, argillaceous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica, pink and smoky quartz, black grains present; top two feet, slightly carbonaceous; bottom two feet, thin-bedded, very carbonaceous; silt and clay increases toward top.
4	3.5	Shale, black, silty, hard, very carbonaceous.
3	5.0	Siltstone, gray, hard, argillaceous, well-bedded; sorting poor; mica present.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
2	7.5	Sandstone, gray, argillaceous, poorly bedded, carbonaceous; grains, very fine to fine, sub-angular, sorting very poor; mica present; top half, light-gray, more argillaceous, grain size slightly larger; bottom half, dark-gray, hard.
1	10.0	Sandstone, light-gray to gray, poorly bedded, argillaceous, carbonaceous in part; grains, very fine, sub-angular to sub-rounded; mica present; black carbonaceous shale partings in top half.
	85.7	*Total thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 4

(Sec. 24, T. 45 N., R. 62 W., Weston Co., Wyo.)

Contact, Mowry shale and Newcastle formation.

NEWCASTLE FORMATION

11	9.0	Sandstone, white, thin- to medium-bedded, calcareous in parts, hard; grains, very fine, sub-angular, sorting poor to good; mica abundant in parts, black grains present that stain sand brown; upper half, sorting fair to good; lower half, sorting poor, much carbonized wood on bedding.
10	1.3	Bentonite, white, hard.
9	1.5	Shale, black, very carbonaceous, sub-lignite; breaks in large pieces.
8	0.9	Sandstone, white, silty, very slightly bentonitic, argillaceous; grains, very fine, sub-angular, sorting poor; mica and black grains present; contains some brown plant fragments.
7	5.0	Sandstone, white, medium-bedded, hard; grains, very fine, angular to sub-angular, sorting good; mica and black grains present; top one foot, calcareous in parts; lower four feet stained brown by oil, greatest in lower one foot.
6	7.0	Shale, light-gray, silty, hard, slightly bentonitic; mica present.
5	2.0	Shale, dark-gray, silty, fissile, carbonaceous; mica present.
4	6.0	Sandstone, light-gray, thin-bedded, large scale cross-bedding, carbonaceous, argillaceous; grains, very fine to fine, angular to sub-angular, sorting poor to fair; mica present, black grains rare.
3	9.5	Sandstone as above; more carbonaceous.
2	3.0	Shale, dark-gray, silty, well-bedded, carbonaceous; mica present.
1	9.0	Sandstone, light-gray, large scale cross-bedding, carbonaceous; grains, very fine to fine, sub-angular to sub-rounded, sorting poor to good; mica and black grains present; top half, argillaceous, sorting poor, hard; bottom half, sorting good.
	54.2	*Total exposed thickness of Newcastle formation.*

Lower part of Newcastle formation not exposed.

SECTION 5

(SW¼ sec. 19, T. 46 N., R. 62 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
		NEWCASTLE FORMATION
Top few feet absent by recent erosion.		
17	3.0	Sandstone, white, weathers light-brown, hard, slightly calcareous; grains, very fine, sub-angular, sorting poor; black grains present but rare; minute pieces of carbonized wood disseminated in the sand; very near the top.
16	8.0	Covered; probably gray shale and thin sandstones with three inches white bentonite five feet above base.
15	0.4	Sandstone, white, weathers light-brown, hard, breaks with sharp edges; grains, very fine, angular to sub-angular, sorting poor; mica and black grains present.
14	2.1	Covered; probably gray shale and thin sandstones.
13	1.0	Sandstone as above.
12	1.5	Shale, gray, silty.
11	3.25	Sandstone as above; thin-bedded; small amount of carbonized wood present.
10	2.0	Shale, light-gray, slightly silty, bentonitic; mica present; one-half inch bentonite in middle.
9	1.75	Shale, gray, silty, bentonitic; minute pieces carbonized wood present; at top, three inches siltstone, light-gray, bentonitic, argillaceous, carbonized wood on bedding.
8	2.0	Siltstone, gray, argillaceous, very bentonitic, hard; mica, black grains present; at top, six inches clay, orange, bentonitic, massive.
7	1.0	Siltstone and sandstone; siltstone, light-gray and pink, thin-bedded, hard, slightly bentonitic; mica and black grains present; sandstone, light-gray, argillaceous; grains, very fine, sorting poor, mica present, black grains rare; some carbonized wood present.
6	4.0	Covered.
5	4.0	Sandstone, white, weathers light yellow-brown, medium-bedded, hard; grains, very fine, angular to sub-angular, sorting good; mica present, black grains rare; carbonized wood present but rare.
4	1.0	Bentonite, light-gray, waxy.
3	4.0	Shale, black, very carbonaceous, slightly bentonitic; mica present but rare.
2	8.2	Covered; gray sandy shale in lower part.
1	17.3	Sandstone, white; grains, very fine to fine, angular to sub-angular, sorting good; pink and smoky quartz, black grains present; upper half, grain size slightly larger; lower half, poorly bedded, slightly argillaceous, and some carbonized wood present.
	64.50	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 6

(S½ sec. 10, T. 45 N., R. 62 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
		NEWCASTLE FORMATION
Top part absent by recent erosion.		
5	7.0	Sandstone, white to light-brown, thin- and cross-bedded; grains, very fine, angular to sub-angular, sorting fair to good; pink quartz, mica, and black grains present; sorting poor in lower part.
4	4.5	Sandstone, white, massive- to medium-bedded, cross-bedded in part; grains, very fine to fine, angular to sub-angular, sorting good; mica, smoky quartz, red and black grains present in small amount.
3	4.5	Sandstone, white, medium- and cross-bedded, slightly carbonaceous, slightly bentonitic; grains, very fine to fine, angular to sub-angular, sorting fair to good; mica, pink quartz and black grains present.
2	6.0	Sandstone, white, medium-bedded, large scale cross-bedding, carbonaceous in part; grains, very fine to fine, angular to sub-angular, sorting fair to good; mica, pink and smoky quartz, and black grains present; some interstitial bentonite in upper part; lower foot of each layer argillaceous and very carbonaceous with many angular fragments of carbonized wood present.
1	6.0	Sandstone as above; thin-bedded, very carbonaceous; sorting poor to fair; very near the bottom.
	28.0	*Total exposed thickness of Newcastle formation.*
Contact Newcastle formation and Skull Creek shale covered.		

SECTION 7

(W½ sec. 4, T. 45 N., R. 62 W., Weston Co., Wyo.)

		NEWCASTLE FORMATION
Top part absent by recent erosion.		
7	2.0	Sandstone, light-brown, thin- and cross-bedded; grains, very fine, sub-angular to sub-rounded, sorting good; near top.
6	0.5	Sandstone, light-brown, very thin-bedded, cross-bedded; grains, very fine, sub-angular to sub-rounded, sorting poor; mica present; less resistant.
5	2.5	Shale, gray, fissile, slightly bentonitic; mica flakes on bedding planes.
4	0.1	Bentonite, white.
3	1.75	Siltstone, light-gray, bentonitic; contains some very fine, sub-angular sand grains.
2	2.0	Sandstone, very light-brown, silty, argillaceous, slightly bentonitic; grains, very fine, sub-angular to sub-rounded.
1	15.5	Sandstone, light-brown, thin- and cross-bedded; grains, very fine, sub-angular, sorting good; mica present in lower part.
	24.35	*Total exposed thickness of Newcastle formation.*
Contact, Newcastle formation and Skull Creek shale.		

SECTION 8

(Sec. 32, T. 46 N., R. 62 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
Contact, Mowry shale and Newcastle formation.		
		NEWCASTLE FORMATION
6	1.5	Sandstone, white, thin-bedded, calcareous in part; grains, very fine, angular to sub-angular, sorting good; mica and dark grains rare.
5	1.0	Sandstone, white, thin- and cross-bedded; grains, very fine to fine, angular to sub-angular; pink and smoky quartz present.
4	3.5	Sandstone as above; slightly bentonitic in upper part.
3	1.5	Sandstone as above; not bentonitic.
2	1.5	Sandstone as above; poorly bedded, less resistant.
1	1.5	Shale, gray, soft.
	24.5	*Total thickness of Newcastle formation.*
Contact, Newcastle formation and Skull Creek shale.		

SECTION 9

(NE¼ sec. 31, T. 46 N., R. 62 W., Weston Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.		
5	3.0	Sandstone, light-gray, weathers brown, thin- and cross-bedded, calcareous upper two feet; grains, very fine, sub-angular to sub-rounded, sorting good; mica abundant lower one foot, pink and smoky quartz present, black grains present that stain sand brown.
4	1.5	Clay, light-gray, silty, bentonitic.
3	1.9	Bentonite, white; selenite crystals present.
2	2.0	Shale, dark-gray to black, bentonitic, very carbonaceous; silicified wood fragments present.
1	6.0	Shale, light-gray, silty.
	14.4	*Total exposed thickness of Newcastle formation.*
Contact, Newcastle formation and Skull Creek shale.		

SECTION 10

(SW¼ sec. 19, T. 46 N., R. 62 W., Weston Co., Wyo.)

NEWCASTLE FORMATION

Top few feet absent by recent erosion.		
7	5.0	Sandstone, very light-brown, thin- and cross-bedded; grains, very fine, sub-angular, sorting good; large mica flakes abundant, pink and smoky quartz present, bright-green grains present but rare in lower foot.
6	3.0	Sandstone, white to light-tan, thin-bedded; grains, very fine, sub-angular to sub-rounded, sorting good; large mica flakes, dark grains present; middle part has carbonaceous matter on bedding planes.
5	0.5	Shale, gray.
4	0.4	Sandstone, white; grains, very fine.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
3	2.0	Bentonite, yellow; selenite crystals present.
2	1.0	Shale, black, slightly carbonaceous.
1	4.0	Shale, gray; poorly exposed.
	15.9	*Total exposed thickness of Newcastle formation.*

Probable contact, Newcastle formation and Skull Creek shale.

SECTION 11

(SE¼ sec. 14, T. 46 N., R. 63 W., Weston Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

16	0.5	Siltstone, light purple-gray, hard, quartzitic, arenaceous; brown plant fragments present.
15	5.0	Shale, light-gray, bentonitic; mica present; lower half, silty.
14	2.0	Sandstone, light-gray, thin- and cross-bedded; grains, very fine, sorting poor; mica and black grains present.
13	1.0	Shale, gray, soft.
12	3.5	Bentonite, light-gray to light-yellow; mica and selenite crystals present.
11	1.5	Shale, dark-brown, bentonitic, carbonaceous; silicified wood fragments, selenite crystals present.
10	1.75	Shale, gray, fissile, bentonitic; mica and selenite crystals present; lower half, slightly silty.
9	1.0	Siltstone, light-brown; mica and dark grains present.
8	5.5	Shale, dark-gray, mottled light-gray, fissile, slightly bentonitic; selenite crystals present.
7	0.25	Sandstone, light-gray, silty, siliceous, hard, slightly carbonaceous; grains, very fine, sorting poor; breaks with sharp, angular edges.
6	5.0	Shale, light-yellow and gray, silty, fissile.
5	0.2	Bentonite, light-yellow.
4	0.5	Shale, gray, silty, hard; mica present; breaks into angular fragments.
3	2.75	Siltstone, light-yellow to light-gray; dark grains and mica present.
2	5.0	Covered.
1	4.5	Siltstone, white to light-gray, bentonitic; very minor amount black carbonaceous matter; in upper half, a one-inch sandstone, white, hard, siliceous, lenticular; grains, very fine; plant markings on bedding plane.
	39.95	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 12

(SW¼ sec. 11, T. 46 N., R. 63 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
		NEWCASTLE FORMATION
Top few feet absent by recent erosion.		
28	1.5	Sandstone, white to very light-brown, thin- and cross-bedded; grains, very fine, sub-angular to sub-rounded, sorting fair; mica, black grains, pink and smoky quartz present; very near top.
27	0.5	Shale, gray, deeply weathered.
26	3.0	Bentonite, pale-yellow and gray-green.
25	2.25	Shale, black, carbonaceous; silicified wood fragments with rounded edges present.
24	1.5	Shale, very light-brown, silty, bentonitic; mica rare; at bottom, one inch irregular ferruginous layer, dark-purple, dark-blue and black mottled, dense, heavy, with selenite-filled vugs.
23	5.5	Shale, very light-brown, slightly silty, bentonitic.
22	1.5	Shale, dark-gray, fissile, bentonitic; minute mica flakes present; at bottom, one-inch irregular ferruginous layer, brown, hard.
21	1.25	Shale, gray, fissile, slightly bentonitic; lower part, poorly bedded, slightly carbonaceous, silty.
20	3.25	Shale, gray, fissile, slightly silty.
19	1.0	Shale, brown, carbonaceous.
18	1.5	Shale, gray, fissile; at base, one-inch ferruginous layer, brown.
17	0.15	Bentonite, white.
16	0.5	Shale, gray, fissile.
15	2.25	Siltstone, white to light-yellow, thin-bedded, slightly bentonitic; mica and dark grains present.
14	1.5	Sandstone, white to light-gray, thin-bedded; grains, very fine, angular to sub-angular; black grains present; ripple-marked; small vertical holes present.
13	2.5	Shale, gray, bentonitic; half-inch bentonite near bottom.
12	2.0	Siltstone, light-yellow to light-gray, bentonitic; mica and selenite crystals present.
11	3.25	Siltstone, white, poorly bedded; upper half, resistant.
10	1.25	Shale, light-gray, silty, bentonitic.
9	0.05	Bentonite, yellow.
8	1.5	Shale, brown to light-gray; upper part, carbonaceous.
7	1.0	Sandstone, brown, argillaceous, bentonitic; grains, very fine, angular to sub-angular, sorting fair; mica present; mud pods present.
6	3.25	Shale, black, fissile, carbonaceous.
5	8.5	Shale, gray, silty.
4	3.0	Shale, black, silty, slightly carbonaceous.
3	7.5	Shale, light-gray, silty, hard.
2	5.5	Sandstone, light gray-brown, silty, poorly bedded; grains, very fine, angular to sub-angular, sorting poor; black grains present; lower part, slightly carbonaceous.
1	4.25	Shale, light-gray, very silty, carbonaceous.
	70.70	*Total exposed thickness of Newcastle formation.*

Lower part of Newcastle formation not exposed.

SECTION 13

(SW¼ sec. 2, T. 46 N., R. 63 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
		NEWCASTLE FORMATION
Top part absent by recent erosion.		
22	1.0	Sandstone, light-yellow to tan, thin-bedded, hard; grains, very fine, sub-angular to sub-rounded, sorting poor; dark grains present; has vertical holes ⅛-inch in diameter, filled with white sandstone.
21	1.5	Shale, dark-gray, soft.
20	0.1	Bentonite, yellow.
19	0.5	Shale, dark-gray, soft.
18	0.15	Bentonite, cream-colored.
17	0.45	Shale, dark-gray.
16	3.25	Siltstone, light-gray, bentonitic, argillaceous, sorting poor; mica and selenite crystals present.
15	1.75	Shale, brown, very carbonaceous; selenite crystals and amber present.
14	1.5	Shale, light-gray, silty, bentonitic; plant impressions and selenite crystals present.
13	0.75	Sandstone, light-yellow, silty, calcareous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica present.
12	1.0	Shale, dark-gray, soft.
11	1.5	Bentonite, yellow and gray-green; mica present in lower one foot.
10	1.5	Shale, black and dark-brown, fissile, very carbonaceous; small coal fragments present.
9	2.0	Shale, purple-gray, bentonitic; light-brown plant impressions, carbonized wood fragments present.
8	1.5	Siltstone, light gray-brown, lenticular; coal fragments and mica present.
7	4.1	Shale, gray, slightly bentonitic, slightly silty; mica present.
6	0.25	Siltstone, light-brown; mica present.
5	0.75	Shale, light-gray, poorly bedded, silty, carbonaceous.
4	2.0	Siltstone, light-brown to light-gray, lenticular; mica present; some carbonized wood fragments present.
3	3.5	Shale, gray, bentonitic, hard; carbonized wood fragments, amber and coal fragments present.
2	5.0	Shale, light-gray, hard, fissile, bentonitic.
1	4.0	Siltstone, light gray-brown, hard, massive; mica present.
	38.05	*Total exposed thickness of Newcastle formation.*
Lower Newcastle formation not exposed.		

SECTION 14

(N½ sec. 2, T. 46 N., R. 63 W., Weston Co., Wyo.)

		NEWCASTLE FORMATION
Top part absent by recent erosion.		
12	2.5	Sandstone, orange and yellow, thin-bedded; grains, very fine; upper part has vertical holes ⅛-inch in diameter; lower part has intercalations of black shale.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
11	1.75	Shale, dark-gray, soft.
10	0.3	Bentonite, yellow.
9	0.75	Shale, dark-gray, fissile, soft.
8	3.25	Shale, black, carbonaceous, hard, dry.
7	2.5	Siltstone, light-gray, bentonitic, argillaceous; mica present.
6	0.5	Shale, dark-gray, fissile, soft.
5	1.0	Bentonite, light gray-green, bedded; mica present.
4	3.0	Shale, black, very carbonaceous.
3	8.0	Siltstone, light gray-brown, slightly bentonitic, hard, massive.
2	1.75	Sandstone and shale, inter-laminated; sandstone, gray carbonaceous; grains, very fine, sub-angular to sub-rounded, sorting poor, with secondary quartz growth on grains.
1	4.0	Siltstone, light-gray, slightly bentonitic, hard, massive.
	29.30	*Total exposed thickness of Newcastle formation.*

Lower Newcastle formation not exposed.

SECTION 15

(NW¼ sec. 35, T. 47 N., R. 63 W., Weston Co., Wyo.)

Contact, Mowry shale and Newcastle formation.

NEWCASTLE FORMATION

25	1.0	Sandstone, light-gray to light-brown, poorly bedded; argillaceous, silty; grains, very fine, sorting poor; carbonaceous matter present in minor amount.
24	2.0	Shale, light-brown, hard, silty.
23	3.0	Shale, black, fissile; mica present; some thin layers of black silty shale.
22	3.0	Shale, light-gray, bentonitic, silty; mica and minute carbon fragments present.
21	1.0	Sandstone, white to light-gray, thin- and cross-bedded; grains, very fine, sorting poor.
20	1.5	Siltstone, white, bentonitic; three inches gray shale in middle.
19	2.0	Bentonite, light green-gray.
18	1.0	Shale, dark-brown to black, very carbonaceous; contains charcoal pieces, silicified with rounded edges.
17	4.5	Shale, gray; upper half has yellow coating; lower half has blue coating and contains paper-thin layers of siltstone.
16	7.0	Shale, light-gray and dark-gray; top four feet, fissile; bottom three feet, silty, slightly carbonaceous.
15	2.5	Siltstone, white, thin-bedded, slightly carbonaceous; top six inches has vertical holes ⅛-inch in diameter; lower two feet has intercalations of black shale.
14	1.5	Shale, dark-gray, fissile, soft; one-half inch bentonite in middle.
13	0.25	Bentonite, yellow.
12	0.75	Shale, dark-gray, fissile, soft.
11	3.25	Shale, black, carbonaceous, hard, dry.
10	3.0	Siltstone, light-gray, bentonitic, argillaceous; mica present.
9	0.2	Shale, dark-gray, fissile, soft.
8	1.25	Bentonite, light-gray to light gray-green, bedded; mica present.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
7	2.5	Shale, black, very carbonaceous.
6	2.5	Shale, light-gray, carbonaceous, silty.
5	0.5	Covered.
4	5.5	Siltstone, white, slightly bentonitic, hard, resistant, massive; contains some sand grains; minor amount of carbonaceous matter.
3	0.5	Shale, light-gray, hard, slightly bentonitic, silty.
2	1.0	Shale, black, very carbonaceous, hard.
1	2.5	Shale, light-gray, slightly bentonitic, hard, silty.
	53.70	*Total exposed thickness of Newcastle formation.*

Lower Newcastle formation not exposed.

SECTION 16

(SW¼ sec. 26, T. 47 N., R. 63 W., Weston Co., Wyo.)

NEWCASTLE FORMATION

Top few feet absent by recent erosion.

17	5.0	Sandstone, very light-brown, thin- and cross-bedded; grains, very fine, sub-angular to sub-rounded, sorting fair; mica, black and orange grains present; very near the top.
16	0.5	Shale, light-gray, bentonitic.
15	2.5	Bentonite, pale-green; mica and minute selenite crystals present.
14	1.25	Shale, dark-gray to black, very carbonaceous, some amber present; rounded silicified wood fragments present.
13	2.0	Shale, gray, bentonitic, heavy-bedded; yellow and bright-blue coating on parts.
12	8.0	Shale, gray and light-brown, fissile, bentonitic, slightly carbonaceous; lower two feet, light-gray with plant impressions.
11	4.0	Claystone, light-gray to very light-brown, bentonitic, slightly carbonaceous; upper half, thin-bedded; lower half, thick-bedded, hard, with blue coating.
10	1.0	Siltstone, gray, very thin-bedded, bentonitic; mica and minute carbon fragments present; black shale partings.
9	0.9	Shale, gray, bentonitic, fissile; mica rare; thin bed of siltstone in middle.
8	0.25	Bentonite, white to light-gray, hard; mica present.
7	0.6	Siltstone, light-gray, slightly bentonitic, slightly carbonaceous.
6	2.5	Claystone, black, slightly bentonitic, carbonaceous, hard.
5	2.0	Siltstone, light-gray, bentonitic, argillaceous; some plant remains and mica present.
4	1.5	Bentonite, light-gray, bedded; mica present.
3	16.0	Siltstone, light-gray to gray, massive, slightly carbonaceous, slightly bentonitic, arenaceous, hard, resistant; sand grains present are very fine, sub-angular.
2	0.5	Shale, gray, carbonaceous.
1	3.5	Siltstone, gray, slightly bentonitic, slightly carbonaceous, arenaceous; sand grains are very fine, sub-angular.
	52.00	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 17

(SW¼ sec. 27, T. 47 N., R. 63 W., Weston Co., Wyo.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
		NEWCASTLE FORMATION
Top part absent by recent erosion.		
4	2.5	Sandstone, light-gray, hard, resistant, siliceous; grains, very fine, sub-angular, sorting poor; black grains present.
3	4.0	Siltstone, light-gray, arenaceous; sorting very poor.
2	1.0	Sandstone, light-brown; grains, very fine, angular to sub-angular, secondary crystal growth on grains, sorting fair; black and pink grains present.
1	4.0	Sandstone, light-brown, very carbonaceous; grains, very fine, sub-rounded, secondary crystal growth on grains, sorting very poor.
	11.5	*Total exposed thickness of Newcastle formation.*
Contact, Newcastle formation and Skull Creek shale.		

SECTION 18

(W½ sec. 24, T. 47 N., R. 64 W., Weston Co., Wyo.)

		NEWCASTLE FORMATION
Top few feet absent by recent erosion.		
17	3.0	Sandstone, light-gray, calcareous, hard, thin- and cross-bedded; grains, very fine, sub-angular, sorting fair; mica, smoky and pink quartz present; very near the top.
16	3.5	Bentonite, light-gray to light-yellow; minute selenite crystals and mica present; swells very slightly in water.
15	2.0	Shale, brown to black, carbonaceous, with small bits of amber; one-fourth inch coal layer near the bottom.
14	3.5	Siltstone, light-gray to gray, argillaceous; mica and dark grains present.
13	10.5	Shale, light-gray and dark-gray, fissile; mica present in part; top one foot contains a two-inch layer, ferruginous, blue-black to rust-brown; bottom seven feet, silty.
12	0.25	Bentonite, white, hard, minute selenite crystals present.
11	1.5	Shale, gray; lower third, silty.
10	3.5	Siltstone, light-gray, carbonaceous, argillaceous.
9	1.1	Shale, gray; mica present; two inches of white bentonite in middle.
8	7.0	Shale, light- to dark-gray, carbonaceous, silty; bottom half, more carbonaceous with minute pieces of coal.
7	1.5	Mudstone, light-gray, hard, silty; some plant remains; forms ledge.
6	6.0	Shale, gray, silty.
5	0.5	Siltstone, light-gray, hard.
4	1.1	Mudstone, light-gray, silty; a few grains of quartz, fine-grained, sub-angular to sub-rounded.
3	2.5	Shale, dark-gray, very carbonaceous; with plant remains and minute pieces of amber; resistant, lower foot.
2	3.0	Siltstone, light-gray, hard, massive, argillaceous; some plant remains.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
1	2.0	Sandstone, light-brown, silty, carbonaceous; grains, very fine, sub-angular, sorting poor.
	52.45	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 19

(Sec. 27, T. 55 N., R. 67 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

6	5.0	Sandstone, light-gray, dense, calcareous, very hard; grains, fine, sub-angular to sub-rounded, sorting good; pink and orange quartz present, black grains present that stain surrounding grains brown; top half, irregular- and thin-bedded; bottom half, massive.
5	3.25	Sandstone, light-brown, slightly friable; grains, fine, sub-rounded, matt-surfaced, sorting good; black grains common, pink quartz present; top half, massive; lower half, thin-bedded, weathering bright-orange in parts.
4	4.0	Sandstone, white, massive; grains, fine, sub-rounded, sorting good; pink and smoky quartz present; slightly calcareous lower half.
3	4.0	Sandstone, light-yellow, massive, slightly friable; grains, fine, sub-angular to sub-rounded, sorting good; mica, pink and smoky quartz present; grain size smaller in upper part.
2	2.5	Sandstone, light-gray, dense, calcareous, hard, thin- to medium-bedded, cross-bedded in part; grains, fine, sub-angular to sub-rounded, sorting fair; some medium-size grains of quartz present.
1	15.0	Siltstone and sandstone, interbedded: siltstone, light-gray, bentonitic, argillaceous; sandstone, light-gray to yellow, bentonitic, argillaceous; lower three feet, several three-inch sandstones interbedded with dark-gray fissile shale.
	33.75	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 20

(Sec. 33, T. 55 N., R. 66 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

4	8.0	Sandstone, very light-brown, thin- and cross-bedded; grains, very fine, sub-angular, sorting fair to good; mica present, black grains and pink quartz rare.
3	4.0	Sandstone, light-gray to light-yellow, medium- to thick-bedded; grains, very fine, sub-angular to sub-rounded, sorting fair to good; mica, pink and smoky quartz, black grains present; lower two feet, sorting good, grain size slightly larger.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
2	6.0	Sandstone, light-gray to light-yellow, medium-bedded, ripple-marked in part; grains, very fine, sub-angular to sub-rounded, sorting fair; mica, pink and smoky quartz, black grains present.
1	7.0	Sandstone, light-gray, thin-bedded; with thin interbeds of shale increasing in thickness and frequency toward the bottom.
	25.0	*Total exposed thickness of Newcastle formation.*

Lower Newcastle formation not exposed, but a perennial spring of good water is found at the base of this outcrop and appears to be controlled by a very low-angle fault near the base of the formation.

SECTION 21

(S½ sec. 11, T. 55 N., R. 67 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

7	3.0	Sandstone, very light-brown, thin- and cross-bedded, hard, calcareous; grains, very fine to fine, sub-angular to sub-rounded, sorting poor; dark grains common; very near top.
6	5.0	Covered; light-colored sandy soil.
5	2.5	Sandstone, very light-brown, thin- and wavy-bedded, hard, calcareous; grains, fine, sub-angular to sub-rounded, sorting poor; black grains common, black and gray chert present; larger grains have matt surface.
4	1.5	Coverd.
3	12.5	Sandstone, white, thin- to medium-bedded, friable; grains, very fine, sub-angular to sub-rounded, matt-surfaced, sorting good; black grains rare, black mica common, green mica, smoky and pink quartz present; upper nine feet medium-bedded; lower 3.5 feet thin-bedded with vertical worm holes ¼-inch in diameter.
2	1.0	Sandstone, gray to brown, poorly bedded, calcareous, argillaceous, friable; grains, very fine, sorting poor; contains unidentifiable organic remains that resemble fish scales but are not ridged.
1	19.0	Shale and sandstone, interbedded; shale, gray and dark-gray, thin-bedded; sandstone, thin-bedded, maximum thickness of any bed, six inches; grains, very fine.
	44.5	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 22

(W½ sec. 3, T. 55 N., R. 66 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

14	0.5	Sandstone, very light-brown, thin-bedded; grains, very fine, sub-angular to sub-rounded, sorting good; black grains, pink and smoky quartz, green and white mica present.
13	0.7	Shale, light-gray; weathered.
12	1.7	Sandstone, white, thin-bedded; grains, very fine, sub-angular to sub-rounded, sorting fair; mica abundant, smoky quartz present, black grains rare.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
11	6.0	Sandstone and shale, interbedded: sandstone, light-gray, thin-bedded, slightly carbonaceous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica abundant, green mica, pink and smoky quartz present; shale, light-gray, fissile, slightly bentonitic, interbedded with sandy shale.
10	0.9	Sandstone, white, friable; grains, very fine, sub-angular to sub-rounded, sorting poor; mica abundant, black grains, smoky quartz present.
9	2.0	Sandstone and shale, interbedded.
8	0.75	Sandstone, white, thin- and cross-bedded, slightly carbonaceous; grains, very fine to fine, sub-angular to sub-rounded, sorting poor; mica abundant, black grains rare.
7	1.0	Sandstone and shale, interbedded.
6	2.0	Sandstone, white, thin-bedded, slightly carbonaceous; grains, very fine to fine, sub-angular to sub-rounded, sorting fair; pink and smoky quartz present, black grains rare.
5	4.5	Sandstone, white, thin- to medium-bedded; grains, very fine, sub-angular to sub-rounded, sorting poor; mica abundant, green mica present; several shale interbeds.
4	1.0	Sandstone, gray, very hard, dense, calcareous; grains, very fine to coarse, average size fine, sub-angular to rounded, sorting poor; large grains of clear and milky quartz, gray, yellow, and red polished chert grains abundant, small metallic black grains present; fragments of brown wood present.
3	1.5	Sandstone and shale, interbedded; sandstone, bentonitic, argillaceous; grains, very fine to coarse, sub-angular to sub-rounded, sorting very poor; selenite crystals present; shale, dark-gray, slightly bentonitic.
2	0.5	Shale, gray, fissile.
1	0.1	Bentonite, altered, light-gray, hard, lenticular, even-textured; cracked and seamed with selenite.
	23.15	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 23

(NW¼ sec. 17, T. 56 N., R. 66 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

10	1.0	Sandstone, red-brown, medium-bedded, argillaceous; grains, fine, sub-angular to sub-rounded, sorting fair; mica present.
9	7.0	Sandstone, white, thin-bedded, friable; grains, fine, sub-angular to sub-rounded, sorting good; mica abundant, pink and smoky quartz present, black grains rare, green mica present.
8	12.0	Sandstone, white, medium-bedded, very friable; grains, fine, sub-angular to sub-rounded, sorting good; mica abundant, black grains, pink and smoky quartz present, some green mica present; top is ripple-marked; larger sand grains pitted.
7	0.2	Sandstone, light-gray, poorly bedded, bentonitic, argillaceous; grains, fine, sub-angular to sub-rounded, sorting poor; inclusions of gray shale fragments present; sharp contact at top and bottom.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
6	0.2	Sandstone, white; grains, very fine, sorting poor.
5	0.2	Shale, gray, bentonitic.
4	0.5	Sandstone, light-gray, calcareous, hard; grains, fine, sub-angular to sub-rounded, sorting fair; salt crystals present.
3	0.1	Shale, light-gray.
2	0.7	Sandstone, light-gray, thin-bedded, argillaceous, hard; grains, very fine to medium, sub-angular to sub-rounded, sorting very poor; black chert present; the large grains are quartz and chert, sub-rounded, matt-surfaced; lower part bentonitic.
1	0.5	Shale, light-gray, thick-bedded, very hard, bentonitic, fine-textured.
	22.3	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 24

(SW¼ sec. 16, T. 57 N., R. 65 W., Crook Co., Wyo.)

Contact of Mowry shale and Newcastle formation somewhere in covered interval below.

	32.0	Covered; light-colored sandy soil; top three feet, hard black shale.

NEWCASTLE FORMATION

Top contact covered.

33	1.0	Sandstone, light-gray, deeply weathered; grains, very fine; at top, a three-inch ferruginous layer.
32	9.0	Covered.
31	7.0	Sandstone and siltstone, poorly exposed; carbonaceous matter in upper part; at top, a three-inch layer, dark-brown to blue-black, irregularly bedded.
30	3.0	Sandstone, white to light-gray, thin-bedded, soft, poorly exposed; grains, very fine to silt size, sorting poor; mica and black grains present.
29	3.5	Siltstone, white, thin-bedded, arenaceous; mica, smoky quartz, black grains present; gradational with sandstone below.
28	1.5	Sandstone, white, thin-bedded, weathers easily; grains very fine, sub-angular, matt-surfaced, sorting fair to good; mica, smoky quartz, black grains present.
27	2.0	Shale, dark-brown, very carbonaceous, poorly bedded.
26	1.0	Bentonite, impure; plant stems present.
25	3.5	Siltstone, light-yellow to light-gray, bentonitic, thin-bedded, poorly bedded; mica present.
24	2.0	Shale, light-gray, bentonitic.
23	6.0	Covered.
22	4.0	Sandstone, white to light-gray, thin-bedded; grains, very fine, sub-angular, matt-surfaced, sorting poor to good; smoky quartz present, mica, black grains rare; top three feet, sorting good, grains smaller; bottom foot, slightly calcareous, weathers to loose sand.
21	3.5	Shale and siltstone, interbedded: shale, light-gray to gray, bentonitic; siltstone, light-gray to light-yellow, argillaceous, bentonitic, slightly carbonaceous.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
20	1.0	Shale, gray, very bentonitic, slightly carbonaceous.
19	4.3	Siltstone, light-gray, hard, argillaceous, bentonitic, poorly bedded; brown wood fragments in upper part.
18	1.8	Shale, light-gray, bentonitic; contains balls and irregular masses of bentonite.
17	2.3	Claystone, light-gray, hard, very bentonitic.
16	0.8	Bentonite, light gray-brown, altered, hard, silty.
15	1.5	Bentonite, yellow and light-gray.
14	4.5	Shale, black, poorly bedded, very carbonaceous.
13	4.2	Covered.
12	0.5	Sandstone, white to light-gray, hard; grains, very fine, angular to sub-angular, sorting fair to good; mica, smoky quartz, and black grains present; contains small holes left by plant stems.
11	1.0	Covered.
10	1.25	Sandstone, white to light-gray, massive, hard; grains, very fine, sub-angular to sub-rounded, sorting fair; smoky quartz present, black grains rare.
9	1.75	Sandstone, light-gray, poorly bedded, silty, argillaceous, carbonaceous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica present.
8	1.5	Siltstone, gray, thin-bedded, bentonitic, argillaceous, slightly carbonaceous; mica present; thin interbeds of dark-gray shale.
7	2.0	Sandstone, light-gray, very argillaceous, carbonaceous; grains, very fine, sorting poor; mica present.
6	1.3	Shale, black, very carbonaceous; contains fragments of charcoal.
5	3.0	Shale, light-gray, bentonitic, arenaceous.
4	0.5	Siltstone, light-gray, bentonitic, arenaceous, slightly carbonaceous; mica present.
3	1.0	Shale, black, bentonitic.
2	2.1	Sandstone, light-gray, massive, very argillaceous, slightly bentonitic; grains, very fine, sub-angular, sorting poor; pink and smoky quartz present.
1	0.5	Siltstone, gray, thin-bedded, arenaceous, bentonitic, slightly carbonaceous.
	83.80	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 25

(Sec. 24, T. 57 N., R. 64 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

8	2.5	Sandstone, light-gray to white, thin- and cross-bedded; grains, very fine, sub-angular, sorting fair to good; smoky quartz and black grains rare.
7	1.0	Shale, dark-brown, very carbonaceous; many angular pieces of black carbonized wood present.
6	2.0	Shale, light-gray, arenaceous, bentonitic.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
5	1.5	Sandstone, very light gray-brown, poorly bedded, carbonaceous, slightly bentonitic; grains, very fine, sorting very poor; black carbonized wood fragments abundant.
4	0.9	Bentonite, light-yellow, flaky.
3	1.5	Siltstone, dark-brown and gray, carbonaceous; sorting poor.
2	2.0	Sandstone; same as unit No. 5.
1	14.0	Sandstone, gray, bentonitic, argillaceous, slightly carbonaceous, very poorly consolidated; grains, very fine, sorting very poor; black carbonized wood fragments present.
	25.4	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 26

(Sec. 7, T. 56 N., R. 62 W., Crook Co., Wyo.)

NEWCASTLE FORMATION

Top part absent by recent erosion.

4	3.0	Bentonite, white, bedded, hard.
3	6.75	Siltstone, light-gray, poorly bedded, argillaceous, bentonitic, slightly carbonaceous, hard.
2	0.75	Sandstone, light-gray, argillaceous.
1	2.75	Bentonite, light gray-green, bedded.
	13.25	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

SECTION 27

(NW¼ sec. 3, T. 4 N., R. 6 E., Meade Co., S. Dak.)

NEWCASTLE FORMATION

Top few feet absent by recent erosion.

4	2.0	Shale and sandstone, interbedded: shale, light-gray, soft, bentonitic; sandstone, dark-purple to black, ferruginous, hard, irregularly bedded; grains, very fine, sorting poor, mica abundant.
3	5.0	Sandstone, orange brown, ripple-marked in part, thin-bedded, cross-bedded in part, friable; grains, fine, sub-angular to sub-rounded, sorting good; mica abundant, black grains rare; mud-lined cavities present.
2	0.5	Sandstone, rust-brown, slightly resistant; grains, fine, sub-angular to sub-rounded, sorting good; mica present, black grains rare.
1	10.0	Sandstone, light-brown, cross-bedded, very friable; grains, fine, sub-angular to sub-rounded, sorting good; mica, pink and smoky quartz, black grains present; mud-lined cavities present in part.
	17.5	*Total exposed thickness of Newcastle formation.*

Probable contact, Newcastle formation and Skull Creek shale.

SECTION 28

(S½ sec. 26, T. 2 N., R. 7 E., Pennington Co., S. Dak.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
Contact. Mowry shale and Newcastle formation.		
		NEWCASTLE FORMATION
6	1.0	Sandstone, light-yellow, thin-bedded, slightly calcareous, hard; grains, very fine, sub-angular to sub-rounded, sorting fair; mica, black grains, pink and smoky quartz present.
5	2.25	Sandstone, light-yellow, well-bedded, bentonitic, argillaceous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica present, black grains rare.
4	4.5	Shale, light-gray, bentonitic; top half, silty; lower half, very bentonitic.
3	2.25	Siltstone, light gray-brown, thin-bedded, argillaceous, slightly bentonitic; sorting poor; mica present.
2	10.0	Sandstone, light-gray, silty, argillaceous, poorly bedded; grains, very fine, sub-angular to sub-rounded, sorting poor; mica present in part, pink and smoky quartz, black grains rare; plant impressions present; top two feet hard, well-bedded; lower part, slightly bentonitic and slightly calcareous.
1	5.0	Sandstone, white to light-yellow; grains, very fine, sub-angular to sub-rounded, coated with yellow clay, sorting poor, top three feet, good, bottom two feet; black grains present, pink and smoky quartz rare; top one foot, channeled and plant impressions present.
	25.0	*Total exposed thickness of Newcastle formation.*
Lower part of Newcastle formation not exposed.		

SECTION 29

(SW¼ sec. 18, T. 2 S., R. 8 E., Pennington Co., S. Dak.)

Contact. Mowry shale and Newcastle formation.		
		NEWCASTLE FORMATION
5	1.0	Sandstone, white, hard, slightly carbonaceous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica rare, pink and smoky quartz, black grains present.
4	1.0	Sandstone, white, weathers light-brown; grains, very fine to fine, sub-angular to sub-rounded, sorting fair; black grains rare, pink and smoky quartz present.
3	1.0	Sandstone, white, weathers light-brown, slightly carbonaceous; grains, very fine, sub-angular to sub-rounded, sorting good; mica, pink and smoky quartz, black grains present.
2	1.0	Sandstone, as above; friable; grains, very fine to fine, sorting fair.
1	12.0	Sandstone, white, weathers light-brown, cross-bedded, friable in part; grains, fine, sub-angular to sub-rounded, sorting fair to good; pink and smoky quartz present, black grains rare, mica present in middle; sorting good, lower part.
	16.0	*Total exposed thickness of Newcastle formation.*
Lower part of Newcastle formation not exposed.		

SECTION 30

(NE¼ sec. 36, T. 2 S., R. 7 E., Custer Co., S. Dak.)

Unit No.	*Thickness (in feet)*	*Lithologic Description*
Contact, Mowry shale and Newcastle formation.		
		NEWCASTLE FORMATION
20	1.0	Sandstone, light-brown to light-gray, argillaceous, very carbonaceous; grains, very fine, sub-angular to sub-rounded, sorting poor; mica and black grains present; carbonized wood fragments present.
19	0.5	Sandstone, brown, argillaceous.
18	2.0	Shale, gray.
17	0.5	Sandstone, argillaceous.
16	1.0	Shale, dark-gray, soft.
15	3.0	Covered.
14	2.0	Sandstone, white, thin-bedded; grains, very fine, angular to sub-angular, sorting poor; mica, black grains, and some smoky quartz present.
13	5.0	Covered.
12	4.75	Sandstone, white, thin- and cross-bedded; grains, very fine, sub-angular to sub-rounded, sorting good, slightly frosted; mica, pink and smoky quartz, and black grains present; top half, resistant.
11	3.5	Sandstone, light-brown, slightly argillaceous; grains, very fine to fine, sub-angular to sub-rounded, sorting good, slightly frosted; mica and black grains present.
10	1.5	Sandstone, gray, very hard, quartzitic, flinty; grains, very fine, sub-angular, sorting good; black grains rare; breaks with smooth surfaces and sharp edges; contains vugs lined with milky or clear crystalline silica; the vugs may be plant impressions.
9	3.5	Sandstone, white, hard; grains, very fine, sub-angular to sub-rounded, sorting fair; mica, pink and smoky quartz, and black grains present.
8	11.0	Sandstone, white; grains, fine, sub-angular to sub-rounded, sorting good; black grains, pink and smoky quartz present; forms sheer cliff face.
7	4.5	Sandstone, white, cross-bedded; grains, very fine to fine, sub-angular to sub-rounded, sorting fair; mica, black grains, pink and smoky quartz present; impressions of flattened wood stems; top one foot, grains, fine, sorting good.
6	3.5	Sandstone, white, silty, top thin- and cross-bedded; grains, very fine, sub-angular, sorting fair; mica, black grains, pink quartz rare; plant impressions on bedding.
5	3.0	Covered.
4	4.0	Sandstone, white, weathers light-brown, medium-bedded; grains, very fine to fine, sub-angular to sub-rounded, sorting fair to poor; mica, smoky and pink quartz, black grains present, latter stain surrounding grains brown; plant impressions, lower one foot.

Unit No.	*Thickness (in feet)*	*Lithologic Description*
3	1.5	Sandstone, white, bentonitic; grains, fine, sub-angular to sub-rounded, sorting good; black grains present.
2	2.0	Covered.
1	2.0	Bentonite, light-gray to white.
	59.75	*Total exposed thickness of Newcastle formation.*

Contact, Newcastle formation and Skull Creek shale.

PLATE 1. Correlation of the Newcastle formation, Osage-Newcastle area, Weston County, Wyoming.