The Yampa Bed—A Regionally Extensive Tonstein in the Williams Fork Formation, Northwestern Piceance Creek and Southern Sand Wash Basins, Colorado

Contributions to Stratigraphy

Scientific Investigations Report 2008–5033

U.S. Department of the Interior
U.S. Geological Survey

Cover. Excavated exposure of the Yampa Bed at the type locality, south of Craig, Colo. Yampa Bed is about 38 in. thick.
Note 24-in. shovel for scale.

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Contents

Plates

Figures

Conversions and Abbreviations

To convert	Multiply by	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km)

Abbreviations Used in This Report

ft	foot, feet
in.	inch, inches
Ma	Mega-annum (millions of years ago)
mi	mile, miles
mi^2	square mile, square miles
T., R.	township, range
USGS	United States Geological Survey

The Yampa Bed—A Regionally Extensive Tonstein in the Williams Fork Formation, Northwestern Piceance Creek and Southern Sand Wash Basins, Colorado

By Michael E. Brownfield and Edward A. Johnson

Abstract

The Upper Cretaceous Williams Fork Formation of the Mesaverde Group in northwestern Colorado consists of nonmarine to marginal-marine lithofacies that were deposited along the western edge of the Cretaceous Western Interior seaway. Complex intertonguing and rapid lateral facies changes, which are characteristic of the Mesaverde Group, commonly make correlation of lithofacies difficult. However, an altered volcanic ash bed (tonstein) has been identified within the Williams Fork Formation that greatly facilitates regional correlations within the Piceance Creek and Sand Wash Basins, Colorado. This regionally persistent and distinctive unit of Upper Cretaceous age is here formally named the Yampa Bed of the Williams Fork Formation for exposures in the Yampa, Danforth Hills, and Grand Hogback coal fields, Moffat and Routt Counties, northwestern Colorado; the name is derived from the Yampa River valley. The type section was measured in the NE¼SW¼ sec. 6, T. 5 N., R. 91 W., about 8 miles south of Craig, Colo., where the bed is 38 inches thick and lies within the C-D coal bed in the lower part of the Williams Fork, about 165 feet above the Trout Creek Sandstone Member of the Iles Formation. The Yampa Bed is dated at 72.2±0.1 mega-annum (Ma) using the K-Ar method.

Regionally, the Yampa Bed is a 0.5- to 5-foot-thick, regionally persistent tonstein that can be readily identified in several different lithofacies in the lower part of the Williams Fork Formation. The unit is useful as a regional datum in the correlation of facies within the Williams Fork and in paleogeographic reconstructions for the lower part of the formation. It is easily recognized on geophysical logs by its low resistivity response. X-ray diffraction analysis of selected outcrop and drill-hole samples indicates that the Yampa Bed consists principally of kaolinite and smectite in varying proportions. Evidence that the bed is a diagenetically altered airfall ash consists of the following: (1) petrographic studies of thin sections reveal a relict vitroclastic texture that was produced by clay-mineral replacement of glass shards; (2) samples characteristically contain phenocrysts of euhedral to subhedral ß-quartz (α-quartz after ß-quartz), biotite, apatite, andesine, sanidine, and zircon; and (3) outcrop and subsurface studies indicate a widespread areal distribution.

Introduction

Northwestern Colorado contains nine major coal fields that host many mineable coal beds within the coal-bearing Mesaverde Formation (or Group) in the southeastern Sand Wash and Piceance Basins (fig. 1). The coal-bearing rocks of the Mesaverde Formation and (or Group) crop out more or less continuously around the Piceance Basin and the southern boundary of the Sand Wash Basin.

The Yampa coal field (fig. 1), covering about 1,700 square miles (mi^2), is located in northwestern Colorado in Routt, Moffat, and Rio Blanco Counties (figs. 1, 2). U.S. Highway 40 traverses the coal field on the north and connects the small communities of Milner and Lay, which roughly define the east and west limits, respectively, of the coal field (fig. 2). Major cities in the area are Hayden in the central part of the field and Craig in the western part (fig. 2). The coal field is also traversed by the west-flowing Yampa River (fig. 2). The Yampa coal field is characterized by southwest-facing cliffs separated by steep canyons on the south boundary and by north-dipping slopes along the north boundary of the Williams Fork Mountains. Elevations in the coal field range from about 6,000 feet (ft) above sea level near Lay to just over 10,600 ft in the northeastern part of the coal field.

Coal-bearing rocks of the Upper Cretaceous Williams Fork Formation of the Mesaverde Group consist mostly of nonmarine to marginal-marine lithofacies that were deposited along the western shoreline of the Cretaceous Western Interior seaway. Complex intertonguing and rapid lateral facies changes, which are characteristic of the Mesaverde Group, commonly make regional correlation of lithofacies difficult when those correlations are based on time-transgressive sandstone units or coal beds of limited areal extent. In addition, even where good exposures are present, the numerous and complexly distributed coals in the Williams Fork Formation are commonly burned, forming baked strata (clinker) that makes surface and subsurface correlation of coal beds extremely difficult (fig. 3). Within the Western Interior of North America, several Cretaceous and Tertiary coal beds and associated fine-grained strata contain numerous laterally continuous claystone partings. Laboratory studies have shown that many of these

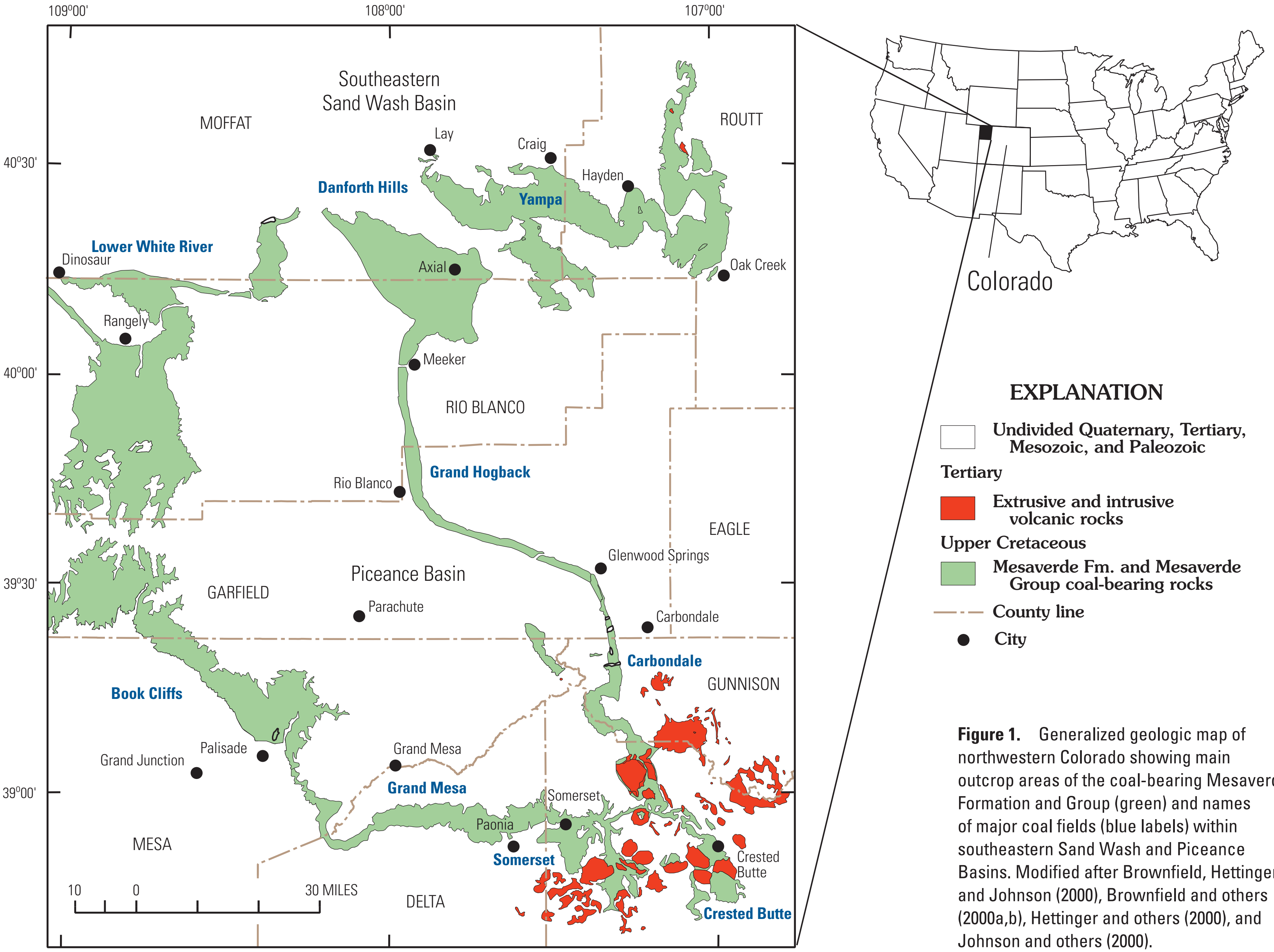

Figure 1. Generalized geologic map of northwestern Colorado showing main outcrop areas of the coal-bearing Mesaverde Formation and Group (green) and names of major coal fields (blue labels) within southeastern Sand Wash and Piceance Basins. Modified after Brownfield, Hettinger, and Johnson (2000), Brownfield and others (2000a,b), Hettinger and others (2000), and Johnson and others (2000).

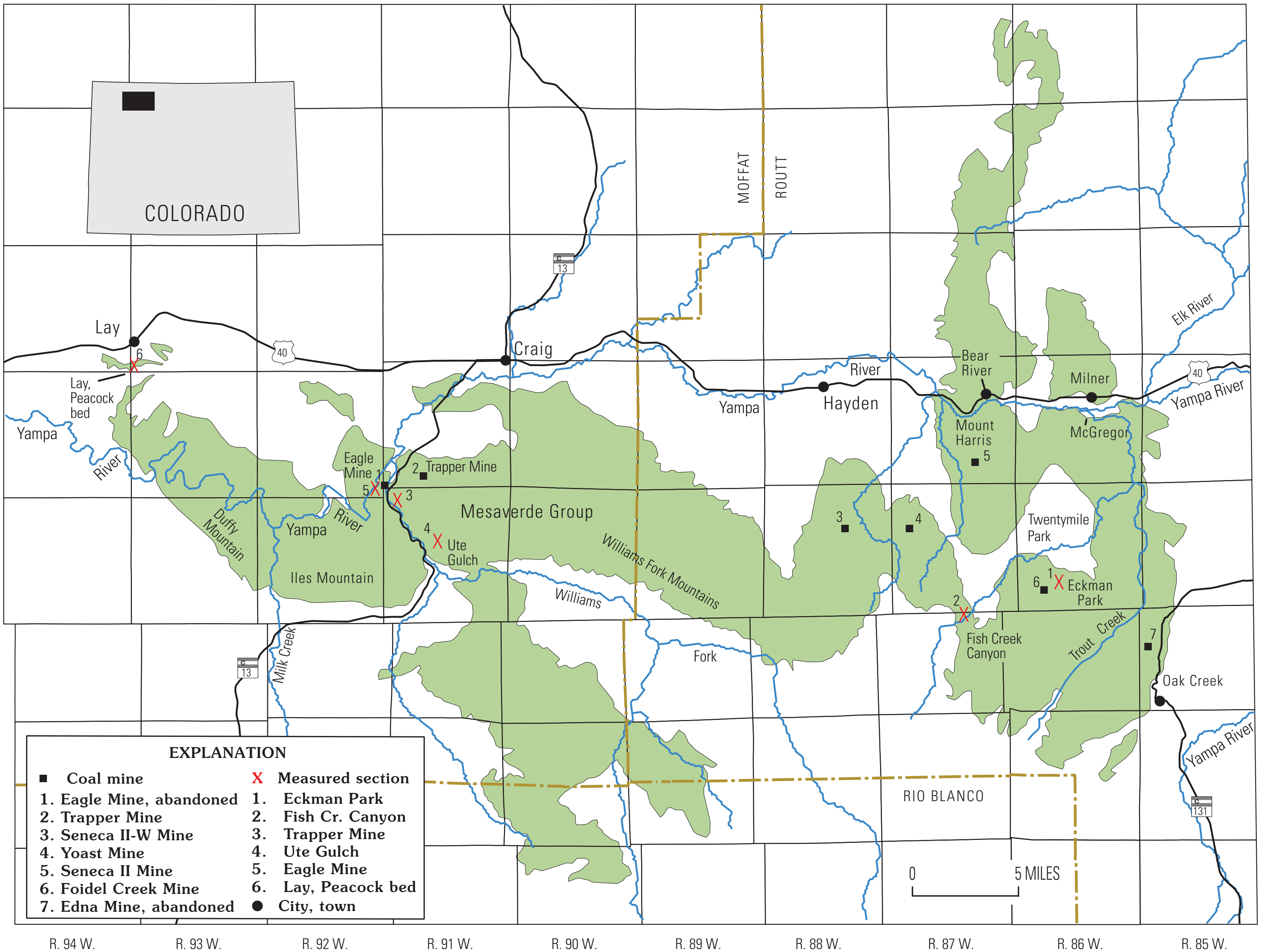

Figure 2. Location of Yampa coal field and approximate locations of mines and measured sections, Moffat, Rio Blanco, and Routt Counties, Colo. Outcrops of Mesaverde Group (green) delineate boundaries of coal field.

regionally extensive units are altered airfall ash (Bohor and others, 1976; Bohor and others, 1979; Ryer and others, 1980; Triplehorn and Bohor, 1981; Brownfield and Johnson, 1986; Johnson and Brownfield, 1986). For many years, European geologists have successfully used kaolinitic claystone partings called "tonsteins" for correlation of Carboniferous coal-bearing strata. Bohor and Triplehorn (1993) presented an excellent discussion on the characterization and usage of tonsteins in nonmarine rocks. Although altered ash beds are common in Western Interior Cretaceous rocks they have not been widely used in regional correlation of nonmarine strata because they were not recognize as being of volcanic origin. Bentonites, which are marine equivalents of the nonmarine altered ash beds, however, have been recognized for many years as a valuable tool for correlating marine strata.

A thick, regionally extensive, tonstein bed has been identified in the lower part of the Williams Fork Formation in northwestern Colorado (figs. 1, 2). The tonstein bed was first recognized in the summer of 1977 during a U.S. Geological Survey (USGS) coal exploration drilling program. Because it has since been demonstrated that this ash bed provides a means for making precise regional stratigraphic correlations within the Piceance Creek and Sand Wash Basins of northwestern Colorado (fig. 1) (for example, see Brownfield and Johnson, 1986; Johnson and Brownfield, 1988; Brownfield and others, 2000a,b; Johnson and others, 2000), we introduce the term "Yampa Bed" as a formal name for this unit. The designated type section is in the NE¼SE¼ sec. 6, T. 5 N., R. 91 W., which is located in the Yampa coal field about 8 miles (mi) southwest of Craig, Colo. (fig. 2, measured section 3); the bed there is 38 inches (in.) thick, and lies within the C-D coal bed of the Williams Fork Formation, about 165 ft above the Trout Creek Sandstone Member of the Iles Formation (fig. 4). The name is derived from the Yampa River valley. Local and regional stratigraphic relations are discussed in a later section.

Geologic Setting

Cretaceous Paleogeography

During the Cretaceous Period, a large, north-trending epicontinental seaway, the Western Interior Seaway, occupied what is now central North America (fig. 5). The seaway extended north-south from Mexico to Alaska and east-west from

Figure 3. Burned or baked strata (clinker) above Trout Creek Sandstone Member of the Iles Formation, Mesaverde Group, on Iles Mountain (see fig. 2), northwestern Colorado.

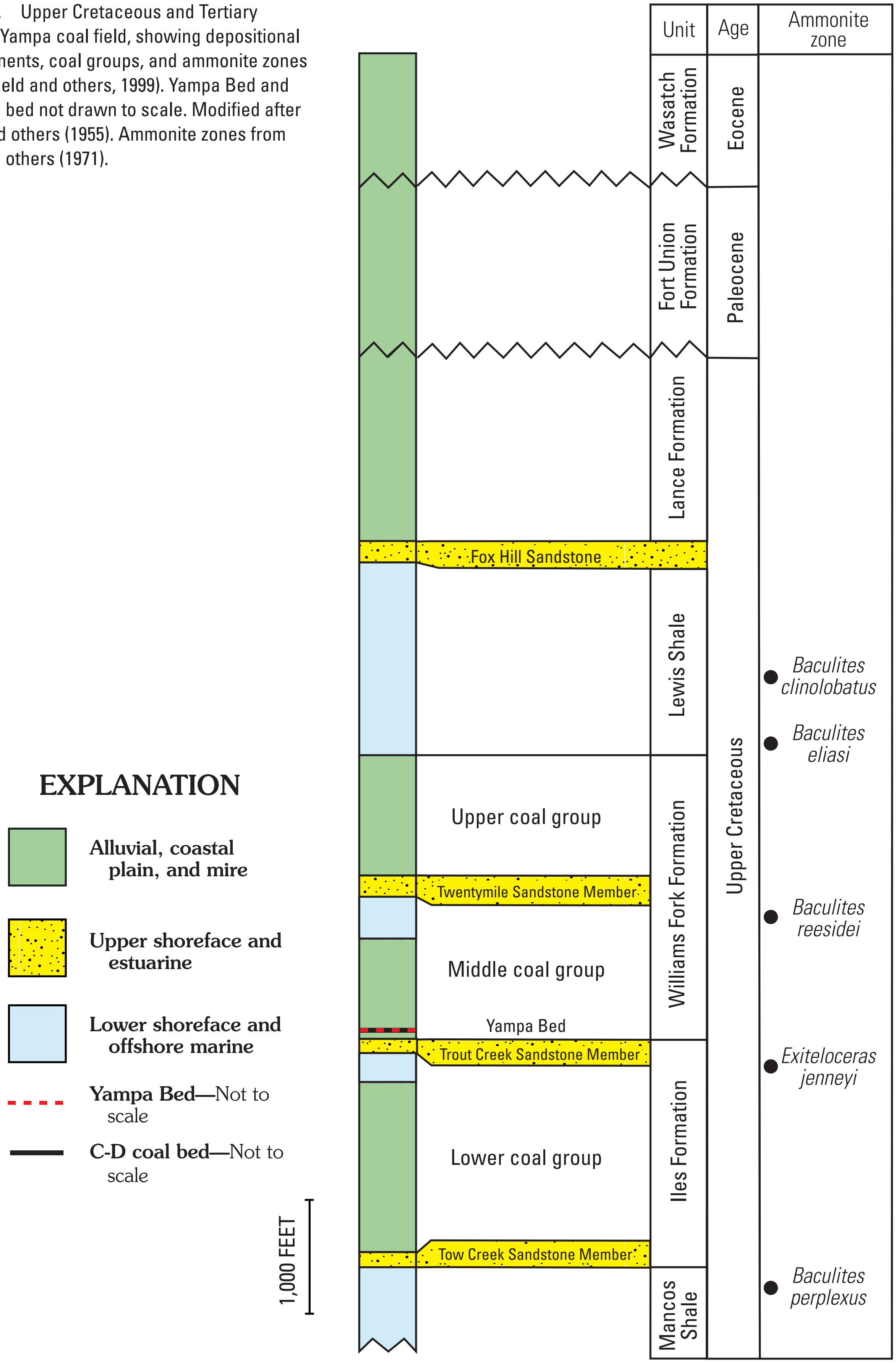

Figure 4. Upper Cretaceous and Tertiary rocks in Yampa coal field, showing depositional environments, coal groups, and ammonite zones (Brownfield and others, 1999). Yampa Bed and C-D coal bed not drawn to scale. Modified after Bass and others (1955). Ammonite zones from Izett and others (1971).

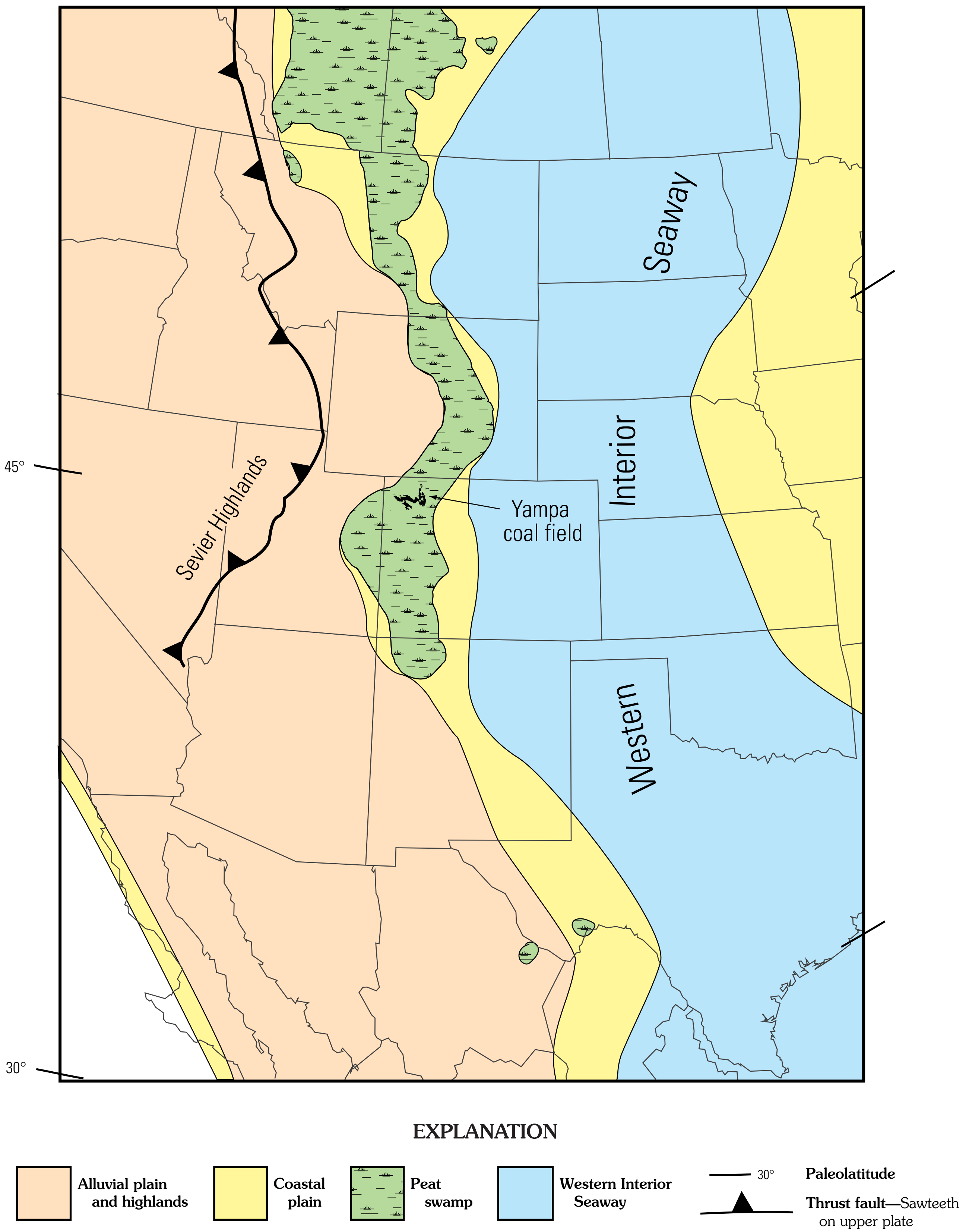

Figure 5. Paleogeographic map of central part of North America during late Campanian Stage of the Cretaceous Period. Yampa coal field shown in relation to western shoreline, coastal plain, and peat swamps associated with the Western Interior seaway. Modified from Roberts and Kirschbaum (1995).

central Utah to eastern Nebraska. A stable cratonic platform bordered the seaway on the east, and the tectonically active Sevier orogenic belt bordered the seaway on the west. Sediments transported eastward from the Sevier orogenic highlands (fig. 5) were deposited along the fluctuating western shoreline, resulting in a complex package of intertonguing marine and nonmarine rocks.

Stratigraphy of Upper Cretaceous Rocks in Northwestern Colorado

The Cretaceous sedimentary rocks exposed in the study area range in age from Early Cretaceous (Albian) to Late Cretaceous (Maastrichtian) and include the Mancos Shale, Mesaverde Group (Iles and Williams Fork Formations), Lewis Shale, Fox Hills Sandstone, and Lance Formation (fig. 4). The Cretaceous rocks are unconformably overlain by Tertiary rocks. The main coal-bearing rocks in the Yampa coal field are the Upper Cretaceous Iles and Williams Fork Formations of the Mesaverde Group (fig. 6). These units are exposed from Oak Creek to Lay, Colo., southwest to the Danforth Hills and Lower White River coal fields, and south to the Grand Hogback coal field (fig. 1).

Mesaverde Group in the Yampa Coal Field

Holmes (1877) first applied the name Mesaverde Group to a sequence of sandstone, siltstone, mudstone, shale, claystone, and coal in southwestern Colorado. Fenneman and Gale (1906a,b), noting a similar sequence of rocks in the Yampa coal field, extended the name Mesaverde into northwestern Colorado; they did not subdivide the sequence into formations but described two regional sandstones, which they named the Trout Creek and the Twentymile Sandstone Members. In addition, they subdivided the coal in the Mesaverde into lower, middle, and upper coal groups. The lower group contains all the coal below the Trout Creek, the middle group contains all the coal from the Trout Creek through the Twentymile, and the upper group contains all of the coal above the Twentymile.

Hancock (1925) later subdivided the Mesaverde Group into the Iles Formation and overlying Williams Fork Formation, and he defined the Trout Creek Sandstone as a member at the top of the Iles and the Twentymile as a member more or less in the middle of the Williams Fork (figs. 4, 6). Bass and others (1955) later extended these names into the eastern part of the coal field. Masters (1966) introduced the name Mount Harris member for the lower part of those rocks between the Trout Creek and the Twentymile and he reintroduced an earlier name, Holderness member, for those rocks in the Williams Fork above the Twentymile; neither of these names is commonly used today.

In northwestern Colorado, the Mesaverde (figs. 7, 8) comprises an eastward thinning, wedge-shaped package of marine and nonmarine rocks that overlies and intertongues with the Mancos Shale; it contains *Baculites perplexus* in its upper part (fig. 4), and it underlies the Lewis Shale, which contains *Baculites eliasi* and *Baculites clinolobatus* (Izett and others, 1971). To the east, the Mesaverde grades into marine rocks of the Pierre Shale, but evidence of this transition was removed by erosion that resulted from uplift of the Park Range during the Tertiary. To the west, the Mesaverde becomes increasingly fluvial and, in central Utah just east of the Sevier orogenic belt, equivalent strata are composed almost exclusively of conglomerate.

Detailed Stratigraphy of Coal-Bearing Upper Cretaceous Rocks

Iles Formation

The Iles Formation (fig. 4) of the Mesaverde Group was named by Hancock (1925) for coal-bearing strata exposed at Iles Mountain in the western part of the Yampa coal field (fig. 2). The formation is conformable with the Mancos Shale below and the Williams Fork Formation above and consists of sandstone interbedded with siltstone, mudstone, shale, claystone, carbonaceous shale, and coal. It ranges in thickness from about 1,300 ft in the western part of the coal field (Hancock, 1925) to 1,500 ft in the eastern and central parts (Bass and others, 1955).

The lower two-thirds of the Iles Formation consists of massive ledge-forming sandstone beds interbedded with mudrock, carbonaceous shale, and coal that form steep cliffs rising above the broad lowland formed on the Mancos Shale along the south and west boundaries of the Yampa coal field. Most of the coal beds within the lower coal group (fig. 5) are in the upper part of the Iles Formation about 400 ft above the base (Bass and others, 1955). Three principal coal beds or zones were recognized by Fenneman and Gale (1906a,b) in the lower coal group at Oak Creek; these beds were referred to as No. 1, No. 2, and No. 3 coal zones (fig. 9) by Bass and others (1955). The uppermost part of the formation consists of a mudrock sequence capped by cliff-forming sandstone. The mudrock sequence is a transgressive marine tongue (figs. 7, 8) that ranges in thickness from about 400 ft just west of Oak Creek to about 100 ft in the western part of the coal field and pinches out in the Danforth Hills coal field. It is capped by the regressive Trout Creek Sandstone Member (figs. 7, 8).

Three persistent sandstone units in the Iles Formation deserve special mention as guides for correlation within the eastern part of the coal field (fig. 9). They are the Tow Creek Sandstone Member at the base, the informally named “Double-ledge sandstone” unit about 400 ft above the base, and the Trout Creek Sandstone Member at the top of the formation.

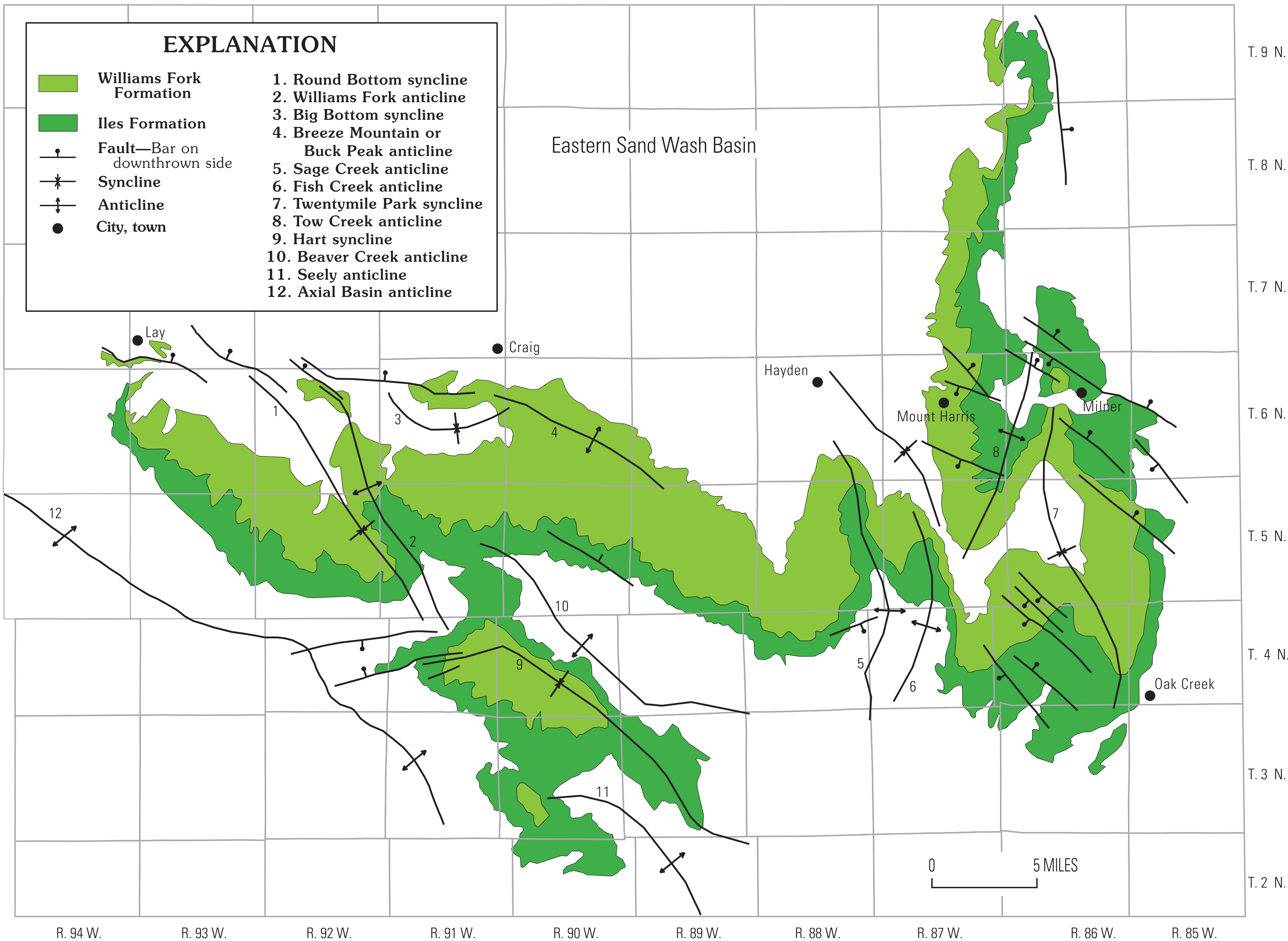

Figure 6. Generalized geologic map of Yampa coal field, showing distribution of Iles and Williams Fork Formations of Upper Cretaceous Mesaverde Group and major faults and folds. Modified after Tweto (1976).

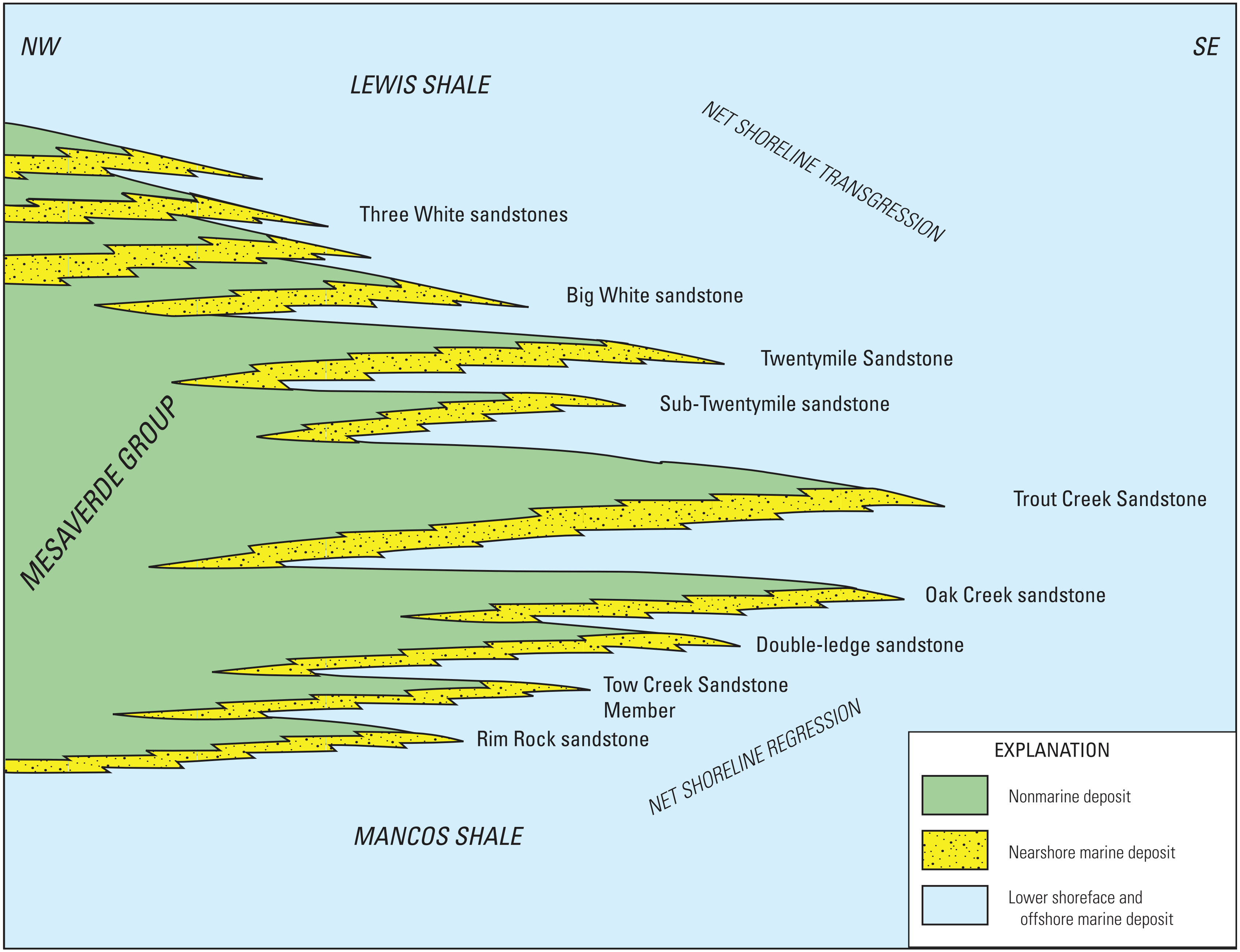

Figure 7. Generalized northwest-southeast cross section of Mesaverde Group in the Yampa coal field, showing stratigraphic positions of major sandstone units and related major regressions and transgressions. Modified after Siepman (1985).

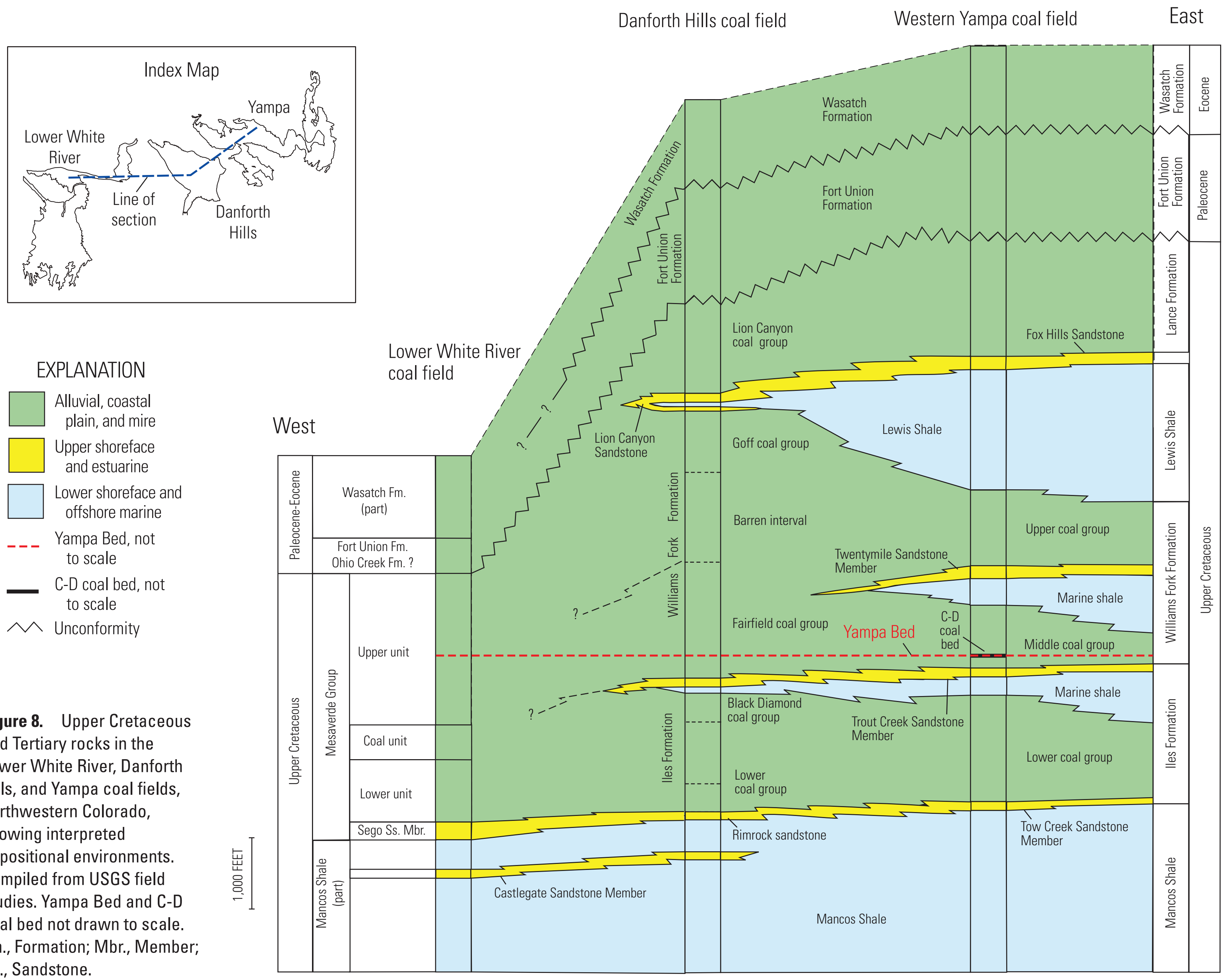

Figure 8. Upper Cretaceous and Tertiary rocks in the Lower White River, Danforth Hills, and Yampa coal fields, northwestern Colorado, showing interpreted depositional environments. Compiled from USGS field studies. Yampa Bed and C-D coal bed not drawn to scale. Fm., Formation; Mbr., Member; Ss., Sandstone.

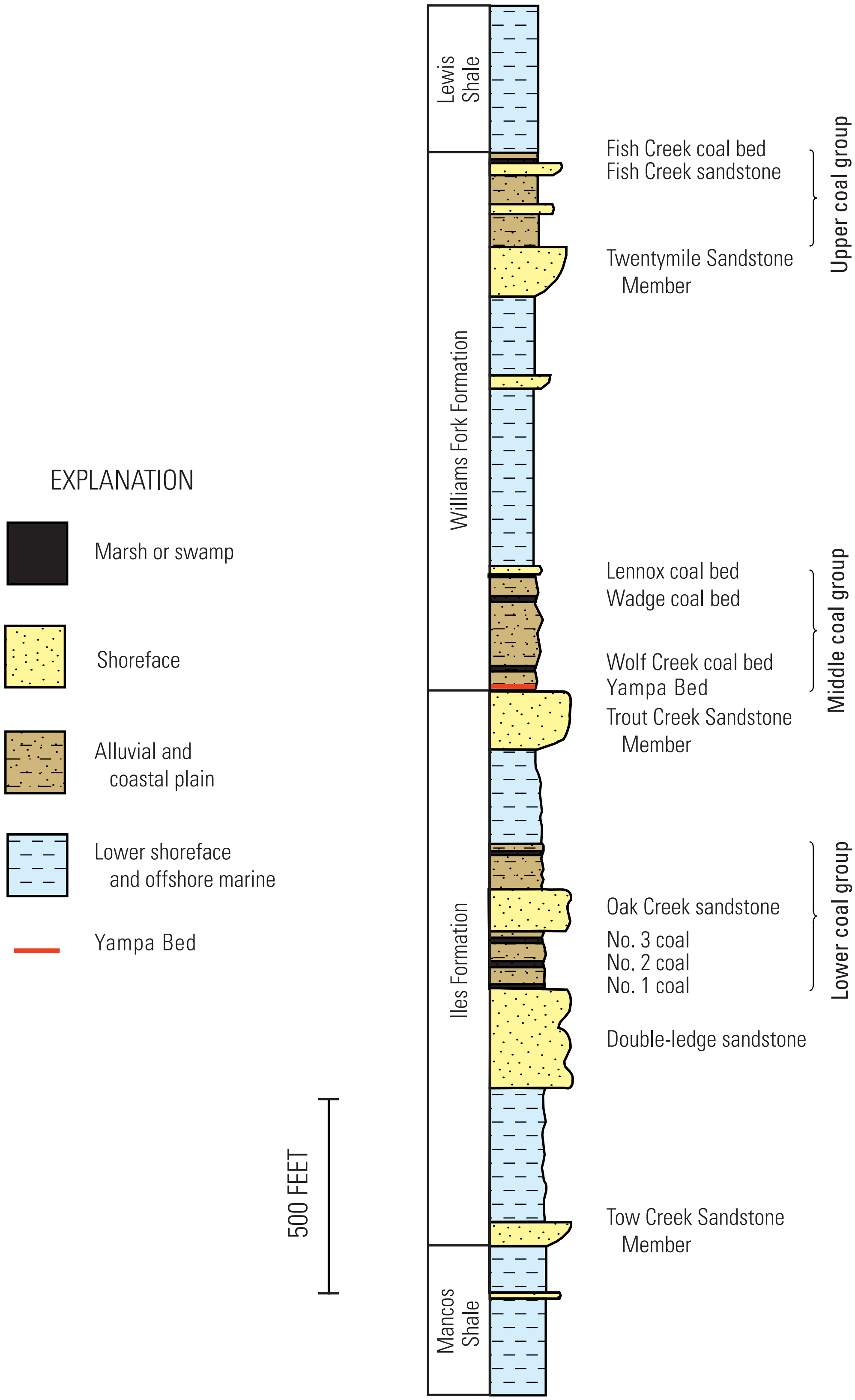

Figure 9. Composite stratigraphic section of Eckman Park area (see fig. 2, measured section 1) showing Yampa Bed, interpreted depositional environments, and major coal beds in eastern part of Yampa coal field (Brownfield and others, 1999). Compiled from U.S. Geological Survey coal-exploration drill holes and field studies. Coal bed names from Bass and others (1955).

Tow Creek Sandstone Member

The Tow Creek Sandstone Member of the Iles Formation (figs. 4, 7, 8, 9) is the basal unit in the Iles in the eastern part of the Yampa coal field. Crawford and others (1920) named the Tow Creek for exposures between Milner and Bear River (fig. 2). The Tow Creek consists of light gray to white sandstone ranging in thickness from 35 to 125 ft (Bass and others, 1955). This unit is prominent west of Fish Creek canyon (fig. 2) in the south-central part of the coal field.

Double-Ledge Sandstone

The "Double-ledge sandstone" (figs. 7, 9), informally named by Bass and others (1955) and consists of 1 to 3 beds of light-gray and white cliff-forming sandstone and interbedded siltstone about 400 to 460 ft above the base of the Iles Formation. The unit ranges in thickness from 130 to 250 ft and forms prominent ledges visible along the steep south-facing cliffs of the Williams Fork Mountains in the eastern and south-central parts of the Yampa coal field.

Trout Creek Sandstone Member

Fenneman and Gale (1906b) named the Trout Creek Sandstone Member of the Iles Formation (fig. 4) for exposures in the eastern part of the Yampa coal field. The Trout Creek is a cliff-forming unit of regional extent that transitionally overlies a sequence of marine shale (figs. 4, 7, 8, 9) containing *Exiteloceras jenneyi* (Izett and others, 1971) and is overlain by coal-bearing rocks. Fenneman and Gale (1906b) and Bass and others (1955) reported the Trout Creek to be about 100 ft thick in the eastern part of the coal field, and Johnson (1987) reported the unit as ranging from 67 to 79 ft thick in the western part. Siepman (1985), in his regional study of the unit, determined that it ranges from 140 ft thick near Mount Harris to 31 ft thick just west of Oak Creek (fig. 2). The unit has an average thickness of about 67 ft. Toward the northwest, the Trout Creek pinches out in the subsurface of the Sand Wash Basin (Siepman, 1985; Roehler, 1987). Regionally, the Trout Creek (fig. 8) is well exposed in the Danforth Hills (Hancock and Eby, 1930) and to the west pinches out just east of the Lower White River coal field (Hail, 1974; Barnum and Garrigues, 1980). To the south, the Trout Creek Sandstone Member is equivalent to the Rollins Sandstone Member of the Mesaverde Formation (or Mount Garfield Formation) in the southern Piceance Basin of west-central Colorado (Collins, 1976).

Williams Fork Formation

Hancock (1925) named the Williams Fork Formation for coal-bearing strata in the upper part of the Mesaverde Group. It conformably overlies the Trout Creek Sandstone Member of the Iles Formation (figs. 7, 8, 9) and is also conformable with the Lewis Shale. The formation consists of interbedded mudrock, sandstone, and lesser amounts of carbonaceous shale and coal, which are especially well exposed in the Williams Fork Mountains (fig. 2). Approximate thicknesses have been reported as follows: (1) 1,600 ft in the western part of the Yampa coal field (Hancock, 1925) (2) 1,800 ft thick in the Round Bottom quadrangle southwest of Craig (Johnson, 1987) and (3) 1,600 ft thick near Mount Harris in the eastern part of the Yampa coal field (fig. 2) to nearly 2,000 ft thick farther to the west (Bass and others, 1955). Four USGS coal exploration drill holes located in the western part of the coal field show an average thickness of 1,915 ft for the Williams Fork.

The lower two-thirds of the Williams Fork Formation consists of thick ledge-forming light-gray and white sandstones interbedded with mudrock, carbonaceous shale, and coal of the middle coal group (figs. 4, 8). Throughout the eastern part of the coal field the principal coal beds are, in ascending order, the Wolf Creek, Wadge, and Lennox (Bass and others, 1955). These beds are in the lower 400 ft of the Williams Fork, immediately above the Trout Creek Sandstone Member of the Iles Formation. Data compiled by the authors indicate that the number of coal beds in the middle coal group increases westward in the Yampa coal field (Johnson and Brownfield, 1988; Johnson and others, 2000). The upper part of the middle coal group is characterized by mudrock capped by cliff-forming sandstone. The upper third of the Williams Fork Formation contains the upper coal group and consists of sandstone, mudrock, carbonaceous shale, and coal.

A regional cross section by Roehler (1987) extending from the vicinity of Mount Harris, Colo., northwest to Rock Springs, Wyo., shows that the Williams Fork is roughly equivalent to the upper part of the Ericson Sandstone and the Almond Formation. Southwest of the Yampa coal field, the name Williams Fork Formation is also used in the Danforth Hills (figs. 1, 8) coal field (Hancock, 1925, Hancock and Eby, 1930)

Five persistent stratigraphic units recognized in the Williams Fork Formation are valuable guides for correlations within the Yampa coal field; they are, in ascending order, (1) the Yampa Bed, (2) the informally named "sub-Twentymile sandstone" in the middle coal group, (3) the Twentymile Sandstone Member, (4) the informally named "Big White sandstone" in the upper coal group, and (5) the informally named "Three White sandstones" at the top of the formation (fig. 7).

Sub-Twentymile Sandstone

The name "sub-Twentymile sandstone" was informally introduced by Kitely (1983) for a sandstone unit that lies about 150 ft below the base of the Twentymile Sandstone Member in the east-central part of the Yampa coal field (fig. 7). Most of what is known about this unit comes from the subsurface, but it probably has many physical characteristics in common with the Trout Creek and Twentymile Sandstone Members of the Iles Formation and Williams Fork Formation, respectively. The unit averages about 30 ft thick and contains one to three sandstone bodies. Masters (1966) defined a sandstone unit, the Hayden Gulch sandstone, at this same stratigraphic level that is likely equivalent to the sub-Twentymile. Siepman (1985) recognized the sub-Twentymile and included it at the top of his sub-Twentymile unit. The sub-Twentymile grades into Mancos Shale to the east, and to the west it loses its distinctiveness by splitting into a number of smaller sandstone bodies.

Twentymile Sandstone Member

The Twentymile Sandstone Member of the Mesaverde Formation was named by Fenneman and Gale (1906b) for exposures in Twentymile Park (fig. 2) in the eastern part of the Yampa coal field and was later revised and assigned to the Williams Fork Formation by Hancock (1925). The stratigraphic thickness from the top of the Trout Creek Sandstone Member and the base of the Twentymile Sandstone Member ranges from about 900 to 1,100 ft (Bass and others, 1955). The marine shale unit below the Twentymile Sandstone Member in the Fish Creek canyon area (fig. 2) contains *Baculites reesidei* (Izett and others, 1971). The Twentymile typically forms distinctive cliffs of yellowish-gray to white sandstone and, unlike the Trout Creek, generally consists of two to three sandstone units separated by finer grained strata. Bass and others (1955) reported that the Twentymile is about 100 to 200 ft thick in the eastern part of the coal field. Siepman (1985) reported that the unit ranges from 184 ft thick in Fish Creek Canyon in the eastern part to 28 ft thick at Duffy Mountain in the western part. The Twentymile Sandstone Member begins to lose its identity on the western edge of the coal field (fig. 8), and it grades into nonmarine rocks toward the northwest in the subsurface of the Sand Wash Basin (Siepman, 1985) and to the southwest short of the Danforth Hills (Brownfield and others, 2000b).

Big White Sandstone

The term “Big White sandstone” was informally introduced by geologists of the W.R. Grace and Company while they were conducting coal-exploration drilling in the late 1970s; the term refers to a sandstone unit that crops out about 200 ft above the Twentymile Sandstone Member in the central part of the Yampa coal field (fig. 7). In the western part of the coal field, a discontinuous sandstone exists at the same stratigraphic level as the Big White sandstone that is referred to informally by USGS geologists as the “Fuhr Gulch sandstone” of the Williams Fork Formation (Johnson, 1987). Johnson (1987) described this unit at the mouth of Fuhr Gulch as a 40-ft-thick light gray, very fine grained to fine-grained sandstone. In the eastern part of the coal field, Campbell (1923) informally named a sandstone unit at the same stratigraphic level as Big White (in Eckman Park, figs. 2, 9) the “Fish Creek sandstone.” On the basis of regional correlations, all three sandstone units are stratigraphically equivalent and represent a poorly exposed, regional sandstone unit (Brownfield and others, 1999; Johnson and others, 2000).

Three White Sandstones

The term “Three White sandstones” was informally applied by Brownfield and others (1999) and Johnson and others (2000) in the western part of the coal field, just south of Craig (fig. 2), to three vertically stacked, 50- to 60-ft-thick sandstone units in the upper part of the Williams Fork Formation (fig. 7). Lithologically, they resemble the Twentymile Sandstone Member. In addition, each sandstone unit overlies a thin sequence of marine rocks and is overlain by nonmarine rocks. Where best exposed along the Yampa River southwest of Craig, the base of the lower sandstone lies about 310 ft above the top of Big White sandstone. The stratigraphic distance between the base of the lower sandstone and the base of the Lewis Shale is about 435 ft. To the west, the lower and middle sandstones grade into nonmarine rocks, but the upper sandstone continues to the west edge of the coal field. To the east, the three sandstones extend for several miles east of the Yampa River before grading into Mancos Shale.

Depositional Setting of the Mesaverde Group

During the Late Cretaceous, the west edge of the Western Interior Seaway was continually being modified by sediment influx from the tectonically active Sevier orogenic belt to the west (fig. 5). According to Haun and Weimer (1960), as much as 11,000 feet of sediment was deposited in the seaway during this time. Along the west margin of the seaway, Mesaverde deposition is characterized by a series of westward transgressions and eastward regressions of the shoreline that resulted in the cyclic deposition of marine and nonmarine lithofacies (Weimer, 1960; Zapp and Cobban, 1960).

The sediments deposited in northwestern Colorado during this time include the Mancos Shale and the Iles and Williams Fork Formations of the Mesaverde Group (fig. 4). Variation in the sedimentation rates, drainage patterns, amounts of basin subsidence, and eustatic sea level changes contributed to the complex cyclic deposition of Upper Cretaceous lithofacies. Masters (1966) recognized three large-scale regressive cycles in the Mesaverde: one from the base of the Iles to the base of the marine shale underlying the Trout Creek Sandstone Member, a second from the base of the Trout Creek Sandstone Member to the base of the marine shale underlying the Twentymile Sandstone Member, and a third from the base of the Twentymile Sandstone Member to the top of the Williams Fork (fig. 9). In each cycle, the top of the coal-bearing package and the base of the overlying marine shale are separated by a disconformity. In general, the Iles represents net shoreline regression, and the Williams Fork represents a net shoreline transgression. However, in detail the Williams Fork shows evidence of several shoreline fluctuations, as indicated by the vertical juxtaposition of the formation’s three major depositional settings: offshore marine, nearshore marine, and fluvial.

The westward-thinning tongues of marine shale that directly underlie the Trout Creek and Twentymile Sandstone Members were deposited on an open-marine shelf, as indicated by the presence of marine fossils and deep-marine trace fossils. Most likely, this same environment is represented in the strata that underlie the sub-Twentymile sandstone in the central part of the coal field. A marginal-marine environment is interpreted for the strata that underlie the Three White sandstones on the basis of shallow-marine trace fossils in the western part of the coal field.

The thick sandstones, such as the Trout Creek and Twenty-mile Sandstone Members and the sub-Twentymile, Big White, and Three White sandstones, were deposited in a progradational shoreface environment (Boyles and others, 1981). This conclusion is supported by an upward increase in grain size and a corresponding upward decrease in bed thickness, by hummocky cross stratification followed upward by trough cross stratification, and by the presence of shallow-marine trace fossils. Relatively complete stratigraphic sections of the Trout Creek and Twentymile Sandstone Members reveal that the units generally consist of a basal transitional part that was deposited below wave base and an overlying shoreface part deposited above wave base; rarely foreshore and backshore deposits are also preserved. Many workers (for example, Siepman, 1985) believe that these sandstone units were deposited along wave-dominated deltaic, strand plain, and barrier island systems, in a microtidal setting.

The strata that overlie the nearshore marine sandstones display sedimentological characteristics indicating fluvial, lagoonal, salt marsh, and freshwater swamp environments on a coastal plain that sloped gently seaward with little topographic relief. The fluvial lithofacies is composed of channel sandstones and associated overbank deposits of sandstone, siltstone, shale, and lenticular coal beds. The lagoonal and bay environments are represented by low-energy deposits of shale, siltstone, and minor amounts of fine-grained sandstone. The lagoonal sandstones include washover fans, flood-tidal deltas, and crevasse splay deposits. The salt marsh lithofacies contain evenly laminated, fine-grained deposits consisting of carbonaceous shale, siltstone, very fine grained sandstone, and impure coal. The freshwater swamp lithofacies are represented by coal.

Origin, Description, and Distribution of the Yampa Bed

The Yampa Bed has been identified in lagoonal, freshwater swamp, and fluvial environments throughout the study area in the lower part of the Williams Fork Formation. The bed, regionally 0.5–5 ft thick, is generally poorly exposed in outcrop and only nine locations have been studied in detail.

Thin section analyses of several outcrop samples reveal coarse crystals of authigenic kaolinite, giving the material the appearance of a sandy siltstone (Brownfield and Johnson, 1986). Results of X-ray diffraction analysis of selected outcrop and drill-hole samples show that the Yampa Bed consists primarily of kaolinite and smectitic clays in varying proportions. Diffractograms showing kaolinite display sharp, narrow basal peaks (00l) and well-defined prism reflections indicating an authigenic origin in samples collected in the upper and lower parts of the bed (Brownfield and Johnson, 1986). X-ray diffraction analysis of samples collected from the central part displayed greater amounts of smectitic clays and relict volcanic minerals where the unit is greater than 12 in. thick. Heavy-liquid separations reveal that the nonclay minerals compose a relatively small percentage of the total sample by weight. The lightweight fraction of the nonclay minerals consists of angular grains of euhedral to subhedral quartz, sanidine, andesine, and biotite partly altered to chlorite. The quartz component of this fraction includes euhedral grains of ß-quartz-form phenocrysts (α-quartz after ß-quartz). The heavier fraction is minor and consists mainly of euhedral apatite and zircon crystals.

Where exposed on the surface or observed in drill core, the Yampa Bed is a white to grayish-white massive claystone (figs. 10, 11). In the subsurface, it becomes an important regional marker bed that is easily identified on drill-hole geophysical logs and ranges in thickness from less than 1 ft to 6 ft. In the central and western parts of the coal field, the unit lies about 100 and 260 ft, respectively, above the top of the Trout Creek Sandstone Member. However, in the eastern part of the coal field the stratigraphic separation is less than 20 ft, and on some geophysical logs the Yampa Bed appears to rest directly on the Trout Creek.

The type locality is located in the NE¼SW¼ sec. 6, T. 5 N., R. 91 W., about 8 mi south of Craig, Colo. (fig. 2, measured section 3). The Yampa Bed is located in the informally named C-D coal bed (Johnson and Brownfield, 1988) about 165 ft above the Trout Creek Sandstone Member of the Iles Formation (figs. 4, 7).

At the type locality (fig. 10), the Yampa Bed of the Williams Fork Formation is 38 in. thick. Where observed, it typically weathers white to cream or, less commonly, to light gray, yellow gray, or light tan. The bed appears to lack stratification, is highly cohesive when moist, and displays a distinct blocky fracture (fig. 10). The upper 1 to 2 in. displays rooting. The upper and lower contacts are generally sharp where the Yampa Bed is interbedded with coal (figs. 10, 12), and the contacts display sedimentary structures indicating minor transport or ponding during deposition. At the type locality, the Yampa Bed (fig. 13) is overlain by a 4-in.-thick carbonaceous mudstone to siltstone unit. The lower part of the units is massive and the upper part is laminated. It is underlain (fig. 14) by a 2-in. thick layer of hard carbonaceous mudstone and siltstone that is strongly laminated. The mudstone contains plant material, and jarosite was observed. Where associated with lagoonal or fluvial rocks, the upper and lower contacts of the Yampa Bed contain rip-up clasts that again indicate minor transport. Where the altered ash is associated with clinkered rocks it has been further altered to a highly resistant white to cream-colored porcellanite.

Figure 10. Excavated exposure of the Yampa Bed at the type locality, south of Craig, Colo. (see fig. 2, measured section 3). The Yampa Bed is about 165 ft above Trout Creek Sandstone Member of the Iles Formation and is a parting in the 12-ft-thick C-D coal bed. Upper contact rooted and burrowed. Upper and lower contacts contain bedding structures indicative of reworking in the mire. Note 24-in. shovel for scale.

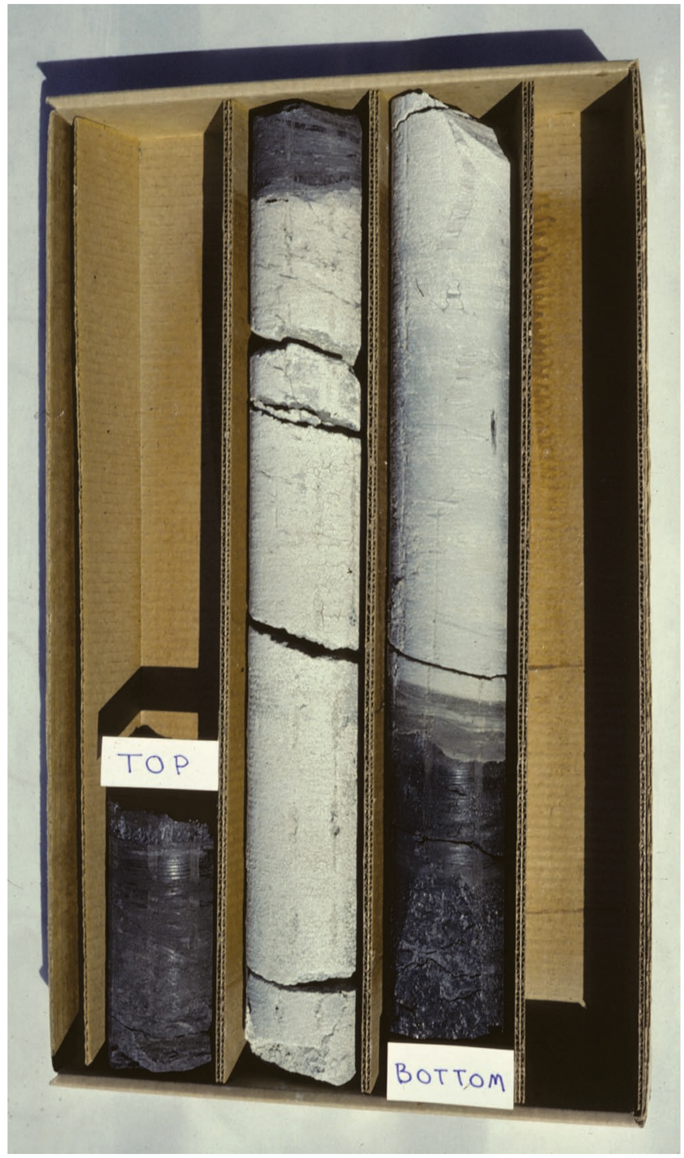

Figure 11. Drill core of Yampa Bed in the C-D coal bed (Johnson and Brownfield, 1988) from the Eagle Mine (also known as the Empire Mine, now abandoned). See fig. 2, mine location 5. The Yampa Bed is about 38 in. thick. Lower contact displays bedding structures indicative of reworking, whereas upper contact displays rooting, possible burrows, and bedding structures.

Evidence that the Yampa Bed is a diagenetically altered airfall ash includes the following: (1) petrographic studies of thin sections reveal a relict vitroclastic texture that was presumably preserved by the clay-mineral replacement of the original glass shards; (2) samples characteristically contain euhedral to subhedral phenocrysts of ß-quartz-form, biotite, sanidine, andesine, and zircon, all of which are common in volcanic rocks; and (3) outcrop and subsurface studies indicate a widespread areal distribution. Moreover, detailed laboratory studies of similar diagenetically altered volcanic ash in other study areas have shown that they originated as airfall ash (Bohor and others, 1979; Ryer and others, 1980; Brownfield and others, 1987; Bohor and Triplehorn, 1993).

Four dating methods were considered to determine the age of the Yampa Bed: (1) fission track dating of zircons, but results from other similar claystones reportedly gave dates that were known to be too young; (2) K-Ar dating of biotite, but most of the biotite was altered to chlorite; (3) K-Ar dating using sanidine, but properly cleaning the sanidine was difficult; and (4) K-Ar dating using plagioclase (andesine), which has a higher analytical error owing to the lower potassium content in the plagioclase. However, using K-Ar methods on andesine, the unit was dated at 72.5±5.1 mega-annum (Ma) (Richard Marvin, U.S. Geological Survey, written commun., 1983).

Figure 12. Closeup of excavated exposure of Yampa Bed at type locality (see fig. 2, measured section 3). The bed is 38 in. thick and displays a blocky texture. Upper and lower contacts are sharp with the C-D coal bed (Johnson and Brownfield, 1988). Upper contact is rooted and burrowed, and upper and lower contacts contain bedding structures resulting from reworking in the mire. Note 24-in. shovel and penny (white dot, upper left) for scale.

A possible source was the Late Cretaceous eruption of the Elkhorn Mountains in southwestern Montana (Smedes, 1966) that produced a wide variety of volcanic rocks bracketing the ages of the Williams Fork Formation ammonite zones (Obradovich, 1993; Roberts and Kirschbaum, 1995); it has the composition of the relict volcanic mineralogy of the Yampa Bed (Smedes, 1966). This source seems to provide the best correlation but the actual source remains highly uncertain.

The Yampa Bed has been observed in several outcrops and on many geophysical logs throughout the southeastern Sand Wash Basin and northeastern Piceance Creek Basin (fig. 1; pls. 1, 2). In particular, the Yampa Bed has been identified throughout the Yampa and Danforth Hills coal fields (fig. 1), encompassing an area of more than 2,000 mi^2 (Brownfield and Johnson, 1986; Brownfield and others, 2000a,b; Johnson and others, 2000); all locations discussed below are within the Yampa coal field (fig. 2).

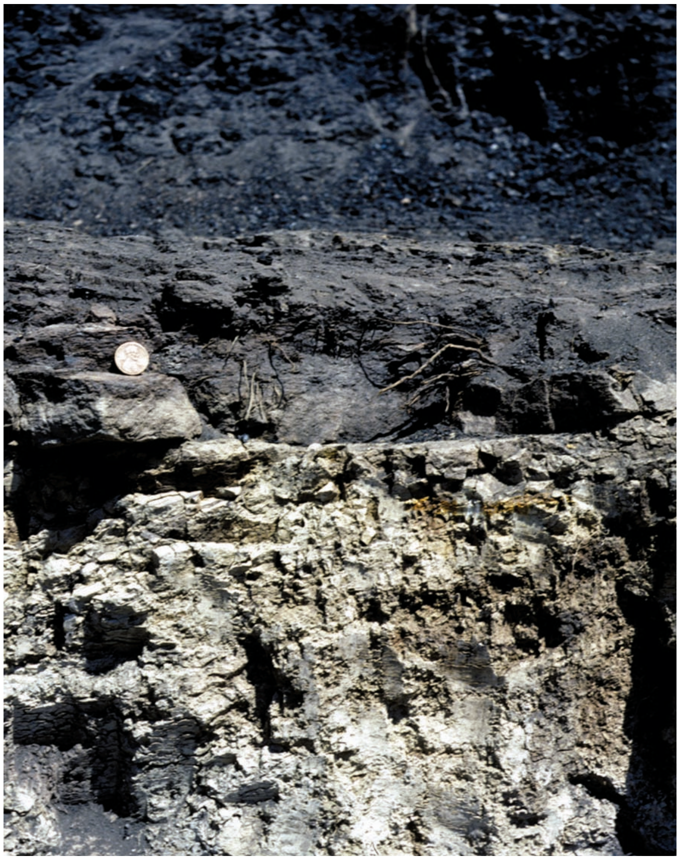

Figure 13. Excavated exposure of upper contact of Yampa Bed at Trapper Mine, south of Craig, Colo. (see fig. 2, measured section 3). Upper contact is rooted and contains sedimentary structures indicating reworking. The 4-in.-thick carbonaceous shale on top of bed indicates reestablishment of the coal mire and marks the start of deposition of the D coal bed (Johnson and Brownfield, 1988). Note penny for scale.

Figure 14. Excavated exposure of lower contact of the Yampa Bed (top of photograph) at Trapper Mine, south of Craig, Colo. (see fig. 2, measured section 3). Lower contact contains sedimentary structures indicating reworking. Carbonaceous shale at bottom of Yampa Bed marks the termination of peat deposition of the C coal bed (Johnson and Brownfield, 1988). Note penny for scale.

Yampa Coal Field

Eckman Park Measured Section

Eckman Park, about 7 mi northwest of Oak Creek (fig. 2, measured section 1), contains gently northward dipping strata of the middle coal group of the Williams Fork Formation, from which the Wadge coal bed (fig. 9) is mined at the Foidel Creek (longwall) Mine (coal mine 6, fig. 2). In this area, the Trout Creek Sandstone Member of the Iles Formation is conformably overlain by a 330-ft-thick section of the middle coal group (fig. 9). This section, in turn, is overlain by a 600-ft-thick sequence of marine strata containing late Campanian *Baculites reesidei* (Izett and others, 1971) above which, on the north and west sides of the park, the Twenty-mile Sandstone Member of the Williams Fork Formation forms massive, white sandstone cliffs. The next younger sequence, the upper coal group, is about 190 ft thick and contains the 1- to 6-ft-thick Fish Creek coal bed (fig. 9) that was mined by Energy Fuels Corporation in the 1970s. The Lewis Shale conformably overlies the Williams Fork.

The Yampa Bed crops out from 0 to about 15 ft above the Trout Creek Sandstone in Eckman Park (fig. 2) and ranges from 0 to less than 1 ft thick (figs. 9, 15). The bed lies about 5 ft above the Trout Creek Sandstone Member northeast of Eckman Park (fig. 15) but was not preserved in the Edna Mine area (fig. 2), where it was deposited and subsequently reworked in an estuary or salt marsh environment.

Figure 15. Excavated exposure of Yampa Bed (white), northeast of Eckman Park (see fig. 2, measured section 1). Yampa Bed is approximately 5 ft above the Trout Creek Sandstone Member of the Iles Formation. Note 12-in. hammer above the Yampa Bed for scale.

Fish Creek Canyon Measured Section

Fish Creek Canyon contains one of the best stratigraphic sections (fig. 16) of the uppermost Mancos Shale and the Mesaverde Group in the eastern part of the Yampa coal field (fig. 2, measured section 2). This section, previously measured by Bass and others (1955), was remeasured and the depositional environments were interpreted. On the west end of Fish Creek Canyon there are excellent exposures of marine sandstone units in the upper part of the Mancos Shale, which also contains shale units with *Baculites perplexus* (Izett and others, 1971). The eastward dip of the canyon section is about 40° on the western end and 55° at the eastern end. The Iles Formation within the canyon contains four progradational shoreface sandstone units: they are, in ascending order, the Tow Creek Sandstone Member, the informally named "Double-ledge sandstone" (Bass and others, 1955), the informally named "Oak Creek sandstone" (Kucera, 1959), and the Trout Creek Sandstone Member. The Tow Creek Sandstone Member is the basal unit of the Iles Formation and is about 70 ft thick. Bass and others (1955) informally named the "Double-ledge sandstone" for a 250-ft-thick, massive ledge-forming sandstone about 340 ft above the Tow Creek. Kucera (1959) applied the name "Oak Creek sandstone" to a 100-ft-thick cliff-forming sandstone that crops out about 3 mi north of Oak Creek (fig. 2). This unit was mapped by the authors from that location through Trout Creek and Eckman Park to the Fish Creek Canyon (fig. 2), where it is about 85 ft thick (fig. 16). A strike valley above the Oak Creek sandstone is formed in the marine strata that underlie the Trout Creek Sandstone. The Trout Creek, about 110 ft thick, is well exposed in this section and the marine shale below the Trout Creek contains *Exiteloceras jenneyi* (Izett and others, 1971). Directly above the Trout Creek is carbonaceous shale that we interpret as a salt marsh; this shale, in turn, is overlain by rippled sandstone and siltstone interpreted as a washover fan deposit. The Yampa Bed (Brownfield and Johnson, 1986), about 20 in. thick, is exposed above the washover fan in lagoonal or mire deposits (fig. 17) and is both underlain and overlain by carbonaceous shale. The Wolf Creek coal bed is burned (clinkered) in the canyon but the Wadge coal bed (about 11.8 ft thick) was mined for a short period. The Lennox coal bed was not observed. The Twentymile Sandstone Member, interpreted to be a shoreface sandstone, forms a massive white cliff and dip slope on the eastern end of the canyon and is about 185 ft thick. The Twentymile and Trout Creek are much thicker than modern shoreface deposits, and Siepman (1985) believed that these thicknesses resulted from vertical stacking of shoreface sand units. The overlying strata of the Williams Fork Formation represent lagoon and tidal inlet deposits that are, in turn, overlain by Lewis Shale.

Ute Gulch Measured Section

The Yampa Bed crops out in Ute Gulch, south of Craig, Colo., (fig. 18) in the NW¼SW¼ sec. 9, T. 5 N., R. 91 W., approximately 170 ft above the Trout Creek Sandstone Member of the Iles Formation (see fig. 2, measured section 4). The unit there is about 4.3 ft thick (fig. 19) and is in the C-D coal bed (figs. 4, 8) (Johnson and Brownfield, 1988). The upper and lower contacts are generally sharp with carbonaceous shale units both above and below. Even where good exposures are present, the numerous and complexly distributed coals are burned and form baked strata or clinker (for example, see fig. 3), which makes surface mapping of the coal beds and projection of coal beds into the subsurface extremely difficult.

Eagle Mine Measured Section

The Yampa Bed crops out just south of the Eagle Mine (also known as the Empire Mine, now abandoned; see fig. 2, mine location 1), in SE¼NE¼ sec. 36, T. 6 N., R. 92 W. (fig. 20). The bed there is approximately 170 ft above the Trout Creek Sandstone Member of the Mesaverde Group; it is about 38 in. thick and lies within the C-D coal bed (figs. 5, 8) (Johnson and Brownfield, 1988). The upper and lower contacts are generally sharp and display sedimentary structures probably resulting from minor transport or ponding. The upper contact is rooted and overlain by carbonaceous mudstone or siltstone; the lower part of the carbonaceous unit is massive and the upper part is laminated. The unit below consists of carbonaceous mudstone or siltstone that displays strong lamination.

Lay, Colo., Measured Section

About 1.5 mi south of Lay, Colo. (fig. 2, location 6), the Yampa Bed crops out in the SE¼SW¼ sec. 31, T. 7 N., R. 93 W., within the Peacock coal bed zone (Brownfield and Anderson, 1988; Brownfield and Prost, 1979; Johnson and Brownfield, 1988). At that location, the bed is about 25 in. thick and lies about 210 ft above the Trout Creek Sandstone Member of the Iles Formation (figs. 21, 22). The upper and lower contacts are generally sharp and sedimentary structures indicate minor transport; the uppermost part is rooted, indicating the reestablishment of the mire following deposition of the ash bed. Units above and below the ash consist of carbonaceous mudstone and siltstone.

Danforth Hills Coal Field

The Yampa Bed is in the lower part of the Fairfield coal group of the Williams Fork Formation (Brownfield and others, 2000b) in the Danforth Hills coal field (figs. 1, 23, 24). This coal group, which was named for the Fairfield Mine near the town of Meeker (fig. 23), is at the base of the Williams Fork and averages 1,300 ft in thickness (Hancock and Eby, 1930), but the complete interval was rarely penetrated in the drill holes studied. The Fairfield is equivalent to the Cameo-Wheeler coal zone in the southern part of the Piceance Basin and to the Wheeler-Fairfield coal zone along the southern part of the Grand Hogback (Hettinger and others, 2000). It is correlated with the middle coal group of the William Fork Formation (fig. 8) in the Yampa coal field (Brownfield and others, 2000b). The Fairfield coal group is predominately terrestrial in origin and consists of thin to thick beds of sandstone interbedded with mudstone, carbonaceous shale, and coal deposited in a coastal plain environment.

Where exposed on the surface or observed in drill core (fig. 25), the Yampa Bed is a white to grayish-white structureless claystone with a sharp base and a rooted upper contact. In the subsurface, it serves as an important regional marker bed that is easily identified on geophysical logs (Brownfield and others, 2000b). In the Danforth Hills coal field, the Yampa Bed ranges in thickness from less than 1 to more than 3 ft and lies from 100 and 300 ft above the top of the Trout Creek Sandstone Member.

Piceance and Sand Wash Basins

An ash bed was excavated near the expected stratigraphic position of the Yampa Bed in Upper Cretaceous Mesaverde Group rocks in the northern part of the Piceance Creek Basin, in the western part of the Lower White River coal field (figs. 1, 8). Another ash bed, ranging from less than 1 to about 3 ft thick and lying above the Rollins Sandstone Member of the Mesaverde Formation, has been observed in outcrop and recognized on geophysical logs in the southern part of the Piceance Creek Basin and the Grand Mesa coal field (Eager, 1978; geophysical logs discussed below). C.R. Dunrud (U.S. Geological Survey, retired, oral commun., 2007) reported a 3-ft-thick ash bed in the B coal bed, 75 ft above the Rollins Sandstone Member of the Mesaverde Formation, near Paonia (fig. 1) in the southernmost part of the Piceance Basin. In a measured section near Palisade, Colo., (fig. 1) Cole and Cumella (2003) reported an ash bed above the Rollins Sandstone Member of the Mesaverde Formation in the Book Cliffs coal field (fig. 1). That ash bed is 1 ft thick in the “ash coal” and lies about 102 ft above the Rollins Sandstone. If one uses the projected Rollins Sandstone Member or Trout Creek Sandstone Member strandlines of Zapp and Cobban (1960), that ash bed is in the same stratigraphic position as the Yampa Bed in the Danforth Hills and Yampa coal fields.

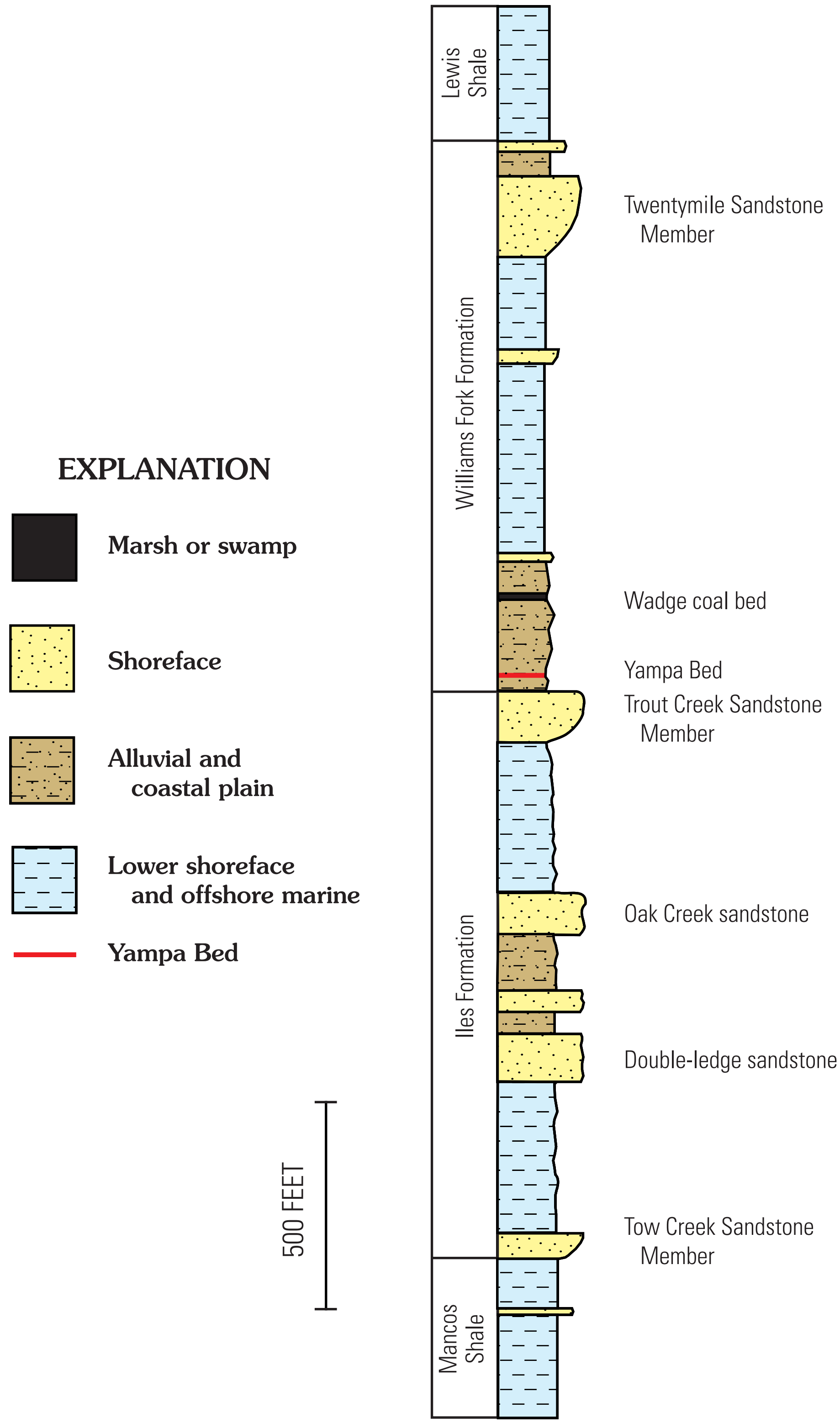

Figure 16. Strata in Fish Creek Canyon (see fig. 2, measured section 2) showing interpreted depositional environments and position of Yampa bed (Brownfield and others, 1999). Interpreted depositional environments compiled from U.S. Geological Survey field studies. Major geologic units modified after Bass and others (1955).

Figure 17. Excavated exposure of Yampa Bed in Fish Creek Canyon, west of Oak Creek, Colo. (see fig. 2, measured section 2). Yampa Bed lies above a washover fan in lagoonal or mire deposits and is about 20 in. thick. Directly above Trout Creek Sandstone Member of the Iles Formation (far left) is carbonaceous shale that is interpreted as a salt marsh deposit and is overlain by a washover fan consisting of rippled sandstone and siltstone. Note 16-in. shovel below ash and 12-in. hammer above ash for scale.

Figure 18. Outcrop of Yampa Bed in Ute Gulch (see fig. 2, measured section 4), northwestern Colorado. Yampa Bed is approximately 170 ft above Trout Creek Sandstone Member of the Iles Formation and is 4.3 ft thick in the C-D coal bed (Johnson and Brownfield, 1988). Much of the coal-bearing interval has been burned or baked forming baked strata or clinker. Area within white box shown in figure 19.

Figure 19. Closeup of excavated exposure (see fig. 18) of the Yampa Bed in Ute Gulch (see fig. 2, measured section 4), northwestern Colorado. Yampa Bed is approximately 170 ft above the Trout Creek Sandstone Member of the Iles Formation and is 4.3 ft thick within the C-D coal bed (Johnson and Brownfield, 1988). Note 16-in. shovel in center of photo for scale.

Figure 20. Excavated exposure of the Yampa Bed south of the Eagle Mine (also known as the Empire Mine, now abandoned; see fig. 1, mine location 1), northwestern Colorado. Yampa Bed is approximately 170 ft above Trout Creek Sandstone Member of the Iles Formation and is 38 in. thick within the C-D coal bed (Johnson and Brownfield, 1988). Note 12-in. hammer for scale.

The Yampa Bed has also been traced with geophysical logs from the central part of the Yampa coal field to near the Wyoming state line in the Sand Wash Basin. The unit becomes harder to identify in the northwestern and westernmost parts of the study area owing to local reworking of the ash by fluvial processes.

Figure 21. Outcrop of Peacock coal bed (Brownfield and Prost, 1979; Brownfield and Anderson, 1988) and the Yampa Bed south of Lay, Colo. (see fig. 2, measured section 6). Yampa Bed is about 210 ft above Trout Creek Sandstone Member of the Iles Formation of the Mesaverde Group. Area within white box shown in figure 22.

Figure 22. Closeup of excavated exposure of the Peacock coal bed (fig. 21) (Brownfield and Prost, 1979; Brownfield and Anderson, 1988) and the Yampa Bed, south of Lay, Colo. (see fig. 2, measured section 6). Yampa Bed is about 210 ft above Trout Creek Sandstone Member of the Iles Formation of the Mesaverde Group and is 25 in. thick. Note 12-in. hammer for scale.

Geophysical Log Response

The Yampa Bed is easily recognized on geophysical logs—the Buckpeak State 11–30 and the USGS BRG–3 drill holes are excellent examples of the distinctive geophysical log signatures of the unit (fig. 26)—and therefore it is a valuable marker for both local and regional subsurface correlations (see next section). On oil and gas logs, the bed is characterized by a low resistivity response that can readily be identified by a corresponding sharp high-conductivity spike. On coal logs, it typically registers the lowest low single-point resistance value within the logged interval (figs. 26, 27). The natural gamma response is typically high. Yampa Bed density log responses, although higher than those for coal, are generally not useful for reliable identification (figs. 26, 27). Log responses can differ because of differences in the mineral composition of the altered ash, so the bed can display different combinations of low resistivity–high conductivity and high gamma responses (the low resistivity–high conductivity response is the more common).

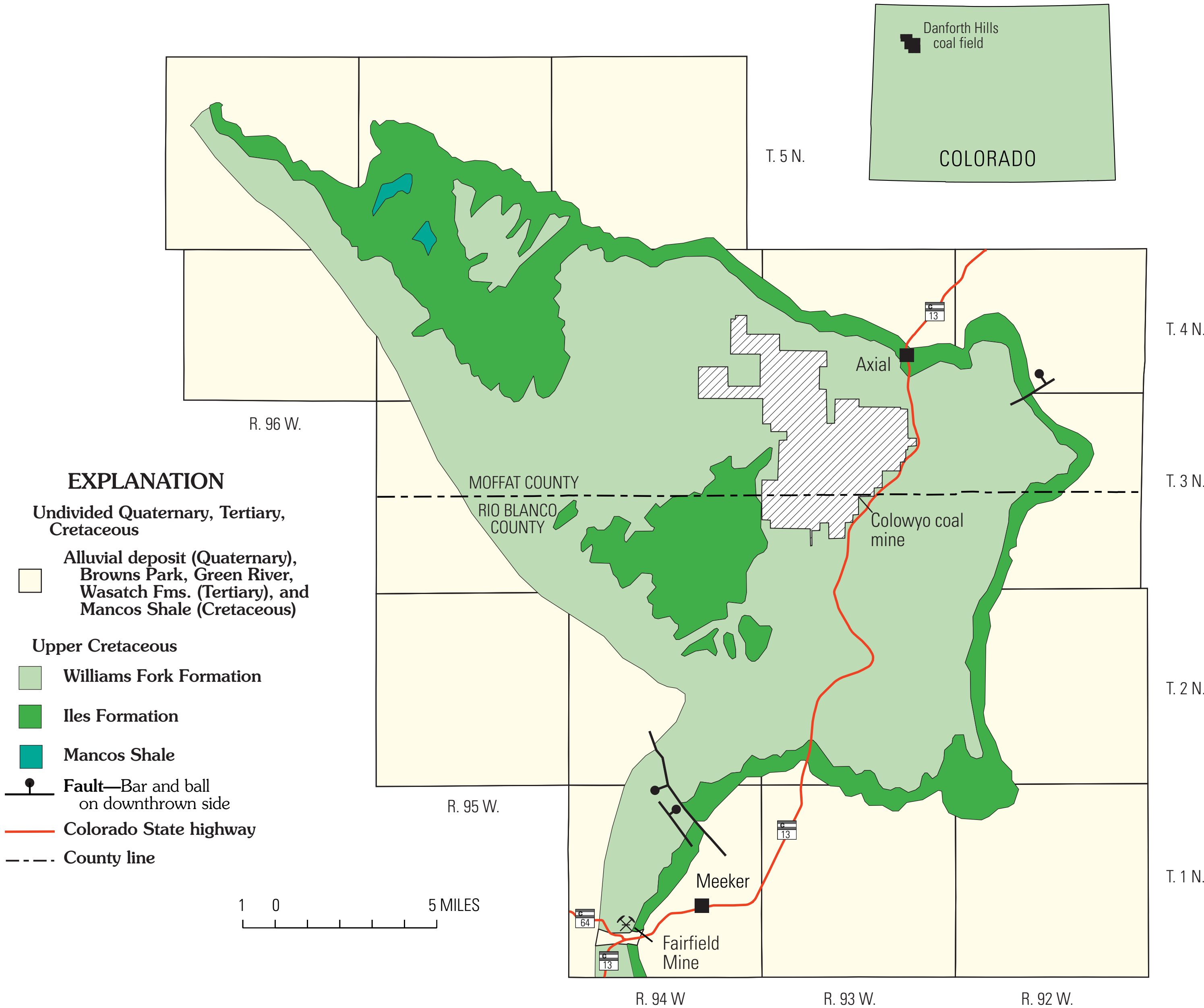

Figure 23. Danforth Hills coal field (shades of green) in Moffat and Rio Blanco Counties, northwestern Colorado, showing general geology, outline of Danforth Hills coal field drawn on the base of the Iles Formation, area of Colowyo coal mine, and location of abandoned Fairfield Mine.

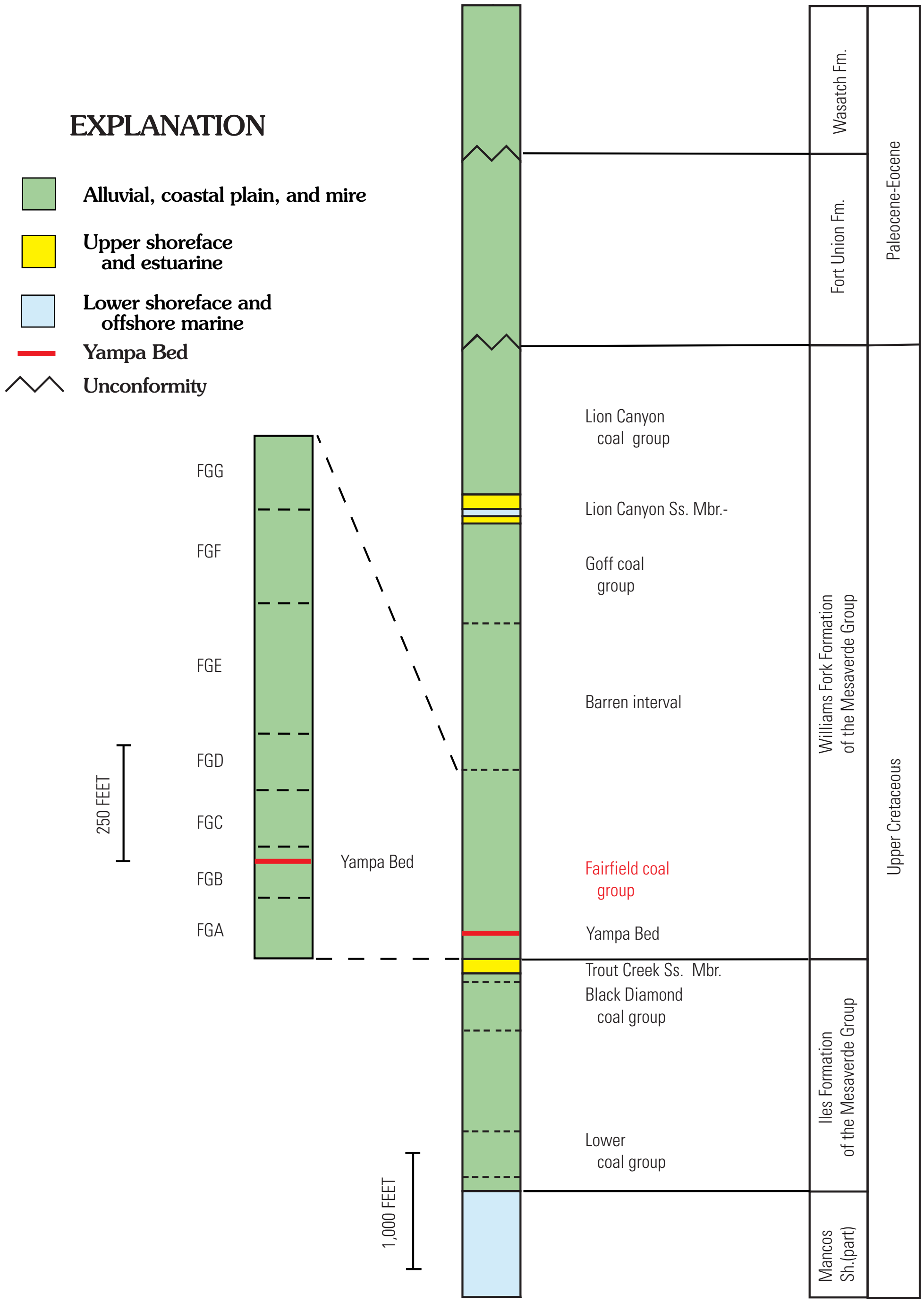

Figure 24. Generalized stratigraphic column showing depositional environments for a portion of the Upper Cretaceous and Tertiary rocks in the Danforth Hills coal field (fig. 1) about 25 mi south of Craig, Colo. (see fig. 1). Shown are major divisions of the Fairfield coal group (FGA–FGG) (Brownfield and others, 2000b) and stratigraphic position of Yampa Bed within the Williams Fork Formation. Yampa Bed not drawn to scale. Fm., Formation; Mbr., Member; Sh., Shale; Ss., Sandstone. Modified after Hancock and Eby (1930) and Brownfield and others (2000b).

Figure 25. Drill core from Danforth Hill coal field, south of Colowyo Mine (pl. 2, part *A*) about 25 mi south of Craig, Colo. (fig. 1). Yampa Bed here is 21.5 in. thick and lies about 170 ft above Trout Creek Sandstone Member of the Iles Formation.

Yampa Bed as a Correlation Tool

The Mesaverde Group is characterized by complex intertonguing that generally makes regional correlation of lithofacies difficult; in early stratigraphic studies in northwestern Colorado and adjacent areas, this difficulty led to errors in regional correlations of coal beds and associated lithofacies. Since its importance as a precise regional time line was recognized many years ago, however, the Yampa Bed has been used extensively as a datum in subsurface research. The Yampa Bed has been used to correlate coal beds in the Yampa and Danforth Hills coal fields and in regional lithofacies correlations of the Mesaverde Group throughout northwestern Colorado (Affolter and Brownfield, 1987; Brownfield and Affolter, 1988; Johnson and Brownfield, 1988; Brownfield and others, 2000b; Johnson and others, 2000).

Five cross sections that use drill-hole geophysical logs are presented to illustrate the importance and usefulness of the Yampa Bed as a regional datum in stratigraphic correlations in the Piceance and Sand Wash Basins and, in particular, the Yampa and Danforth Hills coal fields. These cross sections are as follows:

Figure 27. Correlation of the E coal bed (Johnson and Brownfield, 1988) and associated lithofacies in the lower part of the Williams Fork Formation in the western part of the Yampa coal field.

Figure 28. Correlation of the Trout Creek Sandstone Member of the Iles Formation and the Twentymile Sandstone Member of the Williams Fork Formation across the western part of the Yampa coal field.

Plate 1, cross sections A-A’ and B-B’—Correlation of units and distribution of coal zones within the middle coal group and the Twentymile Sandstone Member of the Williams Fork Formation and correlation of the Trout Creek Sandstone Member of the Iles Formation across the Yampa coal field.

Plate 2, cross section A-A’—Correlation of units and distribution of coal zones within the Fairfield coal group of the Williams Fork Formation and Trout Creek Sandstone Member of the Iles Formation across the Danforth Hill coal field.

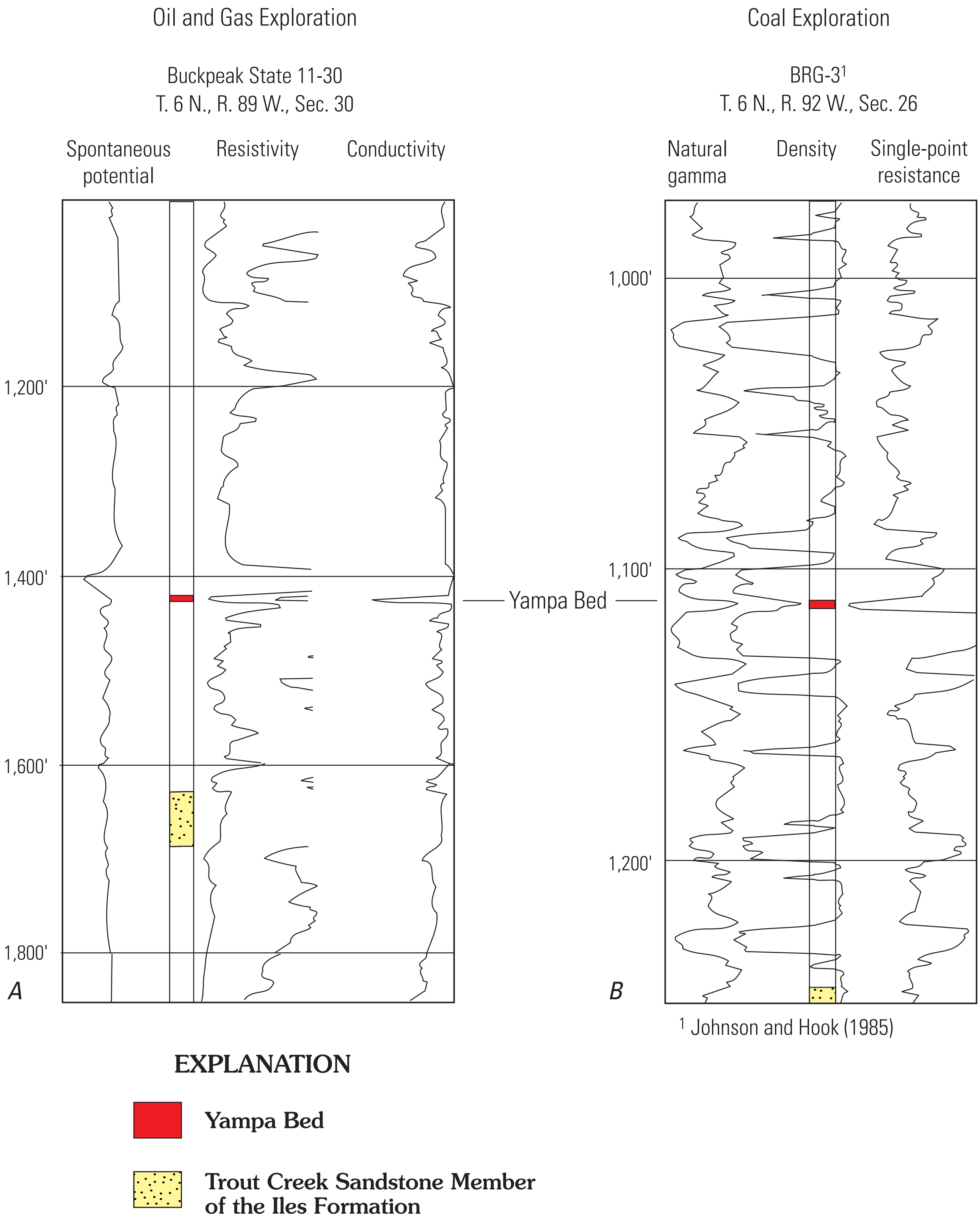

Figure 26. Examples of geophysical log responses of the Yampa Bed. *A*, oil and gas exploration geophysical log showing spontaneous potential, resistivity, and conductivity logs; *B*, coal exploration geophysical log showing natural gamma, density, and single- point resistance logs.

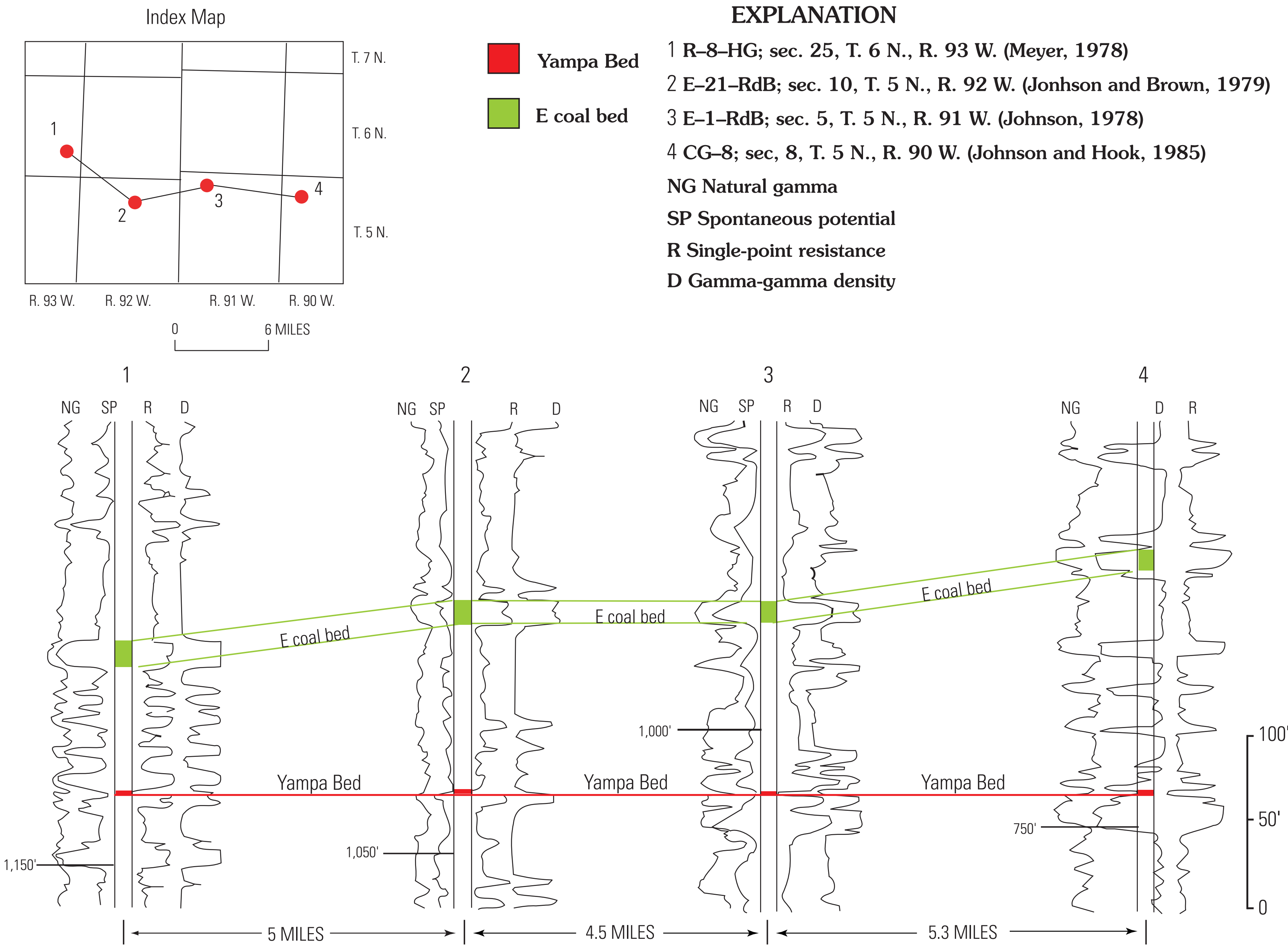

Figure 27. Subsurface correlation of E coal bed in Williams Fork Formation, western part of the Yampa coal field, using Yampa Bed as datum. Based on Johnson (1978) and Johnson and Brownfield (1988).

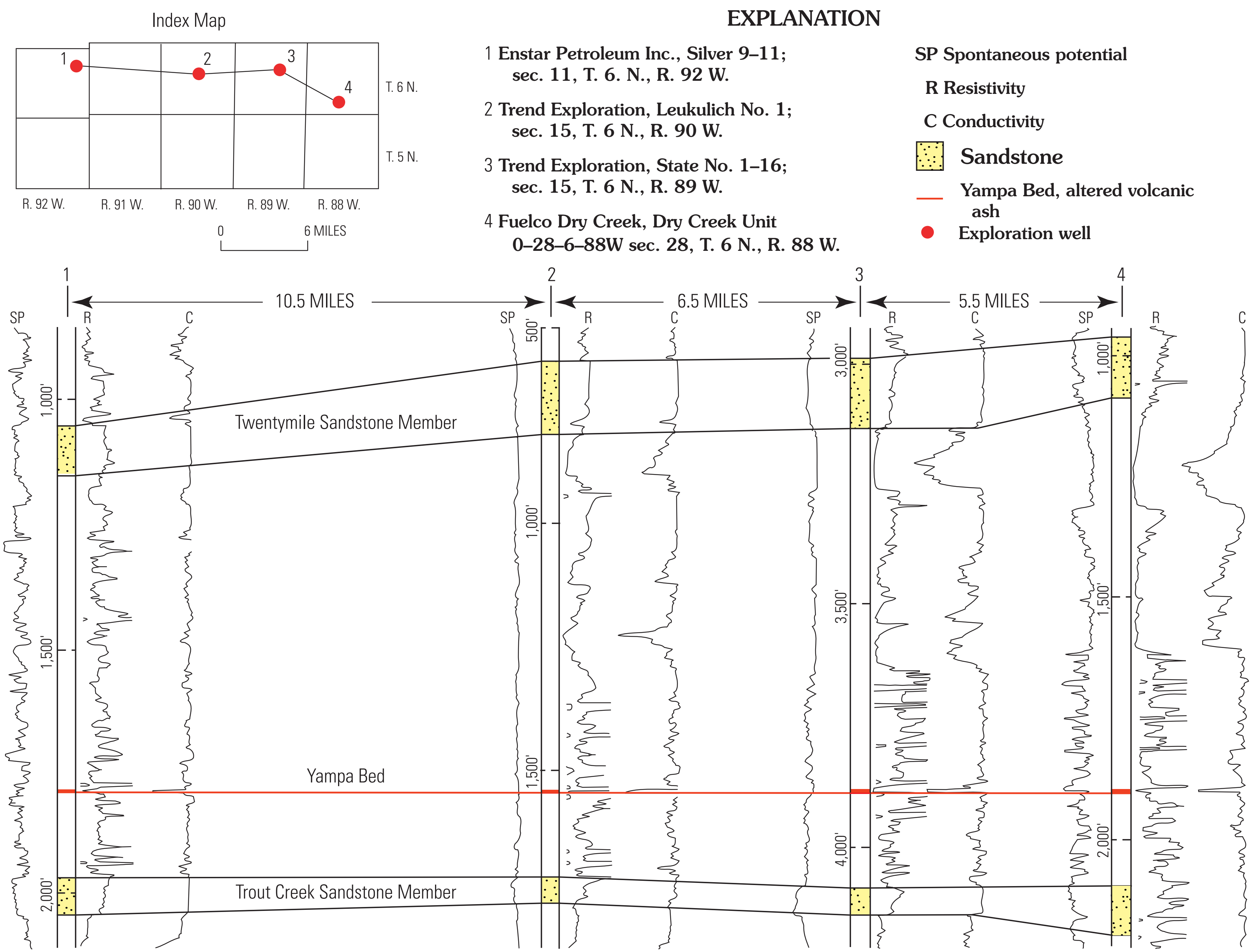

Figure 28. Subsurface correlation of Trout Creek Sandstone Member of the Iles Formation and Twentymile Sandstone Member of the Williams Fork Formation in the Yampa coal field, using Yampa Bed as datum. Based on Johnson and Brownfield (1988).

Summary

The Yampa Bed is a formal name given to a regionally persistent tonstein bed that was deposited in the Late Cretaceous as an airfall ash that settled in several different coeval environments during the deposition of the Williams Fork Formation. The name is derived from the Yampa River valley in northwestern Colorado. The diagenetically altered ash bed consists primarily of kaolinite and smectitic clays with a minor nonclay mineral fraction that includes ß-quartz-form phenocrysts, biotite, sanidine, andesine, and zircon. Outcrop and subsurface studies indicate that the unit has a wide areal distribution in the Yampa, Danforth Hills, and Grand Hogback coal fields, Moffat and Routt Counties, northwestern Colorado. The Yampa bed was dated at 72.5±5.1 Ma using K-Ar methods on andesine. The persistent tonstein bed is here named the Yampa Bed of the Williams Fork Formation. The Yampa Bed was named for the Yampa River valley.

Evidence that the Yampa Bed is a diagenetically altered airfall ash consists of the following: (1) petrographic studies of thin sections reveal a relict vitroclastic texture that was presumably preserved by the clay-mineral replacement of the original glass shards; (2) samples characteristically contain grains of euhedral to subhedral ß-quartz-form phenocrysts and biotite, sanidine, andesine, and zircon, all of which are common in volcanic rocks; and (3) outcrop and subsurface studies indicate a widespread areal distribution.

The Yampa Bed is extremely useful as a regional datum in correlations of facies and paleogeographic reconstructions within the Upper Cretaceous coal-bearing rocks in the Piceance Creek and southeastern Sand Wash Basins.

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