Sedimentology, Mineralogy, Palynology, and Depositional History of Some Uppermost Cretaceous and Lowermost Tertiary Rocks along the Utah Book and Roan Cliffs East of the Green River

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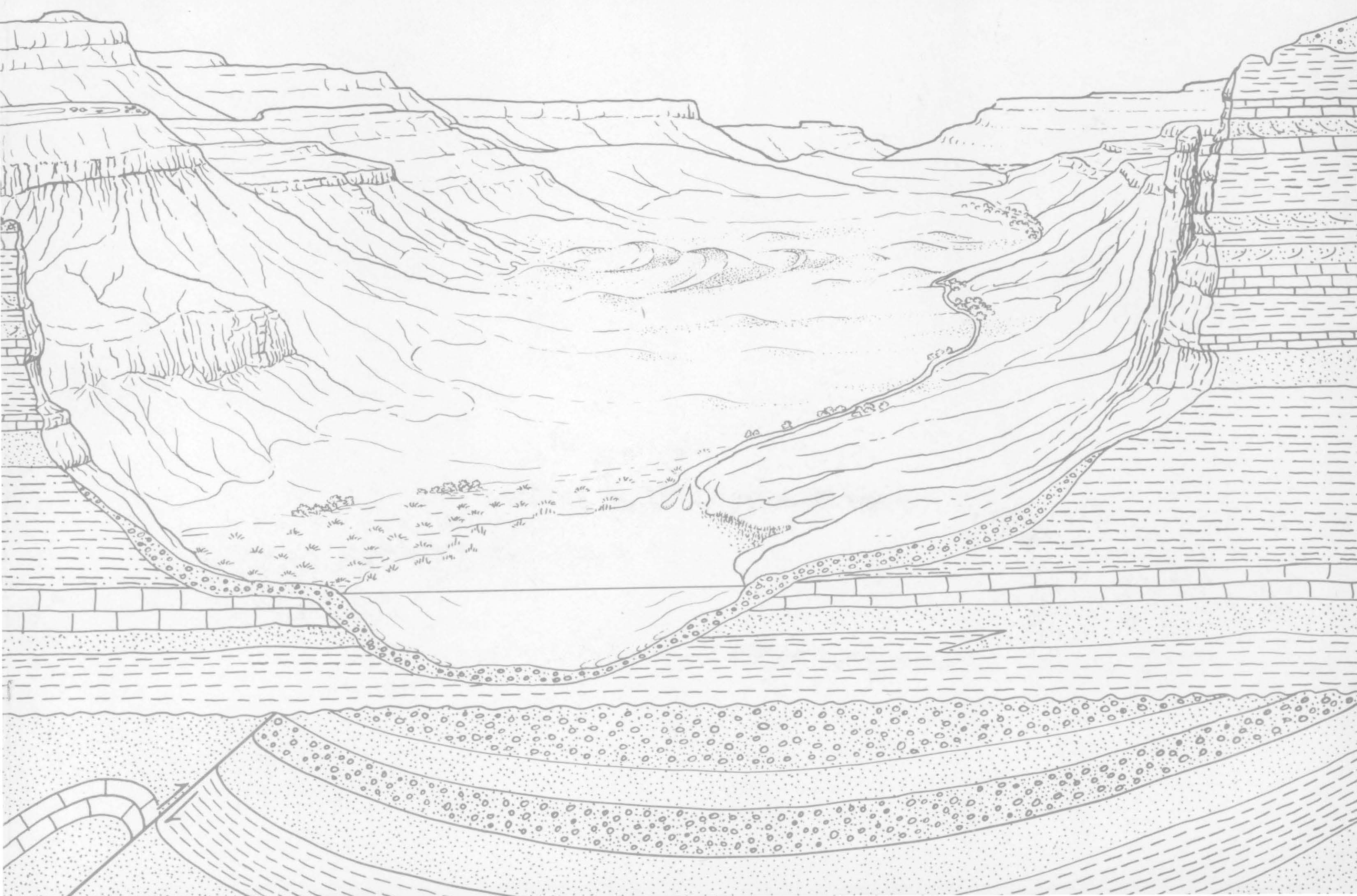

Chapter N

Sedimentology, Mineralogy, Palynology, and Depositional History of Some Uppermost Cretaceous and Lowermost Tertiary Rocks along the Utah Book and Roan Cliffs East of the Green River

By KAREN J. FRANCZYK, JANET K. PITMAN, and DOUGLAS J. NICHOLS

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

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EVOLUTION OF SEDIMENTARY BASINS—UINTA AND PICEANCE BASINS

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CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	0.4536
Degrees Fahrenheit (°F)	Degrees Celsius (°C)	Temp °C = (temp °F-32)/1.8

Sedimentology, Mineralogy, Palynology, and Depositional History of Some Uppermost Cretaceous and Lowermost Tertiary Rocks along the Utah Book and Roan Cliffs East of the Green River

By Karen J. Franczyk, Janet K. Pitman, *and* Douglas J. Nichols

Abstract

The Upper Cretaceous sequence from the Buck Tongue of the Mancos Shale through the Tuscher Formation along the Book and Roan Cliffs was deposited over a period of about 4–5 million years from early late to middle late Campanian time. Easterly and northeasterly flowing rivers provided abundant quartz- and lithic-rich sediments from the thrust belt area to the coastal plain and shoreline that were prograding across eastern Utah during the final regression of the Cretaceous sea. Frequent oscillations of the shoreline and deposition in back-barrier environments prohibited accumulation of thick peat deposits on the lower coastal plain. The last major influx of clastic material from the thrust belt is marked by deposition of the Bluecastle Tongue of the Castlegate Sandstone. The sediment source then shifted to areas south and southwest of the thrust belt where sedimentary, igneous, and volcanic rocks contributed feldspathic- and lithic-rich detritus to northeasterly flowing rivers. An alluvial plain succeeded the coastal plain, and the rivers, although still sinuous, became larger. Incipient movement of the San Rafael uplift in late Campanian time may have slowed subsidence rates and caused the rivers to migrate more extensively, producing localized, thick, stacked, channel-fill sequences of the Tuscher Formation. Deposition ended when subsidence of the foreland basin ceased. Early Maastrichtian-age rocks in the subsurface of the central Uinta basin indicate either that deposition continued for a slightly longer time or that less erosion occurred than along the Book Cliffs area. After a hiatus of about 10 million years, braided rivers originating in rising Laramide uplifts to the south deposited the Dark Canyon sequence of the Wasatch Formation during late early Paleocene time. Another hiatus of 6 million years or more occurred before upper Paleocene lacustrine and alluvial strata were deposited in the Book Cliffs area.

Manuscript approved for publication, August 2, 1989.

INTRODUCTION

The thick Upper Cretaceous and lower Tertiary sedimentary sequence exposed along the Book and Roan Cliffs in Utah and Colorado records temporal and spatial changes in sedimentology, mineralogy, and subsidence associated with the final phase of foreland basin deposition and the initiation of intermontane basin deposition. Changes in depositional environments, paleodrainage directions, and mineralogy in this sequence within the Utah Book Cliffs west of the Green River document major changes in depositional systems, source areas, and tectonic events during late Campanian time (Lawton, 1986). East of the Green River, however, this interval thickens and the distribution and lateral relations of stratigraphic units exhibit some differences. We examined part of the Upper Cretaceous and lower Tertiary section east of the Green River to determine if Lawton's observations persist regionally; to document local stratigraphic variations; and to collect outcrop data on facies distributions, depositional environments, and mineralogy for comparison with similar data obtained in ongoing subsurface studies of this interval.

Outcrop data consist of measured sections (pls. 1, 2) at Tusher Canyon, Sego Canyon, Cottonwood Canyon, and Bitter Creek (fig. 1), beginning at or just below the top of the upper Campanian Castlegate Sandstone and extending into the basal Paleocene part of the main body of the Wasatch Formation. Samples were collected from the sections and in adjacent areas for petrographic and palynologic analysis. Additional data from previous subsurface studies (Keighin and Fouch, 1981; Pitman, Anders, Fouch, and Nichols, 1986; Pitman, Franczyk, and Anders, 1987, 1988) and outcrop studies (Dickinson and others, 1986; Lawton, 1986; Willis, 1986; Franczyk and Pitman, 1987; Franczyk, 1988) supplement the measured section data.

The stratigraphic interval of this study contains abundant energy resources both in outcrop and in the subsurface. The Cretaceous sequence formed as the sea withdrew from Utah and was succeeded by coastal and alluvial plains. The depositional setting of the Sego shoreline controlled the thickness, distribution, and quality of coal beds that occur locally within the overlying coastal-plain deposits of the Neslen Formation. Abundant organic-rich material that occurs throughout the Neslen is a hydrocarbon source in the subsurface (Pitman and others, 1987). The fluvial Tuscher and Farrer Formations are hydrocarbon reservoirs in the subsurface, and the geometry and internal structure of the reservoir units are directly related to the types of fluvial systems that deposited these units (Pitman and others, 1986). The Dark Canyon sequence of the Wasatch Formation, the Tertiary unit measured in these sections, is also a local hydrocarbon reservoir (Peterson, 1973; Fouch, 1975). It was deposited during a brief event prior to the major episode of subsidence in the southeastern Uinta basin, and its distribution and lithologies vary greatly across the study area.

The detailed measured sections presented here, along with Upper Cretaceous and lower Tertiary measured sections along the Book Cliffs west of the Green River (Lawton, 1983) and east of the Utah-Colorado State line (Johnson and others, 1980; Johnson, 1985), provide a line of regionally extensive outcrop data across the southern Uinta and Piceance basins. These data permit improved regional depositional history synthesis, subsurface correlations, and interpretations of lithology and depositional environment from geophysical well logs.

Acknowledgments.—Melisa Fry, Doug Owens, Becky Hammond, and Sarah Griscom provided much appreciated field assistance. Discussions during all phases of this project with Bill Cashion, Tom Fouch, and Tim Lawton were extremely helpful and encouraging. Thoughtful reviews by Tim Lawton and Chris Schenk improved this manuscript. The U.S. Geological Survey Evolution of Sedimentary Basins Program funded the research.

METHODS

The sections were measured on well-exposed strata using a Jacob's staff, Abney level, and tape. Offsets in a section were made at formation boundaries or on laterally continuous beds; however, because many of the formations have gradational contacts and most of the nonmarine units have a lenticular geometry, errors involved in offsetting may be as high as 10 percent for an entire section. The thicknesses of sections from the top of the Castlegate Sandstone to the base of the Dark Canyon sequence are in good agreement with thicknesses obtained by Fisher and others (1960) in nearby areas. In the Tusher Canyon area our section is 1,690 ft (515 m), as compared to 1,485 ft (453 m) for the section of Fisher and others; in the Sego Canyon area our section is 2,055 ft (626 m), as compared to 2,039 ft (621 m); and in the Cottonwood Canyon area our section is 2,065 ft (629 m), as compared to 2,070 ft (631 m). The thickness (1,690 ft, 515 m) of our Cretaceous section at Tusher Canyon is significantly different from that (2,536 ft, 773 m) measured by Lawton (1983) in the same area.

Rock types, relative resistance to weathering, dominant grain size, primary sedimentary structures, and accessory constituents are displayed for each section (pls. 1, 2). Abrupt versus gradational grain-size changes are the best indicators of the type of contact between depositional units. Colors of dominantly fine grained rock were recorded locally throughout a section using a Rock-Color Chart (Goddard and others, 1963). Colors are useful in distinguishing the relative abundance of preserved organic material and the relative degree of oxidation. An arrow and associated number in the accessory column show the average mean vector of paleocurrent measurements, obtained from both trough crossbed axes and steeply dipping foresets of trough crossbeds, and the number of measurements from that unit. In some intervals, especially through the Tuscher Formation and the upper part of the Farrer Formation, only a few paleocurrent readings were obtained because sheer, flat, stained, and mud-coated cliff faces restricted good three-dimensional exposures and obscured sedimentary structures.

Sandstone samples were collected from each section for petrographic analysis to determine stratigraphic and geographic compositional differences. For regional comparison, samples also were collected at other localities. Individual thin sections were impregnated with blue-dyed epoxy to reveal porosity and were stained with combined alizarin red-S and potassium ferricyanide to differentiate iron-bearing from iron-free calcite and with sodium cobaltinitrite to distinguish potassium-rich from sodium-rich feldspar. Modal analyses for each sample were obtained by counting 300 grains per thin section; the resulting mineralogic compositions are summarized graphically (pls. 1, 2), and mean compositions for individual formations are shown in table 1. No significant variation in sandstone composition was noted geographically within a stratigraphic unit; however, there are systematic

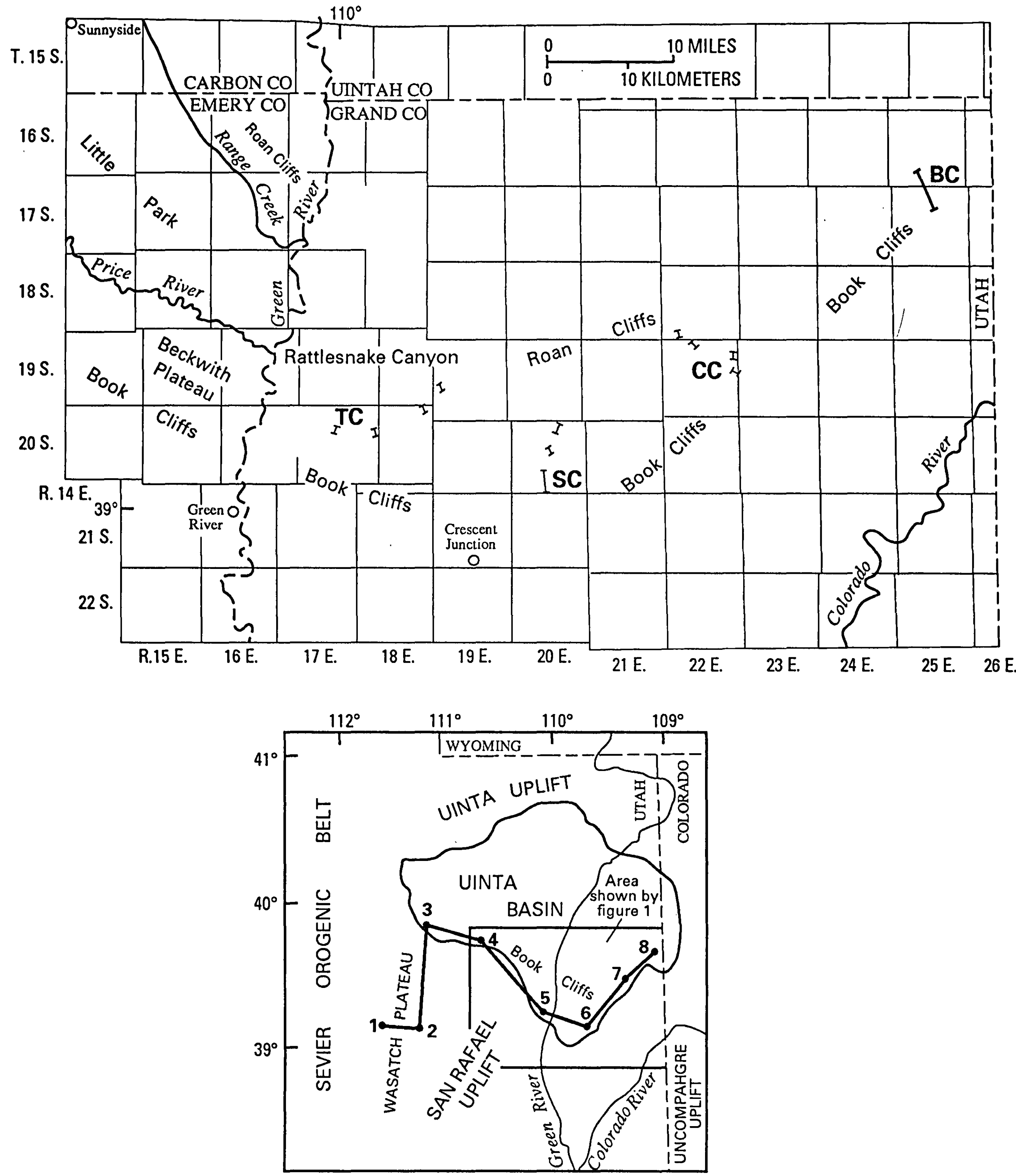

Figure 1. Locations of measured sections, Uinta basin, Utah. TC, Tusher Canyon; SC, Sego Canyon; CC, Cottonwood Canyon; BC, Bitter Creek. The numbers shown along the line of section in the inset map correspond to localities shown in figure 2.

Table 1. Summary of sandstone compositions in the Upper Cretaceous Mesaverde Group
[Petrographic data in percent; leaders (--) indicate not present]

Measured section	Quartz	Feldspar	Lithic fragments	Chert	Matrix	Other	Number of samples
Tuscher and Farrer Formations							
Tusher Canyon	34	10	12	13	2	29	13
Sego Canyon	30	12	13	11	3	14	13
Bitter Creek Canyon	27	12	18	10	8	25	14
Cottonwood Canyon	32	10	14	13	5	26	15
Bluecastle Tongue of Castlegate Sandstone							
Tusher Canyon	61	--	5	6	2	26	4
Neslen Formation							
Tusher Canyon	59	2	4	2	10	23	9
Sego Canyon	47	4	13	6	3	27	3
Bitter Creek Canyon	45	3	12	4	8	28	5
Cottonwood Canyon	44	4	10	10	4	28	5
Sego Sandstone							
Bitter Creek Canyon	47	4	12	4	6	27	6
Cottonwood Canyon	45	3	8	4	10	30	4

compositional differences between units that reflect tectonic events and changes in source areas. Minor compositional variations within a formation can be attributed to differences in sorting and to stratigraphic position; the coarser grained, basal part of a channel sandstone contains more dark-colored grains than the finer grained, middle to upper parts.

Age data are sparse from the Tuscher Formation, the Dark Canyon sequence of the Wasatch Formation, and the main body of the Wasatch Formation in the study area; therefore, these units were the principal ones sampled in the measured sections for palynological study. Additional samples of the uppermost Cretaceous and lower Tertiary units in the eastern part of the Uinta basin include material from outcrop sections along the Book Cliffs in Utah and from cores from the east-central part of the basin. Productive samples from outcrops of the Tuscher Formation include those from Bryson Canyon (USGS paleobotany locality D6873, sec. 36, T. 16 S., R. 24 E.), Dark Canyon (D6301, T. 17 S., R. 23 E.), Jim Canyon (D6754, sec. 11, T. 16 S., R. 25 E.), Nash Canyon (D6299-A, D6299-C, sec. 18, T. 19 S., R. 21 E.), and Sego Canyon (D6297, D6757). The Dark Canyon sequence yielded productive samples at Dark Canyon (D6300), Sego Canyon (D6298), Tuscher Canyon (D6867), and Cottonwood Wash (D6872). The undifferentiated Tuscher and Farrer Formations and the Neslen Formation were also sampled from cores in the Natural Buttes (D6192) and Southman Canyon (D5929) fields in the Uinta basin. Preliminary results of studies of some of these and other outcrop samples are reported in Fouch and Cashion (1979) and Fouch and others (1983); the palynology of cores from the Natural Buttes field (sec. 15, T. 10 S., R. 22 E.) is discussed in Pitman, Anders, Fouch, and Nichols (1986) and Pitman, Franczyk, and Anders (1987). Cores from the Southman Canyon field (sec. 24, T. 10 S., R. 23 E.) are described by Keighin and Fouch (1981), but palynological data are not included in that report. Interpretations of palynostratigraphic relations of outcrop and subsurface sections presented in this report are new.

NOMENCLATURAL HISTORY

Because of numerous regional facies changes, Fisher and others (1960) used different stratigraphic nomenclature for the Cretaceous sequence along the Book Cliffs west of the Green River, east of the Green River to the Utah-Colorado State line, and in Colorado. We use the nomenclature of Fisher and others (1960) for Utah east of the Green River, as modified by Fouch and others (1983) and Franczyk and Pitman (1987) (fig. 2). Although Fisher (1936) first used the names Sego, Neslen, Farrer, and Tuscher, he did not designate a type section or locality for these units. The Tusher Canyon measured section (fig. 1, pl. 1) is herein designated the type section for the Farrer and Tuscher Formations, and the Sego Canyon measured section (fig. 1, pl. 1) is herein designated the type section for the Sego Sandstone and the Neslen Formation. Contacts between the nonmarine Neslen, Farrer, and Tuscher Formations are gradational and, as discussed by Keighin and Fouch (1981), difficult to distinguish, especially in the subsurface. The contact between the coal-bearing Neslen and the sandier, less carbonaceous Farrer is usually readily identifiable, although its stratigraphic position is regionally variable. The major difficulty is defining the Tuscher and distinguishing it from the Farrer.

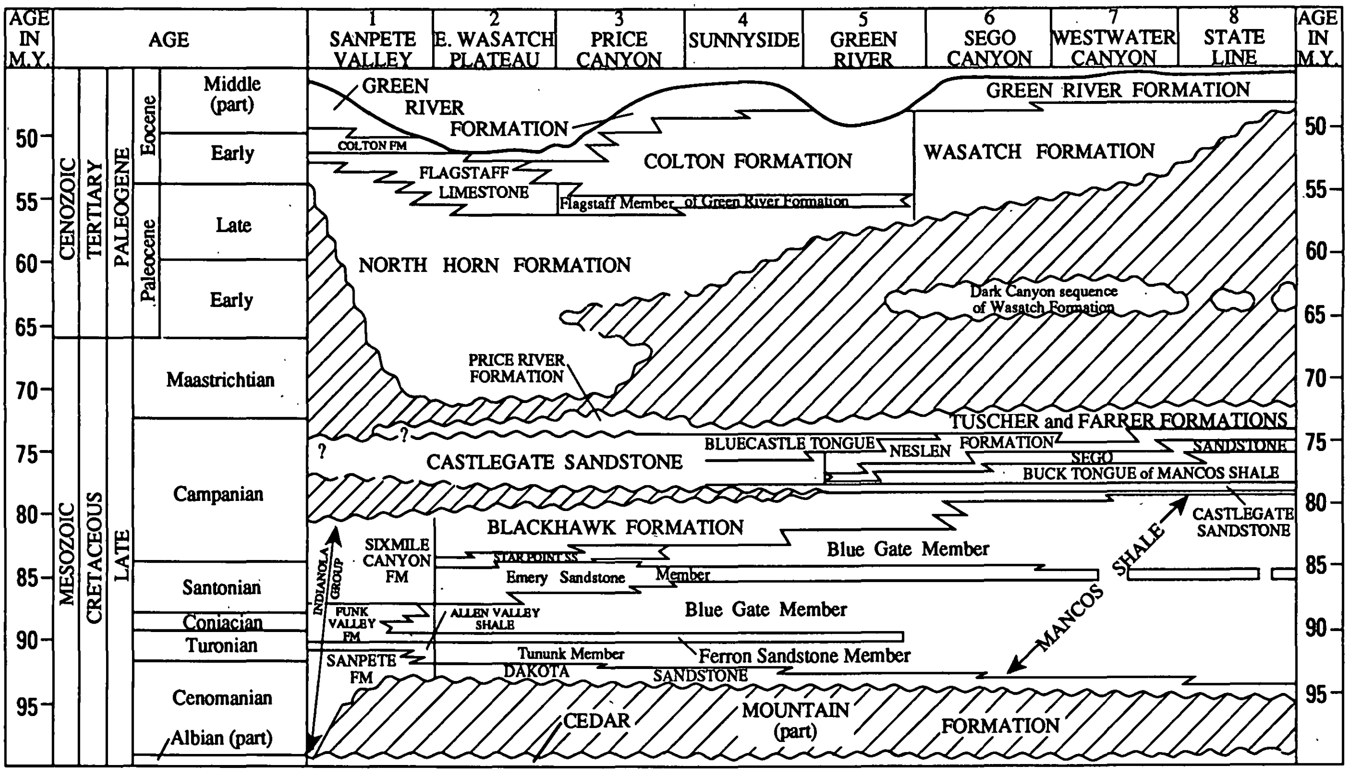

Figure 2. Stratigraphic nomenclature and correlation of major Albian to middle Eocene rock units from the Sanpete Valley of central Utah eastward to the Book Cliffs of eastern Utah. Line of section shown in inset map on figure 1. Modified from Fouch and others (1983).

Fisher (1936) named the Tuscher Formation from exposures in Tusher (present spelling on topographic maps) Canyon and assigned it a tentative Tertiary age, whereas Fisher and others (1960) considered it to be of Cretaceous age. A type section was not defined. As described by Fisher (1936), the Tuscher is composed of massive, light-gray to white, cliff-forming sandstone beds containing minor shale beds; it is lighter in color than the underlying Farrer Formation and lacks the variegated beds that characterize the overlying Wasatch Formation. Fisher's (1936) description made it difficult to consistently pick a lower boundary, and subsequent workers included different parts of the nonmarine Cretaceous sequence in the Tuscher Formation.

Lawton (1983, 1986) included in the Tuscher Formation all of the section that contained greater than 50 percent sandstone: therefore, his Tuscher Formation includes a significant thickness of what many workers would map as Farrer Formation. For example, in the Tusher Canyon area, Fisher and others (1960) measured 270 ft (82 m) of Tuscher Formation, as compared to 919 ft (280 m) measured by Lawton (1986). Keighin and Fouch (1981) referred to the nonmarine Cretaceous sequence above the Neslen as the undifferentiated Farrer and Tuscher Formations. Geologic maps (Cashion, 1973; Gualtieri, 1988) distinguish the Tuscher from the Farrer throughout the Book Cliffs from the Green River to the State line; however, W.B. Cashion (U.S. Geological Survey, oral commun., 1987) stated that a lower Tuscher contact was very difficult to determine in the eastern part of this area because although the uppermost part of the Cretaceous nonmarine sequence locally contains thick sandstone beds, these beds rapidly grade laterally into thinner sandstone units separated by slope-forming intervals.

In measured sections, we differentiated the Farrer from the Tuscher, where possible, by using Fisher's (1936) original description. In the Tusher and Sego Canyon areas, we applied the Tuscher Formation to the upper few hundred feet of the nonmarine Cretaceous section that is characterized by a succession of stacked, virtually unscalable, fluvial sandstone units, each commonly thicker than 50 ft (15 m) (fig. 3). Using this terminology locally is advantageous because of the interval's distinct outcrop appearance and because of its implications in marking changes in basin depositional patterns. East of the Sego Canyon area, the character of this interval begins to change: more fine-grained material and fewer thick sandstone units are present. Willis (1986) noted that within the Sego Canyon 7-1/2′ quadrangle map the two formations are difficult to distinguish, and he mapped a questionable contact between them. We draw a questionable Farrer-Tuscher contact at the

Figure 3. Thick, stacked, tabular, sandstone bodies separated by thin, tree-covered, slope-forming intervals characterize the Tuscher Formation in the western part of the study area. Internally, each sandstone body contains numerous discrete sandstone units separated by scour contacts. The contact between the Tuscher Formation (Kt) and underlying Farrer Formation (Kf) is gradational and placed where the increase in thickness of the sandstone bodies is most pronounced. Looking northwest up Sego Canyon.

Cottonwood Canyon section. Farther east at the Bitter Creek section, no systematic vertical change occurs in the Farrer Formation, and we apply the term undifferentiated Farrer and Tuscher Formations to the entire Cretaceous section above the Neslen Formation. Thus, if Fisher's (1936) original definition is used to distinguish the Tuscher, the formation exists only in the vicinity of the Green River.

An unconformity separates the Cretaceous Tuscher Formation or undifferentiated Farrer and Tuscher Formations from the overlying Tertiary Wasatch Formation. In all the measured sections except Bitter Creek, an unconformity-bounded, late early Paleocene-age conglomerate sequence forms the basal part of the Wasatch Formation (fig. 2). In their measured sections, Fisher and others (1960) described a conglomerate and conglomeratic sandstone that at some locations is placed at the base of the Wasatch Formation but in other locations is included within the Tuscher Formation. Fouch and Cashion (1979) first referred to this conglomerate sequence as the "beds at Dark Canyon" in a subsurface cross section and, based on palynological data, assigned it a Paleocene age. Later it was referred to as the "conglomerate at Dark Canyon" (Keighin and Fouch, 1981) or the "conglomerate beds at Dark Canyon" (Fouch and others, 1983). Because of its lithologic diversity, Franczyk and Pitman (1987) referred to this unit as the Dark Canyon sequence. They included it in the Wasatch Formation but did not designate a type section. Therefore, the Sego Canyon measured section (fig. 1, pl. 1) is herein designated as the type section for the Dark Canyon sequence. The Dark Canyon sequence is continuous along much of the Utah Book Cliffs east of the Green River. It pinches out a short distance west of the Tusher Canyon measured section. Pebbly sandstone in the uppermost part of the Tuscher Formation in the Green River area has led to confusion in correlating uppermost Cretaceous and lower Tertiary units, in determining their lateral equivalents, and in interpreting their depositional origins. Toward the Colorado-Utah State line, the Dark Canyon sequence thins and is only locally preserved due to postdepositional erosion.

A thin sequence of undifferentiated North Horn Formation and Flagstaff Member of the Green River Formation, consisting of marginal- and open-lacustrine limestone, siltstone, and mudstone interbedded with variegated alluvial deposits, extends a short distance east of the Green River and unconformably overlies the westernmost part of the Dark Canyon sequence (fig. 2). The lacustrine deposits pinch out into the completely alluvial sequence of the main body of the Wasatch Formation between Tusher and Sego Canyons.

PALYNOLOGY AND AGE RELATIONS

Palynological studies of this interval are difficult because of the generally poor recovery of palynomorphs from the predominantly sandy and silty lithologies. Many samples orginally collected for palynological analysis were completely barren of palynomorphs and others yielded very few specimens. Sparse assemblages can be difficult or impossible to date because they may lack species having biostratigraphic significance.

The existing palynostratigraphic zonation of the Campanian and Maastrichtian in the region (Nichols and others, 1982) places most of the upper Campanian and lower part of the Maastrichtian within a single formally defined zone. The Neslen, Farrer, and Tuscher Formations all lie within this broadly defined zone, and it is difficult to further refine age relations among these units. As these units thicken away from the areas where they were named along the Book Cliffs and into the Uinta basin, their palynologic as well as lithologic distinctions become blurred. The combination of these constraints with poor recovery of palynomorphs greatly limits the application of palynostratigraphy to detailed age determination and correlation of the rocks of the region.

With these caveats in mind, age relations and correlations are suggested by evidence presented below. Some refinement of the Cretaceous zonation is suggested by the presence of palynomorph species indicative of the lower of two informally defined subzones within the upper Campanian and by recognition of an assemblage apparently characteristic of the lower Maastrichtian. The subdivisions of the Campanian, Maastrichtian, and Paleocene cited below are essentially relative ages and are not formally defined; they are based on comparisons of palynologic assemblages within the Uinta basin and elsewhere in the Rocky Mountain region. In most cases, ages are inferrred from biostratigraphic correlation with independently dated stratigraphic units outside the basin.

The age of the Castlegate Sandstone was determined (Fouch and others, 1983) to be early late Campanian, about 74–79 Ma based on correlations with occurrences of marine mollusks of the *Exilitoceras jennyi* through *Baculites asperiformis* zones reported by Gill and Hail (1975). Based on new outcrop and subsurface correlations, Franczyk (1988) postulated that the Bluecastle Tongue of the Castlegate was in the *Baculites scotti* zone and thus no younger than 75 Ma. Few palynomorphs have been recovered from the Castlegate in outcrops along the Book Cliffs. Biostratigraphically important palynomorphs from the Castlegate (including the Bluecastle Tongue of the Castlegate) reported in Fouch and others (1983, fig. 15) include *Tricolpites interangulus* and species of *Aquilapollenites* and *Proteacidites*. Occurrences of these taxa are consistent with, but not definitive of, the early late Campanian age defined by the mollusk data cited above.

No palynomorphs were collected from the Sego Sandstone, but marine mollusks of the upper Campanian *Baculites scotti* faunal zone were reported by Gill and Hail (1975) from the upper part of the Sego in western Colorado. Diagnostic fossils were not found in the Sego in Utah during this study, and none have been reported by previous workers. In eastern Utah, the Buck Tongue of the Mancos Shale contains fossils of the *Baculites perplexus* zone (Gill and Hail, 1975).

A sample of coal from the Neslen Formation in outcrop (locality D6338; Fouch and others, 1983) is characterized primarily by long-ranging spore taxa derived from the local swamp flora. The only biostratigraphically significant form reported was *Proteacidites* sp., angiosperm pollen broadly indicative of Senonian (Coniacian through Maastrichtian) age. The Neslen in the subsurface was cored in the Natural Buttes (Pitman and others, 1987) and Southman Canyon gas fields, and a more diverse palynomorph assemblage was recovered from these samples. For age determination, the most useful taxa in this assemblage are *Aquilapollenites trialatus*, *Erdtmanipollis* sp., *Mancicorpus calvus*, and *Siberiapollis montanensis*. Collectively, these species and the others present in the Neslen in the subsurface are indicative of a middle late Campanian age, equivalent to that of the Judith River Formation of Montana. They suggest the presence of the *Siberiapollis montanensis* subzone of the *Aquilapollenites quadrilobus* Interval Zone of Nichols and others (1982).

A palynomorph assemblage, resembling that of the Judith River Formation, recovered from the Farrer and Tuscher Formations at several localities along the Book Cliffs in Utah (Fouch and others, 1983; this study) indicates a middle late Campanian age for these units in outcrop. Table 2 lists taxa identified; specimens of some species are illustrated in plate 3. No important biostratigraphic differences are evident between the Farrer and Tuscher palynologically because of generally mediocre recovery and because both units are within the *Aquilapollenites quadrilobus* Interval Zone of Nichols and others (1982). The presence of *Kuylisporites scutatus* in samples from within 10 m below the Cretaceous-Tertiary unconformity in Sego Canyon, Jim Canyon, and Bryson Canyon in the eastern Book Cliffs indicates that the uppermost Tuscher is in the lower part of the *A. quadrilobus* Zone and is no younger than late Campanian.

In contrast, the assemblage from the upper part of the undifferentiated Farrer and Tuscher Formations in the subsurface reported and, in part, illustrated in Pitman and others (1986, table 1, fig. 5) may be as young as early Maastrichtian. The assemblage from the undifferentiated

Table 2. Palynomorph assemblage from the upper part of the Tuscher Formation in outcrop along the Book Cliffs

Bryophyte and pteridophyte spores	
Appendicisporites sp.	*Kuylisporites scutatus* Newman
Camarozonosporites insignis Norris	*Laevigatosporites* spp.
Cicatricosisporites sp.	*Reticuloidosporites* sp.
Cyathidites minor Couper	*Seductisporites eminens* Tschudy
Cyathidites sp. "T"	*Seductisporites* spp.
Foraminisporis wonthaggiensis (Cookson & Dettman) Dettman	*Stereisporites* spp.
Gleicheniidites senonicus Ross	*Toroisporis* sp.
Gymnosperm pollen	
Araucariacites sp. cf. *A. australis* Cookson	*Ilexpollenites compactus* Stone
Corollina sp.	*Liliacidites* sp. cf. *L. complexus* (Stanley) Leffingwell
Ephedra sp. "D"	*Loranthacites* sp. "F"
Eucommiidites couperi Anderson	*Mancicorpus* sp. cf. *M. calvus* (Tschudy and Leopold) Tschudy
Eucommiidites minor Groot and Penny	*Pandaniidites typicus* (Norton) Sweet
Monocolpopollenites sp. cf. *Rectosulcites latus* Anderson	*Proteacidites retusus* Anderson
Pityosporites spp.	*Proteacidites* spp.
Taxodiaceaepollenites hiatus (Potonié) Kremp ex Potonié	*Pseudoplicapollis newmanii* Nichols and Jacobson
Aquilapollenites attenuatus Funkhouser	*Retitrescolpites* spp.
Aquilapollenites quadrilobus Rouse	*Tricolpites interangulus* Newman
Aquilapollenites turbidus Tschudy and Leopold	*Triporopollenites* spp.
Arecipites sp.	*Ulmipollenites* sp.
Cupuliferoidaepollenites sp.	

Table 3. Palynomorph assemblage from the Dark Canyon sequence of the Wasatch Formation

Pteridophyte spores	
Cyathidites sp.	*Zlivisporis* sp.
Osmundacidites sp.	
Gymnosperm pollen	
Corollina sp.	*Taxodiaceaepollenites hiatus* (Potonié) Kremp ex Potonié
Pityosporites spp.	
Angiosperm pollen	
Alnus speciipites Wodehouse	*Momipites waltmanensis* Nichols and Ott
Arecipites tenuiexinous Leffingwell	*Nyssapollenites* sp.
Brevicolporites colpella Anderson	*Pandaniidites typicus* (Norton) Sweet
Chenopodipollis sp.	*Rhoipites* sp.
Cupuliferoidaepollenites sp.	*Tilia vescipites* Wodehouse
Momipites dilatus (Fairchild) Nichols	*Retitrescolpites angululuminosus* (Anderson) Frederiksen
Momipites inaequalis Anderson	*Retitrescolpites* sp.
Momipites leffingwellii Nichols and Ott	*Triporopollenites* spp.
Momipites tenuipolus Anderson	*Ulmipollenites krempii* (Anderson) Frederiksen

Farrer and Tuscher in the Natural Buttes field includes *Aquilapollenites quadrilobus*, *A. reticulatus*, *Cranwellia* sp. cf. *C. rumseyensis*, *Ilexpollenites compactus*, *Mancicorpus striatus*, *Pandaniidites typicus*, *Proteacidites* spp., and *Tricolpites interangulus*, among others. This assemblage closely resembles that from the Almond Formation in southwestern Wyoming described by Stone (1973). Especially important is *Mancicorpus striatus*, which appears to be stratigraphically restricted to this interval, which is early Maastrichtian in age (equivalent to the ammonite zones *Baculites reesidei* through *B. baculus*). On this basis, Nichols and Sweet (in press) recognized an informal assemblage zone (*Mancicorpus striatus* zone) of early Maastrichtian age.

No outcropping or subsurface Upper Cretaceous unit in the Book Cliffs of Utah or the eastern Uinta basin appears to be as young as late Maastrichtian. No palynologically productive samples analyzed have yielded species of the distinctive *Wodehouseia spinata* Assemblage Zone of Nichols and others (1982), which is well dated as late Maastrichtian throughout the Western Interior of the United States (Nichols and Sweet, in press). Thus, the Cretaceous-Tertiary unconformity in the area of the southeastern Uinta basin probably encompasses at least 3–4 million years of latest Cretaceous time.

The conglomerate and sandstone of the Dark Canyon sequence of the Wasatch Formation have been exceedingly difficult to date, although previous studies indicate that they are early Tertiary in age. Data presented in Fouch and others (1983) indicate that some of these beds could be as young as late Paleocene, but the locality in question (D5961–A) is stratigraphically above the Dark Canyon sequence. As reported by Franczyk and

Nichols (1986), the basal Tertiary unit in the area of the southeastern Uinta basin has heretofore yielded only sparse assemblages including a few Paleocene palynomorph species whose long range precludes precise age determination. The new locality in Cottonwood Canyon (D6872) is the most productive to date. The analyzed sample consisted of a pod of carbonaceous shale within the lower part of the Dark Canyon sequence. Species of the biostratigraphically important pollen genus *Momipites* are present, including *M. dilatus*, *M. inaequalis*, *M. leffingwellii*, *M. tenuipolus*, and *M. waltmanensis*, among which *M. waltmanensis* is especially abundant. Abundance of this species indicates an early but not earliest Paleocene age, equivalent to zone P2 of Nichols and Ott (1978), originally described in central Wyoming. The complete list of taxa identified is given in table 3, and some are illustrated on plate 3. Species characteristic of middle through late Paleocene zones P3 through P6 are absent from the Dark Canyon sequence at all localities sampled. Consequently, on this basis we suggest stratigraphic revision of the Dark Canyon sequence as shown by Fouch and others (1983, fig. 3) from late Paleocene to late early Paleocene in age.

Few palynological data are available with which to date the Wasatch Formation in the Book Cliffs of Utah. As mentioned above, a sample from locality D5961–A at the head of Dark Canyon was determined to be from the basal part of main body of the Wasatch in that area. Palynomorphs recovered, especially the pollen species *Caryapollenites veripites* Nichols and Ott, indicate a late Paleocene age. On that basis, a hiatus involving perhaps 6 million years or more may be present in that area between the Dark Canyon sequence and the main body of the Wasatch Formation.

SEDIMENTOLOGY AND DEPOSITIONAL HISTORY

Buck Tongue of the Mancos Shale

The Buck Tongue consists of an upward-coarsening sequence of interbedded, medium- to dark-gray sandstone and siltstone and lesser amounts of mudstone. It has a sharp, abrupt lower contact with the Castlegate Sandstone and a gradational upper contact with the Sego Sandstone. Measured sections place the lower contact directly above the ledge-forming Castlegate Sandstone (pls. 1, 2). Lawton (1983, 1986), at his Green River and Tusher Canyon sections, placed the Castlegate-Buck Tongue contact about 45 ft above the resistant sandstone of the Castlegate at a thin, laterally persistent, hematitic mudstone and siltstone bed that he interpreted to be a paleosol. We did not observe this bed in the measured sections east of Tusher Canyon. The western pinchout of the Buck Tongue is in the Beckwith Plateau area (fig. 1). The Buck Tongue thickens progressively eastward until it merges with the main body of the Mancos Shale east of the State line where the Castlegate Sandstone grades into a slope-forming siltstone sequence within the Mancos.

The Buck Tongue represents deposition during the final incursion of the Cretaceous sea into eastern Utah. The upward-coarsening grain-size trend, the gradational upper contact with the Sego Sandstone, and the types and sequences of sedimentary structures indicate deposition in a shoaling open-marine environment during progradation of the Sego shoreline.

Sego Sandstone

The western pinchout of the Sego Sandstone is in the same vicinity as that of the Buck Tongue. The Sego also thickens eastward within the study area but thins and grades into the Mancos in western Colorado. Using surface and subsurface data, Franczyk (1988) provided a detailed description of lithologic sequences and regional thickness trends in the Sego along the eastern Utah Book Cliffs. The contact of the Sego with the overlying Neslen Formation is generally sharp but conformable and is picked at the top of a thick, cliff-forming sandstone. In the Tusher Canyon section, the top of the Sego is difficult to pick because only a thin part of the sandstone unit weathers to a resistant ledge; however, 130 ft (40 m) of sandstone with only minor siltstone interbeds forms a slope-forming interval above the resistant ledge. Lawton (1983) and Pitman and others (1987) included and described this slope-forming part in the lower part of the Neslen Formation. The well-log response of this slope-forming interval is similar to that of the more typical cliff-forming sections (Franczyk, 1988); as a result, this thick, dominantly sandstone interval is considered Sego although its slope-forming weathering character makes it more difficult to place the upper contact in outcrop. For the same reason, a thinner, slope-forming sandstone interval above the cliff-forming sandstone is included in the Sego Sandstone in the Sego Canyon section.

East of the Colorado-Utah State line, the Sego is split into an upper and lower part by the Anchor Mine Tongue of the Mancos Shale (Erdmann, 1934). Measured sections of Gill and Hail (1975) show the Anchor Mine Tongue extending into eastern Utah; however, subsurface correlations (Franczyk, 1988) indicate that this tongue pinches out into the Sego east of the State line, and we do not recognize it in our Bitter Creek measured section.

Lithologically, the Sego is characterized by stacked, upward-coarsening sandstone units that in a complete cycle (60–90 ft (18–27 m) thick) show a vertical change from hummocky cross-stratified, horizontally laminated, ripple cross-laminated beds that are slightly to intensively burrowed, to trough cross-stratified beds, and finally to low-angle, parallel-laminated beds. In the Tusher and Sego Canyon sections, especially in the slope-forming intervals, stacked fining-upward sandstone units are generally characterized by current- and wave-ripple-laminated, planar-laminated, wavy, and flaser beds. These sandstone units also locally contain oyster-shell beds and thin interbeds of siltstone, mudstone, or carbonaceous shale (fig. 4).

Franczyk (1988) interpreted the upward-coarsening units as shoreface sequences deposited along a microtidal barrier-island coastline, and the fining-upward units as back-barrier tidal-flat, tidal-delta, tidal-channel, and washover deposits locally interbedded with marsh, lagoon, and bay deposits. Lawton (1986) also interpreted tidal flats to lie landward of the Sego shoreline. Willis (1986), in contrast, interpreted the Sego Sandstone in the Sego Canyon 7-1/2′ quadrangle to have been deposited in wave-dominated deltas because he did not interpret any deposits to be of tidal inlet or flood tidal delta origin. Tidal inlets occur but are rare in the Sego. Many of the thick, predominantly ripple laminated, fining-upward sandstone units locally interbedded with oyster-shell beds resemble deposits described from modern and ancient tidal environments (MacKenzie, 1972; Sellwood, 1975; Hayes and Kana, 1976; Reineck and Singh, 1980; Weimer and others, 1982) Deposits described from backshore environments of wave-dominated delta systems have different lithofacies distributions and sedimentologic characteristics (Balsley, 1982).

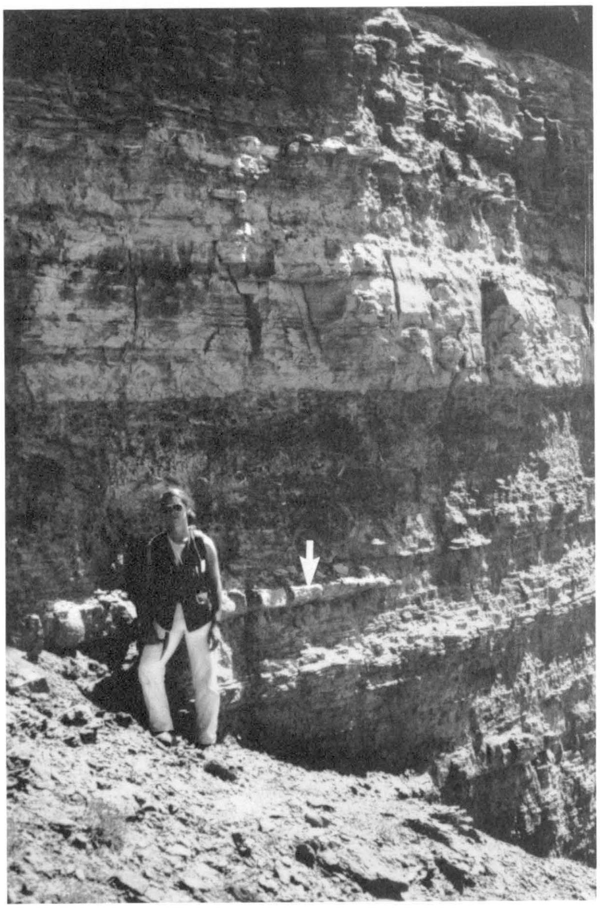

Figure 4. Rare cliff-forming exposure of the thick, dominantly flaser- and wavy-bedded sandstone sequence in the upper part of the Sego Sandstone in the Tusher Canyon area. The arrow points to a bed of disarticulated oyster shells that pinches out into rippled sandstone. The darker gray, less resistant intervals are beds of mudstone or carbonaceous shale interbedded with the sandstone. This interval is interpreted to represent composite tidal flat, marginal flood-tidal delta, and lagoonal deposits. Oyster-shell beds throughout this interval indicate that intertidal conditions were maintained throughout its deposition.

The interpretation of the Sego shoreline system is difficult. The Sego Sandstone differs significantly from the Blackhawk Formation that Balsley (1982) interpreted as deposits of a wave-dominated delta system. An individual, complete, shoreface sequence may be as thick as 130 ft (40 m) in the Blackhawk (Balsley, 1982), as compared to a maximum thickness of 90 ft (27 m) in the Sego shoreface sequence. Also, the prograding Blackhawk strandlines formed stable platforms that hosted extensive and persistent marshes recorded in the thick sequences of coal overlying shoreface sandstone. The shoreface sandstone units in the Sego are not associated with coal or carbonaceous shale deposits, even in the Sego Canyon area. Willis (1986) attributed this to lack of establishment of back-swamp conditions during most of the shoreline progradation events; however, even the stratigraphically highest shoreface unit, deposited during the final Sego shoreline progradation, is not overlain by coal. The sequences interpreted here as back-barrier deposits are unusual in that they are much sandier and lack the extensive fine-grained lagoonal deposits that would be expected to form behind a microtidal barrier-island shoreline. The thrust belt to the west provided abundant sand to the Sego shoreline system. Sandy backshore environments could be maintained locally for an extended period of time because the combination of subsidence rate or sea level change and sediment influx resulted in multiple episodes of shoreline advance and retreat within a restricted geographic area. These conditions produced stacked (locally as many as five) partial shoreface sequences. Comparison of both shoreface-sequence thicknesses and regional sandstone body geometries between the Blackhawk and Sego suggests that subsidence rates may have been slightly lower during Sego deposition. Landward of the Sego shorelines, thick backshore deposits accumulated, but the lagoons may have been shallow and frequently

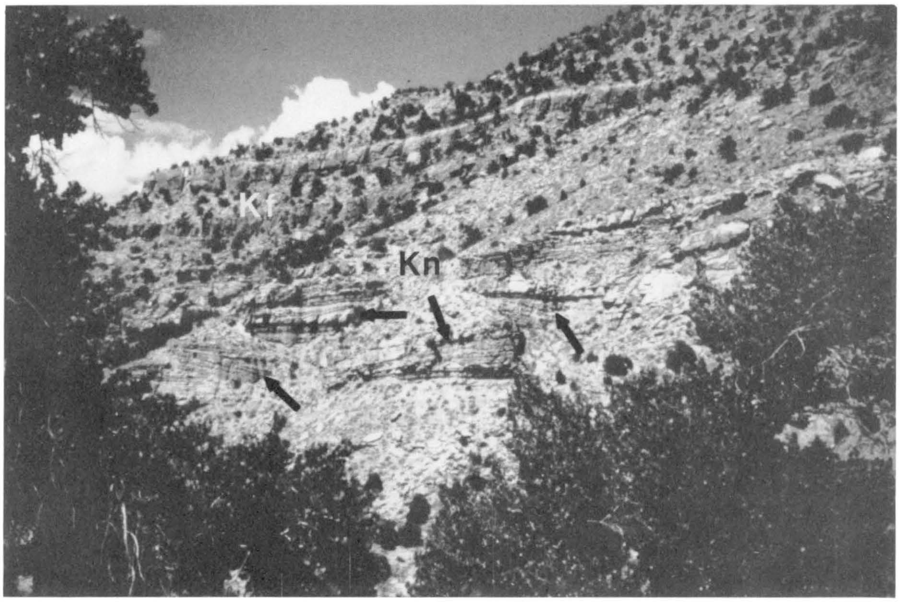

Figure 5. Outcrop of the Neslen Formation (Kn) and part of the overlying Farrer Formation (Kf) on the north side of Cottonwood Canyon; view looking north. The more resistant units in the dominantly slope-forming Neslen Formation are lenticular and show well-developed lateral accretion bedding (arrows); they are interpreted to have been deposited by meandering rivers. The dark zones at the base or top of channel deposits are thin coal beds or carbonaceous shale beds.

infilled by sand because of continual shifts of the shoreline position. The shifting shoreline also prevented the marshes from being maintained long enough to generate thick peat deposits. Additional, very detailed depositional environment reconstruction is needed to resolve the nature of the Sego shoreline system.

Neslen Formation

Fisher (1936) defined the Neslen Formation as the coal-bearing sequence of shale and sandstone above the Sego. The thickness of the Neslen varies because its contact with the overlying Farrer Formation, except where the Bluecastle Tongue of the Castlegate Sandstone occurs, is gradational and is placed where greenish shale and abundant fluvial sandstone beds replace the more carbonaceous Neslen lithologies. In our four measured sections, the thickness of the Neslen ranges from 175 ft (53 m) at the Tusher Canyon section, where the Bluecastle Tongue is present, to 670 ft (204 m) at the Bitter Creek section, where more abundant fine-grained material makes the contact difficult to pick.

The Neslen shows a regional upward-coarsening pattern. Carbonaceous shale, coal, and organic-rich siltstone and mudstone units are thickest and most abundant in the lower part of the formation; channel-form sandstone units increase in abundance in the upper part of the formation. Individual channel-form sandstone units are generally less than 10 ft (3 m) thick and a few hundred feet (tens of meters) wide; stacked units 40 ft (12 m) thick occur locally. Large-scale lateral accretion bedding is prominent in many of these channel-form sandstone units (fig. 5). The Neslen is the major coal-bearing unit in the eastern Utah Book Cliffs, and Fisher (1936) named four coal zones within this formation. The coal beds, except in a few local areas, are generally thin and discontinuous and contain abundant splits of carbonaceous shale or siltstone. The thickest coal beds are in the Sego Canyon area, and Willis (1986) provided the most detailed, recent description of those beds.

Lithologic assemblages in the Neslen indicate deposition initially in fresh- and brackish-water environments in a lower coastal plain (Franczyk, 1988). During shoreline progradation, the lower coastal plain was succeeded by an upper coastal plain and lower alluvial plain characterized by small, generally shallow, meandering rivers crossing extensive flood plains (Keighin and Fouch, 1981; Lawton, 1986, Pitman and others, 1987). The well-developed lateral-accretion bedding associated with these channel deposits is typical of that formed by meandering streams in low-energy fluvial and tidally influenced environments where mud is deposited and preserved on point bars. Smith (1987) noted that, in contrast, lateral-accretion bedding is commonly not as well developed in higher energy, sand-rich meandering rivers because mud interbeds are commonly absent. Paleocurrent measurements from the fluvial sandstone indicate predominantly eastward-flowing streams. The frequently fluctuating shoreline position, the inherent instability of the lower coastal-plain environments, and the channel avulsion and crevasse splay formation in the upper coastal and lower alluvial plain prohibited establishment of stable, long-term peat-forming swamps. In the Sego Canyon area, where coal is best developed, two thick coal beds (the Ballard and the Chesterfield), which are more than 100 ft (30 m) above the base of the Neslen, are interbedded with brackish-water deposits. These coal beds probably formed when the gradient of the coastal plain and clastic influx decreased in response to coastal-plain flooding associated with a widespread transgression (Franczyk, 1988). The thickest Neslen section, at Bitter Creek, formed landward of the thick stacked sequence of shoreface and marginal-marine deposits in the Mount Garfield Formation in the western Colorado Book Cliffs (Franczyk, 1988). Although the Neslen section at Bitter Creek contains abundant carbonaceous shale and siltstone beds, no thick coal beds are present.

Bluecastle Tongue of the Castlegate Sandstone

East of the Green River, the Bluecastle Tongue of the Castlegate Sandstone is recognizable as a distinct unit only at the Tusher Canyon section; the lower contact is sharp and occurs at the base of a 55-ft-thick (17 m) sandstone ledge. This ledge-forming sandstone constitutes the entire Bluecastle of Fisher and others (1960). We include an additional 120 ft (37 m) of interbedded channel-form and tabular sandstone and slope-forming sandstone and siltstone in the Bluecastle because most of the sandstone units are mineralogically similar to the basal, quartzose, ledge-forming sandstone. The lower contact of the Farrer Formation was placed at the base of the first laterally persistent, chert-rich sandstone above the highest quartzose sandstone. East of the Tusher Canyon area, the basal ledge-forming part of the Bluecastle separates into thin, isolated sandstone units indistinguishable from the Neslen Formation. Lawton (1986) described the top of the ledge-forming Bluecastle as variably bleached and oxidized and as mineralogically distinct from the overlying sandstone, and he used these observations as evidence for a disconformity at this horizon. We observed, however, a more gradational lithologic change between the ledge-forming, quartz-rich Bluecastle and the base of our chert-rich Farrer Formation.

The fine- to coarse-grained and locally granule-bearing channel-form sandstone units in the Bluecastle are characterized by trough cross-stratification that grades into ripple laminations at the top. Thin interbeds of siltstone occur between the sandstone units in the lower part of the sequence and become thicker and more abundant upward. We did not observe large-scale lateral-accretion bedding, but Lawton (1986) reported these structures and interpreted them to represent point-bar deposits formed in sinuous, possibly meandering streams.

The stacked ledge-forming channel units at the base of the member formed by streams migrating extensively across the alluvial plain. A change to more rapid, higher sediment influx possibly combined with a higher regional gradient or a lower subsidence rate could produce this fluvial response. Although planar-crossbed sets indicating deposition on bars within a braided stream are not present, well-developed point-bar sequences are also not present. The streams may have been moderately sinuous, and migration by subsequent channels may have eroded the upper part of underlying channel deposits. Pfaff (1985) placed the meanderbelt facies of the Bluecastle west of the Tusher Canyon area, but the lateral and vertical changes through the Bluecastle in this area indicate that the fluvial system evolved through Bluecastle deposition. The streams definitely became meandering and migrated less extensively as the alluvial plain graded eastward into the Neslen coastal plain and vertically into the Farrer alluvial plain. Numerous paleocurrent measurements from this sequence (Lawton, 1986) show a northeast through southeast range and a calculated average mean vector direction to the northeast. Paleocurrent measurements from Pfaff (1985) and this study of the Bluecastle at Tusher Canyon also indicate predominantly northeast flow.

Farrer Formation

The thickness of the Farrer Formation, where it is distinguishable from the Tuscher Formation, varies regionally; however, the entire Upper Cretaceous nonmarine section above the Sego thickens progressively eastward from 1,400 ft (427 m) at Tusher Canyon to 1,940 ft (591 m) at Bitter Creek. The tabular geometry and greater abundance of sandstone units, the lesser amount of preserved organic material in the fine-grained units, and the more olive color of the fine-grained units distinguish the Farrer from the underlying Neslen.

Sandstone sequences that have broadly lenticular to tabular or ribbonlike geometries compose about 40–60 percent of the Farrer (fig. 6). There is no apparent consistent vertical or regional change in thickness or abundance of these sandstone bodies. Internally, they commonly are composed of two or three stacked channel-form units separated by units of differential weathering that occur along basal scour surfaces where claystone or siltstone rip-up clasts are concentrated. Individual channel-form units range in thickness from

Figure 6. Typical geometry and distribution of Farrer sandstone bodies, north side of Cottonwood Canyon. The laterally extensive, tabular sandstone bodies contain one or commonly two stacked channel-deposit sequences. The slope-forming intervals that surround them contain overbank deposits. The contact between the Neslen (Kn) and Farrer (Kf) Formations is gradational and placed where the sandstone beds become more abundant and laterally extensive and the organic content of the fine-grained, slope-forming material decreases.

less than 10 to 30 ft (3–9 m) and average about 15–20 ft (5–6 m). The grain size generally decreases slightly upward from dominantly medium and locally coarse grained sandstone to fine-grained sandstone. At the top of many units, medium- or fine-grained sandstone very abruptly changes to siltstone. Internally, the channel-form units are dominated by trough cross-stratification that decreases in scale upward. Horizontal laminations are locally present and planar cross-stratification is rare. Ripple and climbing-ripple laminations occur in the uppermost part of units. The rippled intervals may be thicker than shown on the lithologic columns because the very tops of the units locally weather into a partly covered, slope-forming, apparently structureless sandstone. Soft-sediment deformation structures are abundant and locally occur throughout an entire channel-form unit. Lateral-accretion bedding, which is well developed in the Neslen units, is rarely observed in the Farrer units.

The slope-forming, partly to completely covered intervals between the channel-form units are composed of thinly interbedded sandstone and siltstone, olive-gray siltstone, resistant tabular sandstone, and less abundant dark-brown shale. Root casts, plant impressions, and straight burrows are locally abundant. In well-exposed areas, these lithologies can be observed locally within lenticular, scour-based features. The resistant tabular sandstone units range from less than 1 to 8 ft (0.3–3 m) in thickness, show an upward-fining or upward-coarsening grain-size trend or have a consistent grain size throughout, and are dominantly ripple laminated with minor amounts of small-scale trough cross-stratification.

The scour-based, broadly lenticular to tabular sandstone units are channel deposits. The dominance of trough cross-stratification in these units indicates that the channels filled primarily by the accretion of dunes migrating along the channel floor. In the shallower parts of the channels, ripples predominated and flat bedding developed locally (fig. 7); during flood events or waning flow conditions, thick sequences of climbing ripple lamination sequences were deposited. The extent of lateral accretion within the channels is uncertain; lateral accretion bedding was rarely observed and definite point-bar sequences were not identified. Channel widths exceeded a few hundred feet, but exact channel dimensions are not known because of scouring by overlying units and slope cover at the margins of many channel units.

The geometry, internal sedimentary structures, and distribution of channel and overbank deposits within the Farrer Formation do not resemble those of anastomosing fluvial systems in which channels fill by vertical accretion (Smith, 1983). Several factors indicate channels having some degree of sinuosity rather than braided rivers. Sequences of sedimentary structures characteristic of sandy braided rivers, such as abundant planar cross-

Figure 7. Ripple-laminated sandstone characteristic of channel-margin deposits in the Farrer Formation. Soft-sediment deformation (arrow) is common, and flat-bedded sandstone may locally occur. This sandstone grades laterally into dominantly trough cross-stratified sandstone that composes the largest part of the channel deposits. Notebook at edge of photo is 9 in. (23 cm) long.

stratification formed by accretion on transverse bars or thick horizontally stratified beds formed on longitudinal bars (Miall, 1978), are absent in these channel deposits. The vertical grain-size variation and change in type and scale of sedimentary structures are typical of sinuous streams that accrete laterally. The local, abrupt change in grain size at the top of channel-form sandstone units and the lenticular fine-grained sequences indicate avulsion and infilling of abandoned channels. Lawton (1986) also reported lateral accretion bedding associated with abandoned channel deposits, which possibly suggests partial channel reactivation. The interbedded sandstone and siltstone, siltstone, and mudstone show features typical of levee and flood-plain deposits that flank meandering streams. The fine to very fine grained, ripple-laminated, tabular sandstone beds formed as crevasse splays when channels were breached during flood events.

Lawton (1986) and Keighin and Fouch (1981) interpreted the channel-form units in the Farrer to have been deposited by meandering streams, and Willis (1986) interpreted the Farrer fluvial system to be transitional between braided and meandering with meandering-type streams more predominant. Because the thickness of sandstone ledges increases where the Tuscher Formation is readily identifiable in the Green River area, these workers believed that the Farrer streams increased in size through time. Regionally consistent progressive thickening and increase in abundance of sandstone sequences does not occur through the Farrer Formation. Locally, the number of stacked channel units forming a thick sandstone ledge may vary, but generally the average thicknesses of individual channel deposits are constant. This consistency suggests that streams did not significantly vary in size regionally.

Lawton (1986) obtained northeasterly through southeasterly paleocurrent directions and calculated an easterly average mean vector using crossbed measurements from his Farrer Formation (corresponding to the lower half to two-thirds of our Farrer) at measured sections east of the Green River. Paleocurrent measurements from our sections show a strong northeasterly trend; the greatest variablity occurs directly above the Bluecastle in the Tusher Canyon area where sandstone units show northwesterly and northerly flow directions.

Tuscher Formation

The top of the Cretaceous sequence in the Green River area is a distinct zone of thick, stacked, sheetlike, cliff-forming sandstone units that we include in the Tuscher Formation (fig. 3). The thickness of these sandstone units distinguishes them from sandstone units in the Farrer Formation. Internally, the Tuscher sandstone bodies are composed of more numerous channel-form units than the Farrer, and locally the Tuscher contains thick, flat-bedded sandstone intervals. The types and sequences of sedimentary structures are generally similar within these sandstone bodies in both formations. Lawton (1986) reported that sandstone bodies in the Tuscher do not show the fining-upward grain-size trend seen in the Farrer; however, erosion of the upper part of a channel deposit by the succeeding channel system would result in a thick sandstone body having no apparent grain size change. A slight fining-upward trend is commonly present in the highest channel-form unit, and in areas of good exposure interbedded sandstone and siltstone is locally observed. In most areas, the slope-forming, fine-grained intervals are covered by fallen sandstone blocks and debris from the overlying sandstone bodies. Where the fine-grained intervals are exposed, they exhibit the same characteristics as those in the Farrer.

Pebbly sandstone is present in the uppermost part of the Tuscher in outcrops in a very restricted area directly east and west of the Green River (Lawton, 1986). We did not observe pebbles in the Tuscher or in the undifferentiated Farrer and Tuscher Formations east of the Tusher Canyon section. Where present, the pebbles increase in abundance both upward and from our Tusher Canyon section westward to the Green River. They are generally concentrated at the bases of troughs but also are scattered through the sandstone (fig. 8); Lawton (1986) reported pebbles in lenticular scour-and-fill structures. The pebbles are rounded, have a maximum diameter of 1 in. (2.5 cm), and are composed of gray, black, red, brown, and banded chert; white, gray, and pink quartzite; sandstone; white altered chert; and mudstone. This description corresponds to that of Fisher and others (1960) for pebbles within the Tuscher in their Tusher Canyon section. Although the composition is similar to the pebbles in the Dark Canyon sequence, the pebbles within the Tuscher are much smaller.

The pebbly part of the Tuscher is also distinct from Lawton's (1986) "pebbly beds," which are composed of an erosional-based, white-weathering, western-sourced quartzose sandstone that locally contains small pebbles (<1 in., 2.5 cm, diameter) near the base. The pebbly beds unit locally occurs at the top of the Cretaceous section west of the Green River and is best developed in the Little Park area (fig. 1). It overlies a progressively thicker Cretaceous section to the east of the Little Park area, and Lawton (1986) believed that a slight angular unconformity separates it from the overlying Tertiary sequence. In the Rattlesnake Canyon area (fig. 1), a pebbly quartzose sandstone unit is present between more feldspathic, pebbly sandstone beds in the upper 75 ft (23 m) of the Tuscher (Franczyk, unpublished data, 1986). If this quartzose unit is equivalent to the pebbly beds unit, then the pebbly beds unit was deposited contemporaneously with the uppermost part of the Tuscher Formation in the Green River area.

Keighin and Fouch (1981) and Lawton (1986) believed that the meandering fluvial system of the Farrer evolved into a braided-river system during Tuscher deposition. Braided streams typically produce thick, laterally extensive, coarse-grained channel deposits; only minor amounts of fine-grained overbank deposits are preserved. The pebbly part of the Tuscher is distinct from the underlying sequences. The geometry, size, and stacking pattern of the scour-and-fill units and the grain-size distribution most closely fit deposition in a braided-river system. As discussed in the summary, this pebbly interval may represent a local, discrete depositional episode; however, the similarities between the individual channel deposits within the Farrer and the nonpebbly Tuscher sandstone bodies suggest that the fluvial systems were not too different. The increase in flat-bedded sandstone in the Tuscher units indicates either more sheet-flood events or the establishment of longitudinal bars within the channel. These processes could signal

Figure 8. Aerial photograph of the uppermost part of the Tuscher Formation in the vicinity of the Green River shows dark zones of pebbly sandstone within white-weathering sandstone. Pebbly sandstone within the Tuscher is restricted to this area and is absent east of Tusher Canyon. Locally in the uppermost part of the Cretaceous sequence, feldspar altered to kaolinite produces this white-weathering appearance. The white sandstone interval is about 75–100 ft (23–30 m) thick.

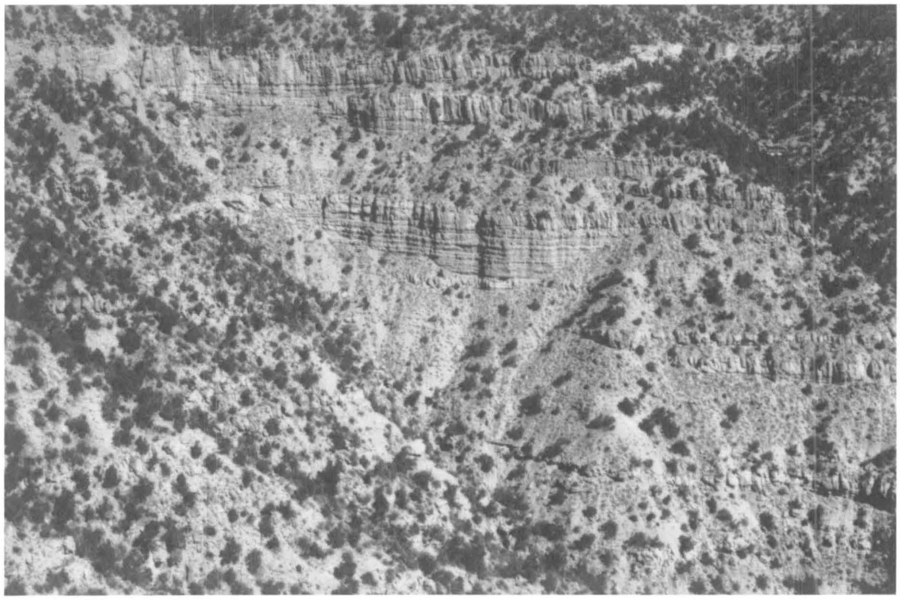

Figure 9. Abundant interbedded sandstone and siltstone and slope-forming intervals between cliff-forming fluvial sandstone bodies in the uppermost part of the undifferentiated Farrer and Tuscher Formations in the Bitter Creek area. A thick interval of stacked, cliff-forming sandstone bodies characteristic of the Tuscher Formation in the western part of the study area (fig. 3) was not developed in this area. The interval shown is about 400 ft (122 m) thick.

either more unconfined flow or the breakup of a single channel into a braided channel pattern.

If the channel morphology was not significantly different during Farrer and Tuscher deposition, then the Tuscher rivers must have migrated more extensively and eroded more overbank deposits in order to produce the thicker, laterally extensive channel deposits. Meandering fluvial systems can respond in this way if subsidence rates decrease (Allen, 1978) or if aggradation rates are low (Bridge and Leeder, 1979). An expected decrease in subsidence rates near the end of Cretaceous foreland basin deposition appears to have had a most pronounced affect on deposition in the Green River area.

Incipient movement on the San Rafael uplift (fig. 1) may have locally resulted in less subsidence and may explain the restricted development of the thick Tuscher sandstone bodies. The lack of development of a thick, distinct sequence of Tuscher-like sandstone bodies in the upper part of the Cretaceous nonmarine section in the eastern part of the study area (fig. 9) indicates either that the Farrer meandering fluvial system maintained a more constant rate of aggradation or that subsidence rates did not vary significantly during deposition of the preserved section. Willis (1986) also noted an eastward change in the area of the Sego Canyon 7-1/2′ quadrangle in channel-sandstone morphologies that he attributed to a corresponding change from braided to meandering streams. Paleocurrent measurements of the Tuscher Formation from this study and that of Lawton (1986) indicate dominantly northeasterly flow. Downstream equivalents of the thick Tuscher sandstone units therefore would lie in the subsurface of the Uinta basin but would not be exposed in outcrop directly to the east. The entire Bitter Creek nonmarine section is 540 ft (165 m) thicker than that of the Tusher Canyon section; this suggests either higher subsidence rates or less post-depositional erosion in the eastern areas.

Age determinations using palynomorphs are not precise enough to show if the upper part of the nonmarine Cretaceous section is time equivalent across the study area. Unconformities related to sediment erosion and reworking due to rising Laramide uplifts may be present within the uppermost part of the Tuscher in the Green River area. In the southeastern Wasatch Plateau, west- to northwest-flowing, pebbly braided streams record incipient movement of the San Rafael uplift in late Campanian or earliest Maastrichtian time (Franczyk and Nichols, 1988). Deposition of the pebbly part of the Tuscher in the Green River area may be temporally equivalent to the pebbly, braided-stream deposits to the southwest. An average mean vector of 4°, calculated from 147 paleocurrent measurements, was obtained for the upper 150 ft (46 m) of the Tuscher directly east and west of the Green River (Franczyk, unpublished data, 1986). The pronounced northerly drainage trend suggests that the eastern side of the San Rafael uplift may have controlled river alignment during uppermost Tuscher deposition. This flow direction contrasts with the northeasterly flow direction that existed during deposition of much of the Farrer and Tuscher Formations.

Dark Canyon Sequence of the Wasatch Formation

The Dark Canyon sequence of the Wasatch Formation of late early Paleocene age unconformably overlies the late Campanian Tuscher or undifferentiated Farrer and Tuscher Formations. The western pinchout of the Dark Canyon sequence is about 10 mi (16 km) east of the Green River. The sequence thickens rapidly eastward to 150 ft (49 m) in less than 15 mi (24 km); east of Westwater Canyon (sec. 22, T. 17 S., R. 23 E.), the sequence thins and rarely is thicker than 25–35 ft (8–11 m). Near the Colorado-Utah State line, only thin, isolated remnants occur. In most areas, the Dark Canyon sequence appears to have a sharp, planar, and locally bleached top. Near the Green River, laterally extensive lacustrine limestone beds containing mollusks of late Paleocene age (Franczyk and Hanley, 1987) lie only a few tens of feet (several meters) above the conglomerate. Where the lacustrine deposits pinch out to the east, the Dark Canyon sequence is abruptly overlain by red siltstone and mudstone or has an erosional contact with a fluvial sandstone. The progressive thinning and younging of the main body of the Wasatch Formation from west to east (Cashion, 1967; Fouch and Cashion, 1979; Fouch and others, 1983) indicates depositional onlap onto the Douglas Creek arch. These facies and stratigraphic relations indicate a period of nondeposition and erosion after late early Paleocene deposition of the Dark Canyon sequence.

Massive to crudely horizontally stratified conglomerate and local thin interbeds of horizontally stratified sandstone compose the lower part of the Dark Canyon sequence. The size and abundance of pebbles decreases upward, and trough cross-stratified and horizontally stratified sandstone and pebbly sandstone are dominant in the upper part. Stacked, large-scale, channel-form structures having scour bases characterize this part of the sequence (fig. 10). Abundant rip-up clasts of light-gray to yellowish-orange pedogenic carbonate nodules distinguish fluvial sandstones at the base of the main body of the Wasatch from sandstone in the upper part of the Dark Canyon sequence.

Less abundant and smaller pebbles occur in the Dark Canyon sequence where it thins east of Westwater Canyon. The conglomerate is dominantly matrix supported but is locally clast supported; pebble imbrication is only rarely developed. Subequal portions of chert and quartzite compose about 95 percent of the pebble suite. Chert pebbles are dominantly black and gray, but white, red, banded gray and white and red and black, and veined and brecciated chert pebbles also occur. Quartzite pebbles are white, black, and gray, with less abundant red and banded varieties. Silicified limestone pebbles containing late Paleozoic fossil fragments are also common. Quartzarenite and litharenite sandstone pebbles and blue-green siliceous pebbles are scarce, and limestone pebbles are rare. The pebbles are rounded to subrounded and slightly elongate to equidimensional. Throughout the Dark Canyon sequence, the average size is 1–2 in. (25–50 mm) and the largest pebbles are 4–6 in. (100–150 mm) in the longest dimension.

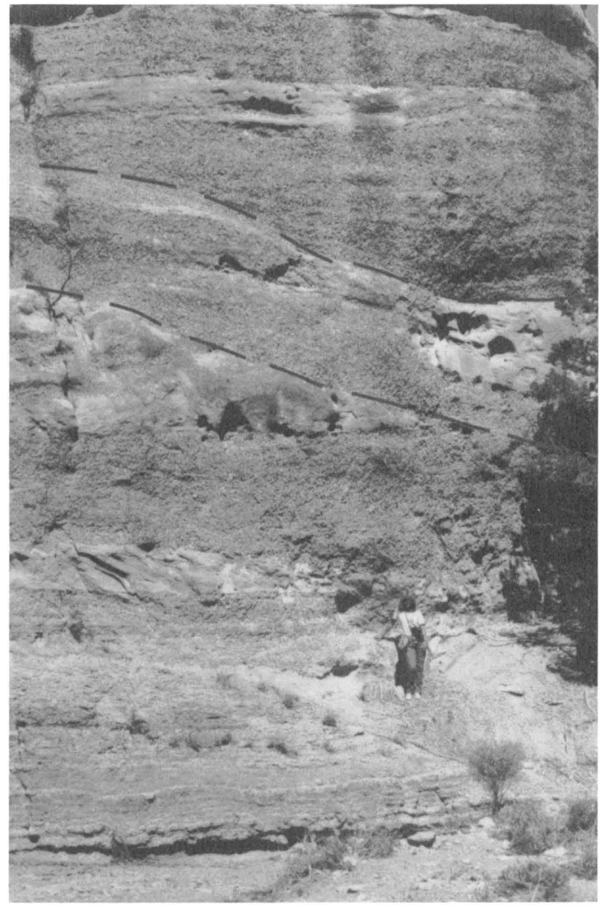

Figure 10. Stacked, large-scale, channel-form structures with scour bases in the Dark Canyon sequence of the Wasatch Formation in the Sego Canyon area. The dashed lines outline the bases of these structures, which average about 10 ft (3 m) thick. These structures form the largest scale depositional elements observed in the Dark Canyon sequence.

The rock types, textures, sedimentary structures, and geometry of the Dark Canyon sequence indicate deposition on an extensive medial to distal, braided-river alluvial plain (Franczyk and Pitman, 1987). Through time, the Dark Canyon fluvial system evolved from a

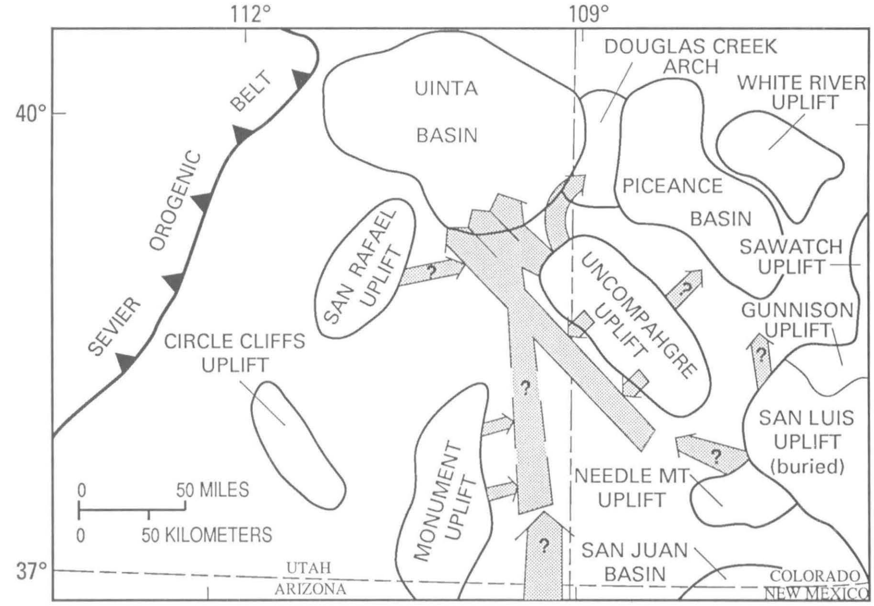

Figure 11. Structural elements and reconstructed drainage patterns in the Uinta basin and adjacent areas during deposition of the Dark Canyon sequence of the Wasatch Formation. Modified from Franczyk and Pitman (1987).

gravel-dominated to a sand-dominated braided-river system. Paleocurrent measurements taken on trough axes within conglomeratic sandstone and sandstone show the dominant flow direction was to the northwest, except in the eastern outcrop area where the flow was to the northeast (Franczyk and Pitman, 1987). These directions and the occurrence of the most abundant conglomerate in the western outcrop area correspond to a main fluvial system that flowed parallel with and along the west flank of the Uncompahgre uplift (fig. 11). Northwest drainage in the north-central part of the uplift, obliquely across the Douglas Creek arch (fig. 11), indicates that the west flank of the arch was not positive during Dark Canyon deposition. There is no paleocurrent evidence in outcrops of the preserved Dark Canyon sequence for a major drainage originating from areas to the southwest of the Green River. The San Rafael uplift appears to have controlled the western depositional extent of the sequence but was probably not a major source area. The almost exclusively siliceous Dark Canyon pebble suite indicates that the source rocks were frequently recycled; erosion of pebble-bearing Mesozoic sedimentary rocks from rising Laramide uplifts to the south probably provided much of the sediment.

The beginning of deposition of the thick, alluvial, late Paleocene- to Eocene-age main body of the Wasatch Formation that lies above the Dark Canyon sequence marks the onset of intermontane basin subsidence in the southeastern Uinta basin. This subsidence coincides with a major tectonic event in southwestern Colorado that supplied sediment to this alluvial system (Dickinson and others, 1986). The regional relations mentioned above and the mollusk and palynomorph assemblages of late Paleocene age recovered from the lower part of the main body of the Wasatch throughout the study area indicate locally a break in deposition of possibly 6 million years following deposition of the Dark Canyon sequence.

MINERALOGY

Distinct mineral facies, based on framework-grain composition, characterize individual formations or groups of formations within the measured interval (figs. 12–15). The top of the Neslen, or the top of the Bluecastle where present, marks the break between a lithic-rich compositional suite and a feldspar-dominated compositional suite (Lawton, 1986). The Neslen Formation and Sego Sandstone are similar in composition and consist of sublitharenite and litharenite (fig. 12) that contain abundant detrital quartz, chert, fine-grained sedimentary lithic fragments, and detrital carbonate grains. Both units are typically devoid of feldspar. The Bluecastle Tongue, as defined at the Tusher Canyon section, is a quartzarenite to sublitharenite (fig. 13) composed of quartz and minor amounts of chert. Sandstone in the Farrer and Tuscher Formations and in the Dark Canyon sequence (figs. 14, 15) are feldspar and lithic rich and range in composition from feldspathic litharenite to litharenite. Typically, sandstone in these formations contains a mixed lithic assemblage composed of volcanic grains, sedimentary rock fragments

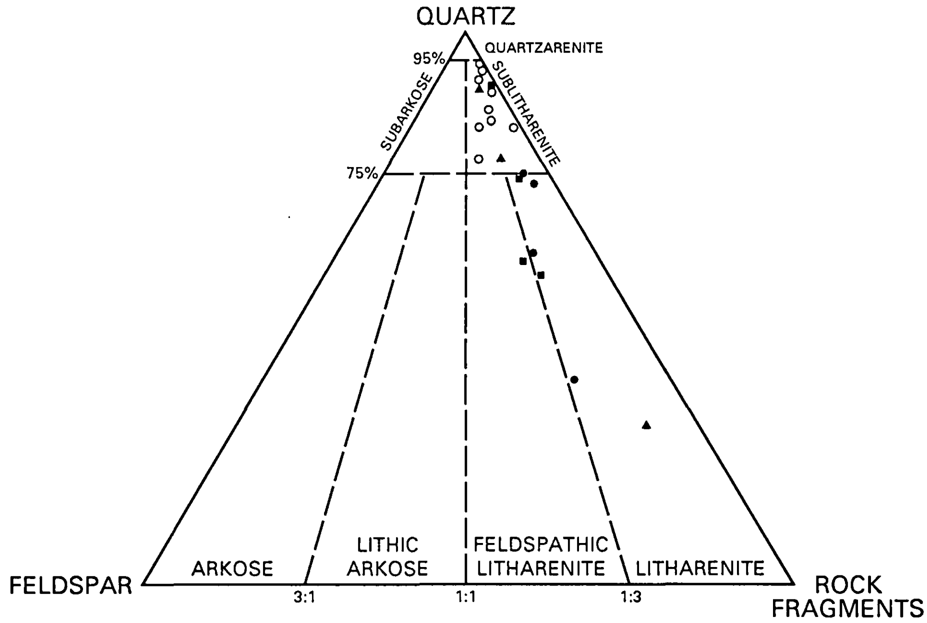

Figure 12. Classification of sandstones in the Neslen Formation. Measured sections: open circle, Tusher Canyon; triangle, Sego Canyon; solid circle, Bitter Creek; solid square, Cottonwood Canyon. Chert is plotted with rock fragments. Classification scheme from Folk (1980).

(chert, carbonate, and argillite), and minor metamorphic clasts.

Detrital Constituents

Detrital quartz is ubiquitous in Upper Cretaceous sandstones in the study area and consists of angular to subrounded, monocrystalline grains that are generally unstrained and may contain minute vacuoles, rare inclusions of rutile, and poorly developed overgrowths. The size of individual quartz grains varies within and between individual beds and formations; some units show a bimodal size distribution. Long concave-convex and point contacts between grains are common in many sandstones and indicate varying degrees of compaction.

Both the occurrence and distribution of feldspar vary with stratigraphic position. Feldspar is most abundant in sandstones in the Farrer and Tuscher Formations and is rare to absent in the older units and in the pebbly beds of Lawton (1986). Sodium and potassium feldspar varieties are distributed in subequal amounts, both as single grains and as constituents in fine- to medium-crystalline, volcanic lithic fragments. Potassium feldspar grains consist of twinned and untwinned varieties including rare microcline and abundant orthoclase; the dominant variety of sodium feldspar is plagioclase that exhibits both Carlsbad and albite twinning. Most individual feldspar grains are subangular to subrounded, approximately the size of other detrital constituents, and either are fresh or show the effects of alteration by clay or carbonate replacement. Grains that are partly replaced by calcite or show evidence of dissolution of preexisting calcite are locally widespread. The delicate framework that characterizes many partly dissolved feldspar grains indicates that they underwent leaching after they were transported.

Lithic fragments of diverse origin constitute a large fraction of the detrital mineral assemblage in these Cretaceous sandstone units. Commonly they consist of fine-crystalline polymineralic aggregates that are difficult to classify owing to their fine grain size and variable composition. Moreover, mechanically unstable fragments, locally abundant in some beds, have been subjected to various degrees of compaction resulting in indistinct grain boundaries that make recognition difficult. Of the clasts that can be readily distinguished, most are similar in size to adjacent sand grains.

Sedimentary rock fragments including sandstone, siltstone, shale, and mudstone are ubiquitous in all units, although they are generally more abundant at the Bitter Creek and Cottonwood Canyon localities. Typically these grains are subrounded to rounded, gray to brown, and fresh to extensively altered. Many fragments display clay-mineral alteration or varying degrees of deformation owing to burial compaction. Chert grains are an abundant sedimentary constituent in many sandstones; they are subrounded and fine to coarse crystalline and show various degrees of weathering. Some clasts have

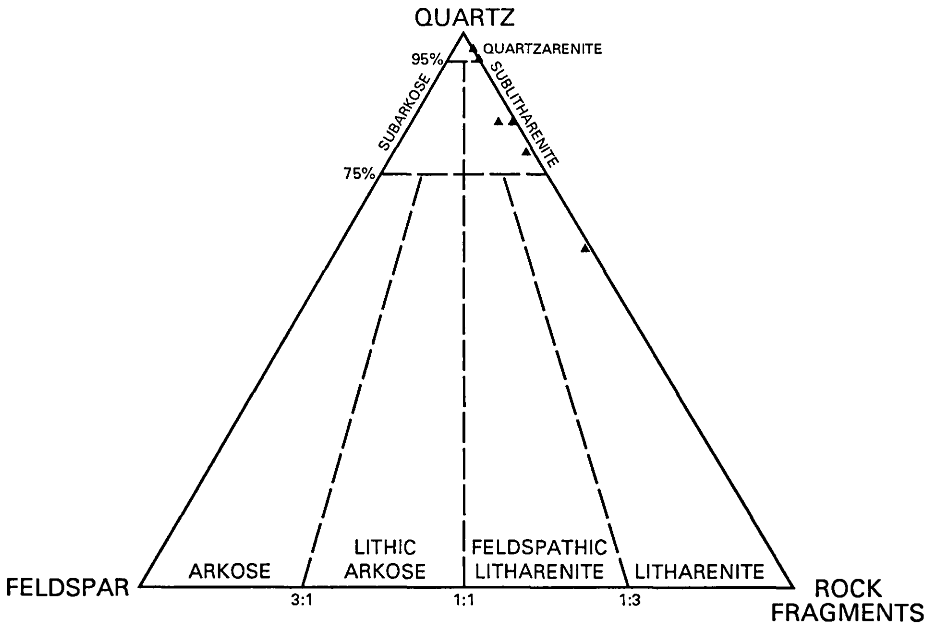

Figure 13. Classification of sandstones in the Bluecastle Tongue of the Castlegate Sandstone. All samples are from Tusher Canyon. Chert is plotted with rock fragments. Classification scheme from Folk (1980).

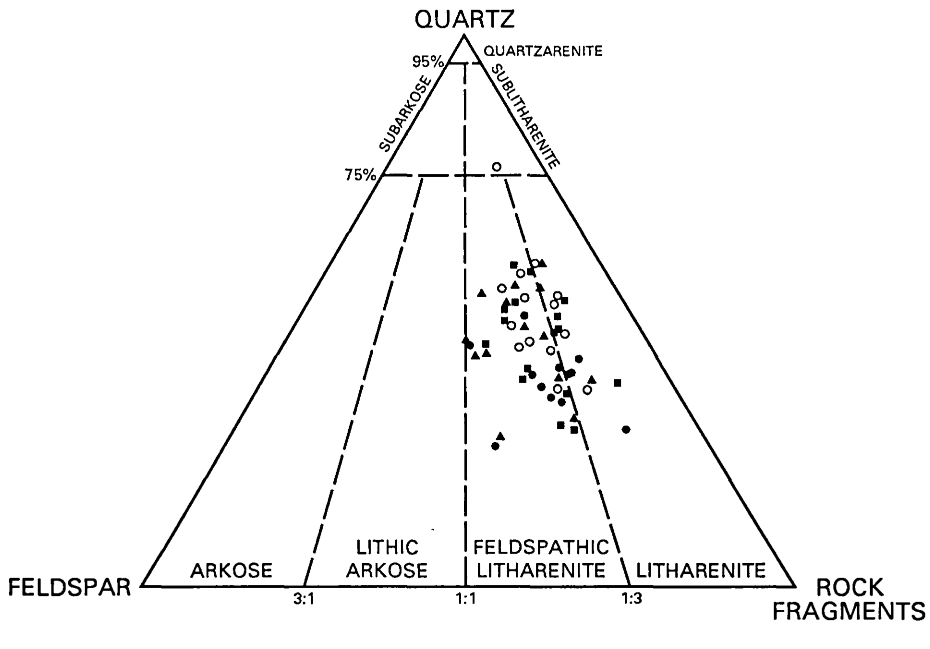

Figure 14. Classification of sandstones in the Farrer and Tuscher Formations. Measured sections: open circle, Tusher Canyon; triangle, Sego Canyon; solid square, Cottonwood Canyon. Chert is plotted with rock fragments. Classification scheme from Folk (1980).

been replaced by tiny dolomite rhombs, show ghosts of fossil fragments that are now silicified, or are cut by veins filled with quartz or chalcedony. Detrital carbonate grains are common in sandstone of the Sego and Neslen. The most common constituent is dolomite distributed as rounded polycrystalline clasts and as subhedral rhombs that have an iron-rich overgrowth. The abraded nature of most overgrowths suggests that the grains were recycled from the source area to the site of deposition. Limestone fragments also display a polycrystalline morphology.

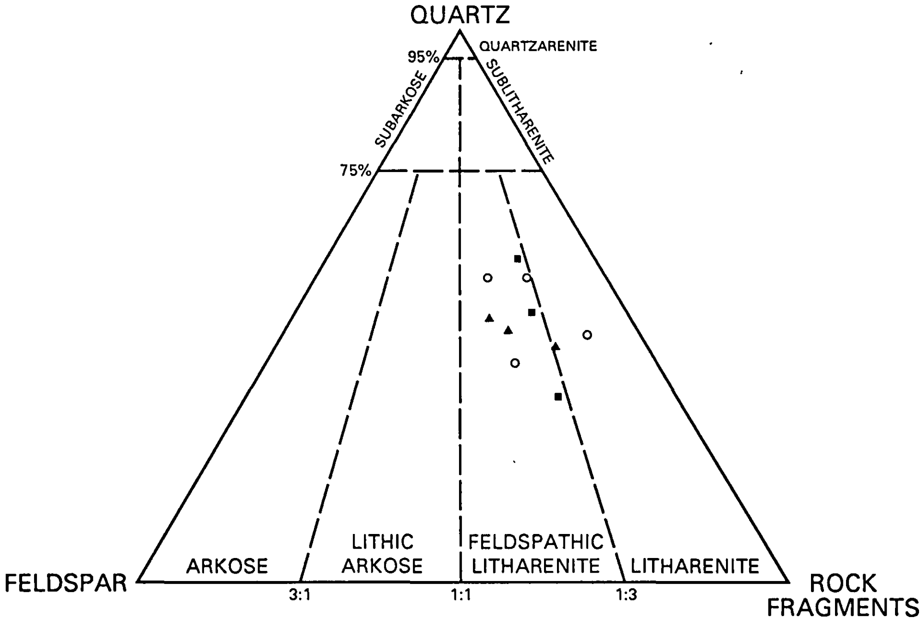

Figure 15. Classification of sandstones in the Dark Canyon sequence of the Wasatch Formation. Measured sections: open circle, Tusher Canyon; triangle, Sego Canyon; solid square, Cottonwood Canyon. Chert is plotted with rock fragments. Classification scheme from Folk (1980).

Detrital volcanic grains are most abundant in feldspathic sandstones in the upper part of the combined Farrer and Tuscher Formations, where they comprise as much as one third of the lithic fraction; they are typically rare to absent in the older quartz-rich units. Commonly, volcanic grains are fine grained and extensively altered or are deformed and therefore are difficult to distingish from other clastic fragments. Three grain types dominate the volcanic suite. Microlitic fragments are composed of tiny feldspar crystals, mostly potassium rich, in a felted mass displaying a pilotaxitic or trachytic texture. Porphyritic fragments are composed of euhedral phenocrysts of plagioclase feldspar in an altered aphanitic groundmass. Both grain types may show varying degrees of replacement of feldspar to sericite and mafic minerals to chlorite. Felsite fragments, the most abundant volcanic constituent, are composed of tiny potassium feldspar grains or fine-crystalline quartz; we may have misidentified many of the quartz-rich grains as chert. With increasing crystallite size, felsite grades into complex quartz-feldspathic intergrowths of presumed hypabyssal origin. A few grains now partly chlorite may once have been glass.

Metamorphic grains comprise a relatively small part of the detrital lithic suite. Most common are polycrystalline quartz grains composed of crystals that have straight to strongly undulose extinction and curved to sutured boundaries. Aggregate grains of probable granitic origin containing intergrown quartz and feldspar occur in coarser grained sandstone in the Farrer and Tuscher Formations. A few unidentified grains with a foliated texture are also present.

Matrix and Cement

Matrix material occurs in varying amounts and commonly is difficult to distinguish from the pseudomatrix that results from deformation of unstable lithic fragments between framework grains. Matrix is least abundant in sandstones of the Bluecastle Tongue but constitutes as much as 10 percent in other units. X-ray diffraction analysis indicates that much of the matrix is allogenic clay composed of illite and mixed-layer illite-smectite.

Carbonate cement, typically calcite, occurs in variable amounts in Farrer and Tuscher sandstone beds but is uncommon in the Neslen Formation and Sego Sandstone. The distribution and relative abundance of carbonate is probably related to sandstone composition and, to a lesser extent, to grain size and sorting. Sandstone that is coarse grained and well sorted and contains only minor labile grains and matrix material is most likely to contain authigenic carbonate. In areas where carbonate is widespread, it fills intergranular pores, partly replaces framework grains, and in some cases masks matrix and other interstitial cements. Rocks that have good secondary porosity contain relicts of carbonate cement in pores that suggest its former presence. Temporally equivalent rocks in the subsurface show the same varieties and distribution patterns of carbonate cement as those on outcrop (Keighin and Fouch, 1981; Pitman, Anders, and others, 1986; Pitman, Franczyk, and Anders, 1987, 1988).

Secondary quartz generally is rare except in the Bluecastle Tongue, where it locally forms pervasive, subhedral to euhedral, syntaxial overgrowths that have coalesced to form a cement.

Stratigraphic Mineral Distribution

The Sego Sandstone is a litharenite consisting of 45–47 percent quartz, 3–4 percent feldspar, 8–12 percent sedimentary lithic fragments, 4 percent chert, and 6–10 percent matrix. The Neslen Formation has a similar composition; it consists of 44–59 percent quartz (significantly higher than in the overlying Farrer and Tuscher), 6–20 percent sedimentary lithic fragments, 2–10 percent chert, and 3–10 percent matrix. Trace amounts of sodium and potassium feldspar (< 4 percent) are present in the Neslen; individual grains of limestone and dolomite are locally abundant and volcanic grains are generally absent. There is no apparent vertical change in mineral content. Cored sequences of Neslen in the Southman Canyon and Natural Buttes fields in the east-central part of the basin display a quartz and lithic fragments assemblage that is similar in type and abundance (Keighin and Fouch, 1981; Pitman and others, 1987). The similar compositions of the Sego and Neslen suggest that they were probably derived from the same source.

The Bluecastle Tongue of the Castlegate Sandstone, as used in this study, is present only at the Tusher Canyon section; it consists of about 60 percent quartz, 5 percent sedimentary lithic fragments, 6 percent chert, and 2 percent matrix. The detrital quartz grains are moderately sorted and subangular to subrounded and display embayed grain and overgrowth boundaries. This composition for the Bluecastle closely approximates those reported for the Bluecastle at Range Creek and the Green River (T.F. Lawton, New Mexico State University, written commun., 1987). The Bluecastle is the most quartz rich unit within the Tusher Canyon measured section.

Sandstones in the Farrer and Tuscher Formations are heterogeneous in composition compared to the underlying rocks. They are distinguished by their high proportion of volcanic grains and abundance of plagioclase and potassium feldspar. No significant compositional variation occurs geographically within these two formations. Sandstones from the four measured sections of the Farrer and Tuscher consist of 27–34 percent quartz, 10–12 percent feldspar, and 24–28 percent lithic fragments. The mean quartz content at each of these sections is similar to the amount of quartz reported for stratigraphically equivalent rocks in the subsurface at the Natural Buttes (41 percent; Pitman and others, 1986) and Southman Canyon (32 percent; Keighin and Fouch, 1981) gas fields, and in exposures along Range Creek and the Green River (35 percent; T.F. Lawton, 1988, written commun.). The quartz content reported for Farrer and Tuscher sandstones in the central part of the Uinta basin in the Wilkin Ridge well (55 percent; Pitman and others, 1988) is greater than in the Book Cliff measured sections. Pitman and others (1988) showed that diagenetic alteration in the Wilkin Ridge well involved extensive replacement of framework feldspar and lithic fragments by authigenic carbonate and sulfate minerals. Replacement of these detrital grains or, in some cases, dissolution of the replacement phase has resulted in quartz percentages that are higher than expected.

The mean abundance of plagioclase in Farrer and Tuscher sandstones at the four measured sections ranges from 1 to 5 percent; the mean abundance of potassium feldspar is slightly higher (6–7 percent). In sandstones in the subsurface in the central part of the basin, the relative amount of potassium feldspar (< 2 percent) is well below the range for stratigraphically equivalent surface samples. Petrographic studies reveal that the low concentrations of detrital feldspar are a result of burial diagenesis involving dissolution of replacement carbonate, extensive clay-mineral alteration, and local albitization (Pitman, Anders, and others, 1986; Pitman, Franczyk, and Anders, 1988). West of the San Rafael uplift, coeval rocks in the upper Campanian Price River Formation are less feldspathic than stratigraphically equivalent beds in the Farrer and Tuscher Formations to the east (Lawton, 1986; J.K. Pitman, unpublished data, 1988). In the Price River sandstones, potassium varieties of feldspar are dominant, rock fragments consist of chert and other sedimentary lithic constituents, and the detrital volcanic component is small.

The Farrer and Tuscher Formations show a diverse lithic assemblage consisting of sedimentary rock fragments, a significant volcanic component, and a minor number of metamorphic grains. Detrital carbonate grains are generally absent. The mean abundance of lithic fragments at the four study sites ranges from about 12 to 18 percent, with the highest concentrations at Bitter Creek. These amounts are similar to those reported for stratigraphically equivalent rocks in the subsurface in the Uinta basin (Southman Canyon field, 12 percent, Keighin and Fouch, 1981; Natural Buttes field, 18 percent, Pitman, Anders, and others, 1986; Wilkin Ridge well, 10 percent, Pitman, Franczyk, and Anders, 1988) but are slightly less than those reported for sections at Range Creek and along the Green River (21 and 25 percent, respectively; T.F. Lawton, written commun., 1988). The higher amounts may reflect differences in visually differentiating pseudomatrix from altered and deformed rock fragments.

Sedimentary rock fragments in the Farrer and Tuscher consist of shale, siltstone, limestone, and chert. At the four measured sections, chert varies in abundance from 10 to 13 percent, somewhat higher than reported for stratigraphically equivalent rocks in the subsurface (Southman Canyon field, 4 percent, Keighin and Fouch, 1981; Natural Buttes field, 7 percent, Pitman, Anders, and others, 1986; Wilkin Ridge well, 7 percent, Pitman, Franczyk, and Anders, 1988) and in surface sections at Range Creek and the Green River (8 and 5 percent, respectively; T.F. Lawton, written commun., 1988). The low concentrations of chert and the correspondingly lower amounts of feldspar in the subsurface likely reflect postdepositional alteration during burial.

Volcanic grains in Farrer and Tuscher sandstones consist of both sodium-and potassium-rich varieties that locally compose as much as one-third of the lithic fraction at localities east of the Green River. Farther west the volcanic component is significantly less; however, at Price Canyon beds in the Price River Formation contain abundant volcanic grains (T.F. Lawton, written commun., 1988). Plutonic rock fragments are scarce and are generally confined to the coarsest sandstones. Likewise, polycrystalline quartz grains increase in abundance with increasing sandstone grain size. Some of these grains may have been derived from a metamorphic source.

Lawton's (1986) pebbly beds, which occur discontinuously at the top of the Cretaceous section west of the Green River and locally east of the Green River (but not as far east as our measured sections), are sublitharenites and litharenites (fig. 16) similar in composition to rocks of the Sego, Neslen, and Bluecastle. In contrast to the rocks they overlie, the pebbly beds are virtually devoid of feldspar. They contain abundant chert- and quartz-rich detritus that is bimodal in grain size, angular, and commonly poorly sorted. Polycrystalline quartz grains are particularly abundant, and many of the small grains were probably derived from larger polycrystalline quartz grains. The sandstone mineralogy and paleocurrent trends in this unit indicate a source from older recycled Cretaceous rocks to the west (Lawton, 1986) or from the thrust belt.

The upper lower Paleocene Dark Canyon sequence of the Wasatch Formation contains the same abundance and distribution of grain types as the older Farrer and Tuscher Formations (figs. 14, 15). Southerly equivalents of these feldspar-bearing Cretaceous units provided the sand-sized sediment as they were eroded from Laramide uplifts.

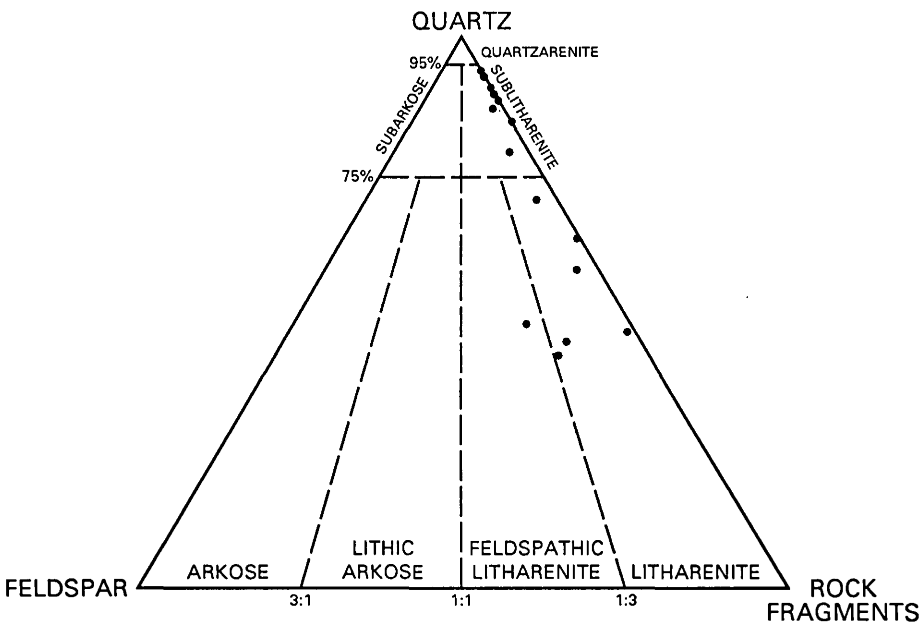

Figure 16. Classification of sandstones in "pebbly beds" of Lawton (1986) from localities west of and in the vicinity of the Green River. Chert is plotted with rock fragments. Classification scheme from Folk (1980).

SUMMARY

The Upper Cretaceous sequence along the Book and Roan Cliffs, from the Buck Tongue of the Mancos Shale through the Tuscher Formation, was deposited during a 4–5-million-year period from early late to middle late Campanian time. During this time, the Cretaceous sea retreated from eastern Utah for the last time and marine and coastal-plain environments were succeeded by alluvial-plain environments. The source area in the thrust belt that supplied quartz- and lithic-rich sediments to the area of study shifted to the south and southwest, from which igneous and volcanic rocks contributed feldspathic-rich sediment, and subsidence in this part of the foreland basin slowed and finally ceased. The presence of an early Maastrichtian-age part of the undifferentiated Farrer and Tuscher Formations farther north in the subsurface of the present-day Uinta basin indicates either that deposition continued there for a slightly longer time, or that less erosion occurred, or that fossils of this age were not preserved along the outcrop. After a hiatus of about 10 million years, braided rivers carrying sediment derived from rising Laramide uplifts deposited the Dark Canyon sequence of the Wasatch Formation during late early Paleocene time. Another hiatus lasting 6 million years or more occurred before the late Paleocene lacustrine and alluvial systems were established in the Book Cliffs area of eastern Utah.

Deposition of the Buck Tongue of the Mancos Shale and the Sego Sandstone records the final retreat of the Cretaceous sea from east-central Utah. The stacking pattern of the Sego shoreface and backshore deposits and the lack of coal beds above foreshore deposits distinguish the Sego from most other Cretaceous marginal-marine sequences in Utah. Interaction of the rates of subsidence, clastic influx, and sea-level rise resulted in frequent migration of the Sego shoreline, and thick deposits associated with a single progradational event did not accumulate. Partial shoreface sequences therefore are stacked in the eastern part of the study area, whereas sand-dominated backshore sequences are stacked in the western part of the study area. Many of the backshore sequences show characteristics of tidally influenced deposition. Because regional tidal ranges in the Western Interior epicontinental Cretaceous seaway are estimated to be in the microtidal range (Slater, 1985) and because abundant tidal-inlet deposits were not observed in the Sego, a microtidal barrier-island coastline is postulated for much of the Sego in Utah. Extensive lagoons were not established, possibly because of both the frequent shoreline fluctuations and the sand-dominated back-barrier environments.

Deposition in the coastal plain behind the Sego shorelines produced the Neslen Formation. Meandering streams flowing northeast to southeast crossed extensive flood plains that contained local peat-forming swamps. Because of channel avulsion and overbank flooding, these swamps were not long lived, and coal beds within the Neslen are generally thin and discontinuous and contain splits of clastic material. The thickest coals in the Neslen probably formed in response to regional flooding of the coastal plain during a marine transgression. As a result of an influx of coarse-grained, quartzose sediments, the rivers in the area of the present-day Green River and farther to the west became less sinuous and migrated more frequently, producing the dominantly cliff-forming, sheetlike Bluecastle Tongue of the Castlegate Sandstone. East of the Tusher Canyon area, the Bluecastle rivers became more meandering and their deposits cannot be distinguished from those of the Neslen rivers.

The change in petrofacies from a quartzose to a feldspathic-lithic suite (Lawton, 1986) can be traced across our study area. Sandstone mineralogy in the Sego, Neslen, and Bluecastle consists primarily of quartz and sedimentary lithic fragments of chert, detrital dolomite, and fine-grained siliciclastic rocks and indicates erosion of Paleozoic clastic and carbonate rocks and Precambrian rocks within the Utah thrust belt and possibly erosion of older Cretaceous deposits in the western part of the foreland basin. Deposition of the Farrer Formation represents not only the succession of a coastal plain by an alluvial plain but also the introduction of sediment from a different source terrane.

Feldspar is common within the Farrer and Tuscher Formations, and volcanic grains are ubiquitous in the upper part of the combined Farrer and Tuscher Formations. The presence of potassium feldspar (especially where the volcanic component is minor), abundant plutonic quartz, and granitic rock fragments indicates plutonic rocks in the source area. Where volcanic lithic fragments are common in the Farrer and Tuscher Formations, the positive correlation between the abundance of feldspar, particularly plagioclase, and volcanic grains suggests that some fraction of the feldspar may be of volcanic origin, derived from the breakup of fine-crystalline extrusive rocks in the source area. The variety in volcanic grain types reveals parent rock that ranges from acidic to intermediate in composition. The dominant northeast transport directions of the Farrer and Tuscher fluvial systems indicate that the source of the plutonic and volcanic material was to the southwest. These rocks do not exist within the preserved thrust sheets in Utah, and their source must have been to the southwest and perhaps to the south of the thrust belt (Lawton, 1986). Although the exact location and nature of the contributing plutonic and volcanic source terrane is unknown, late Campanian-age igneous rocks are present in southwestern Arizona and southeastern California (Armstrong and Suppe, 1973). In southwestern Utah, the fluvial Kaiparowits Formation is feldspathic and the conglomeratic lower part of the Canaan Peak Formation contains abundant volcanic pebbles (Bowers, 1972). Rivers draining these sources probably supplied material for these late Campanian-age formations. The downstream part of these same rivers may have supplied the material for the Farrer and Tuscher Formations (Lawton, 1986).

The Farrer rivers were larger and probably less sinuous than those of the Neslen. The dominance of trough cross-stratification within the Farrer channel sandstone units indicates that channels filled by accretion of sinuous-crested dunes migrating along the channel floor. The extent of point-bar lateral accretion is unknown because lateral-accretion bedding is rare on outcrops, probably owing to lack of development or preservation of clay drapes. The Farrer channel sandstone units do not exhibit the characteristics of braided river deposits, and the abandoned channel and overbank deposits are typical of those of a sinuous fluvial system.

Keighin and Fouch (1981) and Lawton (1986) believed that evolution of Farrer rivers from meandering to braided resulted in the thick, stacked channel-fill sequences of the Tuscher Formation. Except for the very local occurrence in the Green River area of a pebbly sandstone interval that shows characteristics of braided-river deposition at the top of the Tuscher, the internal structure of the Tuscher channel units is generally similar to that in the Farrer. The Tuscher Formation is distinguishable only in the western part of the study area, and as it loses its identity to the east the undifferentiated Farrer and Tuscher interval thickens. These factors all suggest that the river system did not change regionally but that extensive local migration of the rivers resulted in erosion of the overbank deposits and formation of thick, stacked channel-fill sequences. The Tuscher Formation occurs slightly to the north and northeast of the San Rafael uplift, and incipient movement of this structure may have locally decreased subsidence rates and produced this fluvial response.

In the Green River area, the rivers switched from a northeasterly to a northerly flow direction during deposition of about the upper 150 ft (46 m) of the Tuscher Formation. This drainage realignment may be a further step in the progressive response of the fluvial system to movement of the San Rafael uplift. Depositional hiatuses are possible within the uppermost part of the Tuscher Formation in this area. A quartzose sandstone unit similar in composition to Lawton's (1986) pebbly beds is interbedded with pebbly feldspathic sandstone at the top of the Tuscher near the Green River. This relationship suggests that the pebbly beds may be Late Cretaceous in age, but no age-diagnostic palynomorph assemblages have been recovered from these beds. The mineralogy of the quartzose unit is similar to that of the Sego, Neslen, and Bluecastle, and paleocurrent measurements indicate a westerly source in the thrust belt. West of the Green River, the pebbly beds unconformably overlie an erosionally thinned Cretaceous section and are unconformably overlain by Paleocene rocks. The main episode of feldspathic sand deposition in the Green River area may also have ceased prior to deposition of the quartzose unit. The thin feldspathic sequence overlying the quartzose sandstone unit in the Green River area could be a lag of reworked Cretaceous sediments eroded from rising uplifts during the latest Cretaceous or possibly the earliest Tertiary.

Palynomorph assemblages indicating a middle late Campanian age were recovered from the uppermost Tuscher or undifferentiated Farrer and Tuscher Formations along the Book Cliffs. To the north, in the subsurface of the Uinta basin, an assemblage of early Maastrichtian age occurs in the undifferentiated Farrer and Tuscher interval; deposition in this interval may have continued longer or postdepositional erosion may have been less extensive. No late Maastrichtian palynomorph assemblages have been recovered from this area of the Uinta basin. Along the Utah Book Cliffs east of the Green River, an unconformity encompassing about 10 million years exists between the Cretaceous sequence and the Dark Canyon sequence of the Wasatch Formation of late early Paleocene age. The similarity between the sandstone mineralogy of the Dark Canyon sequence and that of the Farrer and Tuscher Formations and the almost exclusively siliceous pebble suite of the Dark Canyon sequence suggest that the source material was Mesozoic rocks derived from Laramide uplifts to the south. Braided rivers, whose main drainage was along the western flank of the now active Uncompahgre uplift, transported this material northward to be deposited in a medial to distal braidplain setting in the Book Cliffs area.

Possibly 6 million years lapsed between deposition of the Dark Canyon sequence and the overlying Tertiary sequence. No middle Paleocene-age palynomorph assemblages have been recovered from the Tertiary sequence in the study area. Deposits of a late Paleocene-age, mixed lacustrine and alluvial system containing clastic material derived dominantly from the west overlie the Dark Canyon sequence in the Tusher Canyon section. These deposits pinch out eastward into the completely alluvial sequence of the main body of the Wasatch Formation that contains a late Paleocene-age palynomorph assemblage. A major tectonic event in southwestern Colorado supplied sediment to the Wasatch system (Dickinson and others, 1986), and deposition of this unit marks the onset of the major period of intermontane basin subsidence along the outcrop belt in the southeastern Uinta basin.

REFERENCES CITED

Allen, J.R.L., 1978, Studies in fluviatile sedimentation; an exploratory quantitative model for the architecture of avulsion-controlled alluvial suites: Sedimentary Geology, v. 21, p. 129–147.

Armstrong, R.L., and Suppe, J., 1973, Potassium-argon geochronometry of Mesozoic igneous rocks in Nevada, Utah, and southern California: Geological Society of America Bulletin, v. 84, p. 1375–1392.

Balsley, J.K., 1982, Cretaceous wave-dominated delta systems, Book Cliffs, east-central Utah: American Association of Petroleum Geologists Guidebook, 219 p.

Bridge, J.S., and Leeder, M.R., 1979, A simulation model of alluvial stratigraphy: Sedimentology, v. 26, p. 617–644.

Bowers, W.E., 1972, The Canaan Peak, Pine Hollow, and Wasatch Formations in the Table Cliff Region, Garfield County, Utah: U.S. Geological Survey Bulletin 1331–B, 39 p.

Cashion, W.B., 1967, Geology and fuel resources of the Green River Formation, southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey Professional Paper 548, 48 p.

_____ 1973, Geologic and structure map of the Grand Junction quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–736, scale 1:250,000.

Dickinson, W.R., Lawton, T.F., and Inman, K.F., 1986, Sandstone detrital modes, central Utah foreland region; stratigraphic record of Cretaceous-Paleogene tectonic evolution: Journal of Sedimentary Petrology, v. 56, p. 276–293.

Erdmann, C.E., 1934, The Book Cliffs coal field in Garfield and Mesa Counties, Colorado: U.S. Geological Survey Bulletin 851, 150 p.

Fisher, D.J., 1936, The Book Cliffs coal field in Emery and Grand Counties, Utah: U.S. Geological Survey Bulletin 852, 104 p.

Fisher, D.J., Erdmann, C.E., and Reeside, J.B., Jr., 1960, Cretaceous and Tertiary formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah, and Garfield and Mesa Counties, Colorado: U.S. Geological Survey Professional Paper 332, 80 p.

Folk, R.L., 1980, Petrology of sedimentary rocks: Austin, Tex., Hemphill's, 182 p.

Fouch, T.D., 1975, Oil- and gas-bearing Upper Cretaceous and Paleogene fluvial rocks in central and northeast Utah, *in* Recognition of fluvial depositional systems and their resource potential: Society of Economic Paleontologists and Mineralogists Short Course 19, p. 241–272.

Fouch, T.D., and Cashion, W.B, 1979, Distribution of rock types, lithologic groups, and depositional environments for some lower Tertiary and Upper and Lower Cretaceous, and Upper and Middle Jurassic rocks in the subsurface between Altamont oil field and San Arroyo gas field, northcentral to northeastern Uinta basin, Utah: U.S. Geological Survey Open-File Report 79–365, 2 sheets.

Fouch, T.D., Lawton, T.F., Nichols, D.J., Cashion, W.B., and Cobban, W.A., 1983, Patterns and timing of synorogenic sedimentation in Upper Cretaceous of central and northeast Utah, *in* Reynolds, M.W., and Dolly. E.D., eds., Mesozoic paleogeography of the west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists Symposium, 2nd, Denver, Colo., p. 305–336.

Franczyk, K.J., 1988, Depositional controls on the late Campanian Sego Sandstone and implications for associated coal-forming environments in the Uinta and Piceance basins: U.S. Geological Survey Bulletin 1787–F, 17 p.

Franczyk, K.J., and Hanley, J.H., 1987, Laramide tectonic controls on late Paleocene lacustrine systems and associated depositional environments, southwestern Uinta Basin, Utah: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 276.

Francyzk, K.J., and Nichols, D.J., 1986, Unconformity-bounded Paleocene conglomerate sequence, southeastern Uinta basin [abs.]: American Association of Petroleum Geologists Bulletin, v. 70, no. 8, p. 1039–1040.

_____ 1988, Changing depositional systems reflecting foreland to intermontane basin transition in Campanian to Paleocene time, Book Cliffs and Wasatch Plateau, Utah: Geological Society of America Abstracts with Programs, v. 20, p. A219.

Franczyk, K.J., and Pitman, J.K., 1987, Basal Tertiary conglomerate sequence, southeastern Uinta Basin Utah; a preliminary report, *in* Campbell, J.A., ed., Geology of Cataract Canyon and vicinity: Four Corners Geological Society Field Conference, 10th, Guidebook, p. 119–126.

Gill, J.R., and Hail, W.J., Jr., 1975, Stratigraphic sections across Upper Cretaceous Mancos Shale-Mesaverde Group boundary, eastern Utah and western Colorado: U.S. Geological Survey Oil and Gas Investigations Chart OC–68, 1 sheet.

Goddard, E.N., Trask, P.D., DeFord, R.K., Rove, O.N., Singewald, J.T., Jr., and Overbeck, R.M., 1963, Rock-color chart: Boulder, Colo., Geological Society of America.

Gualtieri, J.L., 1988, Geologic map of the Westwater 30′ × 60′ quadrangle, Grand County, Utah and Garfield and Mesa Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–1765, scale 1:100,000.

Hayes, M.O., and Kana, T.W., 1976, Terrigenous clastic depositional environments: Coastal Research Division, University of South Carolina, Technical Report 11–CRD, part I, 131 p.; part II, 171 p.

Johnson, R.C., 1985, Preliminary geologic map of the Baxter Pass quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–1813, scale 1:62,500.

Johnson, R.C., May, Fred, Hansley, P.L., Pitman J.K., and Fouch, T.D., 1980, Petrography, X-ray mineralogy, and palynology of a measured section of the Upper Cretaceous Mesaverde Group in Hunter Canyon, western Colorado: U.S. Geological Survey Oil and Gas Investigations Chart OC–91.

Keighin, C.W., and Fouch, T.D., 1981, Depositional environments and diagenesis of some nonmarine Upper Cretaceous reservoir rocks, Uinta basin, Utah, *in* Ethridge, F.G., and Flores, R.M., eds., Recent and ancient nonmarine depositional environments; models for exploration: Society of Economic Paleontologists and Mineralogists Special Paper 31, p. 109–125.

Lawton, T.F., 1983, Tectonic and sedimentologic evolution of the Utah foreland basin: Tucson, University of Arizona, Ph.D. thesis, 217 p.

______ 1986, Fluvial systems of the Upper Cretaceous Mesaverde Group and Paleocene North Horn Formation, central Utah; a record of transition from thin-skinned to thick-skinned deformation in the foreland region, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, p. 423–442.

MacKenzie, D.B., 1972, Tidal sand flat deposits in Lower Cretaceous Dakota Group near Denver, Colorado: The Mountain Geologist, v. 9, p. 269–277.

Miall, A.D., 1978, Lithofacies types and vertical profile models in braided river deposits; a summary, *in* Miall, A.D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 597–604.

Nichols, D.J., Jacobson, S.R., and Tschudy, R.H., 1982, Cretaceous palynomorph biozones for the central and northern Rocky Mountain region of the United States, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt: Denver, Colo., Rocky Mountain Association of Geologists, v. 2, p. 721–733.

Nichols, D.J., and Ott, H.L., 1978, Biostratigraphy and evolution of the *Momipites-Caryapollenites* lineage in the early Tertiary in the Wind River basin, Wyoming: Palynology, v. 2, p. 93–112.

Nichols, D.J., and Sweet, A.R., in press, Biostratigraphy of Upper Cretaceous nonmarine palynofloras in a north-south transect of the Western Interior basin: Geological Association of Canada Special Paper.

Peterson, P.R., 1973, Fence Canyon field: Utah Geological and Mineralogical Survey Oil and Gas Field Studies 9, 4 p.

Pfaff, B.J., 1985, Sedimentologic and tectonic evolution of the fluvial facies of the Upper Cretaceous Castlegate Sandstone, Book Cliffs, Utah: Salt Lake City, University of Utah, M.S. thesis, 124 p.

Pitman, J.K., Anders, D.E., Fouch, T.D., and Nichols, D.J., 1986, Hydrocarbon potential of nonmarine Upper Cretaceous and lower Tertiary rocks, eastern Uinta basin, Utah, *in* Spencer, C.W., and Mast, R.F., eds., Geology of tight gas reservoirs: American Association of Petroleum Geologists Studies in Geology 24, p. 235–252.

Pitman, J.K., Franczyk, K.J., and Anders, D.E., 1987, Marine and nonmarine gas-bearing rocks in the Upper Cretaceous Blackhawk and Neslen Formations, eastern Uinta Basin, Utah—Sedimentology, diagenesis and source rock potential: American Association of Petroleum Geologists Bulletin, v. 71, p. 76–94.

______ 1988, Diagenesis and burial history of nonmarine Upper Cretaceous rocks in the central Uinta Basin, Utah: U.S. Geological Survey Bulletin 1787–D, 24 p.

Reineck, H.E., and Singh, I.B., 1980, Depositional sedimentary environments: New York, Springer-Verlag, 549 p.

Sellwood, B.W., 1975, Lower Jurassic tidal-flat deposits, Bornholm, Denmark, *in* Ginsburg, R.N., ed., Tidal deposits: New York, Springer-Verlag, p. 93–101.

Slater, R.D., 1985, A numerical model of tides in the Cretaceous seaway of North America: Journal of Geology, v. 93, p. 333–345.

Smith, D.G., 1983, Anastomosed fluvial deposits; modern examples from western Canada, *in* Collinson, J.D., and Lewin, J., eds., Modern and ancient fluvial systems: International Association of Sedimentologists Special Publication 6, p. 155–168.

______ 1987, Meandering river point bar lithofacies models: modern and ancient examples compared, *in* Ethridge, F.G., Flores, R.M., and Harvey, M.D., eds., Recent developments in fluvial sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 83–91.

Stone, J.F., 1973, Palynology of the Almond Formation (Upper Cretaceous), Rock Springs uplift, Wyoming: Bulletins of American Paleontology, v. 64, no. 278, 135 p.

Weimer, R.J., Howard, J.D., and Lindsay, D.R., 1982, Tidal flats, *in* Scholle, P.A., and Spearing, D., eds., Sandstone depositional environments: American Association of Petroleum Geologists Memoir 31, p. 191–247.

Willis, G.C., 1986, Geology, depositional environment, and coal resources of the Sego Canyon 7-1/2-minute quadrangle, near Green River, east-central Utah: Brigham Young University Geology Studies, v. 33, pt. 1, p. 175–208.

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PLATE 3

Contact photographs of the plate in this report are available,
at cost, from U.S. Geological Survey Photographic Library,
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PLATE 3

[Magnification × 1,000]

Figures 1. *Aquilapollenites attenuatus* Funkhouser. D6757, Tuscher Formation, Sego Canyon.

2. *Aquilapollenites quadrilobus* Rouse. D6873, Tuscher Formation, Bryson Canyon.

3. *Aquilapollenites turbidus* Tschudy & Leopold. D6757. Tuscher Formation, Sego Canyon.

4. *Tricolpites interangulus* Newman. D6757, Tuscher Formation, Sego Canyon.

5. *Proteacidites retusus* Anderson. D6757, Tuscher Formation, Sego Canyon.

6. *Proteacidites* sp. 1. D6757, Tuscher Formation, Sego Canyon.

7. *Proteacidites* sp. 2. D6301, Tuscher Formation, Dark Canyon.

8. *Loranthacites* sp. "F". D6301, Tuscher Formation, Dark Canyon.

9. *Ilexpollenites compactus* Stone. D6757, Tuscher Formation, Sego Canyon.

10. *Arecipites* sp. D6757, Tuscher Formation, Sego Canyon.

11. *Liliacidites* sp. cf. *L. complexus* (Stanley) Leffingwell. D6873, Tuscher Formation, Bryson Canyon.

12. *Pandaniidites typicus* (Norton) Sweet. D6757, Tuscher Formation, Sego Canyon.

13. *Eucommiidites couperi* Anderson. D6757, Tuscher Formation, Sego Canyon.

14. *Kuylisporites scutatus* Newman. D6873, Tuscher Formation, Bryson Canyon.

15. *Momipites dilatus* (Fairchild) Nichols. D6872, Dark Canyon sequence, Cottonwood Wash.

16. *Momipites inaequalis* Anderson. D6872, Dark Canyon sequence, Cottonwood Wash.

17. *Momipites leffingwellii* Nichols & Ott. D6872, Dark Canyon sequence, Cottonwood Wash.

18. *Momipites leffingwellii* Nichols & Ott. D6872, Dark Canyon sequence, Cottonwood Wash.

19. *Momipites tenuipolus* Anderson. D6872, Dark Canyon sequence, Cottonwood Wash.

20. *Momipites waltmanensis* Nichols & Ott. D6872, Dark Canyon sequence, Cottonwood Wash.

21. *Momipites waltmanensis* Nichols & Ott. D6872, Dark Canyon sequence, Cottonwood Wash.

22. *Ulmipollenites krempii* (Anderson) Frederiksen. D6872, Dark Canyon sequence, Cottonwood Wash.

23. *Pandaniidites typicus* (Norton) Sweet. D6872, Dark Canyon sequence, Cottonwood Wash.

24. *Retitrescolpites* sp. D6872, Dark Canyon sequence, Cottonwood Wash.

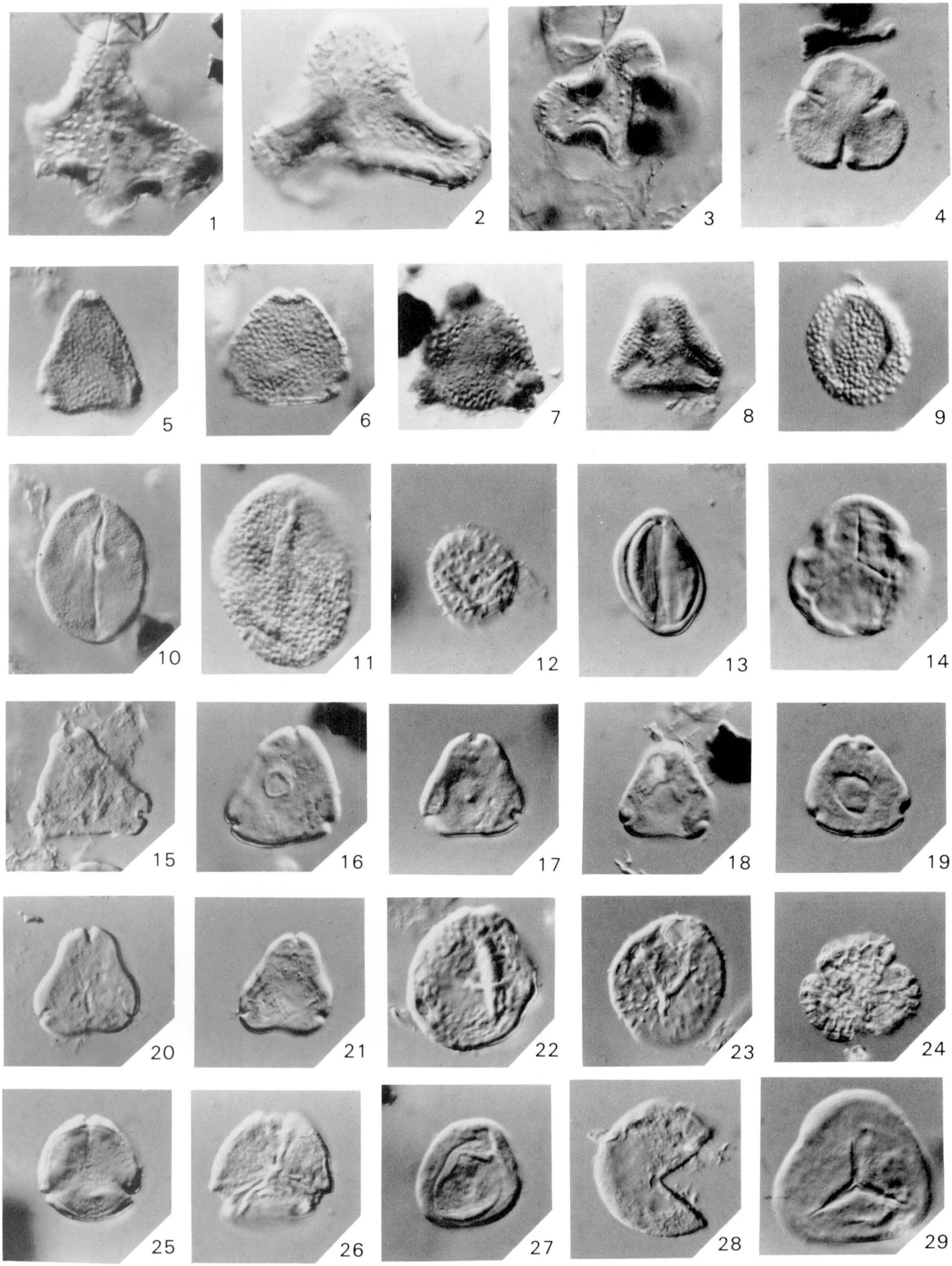
25. *Brevicolporites colpella* Anderson. D6872, Dark Canyon sequence, Cottonwood Wash.

26. *Nyssapollenites* sp. D6872, Dark Canyon sequence, Cottonwood Wash.

27. *Corollina* sp. D6872, Dark Canyon sequence, Cottonwood Wash.

28. *Taxodiaceaepollenites hiatus* (Potonie) Kremp ex Potonie. D6872, Dark Canyon sequence, Cottonwood Wash.

29. *Cyathidites* sp. D6872, Dark Canyon sequence, Cottonwood Wash.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