A Study of the Cretaceous-Tertiary Unconformity in the Piceance Creek Basin, Colorado: The underlying Ohio Creek Formation (Upper Cretaceous) Redefined as a Member of the Hunter Canyon or Mesaverde Formation

GEOLOGICAL SURVEY BULLETIN 1482-B

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By RONALD C. JOHNSON *and* FRED MAY

CONTRIBUTIONS TO STRATIGRAPHY

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Palynomorph ages are given for rocks above and below the unconformity, along with a description of the deep paleoweathering profile found below

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By RONALD C. JOHNSON and FRED MAY

ABSTRACT

Detailed work in the southwest Piceance Creek basin and reconnaissance work elsewhere in the basin have shown the presence of a major regional unconformity between rocks of Late Cretaceous and Tertiary age. The time gap represented by this unconformity in the southwestern part of the basin, based on palynomorph studies, is from late Campanian or early Maestrichtian to late Paleocene time. The Cretaceous rocks beneath the unconformity consist of gray-weathering lenticular sandstone units as thick as 30 m and more, separated by gray claystone, gray mudstone, and thin coal beds. Lenses of small chert pebbles are scattered throughout the upper 410 m of Cretaceous strata underlying the unconformity, but they are most abundant in the uppermost 150 m.

The uppermost 50 to 150 m of the section beneath the unconformity crop out in a distinctive white color. Petrographic and X-ray mineralogy studies at Hunter Canyon in the southwestern part of the basin show that the white color is due to a breakdown of feldspar and subsequent accumulation of kaolinite, and it probably marks a paleoweathering profile developed during the time interval represented by the unconformity. Paleosoils are locally preserved in the upper few meters as well. If the kaolinitic zone is a paleoweathering profile as we believe, however, then it is a secondary characteristic superimposed on whatever rocks were being subjected to surface weathering at that time. Rates of erosion during this time interval were probably not constant throughout the basin and consequently the presently preserved kaolinitic zone is probably not everywhere at the same stratigraphic level.

This kaolinitic, sparsely conglomeratic zone has been called the Ohio Creek Conglomerate or the Ohio Creek Formation by previous workers. The presence of conglomerate and the white color, the two features used to define the formation, are independent of each other, however, and need not occur together. We recommend, therefore, that the Ohio Creek Formation be reduced in stratigraphic rank to member and redefined as the white-colored kaolinitic zone, which may or may not contain chert-pebble conglomerate, found at the top of the Hunter Canyon or Mesaverde Formation.

INTRODUCTION

This report presents evidence of a major regional unconformity in the southwestern Piceance Creek basin between rocks of Cretaceous and Tertiary age. The Ohio Creek Formation, previously thought to be Tertiary in age, is below this unconformity. The mineralogy of the Ohio Creek Formation was profoundly altered by weathering during the time interval represented by the unconformity, and its distinctive white color was developed at this time; therefore, the Ohio Creek Formation is not a formation in the traditional sense at all, but rather a weathered zone superimposed on older rocks. At all localities examined, the palynomorph age of the Ohio Creek Formation was found to be indistinguishable from that of the underlying rocks. For these reasons, we reduce the stratigraphic rank of the Ohio Creek Formation to that of a member of the underlying formation. In the southwest Piceance Creek basin, the underlying formation is called either the Hunter Canyon or Mesaverde.

The Ohio Creek Member was studied in detail in the southwestern part of the Piceance Creek basin between Hunter Canyon and DeBeque (fig. 1). This detailed study includes measured sections, petrographic and X-ray mineralogy studies, and identification of palynomorph assemblages that were extracted from a preliminary study of the Upper Cretaceous Mesaverde Group and the Tertiary Wasatch and Green River Formations in the southwest Piceance Creek basin (Johnson and May, 1978b; Johnson and others, 1979). The preliminary study was supplemented by a study of a core from the C.E.R. Geonuclear Corp. RB-1 drill hole to the north (fig. 1) and by the measurement of two sections of the Ohio Creek Member in the southern part of the basin (fig. 1), one from the type locality along Ohio Creek and the other from along Muddy Creek about 35 km northwest of the type locality. The Cretaceous-Tertiary boundary was not examined in the northeastern part of the basin.

HISTORY OF OHIO CREEK NOMENCLATURE

First mention of the unusual white unit found beneath the Wasatch Formation (then known as the Ruby beds) was by Hills (1890, p. 390–391), who described the unit along Ohio Creek at the extreme south end of the Piceance Creek basin and along Coal Ridge, about 90 km to the north (fig. 1). Of the Coal Ridge area he said: "South of the Great Hogback at Coalridge there is an abrupt change in the composition of the sediments previously regarded as Laramie. The firm gray sandstones of the coal measures are there succeeded by about 200 feet of soft white sandstones and yellow clays* * *." Hills

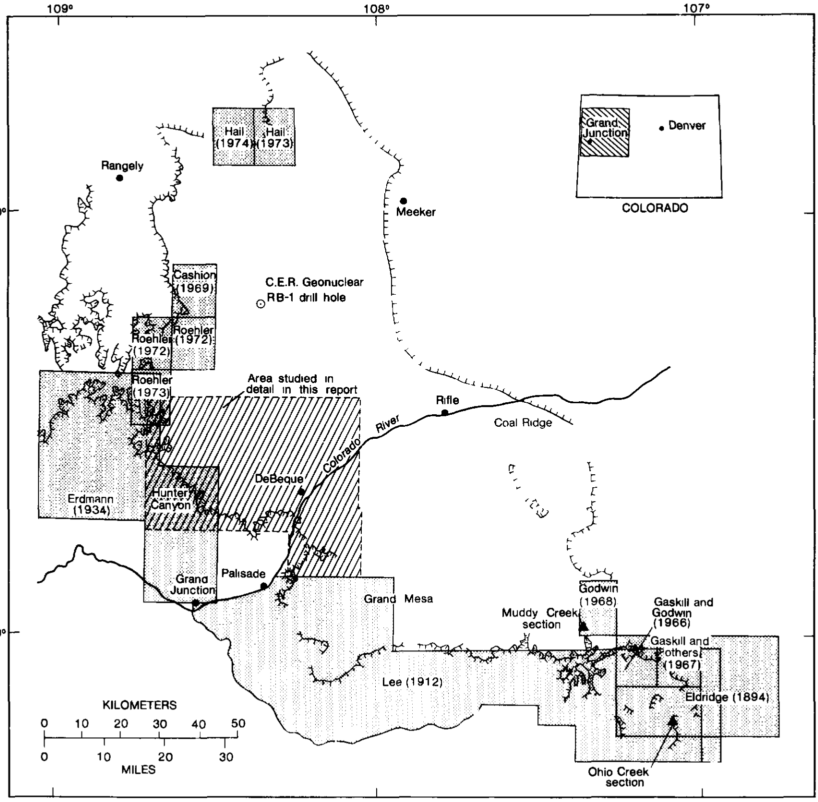


FIGURE 1.—Index to mapping and outline of Cretaceous-Tertiary boundary (hachured line) in the Piceance Creek basin, Colorado. Sections of the Ohio Creek Member are delineated. (From Tweto, 1976.)

described the overlying Wasatch Formation or Ruby beds as "* * *about 300 feet of tuffaceous strata, more or less conglomeratic and loosely aggregated, but resting on a hard coarse basal conglomerate about 40 feet thick, made up wholly of eruptive debris." Of the white unit along Ohio Creek, Hills said: "The strata which appear between the Ruby beds and the coal measures on Grand River may be represented in the Ruby Peak region by certain friable sandstones overlying the Laramie on Ohio Creek which differ from the true Laramie sandstones in containing an abundance of chert pebbles, sometimes fossiliferous, derived from the erosion of Lower Carboniferous beds."

The name Ohio Creek Formation was first applied to the unit by Eldridge (1894) in the Anthracite and Crested Butte Quadrangles (fig. 1), of which he said: "This formation consists of about 200 feet of sandstones and conglomerates which rest unconformably on the Laramie.* * *The sandstones are gray, weathering buff and red, and are made up almost wholly of coarse, loosely agglomerated grains of quartz."

Lee (1912, p. 48–49) called the unit the Ohio Creek Conglomerate in a report on coal resources in the Grand Mesa–West Elk Mountain area (fig. 1). According to Lee, the formation is: "* * *white and contrasts sharply with the overlying Wasatch ("Ruby") Formation, which is highly colored. In the Grand Mesa Field, it does not differ from the formation as described by Eldridge except that it is thinner, and the pebbles are smaller than in the type locality." Lee was the first to note a similar "white conglomerate sandstone" near Palisade in the area studied in detail in this report. Lee thought that the base of his Ohio Creek Conglomerate was unconformable with the underlying Hunter Canyon Formation. Lee provisionally assigned the Ohio Creek Conglomerate to the Tertiary on the basis of fossil plants found by Gale (1910, p. 79–80) in rocks that Lee assumed occupied a similar stratigraphic position.

Erdmann (1934, p. 53–55) described what he believed to be the equivalent of Lee's Ohio Creek Conglomerate along the Book Cliffs north of Palisade. He described the unit as 155 to 370 ft. thick[1], composed of about 38 percent sandstone and 50 percent shale with pebbles of gray and black chert occurring in strings and stringers. Erdmann stated that, "Because of their white and light gray colors and cliff-forming habit, the sandstone beds of this unit are especially conspicuous." He described the unit as unconformable with the underlying Hunter Canyon Formation and gave a detailed description of a basal conglomerate or conglomeratic sandstone that is present in most places.

Gaskill and Godwin (1963) mapped the Ruby–West Elk Mountain area in detail and found conglomeratic lenses far below the base of Lee's Ohio Creek Conglomerate, in what Lee had mapped as the Mesaverde Formation. After examining the type locality along Ohio Creek, they redefined the Ohio Creek Formation in the Ruby–West Elk Mountain area to include these lower beds, making the formation 380–430 ft thick. Gaskill and Godwin interpreted the lower contact of the redefined formation as gradational, and arbitrarily placed the lower contact at the base of the lowest pebbly bed. Gaskill (1961) collected leaves identified as Paleocene in age from the lower part of the redefined formation about 16 km northwest of the type locality. This Paleocene age presented many problems, because Gaskill considered the unit to be conformable with the underlying

[1]Measurements cited from an older report are given in the units of that report; 1 ft=0.3048 m.

Mesaverde Formation of known Late Cretaceous age. R. H. Tschudy (oral commun., 1978) suggested that most of the leaf identifications such as those identified for Gaskill need to be reexamined.

Gaskill and Godwin (1963) measured three sections in the DeBeque area, and stated (p. C38): "Reconnaissance examination of scattered outcrops along the Grand Hogback and in the DeBeque-Mesa, Colo., area has convinced the authors that beds present at each of the numbered localities* * *are equivalent in part to the redefined Ohio Creek Formation." They later cautioned, however, that the beds should be traced along outcrop to the Ruby-West Elk Mountain area to be certain. Their graphic sections portray the Ohio Creek Formation as a conglomeratic sandstone 20-60 m thick with an indefinite top and base.

Donnell (1961, p. 843), in a report on the northern part of the Piceance Creek basin between the Colorado and White Rivers, described the Ohio Creek Conglomerate as "composed mostly of pebbles and cobbles of red and black chert and quartzite, ranging from the size of a pea to 4 or 5 inches in diameter. At all exposures examined the cobbles and pebbles are associated with poorly indurated coarse-grained white sandstone (pl. 56); at places they occur within the white sandstone and at other places in a brown sandstone matrix either just above or just below the white sandstone." Donnell assigned a Tertiary age to the Ohio Creek.

Donnell (1961, p. 844) also stated: "The observed range in thickness of the conglomerate in the area is from 5 feet at a locality in T. 9 S., R. 97 W., to about 20 feet on Highway 64, 3 miles west of Meeker." The locality Donnell mentioned in T. 9 S., R. 97 W. is in the same area where Gaskill measured a thickness of 20 to 60 m for the Ohio Creek Formation. The difference in reported thickness is probably due to the fact that these authors were not describing the same unit. This discrepancy is dealt with in the section on DeBeque area stratigraphy.

A unit tentatively correlated with the Ohio Creek Formation has recently been mapped by several workers in the west and northwest parts of the Piceance Creek basin. In the Black Cabin Gulch Quadrangle, Cashion (1969) described the formation as "light-gray very fine grained ledge-forming sandstone, gray and green mudstone and shale; a few lenses of conglomerate,* * *thickness (on outcrop) 80-300 feet." In the Calf Canyon, Razorback Ridge, and Brushy Point Quadrangles, Roehler (1972a, 1972b, 1973) described the formation as "gray very fine to fine grained crossbedded sandstone, locally coarse grained and containing thin lenses of conglomerate." The thickness in the three quadrangles varies from 0 to 230 ft. Farther north the Ohio Creek Formation was found by Hail (1973, 1974) to be discontinuous in the Rough Gulch and Smizer Gulch

Quadrangles, where he described it as "light brown to white sandstone, massive to crossbedded locally containing very sparse chert or quartzite pebbles. Nonpersistent; cannot be recognized with certainty throughout quadrangle. Maximum thickness about 80 feet." All these workers tentatively assigned the Ohio Creek(?) Formation to the Tertiary.

TYPE LOCALITY OF THE OHIO CREEK MEMBER OF THE MESAVERDE FORMATION

An outcrop of white friable sandstone is found on the east side of Ohio Creek about 2½ km north of the junction between Ohio Creek and Pass Creek and was first mapped as the Ohio Creek Formation by Eldridge (1894). The outcrop is the best exposure of the unit along Ohio Creek and was designated as the type locality of the then Ohio Creek Formation. At the type locality, the Ohio Creek is a member of the Mesaverde Formation. The outcrop consists of two resistant, friable white sandstone units, each about 15 m thick, separated by a covered interval about 40 m thick (fig. 2). The sandstone units are medium to coarse grained, containing sparse lenses of pebbles with pebbles as much as 3 cm in diameter. The pebbles are chert of various colors. The units are generally weakly crossbedded with bed sets as much as 1 m high. Clay ripups occur just below the top. The base of the lower sandstone outcrop is buried in talus and the base of the member cannot be well defined. Therefore, a principal reference section has been chosen at Hunter Canyon, an area with better exposures of the Ohio Creek interval.

The Ohio Creek Member is unconformably overlain at the type locality by about 20 m of slope-forming mottled maroon and gray, medium- to coarse-grained conglomeratic sandstone of the Wasatch Formation. Pebbles are as much as 7 cm in diameter, consist of various colors of chert, and make up about 5 to 10 percent of the rock. This mottled unit is similar to the basal conglomerate of what Eldridge (1894) called the Ruby Formation. The basal conglomerate according to Eldridge is "* * *from 20 to 30 feet thick and consists mainly of chert and quartz pebbles with a few Archean rocks." The rest of the Ruby Formation is described as "red, purple, and green sandstones and shales with a few beds of conglomerate made up, for the most part, of debris of various eruptive rocks." No rocks suitable for palynomorph dating are exposed at the type locality of the Ohio Creek Member along Ohio Creek.

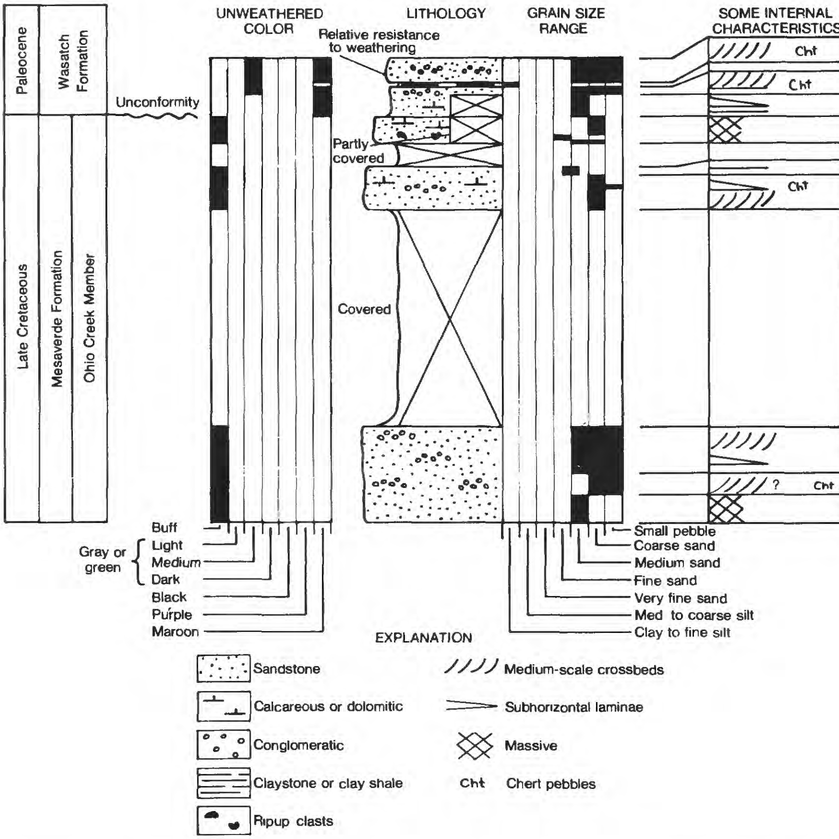


FIGURE 2.—Type locality of the Ohio Creek Member of the Mesaverde Formation at Ohio Creek. Vertical scale: 1 cm=13.2 m.

HUNTER CANYON AREA STRATIGRAPHY

The Cretaceous-Tertiary boundary was determined in the Hunter Canyon area on the basis of palynomorphs. (See section, "Palynomorph results.") The uppermost 300 m of Upper Cretaceous rocks in the Hunter Canyon area consists of about 75 percent medium- to coarse-grained sandstone units interbedded with about 25 percent gray carbonaceous shale and some nonpersistent coal (fig. 3). The sandstone units are as much as 30 m thick, are fairly persistent laterally though irregular in thickness, and generally display well-developed later accretion units typical of point bar deposits of meandering streams (Bernard and others, 1970). Each accretion unit consists internally of alternating zones of ripup clasts, trough crossbeds, and even, parallel laminae. Drift ripple laminae, also

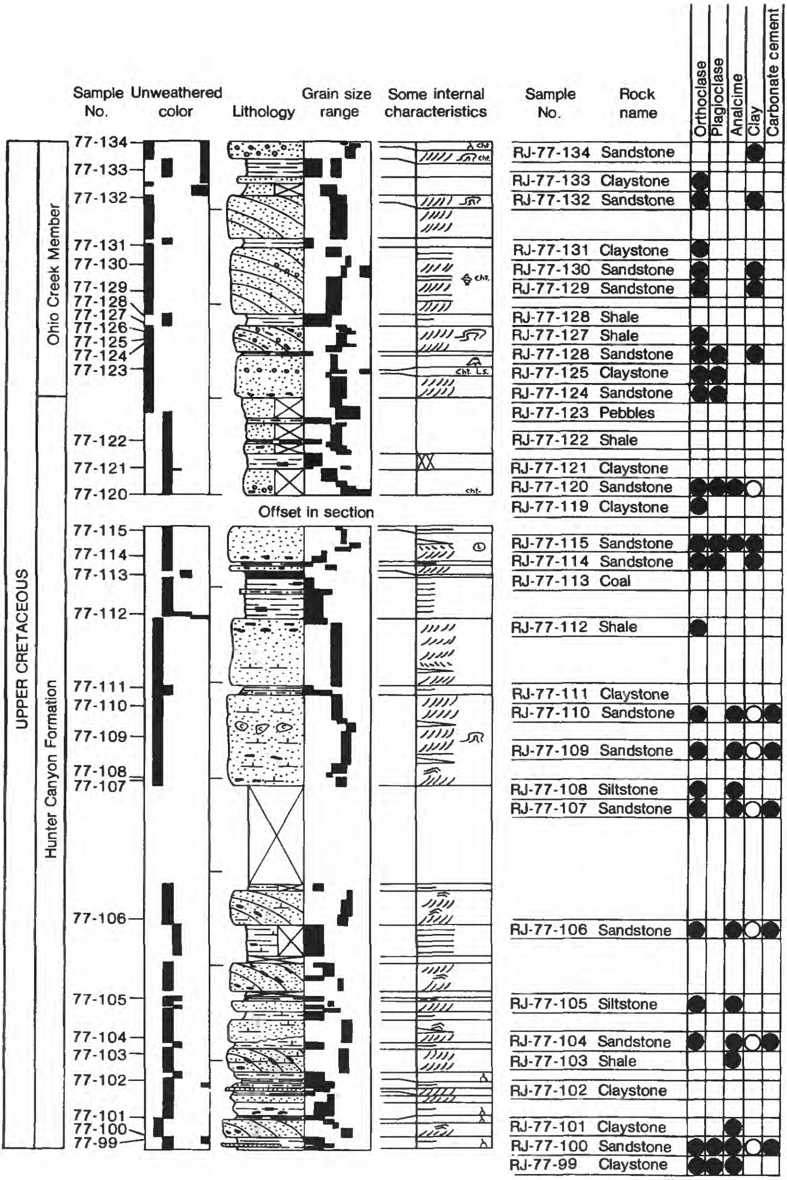
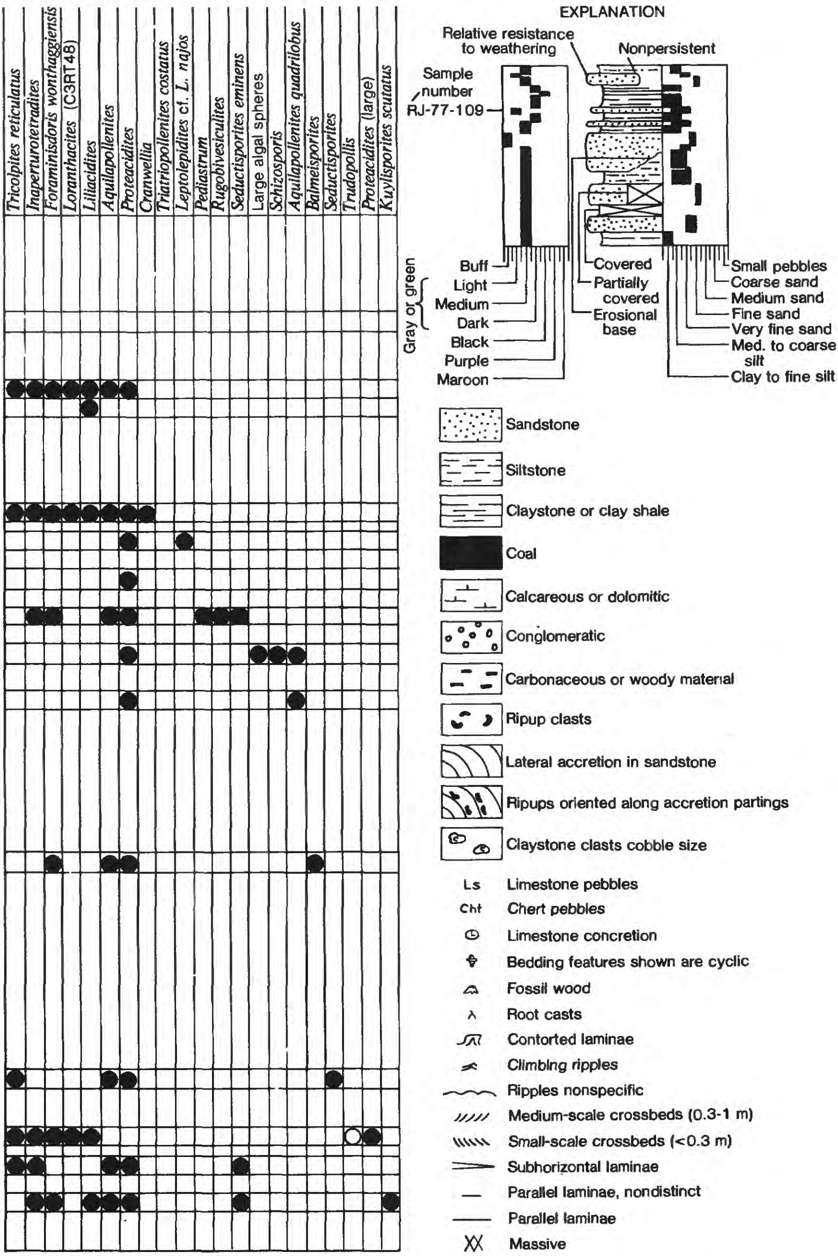


FIGURE 3.—Upper part of Cretaceous section at Hunter Canyon (from Johnson and mineralogy and fossil content: solid circle, major constituent; open circle,



others, 1979). See figure 10 for location. Mineralogy from bulk X-ray analysis. For minor constituent; queried where indefinite. Vertical Scale: 1 cm = 24 m.

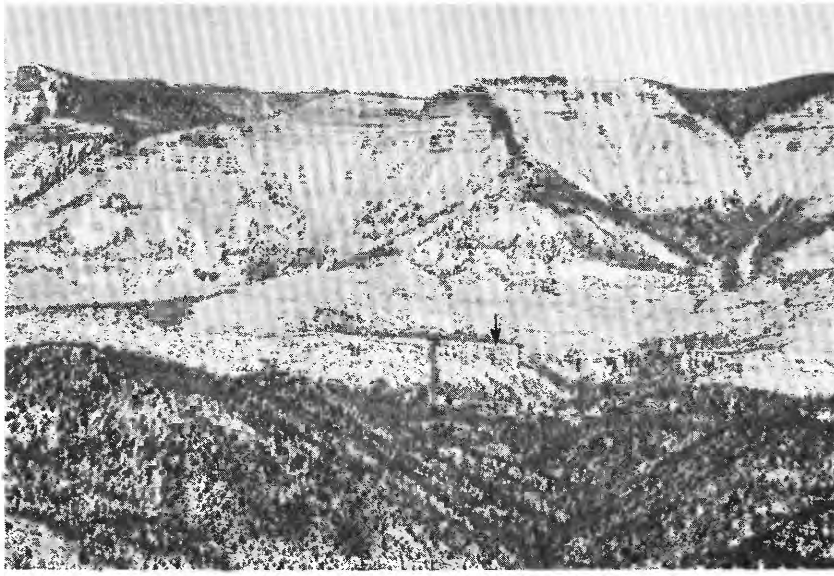


FIGURE 4.—View of Cretaceous-Tertiary unconformity in Hunter Canyon area (arrow). Brackets show approximate limits of kaolinitic zone.

characteristic of point bar deposits, are present only locally. Some of the thicker units, however, have no obvious accretion features and consist mostly of crosscutting sets of trough crossbeds. Pebbles of dark chert, silicified limestone, and laminated silicified siltstone first occur about 115 m below the top. In accretion units, the pebbles are in the basal scoured zone. In the sandstone bodies without accretion units, the pebbles are in scattered lenses. The pebbles constitute less than 5 percent of the sandstone bodies. The contact between the nonpebbly part of the Cretaceous section and the overlying pebbly part is gradational. The position of the lowest occurrence of pebbles varies considerably over short distances and does not constitute a mappable contact.

The Cretaceous rocks are separated from the overlying Paleocene Atwell Gulch Member of the Wasatch Formation by a major regional unconformity. A well-developed paleoweathering profile is found beneath the unconformity surface at Hunter Canyon, which gives sandstone units in the upper 70 to 90 m of the underlying Upper Cretaceous rocks a distinctive white color (fig. 4). Some irregular zones of secondary oxidation are also present.

The white color is caused by breakdown of feldspars and the consequent development of abundant kaolinite. Plagioclase is almost completely destroyed to a depth of about 60 m below the unconformity and potassium feldspar to a depth of about 6 m. This weathering is

FIGURE 5.—Closeup of the top of the Ohio Creek Member near Hunter Canyon. Massive zone in foreground is thought to be a paleosoil. Note man in upper right for scale. View northward in SE1/4SE1/4 sec. 34, T. 8 S., R. 100 W.

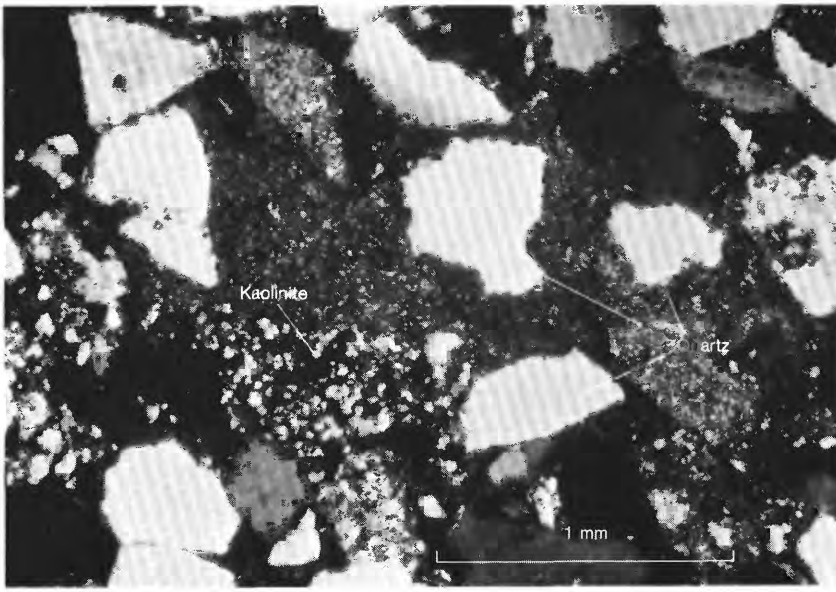


FIGURE 6.—Photomicrograph of highly altered sandstone from Ohio Creek Member of Hunter Canyon Formation. Photo is of sample locality 77-134 (fig. 3).

extreme in the upper 6 m (fig. 5), where kaolinite makes up as much as 60 percent of the rock and all original bedding has been destroyed. A thin section of a sample from this zone (fig. 6) revealed only kaolinite, coarse-grained quartz, and chert. Vertical root casts extend downward from the unconformity for a distance of about 2 m (fig. 7). This 6-m-thick, intensely weathered sequence beneath the unconformity is almost certainly a paleosoil zone.

Very little relief on the unconformity surface is evident in the Hunter Canyon area; however, the thickness of the white zone and paleosoil varies widely, and the paleosoil is locally absent.

Cementing agents typical of the underlying Upper Cretaceous rocks are also absent beneath the unconformity and apparently have been removed by leaching. Carbonate cement is absent to a depth of 170 m below the unconformity and analcite cement to a depth of 120 m.

The description of this weathered zone is very similar to the description Erdmann (1934) gave for his Tertiary(?) sandstone in the Hunter Canyon area, which he correlated with the Ohio Creek Formation. The two units are probably largely the same; however, Erdmann described an unconformity at the base of his Tertiary(?) sandstone overlain by conglomerates. These features could not be located in our study area. The unit is largely fluvial, and many channeled surfaces

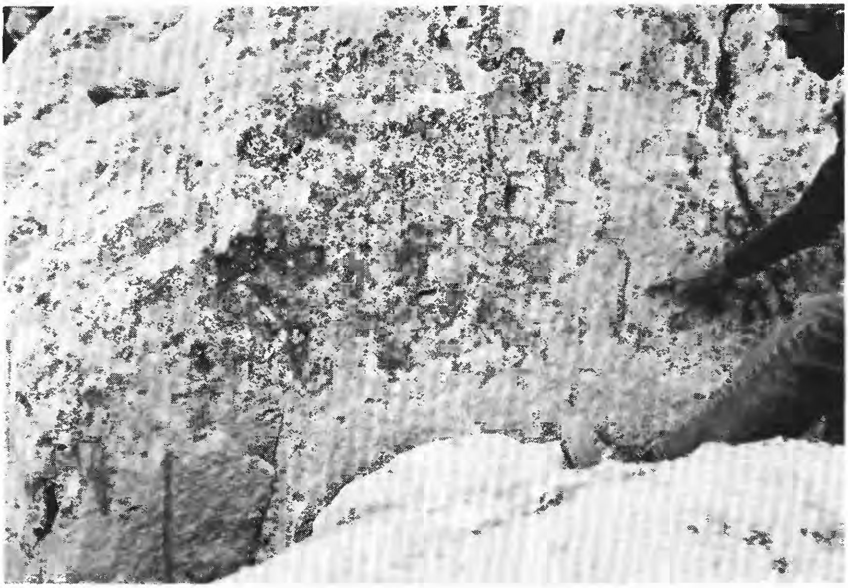


FIGURE 7.—Root zone at top of Upper Cretaceous rocks (sec. 34, T. 8 S., R. 100 W.).

of limited extent occur; it is possible Erdmann was using one or more of these surfaces as his base. Also, in the detailed section at Hunter Canyon, the lowermost occurrence of conglomerate is about 25 m below the lowermost noticeable kaolinite accumulation, and it is unclear which criteria Erdmann was using to define his unit.

OHIO CREEK MEMBER—PRINCIPAL REFERENCE SECTION

The Hunter Canyon section is designated as the principal reference section for the Ohio Creek Member because the unit is much better exposed here than at its original type locality along Ohio Creek. The top of the member is defined as the unconformity, and the base is defined as the base of the lowest white sandstone. At Hunter Canyon, the Ohio Creek Member is a member of the Hunter Canyon Formation. Erdmann (1934) excluded the rocks now known as the Ohio Creek Member from the original definition of the Hunter Canyon Formation, and we therefore redefine the Hunter Canyon Formation to include these rocks.

Overlying the unconformity at Hunter Canyon in the Atwell Gulch Member of the Wasatch Formation is a black carbonaceous claystone unit about 50 m thick that contains thin coal zones. This unit forms a conspicuous dark-gray band on outcrop and can be traced eastward from Hunter Canyon into the DeBeque area.

DEBEQUE AREA STRATIGRAPHY

Because of the conspicuous white kaolinitized zone (Ohio Creek Member of Hunter Canyon Formation) just beneath it (fig. 8), the unconformity was easily traced by aerial photos and on the ground from Hunter Canyon into the DeBeque area where Donnell (1961) and Gaskill and Godwin (1963) assigned conglomeratic units to the Ohio Creek Formation. The dark-gray carbonaceous claystone zone that lies just above the unconformity at Hunter Canyon is 85 m above the unconformity at the west end of Horse Thief Mountain (figs. 9, 10), just south of DeBeque. Some of this disparity may be due to a lateral facies change, but much of it is probably due to onlap on the unconformity surface. Deposition began in the DeBeque area while the Hunter Canyon area was still a relative upland subject to some erosion. The 85 m of section below the black claystone sequence at DeBeque but not found at Hunter Canyon consists of variegated mudstone and claystone with a few small lenticular sandstone bodies and a basal conglomeratic sandstone about 15 m thick. Pebbles compose as much as 40 percent of the basal conglomeratic sandstone and consist of varicolored chert and red and gray sandstone. This suite of pebbles is more variable in composition than the suite in the pebbly part of the underlying Cretaceous section. Some of the clasts attain a diameter of 20 cm or more. The upper 60 to 90 m of the Cretaceous section contain widely scattered lenses of pebbles at DeBeque and are similar in character to the unit at Hunter Canyon.

Thickness of the white kaolinitized Ohio Creek Member in the DeBeque area is highly variable but locally is at least 70 m. The upper part of the member is locally oxidized red, but no obvious paleosoil is present. Almost no relief has been detected on the unconformity surface except where it is locally channeled. A small channel filled with conglomerate is found on the unconformity surface in SE ¼ SE ¼ sec. 22, T. 9 S., R. 97 W. (fig. 11). The channel fill is about 3 m thick, 10 m wide, and of indeterminate length; it is composed of as much as 70 percent conglomerate. Pebbles of the conglomerate are as much as 4 cm in diameter and are similar in composition to pebbles in the overlying basal conglomeratic sandstone of the Atwell Gulch Member of the Wasatch Formation. The channel deposit, however, is white colored, like the upper part of the underlying Cretaceous section. No concentration of pebbles such as this has been observed within the underlying Cretaceous section itself. These pebbles may have been deposited by a stream flowing across the unconformity surface shortly before basin sedimentation began in the area. Such deposits could have been preserved by being rapidly buried beneath basin sediments.

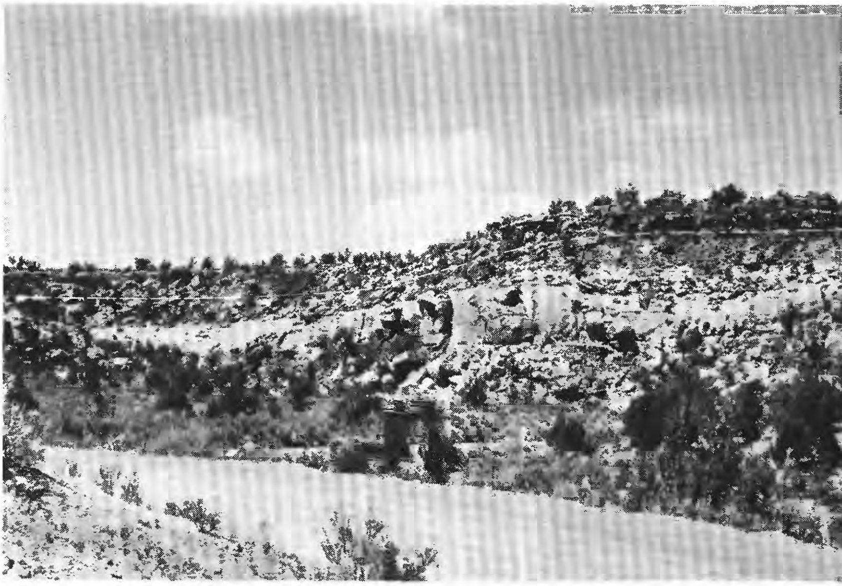


FIGURE 8.—View of Cretaceous-Tertiary unconformity (dashed line) taken along DeBeque cutoff road south of DeBeque.

Donnell's description (1961, p. 843) of the Ohio Creek Formation in the DeBeque area closely fits the description of the Tertiary basal conglomerate of the Atwell Gulch Member of the Wasatch Formation. However, he described the pebbles as being "within the white sandstone and at places in a brown sandstone matrix either just above or just below the white sandstone." The mention of white sandstone suggests that he may have locally included some of the underlying Cretaceous section or conglomeratic channels on the unconformity surface. The unit that Gaskill and Godwin (1963) assigned to the Ohio Creek Formation in the DeBeque area is very similar to the white kaolinitized zone or Ohio Creek Member of this report at the top of the Cretaceous section. The indefinite base they showed for the unit is understandable because both the thickness of the white zone and the position of the lowest occurrence of chert pebbles, the other characteristic formerly used to define the Ohio Creek Member, vary laterally.

MUDDY CREEK SECTION

The Ohio Creek Formation (Ohio Creek Member of this report) was mapped by Godwin (1968) along East Muddy Creek south of McClure

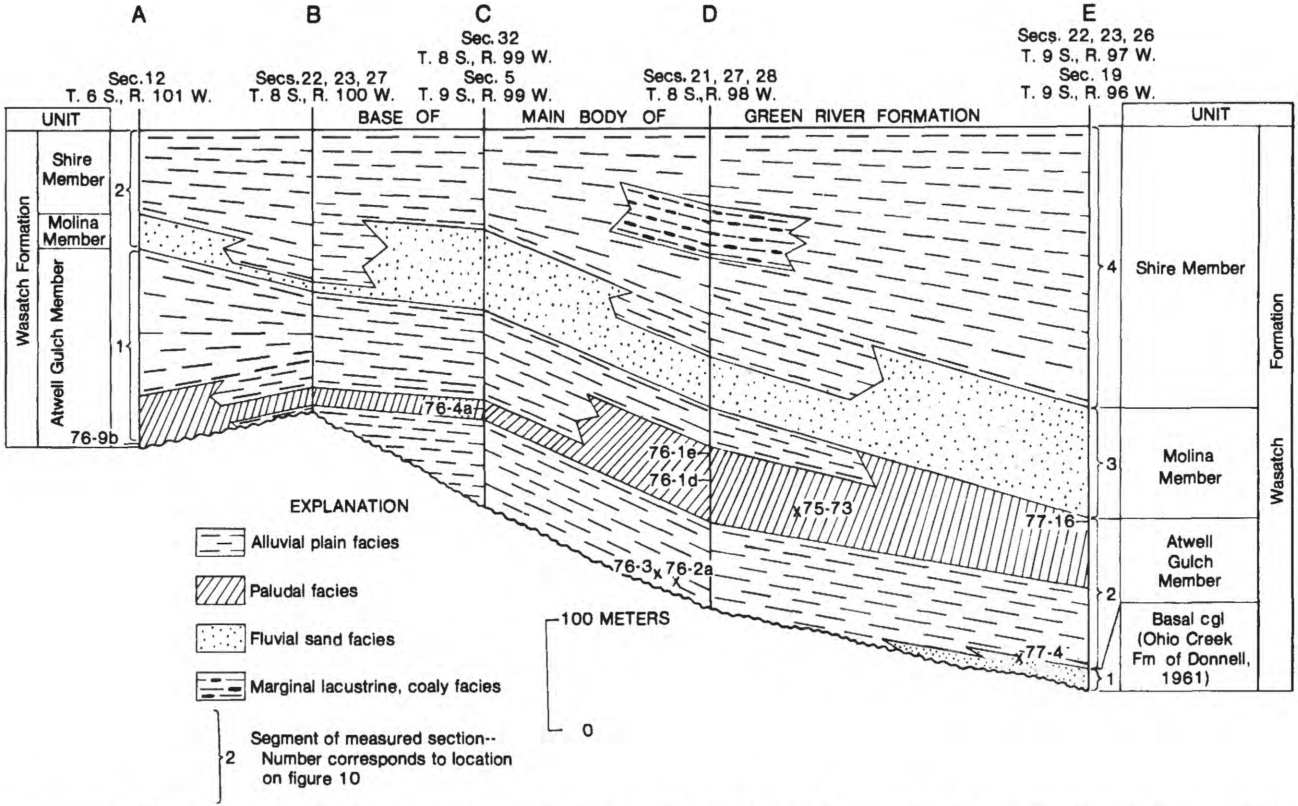


FIGURE 9.—Stratigraphic and facies diagram for the Tertiary rocks from Hunter Canyon to DeBeque. Numbers indicate positions of palynomorph samples. Samples 76-3, 76-2a, 75-73, and 77-4 were collected outside the line of sections and are projected into their approximate stratigraphic positions. Locations of measured sections shown in figure 10.

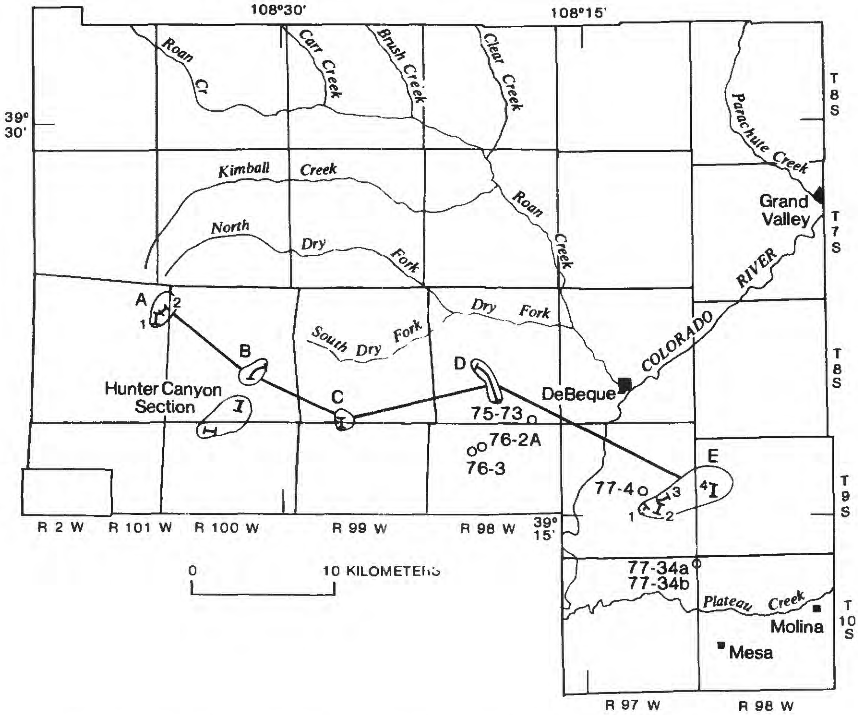


FIGURE 10.—Locations of measured sections and palynomorph samples.

Pass (fig. 1). Godwin divided the unit into three parts. The upper and lower parts are described briefly as light-gray or white conglomeratic sandstone. The middle part is described as interbedded sandstone, siltstone, and shale with some thin coal lenses. The total thickness is 440 ft (135 m). For this study, a section was measured of the upper 48 m of Ohio Creek Member (of Mesaverde Formation) where it is exposed about 2.9 km north of the junction of East and West Muddy Creeks and 3.5 km south of Gaskill and Godwin's (1963) measured section 3. The lower 18 m of section consist of very fine to medium-grained gray sandstone interlayered with olive-green mudstone and gray to dark-gray carbonaceous mudstone (fig. 12). Sandstone units contain near horizontal and trough crossbeds with crossbed sets as thick as 1 m. The upper 33 m of the Ohio Creek Member is cliff-forming, light-gray- to white-weathering, medium- to coarse-grained sandstone with abundant clay ripups. Sparse lenses of gray and tan chert pebbles as much as 3 cm in diameter occur in the upper 10 m. Trough crossbeds are abundant, and the sets vary in thickness from ⅓ to 1 m in the lower part of this white zone to almost 3 m in the upper part.

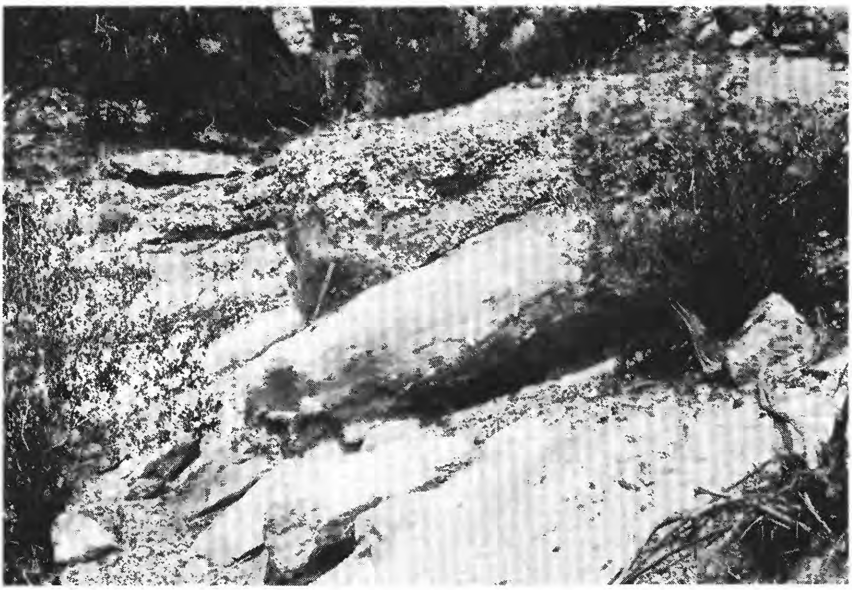


FIGURE 11.—Conglomeratic channel at unconformity near DeBeque. Hammer for scale.

The overlying Wasatch Formation consists mostly of poorly exposed nonresistant maroon, purple, and olive-green mudstone and sandstone. A conglomeratic sandstone unit 1½ m thick is found 9 m above the base of the Wasatch and contains as much as 50 percent pebbles of gray chert and possibly gray quartzite of at least 10 cm in diameter.

C.E.R. GEONUCLEAR CORPORATION DRILL HOLE

The C.E.R. Geonuclear RB-1 drill hole was drilled for project Rio Blanco, which was an attempt to stimulate natural gas production by fracturing tight reservoirs with nuclear devices. The hole was drilled to a depth of 7,800 ft (2,400 m) or approximately 2,200 ft (675 m) into the Hunter Canyon Formation. The Cretaceous-Tertiary boundary is picked at the abrupt change in electric log character (fig. 13) that corresponds to a lithologic change from predominant thick sandstone units of Cretaceous age to predominant mudstones and claystones of Tertiary age. This contact is easily traced from surface exposures in the DeBeque area to the vicinity of the RB-1 hole (Johnson, 1978) through the use of electric log correlations. Five intervals were cored. The highest core starts at 5,710 ft (1,750 m) or about 110 ft (34 m) below the Cretaceous-Tertiary boundary, and the lowest ends at 7,752 ft (2,360 m). Because only a few intervals were cored, the base

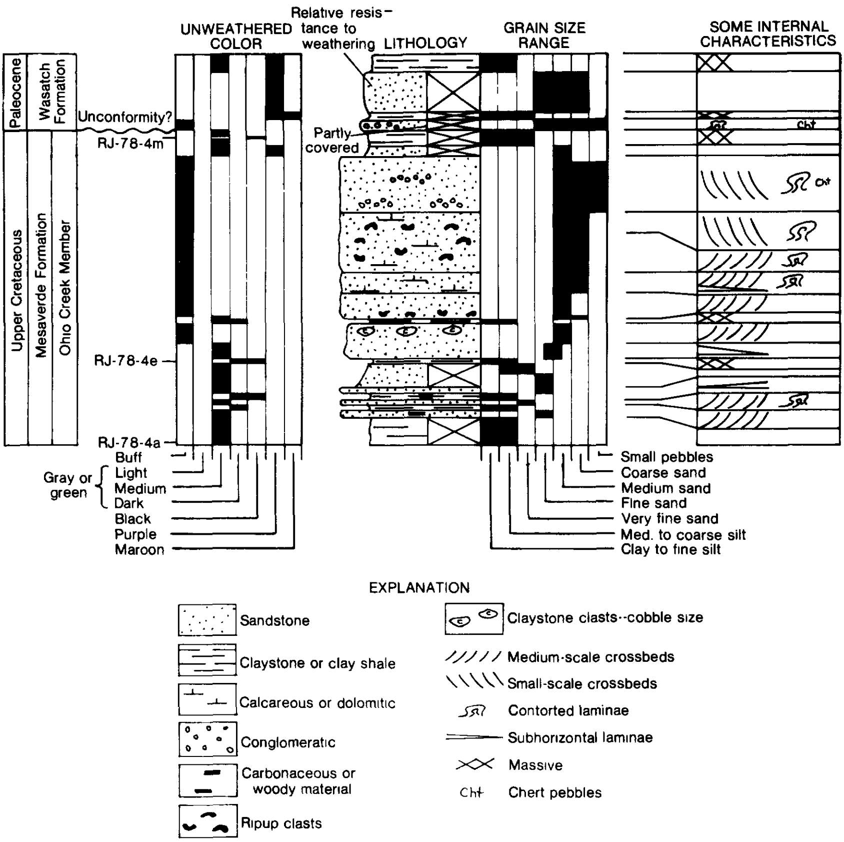


FIGURE 12.—Measured section at Muddy Creek. Vertical scale: 1 cm=12.4 m.

of the Ohio Creek cannot be determined. Chert and quartzite pebbles are found between 5,720 ft and 5,730 ft (1,750 m and 1,753 m), 5,860 ft and 5,890 ft (1,790 m and 1,800 m), and at about 6,940 ft (2,120 m). The lowest pebbles are about 1,340 ft (410 m) below the unconformity. This indicates that chert pebbles can occur much lower in section than previously thought.

PALYNOMORPH RESULTS

HUNTER CANYON

Thirteen samples collected in the upper 300 m of section beneath the unconformity at Hunter Canyon yielded pollen (fig. 2).

Seven samples from the section beneath the lowest white sand-

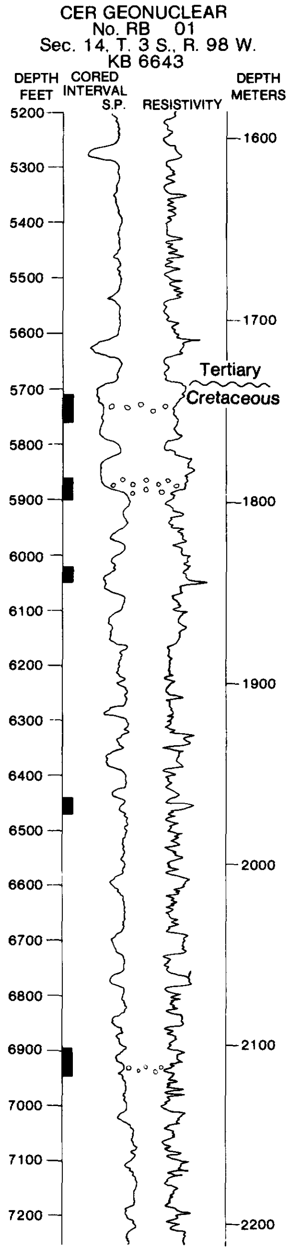


FIGURE 13.—Log profile and cored conglomerate zones, C.E.R. Geonuclear drill hole; cored intervals shown by bar on vertical scale. Small circles indicate chert-pebble conglomerate. Sec. 14, T. 3 S., R. 98 W.

stone, or more than 85 m below the top, yielded the following pollen diagnostic of Cretaceous age:

Proteacidites—Turonian to Maestrichtian
Cranwellia—early Campanian to Maestrichtian
Loranthacites sp. (C3RT48 Denver USGS Ident.)—early Campanian to probably early Maestrichtian
Tricolpites reticulatus—early Campanian to probably early Maestrichtian
Kuylisporites scutatus—early Campanian to probably early Maestrichtian.

The range for *Proteacidites* is generally accepted to be Turonian to Maestrichtian, and the range of *Cranwellia* has been determined by examining the reference collections of the U.S. Geological Survey, Denver, Colo.

These results suggest an early Campanian to early Maestrichtian age for the Cretaceous section below the Ohio Creek Member; however, a late Campanian baculite was found in the Sego Sandstone at Hunter Canyon (Gill and Hail, 1975), which is stratigraphically lower than the Hunter Canyon Formation. This would further restrict its age to late Campanian to early Maestrichtian.

Two pollen-bearing samples from the white kaolinitic Ohio Creek Member at Hunter Canyon indicate the same age as the underlying part of the Hunter Canyon Formation. Forms identified include *Proteacidites, Cranwellia, Loranthacites* (C3RT48), and *Tricolpites reticulatus.* The base of the white kaolinitic zone is about 85 m below the unconformity and about 25 m above the lowest pebbly zone observed. A late Maestrichtian (Hell Creek) age for this white unit reported by the authors in an earlier publication (Johnson and May, 1978a) was based on incomplete palynomorph studies.

DEBEQUE AREA

One sample (77-34a), collected from beneath a 3-cm-thick bed about 30 m below the top of the white kaolinitic zone or Ohio Creek Member south of DeBeque (fig. 10), yielded the following palynomorphs: *Maceopolipollenites, Proteacidites, Liliacidites,* and *Loranthacites* (C3RT48). *Loranthacites* (C3RT48) indicates a late Campanian to early Maestrichtian age, the same as the white kaolinitic unit at Hunter Canyon.

Eight samples from the Atwell Gulch Member of the Wasatch Formation yielded palynomorphs. Five of these are from the measured sections in the stratigraphic diagram shown on figure 9, and their positions are shown on the diagram. Samples numbered 76-2a, 76-3, and 77-4 were collected from outcrops near the measured sections and are projected into the plane of the cross section. The locations of the measured sections and of samples 76-2a, 76-3, and 77-4 are shown on figure 9. The palynomorph assemblages are listed on figure

Sample No.	Locality Sec., T.S., R.W.	Interval above unconformity (m)	*Carya*	*Ulmipollenites*	*Zlivisporis*	*Alnipollenites*	*Maceopolipollenites amplus*	*Pistillipollenites*	*Tetraporina*	Moraceae	*Maceopolipollenites*	*Symplocospollenites*	*Symplocoipollenites*	3- and 4-pored *Alnipollenites*	*Quercus explanata*	*Pterocarya*	5-6-pored *Alnipollenites*	Onagraceae	*Paraalnipollenites*	*Foraminisporis*	*Pediastrum*	*Tricolpites anguloluminosus*	*Momipites sanjuanensis*	3-6-pored *Alnipollenites*
77-16	23-9-97	155	●	●	●																			
76-1e	27-8-98	135		●		●	●																	
76-1d	27-8-98	122		●				●	●	●														
75-73	35-8-98	93	●				●	●			●	●	●	●	●	●	●	●	●	●				
76-4a	5-9-99	86	●				●	●	●	●	●													
76-9b	12-8-101	3	●	●		●	●	●			●		●								●	●		
76-3	9-9-98	12		●		●	●																●	
76-2a	9-9-98	12		●			●			●											●		●	●

FIGURE 14.—List of palynomorphs identified from samples collected from above the Cretaceous-Tertiary unconformity. Samples are listed in approximate stratigraphic sequence. All samples carbonaceous shale except No. 77-16, gray, silty claystone.

14 in approximate stratigraphic order. Age-diagnostic pollens recovered from this interval are:

Maceopolipollenites amplus	late Paleocene
Carya	late Paleocene to Oligocene
Maceopolipollenites triorbicularis	middle Paleocene to middle Eocene(?)
Pistillipollenites	late Paleocene to middle Eocene
Symplocoipollenites	late Paleocene(?) to middle Eocene
Tricolpites anguloluminosus	Paleocene
Symplocospollenites	late Paleocene to middle Eocene
Paraalnipollenites	Maestrichtian to Paleocene

The ranges of *Symplocospollenites* and *Symplocoipollenites* have been determined through examination of reference collections of the U.S. Geological Survey, Denver (R. H. Tschudy, oral commun., March 1978). The ranges of *M. amplus*,- *M. triorbicularis* (with exception of its middle Eocene occurrence; see Green River discussion, Johnson and May, 1978b), and *T. anguloluminosus* are published in Leffingwell (1966). The ranges of *Carya* and *Pistillipollenites* are reported in Leopold and MacGinitie (1972), and the range of *Paraalnipollenites* is reported in Hills and Wallace (1969). Thus, the age of the Atwell Gulch Member of the Wasatch Formation is suggested to be late Paleocene.

One sample, No. 77-4, was collected just south of DeBeque from the basal conglomerate of the Atwell Gulch Member, about 11 m above the unconformity. Only one species, *Symplocoipollenites*, was recovered from this sample. The accepted range for this species is late Paleocene to middle Eocene. Inasmuch as late Paleocene pollen was collected stratigraphically above the sample, its age must also be late Paleocene.

MUDDY CREEK SECTION

Eight samples from the Muddy Creek section were processed and examined for palynomorphs; only three yielded pollen and (or) spores. Two samples (Nos. RJ78–4a and RJ78–4e) are from the Ohio Creek Member of the Mesaverde Formation, and one sample (RJ78–4m) is from a partially oxidized zone thought to be Wasatch Formation, about 3 m above the top of the highest white sandstone of the Ohio Creek.

The two Ohio Creek Member samples appear to be of Cretaceous age, yielding *Stereisporites* (Late Cretaceous to Holocene), *Araucariacites* (Cenomanian through Maestrichtian), and *Balmeisporites* (Campanian through Maestrichtian) (R. H. Tschudy, oral commun., 1979). No pollens indicative of a Tertiary age were observed.

The single sample thought to be Wasatch Formation also yielded an assemblage of Cretaceous appearance, including *Stereisporites* (Late Cretaceous to Holocene) and *Aquilapollenites senonicus* (Campanian-Maestrichtian) (Tschudy and Leopold, 1970), plus a few nondiagnostic pollen and spores. No pollens characteristic of Paleocene or younger age were observed. The Cretaceous age for this sample suggests that the unconformity is somewhat above the top of the highest white sandstone at Muddy Creek.

DISCUSSION

The stratigraphic sequence found near the Cretaceous-Tertiary boundary throughout the southwestern part of the Piceance Creek basin has certain characteristic features. The gray-weathering largely fluvial sandstones and mudstones of the Hunter Canyon or Mesaverde Formation of Late Cretaceous age are overlain by about 50 to 150 m of Upper Cretaceous fluvial rocks that are white or light buff colored on outcrop but are otherwise similar to the underlying strata. The white rocks are in turn overlain by Paleocene variegated rocks of the Wasatch Formation. Scattered lenses of small chert pebbles are sometimes found in the Cretaceous rocks, whereas large concentrations of pebbles and cobbles are commonly found at the base of the overlying Wasatch Formation. Because of the distinctive color and the presence of chert pebbles, the white zone (Ohio Creek Member of this report) has been considered a separate unit by numerous stratigraphers and has been named the Ohio Creek Formation or Ohio Creek Conglomerate. The conglomerates overlying the Ohio Creek are usually included in the basal part of the Wasatch Formation; however, some workers have mistakenly called these conglomerates Ohio Creek Formation or Ohio Creek Conglomerate.

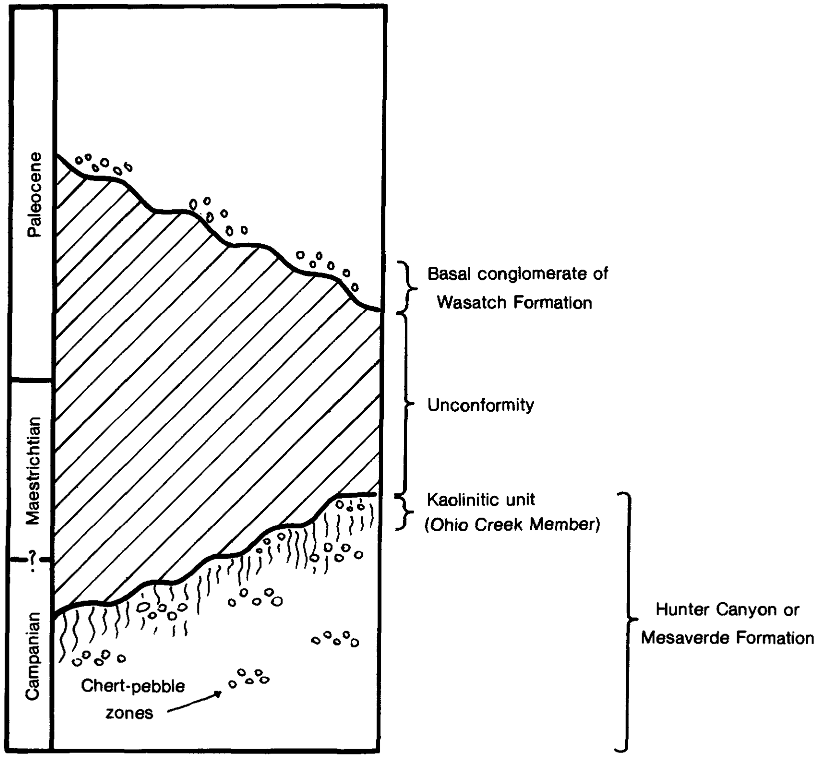


FIGURE 15.—Possible stratigraphic relationships of the Ohio Creek Member.

Palynomorph studies in the Hunter Canyon, DeBeque, and Muddy Creek areas have shown that a major unconformity occurs at the top of the Ohio Creek, whereas no detectable time gap occurs at its base. This finding is in conflict with the fossil leaf data reported by Gaskill and Godwin (1963) from 16 km northwest of the type locality, which date the Ohio Creek as Paleocene—the same age as the lower part of the overlying Wasatch Formation. However, R. H. Tschudy (oral commun., 1978) has said that early leaf identifications such as these are no longer considered reliable. We will tentatively assume that this Paleocene age is in error.

At Hunter Canyon, the white color of the Ohio Creek is due largely to a buildup of kaolinite and is only one of several mineralogical changes that occur in the rocks beneath the disconformity surface. Some of these changes, such as the loss of carbonate cement, extend beneath the kaolinitic zone in the underlying rocks as well. The most logical explanation for these changes is that they are products of intense weathering that took place during the time represented by the unconformity. Locally preserved paleosoils at the top of the white zone would also support this hypothesis.

If this hypothesis is true, then the white color, a primary characteristic used to define the Ohio Creek Formation of former usage, was not present when the rock was originally deposited. The potential problems that this presents are outlined on figure 15. If the kaolinite zone was formed by intense weathering during the time interval represented by the unconformity, then the zone would not necessarily be in the same stratigraphic position everywhere. The weathered zone would occur stratigraphically lower in areas with rapid erosion rates than in areas with slow erosion rates. The only requirement needed to preserve a kaolinite zone would be that the rate of formation of the kaolinitic zone at the end of the time interval represented by the unconformity was faster than the rate of erosion.

The presence of chert pebbles, the other characteristic most workers used to define the Ohio Creek, is problematical as well. Chert-pebble lenses occur 25 m below the base of the white zone at Hunter Canyon. Core from the C.E.R. Geonuclear drill hole has shown that scattered lenses of chert pebbles can occur anywhere in at least the upper 410 m of the Upper Cretaceous section. The density of chert pebbles is so low that it is possible that people working with outcrops have overlooked them. The upper part of the Cretaceous section as a whole is a monotonous sequence of discontinuous sandstones that is generally passed over quickly by workers in the field, whereas the white kaolinitic zone has drawn the attention of many workers. This may explain why pebble occurrences are better documented here. Figure 15 shows that it is possible that the unconformity surface could intersect several different chert-pebble zones in the Hunter Canyon Formation.

The Ohio Creek Member cannot be defined everywhere as both white in color and chert pebbly, because the two features are unrelated and need not occur together. If the presence of a few chert pebbles is chosen as the defining characteristic, then, at localities such as the C.E.R. Geonuclear drill hole, the member would be at least 410 m thick. We feel that this is not the intent of previous workers.

It seems, therefore, that if we are to define the unit on the basis of one of these two characteristics, we must select its white color. This, too, presents problems, for if the Ohio Creek Member is defined as a white unit found at the top of the Hunter Canyon or Mesaverde Formation, then it is defined on the basis of a secondary characteristic that was overprinted on rocks of varying stratigraphic position after deposition. This is somewhat analogous to mapping metamorphic facies. A map of the white zone would show variations in thickness of the kaolinite accumulation, which may tell something about conditions during the time interval represented by the disconformity. The thickest accumulations of kaolinite may outline areas where the rate of erosion was the slowest.

We recommend that the Ohio Creek Formation be reduced in rank to Ohio Creek Member of the Hunter Canyon or Mesaverde Formation, and be redefined as the light-gray or white kaolinitic unit of Late Cretaceous age found at the top of the Hunter Canyon or Mesaverde Formation in the south and southwest parts of the Piceance Creek basin. The redefined Ohio Creek may or may not contain sparse zones or lenses of chert pebbles, is truncated at the top by a regional unconformity, will usually have a gradational base, and is probably not everywhere at the same stratigraphic position.

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