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GEOLOGIC AND BIOSTRATIGRAPHIC MAP OF THE PIERRE SHALE BETWEEN JARRE CREEK AND LOVELAND, COLORADO

By Glenn R. Scott and William A. Cobban

INTRODUCTION

The Pierre Shale, a thick unit of Upper Cretaceous marine strata, crops out in a belt as much as 20 miles wide that parallels the Front Range in Colorado. In terms of the standard stages of the Cretaceous, the known age of the Pierre Shale in this part of Colorado ranges from some part of the late early Campanian through the early Maestrichtian. Ammonites, which are abundant, have proved very useful for zoning the shale and for revealing structural patterns in the shale. The purpose of this report is to describe the ammonite zones, show their stratigraphic positions, and, by means of a geologic map, show their utility in delineating structure in the thick and unprepossessing shale. Collections of fossils from 683 localities in the mapped area were employed in the preparation of the map.

We are indebted to the following colleagues for information from unpublished U.S. Geological Survey mapping: Richard Van Horn, Golden and Ralston Buttes quadrangles; F. D. Spencer, Niwot quadrangle; and R. F. Wilson, Boulder quadrangle. Eric Schlaikjer, Lakota Petroleum Corporation, has kindly granted us permission to publish his interpretation of the anticlinal axes of the Loveland oil field as drawn on top of the "Lakota Sandstone" (Lytle Formation). The fossils were prepared for study by Flavius Rowell and R. E. Burkholder. The drawings of *Exiteloceras* and the three species of *Didymoceras* are detailed reconstructions of fragmentary specimens by John R. Stacy under the supervision of the authors.

STRATIGRAPHY

The Pierre Shale is underlain by the calcareous Niobrara Formation and overlain by the Fox Hills Sandstone. Both contacts are conformable and transitional. The base of the Pierre is at the top of a persistent orange-weathering chalk bed that forms a hogback at the top of the Smoky Hill Shale Member of the Niobrara Formation.

The thickness of the Pierre Shale ranges from 5,200 feet in the Kassler quadrangle to more than 8,000 feet northeast of Boulder. This northward increase in thickness coincides with a northward increase in sandiness.

The Pierre Shale is divided into four broad units whose predominant lithologies are, in ascending order, shale, sandstone, shale, and sandstone. The lower shale unit lies between the Niobrara Formation and the Hygiene Sandstone Member. The lower sandstone unit includes, in ascending order, the Hygiene, Terry, Rocky Ridge, Larimer, and Richard Sandstone Members separated from each other by shale. The upper shale unit lies between the top of the Richard Sandstone Member and the base of the upper transition member, a sandstone unit that is transitional to the Fox Hills Sandstone. These broad divisions are the primary units in the ensuing discussion. Within each broad unit the secondary units are the ammonite zones, for each of which the lithology, thickness, and important associated fossils are shown.

Lower shale unit

The lower shale unit of the Pierre is 1,650 feet thick. In its lowest part no ammonites were found, but elsewhere in the Western Interior three ammonite zones occupy the rocks in this interval; these ammonites are, in ascending order, (1) a smooth species of *Baculites*, (2) a species of *Baculites* that has weak lateral ribs, and (3) a weakly ribbed early form of *Baculites obtusus* associated with *Trachyscaphites praespiniger*.

At the base of the Pierre a lower transition member contains calcareous nonconcretionary shale that ranges in thickness from 80 feet near Kassler to less than 45 feet north of Boulder. This shale contains only one genus, *Inoceramus*.

From Loveland to just south of Boulder the calcareous beds are overlain by dark-gray noncalcareous shale that contains dark yellowish-orange and dusky-red ironstone concretions having *Inoceramus* aff. *I. cycloides*.

The ironstone-bearing shale is overlain by dark olive-gray clayey shale that contains many thin beds of bentonite and some ironstone concretions. This bentonite-bearing unit is the equivalent of the Sharon Springs Member, which is typically developed both north and south of the area mapped. The contacts of the Sharon Springs Member cannot be determined in this area because the member does not have its typical hard organic-rich aspect. The probable position of the Sharon Springs equivalent is indicated by numerous beds of bentonite between 120 and 340 feet above the base of the Pierre. However, owing apparently to greater sedimentation in this area, the bentonite beds are intercalated with a great amount of shale, and the organic material is diluted.

Baculites obtusus was found in one layer of yellowish-gray limestone concretions near Boulder, but it probably also ranges above the Sharon Springs equivalent or through about 250 feet of section. This species is characterized by strong closely spaced nodelike lateral ribs on specimens one-fourth inch to 1 inch in diameter and by weakening or loss of ribbing on larger specimens.

Above the zone of *B. obtusus* is 560 feet of olive-gray soft silty shale that contains ironstone concretions. Near Golden and Hygiene the lower 140 feet of this olive-gray shale contains *Baculites mclearni* in red siltstone concretions. This baculite resembles *B. obtusus* at diameters

between one-half inch and 1 inch, but smaller specimens have more widely spaced nodes, and larger specimens tend to retain their lateral ribbing to greater diameters. The upper 420 feet of shale in this interval contains septarian limestone concretions, thickens from south to north, and increases in grain size as it is traced toward a thick correlative sandy unit near the Colorado-Wyoming State line. *Baculites asperiformis*, a species characterized by widely spaced lateral nodes on juveniles and by smooth flanks on adults, is fairly abundant in the concretions.

The upper 600 feet of the lower shale unit below the Hygiene Sandstone Member consists of slightly silty shale containing abundant limestone and ironstone concretions. This part is equivalent to about the lower 190 feet of the Rusty zone of Gilbert (1897, p. 3) at Pueblo, Colo. *Baculites perplexus* is common and ordinarily is well preserved. This is a variable species that tends to have weak lateral ribs and strong ventral ribs.

Lower sandstone unit

The lower sandstone unit of the Pierre is 2,400 feet thick. Its basal unit is the Hygiene Sandstone Member, which is about 600–800 feet thick in the area. At its type locality near Hygiene the member consists of a lower soft sandstone separated from an upper hard glauconitic ridge-forming sandstone by shale that contains ironstone concretions. The two sandstone beds merge toward the south end of the area mapped. Toward the north end of the area mapped the lower sandstone grades into sandy siltstone that contains layers of soft sandstone. Tepee buttes, a name applied by Gilbert (1896) to small conical hills or mounds of limestone that occurs in blobs in the shale and weathers out differentially, are more numerous in the south, but they also are known in the sandy siltstone at the base of the member near Loveland. *Baculites perplexus* is found sparingly in the basal beds of the Hygiene. *Baculites gregoryensis* (unmapped except in northern part of area) is rare in the lower 140–250 feet of the Hygiene, and the lowest range for this baculite zone in the mapped area is about the base of the Hygiene. *Baculites gregoryensis* has a suture pattern different from and more complex than that of *B. perplexus*, and only the larger adults have lateral ribs. This zone of *B. gregoryensis* also contains a species of *Didymoceras*. This is the earliest appearance of that spirally coiled ammonite in the Western Interior. In the southern part of the area *Baculites scotti* (unmapped) is common in the upper part of the Hygiene and in the overlying 100–200 feet of sandy shale (total range of more than 600 feet). This baculite resembles *B. gregoryensis* in its suture but differs in its gentler taper and nearly smooth venter. The base of the *B. scotti* ammonite zone lies about one-fourth of the distance between the bottom and top of the Hygiene; the top of the zone lies 100–200 feet above the Hygiene.

In the Hygiene, the zone of *B. scotti* is characterized by a diverse fauna of ammonites in thin unmapped zones. The base of the zone, near the top of the lower sandstone of the Hygiene, is marked by gray limestone concretions containing a variant of *B. scotti* that has moderately widely spaced broad lateral ribs. Undescribed aberrant ammonites associated with this variant include an early small form of *Exiteloceras*, a species of *Anaklinoceras* that is the earliest and largest in the Western Interior, and a coarse-ribbed species of *Didymoceras*. Also at the base, and extending upward almost 200 feet into beds containing typical *B. scotti* are *Anapachydiscus*? *complexus* and *Menuites*? n. sp. Overlapping the upper few feet of the *Anapachydiscus* zone is a 30-foot-thick zone that is just below the top of the Hygiene and contains a loosely coiled underscribed species of *Didymoceras* having periodic constrictions on the whorls. At the top of its range, this species slightly overlaps a tightly coiled undescribed species of *Didymoceras* which ranges through about 40 feet of section. The base of the Tepee zone of Gilbert (1897, p. 3) at Pueblo, Colo., is marked by this last species. Scaphites, a group of partly uncoiled ammonites, are present in the upper part of the range of *B. scotti* in the area south of Golden; they are unknown in the rest of the range of *B. scotti* as well as in the older zone of *B. gregoryensis*.

About 800 feet of claystone and sandy siltstone separates the Hygiene from the Terry Sandstone Member and forms the middle part of the lower sandstone unit of the Pierre Shale. *Didymoceras nebrascense*, a large densely ribbed helicoid ammonite, is common 275–400 feet above the Hygiene, and its total range is probably 150–550 feet above the Hygiene. This species was not found north of St. Vrain Creek. *Didymoceras stevensoni*, which is more coasely ribbed and more tightly coiled than *D. nebrascense*, is common in large dark-gray limestone concretions stratigraphically higher in the lower sandstone unit *Didymoceras stevensoni* ranges through nearly 300 feet of beds at Boulder, but southward it ranges through less than 150 feet.

The 60-foot-thick Terry Sandstone Member was not mapped. This member can be recognized almost as far south as Boulder, where it becomes quite soft and silty. *Exiteloceras jenneyi*, an easily identified uncoiled planospiral ammonite, is characteristic of the member.

The Terry Sandstone Member is separated from the Rocky Ridge Sandstone Member by about 600 feet of siltstone and shale. The 150 feet of beds immediately overlying the Terry contain rare *Didymoceras cheyennense*, a loosely and spirally coiled ammonite that is readily recognized by its long J-shaped living chamber. The middle of this 150-foot-thick zone has large brown-weathering sandy limestone concretions commonly crowded with *Inoceramus vanuxemi*.

The rest of the unit (as much as 450 feet) separating the Terry from the Rocky Ridge Member and consisting chiefly of sandy siltstone contains *Baculites compressus* in its lower part, *B. cuneatus* somewhat higher, and *B. reesidei* throughout its upper one-half. All these species have a characteristic suture in which the terminal branches of the lateral lobe are constricted at their base--an entirely different arrangement from that of older baculites. *Baculites compressus* has a slender (compressed) ovate cross section and a smooth or nearly smooth venter. It is found in large brown silty limestone concretions in a 75-foot-thick sandy siltstone near the town of Hygiene. South of Boulder, fossils in this zone are scarce. Phosphatic nodules in shale in the area between Coal Creek and Kassler possibly lie in the zone. *Baculites cuneatus* has a wedge-shaped (cuneate) cross section and has been found mostly north of Boulder, where it ranges through at least 100 feet of section. *Baculites reesidei* closely resembles *B. compressus* but tends to have a distinctly ribbed venter.

It is common in the northern part of the area. The base of the *B. reesidei* zone was mapped only near Hygiene; it continues to the north below the Rocky Ridge Member, but is too poorly exposed to map.

The Rocky Ridge Sandstone Member is a fine- to medium-grained glauconitic ridge-forming sandstone that contains hard brown calcareous sandstone concretions as much as 4 feet in diameter. *Baculites reesidei* and *Inoceramus oblongus* are characteristic fossils.

The Larimer Sandstone Member is poorly separated from the Rocky Ridge by soft sandstone. In the northern part of the area the Larimer is a soft but persistent nonridge-forming sandstone that contains very fossiliferous calcareous sandy concretions. Being large and varied, the fauna includes, besides numerous *B. reesidei*, small undescribed species of *Anaklinoceras* and small specimens of *Nostoceras* cf. *N. colubriformis*. The top of the zone of *B. reesidei* seems to coincide with the top of the Larimer. The Larimer was traced as far south as Ralston Reservoir, where it is a hard medium-grained sandstone hardened by the Ralston dike.

The uppermost part of the lower sandstone unit consists of about 100 feet of clayey micaceous siltstone that is equivalent to the Richard Sandstone Member north of the mapped area. *Baculites jenseni* occurs in this siltstone north of Boulder. This fossil resembles its immediate ancestor *B. reesidei* in its suture pattern but differs in its stouter cross section and more weakly ribbed venter.

Upper shale unit

The upper shale unit of the Pierre Shale is chiefly silty shale that contains beds of gray- or brown-weathering silty calcareous concretions, iron-stained limestone concretions, and brown to dusky-red ironstone concretions. The thickness is 2,800 feet near Boulder. Four baculite zones can be recognized; these are, from oldest to youngest, *Baculites eliasi, B. baculus, B. grandis*, and *B. clinolobatus*.

Baculites eliasi is an easily recognized species. It has an elliptical cross section, smooth flanks, smooth or nearly smooth venter, and suture like that of the *B. compressus-B. jenseni* sequence. It occurs abundantly throughout the lower 910 feet of the upper shale unit. The *B. eliasi* zone contains numerous ironstone concretions in its lower part and limestone concretions in its upper part. The uppermost limestone concretions that make tepee buttes in the Pierre Shale are present in this zone.

Baculites baculus is a migrant from the Gulf coastal area. It has a nearly circular cross section, has broad riblike swellings along its flank, and attains diameters as large as 4 inches. The suture is simple, much like that of the oldest species in the Pierre Shale below the Hygiene Sandstone Member. *Baculites baculus* occurs through about 770 feet of the upper shale unit in olive-gray shale containing yellowish-orange limestone concretions. A 35-foot-thick ridge-forming bed of yellowish-gray sandstone lies near the base of the zone in the northern part of the area. Limestone concretions crowded with *Inoceramus typicus* are common in the zone of *B. baculus*.

Baculites grandis descended from *B. baculus* by assuming a more ovate cross section. These species are difficult to distinguish in small collections. In the southern part of the area, *B. grandis* is found in shale, about 150 feet thick, containing black manganese-coated limestone concretions. In the northern part of the area, the species is common through a 750-foot-thick shale capped by a shaly sandstone.

Baculites clinolobatus descended from *B. grandis* by the adults becoming more trigonal in cross section. Its venter is narrower, its dorsum flatter, and its lateral swellings or undulations are more widely spaced than those of *B. grandis*. Owing to considerable variation within *B. clinolobatus* and *B. grandis*, small collections are difficult to identify with certainty. Near Boulder, *B. clinolobatus* is found in silty limestone concretions in the silty and sandy shale forming the upper 270 feet of the upper shale unit. *Inoceramus? fibrosus*, a pelecypod that has radial folds dominant over concentric folds, is common in this zone and rare in the older zone of *B. grandis*.

Upper transition member

The upper transition member contains beds intermediate in character between the Pierre and the Fox Hills, and its assignment has therefore always been controversial. This member, which is about 1,200 feet thick in the southern part of the area and about 2,000 feet thick in the northern part, is composed of friable sandstone and soft shaly sandstone containing thin-bedded sandy shale and large calcareous sandstone concretions. In the southern part of the area, the upper 500 feet is shaly and contains layers of limonite nodules and phosphatic pebbles. At the north edge of the area, the lower one-half contains a few *B. clinolobatus*, and the upper three-fourths contains sparse *Sphenodiscus* (*Coahuilites*); the two fossils overlap slightly in range. *Coahuilites* is a dislike ammonite that has two rows of small nodes on each flank and a distinctive suture pattern reminiscent of the Triassic ceratites.

Prior to 1932 all of the upper transition member was included in the Fox Hills Sandstone (Mather and others, 1928, p. 93), but, as the result of a decision of the Rocky Mountain Association of Petroleum Geologists (Lovering and others, 1932), the lower boundary of the Fox Hills was elevated to a position only 250 feet below the Laramie Formation or about 60 feet below the base of the Milliken Sandstone Member of the Fox Hills Sandstone. We found that this recommended lower boundary of the Fox Hills is unmappable except in small areas of excellent outcrops; therefore, we selected the more easily mappable contact at the base of the Milliken Sandstone Member of the Fox Hills Sandstone. Because of poor outcrops, even this boundary was difficult to draw. From near the latitude of Longmont to the south end of the Niwot quadrangle the Milliken could not be identified with certainty. From the Niwot quadrangle southward, contacts were traced from maps by Spencer (1961), Van Horn (1957), Smith (1964), and Scott (1962 and 1963) with minimum field checking; however, we know that in most of this area the mapped boundary lies below a yellowish-brown sandstone that is possibly equivalent to the Milliken Sandstone Member. We do not propose that the base of the Milliken be designated as the base of the Fox Hills, but a more satisfactory boundary will have to await a detailed stratigraphic study of the Fox Hills.

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