Palynostratigraphy in Relation to Sequence Stratigraphy, Straight Cliffs Formation (Upper Cretaceous), Kaiparowits Plateau, Utah

U.S. GEOLOGICAL SURVEY BULLETIN 2115–B

AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that may be listed in various U.S. Geological Survey catalogs (**see back inside cover**) but not listed in the most recent annual "Price and Availability List" may no longer be available.

Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices listed below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

U.S. Geological Survey, Information Services
Box 25286, Federal Center
Denver, CO 80225

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained ONLY from the

Superintendent of Documents
Government Printing Office
Washington, DC 20402

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

U.S. Geological Survey, Information Services
Box 25286, Federal Center
Denver, CO 80225

Residents of Alaska may order maps from

U.S. Geological Survey, Earth Science Information Center
101 Twelfth Ave., Box 12
Fairbanks, AK 99701

OVER THE COUNTER

Books and Maps

Books and maps of the U.S. Geological Survey are available over the counter at the following U.S. Geological Survey offices, all of which are authorized agents of the Superintendent of Documents.

- **ANCHORAGE, Alaska**–Rm. 101, 4230 University Dr.
- **LAKEWOOD, Colorado**–Federal Center, Bldg. 810
- **MENLO PARK, California**–Bldg. 3, Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**–USGS National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**–Federal Bldg., Rm. 8105, 125 South State St.
- **SPOKANE, Washington**–U.S. Post Office Bldg., Rm. 135, West 904 Riverside Ave.
- **WASHINGTON, D.C.**–Main Interior Bldg., Rm. 2650, 18th and C Sts., NW.

Maps Only

Maps may be purchased over the counter at the following U.S. Geological Survey offices:

- **FAIRBANKS, Alaska**–New Federal Bldg, 101 Twelfth Ave.
- **ROLLA, Missouri**–1400 Independence Rd.
- **STENNIS SPACE CENTER, Mississippi**–Bldg. 3101

Palynostratigraphy in Relation to Sequence Stratigraphy, Straight Cliffs Formation (Upper Cretaceous), Kaiparowits Plateau, Utah

By Douglas J. Nichols

SEDIMENTOLOGIC AND STRATIGRAPHIC INVESTIGATIONS OF COAL-BEARING STRATA IN THE UPPER CRETACEOUS STRAIGHT CLIFFS FORMATION, KAIPAROWITS PLATEAU, UTAH

U.S. GEOLOGICAL SURVEY BULLETIN 2115–B

An analysis of the distribution of fossil spores, pollen, and dinoflagellate cysts in samples from cores drilled in coal-bearing strata independently interpreted according to sequence-stratigraphic principles

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1995

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For sale by U.S. Geological Survey, Information Services
Box 25286, Federal Center
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Nichols, Douglas J.
Palynostratigraphy in relation to sequence stratigraphy, Straight Cliffs Formation (Upper Cretaceous), Kaiparowits Plateau, Utah / by Douglas J. Nichols.
p. cm. — (Sedimentologic and stratigraphic investigations of coal-bearing strata in the Upper Cretaceous Straight Cliffs Formation, Kaiparowits Plateau, Utah ; B) (U.S. Geological Survey bulletin ; 2115)
Includes bibliographical references (p.).
Supt. of Docs. no.: I 19.3:2115B
1. Palynology—Utah—Kaiparowits Plateau. 2. Paleobotany—Cretaceous. 3. Geology, Stratigraphic—Cretaceous. 4. Straight Cliffs Formation (Utah) I. Title. II. Series. III. Series: U.S. Geological Survey bulletin ; 2115.
QE75.B9 no. 2115-B
[QE993]
557.3 s—dc20 95-16541
[551.7′7′0979251] CIP

CONTENTS

PLATE

[Plate follows references cited]

FIGURES

TABLES

Palynostratigraphy in Relation to Sequence Stratigraphy, Straight Cliffs Formation (Upper Cretaceous), Kaiparowits Plateau, Utah

By Douglas J. Nichols

ABSTRACT

Selected samples from two cores in the Straight Cliffs Formation (middle Turonian–lower Campanian?) in the Kaiparowits Plateau, south-central Utah, yielded abundant nonmarine and rare marine palynomorphs. The lithostratigraphy of the sampled interval has recently been interpreted in accordance with sequence-stratigraphic concepts. The palynostratigraphy provides support for some of the new interpretations.

Palynomorph assemblages analyzed are primarily from the coal-bearing John Henry Member of the Straight Cliffs Formation. Most are numerically dominated by spores of ferns and other cryptogams and pollen of gymnosperms. Pollen of angiosperms, although less abundant, is common and is biostratigraphically useful. The *Nyssapollenites albertensis* Zone (upper Cenomanian through mid-Coniacian) is present in the lower part of the sampled interval, and the *Proteacidites retusus* Zone (mid-Coniacian through upper Santonian) is present in the upper part. The base of the *P. retusus* Zone coincides with the interpreted position within the cores of the A- sequence boundary, in the lower part of the John Henry Member. Rare marine dinocysts are present in about 50 percent of samples interpreted by sedimentological criteria as deposited under tidal influence. These palynostratigraphic and paleoecologic data corroborate sedimentologic interpretations of facies within the sequence-stratigraphic framework.

The flora of the coal-forming mires of the John Henry Member consisted largely of ferns and mosses, with certain angiosperms (which possibly were trees) also as major components. Common spores and pollen of the Straight Cliffs palynoflora are illustrated, and a new species, *Foveotricolporites johnhenryensis*, is described.

INTRODUCTION

This report summarizes palynostratigraphic analyses of samples collected from two 300-m (meter) cores drilled in the Straight Cliffs Formation in the Kaiparowits Plateau, south-central Utah. The Straight Cliffs Formation contains major coal deposits of Late Cretaceous (Coniacian-Santonian) age. Palynostratigraphic analyses serve to test some of the sequence-stratigraphic interpretations of Shanley (1991), Shanley and McCabe (1991), Shanley and others (1992), and Hettinger (1993, 1995) by providing a temporal framework for age-determination and correlation of sequences, by confirming the position of a sequence-bounding unconformity as interpreted in the cored intervals, and by supporting sedimentological interpretations of depositional environments. Palynological analyses of the coal beds also can provide data on floristic composition of coal-forming mires. Finally, these data contribute to knowledge of Upper Cretaceous palynology of the southern part of the Western Interior.

This report presents initial observations and interpretations of distribution of palynomorphs of marine and nonmarine origin in selected samples from USGS cores SMP-1-91 and CT-1-91 (Hettinger, 1993, 1995). Results are initial because taxonomic study of the palynoflora is preliminary and interpretations of occurrence and distribution of palynomorphs rely primarily on presence/absence data. Paleoecologic data presented here are restricted to observations of possible marine-tidal influence in some facies within the cored intervals and of the floristic composition of mires in coastal plain settings.

STUDY AREA AND MATERIALS

The Kaiparowits Plateau covers an area of about 3,600 km^2 in south-central Utah (fig. 1) and incorporates an interval of Upper Cretaceous rocks more than 2 km thick (Eaton, 1991; Shanley and McCabe, 1991). The Straight Cliffs Formation, of middle Turonian to early Campanian age, includes 295–493 m of sandstone-dominated, coal-bearing strata of marginal marine, estuarine, and nonmarine (fluvial) origin (Peterson, 1969; Eaton, 1991). The formation thickens northward from the Tibbet Canyon area in the

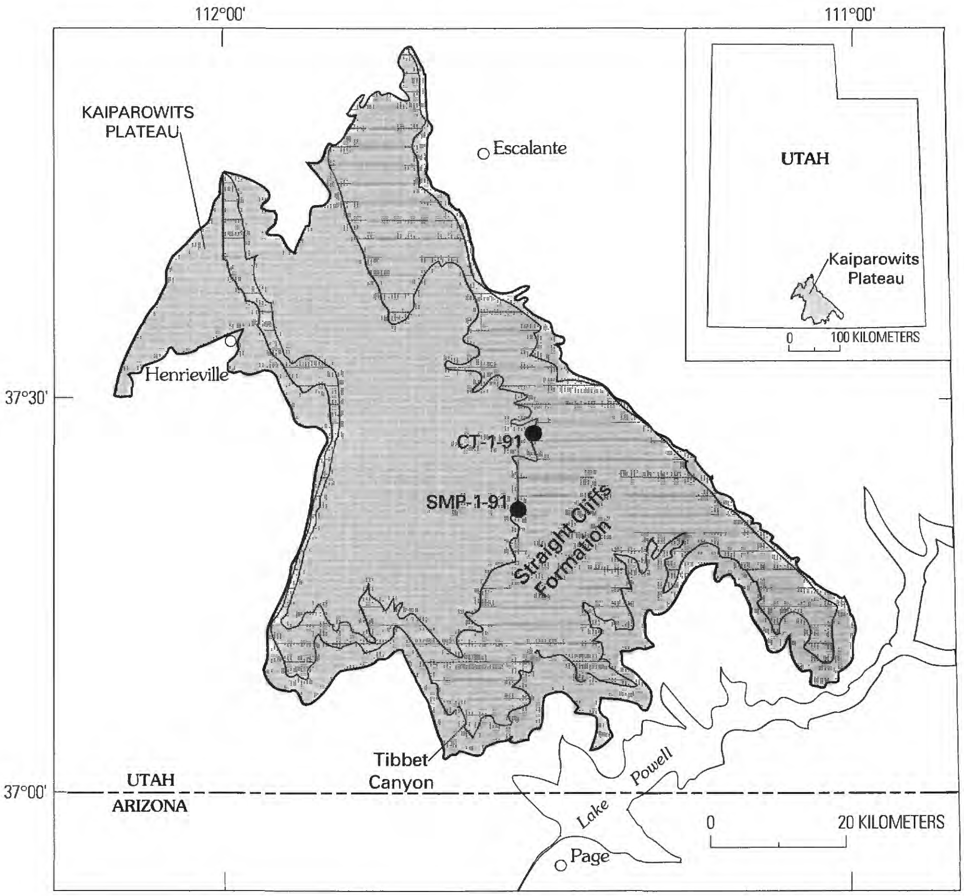


Figure 1. Map of study area showing Kaiparowits Plateau (shaded), outcrop areas of Straight Cliffs Formation (horizontal line pattern), underlying and overlying rocks (no horizontal pattern), and locations of drill sites for cores CT-1-91 and SMP-1-91 (modified from Hettinger, 1995).

southern part of the plateau to the vicinity of Henrieville, Utah, in the northwest (Eaton, 1991). The formation is well exposed for about 80 km along strike in the northwest-trending Straight Cliffs escarpment, from the vicinity of Lake Powell to Escalante, Utah. The marine facies are developed predominantly along this east edge of the plateau and grade westward to fluvial-dominated facies (Shanley and McCabe, 1991). Thick deposits of coal, which are in the John Henry Member of the Straight Cliffs Formation (Peterson, 1969), are present in the east-central part of the plateau, between cliff-forming, stacked, shoreface-sandstone units and alluvial plain deposits to the west (McCabe and Shanley, 1992).

The two cores on which the present palynostratigraphic study is based are from U.S. Geological Survey drill holes SMP-1-91 and CT-1-91 (Hettinger, 1993, 1995). The drill holes are located in the interior part of the Kaiparowits Plateau, respectively in the Ship Mountain Point (SMP) and Collet Top (CT) 7.5 minute quadrangles. Both holes were spudded near the top of the Straight Cliffs Formation. SMP-1-91 has a total depth (TD) of 293.4 m and core was recovered from the interval from 60 to 962.7 ft (18.3 to 293.4 m). CT-1-91 has a TD of 322.3 m and core was recovered from the interval from 141.1 to 1,057.4 ft (43.0 to 322.3 m). Units within the Straight Cliffs Formation sampled by these cores (in both conventional and sequence-stratigraphic terms) are noted in the following sections of this report. Most samples are from the John Henry Member of the Straight Cliffs Formation.

Samples discussed in this report are listed in tables 1 and 2. They were collected at selected intervals from rock types having high potential for recovery of palynomorphs. These include, for example, carbonaceous shale and gray mudrock but exclude sandstone. Coal samples also have high potential for recovery of palynomorphs. Except for beds measuring only a few centimeters in thickness, all coal present in the cores had been removed for other analyses prior to collection of samples listed in table 1. Analyses of selected splits of samples from two of the coal beds that were removed are discussed. These samples include the floor and roof of each bed and clastic partings within the beds in addition to coal. In all, 90 samples were analyzed palynologically, 49 from core SMP-1-91 and 41 from core CT-1-91.

Table 1. Palynological samples from core SMP-1-91.

[USGS Paleobotany Locality Number D7941, including detailed samples of two thick coal beds respectively designated D8020 and D8068. Depths in the core are averaged for the detailed samples from the thick coal beds. Depths given in feet are original measurements marked on cores. Depositional environments indicated are based on interpretations of Hettinger (1993, 1995). Asterisks denote samples containing marine dinoflagellate cysts]

Sample No.	Depth in core	Rock type	Dep. environment
D7941-EE	75.9 ft (23.1 m)	mudrock	fluvial channel
D7941-DD	165.0 ft (50.3 m)	carbonaceous mudrock	floodplain
D7941-CC	187.2 ft (57.0 m)	mudrock	floodplain
D7941-BB	205.5 ft (62.6 m)	mudrock	floodplain
D7941-AA	233.4 ft (71.1 m)	carbonaceous mudrock	floodplain
D7941-Z	247.2 ft (75.3 m)	carbonaceous mudrock	floodplain
D7941-Y	306.5 ft (93.4 m)	carbonaceous shale	floodplain
D7941-X	321.0 ft (97.8 m)	carbonaceous shale	floodplain *
D7941-W	344.1 ft (104.9 m)	mudrock	tidal
D7941-V	351.8 ft (107.2 m)	mudrock	floodplain
D7941-U	378.2 ft (115.3 m)	carbonaceous shale	floodplain
D7941-T	396.9 ft (121.0 m)	coal	mire
D7941-S	474.3 ft (144.6 m)	shale	tidal
D7941-R	547.8 ft (167.0 m)	carbonaceous shale	floodplain
D7941-Q	580.5 ft (176.9 m)	mudrock	floodplain
D8020-M	177.1 m	carbonaceous shale	floodplain
D8020-L	177.2 m	coal	mire
D8020-K	177.9 m	coal	mire
D8020-J	180.4 m	coal	mire
D8020-I	181.1 m	coal	mire
D8020-H	181.2 m	coal	mire
D8020-G	181.7 m	coal	mire
D8020-F	182.3 m	coal	mire
D8020-E	182.8 m	coal	mire
D8020-D	183.3 m	coal	mire
D8020-C	183.6 m	coal	mire
D8020-B	183.7 m	coal	mire
D8020-A	183.8 m	mudrock	floodplain
D7941-P	615.6 ft (187.6 m)	mudrock	tidal *
D7941-O	636.2 ft (193.9 m)	carbonaceous shale	floodplain
D7941-N	655.0 ft (199.6 m)	carbonaceous shale	floodplain
D7941-M	680.3 ft (207.4 m)	mudrock	tidal
D7941-L	732.1 ft (223.1 m)	mudrock	tidal
D8068-EE	231.3 m	shale	floodplain
D8068-Z	234.0 m	coal	mire
D8068-O	236.8 m	shale (parting)	floodplain
D8068-D	237.5 m	coal	mire
D8068-A	238.1 m	shale (parting)	floodplain
D7941-K	786.8 ft (239.8 m)	carbonaceous shale	floodplain
D7941-J	796.2 ft (242.7 m)	mudrock	tidal
D7941-I	803.0 ft (244.8 m)	mudrock	floodplain
D7941-H	832.5 ft (253.7 m)	carbonaceous shale	tidal *
D7941-G	835.9 ft (254.8 m)	carbonaceous shale	floodplain
D7941-F	868.1 ft (264.6 m)	carbonaceous shale	floodplain *
D7941-E	871.9 ft (265.8 m)	carbonaceous shale	tidal *
D7941-D	876.5 ft (267.2 m)	carbonaceous shale	floodplain
D7941-C	902.7 ft (275.1 m)	coal	mire
D7941-B	927.9 ft (282.8 m)	siltstone	floodplain
D7941-A	947.5 ft (288.8 m)	shale	floodplain

Table 2. Palynological samples from core CT-1-91.

[USGS Paleobotany Locality Number D7993. Depositional environments indicated are based on interpretations of Hettinger (1993, 1995). Asterisks denote samples containing marine dinoflagellate cysts. Sample D7993–B was barren of palynomorphs]

Sample No.	Depth in core	Rock type	Dep. environment
D7993-PP	153.4 ft (46.8 m)	mudrock	fluvial channel
D7993-OO	207.5 ft (63.2 m)	mudrock	floodplain
D7993-NN	214.6 ft (65.4 m)	carbonaceous mudrock	floodplain
D7993-MM	244.1 ft (74.4 m)	mudrock	floodplain
D7993-LL	263.5 ft (80.3 m)	mudrock	floodplain
D7993-KK	298.3 ft (90.9 m)	mudrock	floodplain
D7993-JJ	327.7 ft (99.9 m)	mudrock	tidal
D7993-II	348.2 ft (106.1 m)	mudrock	tidal
D7993-HH	377.0 ft (114.9 m)	carbonaceous mudrock	tidal
D7993-GG	386.2 ft (117.7 m)	mudrock	tidal *
D7993-FF	397.8 ft (121.3 m)	mudrock	tidal
D7993-EE	438.9 ft (133.8 m)	carbonaceous shale	floodplain *
D7993-DD	450.3 ft (137.3 m)	mudrock	floodplain
D7993-CC	464.7 ft (141.6 m)	carbonaceous mudrock	floodplain
D7993-BB	466.9 ft (142.3 m)	mudrock	floodplain
D7993-AA	482.2 ft (147.0 m)	mudrock	tidal *
D7993-Z	490.4 ft (149.5 m)	mudrock	floodplain
D7993-Y	518.5 ft (158.0 m)	mudrock	tidal *
D7993-X	524.1 ft (159.8 m)	carbonaceous mudrock	tidal *
D7993-W	538.5 ft (164.1 m)	mudrock	tidal *
D7993-V	567.9 ft (173.1 m)	mudrock	tidal
D7993-U	602.2 ft (183.6 m)	mudrock	tidal *
D7993-T	630.0 ft (192.0 m)	carbonaceous mudrock	floodplain
D7993-S	647.3 ft (197.3 m)	mudrock	tidal
D7993-R	653.4 ft (199.2 m)	mudrock	floodplain
D7993-Q	654.8 ft (199.6 m)	mudrock	floodplain *
D7993-P	662.5 ft (201.9 m)	carbonaceous shale	floodplain
D7993-O	677.4 ft (206.5 m)	mudrock	floodplain
D7993-N	730.5 ft (222.7 m)	mudrock	tidal
D7993-M	732.5 ft (223.3 m)	mudrock	tidal *
D7993-L	782.2 ft (238.4 m)	mudrock	shoreface *
D7993-K	824.2 ft (251.2 m)	mudrock	floodplain
D7993-J	853.0 ft (260.0 m)	shale	tidal *
D7993-I	855.6 ft (260.8 m)	coal	mire
D7993-H	861.3 ft (262.5 m)	coal	mire
D7993-G	886.2 ft (270.1 m)	shale	tidal *
D7993-F	988.1 ft (301.2 m)	coal	mire
D7993-E	989.5 ft (301.6 m)	carbonaceous shale	floodplain
D7993-D	990.5 ft (301.9 m)	carbonaceous shale	floodplain
D7993-C	1,015.1 ft (309.4 m)	mudrock	floodplain
D7993-B	1,043.0 ft (317.9 m)	mudrock	floodplain
D7993-A	1,046.5 ft (319.0 m)	mudrock	floodplain

CONVENTIONAL LITHOSTRATIGRAPHY

The Straight Cliffs Sandstone was named by Gregory and Moore (1931). Peterson and Waldrop (1965) later applied the name Straight Cliffs Formation to the succession of marine and nonmarine strata that includes fine-grained clastic rocks and coal as well as sandstone. The Straight Cliffs Formation overlies the Tropic Shale (upper Cenomanian to middle Turonian) and underlies the Wahweap Formation (Campanian). Peterson (1969) named four members within the Straight Cliffs Formation, from oldest to youngest the Tibbet Canyon, Smoky Hollow, John Henry, and Drip Tank Members (fig. 2). All of these members have their type localities near the south edge of the plateau. As described by Peterson, the Straight Cliffs Formation ranges in age from middle Turonian to approximately early Campanian. Peterson also described a major unconformity within the Straight Cliffs Formation that apparently represents a significant amount of geologic time. Based on various interpretations of the ages of molluscan fossils from the Tibbet Canyon Member and lower part of the John Henry Member, the missing time includes the late Turonian through middle Coniacian (Peterson, 1969), late Turonian through late Coniacian (Peterson and Kirk, 1977), or the late Turonian (Eaton, 1991).

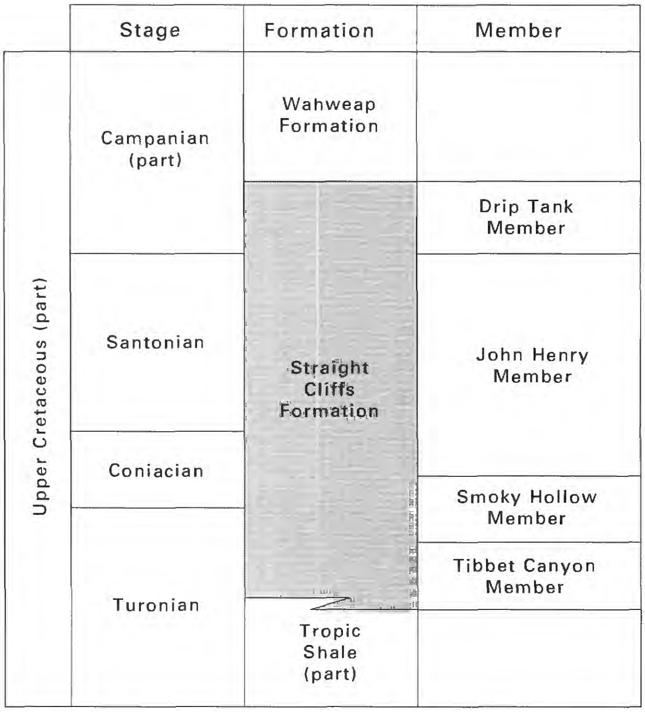


Figure 2. Conventional lithostratigraphic classification of Turonian through lower Campanian rocks in the Kaiparowits Plateau (modified from Eaton, 1991).

TIBBET CANYON MEMBER

At its type locality the Tibbet Canyon Member is about 32 m thick and consists largely of sandstone (Peterson, 1969). Its lower contact with the marine Tropic Shale is gradational, but its upper contact with the Smoky Hollow Member is sharp. Peterson interpreted that the Tibbet Canyon Member was deposited in shallow marine and beach environments because it contains cephalopods, inoceramid pelecypods, shark teeth, and trace fossils.

An age of middle Turonian for the Tibbet Canyon Member is based on the presence of a species of *Inoceramus* indicative of the *Prionocyclus hyatti* ammonite zone (Peterson, 1969; Eaton, 1991). The Tibbet Canyon Member is progradational, and it evidently ranges in age from early middle Turonian (*Collignoniceras woollgari woollgari* zone) in the southwestern part of the plateau to late middle Turonian (*P. hyatti* zone) in the central and eastern parts (Shanley, 1991).

SMOKY HOLLOW MEMBER

At its type locality the Smoky Hollow Member consists of about 35 m of interbedded sandstone, mudrock, carbonaceous shale, and coal; it increases in thickness to about 101 m near Escalante, Utah (Peterson, 1969). Peterson interpreted the Smoky Hollow to have been deposited in nonmarine fluvial, lagoonal, and paludal environments. It includes three informal units: a basal coal zone, a middle barren zone, and an upper unit called the Calico bed. The Calico bed is a distinctive light-gray to white sandstone containing quartz and chert pebbles and lenses of conglomerate. The previously mentioned major unconformity within the Straight Cliffs Formation was interpreted by Peterson (1969) as being at the top of the Calico bed.

The barren zone has yielded vertebrate fossils including rare mammals of probable Turonian age (Eaton, 1991). The Turonian age is determined on the basis of stratigraphic position, because the Smoky Hollow Member is not well dated directly.

JOHN HENRY MEMBER

The John Henry Member consists of interbedded sandstone, mudrock, carbonaceous shale, and coal. At its type locality it is about 226 m thick, but it thickens to about 329 m in the northeastern part of the plateau (Peterson, 1969). Most of the coal in the Straight Cliffs Formation is in the lower part of the John Henry Member. In the central and southwestern parts of the plateau, the member comprises a lower coal zone, lower barren zone, the Christensen coal zone, a middle barren zone, the Rees coal zone, and an upper barren zone (Peterson, 1969). In the southwestern and central parts of the plateau, the member is largely of nonmarine (fluvial, floodplain, paludal, and lagoonal) origin (Peterson, 1969) but includes beds deposited under tidal influence, as in tidal creeks and estuaries (Shanley and McCabe, 1991). In the northeastern part of the plateau, the John Henry comprises a lower marine mudrock tongue, four prominent marine sandstone units respectively designated A- through D-, an upper marine mudrock tongue, the marine G- sandstone, and the Alvey coal zone (Peterson, 1969). In this area the member is interpreted to be predominantly marine in origin and to include beach, shallow water, and offshore deposits (Peterson, 1969). The sandstone units form the Straight Cliffs escarpment. Among these units, the A- sandstone has proved to be the most important in recent reinterpretations of the stratigraphic framework of the John Henry Member.

The age of the John Henry Member probably ranges from Coniacian through Santonian and possibly includes the early Campanian, based on marine mollusks; however, interpretations of the age of these fossils vary. Collections reported by Peterson (1969) come from the lower marine mudrock tongue, the A- sandstone, the upper marine mudrock tongue, and the G- sandstone. Peterson (1969) cited an age of middle or late Coniacian for mollusks from the basal part of the member, but later (Peterson and Kirk, 1977) revised that age determination to early Santonian. Eaton (1991) contended that these fossils are more likely early Coniacian in age. He cited the occurrence of the inoceramid *Volviceramus involutus* and quoted E.G. Kauffman (University of Colorado) as stating that this species is early Coniacian, but this age designation appears to be incorrect. The zone of this species is equivalent to that of the ammonite *Scaphites ventricosus*, which is middle to upper Coniacian. (See also Shanley, 1991.) Peterson (1969) cited an age of Santonian for the middle part of the John Henry. For the upper part of the member he cited an age of early Campanian, but Eaton (1991) concluded that the member is no younger than late Santonian (*Desmoscaphites bassleri* zone). Shanley (1991) reported that the fossils from the same collection belong to the *Scaphites hippocrepis* zone, which is early Campanian in age. Palynostratigraphic evidence from the present study on the age of the John Henry Member is discussed later.

DRIP TANK MEMBER

The Drip Tank Member is a cliff-forming sandstone unit at the top of the Straight Cliffs Formation, the informally designated upper sandstone member of Peterson and Waldrop (1965). At its type locality it is about 43 m thick, but it may be as much as 159 m thick to the northwest (Peterson, 1969). The Drip Tank is interpreted to be of fluvial origin (Peterson, 1969).

The Drip Tank Member contains no age-diagnostic fossils. Its age was inferred to be early Campanian by Peterson (1969), based on the age of the underlying John Henry Member, which he took to be early Campanian in its uppermost part. Eaton (1991) suggested that the age of the Drip Tank Member is constrained by his interpreted late Santonian age of the uppermost John Henry Member and a presumed early Campanian age for the overlying Wahweap Formation.

SEQUENCE STRATIGRAPHY

Shanley (1991) and Shanley and McCabe (1991) reinterpreted the stratigraphy of the Straight Cliffs Formation in the Kaiparowits Plateau according to the concepts and principles of sequence stratigraphy. The concepts hold that sedimentary sequences are deposited in response to creation of accommodation space that, in nearshore and coastal plain strata, is controlled by changes in relative sea level. The changes in sea level are produced by the interaction of basin subsidence and eustasy. Because much of the Straight Cliffs Formation is of nonmarine origin, Shanley (1991) and Shanley and McCabe (1991) related their sequence-stratigraphic interpretations to changes in base level, although ultimately these changes also are governed by relative sea level. Their reinterpretation provides a new view of the depositional architecture of the Straight Cliffs Formation. Shanley and McCabe found that the existing, conventional lithostratigraphic classification and nomenclature are not useful in their reinterpretation, and they developed an alternative subdivision of the interval to describe their results. This section outlines only the broadest aspects of their new interpretations as they pertain to palynostratigraphy; readers are referred to Shanley and McCabe (1991) and Hettinger (1995) for more complete discussions.

Sequence-stratigraphic classification of the upper part of the Tropic Shale and the overlying Straight Cliffs Formation suggests that this interval is formed of five depositional sequences, each of which contains highstand and transgressive systems tracts (fig. 3). The sequences are separated by four sequence-bounding unconformities. These sequence boundaries are recognized by abrupt basinward shifts in facies across erosional surfaces, which developed in response to lowering of base level. Two of the unconformities are major and two are minor (none should be confused with the unconformity interpreted to be at the base of the John Henry Member by Peterson, 1969).

The lower of the two major unconformities is the Calico sequence boundary. It is at the base of the Calico bed, and it separates pebbly sandstone and conglomerate (braided-river deposits) of the Calico bed from underlying sandstone, siltstone, and carbonaceous shale (coastal plain deposits). The juxtaposition of these different facies across an erosion surface having as much as 40 m of relief is evidence for the existence of a regional unconformity and a corresponding basinward shift in facies. Shanley and McCabe (1989) interpreted the Ferron Sandstone Member of the Mancos Shale, which lies northeast of the Kaiparowits Plateau, as the

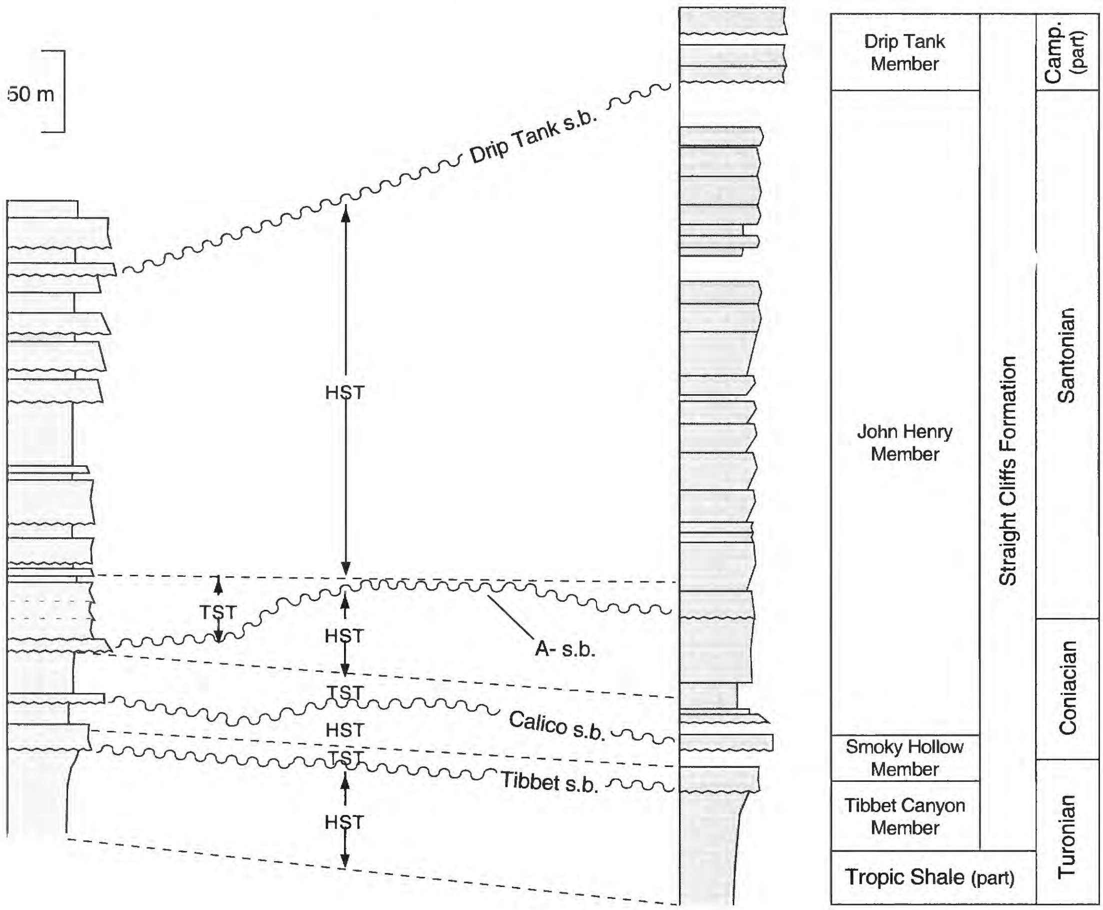


Figure 3. Sequence-stratigraphic classification of the Straight Cliffs Formation (conventional classification shown at right for comparison). Outcrop section at left is in southwestern part of Kaiparowits Plateau; section at right is in central part of Straight Cliffs escarpment on east edge of the plateau; they are about 60 km apart. HST, highstand systems tract; TST, transgressive systems tract; s.b., sequence boundary. Dashed lines indicate correlations of condensed sections and their alluvial equivalents; gaps in outcrop section at right are positions of covered nonmarine intervals, including coal-bearing strata; varying positions of sequence boundaries between outcrop sections are based on data from partial outcrop sections not shown. Diagram modified from Shanley and McCabe (1991) with their interpretations of depositional environments omitted.

basinward deposits equivalent to the hiatus at the Calico sequence boundary. The second major unconformity is near the top of the Straight Cliffs Formation. It is the Drip Tank sequence boundary, and it lies near the base of the Drip Tank Member. It separates coarse-grained braided-river deposits from underlying fine-grained fluvial, coastal plain, and shoreface deposits.

The two comparatively minor but still significant unconformities are the Tibbet sequence boundary and the A- sequence boundary. The Tibbet sequence boundary is an extensive erosion surface within the Tibbet Canyon Member of conventional lithostratigraphy, and it separates estuarine valley-fill deposits from underlying shoreface sandstone. The A- sequence boundary is within the John Henry Member. It is an extensive erosional surface that separates coarse-grained estuarine valley-fill deposits from underlying fine-grained coastal plain deposits and shoreface sandstone. At the east edge of the plateau this unconformity is located within the A- sandstone of Peterson (1969).

The sequence boundaries separate depositional sequences that include transgressive and highstand systems tracts. (Apparently it is conventional that sequences are named after the lowest stratigraphic unit within them. Therefore, the terminology applied to these sequences mimics, but is only partially equivalent to, the conventional lithostratigraphic names. The application of a different set of terms would have been less of a potential source of confusion.) No special name is given to the interval below the Tibbet sequence boundary, a highstand systems tract that includes the upper part of the Tropic Shale and the lower part of the Tibbet Canyon Member. (Figure 3 illustrates these systems tract relationships.) The interval between the Tibbet and Calico sequence boundaries is the Tibbet sequence. It consists of estuarine valley-fill deposits overlain by coastal plain strata. The valley-fill deposits are interpreted as a transgressive systems tract, and the coastal plain deposits as a highstand systems tract. The interval above the Calico sequence boundary is the Calico sequence. It consists of braided-river deposits (the Calico bed) that grade upward into tidally influenced fluvial strata capped by shoreface deposits; this part of the interval is interpreted as a transgressive systems tract. Overlying the transgressive systems tract of the Calico sequence is a highstand systems tract consisting of stacked shoreface parasequences that grade westward into coastal plain and alluvial deposits. The interval above the A- sequence boundary is the A- sequence. The basal part of this interval consists of tidally influenced fluvial and estuarine deposits (transgressive systems tract), and the thick, upper part of this interval consists of stacked shoreface parasequences that grade westward into coastal plain and alluvial strata (highstand systems tract). These deposits constitute most of the John Henry Member of conventional lithostratigraphy and include most of the thick coal beds of the Straight Cliffs Formation. The interval above the Drip Tank sequence boundary is the Drip Tank sequence.

An important aspect of the sequence stratigraphy study in the Kaiparowits Plateau is the recognition of marine tidal deposits and tidally influenced fluvial deposits in nonmarine settings. As mentioned, in the eastern part of the plateau the transgressive systems tract above the Calico sequence boundary consists of braided-river deposits that grade upward into estuarine deposits. These beds have sedimentary structures characteristic of tidal influence (Shanley and others, 1992). Transgression continued from east to west. In the western part of the plateau, the chronostratigraphically correlative intervals above the Calico sequence boundary are braided-river deposits overlain by fluvial-plain deposits that are in turn overlain by tidally influenced alluvial deposits. These tidally influenced beds, which are 60 km or more from the shoreline, represent maximum flooding and are equivalent to the condensed marine section to the east. Estuarine or tidally influenced deposits are recognized also in the lower part of the Tibbet sequence and in the lower part of the A-sequence. The transgressive systems tract in the A- sequence includes tidally influenced channel deposits overlain by marine sandstone in the eastern part of the plateau and a succession of alluvial channel deposits overlain by tidally influenced alluvial deposits in the western part. In addition to sedimentary structures indicative or suggestive of tidal influence, Shanley (1991), Shanley and McCabe (1991), and Shanley and others (1992) used brackish-water trace fossils to identify tidal deposits. Hettinger (1993, 1995) similarly used sedimentary structures observable in cores SMP-1-91 and CT-1-91 to identify such deposits. Palynological analysis of such deposits also can help in their recognition because marine dinoflagellate cysts may be preserved. These palynomorphs represent motile algae that inhabited marine and brackish water. They can be present in estuaries, tidal channels, and rivers whose flow is periodically reversed by tides.

PALYNOSTRATIGRAPHY

PREVIOUS STUDIES

Pertinent previous studies of Cretaceous palynology of the region are limited in number. The most directly relevant study is that of Orlansky (1971). Orlansky described and illustrated 124 palynomorph species from 20 samples of the Straight Cliffs Formation in outcrop near Henrieville, Utah (fig. 1). His study included discussions of seven species of marine dinoflagellates in addition to spores and pollen of terrestrial plants. Although an important contribution when published, subsequent changes in taxonomic concepts and the nomenclature of fossil spores and pollen have rendered much of Orlansky's taxonomy and nomenclature unreliable. May (1972) illustrated but did not describe palynomorphs from coal-bearing strata in Utah, including the Straight Cliffs Formation as exposed in a coal field in the northeastern part of the Kaiparowits Plateau. A photographic plate published by May (1972, pl. 13) is of some value in identification of the palynomorph species he recovered, but his biostratigraphic and paleoecologic conclusions are misleading because they are inadequately documented within his text or by comparative studies.

Some previous palynologic studies in adjacent areas pertain to the present investigation. A study of a correlative Upper Cretaceous interval in the San Juan Basin of northwestern New Mexico was conducted by Tschudy (1976). No illustrations of palynomorphs are included in this report, but the taxonomy is sufficiently detailed for it to be used to establish a palynostratigraphic framework. Tschudy's (1980) survey of records of Normapolles pollen in the Western United States, which includes photomicrographs, is useful and effective for verifying identifications of some of the taxa discussed in his earlier report.

The most recent and most thorough taxonomic study in the southern Western Interior region is that of Jameossanaie (1987). Jameossanaie described and illustrated 172 species of spores and pollen from Upper Cretaceous coal-bearing deposits in northwestern New Mexico. His taxonomy and nomenclature are current, and his specimens are well illustrated in 12 photographic plates. However, the interval discussed by Jameossanaie evidently is younger than the Straight Cliffs Formation in Utah.

The palynostratigraphic zonation of the Upper Cretaceous that has application in the study area is that of Nichols and others (1982). They defined biozones using both marine and nonmarine palynomorphs that are of potential utility in the study area, although these biozones are based on stratotype sections in Wyoming and Montana and their utility in southern Utah was previously untested. The study by

Nichols and others (1982) was updated recently (Nichols, 1994). Results from the study of the Kaiparowits cores show that two of these biozones in fact are present in southern Utah.

ANALYSES OF CORES SMP-1-91 AND CT-1-91

Ninety-one samples were collected and processed for this study, 49 from core SMP-1-91 (14 coal; 35 non-coal) and 42 from core CT-1-91 (3 coal; 39 non-coal, one of which was barren). Because more samples were available from that core, detailed analyses concentrated on SMP-1-91, which served as a standard for biostratigraphic (palynostratigraphic) interpretations, and CT-1-91 was used to verify results. Samples from SMP-1-91 include two series from thick coal beds here designated D8020 and D8068, respectively (fig. 4). Both are within the John Henry Member, but their importance especially concerns the sequence-stratigraphic interpretation of the Straight Cliffs Formation. Coal bed D8020 is 6.5 m thick and is near the middle of the A- sequence; coal bed D8068 is 4.3 m thick and is at the base of the A- sequence (just above the A- sequence boundary). D8020 serves as a representative of the thick coal beds in the A- sequence, and D8068 provides close biostratigraphic control useful for confirmation of the position of the A-sequence boundary.

Distribution of 56 palynomorph taxa in the cores was recorded in this study. Among these taxa are several at the genus level that include more than one species; thus the occurrences and distribution of 70 or more palynomorph species are considered. Pteridophyte spores and gymnosperm pollen are common but have little biostratigraphic importance. Species of angiosperm pollen known or thought to have biostratigraphic importance received special attention in this study, as did dinoflagellate cysts (recorded as a single category) that are indicative of tidal influence in the depositional environment. Percentage relative abundance of palynomorph taxa was determined for coal samples, to determine the composition of mire floras; semiquantitative evaluations of relative abundance were recorded for most other samples.

STRAIGHT CLIFFS PALYNOFLORA

A survey of the samples from cores SMP-1-91 and CT-1-91 shows that the palynoflora of the Straight Cliffs Formation is numerically dominated by spores of ferns and other cryptogams and pollen of gymnosperms, although angiosperm pollen, primarily small tricolpate forms, is numerically abundant in most samples as well. The commonly occurring species are well known in Upper Cretaceous rocks of the Western Interior of North America. However, some of the less common species (especially angiosperm pollen) serve to distinguish the Straight Cliffs palynoflora from others of the same age. A brief overview of the entire palynoflora follows.

The most commonly occurring spores are: species of the fern spore genera *Gleicheniidites* and *Laevigatosporites* (both of which are present in 65–85 percent of samples in each core and numerically dominant in some), species of the bryophyte spore genus *Stereisporites* (sphagnum moss; present in 50–70 percent of samples and abundant in several, notably in coal), and species of the fern spore genera *Cyathidites* and *Reticuloidosporites* (present in 45–60 percent of samples and common in many). *Gleicheniidites* spp. and *Stereisporites* spp. are especially common in coal samples, although they are also common in non-coal samples.

The most commonly occurring species of gymnosperm pollen in the Straight Cliffs Formation belong to the genera *Corollina*, *Araucariacites*, *Pityosporites*, and *Taxodiaceaepollenites*. These are present in 45–65 percent of the samples, but they tend not to be numerically abundant. *Corollina*, occurring usually as monads but also as tetrads, is present throughout the sampled interval, in all members of the formation, and is notably abundant in a few samples. Specimens assignable to species of the other three genera are extremely rare or absent in the coal samples analyzed in this study. This pattern of distribution in the Kaiparowits samples is especially significant for pollen of *Taxodiaceaepollenites* because this pollen is produced in great quantities by trees that are the principal component of swamp-forest vegetation in many Paleocene coal-depositional environments in the Western United States. Evidently these arboreal gymnosperms were not significant components of mire floras in the Kaiparowits area in Late Cretaceous time.

Angiosperm pollen is present throughout the Straight Cliffs Formation. Nondescript tricolpate pollen referable to the genera *Cupuliferoidaepollenites*, *Tricolpites*, and (or) *Retitricolpites* is present in almost every sample. This pollen, which probably has fagaceous or platanaceous affinity, is numerically abundant in many samples and dominant in some. Evidently it represents a major component of the flora. However, because pollen of this morphology is widespread both geographically and stratigraphically, and is of somewhat uncertain botanical affinity, it has little paleoecologic and no biostratigraphic value. Other angiosperm pollen of more distinctive morphology present at least in low numbers in many samples of the Straight Cliffs Formation belongs to species of the tricolporate genera *Nyssapollenites* and *Foveotricolporites* and the triporate genera *Triporopollenites*, *Plicapollis*, *Pseudoplicapollis*, and *Proteacidites*. Some of these species are useful in characterizing the formation palynologically and in interpreting it palynostratigraphically.

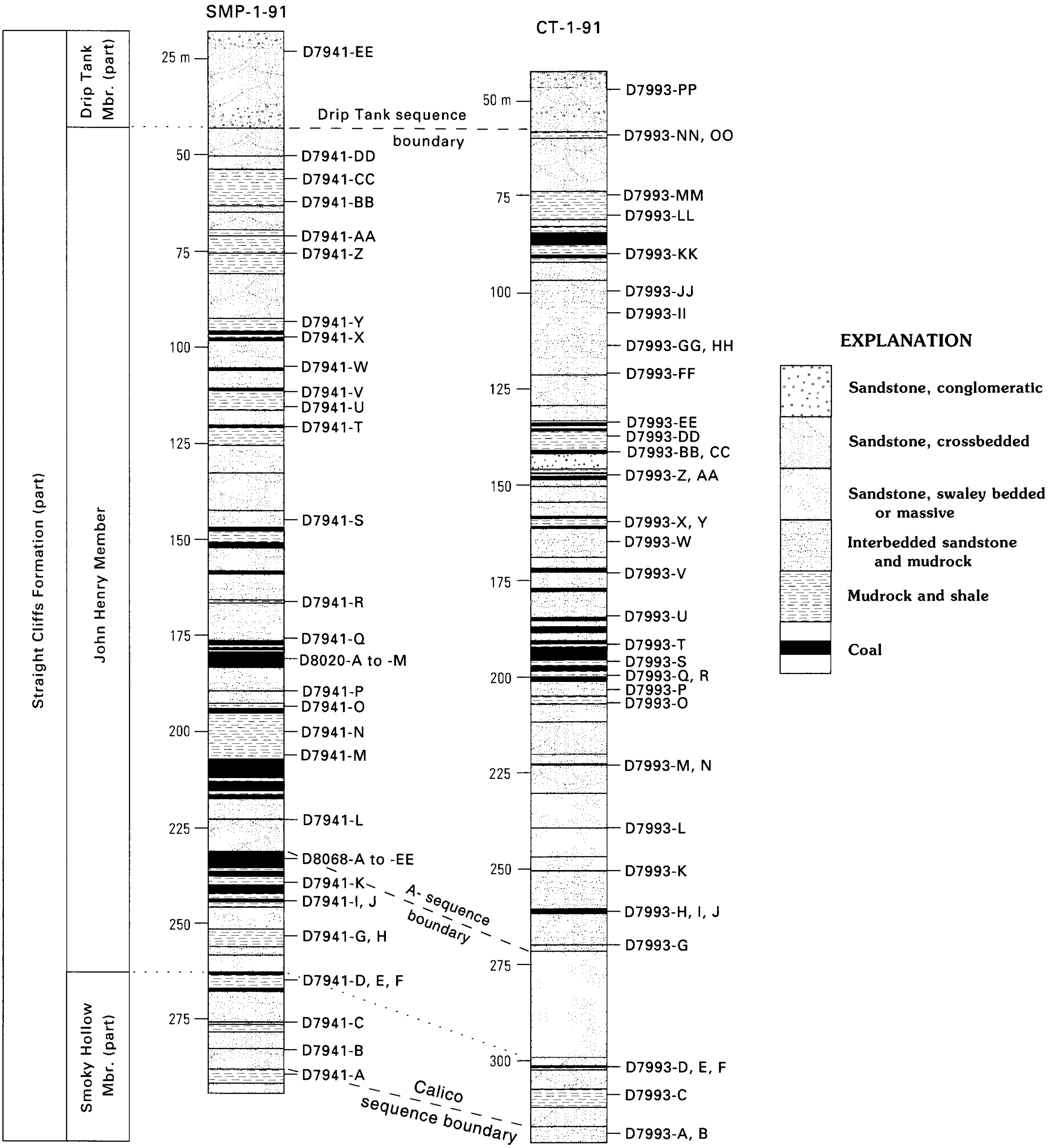


Figure 4. Generalized lithostratigraphy of cores SMP-1-91 and CT-1-91, approximate positions of palynological samples, and inferred correlations between the cores (modified from Hettinger, 1993). Datum is the Drip Tank sequence boundary, which is coincident with the contact between the John Henry and Drip Tank Members in the cores. Scale in meters (m) is depth in core.

CHARACTERISTIC SPECIES

Foveotricolporites johnhenryensis n. sp. is perhaps the single most characteristic species in the Straight Cliffs palynoflora (pl. 1, figs. 17–20). It is distinctive in appearance and relatively common in occurrence, being present in about one-third of all samples of the John Henry Member (it was not recorded in the few Smoky Hollow and Drip Tank Member samples examined). It was not reported in previous studies of the Straight Cliffs Formation by either Orlansky

(1971) or May (1972). A formal description of this tricolporate pollen species is given later in "Taxonomic Notes."

A second tricolporate species occurring in the Straight Cliffs Formation is less typical of the formation but is palynostratigraphically significant; that species is *Nyssapollenites albertensis* (pl. 1, fig. 16). It is present in the Smoky Hollow Member and throughout the John Henry Member (Tibbet and Calico sequences and above); it was not observed in the Drip Tank Member (Drip Tank sequence). It is significant because it (along with some other species) defines a major palynostratigraphic zone, which is discussed later.

Other characteristic species in the Straight Cliffs palynoflora are triporate angiosperm pollen. They are species of the Normapolles genera *Plicapollis* and *Pseudoplicapollis*, and species of *Proteacidites*. *Plicapollis rusticus* (pl. 1, fig. 15) was originally described from the upper Campanian of Tennessee by Tschudy (1975). Later he reported it from the Crevasse Canyon Formation (Coniacian and Santonian) and the basal part of the Menefee Formation (Santonian) in northwestern New Mexico (Tschudy, 1976, 1980). This species was not reported previously from the Straight Cliffs Formation by either Orlansky (1971) or May (1972). *Plicapollis rusticus* is present in the middle part of the John Henry Member, however, both below and above the A-sequence boundary. Species of *Pseudoplicapollis* in the Straight Cliffs are *P. cuneata* and *P. triradiata*. *P. cuneata* (pl. 1, fig. 13) was first described from Santonian of the Atlantic Coastal Plain (Christopher, 1979) and later reported from the lower Campanian of New Mexico by Jameossanaie (1987), who also described *P. triradiata* from the same deposits. Orlansky (1971, pl. 10, fig. 37) illustrated a specimen that appears to be *P. triradiata* (although he identified it as a species of *Cupanieidites*). In the Straight Cliffs Formation these species are present above the A- sequence boundary; *P. triradiata* is present also above the Drip Tank sequence boundary.

The occurrences of *Proteacidites* deserve special mention. Species of this triporate pollen genus characterize the Upper Cretaceous of the Western Interior of North America. Nichols and Jacobson (1982) reviewed all available records of its occurrence and determined that its stratigraphic range in the region is Coniacian through Maastrichtian. The genus has been reported previously in the Straight Cliffs Formation by Orlansky (1971) and May (1972). Species are difficult to distinguish, and in this study they are grouped under the name *Proteacidites* spp. (pl. 1, figs. 11–12). *Proteacidites* spp. is present in the John Henry Member in about half of all samples above the interpreted position of the A- sequence boundary and in the Drip Tank Member, that is, within the A- and Drip Tank sequences.

In addition to *Proteacidites* spp., other species of triporate pollen are present in the Straight Cliffs palynoflora, occurring in 50 percent or more of samples of the John Henry Member. In this study they were recorded as species of the form genus *Triporopollenites*, but some may belong to genera of the Normapolles complex other than *Plicapollis* and *Pseudoplicapollis*. Tschudy (1980) recognized *Vacuopollis* among specimens illustrated by Orlansky (1971, pl. 10, figs. 34–35). Orlansky (1971, pl. 10, figs. 31–32) illustrated two other specimens that he identified as *Sporopollis* sp. They do not belong to that genus, but appear to closely resemble specimens identified by Jameossanaie (1987, fig. 16, specimens 41–44 only) from Campanian rocks in New Mexico as *Complexiopollis abditus*. Similar specimens were observed in the present study, but their identification was not verified because they are very rare and consequently of less importance palynostratigraphically than the species of *Foveotricolporites, Plicapollis, Pseudoplicapollis,* and *Proteacidites* discussed previously.

Finally, the presence of *Arecipites* spp. (pl. 1, figs. 7–8) in the Straight Cliffs Formation is noteworthy. This occurrence may be the stratigraphically oldest record in North America of the genus, which has affinity with the Arecaceae (palm family). Palms have long been considered to be an important component of Cretaceous floras, but their pre-Maastrichtian pollen record is not well documented. In the Straight Cliffs Formation, pollen of *Arecipites* is present sporadically throughout the Coniacian-Santonian John Henry Member.

PALYNOSTRATIGRAPHIC ZONATION

On the basis of occurrences of key palynomorph taxa, two of the Upper Cretaceous palynostratigraphic zones of the Western Interior region are recognizable in the Straight Cliffs Formation. These are the *Nyssapollenites albertensis* Interval Zone and the *Proteacidites retusus* Interval Zone. The *Nyssapollenites albertensis* Zone is late Cenomanian through mid-Coniacian in age (Nichols, 1994). The presence of the *N. albertensis* Zone in the lower part of the Straight Cliffs Formation (Tibbet and Calico sequences) is consistent with the previously discussed late Turonian and early Coniacian age determinations of this interval based on molluscan fossils. *Nyssapollenites albertensis* is present also in the post-Coniacian part of the Straight Cliffs Formation, but there it is present along with species indicative of the overlying palynostratigraphic zone.

The lowest stratigraphic occurrence of the pollen species *Proteacidites retusus* defines the base of the mid-Coniacian through upper Santonian *P. retusus* Zone. The presence of the *P. retusus* Zone in the John Henry Member verifies the Coniacian-Santonian age of that unit. More important with regard to the sequence stratigraphy of the Straight Cliffs Formation, the occurrence of *Proteacidites* pollen coincides with the interpreted position within the John Henry Member of the A- sequence (Hettinger, 1993, 1995). The morphologically distinctive and biostratigraphically important pollen of *Proteacidites* has its lowest stratigraphic occurrence just above the interpreted position of the A- sequence boundary in both cores, at 759 ft (231.3 m) in SMP-1-91 and at 890 ft (271.3 m) in CT-1-91. Pollen of *Proteacidites* is consistent in occurrence in samples above these levels in both cores. That the actual first occurrence datum of the *P. retusus* Zone in both cores just happens to coincide with the interpreted position of the A-sequence boundary is highly unlikely. On the contrary, it is highly likely that the apparent base of the zone coincides with a minor unconformity (the A- sequence boundary), the presence of which enhances the abrupt appearance of palynomorphs that characterize the palynostratigraphic zone. Thus palynostratigraphy supports the interpretation of the A- sequence boundary as a significant stratigraphic horizon, which in turn supports the sequence-stratigraphic interpretation of the Straight Cliffs Formation.

The positions of two other sequence boundaries are interpreted by Hettinger (1993, 1995) within cores SMP-1-91 and CT-1-91. He identified the Calico sequence boundary at the 944.1 ft (287.8 m) level in SMP-1-91 and at the 1,041.1 ft (317.3 m) level in CT-1-91. Palynostratigraphic data are limited at these depths in the cores because only one productive sample was recovered in each core from strata below the interpreted position of the Calico sequence boundary. Although the data are limited, palynostratigraphy provides some support for the presence of an unconformity. In core SMP-1-91, sample D7941–A, which is below the interpreted position of the Calico sequence boundary, yielded a palynomorph assemblage of seven taxa, all of which are present also in overlying strata (fig. 5). The assemblage in sample D7941–B, 6 m above, has 12 additional taxa, all of which are present also in overlying strata. This strong change in the palynoflora, which is much stronger than that between any other two successive samples in the core, is indicative of the presence of an unconformity between the sampled horizons. The palynofloral change across the interpreted position of the Calico sequence boundary is less striking in core CT-1-91 (fig. 6), but still possibly significant. More data are needed to verify these results.

Hettinger (1993, 1995) interpreted the position of the Drip Tank sequence boundary to be at the 143.1 ft (43.6 m) level in core SMP-1-91 and at the 206 ft (62.8 m) level in core CT-1-91. Here again palynologic data are extremely limited, because only one palynologically productive sample could be obtained above those horizons in each core. No significant changes are noted between assemblages bracketing the boundary in either core. In both cores the assemblages both below and above the interpreted position of the boundary are within the *Proteacidites retusus* Zone. Notably absent from all assemblages from the cores are specimens of the pollen species *Pseudoplicapollis newmanii* (although two other species of the genus are present). This biostratigraphically important lower Campanian species defines a palynostratigraphic zone of earliest Campanian age in the Rocky Mountain region (Nichols and others, 1982; Nichols, 1994). Although more data clearly are needed, the evidence at hand is that the basal part of the Drip Tank sequence (and the basal part of the Drip Tank Member) are no younger than late Santonian.

PALEOENVIRONMENTS

Little can be said of the paleoenvironmental setting of the Straight Cliffs Formation, based on palynology, that is not already evident from consideration of stratigraphy, sedimentology, and lithology. As mentioned, the most common species of pollen and spores in the formation are similarly common in contemporaneous rocks throughout the Western Interior region. In this study these species were recovered from a variety of depositional environments ranging from tidal estuaries through coastal plain, fluvial floodplain, and coal-forming mire. A few observations are worth summarizing, however.

About 50 percent of samples collected from intervals interpreted as tidal or tidally influenced deposits (tables 1 and 2) contain rare marine dinoflagellate cysts (dinocysts). Their presence substantiates the sedimentological evidence of tidal influence for these samples. The relative abundance of dinocysts is less than 1 percent in those samples, and additional scans of slides prepared from the other samples interpreted as deposited under tidal influence may reveal dinocysts in some of them, as well. Dinocysts were recorded also in two samples from core SMP-1-91 (table 1) and two from CT-1-91 (table 2) that have been interpreted as being from floodplain deposits. The paleoenvironment of these deposits may bear reevaluation, but their stratigraphic position is in close proximity to beds deposited under tidal influence (Hettinger, 1993, 1995). It is noteworthy that the presence of dinocysts in rocks deposited so far from a marine environment would have been difficult to interpret, had not the stratigraphic and sedimentologic analyses indicated the presence of tidally influenced deposits. These specimens might have been interpreted simply as out of place, perhaps as reworked from underlying marine rocks.

Although data are limited, the palynoflora of coal samples analyzed suggests that the vegetation of the coal-forming mires was dominated by ferns and mosses, with certain angiosperms also present as major components. Interpretations are based on analyses of selected samples from two thick coal beds (D8020 and D8068), and from two thin coal beds in core SMP-1-91 and three thin coal beds in CT-1-91 (see tables 1 and 2).

That these mires were raised bogs, as suggested by McCabe and Shanley (1992), is reasonable. Sphagnum moss (represented by several species of the spore genus *Stereisporites*) is common in several samples of coal analyzed. In some modern peat-forming environments, sphagnum moss forms raised bogs. However, sphagnum moss clearly was only one component of mire vegetation, and it did not

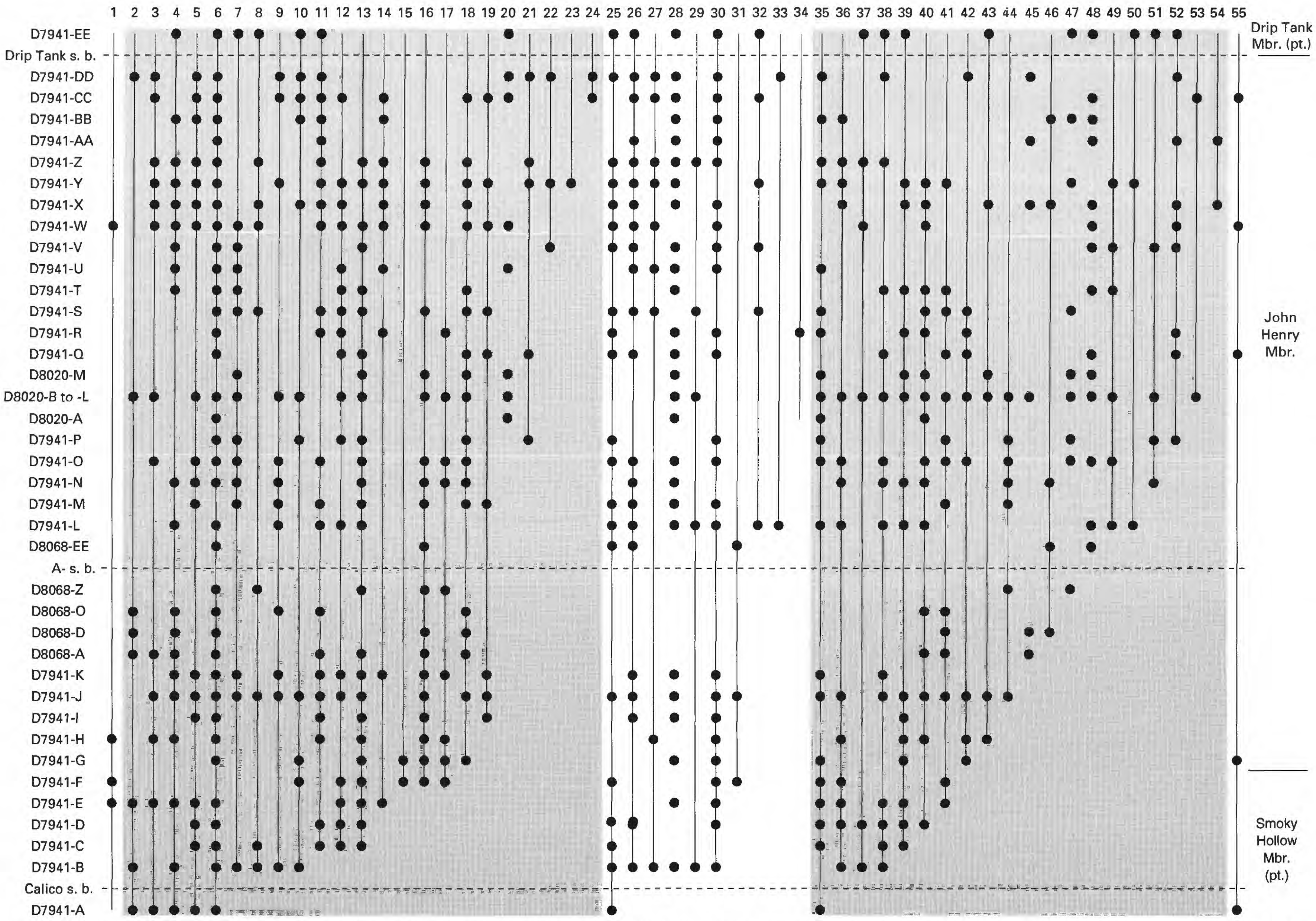


Figure 5. Stratigraphic occurrences of palynomorph taxa by sample in core SMP-1-91. Dots indicate presence. Records for D8020–B to –L are composited from all samples from a single thick coal bed. Numbers are keyed to the list of taxonomic names in table 3. Taxa are divided into major groups: 1, marine dinocysts, undifferentiated; 2–24, bryophyte and pteridophyte spores (shaded); 25–34, gymnosperm pollen; 35–54, angiosperm pollen (shaded); 55, freshwater algal cysts, undifferentiated.

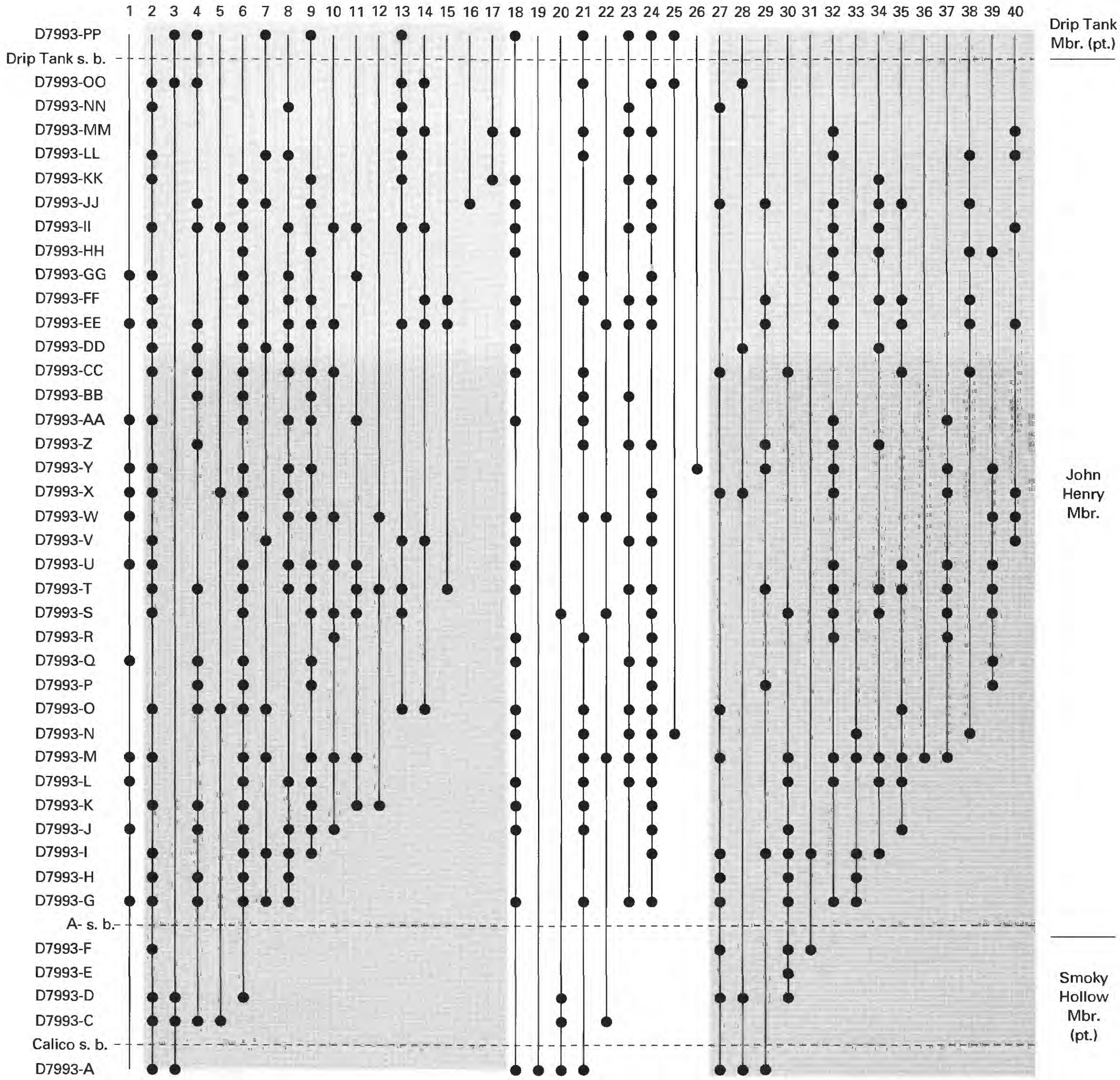


Figure 6. Stratigraphic occurrences of palynomorph taxa by sample in core CT-1-91. Dots indicate presence. Numbers are keyed to the list of taxonomic names in table 4; fewer individual taxa listed than in figure 5 because some are combined and others omitted. Taxa are divided into major groups: 1, marine dinocysts, undifferentiated; 2–17, bryophyte and pteridophyte spores (shaded); 18–26, gymnosperm pollen; 27–40, angiosperm pollen (shaded).

dominate these paleoenvironments to the exclusion of other plant species, as it does in some modern environments. Ferns producing spores assignable to three species of *Gleicheniidites* evidently were the most common plants in mires, and angiosperm pollen of one kind is abundant.

The botanical affinity of the most common angiosperm pollen in coal samples (*Cupuliferoidaepollenites* spp.) is somewhat uncertain, although the pollen morphology is suggestive of the modern family Fagaceae. It is possible, although not demonstrable, that the plants producing this pollen were trees (many modern species of the Fagaceae are arboreal in habit). Forests that grow on raised bogs in the tropics at present have low species diversity (Teichmüller and Teichmüller in Stach and others, 1975). Presumably Late Cretaceous climates of the Kaiparowits area were subtropical or tropical (as indicated, for example, by the presence of palm pollen in the Straight Cliffs palynoflora). Thus, pollen of *Cupuliferoidaepollenites* may represent trees that

Table 3. Alphabetical and numerical lists of palynomorph taxa recorded in samples from core SMP-1-91.

[Numbers are keyed to the distribution chart (fig. 5)]

Alphabetical list	Numerical list
Aequitriradites spinulosus (Cookson & Dettmann) Cookson & Dettmann (24)	1 Dinocysts, undifferentiated
Appendicisporites spp. (2)	2 *Appendicisporites* spp.
Araucariacites australis Cookson ex Couper (26)	3 *Camarozonosporites ambigens* (Fradkina) Playford
Arecipites sp. 1 (43)	4 *Cicatricosisporites* spp.
Arecipites sp. 2 (50)	5 *Deltoidospora* sp. "T"
Biretisporites sp. (22)	6 *Laevigatosporites haardtii* (Potonié & Venitz) Thomson & Pflug
Callialasporites dampieri (Balme) Dev emend. Norris (27)	7 *Echinatisporis varispinosus* (Pocock) Srivastava
Camarozonosporites ambigens (Fradkina) Playford (3)	8 *Matonisporites* sp.
Cicatricosisporites spp. (4)	9 *Triporoletes novomexicanus* (Anderson) Srivastava
Corollina torosa (Reissinger) Klaus emend. Cornet & Traverse (28)	10 Other spores
Cupuliferoidaepollenites spp. (39)	11 *Cyathidites* sp. cf. *C. diaphana* (Wilson & Webster) Nichols & Brown
Cupuliferoipollenites sp. (51)	12 *Gleicheniidites senonicus* Ross emend. Skarby, var. 2
Cyathidites sp. cf. *C. diaphana* (Wilson & Webster) Nichols & Brown (11)	13 *Stereisporites* spp.
Deltoidospora minor (Couper) Pocock (20)	14 *Microreticulatisporites* sp.
Deltoidospora sp. "T" (5)	15 *Foveosporites* sp.
Echinatisporis varispinosus (Pocock) Srivastava (7)	16 *Gleicheniidites senonicus* Ross emend. Skarby, var. 1
Ephedripites sp. "D" (34)	17 *Gleicheniidites senonicus* Ross emend. Skarby, var. 3
Eucommiidites minor Groot & Penny (29)	18 *Reticuloidosporites pseudomurii* Elsik
Foraminisporis wonthaggiensis (Cookson & Dettmann) Dettmann (19)	19 *Foraminisporis wonthaggiensis* (Cookson & Dettmann) Dettmann
Foveosporites sp. (15)	20 *Deltoidospora minor* (Couper) Pocock
Foveotricolporites johnhenryensis n. sp. (40)	21 "*Palaeoisoetes*" sp.
Gleicheniidites senonicus Ross emend. Skarby, var. 1 (16)	22 *Biretisporites* sp.
Gleicheniidites senonicus Ross emend. Skarby, var. 2 (12)	23 *Ornamentifera echinata* (Bolkhovitina) Bolkhovitina
Gleicheniidites senonicus Ross emend. Skarby, var. 3 (17)	24 *Aequitriradites spinulosus* (Cookson & Dettmann) Cookson & Dettmann
Laevigatosporites haardtii (Potonié & Venitz) Thomson & Pflug (6)	25 *Pityosporites* spp.
Liliacidites sp. (46)	26 *Araucariacites australis* Cookson ex Couper
Matonisporites sp. (8)	27 *Callialasporites dampieri* (Balme) Dev emend. Norris
Microreticulatisporites sp. (14)	28 *Corollina torosa* (Reissinger) Klaus emend. Cornet & Traverse
Nyssapollenites albertensis Singh (36)	29 *Eucommiidites minor* Groot & Penny
Nyssapollenites sp. (37)	30 *Taxodiaceaepollenites hiatus* (Potonié) Kremp
Ornamentifera echinata (Bolkhovitina) Bolkhovitina (23)	31 *Rugubivesiculites* sp.
"*Palaeoisoetes*" sp. (21)	32 *Quadripollis krempii* Drugg
Pityosporites spp. (25)	33 *Pristinuspollenites* sp.
Plicapollis rusticus Tschudy (44)	34 *Ephedripites* sp. "D"
Pristinuspollenites sp. (33)	35 *Tricolpites minutus* Sah & Kar
Proteacidites spp. (48)	36 *Nyssapollenites albertensis* Singh
Pseudoplicapollis cuneata Christopher (49)	37 *Nyssapollenites* sp.
Pseudoplicapollis triradiata Jameossanaie (52)	38 Other pollen
Quadripollis krempii Drugg (32)	39 *Cupuliferoidaepollenites* spp.
Reticuloidosporites pseudomurii Elsik (18)	40 *Foveotricolporites johnhenryensis* n. sp.
Rhoipites spp. (45)	41 *Tricolpites* spp.
Rugubivesiculites sp. (31)	42 *Triporopollenites* sp. 2
Sparganiaceaepollenites hospahensis Jameossanaie (53)	43 *Arecipites* sp. 1
Stereisporites spp. (13)	44 *Plicapollis rusticus* Tschudy
Taxodiaceaepollenites hiatus (Potonié) Kremp (30)	45 *Rhoipites* spp.
Triatriopollenites granulatus (Simpson) Leffingwell (54)	46 *Liliacidites* sp.
Tricolpites minutus Sah & Kar (35)	47 *Triporopollenites* sp. 1
Tricolpites spp. (41)	48 *Proteacidites* spp.
Triporoletes novomexicanus (Anderson) Srivastava (9)	49 *Pseudoplicapollis cuneata* Christopher
Triporopollenites sp. 1 (47)	50 *Arecipites* sp. 2
Triporopollenites sp. 2 (42)	51 *Cupuliferoipollenites* sp.
Algal cysts, undifferentiated (55)	52 *Pseudoplicapollis triradiata* Jameossanaie
Dinocysts, undifferentiated (1)	53 *Sparganiaceaepollenites hospahensis* Jameossanaie
Other pollen (38)	54 *Triatriopollenites granulatus* (Simpson) Leffingwell
Other spores (10	55 Algal cysts, undifferentiated

Table 4. Alphabetical and numerical lists of palynomorph taxa recorded in samples from core CT-1-91.

[Numbers are keyed to the distribution chart (fig. 6)]

Alphabetical list	Numerical list
Appendicisporites spp. (15)	1 Dinocysts, undifferentiated
Araucariacites australis Cookson ex Couper (23)	2 *Laevigatosporites haardtii* (Potonié & Venitz) Thomson & Pflug
Arecipites spp. (38)	3 Other spores
Callialasporites dampieri (Balme) Dev emend. Norris (22)	4 *Deltoidospora minor* (Couper) Pocock
Camarozonosporites ambigens (Fradkina) Playford (10)	5 *Foraminisporis wonthaggiensis* (Cookson & Dettmann) Dettmann
Cicatricosisporites spp. (7)	6 *Gleicheniidites* spp.
Corollina torosa (18)	7 *Cicatricosisporites* spp.
Cupuliferoidaepollenites spp. (27)	8 *Reticuloidosporites pseudomurii* Elsik
Cupuliferoipollenites sp. (36)	9 *Stereisporites* spp.
Cyathidites sp. cf. *C. diaphana* (Wilson & Webster) Nichols & Brown (17)	10 *Camarozonosporites ambigens* (Fradkina) Playford
Deltoidospora minor (Couper) Pocock (4)	11 *Echinatisporis varispinosus*
Deltoidospora sp. "T" (13)	12 *Microreticulatisporites* sp.
Echinatisporis varispinosus (11)	13 *Deltoidospora* sp. "T"
Ephedripites sp. "D" (19)	14 *Triporoletes novomexicanum* (Anderson) Srivastava
Foraminisporis wonthaggiensis (Cookson & Dettmann) Dettmann (5)	15 *Appendicisporites* spp.
Foveotricolporites johnhenryensis n. sp. (34)	16 *Ornamentifera echinata* (Bolkhovitina) Bolkhovitina
Gleicheniidites spp. (6)	17 *Cyathidites* sp. cf. *C. diaphana* (Wilson & Webster) Nichols & Brown
Laevigatosporites haardtii (Potonié & Venitz) Thomson & Pflug (2)	18 *Corollina torosa*
Microreticulatisporites sp. (12)	19 *Ephedripites* sp. "D"
Nyssapollenites albertensis (35)	20 *Rugubivesiculites* sp.
Nyssapollenites sp. (28)	21 *Taxodiaceaepollenites hiatus* (Potonié) Kremp
Ornamentifera echinata (Bolkhovitina) Bolkhovitina (16)	22 *Callialasporites dampieri* (Balme) Dev emend. Norris
Pityosporites spp. (24)	23 *Araucariacites australis* Cookson ex Couper
Plicapollis rusticus Tschudy (39)	24 *Pityosporites* spp.
Pristinuspollenites sp. (26)	25 *Quadripollis krempii* Drugg
Proteacidites spp (32)	26 *Pristinuspollenites* sp.
Pseudoplicapollis spp. (40)	27 *Cupuliferoidaepollenites* spp.
Quadripollis krempii Drugg (25)	28 *Nyssapollenites* sp.
Reticuloidosporites pseudomurii Elsik (8)	29 *Tricolpites* spp.
Rhoipites spp. (31)	30 *Tricolpites minutus* Sah & Kar
Rugubivesiculites sp. (20)	31 *Rhoipites* spp.
Stereisporites spp. (9)	32 *Proteacidites* spp.
Taxodiaceaepollenites hiatus (Potonié) Kremp (21)	33 Other pollen
Tricolpites minutus Sah & Kar (30)	34 *Foveotricolporites johnhenryensis* n. sp.
Tricolpites spp. (29)	35 *Nyssapollenites albertensis*
Triporoletes novomexicanum (Anderson) Srivastava (14)	36 *Cupuliferoipollenites* sp.
Triporopollenites spp. (37)	37 *Triporopollenites* spp.
Dinocysts, undifferentiated (1)	38 *Arecipites* spp.
Other pollen (33)	39 *Plicapollis rusticus* Tschudy
Other spores (3)	40 *Pseudoplicapollis* spp.

inhabited raised bogs in the area, and that contributed to the accumulation of coal-forming peat.

As mentioned, pollen of taxodiaceous conifers such as that which dominates palynological assemblages from most thick Tertiary coal beds in the region is very rare. Thus no palynological evidence is available that coniferous trees were major contributors to Straight Cliffs coal. Further detailed analyses of Straight Cliffs coal-depositional environments represented by thick coal beds are warranted, especially in conjunction with coal-petrographic analyses.

CONCLUSIONS

Palynologic analyses demonstrate the presence of two regional palynostratigraphic zones in upper Turonian through upper Santonian strata of the Straight Cliffs Formation in the Kaiparowits Plateau. This stratigraphic interval includes the upper part of the Smoky Hollow Member, the John Henry Member, and lower part of the Drip Tank Member of conventional lithostratigraphy, and corresponding, recently defined sequence-stratigraphic units, namely the upper part of the Tibbet sequence, the Calico and

A- sequences, and the lower part of the Drip Tank sequence. The *Nyssapollenites albertensis* Zone (upper Cenomanian through mid-Coniacian) is present in the upper part of the Smoky Hollow Member and lower part of the John Henry Member (=uppermost part of the Tibbet sequence and the Calico sequence), and the *Proteacidites retusus* Zone (mid-Coniacian through upper Santonian) is present in the middle and upper parts of the John Henry Member and lowermost part of the Drip Tank Member (=the A- sequence and lowermost part of the Drip Tank sequence). No palynomorphs indicative of Campanian age were found in the Drip Tank Member, but very few samples from the Drip Tank were available for analysis.

The boundary between the two palynostratigraphic zones coincides with the position of the A- sequence boundary as interpreted in the cores by Hettinger (1993, 1995). Limited palynostratigraphic data also tend to confirm the interpreted position of the Calico sequence boundary. The interpreted position of the Drip Tank sequence boundary has not been confirmed, but too few samples were available to resolve this question with certainty on the basis of palynostratigraphy.

Tidally influenced deposits in transgressive and highstand systems tracts are indicated by the presence of rare marine dinocysts in predominantly nonmarine strata. They confirm Hettinger's (1993, 1995) interpretation of depositional environment of these beds. These dinocysts are found at considerable distance from the ancient shoreline and would be otherwise difficult to account for in predominantly fluvial deposits.

Unusually thick coal beds are present in the John Henry Member, in highstand systems tracts landward of stacked shoreface parasequences that form the Straight Cliffs escarpment. Palynological analyses of coal samples indicate that the vegetation of the coal-forming mires consisted largely of ferns and sphagnum moss together with certain species of angiosperms. The mire floras may have included arboreal angiosperms.

Some species of angiosperm pollen in the Straight Cliffs palynoflora are biostratigraphically important forms, especially pollen of the Normapolles complex and certain other triporates. Records of occurrence of some pollen and spore species in the study area are contributions to knowledge of Upper Cretaceous palynostratigraphy. One species of angiosperm pollen is new.

Additional palynostratigraphic studies of the Straight Cliffs Formation, especially the unsampled basal and uppermost parts, should provide further tests of sequence-stratigraphic interpretations of these largely nonmarine strata. Further detailed palynologic studies of the thick coal beds should provide a more complete overview of the nature of the coal-forming mires, especially if conducted in close collaboration with coal-petrographic analyses.

TAXONOMIC NOTES

The following comments provide some detail about selected pollen and spore species present in the Straight Cliffs palynoflora. They may serve in further investigations of the palynology of the Kaiparowits area. Formal description of a new species is given. After this description, several previously described taxa are discussed in alphabetical order.

FOVEOTRICOLPORITES JOHNHENRYENSIS n. sp.

Plate 1, figures 17–20.

Holotype: Slide D7993-I (1), England Finder coordinates 27L/1; plate 1, figure 17.

Type Repository: U.S. Geological Survey, Denver laboratory, Palynological Type Collection.

Description: Tricolporate pollen, spheroidal to oblate, amb triangular to slightly rounded triangular with blunt corners; colpi bordered by prominent margines of thickened ektexine 1–1.5 μm wide, extending about one-half of radius toward poles on each hemisphere; pori circular, unbordered, ≈1.5 μm in diameter, obscure in polar view; sculpture foveolate to foveo-reticulate, lumina 0.5–1.0 μm, muri 0.5–1.0 μm, sculpture tending to become finer toward colpi; exine ≈1.5 μm thick; diameter of grains 20–27 μm, most less than 25 μm (19 specimens measured).

Comparison: The genus *Foveotricolporites* was proposed by Pierce (1961) for foveolate, tricolporate pollen; the type species is *F. rhombohedralis* Pierce. *Foveotricolporites johnhenryensis* n. sp. differs from *F. rhombohedralis* from the Cenomanian of Minnesota in having prominent margines and in its oblate rather than prolate form. It differs from *F. callosus* Singh from the Cenomanian of Alberta in its oblate rather than prolate form, and from *Tricolporopollenites* sp. 2 of May (1972) from the Turonian of Utah, with which Singh (1983) compared his species, in form and in smaller size. No other species of *Foveotricolporites* have been described from the Cretaceous. *Foveotricolporites johnhenryensis* n. sp. differs from *Margocolporites varireticulatus* Jameossanaie from the Campanian of New Mexico, to which it bears resemblance, in having oblate rather than prolate form, in tending to have a rounded triangular amb rather than straight to concave sides, and in having shorter colpi. It differs from species of *Nyssapollenites* in the Straight Cliffs palynoflora and elsewhere in having foveolate sculpture, and from Straight Cliffs species and others belonging in the genus *Rhoipites* in being oblate rather than prolate, and in having unbordered pores.

Occurrence: John Henry Member of the Straight Cliffs Formation (Coniacian-Santonian), Kaiparowits Plateau, Utah. This species is present in about one third of the samples analyzed.

ARECIPITES spp.

Plate 1, figures 7–8.

Pollen assigned to this genus is monosulcate and acuminate-oval in polar view. Specimens from the Straight Cliffs Formation are 15–20×30–35 μm in size. The exine is thin, two-layered, and foveolate to finely reticulate. Two species are informally recognized in this study, one having slightly coarser sculpture than the other. Too few specimens were recorded to provide a basis for formal description of new species.

Pollen of this morphology is characteristic of the palm family, Arecaceae (also called Palmae). Similar pollen is common in younger Cretaceous rocks in western North America, but the Kaiparowits specimens may be the stratigraphically oldest, well-documented specimens of palm pollen so far recorded. Similar specimens are present in the Straight Cliffs Formation in the Markagunt Plateau area of southwestern Utah (D.J. Nichols, unpub. data, 1994).

COROLLINA TOROSA (Reissinger) Klaus emend. Cornet & Traverse

Plate 1, figure 6.

Pollen of the species *Corollina torosa* is present in almost all samples of the Straight Cliffs Formation, including those from coal, although it is relatively rare in samples from the thick coal here designated bed D8020. It tends to dominate assemblages from below and within the Calico bed, from some levels sampled within the John Henry Member, and from the Drip Tank Member.

This species was produced by gymnosperms of the extinct family Hirmerelliaceae, cheirolepidiaceous conifers (Traverse, 1988), and it can be considered as characteristic of the Straight Cliffs palynoflora. The plants that produced this pollen must have been prominent members of the plant communities of the Kaiparowits area in mid-Cretaceous (late Turonian through Santonian) time. They apparently were warmth-loving shrubs that grew in thickets in low-lying environments marginal to water (Traverse, 1988).

CUPULIFEROIDAEPOLLENITES spp.

Plate 1, figure 9.

Small, psilate tricolpate pollen from the Straight Cliffs Formation was assigned to *Cupuliferoidaepollenites* spp. Most of these specimens belong to the species *C. minutus* (Brenner) Singh, which is illustrated in plate 1. This pollen is present at least in low numbers in almost all samples and is abundant in some. The specimens recovered have negligible biostratigraphic or paleoecologic significance but are noteworthy as components of the Straight Cliffs palynoflora. They probably represent species of the family Fagaceae.

CYATHIDITES sp. cf. *C. DIAPHANA* (Wilson & Webster) Nichols & Brown

Plate 1, figure 2.

This species is trilete, rounded-triangular in outline with strongly concave sides, and psilate. The laesurae extend little more than halfway from the proximal pole to the margin. Specimens closely resemble *Cyathidites diaphana*, an upper Maastrichtian and lower Paleocene species. The Kaiparowits species is common throughout the Straight Cliffs Formation. These spores were produced by ferns that were present in several Straight Cliffs depositional environments and were not restricted to the coal-forming mires of the John Henry Member, where other species of fern were common. Although the genus name suggests affinity with the modern tree-fern genus *Cyathea*, there is no evidence that these spores represent tree ferns.

ECHINATISPORIS VARISPINOSUS (Pocock) Srivastava

Plate 1, figure 3.

This species is trilete (although the laesurae are obscured on most specimens), circular in outline, and distinctively echinate. It presumably was produced by some kind of fern, although its precise botanical affinity is unclear. These spores are common throughout the Straight Cliffs Formation, are present in most samples analyzed, and are abundant in some. The species has a long range in the Cretaceous of western North America and is notable in the Straight Cliffs palynoflora only because it is so common.

GLEICHENIIDITES spp.

Plate 1, figure 4.

Spores assigned to *Gleicheniidites* spp. in this study are trilete, triangular, and psilate, and are distinctive in having the prominent interradial crassitudes characteristic of the genus. All specimens recorded or observed can be assigned to the rather broadly defined species *Gleicheniidites senonicus* Ross emend. Skarby. Among Straight Cliffs specimens, as many as three species might be distinguished on the basis of details of morphology such as diameter and extent of development of interradial crassitudes, but only cursory effort was made to make such distinctions because the morphologic variants do not differ in stratigraphic occurrence.

These spores, which were produced by gleicheniaceous ferns, are present in almost all samples of the John Henry Member. They are especially common in coal samples and probably represent one or more species of fern that inhabited coal-forming mires in the Kaiparowits area in Late Cretaceous time.

NYSSAPOLLENITES ALBERTENSIS Singh

Plate 1, figure 16.

Nyssapollenites albertensis is tricolporate and psilate, and small in size. The species is present throughout the

Straight Cliffs Formation. Although it is not especially common, it is important because it signifies the presence of the upper Cenomanian to middle Coniacian *Nyssapollenites albertensis* Interval Zone (Nichols, 1994). This zone is present in the lower part of sections sampled in each core, below the position of the A- sequence boundary. Above that horizon, this species occurs with *Proteacidites retusus* in the *Proteacidites retusus* Interval Zone (middle Coniacian–upper Santonian).

PLICAPOLLIS RUSTICUS Tschudy

Plate 1, figure 15.

Plicapollis rusticus is a morphologically distinctive species of the Normapolles complex of pollen originally described from the upper Campanian of Tennessee by Tschudy (1975). Specimens are triporate and the apertures are complexly structured, as is characteristic of Normapolles pollen, and this species is characterized by a prominent triradiate plication or thickening of the exine centered at the pole and extending to the apertures. The specimens recorded in this study are from 25 to 29 µm in diameter (nine specimens measured).

As mentioned, similar specimens, probably of the same species, were illustrated by Tschudy (1980) from the Crevasse Canyon (Coniacian-Santonian) and Menefee Formations (Santonian) in New Mexico. In the Kaiparowits Plateau, this species is present within the John Henry Member of the Straight Cliffs Formation.

PROTEACIDITES spp.

Plate 1, figures 11–12.

Proteacidites spp. includes one or more species of distinctive triporate, reticulate pollen as illustrated in plate 1. Two species, *P. retusus* Anderson and *P. thalmannii* Anderson, were described from New Mexico by Anderson (1960), but many more species may exist in the Senonian rocks of the region. Straight Cliffs Formation specimens resemble these, but no attempt has been made to resolve their taxonomy and nomenclature at the species level.

Species of *Proteacidites* are among the most biostratigraphically important kinds of pollen in western North America, because they are present throughout the Upper Cretaceous, from the Coniacian through the Maastrichtian. As noted in the discussion of palynostratigraphy, the stratigraphic range of the genus is of special importance in this study. It defines the presence of the middle Coniacian-upper Santonian *Proteacidites retusus* Interval Zone in the John Henry Member of the Straight Cliffs Formation specifically within the A- sequence as determined in the cores by Hettinger (1993, 1995). Presence of this biozone reconfirms the age of the formation, which was previously determined (with some uncertainty) on the basis of its molluscan fauna. It also demonstrates that the palynostratigraphic zone, which has its stratotype in western Wyoming, extends as far south as the Kaiparowits area of southern Utah.

PSEUDOPLICAPOLLIS CUNEATA Christopher

Plate 1, figure 13.

Pseudoplicapollis cuneata is another member of the Normapolles complex of pollen. The triporate apertures are distinctive in internal structure. This species is distinguished from others of the genus by the absence of triradiate plications at the poles. As mentioned, this species was first described from the Santonian of the Atlantic Coastal Plain by Christopher (1979) and also has been reported from the lower Campanian of New Mexico by Jameossanaie (1987). In the Kaiparowits Plateau, it is present in the John Henry Member of the Straight Cliffs Formation above the position of the A- sequence boundary as determined in cores SMP-1-91 and CT-1-91 by Hettinger (1993, 1995).

RETICULOIDOSPORITES PSEUDOMURII Elsik

Plate 1, figure 5.

This monolete spore is characterized by rough and irregular sculpture that vaguely resembles reticulation. This species differs from the other species of monolete spore in the Straight Cliffs palynoflora, *Laevigatosporites haardtii* (not illustrated), in its distinctive sculpture.

Reticuloidosporites pseudomurii is biostratigraphically important because it serves to verify the presence of the *Proteacidites retusus* Interval Zone in the Straight Cliffs Formation. It is present only above the A- sequence boundary in core CT-1-91, but it occurs in two samples below this stratigraphic level, still within the John Henry Member, in core SMP-1-91.

STEREISPORITES spp.

Plate 1, figure 1.

Stereisporites spp. includes species that are assigned by some authors to one or more of the genera *Cingutriletes, Distanocorisporis, Distverrusporis*, and *Sphagnumsporites.* Several distinguishable species are present in the Straight Cliffs palynoflora, although only one is illustrated in plate 1.

These spores were produced by Cretaceous species related to the modern genus *Sphagnum*, sphagnum moss. They have no biostratigraphic value because they are known throughout the Upper Cretaceous (as well as older and younger strata), but they are ecologically important because they indicate the presence of sphagnum bogs in the Kaiparowits area during the Coniacian and Santonian. These spores are present throughout the coal-bearing John Henry Member of the Straight Cliffs Formation and are notably abundant in some samples, especially of coal. As mentioned, the coal-forming mires (or bogs) of the John Henry Member also contained abundant ferns (some fern spores are illustrated in pl. 1, figs. 2–5) and some angiosperms.

***TRICOLPITES* spp.**

Plate 1, figure 10.

Small, reticulate, tricolpate pollen is common in the Straight Cliffs palynoflora, occurring in most samples and all members of the formation. Two species were distinguished on the basis of coarseness of sculpture, only one of which is illustrated in plate 1. These species have no biostratigraphic value because they or others virtually indistinguishable from them are common throughout the Cretaceous and Tertiary of western North America. They have little ecologic value, either, because they could represent a wide variety of angiosperms having a variety of ecologic preferences. Botanical affinity probably is with the Platanaceae.

***TRIPOROPOLLENITES* spp.**

Plate 1, figure 14.

Several species of triporate pollen, other than species of the Normapolles complex mentioned previously, are present in the samples analyzed in this study. Only one is illustrated in plate 1. These species differ from Normapolles triporates in having simple aperture structure. They represent several species of angiosperms present in the Kaiparowits area during Coniacian and Santonian time, none of which was especially abundant. However, their presence serves to characterize the Straight Cliffs palynoflora.

REFERENCES CITED

Anderson, R.Y., 1960, Cretaceous-Tertiary palynology, eastern side of the San Juan Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 6, 59 p., pls. 1–11.

Christopher, R.A., 1979, Normapolles and triporate pollen assemblages from the Raritan and Magothy Formations (Upper Cretaceous) of New Jersey: Palynology, v. 3, p. 73–121, pls. 1–9.

Eaton, J. G., 1991, Biostratigraphic framework for the Upper Cretaceous rocks of the Kaiparowits Plateau, southern Utah, *in* Nations, J.D., and Eaton, J.G., eds., Stratigraphy, depositional environments, and sedimentary tectonics of the western margin, Cretaceous Western Interior Seaway: Geological Society of America Special Paper 260, p. 47–63.

Gregory, H.E., and Moore, R.C., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U.S. Geological Survey Professional Paper 164, 161 p.

Hettinger, R.D., 1993, Sedimentological descriptions and geophysical logs of two 300-m cores collected from the Straight Cliffs Formation of the Kaiparowits Plateau, Kane County, Utah: U.S. Geological Survey Open-File Report 93–270, 50 p.

———1995, Sedimentological descriptions and depositional interpretations, in sequence stratigraphic context, of two 300-meter cores from the Upper Cretaceous Straight Cliffs Formation, Kaiparowits Plateau, Kane County, Utah: U.S. Geological Survey Bulletin 2115–A, 34 p.

Jameossanaie, Abolfazl, 1987, Palynology and age of South Hospah coal-bearing deposits, McKinley County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 112, 65 p.

May, F.E., 1972, A survey of palynomorphs from several coal-bearing horizons of Utah, *in* Doelling, H.H., ed., Central Utah coal fields; Sevier-Sanpete, Wasatch Plateau, Book Cliffs and Emery: Utah Geological and Mineralogical Survey Monograph 3, p. 497–542, pls. 1–29.

McCabe, P.J., and Shanley, K.W., 1992, An organic control on shoreface stacking patterns—Bogged down in the mire: Geology, v. 20, p. 741–744.

Nichols, D.J., 1994, A revised palynostratigraphic zonation of the nonmarine Upper Cretaceous, Rocky Mountain region, United States, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic systems of the Rocky Mountain region, U.S.A.: Denver, Colorado, Rocky Mountain Section SEPM, p. 503–521.

Nichols, D.J., and Jacobson, S.R., 1982, Palynostratigraphic framework for the Cretaceous (Albian-Maestrichtian) of the overthrust belt of Utah and Wyoming: Palynology, v. 6, p. 119–147.

Nichols, D.J., Jacobson, S.R., and Tschudy, R.H., 1982 [1983], 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, pl. 1.

Orlansky, Ralph, 1971, Palynology of the Upper Cretaceous Straight Cliffs Sandstone, Garfield County, Utah: Utah Geological and Mineralogical Survey Bulletin 89, 57 p., 11 pls.

Peterson, Fred, 1969, Four new members of the Upper Cretaceous Straight Cliffs Formation in the southeastern Kaiparowits region, Kane County, Utah: U.S. Geological Survey Bulletin 1274–J, 28 p.

Peterson, Fred, and Kirk, A.R., 1977, Correlation of the Cretaceous rocks in the San Juan, Black Mesa, Kaiparowits and Henry Basins, southern Colorado Plateau: New Mexico Geological Society Guidebook, 28th Field Conference, San Juan Basin III, p. 167–178.

Peterson, Fred, and Waldrop, H.A., 1965, Jurassic and Cretaceous stratigraphy of south-central Kaiparowits Plateau, Utah: Utah Geological Society and Intermountain Association of Petroleum Geologists, Guidebook to the Geology of Utah 19, p. 47–69.

Pierce, R.L., 1961, Lower Upper Cretaceous plant microfossils from Minnesota: Minnesota Geological Survey Bulletin 42, 86 p., 3 pls.

Shanley, K.W., 1991, Sequence stratigraphic relationships and facies architecture of Turonian-Campanian strata, Kaiparowits Plateau, south-central Utah: Golden, Colo., Colorado School of Mines Ph. D. dissertation, 390 p.

Shanley, K.W., and McCabe, P.J., 1989, Sequence stratigraphic relationships and facies architecture of Turonian-Campanian strata, Kaiparowits Plateau, south-central Utah [abs.]: American Association of Petroleum Geologists Bulletin, v. 73, p. 410–411.

———1991, Predicting facies architecture through sequence stratigraphy—An example from the Kaiparowits Plateau, Utah: Geology, v. 19, p. 742–745.

Shanley, K.W., McCabe, P.J., and Hettinger, R.D., 1992, Tidal influence in Cretaceous fluvial strata from Utah, U.S.A.—A key to sequence stratigraphic interpretations: Sedimentology, v. 39, p. 905–930.

Singh, Chaitanya, 1983, Cenomanian microfloras of the Peace River area, northwestern Alberta: Alberta Research Council Bulletin 44, 322 p., 62 pls.

Stach, E., Mackowsky, M.-Th., Teichmüller, M., Taylor, G.H., Chandra, D., and Teichmüller, R., 1975, Stach's textbook of coal petrology: Berlin, Gebrüder Borntraeger, 428 p.

Traverse, Alfred, 1988, Paleopalynology: Boston, Unwin Hyman, 600 p.

Tschudy, R.H., 1975, Normapolles pollen from the Mississippi embayment: U.S. Geological Survey Professional Paper 865, 42 p., 20 pls.

———1976, Palynology of Crevasse Canyon and Menefee Formations of San Juan Basin, New Mexico, *in* Beaumont, E.C., Shomaker, J.W., and Stone, W.J., eds., Guidebook to coal geology of northwest New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 154, p. 48–55.

———1980, Normapolles pollen from *Aquilapollenites* province, western United States: New Mexico Bureau of Mines and Mineral Resources Circular 170, 14 p.

Published in the Central Region, Denver, Colorado
Manuscript approved for publication March 21, 1995
Edited by Lorna Carter
Graphics prepared by Norma J. Maes
Photocomposition by Shelly Fields

☆U.S. GOVERNMENT PRINTING OFFICE: 1995-673-046/86127

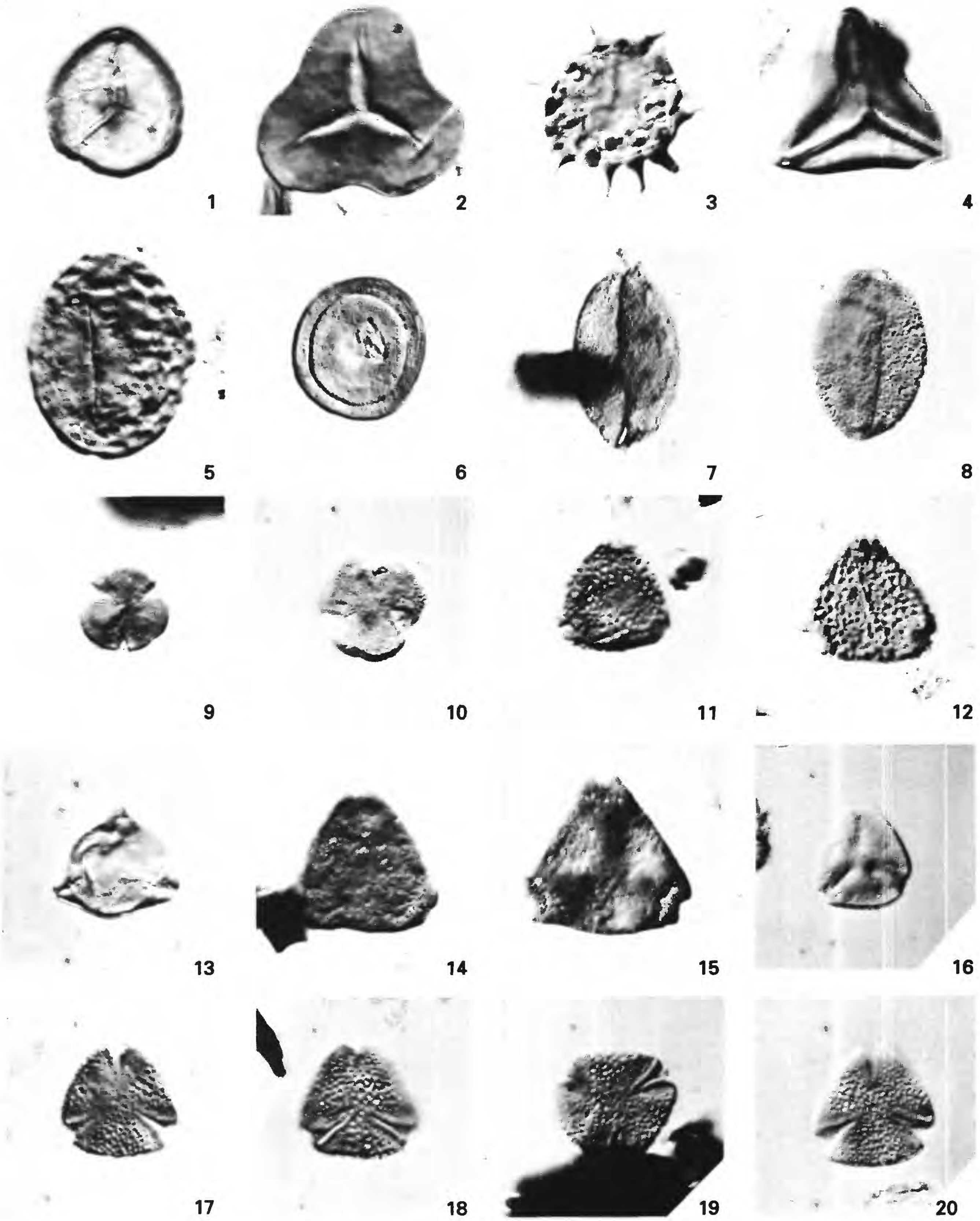
PLATE 1

Contact photographs of the plate in this report are available, at cost, from
U.S. Geological Survey Library, Denver Federal Center, Denver, CO 80225

PLATE 1

[All specimens ×1,000]

Figure 1. *Stereisporites* sp.
2. *Cyathidites* sp. cf. *C. diaphana* (Wilson & Webster) Nichols & Brown.
3. *Echinatisporis varispinosus* (Pocock) Srivastava.
4. *Gleicheniidites* sp. cf. *G. senonicus* Ross emend. Skarby.
5. *Reticuloidosporites pseudomurii* Elsik.
6. *Corollina torosa* (Reissinger) Klaus emend. Cornet & Traverse.
7, 8. *Arecipites* spp.
9. *Cupuliferoidaepollenites minutus* (Brenner) Singh.
10. *Tricolpites* sp.
11, 12. *Proteacidites* spp.
13. *Pseudoplicapollis cuneata* Christopher.
14. *Triporopollenites* sp.
15. *Plicapollis rusticus* Tschudy.
16. *Nyssapollenites albertensis* Singh.
17. *Foveotricolporites johnhenryensis* n. sp., holotype.
18–20. *Foveotricolporites johnhenryensis* n. sp., paratypes.



SPORES AND POLLEN FROM THE STRAIGHT CLIFFS FORMATION

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales, they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. The series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; the principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from USGS Map Distribution, Box 25286, Building 810, Denver Federal Center, Denver, CO 80225. (See latest Price and Availability List.)

"Publications of the Geological Survey, 1879-1961" may be purchased by mail and over the counter in paperback book form and as a set microfiche.

"Publications of the Geological Survey, 1962-1970" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the U.S. Geological Survey, 1971-1981" may be purchased by mail and over the counter in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only.

"Price and Availability List of U.S. Geological Survey Publications," issued annually, is available free of charge in paperback booklet form only.

Selected copies of a monthly catalog "New Publications of the U.S. Geological Survey" is available free of charge by mail or may be obtained over the counter in paperback booklet form only. Those wishing a free subscription to the monthly catalog "New Publications of the U.S. Geological Survey" should write to the U.S. Geological Survey, 582 National Center, Reston, VA 22092.

Note.–Prices of Government publications listed in older catalogs, announcements, and publications may be incorrect. Therefore, the prices charged may differ from the prices in catalogs, announcements, and publications.