Palynology of the Upper Cretaceous Straight Cliffs Sandstone, Garfield County, Utah

by

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PALYNOLOGY OF THE UPPER CRETACEOUS STRAIGHT CLIFFS SANDSTONE, GARFIELD COUNTY, UTAH

by Ralph Orlansky[1]

ABSTRACT

Terrigenous and microplanktonic palynomorphs from the Upper Cretaceous Straight Cliffs Sandstone, Garfield County, Utah, are illustrated.

Stratigraphically allocated for the first time are 59 dispersed spores, 30 gymnosperms, 28 angiosperms and 7 microplanktonic forms, a total of 124 palynomorph species.

Although previously subdivided into members on lithology, the added parameter of distinctive palynomorph assemblages can well aid in discriminating and in correlating lithologically similar beds in the formation.

Generally, the microflora corroborates and amplifies previous correlation, age assignment and interpretation of environment of deposition. Microplanktonic forms appear only in the lower member. Dispersed spores and gymnosperm pollen, occurring throughout the section, are mainly worldwide long-ranging species. Angiosperm pollen grains, the most valuable indicators of the formation's geologic age, occur throughout but more commonly in the middle and upper members. They corroborate the Late Turonian and Coniacian age determination based on mollusks.

The formation was deposited near the western strandline of the Late Cretaceous Western Interior seaway, the lower member in nearshore shallow marine waters, for it contains microplankton, marine megafossils, and terrigenous spores and pollen. The middle member, which contains coal and carbonaceous beds was deposited under reducing conditions in swamps, lagoons and floodplains not far from the strandline where varied spore and pollen microflora represent varied terrestrial environments. The thick well-oxidized sandstone beds and lenses of pebble conglomerate of the upper member indicate accumulation in a fluvial environment. The angiosperm microflora probably represents an upland vegetation.

INTRODUCTION

Background

Favorable economic and geographic factors recently have stimulated exploration and evaluation of southern Utah coal deposits, especially those in the Kaiparowits Plateau region. Controlling factors are an upsurge in the Pacific Southwest's power needs, proximity of large undeveloped coal resources in a sparsely populated area, availability of Lake Powell water for mine-site steam-powered generating plants, and economical methods for transmitting electricity (Hill, 1965; Grose, 1965).

The Upper Cretaceous Straight Cliffs Sandstone contains most of the potentially valuable coal that underlies federal and state lands in the Kaiparowits region. The formation and its coal beds have been mapped in recent years by the Conservation Division of the U. S. Geological Survey (Peterson and Waldrop, 1965, Averitt and Cashion, 1965) and the Utah Geological and Mineralogical Survey (Robison, 1966; Doelling, 1967).

This study fills a gap in previous work by providing a means of correlating the lenticular coal and clastic beds of the Straight Cliffs Sandstone by use of the microflora the beds contain. Marine mollusks in the lower member date that part of the formation, but there is a paucity of megafossils in the higher nonmarine and coal-bearing beds.

These beds and the adjoining clastic units commonly change markedly in thickness and number within short lateral distances. Lateral tracing in outcrop generally is not possible because the coal beds are extensively burned on the surface. Lithologically similar coal and clastic beds contain different microflora assemblages which, used as microlithologic constituents, are valuable for correlation even when botanical knowledge of the forms is minimal and their total range long. For example, Gray and others (1966) used spore and pollen assemblages from coal beds in the Ferron Member of the Mancos Shale in the Castle Valley field, central Utah, to zone and correlate coal horizons in nine drill cores a mile or more apart. Fossil correlations corroborated those based on stratigraphic evidence and so provided a firm basis for calculating reserves.

For those readers unfamiliar with the terminology and techniques used in the field of palynology, a glossary of descriptive terms and two pages of schematic drawings of spores and pollen grains illustrating the terms are included.

Scope and Objectives

The relatively complete surface section of the Straight Cliffs Sandstone was sampled (figure 1, table 1) and the microflora extracted with the following objectives in mind:

To chart stratigraphic occurrence and relative abundance of the palynomorphs.

To compare the microflora with those from other areas.

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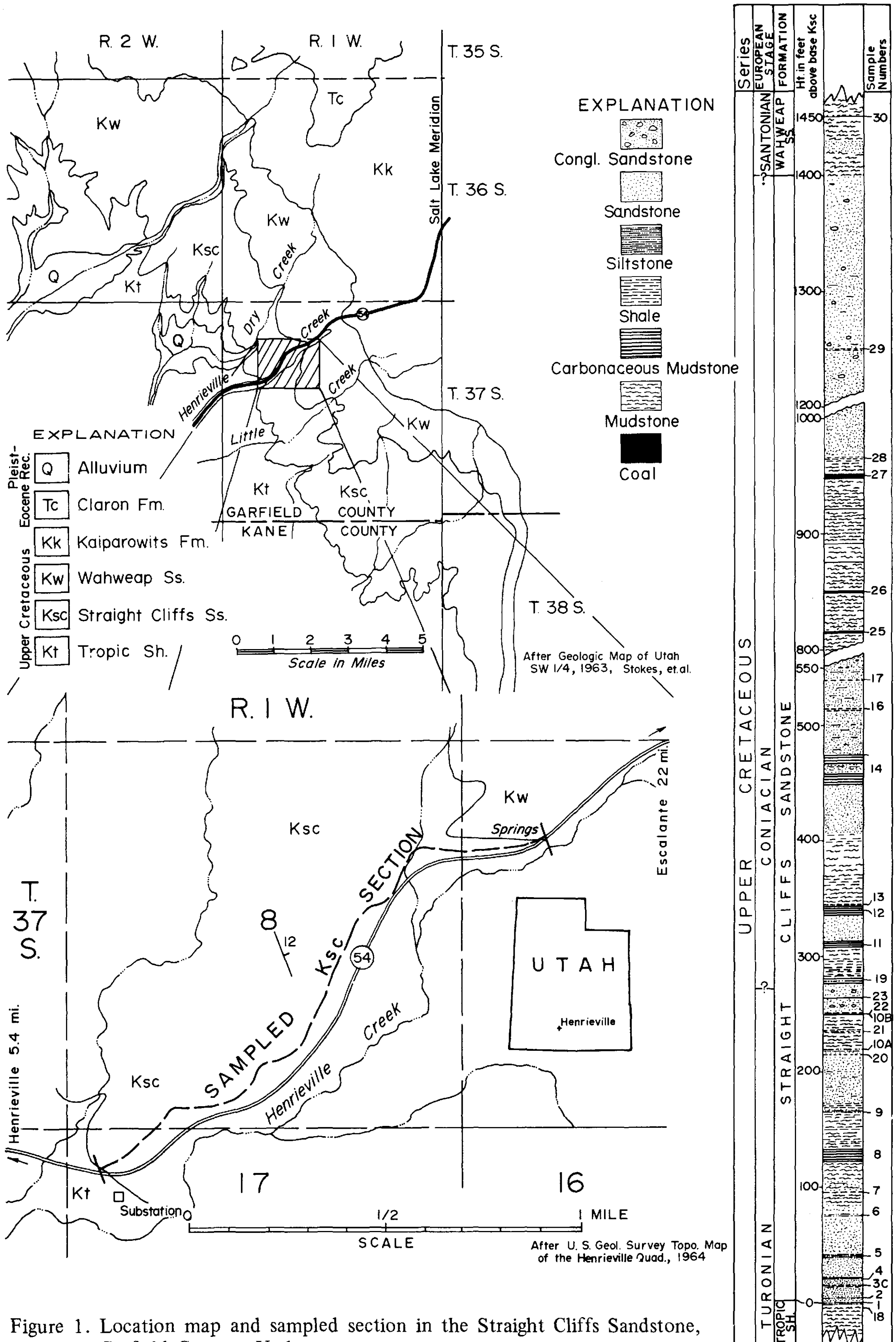


Figure 1. Location map and sampled section in the Straight Cliffs Sandstone, Garfield County, Utah.

To note the effect of various lithologies on occurrence and abundance of the microfloral and other organic constituents.

To set up a palynological section of the Straight Cliffs Sandstone as a basis of comparison for later work in the Kaiparowits region.

To determine whether marine and nonmarine rocks can be distinguished palynologically.

To see if determinations of geologic age and depositional environments based on stratigraphic and megafossil data are corroborated by the microfloral information.

Only one section in the formation, which is widespread in southern Utah, was worked intensely. This report should be considered a preliminary study, and conclusions are therefore provisional pending additional work on the rich and diversified microflora of the Straight Cliffs Sandstone.

Table 2 summarizes and compares pertinent results of some of the more important published and unpublished reports on the palynology of Cretaceous formations in the Western Interior of North America and in the Atlantic and Gulf Coastal Plain of the United States. Workers, locations, formations, age assignments, tallies of spores and pollen, and some ratios between total spore and pollen content, dicot pollen and triporate pollen are listed. The significance of these ratios will be discussed elsewhere in this paper.

METHODS OF STUDY

Source of Material

The Straight Cliffs Sandstone is part of a thick, predominantly clastic section of Upper Cretaceous rocks that are well exposed on the west side of the Kaiparowits Plateau in south central Utah. Regional strike of the strata is north-northwest and dip is 10°-15° NE, toward the Kaiparowits Basin synclinal axis (Gregory and Moore, 1931, plate 16). The section and overlying formations are accessible in Henrieville Creek Canyon, T. 37 S., R. 1 W., Garfield County. The canyon is traversed by Utah State Highway 54.

The 1,400-foot Henrieville Creek section of the Straight Cliffs Sandstone was sampled for this study in 1965 (figure 1). Resistant beds of sandstone about three feet thick mark the lower boundary of the formation. The beds conformably overlie nonresistant mudstone and thin sandstone beds of the Tropic Shale, across the highway from the power substation in Sec. 17, 5.6 miles northeast of the town of Henrieville (figure 1). The upper boundary of the Straight Cliffs Sandstone is marked by the top of a sheer cliff of sandstone and conglomerate. This contact is conformable and dips to road level near a number of springs, about 7,500 feet by road northeast of the substation.

Palynomorphs occurred in black and dark gray shale and clay, brown carbonaceous mudstone and sub-bituminous coal beds. Lithologies favorable for palynomorphs have been discussed by Kuyl and others (1955), Brenner (1963), Cross (1964), Leopold and Pakiser (1964) and Schopf (1964). Processing a variety of such lithologies seems to insure an adequate representation of palynomorphs. Upshaw, in a 1959 study of the Frontier Sandstone, found some microfossil species only in coal and other species only in clastic sediments.

Oxidized rocks, represented by red, yellow or white sandstone and by very light gray or white claystone or siltstone, generally are barren of palynomorphs. Prolonged oxidation during or after sedimentation destroys the otherwise highly resistant fossil exines (Brenner, 1963; Leopold and Pakiser, 1964).

Medium- or coarse-grained sandstone in any state of oxidation illustrates another problem in palynomorph distribution: the microfossils contained are mostly of the size of silt to very fine sand (10 to 120 microns) and with a specific gravity of 1.1 to 1.2, and therefore are not likely to be transported with the coarser, heavy (2.6 specific gravity) quartz grains (Schopf, 1964, p. 54; Berry and Mason, 1959). A thin carbonaceous streak in an otherwise oxidized or coarse clastic sequence should not be overlooked in sampling, however, since it could be rich in palynomorphs (R. H. Tschudy, personal communication, 1965).

The series of samples ranged from the Tropic Shale, 5 feet below the Straight Cliffs Sandstone contact (figure 1, table 1), up to the overlying Wahweap Sandstone, about 50 feet above the formation boundary. These beds were located stratigraphically by means of a Brunton compass, Jacob's staff, and pacing.

Many beds, especially the thinner ones, are lenticular, and change in texture, thickness or lithology within short distances, commonly in the direction of the present dip which coincides with the direction toward which the Cretaceous seaway lay (see section Regional Setting). Abrupt lithologic change of this kind is typical of nearshore and continental deposits. Brenner (1963, p. 165) observed similar lensing in the nonmarine Potomac Group in Maryland. J. C. Lawrence (Robison, 1966, p. 21-23) measured and described a 1,495-foot Straight Cliffs Sandstone section near that sampled for this report. The thick sandstone beds and the coal and carbonaceous mudstone zones appear in both sections, but thinner clastic and carbonaceous units in Robison's section are absent in the Henrieville Creek section.

Samples from 29 stratigraphic levels in the Straight Cliffs Sandstone, Tropic Shale and Wahweap

Table 1. Description of samples and their extracted organic content.

Sample No. (sample per unit)	Thickness of sample or unit	Approx. distance (ft) above base of Straight Cliffs Sandstone	Sample description[1] and organic content[2]
30 (1)	3-6 in.	1,450	Ss. and siltst., gray to black, fissile; lam. 0-5-3.0μ wide alternating thin black org. and thinner light colored material lam.; clasts of qtz., OQ, musc., coarse silt to sd. size; some calc.; bounded by fissile sss. Well preserved CU; few irreg. shaped OQ; very few RB; apparently barren of PM.
29 (1)	3-6 in.	1,250	Clayst. and sh., dark gray, nonfissile; where present lam. are ca. 0.3μ thick; unit lenticular and bounded by sss. and cgls. Abt. CU, RB, OQ, PM; preservation excellent; organic size range 5 to 500μ.
28 (1)	6 in.	965	Clayst. and sh., dark brown to black, nonfissile; lam. where present are 0.4μ wide; much indurated plant debris, thin coal lenses; unit bounded by x-bedded white buff sss. Primarily RB and diverse organics; very few CU, OQ; few well preserved large PM.
27 (1)	2 ft.	950	Clayst., silty, brown, nonlam., much carbonized plant debris; superjacent unit locally thick green sh. and massive buff ss.; subjacent unit buff ss. Primarily ovoidal to spherical RB, more or less carbonized; very few CU, few OQ; moderate no. PM, mainly O type.
26 (1)	2.5 ft.	850	Sh., carb., and compressed plant remains, brown; becomes more argillaceous toward base; light in weight; very fissile, bounded by gray sss. Primarily CU, partly oxidized; fewer RB, very few OQ; appears barren of PM.
25 (1)	2.5 ft.	815	Mudst., carb., brown, nonfissile, stained by yellow jarosite (a hydrous sulphate mineral); becomes more argillaceous toward base; gray-green sh. underlies, and white friable ss. overlies unit. Primarily RB, ovoidal to spherical, some with vesicles and canals; 15-100μ diam.; few CU, very few OQ, very few PM (Reference: Illinois Geol. Surv. Circular 234 for RB).
17 (1)	6 in.	540	Sh., calc., gray, fissile, lam. 0.3-1.0μ wide; flecked with minute carb. blobs; much secondary gypsum coats the shale; unit forms local lens within massive buff ss. Primarily OQ, irreg. shaped, smaller than 50μ; very few RB, CU; fair diversity PM, well preserved; small proportion of organic matter to mineral matter.
16 (1)	1 ft.	515	Clayst., silty, gray, calc., many small carb. plant remains; part of 12-foot nonresistant clastic sequence below massive cliff-forming ss. Many CU, RB, OQ, PM, irreg. shaped organic debris, with few particles smaller than 30μ.
14 (5)	A' - 6 in. A - 1 ft. B - 6 ft. C - 4 ft. D - 8 ft. Total zone 25 ft.	475 Avg.	Mudst., carb., and coally zone equivalent of "Henderson coal zone" of Robison (1966); thickest carb. zone in Henrieville Cr. section. Zone comprises two highly carb. units, separated by less carb., clastic unit. Channel and spot samples: A and B from upper carb. zone; C and D from lower; A. Sh., carb., brown, very fissile, finely lam., and clayst., carb., gray-brown, highest unit in zone. Primarily RB and CU, very few OQ, PM mainly O types. B. Clayst., carb. and sh., carb., brown, finely lam.; jarosite coated, earthy. Primarily CU, many RB, very few OQ, PM mainly O.

[1]Lithology, color, texture, bounding units.
[2]CU-cuticles; O-inaperaturate grains, mainly gymnosperms; OQ-opaque carbonaceous particles; PM-palynomorphs; RB-resinous bodies; abt.-abundant; ca.-circa (about); calc.-calcareous; carb.-carbonaceous; lam.-laminae or laminated; org.-organic; sd.-sand; ss.-sandstone; sh.-shale; clayst.- claystone; mudst.-mudstone; qtz.-quartz; musc.-muscovite.

Table 1 (continued)

Sample No. (sample per unit)	Thickness of sample or unit	Approx. distance (ft) above base of Straight Cliffs Sandstone	Sample description[1] and organic content[2]
			C. Sh., carb., and very thin coal, brown, finely lam., about 0.5μ thick; very fissile, jarosite coated. Similar to 14-B in organic content. D. Clayst., and sh., carb., brown, lam., not fissile, jarosite coated. Primarily RB in varying stages of carbonization, some CU, OQ; few PM-O type.
13 (1)	1 ft.	345	Clayst., calc., dark gray, compact, superjacent buff ss.; subjacent unconsol. silty clay. Large no. PM: O type predominant; fewer CU, RB, OQ.
12 (4 spot)	6-8 ft.	340	Clayst., carb., brown, jarosite coated, with carbonized plant remains; gray-green clayst. at top; bounding units are a sandy sh. below, and a silty clay above. Organic content ranges widely: the clayst. has mainly R, no CU, few OQ, few PM; the basal carb. clayst. has mainly CU, fewer RB, and many PM.
11 (3 spot)	6 ft.	310	Clayst., carb. and sh., jarosite coated in part, with carbonized plant remains; becoming siltier toward base; sub- and superjacent gray sh. and ss. beds. Primarily CU, RB, fewer OQ, mod. vol. PM; O type mainly.
19 (3 spot)	5 ft.	280	Sh., carb., brown, finely lam. and fissile, and carb. clayst. toward base, brown, jarosite stained; carbonized and compressed plant remains; sub- and superjacent gray sh. and ss. beds. Primarily RB, fewer CU, OQ; PM- where present, mainly large O.
23 (1)	2 ft.	265	Sh., silty, gray, finely lam. 0.5-2μ fissile, calc. cement; flecked with musc. and carb. particles to ca. 0.1μ; qtz. clasts silt size; within sd.-sh. sequence. Primarily R and PM, fewer OQ, CU, fair sample range PM.
22 (1)	2 ft.	250	Clayst., silty and sh., light gray, calc. cement, clasts qtz., musc., silt size; larger flecks to sd. size of carb. organic remains; within sd.-sh. sequence. Primarily R, few CU, OQ, very few PM.
10B	9 in. coal lens within 3 ft. clastics; facies of sample 22	250	*Clastic*: Clayst., silty and sh., carb., dark gray and brown, with carbonized fragmental plant remains and compressed coalified stems; silt-sized qtz. clasts; within sh. sequence, grading through carb. clayst., with compressed plant material into coal lens. Contains mainly RB, CU, few OQ, many PM-O and other gymnosperms, and spores. *Coal*: Black, probably subbituminous, lenticular, 50 feet wide downdip. Much organic RB, some CU, OQ, many PM.
21 (1)	2 ft.	235	Sh., gray, lam., nonfissile; lam. 0.5-1.0μ wide, in alternate gray (organic) and buff (inorganic) layers; clasts; silt-sized qtz.; within sd.-sh. sequence. Much fine-grained organic debris, R, OQ, CU, few PM-mainly O types.
10A (1)	6 in.	220	Siltst., brown-gray, finely lam. – 0.15-0.2μ wide; well sorted clasts qtz., musc. .010-.040μ diam., little or no clay; carb. material disseminated, not layered; within massive buff ss. Many CU, PM, fewer OQ, no R; dominant O type PM.
20 (1)	6 in.	215	Clayst., gray, within lighter colored sd.-sh. section. Fairly low organic content, few CU, OQ, PM.
9 (1)	2 ft.	165	Siltst., and ss., (0.2μ thick); lam. 0.3μ thick; qtz. and musc. clasts coarse silt to fine sd. size range; well sorted. Predominant CU, few OQ, few R, few or no PM; CU very well preserved.
8	F - 1.5 ft. E - 6 in.	127 Avg.	F. Coal, black, subbituminous, powders easily.

(continued)

Table 1. (continued)

Sample No. (sample per unit)	Thickness of sample or unit	Approx. distance (ft) above base of Straight Cliffs Sandstone	Sample description[1] and organic content[2]
	D - 4 in. C - 3 in. B - 3 in. A - 3 in. Total 8 ft.		Primarily CU, organic fragments of unknown origin, fewer OQ, very few or no PM. E. Clayst., carb. and carb. sh., brown, jarosite stained, and compressed plant debris; nonfissile. Primarily RB, fewer CU, few OQ; PM almost lacking. D. Coal, subbituminous gray-black, earthy. Excellent preservation of CU, RB, which are the primary constituents; fewer PM, OQ; PM include few spores, gymnosperms, fungi, fewer angiosperms. C. Sh., carb., brown, lam. and fissile; lam. 0.2μ thick, jarosite stained and also weathered (?) CU, RB, few OQ, few or no PM. B. Lignite or coal, subbituminous, dark brown to black, earthy, blocky, not fissile. Large volume CU, OQ; lesser RB; few PM appear carbonized, preservation good. A. Sh., carb. and compressed plant debris, brown, finely lam., 0.2μ thick, fissile; jarosite stained. Primarily well preserved CU, few RB, OQ; very few PM.
7 (1)	2 in.	95	Sh., silty, gray, lam. finer than 0.1μ; fissile; calc., qtz. clasts well rounded; many carb. particles; within lighter sd.-sh. unit. Moderate volume CU, OQ, RB, PM, mainly O types, some spores, saccate grains.
6 (1)	6 in.	75	Silty sh., dark gray, fissile, calc., clasts qtz., musc., carb. flakes ranging to fine sd. size; within lighter-colored sd.-sh. sequence. Large organic volume: CU, fewer RB, OQ, many PM, including dinoflagellates and terrigenous forms.
5 (2)	9 in.	40	Clayst., silty, gray-buff, well sorted, clasts qtz., musc., and carb. particles, calc.; the beds are in form of eastward converging units; separated by 1-foot ss. bed; within a buff sd.-sh. sequence. Primarily CU, RB, fewer OQ, PM, dinoflagellates.
4 (1)	1 ft.	21	Sh., light gray, finely lam. about 0.5 - 1.0μ; alternate darker organic and lighter mineral laminae, not calc., some carb. particles, poorly consolidated. Primarily RB and CU, very few OQ, a few dinoflagellates.
3C (1)	6 in.	14	Sh., silty, dark gray, finely lam., fissile, ca. 0.5-1.0μ; slightly calc., clasts qtz., musc., carb. particles, silt through fine sd. size, poorly sorted, within buff sh. and sd. unit. Predominant OQ, few RB, CU, enormous volume PM, well preserved, terrigenous and microplanktonic forms.
2 (1)	3 in.	3	Clayst., light buff, calc., few clasts qtz., musc., pyrite, silt size, carb. particles to med. sd.-size within sh.-sd. unit. Primarily CU, well preserved, few RB, OQ, very few PM, some diatoms.
1 (1)	6 in.	0 base Ksc.	Sh., light gray, calc., fissile, few qtz. clasts to 75μ, within sh.-sd. unit, buff. Primarily RB, CU, few OQ, very few PM, those well weathered.
18 (1)	1 ft.	-5 Tropic Shale, 5 ft. below Ksc. base	Sh., gray, very fissile, somewhat silty; noncalc.; many black carb. particles and some carb. plant debris. Primarily PM, CU, some OQ, very few RB; excellent suite diverse PM, preservation good; microplanktonic and terrigenous PM.

[1]Lithology, color, texture, bounding units.

[2]CU-cuticles; O-inaperaturate grains, mainly gymnosperms; OQ-opaque carbonaceous particles; PM-palynomorphs; RB-resinous bodies; abt.-abundant; ca.-circa (about); calc.-calcareous; carb.-carbonaceous; lam.-laminae or laminated; org.-organic; sd.-sand; ss.-sandstone; sh.-shale; clayst.- claystone; mudst.-mudstone; qtz.-quartz; musc.-muscovite.

Sandstone are described in table 1. Microscopic organic material extracted from the rocks is composed primarily of tissue and leaf cuticles, waxy resinous bodies, opaque black particles and palynomorphs. Organic content generally is greater in coal and carbonaceous mudstone than in the fine-grained clastic sediments, but most of it is cuticle and resinous material, with few spores or pollen grains.

Sampling and Analysis

A considerable body of recent literature deals with palynological techniques of separating and concentrating microfossils and mounting them for analysis and photography. Useful publications in English are: Funkhouser and Evitt (1959), Jeffords and Jones (1959), Wilson (1959b), Staplin and others (1960), Lee (1964) and Gray (1965a and b). The U. S. Geological Survey (1960) manual on preparation procedures is an excellent summary of the techniques presented by many of these references.

Palynomorphs were obtained for this study using standard techniques and reagents: Soltrol or HF, HNO_3, HCL, KOH, $ZnCl_2$, and short centrifuging. Sanfranin O–stained residues were mounted in Clearcol and HSR (Orlansky, 1968).

Schemes for locating individual grains on strew assemblage slides have been presented by Traverse (1958, 1960) and Pierce (1959). The desired grain is located with respect to a permanently marked point-of-origin by means of an X-Y (horizontal-vertical) coordinate system in millimeters. The SE corner of the cover glass on each slide is the point-of-origin in this study, following Scott (1960).

Palynomorph tallies showing distribution and relative abundance in the Henrieville Creek section are listed in table 4. Significant ratios of species of spores and pollen grains, dicots and triporate pollen are listed in table 2, and ratios of microplanktonic forms to terrestrial palynomorphs in table 5.

STRAIGHT CLIFFS SANDSTONE

Regional Setting

The Straight Cliffs Sandstone is one of 315 Cretaceous rock units in the Western Interior of the United States, most of which are Late Cretaceous in age (Cobban and Reeside, 1952, p. 1011). Weimer (1960, p. 1) explains this proliferation of rock units:

> The Upper Cretaceous rocks of the Rocky Mountain area were deposited in a part of a single large sedimentary basin 1,000-1,500 miles in width and extending from the Gulf of Mexico to the Arctic Ocean. Now the deposits are found in a series of isolated intermontane synclinal basins that were formed during the Laramide orogeny . . . consequently a complex stratigraphic terminology has evolved. Correlations within and between basins are difficult.

The Upper Cretaceous seaway which occupied much of this basin was bounded on the west by a narrow, constantly rising, north-south trending highland which separated the interior sea from the Pacific Ocean (Gill and Cobban, 1966, p. A43). The bulk of clastic sediments was apparently derived from this western cordillera.

The regional setting of sedimentation is described by Weimer (1960, p. 3):

> Stratigraphy of Upper Cretaceous rocks of the Rocky Mountain region can be resolved into a study of . . . sediments which are nearly all marine in the eastern Rocky Mountain and Great Plains region, and all nonmarine in western Utah. Between these localities, a complex intertonguing of marine and nonmarine beds occurs.

That the Upper Cretaceous deposits represent widespread transgressions and regressions is widely accepted. Less widely accepted is the mechanism which controlled movement of the strandline. On the one extreme Weimer (1960, p. 3) says,

> These transgressions are believed to have been controlled by sudden subsidences of the entire sedimentary basin, resulting in the sea inundating large areas . . .

On the other extreme, Gill and Cobban (1966, p. A45) state that

> . . . examination of faunal data and study of the distribution of marine and nonmarine rocks . . . suggest strongly that local uplift, variations in rate of sediment delivery, and local subsidence within the basin and along the basin margins were the causes of transgression . . .

A clearer picture of the stratigraphy and of the depositional environment of the Straight Cliffs is emerging as the gaps in the Late Cretaceous framework are filled in by the detailed work discussed in the next section. Most of the major contributions pertinent to the stratigraphy of the Straight Cliffs Sandstone are found in the following publications:

U. S. Geological Survey Professional Papers 164, 220 and 332.

Utah Geological and Mineralogical Survey Bulletins 54 and 80, and Special Studies 3, 7, 18 and 20.

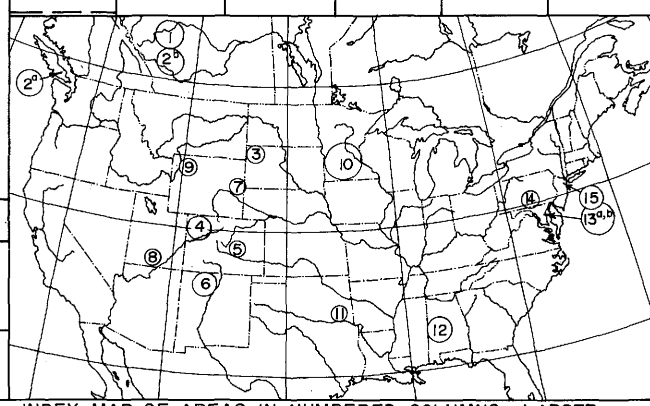
Intermountain Association of Petroleum Geologists Guidebooks in 1954, 1963 and 1965.

Kaiparowits Region and Henrieville Creek Section

The Straight Cliffs Sandstone was named after a prominent sandstone escarpment which bounds the Kaiparowits Plateau on the east (Gregory and Moore,

Table 2. Comparative ratios of dicot pollen and spore tallies of some North American Cretaceous studies.

	WESTERN INTERIOR OF NORTH AMERICA							
REFERENCE AND AREA / EUROPEAN CRETACEOUS STAGES	1 SINGH, 1964 Southern Alberta	2a 2b ROUSE, 1957 Vancouver Is. So. Alberta	3 STANLEY, 1965 Northwestern South Dakota	4 NEWMAN, 1961 U. of Colorado[3] N.W. Colorado	5 CLARK, 1963 U. of Oklahoma[3] So. Colorado	6 ANDERSON, 1960 E. San Juan Bas. New Mexico	7 LEOPOLD AND TSCHUDY, 1965[4] Niobrara Co., Wyo.	8 ORLANSKY, 1967 U. of Utah[3] So. Utah
T PALEOCENE			FT. UNION ▨ △ ⊙ 18 52 34	FT. UNION		NACIMIENTO OJO ALAMO SS.		
CRETACEOUS UPPER SENONIAN MAESTRICHTIAN ?			HELL CREEK (Inc. Collection)	MESAVERDE: LANCE FM. "LEWIS" SH. WMS. FORK ILES FM. ▨ △ ⊙ 12 33 35	VERMEJO FM. ▨ △ ⊙ 13 45 28	KIRTLAND FM. LEWIS SH. ▨ △ ⊙ 21 47 45 ?	PIERRE SH. ▨ △ ⊙ 14 53 27	
CAMPANIAN		COMOX FM. ▨ △ ⊙ 13 40 33		MANCOS SH.				
SANTONIAN		OLDMAN FM. ▨ △ ⊙ 12 42 29						
CONIACIAN								STRAIGHT CLIFFS SS. ▨ △ ⊙ 3 15 23
TURONIAN								
CENOMANIAN								
LOWER ALBIAN	MANNVILLE GROUP △ ⊙ 0 0							
APTIAN								
NEOCOMIAN BARREMIAN								
HAUTERIVIAN								
VALANGINIAN								
BERRIASIAN								



INDEX MAP OF AREAS IN NUMBERED COLUMNS. LARGER CIRCLES INDICATE MORE EXTENSIVE AREAS.

EXPLANATION

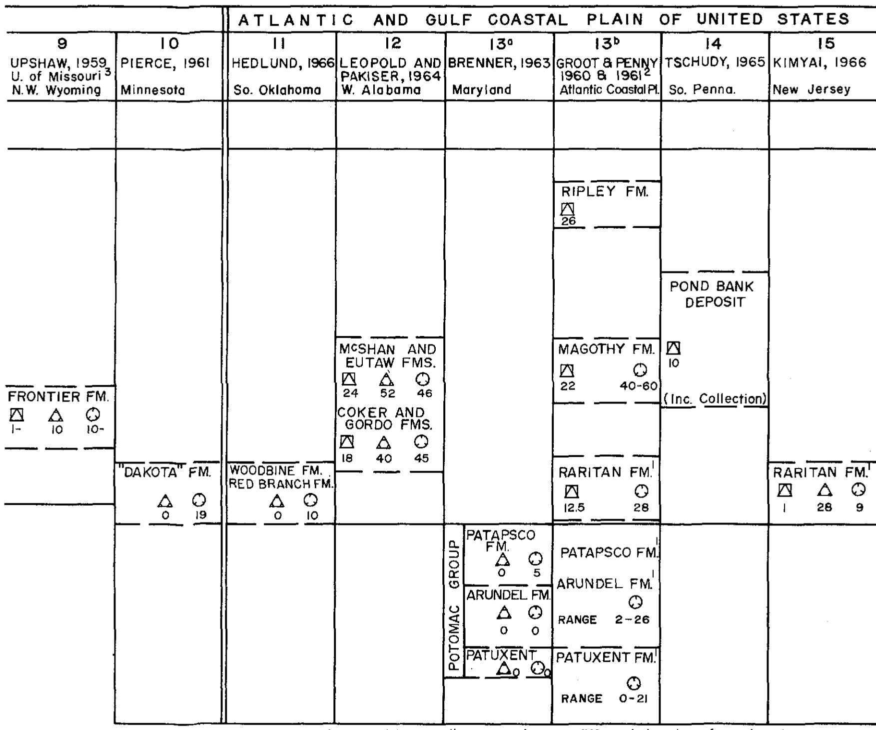
▨ SUM TRIPORATE TAXA. / Sum Spore + Pollen Taxa.

△ SUM TRIPORATE TAXA. / Sum Dicot Taxa.

⊙ SUM DICOT TAXA. / Sum Spore + Pollen Taxa.

— — — APPROXIMATE CHRONOLOGIC BOUNDARY

Age assignment is by cited author



COLUMN	NO. OF POLLEN & SPORE SPECIES or TAXA	NO. OF DICOTS (= SUM OF TRICOLPATES, TRICOLPORATES, TRIPORATES)	NO. OF TRIPORATE TAXA
1	120	0	0
2a	30	10	4
2b	42	12	5
3	80	27	14
4	155	55	18
5	116	33	15
6	84	38	18
7	184	49	26
8	117	27	4
9	99+	10	1
10	101	19	0
11	70	7	0
12	72	33	17
	95	43	17
13a	130	7	0
13b	ca 190	?	50
	ca 55	?	12
	ca 32	?	4
14	ca 60	?	6
15	81	7	2

Spore and Pollen Tallies for Ratios on Adjoining Chart

K.T. '67

[1] Wide range in dicot ratios may be caused by sampling errors, because differentiating these formations is difficult (Groot and Penny, 1960, p. 228).
[2] Also Leopold and Pakiser, 1964 and Tschudy, 1965.
[3] Unpublished dissertation.
[4] U.S.G.S. Open File Report.

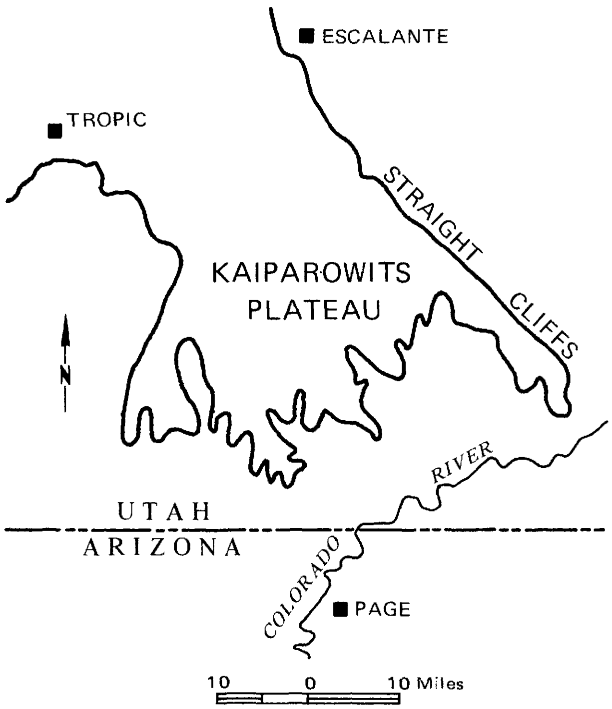


Figure 2. Sketch map showing relationships in Straight Cliffs Sandstone (after Peterson and Waldrop, 1965).

1931, p. 100-104). The lithology of the formation changes regionally. Near the Straight Cliffs it is mainly sandstone (Doelling, 1967); in the south central part of the plateau (figure 2) and in the Tropic and adjoining Henrieville areas, the formation is about half sandstone, the rest mudstone, shale, carbonaceous shale and coal (Peterson and Waldrop, 1965, p. 63; Robison, 1966, p. 20).

Peterson and Waldrop (1965) divided the Straight Cliffs Formation into three informal members. The lower and upper members are mainly sandstones (compare section in figure 1). The middle member contains shale, carbonaceous mudstone, coal and interbedded sandstone. The members generally have contrasting lithologies at their boundaries. The Straight Cliffs Sandstone is about 1,800 feet thick in the Tropic area, 1,400 to 1,500 feet at Henrieville Creek and 1,100 feet in the south central Kaiparowits region. In the Henrieville Creek section, the lower member extends upward to the base of coal and carbonaceous beds, about 125 feet above the base of the formation (lower coal zone of Robison, 1966, p. 35). The middle member extends to the top of a claystone, at about 965 feet above the base, and the upper member extends to the top of the formation, about 1,400 feet above the base of the Straight Cliffs Sandstone.

Environments of Deposition and Facies

Facies of many of the Western Interior Upper Cretaceous rocks are closely influenced by environment of deposition in relation to distance from the strandline of the Cretaceous seaway. Environmental belts extending progressively landward between the open sea and the source area of the clastic sediments were: offshore marine, nearshore marine (neritic), littoral (barrier beach or barrier island), lagoon (including true lagoon, swamp, marsh and estuarine), floodplain, piedmont and highland (Young, 1966, p. 10).

Many vertical lithologic changes apparently reflect responses in sedimentation to shifts of the northwest-trending shoreline. The shifts were dominantly regressive (eastward) during deposition of the lower and upper members of the Straight Cliffs Sandstone, but were mainly oscillatory (reflecting relatively short transgressions and regressions) during deposition of the middle member (Peterson and others, 1966).

The Straight Cliffs Sandstone accumulated in environments transitional between that of the open neritic Tropic Shale and the floodplain and fluvial environments of the Wahweap Sandstone. The lower member was deposited mainly in neritic and littoral zones, the middle member in swamps, lagoons and floodplains near the strandline in the south central Kaiparowits area, but in a shallow neritic area farther east toward the Straight Cliffs (figure 2). The upper member was formed mainly in a fluvial environment but also in brackish or marine environments eastward toward the Cretaceous sea (Peterson and Waldrop, 1965; Gregory and Moore, 1931).

Information about depositional environments in the Western Interior is largely derived from four widespread Cretaceous facies (Weimer, 1960, p. 3) tabulated below.

Environmental Significance of Coal Beds

The coal beds in the Straight Cliffs Sandstone apparently formed primarily from swamp vegetation which grew and accumulated in a narrow discontinuous zone adjoining the Cretaceous strandline. Maps showing distribution and thickness of the coal beds therefore may indicate previous strandline positions, and relative stability and direction of shift of the strandline (Peterson and others, 1966; Young, 1966). The thicker coal beds evidently formed in areas where both the strandline and the adjoining swamps were relatively stable and vegetation accumulated and compacted for a long time. In the Henrieville Creek section, the middle member contains numerous thick beds of highly carbonaceous mudstone and macerated plant remains, and a few coal beds of economic value.

Evidence from a study of the palynomorphs extracted from the carbonaceous strata suggests that the clay is mainly residual. The coal beds, interbedded carbonaceous strata (samples 8, 10B coal and 14 in table 4) and the carbonaceous mudstone (samples 11, 19, 27 and 28) contain a similar microflora of mainly inaperturate gymnosperm grains and rarely a few species of other forms. However, fine-grained clastic samples such as 3C and 13, with textures similar to that of the carbonaceous samples, contain numerous transported palynomorphs. It seems reasonable to assume that had the clay in the carbonaceous beds been transported, it would have been accompanied by displaced microfossils.

Environment	Facies	Representation in Straight Cliffs
Marine		
Deeper neritic	White or gray limestone or marlstone	Apparently not represented; little or no limestone
Shallow neritic	Gray or black shale (with thin limestone, siltstone, sandstone beds	Somewhat in lower member, possibly in part of middle; marine fossils, microplanktonic corroborate
Transitional and marine		
Shallower neritic; littoral and barrier island or beach	White, gray or tan sandstone	Primarily in lower member; also in parts of middle, especially to east; megafossils and palynomorphs corroborate
Nonmarine		
Lagoon and estuarine, swamp, marsh, floodplain, fluvial, lacustrine, piedmont	Gray shale and tan lenticular sandstone with coal, carbonaceous mudstones, conglomerates	Uppermost lower member but mainly in middle and upper members; palynomorphs corroborate; lagoons toward eastern margin

Age and Correlation

The Straight Cliffs Sandstone in the eastern Kaiparowits Plateau area (table 3, No. 2) has both long- and short-ranging pelecypods and gastropods of Niobrara and Colorado age. Elsewhere on the plateau to the west, the lower member of the formation is marine and contains fossils belonging to the diagnostic faunal zone *Callignoniceras hyatti* (table 3, No. 3), also present in the lower Ferron Sandstone Member of the Mancos Shale on the Wasatch Plateau (table 3, No. 5). The Straight Cliffs Sandstone ranges in age from middle Turonian through Coniacian and possibly into early Santonian. Therefore the age of the lower member of the Straight Cliffs Sandstone is closely placed, but closer assignment of the nonmarine middle and upper members must await detailed study of other fossil organisms such as palynomorphs. The faunal criteria for age assignment and correlation of the Straight Cliffs Sandstone and other formations are shown in table 3.

Figure 3, modified from Fisher and others (1960), shows schematically the Upper Cretaceous rocks in the Kaiparowits Plateau and correlative formations in the Henry Mountains, the Wasatch Plateau and the Book Cliffs region. The 1960 diagram is one of the more recent in regional interpretations by Gregory and Moore (1931), Cobban and Reeside (1952), Katich (1954) and Van de Graaff (1963).

Recent biostratigraphic study of the Pierre Shale and its stratigraphic equivalents, based on ammonite range zones in the northern Great Plains (Gill and Cobban, 1966; Fisher and others, 1960, p. 28), changes assignment of the formerly separated Telegraph Creek and Eagle equivalent to the Niobrara. By definition of the Colorado-Montana Group boundary (Cobban and Reeside, 1952), the Telegraph Creek and Eagle are reassigned to the uppermost Colorado Group. In the Kaiparowits area, this places the Wahweap Sandstone wholly within the Niobrara equivalent.

PALYNOLOGY, PALEOECOLOGY AND BIOSTRATIGRAPHY

Palynology

Palynomorphs from the Henrieville Creek section of the Straight Cliffs Sandstone are represented by microfossils grouped as follows:

1. Pteridophytes and bryophytes are represented by 59 species of trilete and monolete dispersed spores which have been separated from fructifications attached to identifiable vegetative remains. Therefore most of the spores have unknown or questionable affinities for the megafossil genera known from Cretaceous rocks. Many of the less generalized spores can be assigned to families such as the Schizaeaceae or the Lycopodiaceae because of close morphological resemblance of the fossil to the recent spores of these families. Almost all of the fossil spores have pteridophyte affinities.

2. Gymnosperms are represented by 30 species of dispersed inaperturate grains, and saccate and nonsaccate pollen grains.

3. Angiosperms are represented by 28 species of monocolpate pollen of probably monocot affinity and tricolpate, tricolporate, triporate and syntricolporate pollen of dicots. As in the spores, some dispersed pollen grains which have unusual or striking morphological characteristics closely resemble pollen from modern plants and may be assigned to a modern family or genus. Most dispersed fossil grains, however, have a generalized morphology and cannot be assigned with any certainty to modern plant taxa.

4. Microplanktonic microfossils are represented by two forms of fossil dinoflagellates. One form,

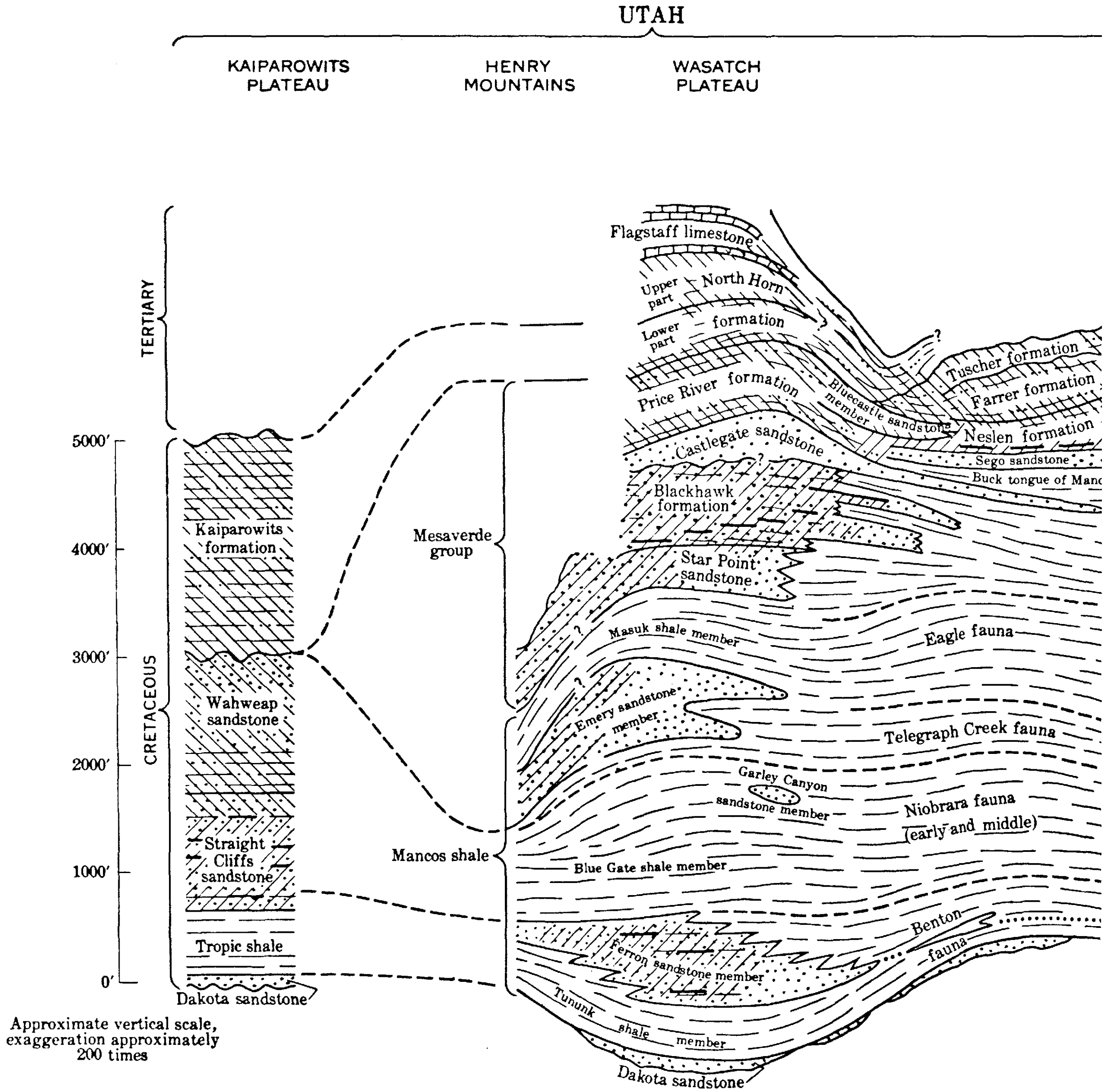
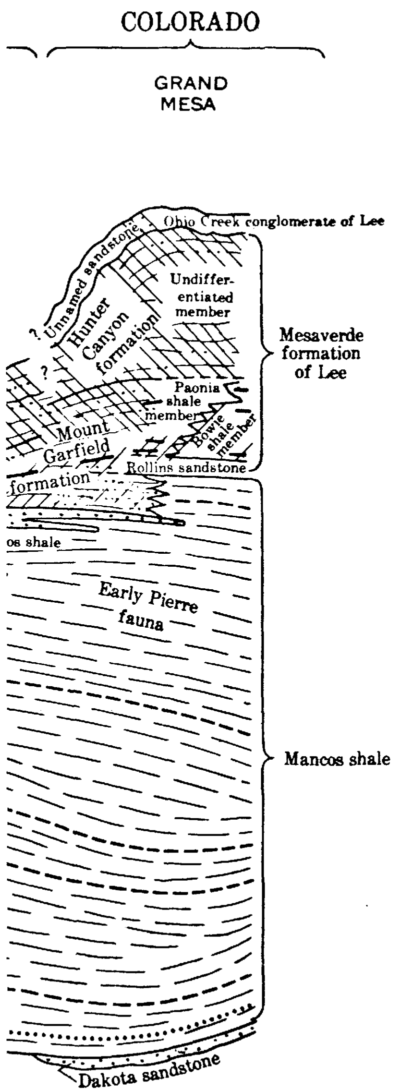
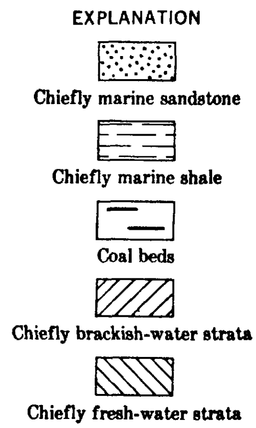
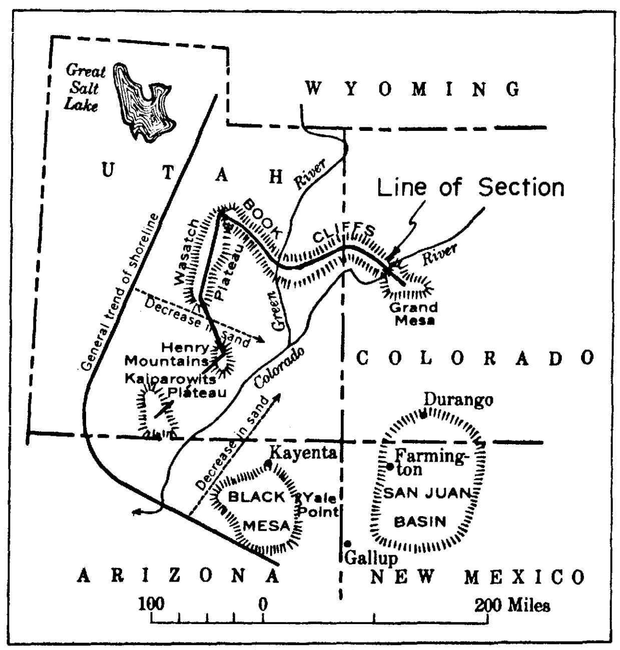


Figure 3. Diagram of correlations of Upper Cretaceous strata from Kaiparowits Plateau, Utah to Eastern Book Cliffs,







INDEX MAP

Colorado (modified from Fisher and others, 1960, pl. 2).

Table 3. Faunal criteria for age assignment of the Straight Cliffs Sandstone and bounding and correlative formations.

Western Interior Reference Sequence (Equivalent European Stage)	Formation and Area	Faunal Criteria	Reference
"Late Cretaceous" Upper Niobrara and Telegraph Creek (?)[1] (Santonian)	1. Lower Wahweap Sandstone South central Kaiparowits Plateau (116-676 ft. above base)	Nonmarine forms only: gastropods pelecypods ostracods vertebrates	Peterson and Waldrop, 1965 Cobban and Reeside, 1952
Niobrara[1] (Coniacian and lower Santonian)	2. Straight Cliffs Sandstone East Kaiparowits Plateau (180 ft. above base to 100 ft. below top)	Marine and brackish invertebrates: *Inoceramus umbonatus* *Ostrea soleniscus* *O. prudentia* *Cardium curtum* *C. pauperculum* *Turritella whitei*	Gregory and Moore, 1931
Blue Hill Shale Member of Lower Carlile Shale (Middle Turonian)	3. Straight Cliffs Sandstone Lower member south central Kaiparowits Plateau	Marine invertebrates: *Callignoniceras hyatti* faunal zone	Peterson and Waldrop, 1965
Turner Sandy Member of the Upper Carlile Shale (Upper Turonian)	4. Upper Ferron Member of the Mancos Shale Wasatch Plateau	Marine invertebrates: *Prionocyclus wyomingensis* *Scaphites warreni* *I. dimidius* *O. lugubris*	Katich, 1954
Blue Hill Shale Member of the Lower Carlile Shale (Middle Turonian)	5. Lower tongue of the Ferron Sandstone Member of the Mancos Shale Wasatch Plateau	*Callignoniceras hyatti* (Stanton)	Peterson and Waldrop, 1965
Fairport Chalky Member of the Carlile Shale	6. Upper part of the Tropic Shale south central Kaiparowits Plateau	*Callignoniceras woolgari*	Peterson and Waldrop, 1965

[1] Note last paragraph under Age and Correlation.

which comprises most of the Straight Cliffs microplankton, closely resembles in shape and morphology the motile stages of armored dinoflagellates. The other form consists of spiny spherical bodies which have previously been termed "hystrichospheres."

Recent study by American and British dinoflagellate workers, especially Evitt, Downie, Sarjeant and Wall (see references in this study and in Sarjeant, 1967), has indicated that the remains of apparently motile stages are in reality dinoflagellate cysts, as are many of the post-Paleozoic spiny forms. The dinoflagellate cysts, which formed internally very close to the armored theca and thus faithfully reflect its structures, are termed *proximate* cysts. Four species of these are described. Many or most of the post-Paleozoic "hystrichospheres" have been shown by Evitt to be another form of dinoflagellate cyst which formed well within the organism. These are now termed *chorate* cysts (Sarjeant, 1967, p. 252). Three species are described from one level in the Straight Cliffs Sandstone.

Stratigraphic Distribution of Palynomorphs

Stratigraphic distribution and relative abundance of the palynomorphs from the Henrieville Creek section are listed in table 4. Provisional observations on abundance and distribution of the microflora from this section are as follows:

1. Fine-grained clastic samples such as samples 18, 3C and 10B clay contain a much larger and more diverse assemblage of forms than do the coal and highly carbonaceous samples such as 8, 10B coal and 14. This is not surprising since the clastic sediments may contain a microflora from diverse upland and lowland environments which have been deposited in a common basin of deposition.

2. Tropic Shale and the lower member of the Straight Cliffs Sandstone contain dinoflagellates, confirming the interpretation of marine or brackish environment based on lithologic and megafossil evi-

Table 4. Distribution and relative abundance of palynomorphs in Henrieville Creek section, Straight Cliffs Sandstone.

R:rare; F:frequent; C:common; A:abundant; D:dominant
to 1% 1 - 10% 10 - 33% 33 - 50% over 50%

Palynomorphs / Ht. in feet above base Ksc Ss.	Pl. No.	-5	0	3	14	21	40	75	95	AV. 127	220	COAL 250	CLAY 250	280	310	345	AV. 475	515	540	950	965	1250
Sample No.		18	1	2	3C	4	5	6	7	8	10A	10B	10B	19	11	13	14	16	17	27	28	29
Microplankton																						
Baltisphaeridium sp. A	11				F																	
sp. B	11				F																	
sp. C	11				R																	
Deflandrea sp. A	11	F			C	C	F	F														
sp. B	11	D			D	D	D	D	R													
Microdinium sp.	11				F	R	F	R	R													
Palaeoperidinium sp.	11				C	R																
Dispersed spores																						
Aequitriradites sp.	4																					R
Apiculatisporis sp. A	5				F																	
sp. B	5				R																	
Appendicisporites tricornitatus	3	R			R								F			R						
sp. A	3												F			R						R
sp. B	3												R									
sp. C	3	R											R									
sp. D	3				R											R						
Cicatricosisporites brevilaesuratus	3				R																	
hallei	3	R			F											R						
sp. A	3	R			F																	
sp. B	3				R																	
sp. C	3	R			R																	R
sp. D	3				R								R			F						
sp. E	3	R			R																	
sp. F	3	R			R																	
Cingulatisporites sp. A	1				R				R													
sp. B	1										R		R					R	F			
sp. C	1				R									R					R			R
Cirratriradites sp.	4				R																	
Concavisporites jurienensis	1		R		R	R										R						
Concavissimisporites punctatus	4							R								R						
Cyathidites minor	1	C			F	F	R	F	R	R	R	R	A		R	C	R	R	R		R	F
Deltoidospora hallii	1	F			F	F	F	F	F	R	F	C	F	R		F	R		R		R	R
sp. A	1	R			R	R					R					R		R				
Densoisporites perinatus	2												R			F						
sp. A	2							R								R						
		Kt	Lower Mbr.							Middle Member												U

Table 4. (continued)

Palynomorphs	Pl. No.	18	1	2	3C	4	5	6	7	8	10A	10Bco	10BcL	19	11	13	14	16	17	27	28	29
Dispersed spores (cont.)																						
Dictyophyllidites sp.	4	R			R											R						
Gleicheniidites																						
circinidites	1				R					R		F			F	R	R					
senor senonicus	1	R		F	F	R		R	R			C	R		F	R				F		R
Hymenophyllumsporites																						
deltoida	2				R							C										
Klukisporites																						
pseudoreticulatus	2							R								R						
Laevigatosporites ovatus	5	R		R	F	F	F	F		R		R	C	R		F			R			R
sp. A	5		R		F				R		R		F					C		R	R	
sp. B	5												R			F		D		R		
sp. C	5															R				R		F
Lycopodiacidites sp.	2				R			R					R									R
Lycopodiumsporites sp. A	2				R			R								R						
sp. B	2	R			R			R								R						
sp. C	2	R	R				R									F						
Lygodiumsporites sp. A	1	R	R		F	F		R	R	R			F		R	F						R
sp. B	1	R	C	R	R	F	R		R					R		R					C	R
Microreticulatisporites																						
sp. A	5				R											R						
sp. B	5				R											R			R			
sp. C	5												F						R			
Osmundacidites comaumensis	5	F											R			F		R	R			
Reticuloidosporites sp. A	5				R								R			R		R				
sp. B	5												R									R
Rugulatisporites sp. A	2				R								R									
sp. B	2															R						
Stereisporites sp.	1	R			R									R					R			
Todisporites minor	5	R			R				R	R	F		F			R			F			R
Trilites sp.	1	R	C			F	R	F	F		F					F			R	R	R	F
Trilobosporites																						
trioreticulosus	4	F			R	R	F	F	F		R					R		R				
Triplanosporites sp. A	5		R		R																	
sp. B	5	R			F			F								R			R			R
Verrucosisporites sp. A	4			R	R				R				R						F			
sp. B	4	R		R	R				R				F			R			F			R
sp. C	4																					R
Gymnosperms, monosulcates, and inaperturates																						
Abietineaepollenites																						
microreticulatus	8	R			R			R														R
Araucariacites australis	6	F		R	F	F	F						C			F			F	F		R
Classopollis classoides	7	F		R	C	F	R									F			F			
Cycadopites formosus	6				F	R	R	R	F								R		F			F
fragilis	6				F	R		R	R										R			R
		Kt	Lower Mbr.							Middle Member												U

Table 4. (continued)

Palynomorphs	Pl. No.	Sample No. 18	1	2	3C	4	5	6	7	8	10A	10Bco.	10Bcl.	19	11	13	14	16	17	27	28	29
Gymnosperms, etc. (cont.)																						
Ephedripites sp. A	6		R													F						
sp. B	6																		F			
ovatus	6															F						R
sp. C	6				R								R									
Foveoinaperturites sp.	9		R		R		R	R														
Inaperturopollenites																						
dubius	8				R	R				R	R					R				R		R
cenomanianus	6	F	C		R	C	D	C	A		C		F		F	C		R	F		R	F
Laricoidites gigantus	7		R			R	R	F	R		F			R	R	R	F	R		F		F
magnus	8	R		R	F	F	F	F		D	C	R	C	D	R	F	D	F		C	C	F
Monosulcites glottus	7						R		R													
spinosus	7				R																	
Parvisaccites sp.	9	R		R	R		R									F			F			F
Piceapollenites sp.	9							R								F			F			F
Pinuspollenites sp.	8	F	F		F	F	R	C	C	R		R	R		R	C		R	A			R
Podocarpidites sp. A	9				R																	R
sp. B	9																					R
sp. C	9																		R			
Schizosporis majusculus	7										R						R					R
spriggi	7		R								R											
sp. A	7	R			R				R			R							R			R
sp. B	7				F	R	R	R	R								R		R			
sp. C	7				R	R		R	R							R				F		
Taxodiaceaepollenites																						
hiatus	8				R			R									R					R
Zonalapollenites dampieri	8				R	R	R	F	R				R			R			R			R
sp. A	8												R									R
Angiosperms																						
Monocolpate pollen																						
Liliacidites sp.	10				R			R				R										
Tricolpate pollen																						
Tricolpites sp. A	10	R			R			F				F			R							
sp. B	10				R	R		R	R				R									
sp. C	10				R	R		R								R						
sp. D	10				R			R		R						R			R			
sp. E	10	R			F	R		R				C	R		R							
sp. F	10					R						R										F
sp. G	10															R			F			F
Retitricolpites sp. A	10	R	F		R	R	R	R	F			F	R									
sp. B	10				F	R	R	R	R	R						R						
sp. C	10				R			R								R						
sp. D	10				R																	
sp. E	10	R			R																	
sp. F	10				R	R		R	R										R			F
		Kt	Lower Mbr.							Middle Member												U

Table 4. (continued)

Palynomorphs	Pl. No.	Sample No. 18	1	2	3C	4	5	6	7	8	10A	10B COAL	10B CLAY	9	11	13	14	16	17	27	28	29
Angiosperms (cont.)																						
Triporate pollen																						
Proteacidites sp. A	10												R			F						
sp. B	10															R						F
Sporopollis sp.	10															R						
Triorites fragilis	10												R			R						
Tricolporate pollen																						
Nyssapollenites sp.	10				R											R						C
Tricolporites sp. A	10												R			R						
sp. B	10				F	R	R					C				R			F			
sp. C	10											R				R			F			
sp. D	10																					F
sp. E	10															R						F
Vitipites sp.	10				F				R							R			F			R
Syn- or tri-colporate pollen																						
Cupanieidites sp. A	10																					R
sp. B	10															R						
sp. C	10																					F
		Kt	Lower Mbr.							Middle Member												U

dence. The absence of dinoflagellates in the remainder of the Straight Cliffs Sandstone section tends to corroborate stratigraphic evidence of fresh-water deposition. Although not unknown in rocks of fresh-water origin, they are very rare in other than marine or brackish strata (Evitt, 1964).

3. The ratios of terrigenous to microplanktonic forms from the Tropic Shale and the lower member of the Straight Cliffs Sandstone are shown in table 5. Theoretically, the great range in values should be useful in detection of ancient shorelines, the lower ratios indicating a smaller supply of terrigenous forms and thus a shoreline more distant from the sampled area (Upshaw, 1964, p. 157), but the many variables in biota supply and factors influencing sedimentation and preservation of palynomorphs make interpretations of ancient strandline positions based solely on such ratios highly speculative. The addition of other parameters based on palynologic analysis of sediments, such as the total pollen count per gram of sediment, the ratio of large- to small-sized pollen grains, and the abundance of microplanktonic forms and foraminifera in samples (Hoffmeister, 1954) probably increases the reliability of palynologic determinations in the detection of the presence of ancient shorelines and hopefully, nearby oil-saturated traps.

4. Numerous spores, some simple tricolpate and tricolporate grains but fewer gymnosperm pollen and no triporate forms form the microflora in the Tropic Shale and the lower member of the Straight Cliffs Sandstone. A smaller proportion of dispersed spores, more tricolporate and triporate grains, and higher proportions of gymnosperm pollen characterize the middle and upper members of the formation. A local or regional paleoecological change rather than an evolutionary one is probably shown, since strata of early Turonian and Coniacian age elsewhere (compare table 2) contain numerous triporate and other dicot forms.

5. The restricted stratigraphic occurrence and abundance in the Henrieville Creek section of a number of species such as *Ephedripites* sp., *Cicatricosisporites brevilaesuratus* and *Hymenophyllumsporites deltoida*, known to be long-ranging elsewhere, show clearly the strong influence of local factors on distribution of microfossils. Species with restricted occurrences offer greater possibilities for use in close stratigraphic zonation and correlation of the Straight Cliffs Sandstone. Future study should indicate the most useful forms for correlative purposes.

Significance of Angiosperm Pollen

The percentage of triporate and dicot grains in the total spore and pollen assemblage and the degree of morphological complexity shown by the dicot

Table 5. Ratio of terrigenous palynomorphs and microplanktonic forms.

Sample Numbers	Spore and Pollen tally / Microplankton tally = Ratio
29 through 8	No microplanktonic forms
7	96.0
6	1.8
5	9.6
4 0.96	0.96
3C	3.2
2	No microplanktonic forms
1	No microplanktonic forms
18	1.3

grains are valuable criteria for generalized dating of Albian and Upper Cretaceous rocks (Tschudy, 1965; Leopold and Pakiser, 1964). Empirical study has shown that the proportion of dicot and triporate grains to spores increases greatly in younger Cretaceous strata.

Pre-Cretaceous "angiosperm" pollen grains are questionable (Scott and others, 1960; Hughes, 1961). The evidence indicates that angiosperms first appeared in Albian time. The earliest dicot microfossils were simple tricolpate grains (table 2, column 13). Previous collections of angiosperm pollen grains from strata believed to be Neocomian and Aptian in age probably are from Upper Cretaceous beds that were incorrectly assigned (Groot and Penny, 1960; table 2, column 13b of this paper).

In strata dated as Cenomanian, a few triporate grains were reported (columns 13b, 15; also, see note 1). Triporate grains were not found elsewhere in strata of this age (columns 10, 11). In the Western Interior, the first appearance of triporates is in strata dated as Turonian by ammonites (columns 8, 9).

In the Henrieville Creek section, the oldest triporate species *(Proteacidites)* appears in the lower middle member, which on megafossil evidence is probably late Turonian or early Coniacian in age. This agrees well with the angiosperm criteria discussed above. Also see discussion of stratigraphic distribution of *Proteacidites* under description of palynomorphs.

Strata of Turonian and Coniacian age in the Atlantic and Gulf Coastal Plain contain large percentages of dicot and triporate pollen grains (columns 12, 13b). In western Europe the first striking increase in dicot pollen occurs in Turonian age strata (Krutzsch, 1957). In contrast, smaller proportions and numbers of dicot and triporate pollen grains are reported from strata of similar age in the Western Interior region (columns 8, 9). In the youngest Cretaceous rocks in the Western Interior, triporate grains comprise about half of the dicot taxa and dicot grains comprise about 1/4 to 1/3 of the total spore and pollen assemblage (columns 3 through 7).

Palynology and Paleontology

Palynomorphs have been described or photographed from a paralic (alternating marine and nonmarine) sequence and from a marine sequence in two significant studies in Wyoming, demonstrating the potential value of the microfossils in solving many stratigraphic problems. Terrigenous spores and pollen grains, marine microplanktonic forms and mollusks are abundant in the paralic Frontier Formation, northwest Wyoming (Upshaw, 1959, 1964) and in the marine Pierre Shale, eastern Wyoming (Leopold and Tschudy, 1965; Gill and Cobban, 1966).

The microfossils from the Frontier Formation are used to delineate marine and nonmarine units and to recognize and zone cycles of sediments. From a 3,000-foot marine section of the Pierre Shale near Red Bird, Wyoming, more than 200 palynomorph species and ammonites belonging to 18 range zones were collected. The terrigenous microflora was present although the Late Cretaceous shoreline lay 40 to 200 miles west of the Red Bird section. Fossils from the Pierre Shale have been under intensive study.

Palynomorphs have proved of value in supplementing fossil groups such as foraminifera and ammonites that have been widely used as indices, because plant microfossils occur in sedimentary sequences where animals seldom occur, such as brackish and terrestrial beds, salt deposits, black shale beds and coal. Palynological study is probably most valuable when integrated with other paleontologic work in new areas and in refining present studies in biostratigraphy, correlation and facies distribution.

Paleoecology and Biostratigraphy

Environmental interpretations of Cretaceous and Tertiary floras are based on the assumption that fossil plants occupied ecological niches similar to those occupied by their modern descendants. Extensive discussions of Cretaceous paleoecological inferences based on common microfloral elements are given in Kuyl and others (1955), Singh (1964), Hedlund (1966), Stanley (1965), Brenner (1963) and Pierce (1961). Some Cretaceous microfloras and the environments they indicate are listed below.

Several dispersed species representing plants from several ecologic niches are found in the same clastic samples. In the Henrieville Creek section, spores represent subtropical forest, acidic ponds, cool uplands, coastal areas and arid areas. Samples 3C, 18, 6, 7, 10B clastic, 13, 17 and 29 all contain abundant mixed microfloral elements, indicating that several or all of the environments existed in different areas more or less contemporaneously during deposition of any of these clastic beds. The reproductive bodies from the floras which occupied these environments were transported varying distances to the common basin of deposition.

Microflora	Indicated Environment and Distribution
Microplanktonic forms	Brackish to marine
Schizaeceae	Tropical, subtropical terrestrial forests mainly; a few temperate
Osmundacidites	Temperate to tropical, swamps to moist woodlands
Stereisporites	Acid lakes, pond; cosmopolitan
Cyathidites	Tropical, subtropical montane forests
Coniferales Taxodiaceae Araucariaceae Podocarpaceae Pinaceae	For most, cool climate or moist upland near water; temperate to subtropical; N.A. temperate; modern in southern hemisphere; mountainous temperature, subtropical to subarctic; northern hemisphere
Classopollis	Probably dry, coastal
Ephedripites	Arid, tropical to temperate; cosmopolitan
Angiosperms	Probably upland to lowland types; some temperate

The displaced spores and pollen grains obviously reflect the climatic conditions of the place of growth, rather than that within the basin of accumulation. The environment of the basin of deposition may be inferred from a synthesis of data from the sediments, the associated organic material such as cuticles and resinous bodies, and the contained microflora. Relevant factors have been discussed by Kuyl and others (1955), Wilson (1956, 1961b), Cousminer (1961), Tschudy (1961) and Cross (1964).

Detailed study of the palynology of the modern Orinoco delta and shelf is applicable to that of the Straight Cliffs Sandstone. Distribution of microfossils in modern Orinoco sediments is related principally to locations of source areas and to the transporting air and water currents. In the delta, transportation is restricted and the local swamp flora is dominant in the sediments. Pollen carried offshore by the river discharge is mixed, with some size sorting of the pollen grains, and spread over a broad area. The typical spore or pollen grain usually has a history of air or water transport and deposition and reworking in one or more cycles (Muller, 1959).

Several parallels can be drawn to the distribution of palynomorphs in the Straight Cliffs Sandstone. The coal and carbonaceous beds in Utah have the dominant swamp flora and restricted circulation of the Orinoco delta. The clastic beds in the Straight Cliffs Sandstone have the mixed floras of the Orinoco shelf pollen but size sorting is not obvious in the Cretaceous rocks; reworking of the fossil grains is possible but difficult to determine accurately.

SUMMARY AND CONCLUSIONS

The Upper Cretaceous Straight Cliffs Sandstone, adjoining beds of the underlying Tropic Shale and the overlying Wahweap Sandstone, was sampled for palynomorphs in Henrieville Creek Canyon, T. 37 S., R. 1 W., Garfield County. The stratigraphic occurrence and relative abundance of palynomorphs were examined in this preliminary study to assess the value of the microfossils for stratigraphic zonation, paleoecological interpretation, age dating and determination of the extent of interrelation of palynology with stratigraphic and other paleontologic methods.

Of 28 levels sampled, 21 produced microfossils, one from the uppermost Tropic Shale and the others from the Straight Cliffs Sandstone. The microflora was extracted from fine-grained unoxidized clastic rocks, highly carbonaceous strata and associated coal beds. Described and stratigraphically allocated are 124 species of palynomorphs, previously unreported from the Straight Cliffs Sandstone. Of these, 59 species are dispersed spores, 30 gymnosperm pollen, 28 angiosperm pollen, and 7 microplanktonic forms.

Lithology and extracted organic content of all samples are summarized in table 1. Palynomorphs occur most abundantly in fine-grained clastic strata deposited under reducing conditions. Distinctive organic assemblages help to distinguish lithologically similar beds.

Stratigraphic allocation and relative occurrence of palynomorphs from the Straight Cliffs Sandstone are given on table 4. Many spores and pollen grains that are long-ranging elsewhere have restricted ranges in the Henrieville Creek section. Areal distribution of these forms is not known. Palynomorphs extracted from the Straight Cliffs Sandstone confirm the presence of depositional environments previously described from stratigraphic and paleontologic evidence.

In the lower member in the Henrieville Creek section, microplanktonic forms corroborate the evidence for nearshore depositional environment. The middle and upper members contain neither marine megafossils nor microplanktonic forms in the south central and western parts of the Kaiparowits Plateau region. Considerable organic material in the strata, even where coal beds did not form, provide evidence of widespread coal-forming swamps in the middle member. Apparently few palynomorphs were transported into the highly vegetated areas. Gymnosperm and angiosperm pollen increase in proportion to the spores in the upper member, confirming the postulated change in environment.

The explosive evolution of angiosperms in the Late Cretaceous makes them excellent relative age indicators, especially where they can be correlated with the well-studied and documented mollusks. In the Henrieville Creek section, the triporate species *Proteacidites,* which is not known elsewhere below the Turonian, corroborates the age of the lower member of the Straight Cliffs Sandstone. The sandstone was dated middle Turonian on fossils belonging to the *Callignoniceras hyatti* faunal zone.

SYSTEMATIC DESCRIPTIONS

Introduction

Palynomorphs from the Henrieville Creek section of the Straight Cliffs Sandstone are divided into four broad groups:

1. Dispersed spores (plates 1-5).

2. Gymnosperms, including inaperturate, nonsaccate and saccate grains (plates 6-9).

3. Angiosperm pollen grains, including colpate, colporate and porate forms (plate 10).

4. Microplanktonic forms (plate 11).

The glossary and figures 4 and 5 explain or illustrate the morphological terms used in the descriptions. Sizes on plate descriptions are grain diameters in microns. Dimensions measured are illustrated on figure 5 . Botanical affinities of the dispersed microfossils are taken from original descriptions, and if not documented, are from the references given below.

OCCURRENCE designates the presence of a taxon in the Henrieville Creek section. For specific occurrence in each sample, refer to table 4. Relative abundance is indicated by the following letter symbols (Leopold and Pakiser, 1964):

R	Rare	to 1 percent
F	Frequent	1-10 percent
C	Common	10-33 percent
A	Abundant	33-50 percent
D	Dominant	over 50 percent

DISTRIBUTION. The following references will serve to document the distribution of the microfossils and are given under most of the descriptions. To minimize repetition of the references, generally only geographic locations or formations will be given of forms which have been described by authors in the following list.

For example, distribution of all microfossils, stated as being in the "Potomac Group" or in "Maryland," are documented by Brenner, 1963.

Reference	Formation and Age	Geog. Area
Brenner, 1963	Potomac Group-L. Cret.	Maryland
Clarke, 1963	Vermejo Fm.-Maestricht.	So. Colorado
Hedlund, 1966	Woodbine Fm.-Cenomanian	So. Oklahoma
Leopold and Pakiser, 1964	McShan, Eutaw, Coker Gordo-Cenoman.-Coniac.	W. Alabama
Singh, 1964	Mannville Gr.-L. Cret.	Alberta
Stanley, 1965	Ft. Union, Hell Cr.-K-T	NW So. Dakota
Traverse, 1955	Brandon Lignite-L. Tert.	Vermont

Figured microfossils are designated on the plate description pages by the slide number on which they are found (which indicates sample number and stratigraphic level of occurrence) and by the slide location coordinates (X or horizontal direction and Y or vertical direction, in centimeters) measured from the SE corner of the cover glass.

Microfossil slides and original samples will be deposited with the Utah Geological and Mineralogical Survey, Salt Lake City, Utah.

Taxonomy and Nomenclature

The taxonomy and nomenclature of fossil spores and pollen from Cretaceous and Tertiary strata have been discussed exhaustively by Traverse (1955, 1957), Pierce (1961) and Stanley (1965). Schools of thought on these problems range from those who name and classify spores and pollen on objective, artificial systems based on morphology (Pierce, Pflug and Erdtman) to those who refer the dispersed fossil forms to recent plant genera when their spores are similar (Traverse, Stanley). A third school occupies middle ground; the microfossil names used suggest affinity to living genera, but modern generic names are not used (Couper, Cookson, Brenner and Singh). For example, *Ephedra* or *Ephedra*-like pollen grains are known from the Triassic (photomicrographs are on plate 6). Stanley and his school name similar Cretaceous forms *Ephedra.* Brenner calls the same fossil grain *Ephedripites,* Singh uses *Equisitosporites*, and for this striate, inaperturate grain, Pierce uses the descriptive name *Striainaperturites.* In this paper *Ephedripites* is used for the *Ephedra*-like pollen grains.

Resolution of taxonomic and nomenclatural problems is beyond the scope of this paper; all systems of nomenclature have advantages as well as shortcomings. In this work, names which seem to be most widely recognized and accepted have been used to establish the stratigraphic and geographic distribution of palynomorph species. As in other fossil groups, fossil lists are compared, and common names have obvious advantages.

Generally, *form-genera* and *organ-genera* have been used.

Nomenclature of form-genera and organ-genera follows the International Code of Botanical Nomenclature (Montreal, 1959) which defines these taxa as follows: "An organ-genus is a genus assignable to a family. A form-genus is a genus unassignable to a family, but it may be referable to a taxon of higher rank" (in Singh, 1964, p. 37).

Glossary of Descriptive Terms

The glossary and figures 4 and 5 are a compilation of definitions and illustrations from the following sources: Kosanke (1950), Erdtman (1952), Traverse (1955), Brenner (1963), Dettman (1963), Evitt (1961, 1964), Faegri and Iverson (1964), Singh (1964) and Kremp (1965). The superscript number following a term refers to the figure in which the term is illustrated.

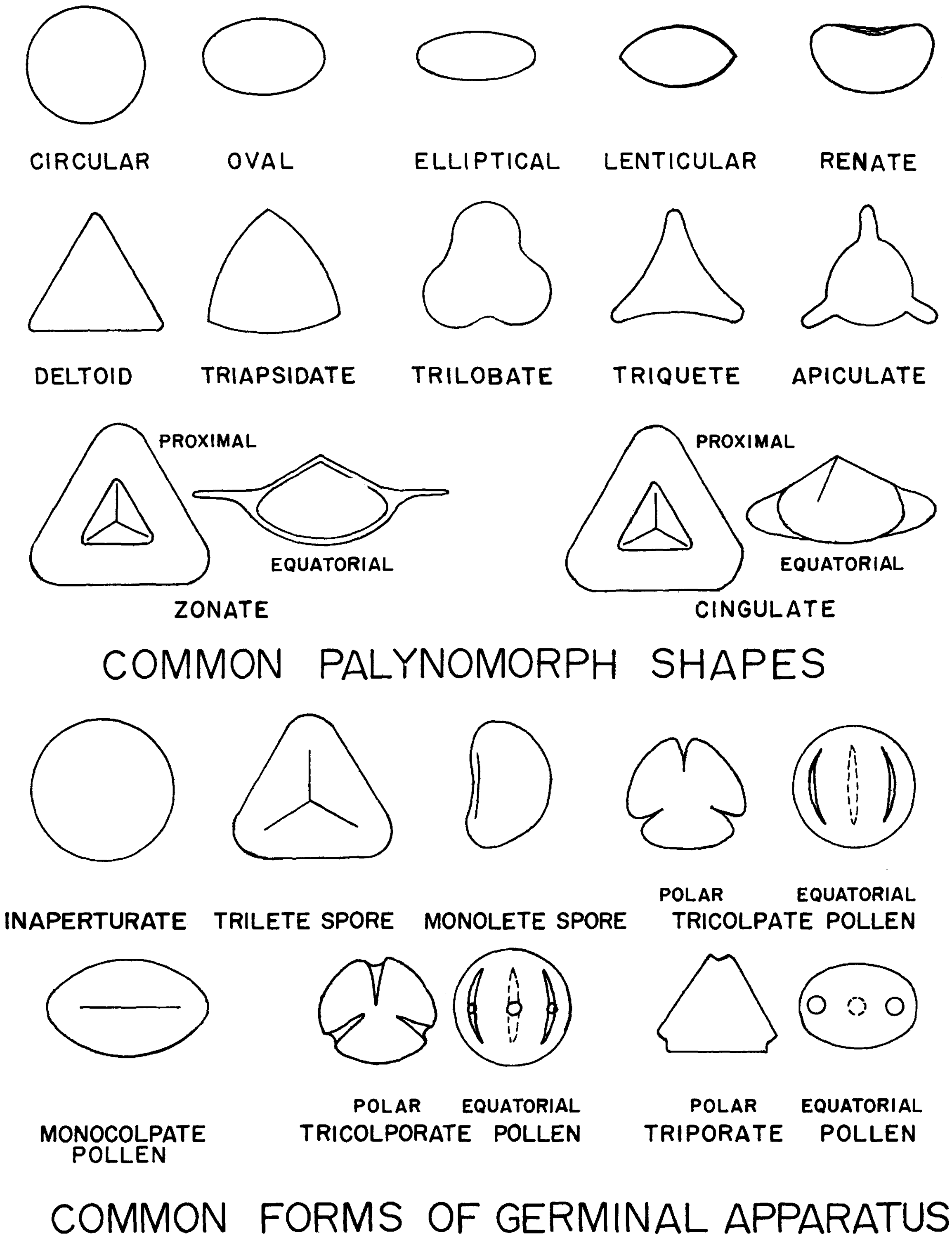


Figure 4. Schematic drawings of spores and pollen grains illustrating descriptive terminology for shapes and germinal apparatus.

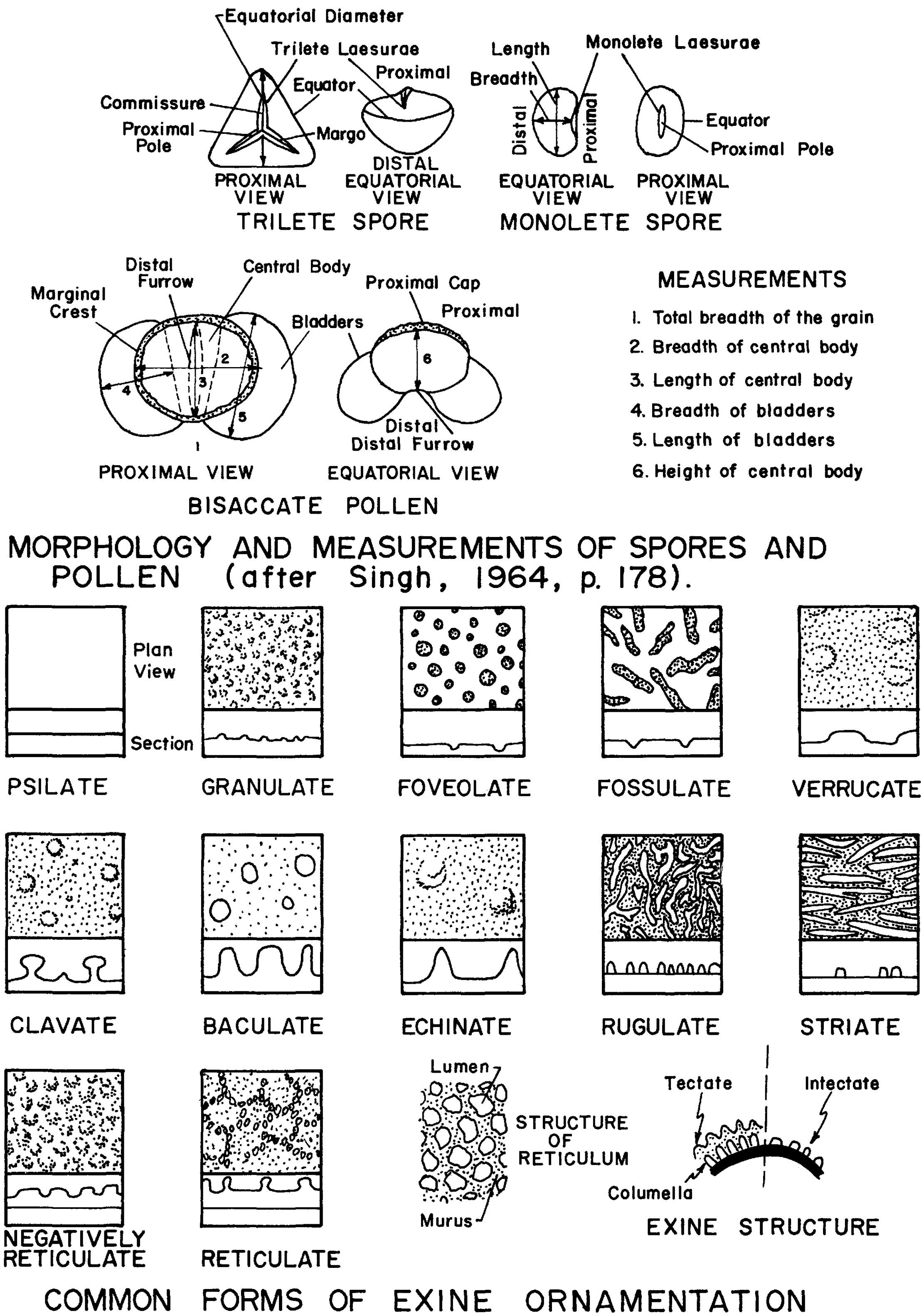


Figure 5. Schematic drawings of spores and pollen grains illustrating morphology, dimensions measured and exine ornamentation terms.

angle	corners or apices of a triangular spore.
anisopolar	having poles of different shape; synonymous with heteropolar.
annulus	a ringlike area around a pore formed by an exine thickening.
aperture[4]	a general term for germinal exitus in pollen grains and spores; it is used for colpi or pores in spermatophytes and for laesurae in pteridophytes and bryophytes; *inaperturate* grains lack apertures.
antapical	in thecate dinoflagellate (those with a resistant theca), the posterior end, frequently extended into two antapical horns.
apical areas[4]	areas adjoining corners of a triangular spore; also refers to the anterior end of elongate dinoflagellate, which is frequently extended into a single apical horn.
apiculae[4]	small conical protuberances at spore corners.
appendici	elongate projections at apices of a triangular spore.
appendiculate	spore with appendici.
archeopyle	distinctive opening in fossil dinoflagellates formed by release of a single plate or group of plates.
arcus (plural arci)	a bandlike, locally thickened exine which extends between apertures.
auriculae	earlike projections at spore corners.
baculate[5]	ornamented with rodlike, unpointed, radial projections (baculae) higher than thick, with tips not expanded; contrast *clavate*.
bisaccate[5]	pollen grain with two ektexinous protuberances or bladders on either side of the central body.
bladders (or sacci)[5]	ektexinous protuberances that stand apart from the central body; most common in some gymnospermous pollen.
canaliculate	a striate type of ornamentation in which width of ridges (lirae) exceeds width of grooves (canals or striae); contrast *cicatricose*.
central body[5]	the central part of saccate pollen or of cingulate or zonate spores.
cicatricose	a striate type of ornamentation in which width of canals exceeds width of lirae; contrast *canaliculate*.
cingulum[4]	a thickened equatorial rim attached to a central body; both are in same plane; compaction of spores sometimes produces the appearance of a cingulum in some forms.
clavate[5]	ornamented with clublike unpointed radial projections (clavae) higher than thick, with expanded tips; contrast *baculate*.
colpate[4]	angiosperm pollen with one or more colpi.
colporate[4]	dicots with a composite aperture of colpi and pores, colpi do not reach poles and pores are equatorial in position.
columella[5]	rodlike element between endexine and outer endexine.
colpus (plural colpi)[4]	a longitudinal furrow perpendicular to equator on pollen grain; length is more than two times width.
commissure[5]	the trace of slit of dehiscence on trilete or monolete spores.
cyst	layer of resistant organic material which apparently forms within the cell wall of dinoflagellates.
deltoid[4]	shape of equilateral triangle with straight sides and sharp apices.
distal[5]	the side of the spore or pollen grain which faces outward in the tetrad; monocolpate pollen grains have a distal furrow which helps distinguish them from similar monolete spores with proximal apertures.
echinate[5]	ornamented with pointed spines with broadened bases.
ektexine	outer layer of exine, composed generally of small grains or elements.
endannulus	see annulus.
endexine	distinct inner layer or exine generally of simple homogeneous structure.
equator[5]	a line separating distal from proximal hemispheres in spores; many spores have biconvex rather than spherical shapes, the polar diameter being generally shorter than the equatorial diameter and thus have a preferred orientation when compacted in enclosing sediment; the equator then becomes identical with the equatorial outline.
equatorial outline[5]	outline of spore in polar (proximal or distal) view.
exine[5]	the outermost highly resistant layer of the pollen and spore wall; it may be simple, of structureless endexine, or a more complex two-layered type (compare *ektexine* and *endexine*). This layer is one which fossilizes; inner layers and cell contents decay rapidly.
fossulate[5]	ornamented with nonparallel elongate grooves (fossulae) which have nonanastomosing cavities.
foveolate[5]	ornamented with circular pits (foveolae) up to two microns in diameter, or with larger pits too widely separated to form a reticulum.
furrow	synonym of colpus.
fusiform	spindle-shaped.
gemmate	ornamented with subspherical projections (gemmae) which have constricted bases; contrast *verrucate*.

girdle — equatorial depression in dinoflagellates.

granulate[5] — ornamented with flattened isodiametric projections (granules) larger than one micron, but smaller than 1/20 the equatorial diameter of a spore that is larger than 20 microns.

intectate[5] — literally, without a tectum; that is, one in which the exine consists generally of a single complete layer; the equivalent of the endexine, although enough unfused ektexine elements may be present to form a sculpture pattern.

laesura (plural laesurae)[5] — triradiate (trilete) or single (monolete) scar, which includes adjoining exine structures such as commissures or margo where present.

lenticular[4] — the shape of a biconvex lens.

lirae — see striate.

LO analysis — (from L: lux, light; O: obscuritas, darkness) a type of analysis that helps to clarify nature of minute (smaller than one micron) ornamentation in which elevations and depressions cannot always be differentiated. Under oil-immersion objective and at different levels of focus, the sculptured exine will show changing bright and dark patterns. For example, in a pitted grain, puncta will appear as minute dark "islands" in high focus, and as bright islands in low focus; in scabrate exines, on the contrary, minute projections appear as bright islands in high focus and as dark ones in low focus.

lumen (plural lumina)[5] — the depression between the ridges (muri) of the netlike reticulum.

margo[5] — distinct area surrounding aperture, distinguished by differences in exine thickness or sculpture from areas more distant from aperture.

monocolpate[4] — pollen with a single longitudinal distal furrow.

monolete[5] — spores, usually renate or bean-shaped, having single proximal laesura.

monosaccate — pollen with a single bladder that surrounds the central body.

muris (plural muri)[5] — netlike ridge bounding lumen in reticulate sculpture.

negatively reticulate[5] — sculpture in which polygonal narrow "ditches" separate higher exine "isles"; commonly found in sculptured exines where projecting elements are closely packed; contrast *reticulate*.

ornamentation[5] — general term used for external modifications of the ektexine which are of great diagnostic value; "sculpture" is essentially synonymous.

outline — see equatorial outline.

oval[4] — the shape of an egg.

palynology — a general term applicable to the studies of acid-resistant microfossils; most commonly, these include plant microfossils: spores, pollen grains, macerated tissues and dinoflagellates, also hystrichospheres and marine microfossils of problematical and diverse origin.

palynomorph — an inclusive name for microfossils found in palynological preparations, such as spores, pollen grains, dinoflagellates and hystrichospheres.

polar island — triangular structure formed by intersecting arci; generally used in describing polar area of some syncolpate forms.

pole — center of distal or proximal surface; the polar axis is a projected line connecting the poles.

pollen — the microgametophyte of sporophytes (gymnosperms and angiosperms).

pore[4] — a more or less isodiametric aperture in sporophytes; length-width ratio is less than 2:1.

proximal[5] — the side of the spore or pollen grain which faces the center of the tetrad; spores generally have trilete or monolete marks on this side.

psilate[5] — ornamentation in which exine is smooth with no sculpturing elements, or the elements are smaller than 0.3 micron in diameter.

punctate — ornamented with minute pits (puncta) smaller than one micron, but larger than 0.3 micron in diameter.

renate — kidney- or bean-shaped.

reticulate[5] — ornamented with a network of anastomosing ridges (muri) that enclose depressions (lumina) which may be regular or irregular in outline.

reticulum — reticulate sculpture.

rugulate[5] — ornamented with elongate, narrow, irregularly distributed ridges (rugulae).

saccate[5] — general term for pollen grains with bladders.

scabrate — ornamented with minute elevations smaller than one micron.

sculpture — see ornamentation.

spore — a reproductive body of pteridophytes and lower plant groups, capable of giving rise to a new individual.

striate[5] — ornamented with elongate linear elements (lirae are raised ridges; striae are grooves between the lirae) which are more or less parallel.

sulcus — a synonym of colpus.

syntricolporate — tricolporate grain with colpi joined at poles.

tectate[5] — refers to exine structure which is at least two-layered; the outer layer (tectum) generally completely veils the inner.

tectum	exine surface formed by fusion of elements of ektexine or of their outer ends, and which is separated from the endexine by columellae.
tetrad	a union of four spores or pollen grains formed by a mother cell by two successive reduction divisions; it is frequently tetrahedral in shape, the spores occupying the corners of the tetrahedron; also see *distal, proximal,* illustrated on plate 5, figure 12.
theca (plural thecae)	resistant cellulose-like covering of dinoflagellates, usually plated, divided by a girdle into hemispheres, epitheca and hypotheca.
torus (plural tori)	a protrusion or invagination of exine which parallels the Y mark.
trilete[5]	refers to triradiate laesurae that mark germinal area on proximal side of spores.
triapsidate[4]	shape resembling that of three equidistant semicircles; synonymous with tricircular.
triquete[4]	shape subtriangular with concave sides.
triradiate ridges	raised ridges which support trilete laesurae.
verrucate[5]	ornamented with isodiametric, flat-topped, wartlike projections (verrucae) in which lower part is not constricted and which are larger than granules; contrast *gemmate.*
zona[4]	a thin equatorial flange around equator of spore.

Descriptions of Palynomorphs

Dispersed Spores

Genus STEREISPORITES Thomson and Pflug, 1953.

Stereisporites sp. Plate 1, figure 1.

DESCRIPTION: Outline subcircular; prominent laesurae extend almost to thick wall which is about 2μ wide; diameter 21-24μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone and uppermost Tropic Shale; rare.

Genus DELTOIDOSPORA Miner, 1935 emend. Potonié, 1956.

Deltoidospora hallii Miner, 1935. Plate 1, figure 2.

OCCURRENCE: Throughout Henrieville Creek section; rare to common.

DISTRIBUTION: Widespread: Lower Cretaceous of Montana, Alberta, Maryland; Upper Cretaceous of Alabama, Colorado, Oklahoma (Hedlund, 1966).

Deltoidospora sp. Plate 1, figure 3.

DESCRIPTION: Exine about 2μ thick, psilate to subgranulate; diameter 41-50μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone and uppermost Tropic Shale; rare.

Genus CINGULATISPORITES Pflug, 1953 emend. Potonié 1956.

REMARKS: Some small-sized species of *Cingulatisporites* tend to have relatively longer laesurae and wider flanges than closely similar species which have been placed in *Sphagnumsporites* Raatz and *Stereisporites* Pflug (which has priority over *Sphagnumsporites* according to Dettman, 1963). These form-genera are not separated, however, by a sharp dividing line.

Cingulatisporites sp. A. Plate 1, figure 6.

DESCRIPTION: Outline triapsidate; prominent trilete mark extends to cingulum; exine smooth; cingulum 4-5μ wide; total diameter range 34-48μ.

Plate 1. Dispersed Spores

Figure
1. *Stereisporites* sp.
Slide 3C-4 at 1.92-1.01; 24μ

2. *Deltoidospora hallii* Miner 1935
Slide 3C-4 at 1.55-1.05; 33μ

3. *Deltoidospora* sp. A
Slide 3C-5 at 0.77-1.69; 48μ

4, 5. *Cingulatisporites* sp. B
4, slide 17-1 at 2.13-0.80; 48μ
5, slide 17-1 at 1.12-0.57; 50μ

6. *Cingulatisporites* sp. A
Slide 3C-4 at 2.50-1.01; 34μ

7. *Cingulatisporites* sp. C
Slide 3C-5 at 1.68-1.62; 50μ

8, 9. *Cyathidites minor* Couper 1953
8, slide 6-2 at 1.67-0.93; 44μ
9, slide 3C-5 at 3.58-0.54; 48μ

10, 11. *Lygodiumsporites* sp. A
10, slide 3C-4 at 3.12-1.19; 58μ
11, slide 6-6 at 1.06-1.51; 49μ

12,13. *Lygodiumsporites* sp. B
12, slide 1-4 at 1.28-0.96, 57μ
13, slide 29-3 at 1.80-1.43; 40μ

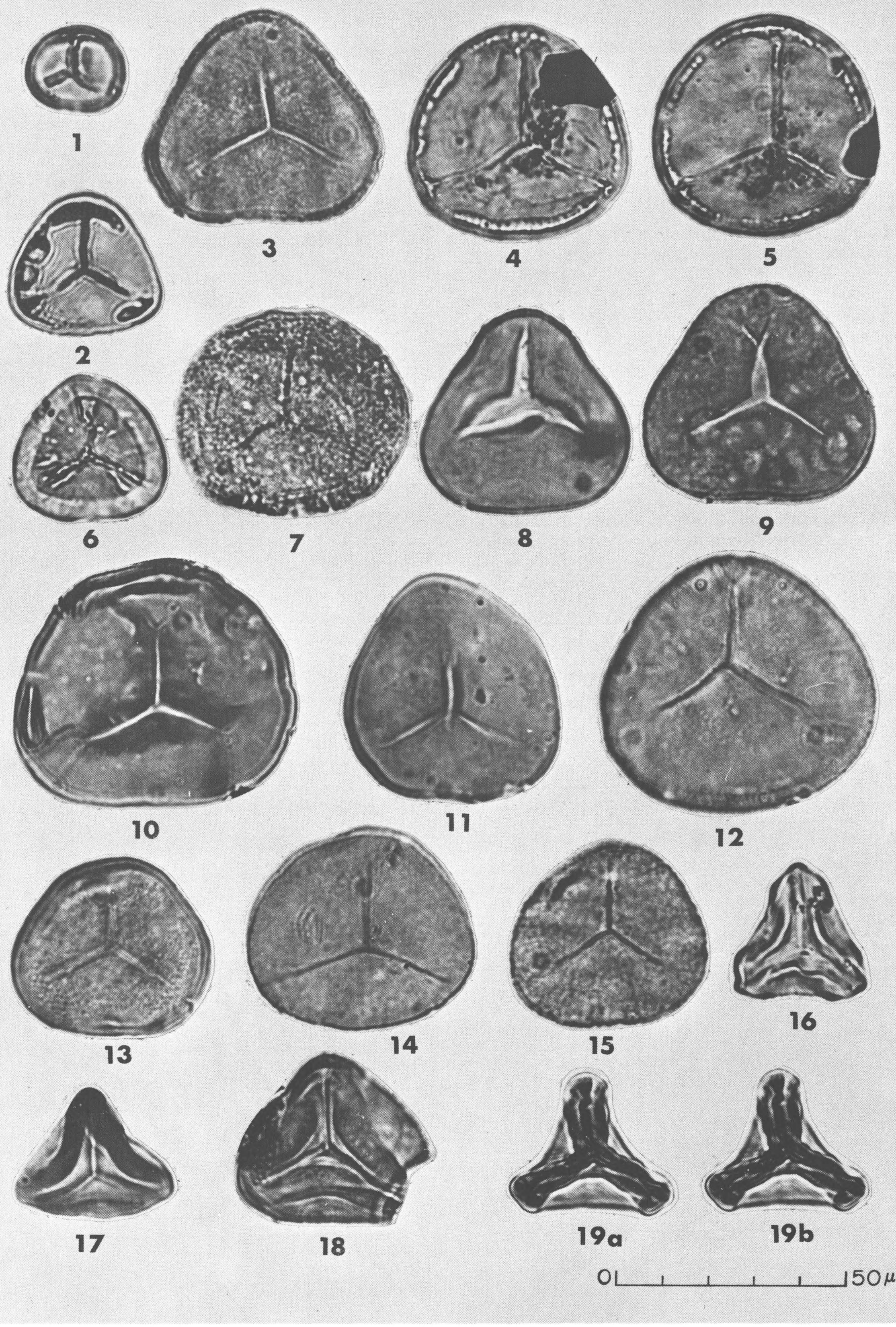
14,15. *Trilites* sp.
14, slide 6-3 at 1.38-0.96; 48 x 44μ
15, slide 6-4 at 2.81-1.01; 42μ

16, 17. *Gleicheniidites senonicus* Ross 1949
16, slide 6-3 at 1.73-1.02; 29μ
17, slide 6-2 at 2.29-0.97; 33μ

18. *Gleicheniidites circinidites* (Cookson) Brenner 1963
Slide 3C-5 at 0.74-1.54; 38μ

19. *Concavisporites jurienensis* Balme 1957
Slide 1-4 at 2.10-1.54; 34μ
19a, high focus; 19b, low focus

PLATE 1



OCCURRENCE: In lower member of Straight Cliffs Sandstone; rare.

Cingulatisporites sp. B. Plate 1, figures 4, 5.

DESCRIPTION: Outline circular to subcircular; laesurae extend to cingulum; exine smooth, sometimes slightly wrinkled; cingulum narrow, of constant 3μ width; total diameter range 48-54μ.

OCCURRENCE: In the middle member at Straight Cliffs Sandstone; frequent.

Cingulatisporites sp. C. Plate 1, figure 7.

DESCRIPTION: Outline circular to subcircular; laesurae simple, extend to cingulum; exine granulate; cingulum 5-9μ wide; total diameter range 47-50 x 41-48μ.

OCCURRENCE: Ranges through Straight Cliffs Sandstone section; rare.

Genus CYATHIDITES Couper, 1953.

Cyathidites minor Couper, 1953. Plate 1, figures 8, 9.

OCCURRENCE: Entire Henrieville Creek section; rare to abundant.

REMARKS: One side of spore is frequently straight, probably as a result of compression; diameter 29-49μ.

Genus LYGODIUMSPORITES Potonié, Thomson and Thiergart, 1950 emend. Singh, 1964.

Lygodiumsporites sp. A. Plate 1, figures 10, 11.

DESCRIPTION: Outline oval to subcircular; laesurae short, about 2/3 spore radius; commonly ends of one or more laesurae show short bifurcations; exine thin, psilate; diameter 46-60μ.

OCCURRENCE: In upper Tropic Shale and throughout Henrieville Creek section of Straight Cliffs Sandstone; rare to frequent.

Lygodiumsporites sp. B. Plate 1, figures 12, 13.

DESCRIPTION: Outline triapsidate, well rounded; laesurae distinct, extend 2/3 to 3/4 spore radius; exine scabrate; diameter 37-57μ.

OCCURRENCE: In upper Tropic Shale and throughout Straight Cliffs Sandstone section; rare to common.

Genus TRILITES Cookson, 1947, ex Couper, 1958.

Trilites sp. Plate 1, figures 14, 15.

DESCRIPTION: Laesurae extend to or nearly to periphery; exine smooth to faintly scabrate; size range 35-50μ.

OCCURRENCE: Ranges through Henrieville Creek section, rare to common.

Genus GLEICHENIIDITES Ross, 1949 emend. Delcourt and Sprumont, 1955.

Gleicheniidites senonicus Ross, 1949. Plate 1, figures 16, 17.

OCCURRENCE: Ranges through the Henrieville Creek section; rare to common.

DISTRIBUTION: Jurassic and Cretaceous (Singh, 1964).

Gleicheniidites circinidites (Cookson, 1953) Brenner 1963. Plate 1, figure 18.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent.

DISTRIBUTION: Upper Jurassic and Cretaceous: Australia, Alberta; in Cretaceous of Atlantic and Gulf Coastal Plain.

Plate 2. Dispersed Spores

Figure

1, 2. *Lycopodiumsporites* sp. A
1, slide 13-3 at 3.29-0.81; 41μ
2, slide 6-2 at 0.31-0.96; 33μ

3. *Lycopodiumsporites* sp. B
Slide 6-1 at 1.50-0.94; 43μ
3a, medium focus; 3b, low focus

4. *Lycopodiumsporites* sp. C
Slide 5L-2 at 1.89-1.41; 48μ
4a, high focus; 4b, low focus

5, 6. *Lycopodiacidites* sp.
5, slide 10B-8 at 3.19-0.56; 36μ
6, slide 6-2 at 1.84-1.17; 44 x 40μ

7, 8. *Rugulatisporites* sp. A
7, slide 3C-3 at 1.22-1.17; 27μ
7a, high focus; 7b, low focus
8, slide 3C-5 at 2.22-1.17; 28μ

9. *Rugulatisporites* sp. B
Slide 13-1 at 1.42-0.80; 44μ
9a, high focus; 9b, medium focus

10. *Hymenophyllumsporites deltoida* Rouse 1957
Slide 3C-4 at 1.90-0.67; 68μ

11. *Densoisporites* cf. *D. perinatus* Couper 1958
Slide 13-1 at 0.27-1.36; 55μ
11a, high focus; 11b, low focus

12. *Densoisporites* sp. A
Slide 6-3 at 2.48-1.77; 37μ

13. *Klukosporites* cf. *K. pseudoreticulatus* Couper 1958
Slide 6-3 at 2.27-0.84; 63μ
13a, high focus; 13b, low focus

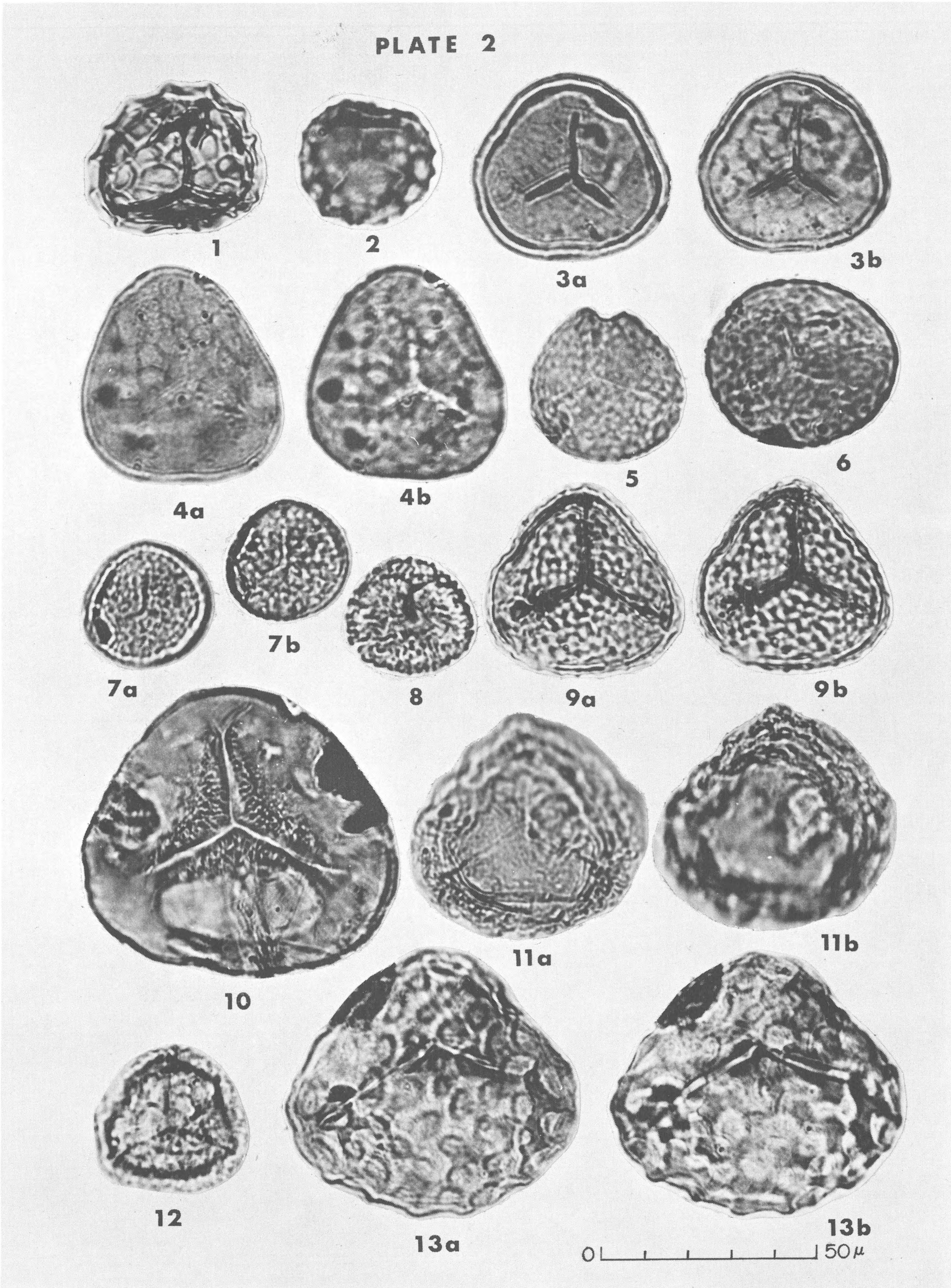


PLATE 2
1
2
3a
3b
4a
4b
5
6
7a
7b
8
9a
9b
10
11a
11b
12
13a
13b
0
50μ

Genus CONCAVISPORITES Pflug, 1953 emend. Delcourt and Sprumont, 1955.

Concavisporites jurienensis Balme, 1957. Plate 1, figure 19.

AFFINITY: Related morphologically to the Gleicheniaceae.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone and uppermost Tropic Shale; rare.

DISTRIBUTION: *C. jurienensis* was described from Lower Jurassic of Perth Basin, western Australia; Cenomanian of Oklahoma.

Genus LYCOPODIUMSPORITES Thiergart, 1938, ex Delcourt and Sprumont, 1955.

Lycopodiumsporites sp. A. Plate 2, figures 1, 2.

DESCRIPTION: Outline subcircular; laesurae extend to or almost to periphery; distally reticulate, lumen 3-8μ in diameter, muri about 1μ thick, projecting to 2μ; equatorial diameter 33-40μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Lycopodiumsporites sp. B. Plate 2, figure 3.

DESCRIPTION: Outline triapsidate, apices well rounded; laesurae distinct, extend 2/3 to outline; exine thin, distally reticulate, lumen about 5μ across; muri thin and not projecting; cingulum 2μ wide surrounds spore; diameter 34-49μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone and upper Tropic Shale; rare.

Lycopodiumsporites sp. C. Plate 2, figure 4.

DESCRIPTION: Outline triapsidate; laesurae short, extending 1/2 to 2/3 to periphery; distally reticulate, lumen 4-7μ across; muri thin and not projecting; diameter 40-48μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone and uppermost Tropic Shale; rare to frequent.

Genus LYCOPODIACIDITES Couper, 1953.

Lycopodiacidites sp. Plate 2, figures 5, 6.

DESCRIPTION: Outline subcircular; narrow laesurae extend almost to periphery; distal face rugulate; exine moderately thin; diameter 37-44μ.

OCCURRENCE: Ranges through the Henrieville Creek section; rare.

Genus RUGULATISPORITES Pflug, *in* Thomson and Pflug, 1953.

Rugulatisporites sp. A. Plate 2, figures 7, 8.

DESCRIPTION: Outline circular; laesurae short, indistinct; margins generally crenulate; diameter about 28μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Rugulatisporites sp. B. Plate 2, figure 9.

DESCRIPTION: Outline triapsidate, margin crenulate, laesurae short, distinct; sculpture densely rugulate; diameter 44μ.

OCCURRENCE: Found only in the lower part of the middle member of Straight Cliffs Sandstone; rare.

Genus HYMENOPHYLLUMSPORITES Rouse, 1957.

Hymenophyllumsporites deltoida Rouse, 1957. Plate 2, figure 10.

Plate 3. Dispersed Spores

Figure

1. *Cicatricosisporites brevilacesuratus* Couper 1958
   Slide 3C-4 at 1.20-0.61; 78 x 70μ

2, 3. *Cicatricosisporites* sp. A
   2, slide 3C-3 at 1.76-1.06; high focus; 51μ
   3, slide 3C-3 at 2.76-1.47; low focus; 54μ

4. *Cicatricosisporites* sp. F
   Slide 3C-4 at 2.07-1.41; 38μ

5. *Cicatricosisporites* sp. B
   Slide 3C-4 at 2.28-0.63; 32 x 30μ

6. *Cicatricosisporites* sp. C
   Slide 3C-5 at 1.17-0.36; 54μ
   6a, medium focus; 6b, low focus

7, 8. *Cicatricosisporites* sp. D
   7, slide 3C-4 at 0.77-1.23; 50 x 44μ
   8, slide 3C-3 at 2.16-1.54; 48μ

9. *Cicatricosisporites hallei* Delcourt and Sprumont 1955
   Slide 3C-4 at 0.92-0.91; 44μ
   9a, low focus; 9b, medium focus

10. *Cicatricosisporites* sp. E
   Slide 3C-5 at 1.26-1.12; 51μ

11. *Appendicisporites tricornitatus* Weyland and Greifeld 1953
   Slide 3C-4 at 1.12-1.73; 48μ

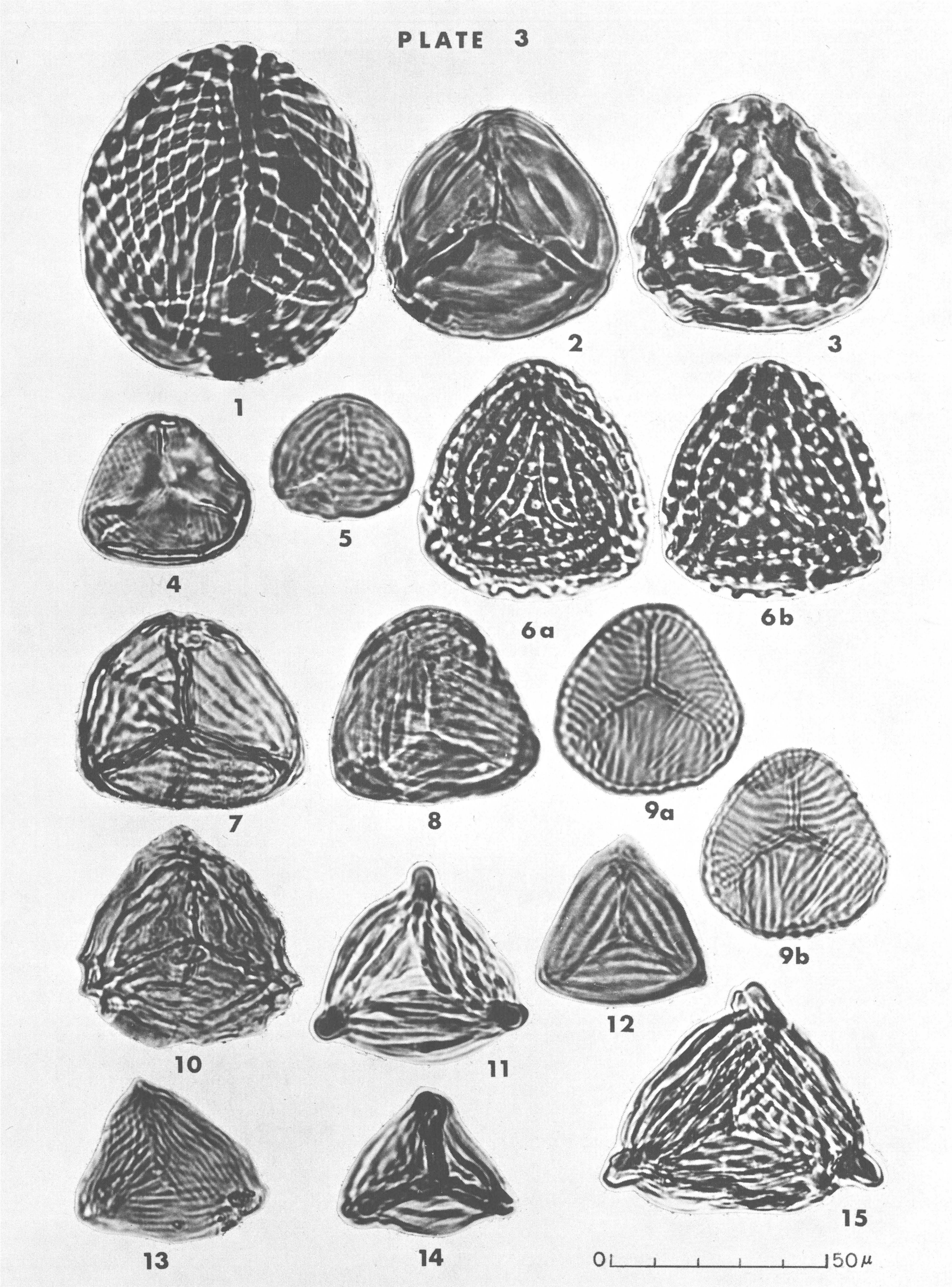
12. *Appendicisporites* sp. A
   Slide 10B-8 at 0.90-1.63; 37μ

13. *Appendicisporites* sp. B
   Slide 10B-8 at 2.40-1.63; 40μ

14. *Appendicisporites* sp. C
   Slide 10B-8 at 1.88-0.43; 37μ

15. *Appendicisporites* sp. D
   Slide 3C-5 at 0.63-0.77; 54μ

PLATE 3



OCCURRENCE: Up to the 250-foot level in the middle member of Straight Cliffs Sandstone; rare to abundant. Although absent in the clastic sample at the 250-foot level, the species is common in the adjoining coal sample.

DISTRIBUTION: Described from Oldman Formation, Santonian of southern Alberta.

Genus DENSOISPORITES Weyland and Krieger, 1953.

Densoisporites cf. *D. perinatus* Couper, 1958. Plate 2, figure 11.

DISTRIBUTION: Jurassic and Lower Cretaceous, England (Couper, 1958, p. 145); Potomac Group, Maryland.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare to frequent.

Densoisporites sp. A. Plate 2, figure 12.

DESCRIPTION: Outline subpentagonal; laesurae extend only to zona; zona thin, 3μ, wide, closely folded; central body indistinctly divided into inner and outer zone; diameter 37μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Genus KLUKISPORITES Couper, 1958.

Klukisporites cf. *K. pseudoreticulatus* Couper, 1958. Plate 2, figure 13.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

DISTRIBUTION: *K. pseudoreticulatus* has been described from Purbeckian and Waldean of England, by Couper (1958) and from the Potomac Group, Maryland (Stover, 1964).

Genus CICATRICOSISPORITES Potonié and Gelletich, 1933.

Cicatricosisporites brevilaesuratus Couper, 1958. Plate 3, figure 1.

OCCURRENCE: Only at 14-foot level (sample 3C) of Straight Cliffs Sandstone; rare.

DISTRIBUTION: Lower Cretaceous, England, Maryland; Cenomanian, Alabama.

Cicatricosisporites sp. A. Plate 3, figures 2, 3.

DESCRIPTION: Triapsidate to subcircular, outline weakly crenulate; laesurae extend to or near equator; canaliculate, ridges parallel to outline; lirae 5-7μ wide, striae narrower than 2μ; diameter 39-54μ.

OCCURRENCE: Lower member Straight Cliffs Sandstone and uppermost Tropic Shale; rare to frequent. About as common as *Cicatricosisporites hallei* (see below).

Cicatricosisporites sp. B. Plate 3, figure 5.

DESCRIPTION: Circular to subcircular, not crenulate; laesurae extend to outline; striate to canaliculate, lirae parallel outline, are concentric, branching; lirae width 2μ; striae narrower; diameter 32μ.

OCCURRENCE: Lower member of Straight Cliffs Sandstone; rare.

Cicatricosisporites sp. C. Plate 3, figure 6.

DESCRIPTION: Triapsidate, outline strongly crenulate; laesurae about 3/4 of spore radius; canaliculate, lirae parallel outline; lirae pitted longitudinally, pits to 2μ; ridges 3-5μ wide, striae about 1μ wide; diameter 43-54μ.

OCCURRENCE: Lower member of Straight Cliffs Sandstone and uppermost Tropic Shale; rare; possibly ranges to near top of Straight Cliffs Sandstone where one spore was found.

Cicatricosisporites sp. D. Plate 3, figures 7, 8.

DESCRIPTION: Triapsidate to subcircular; laesurae are as long as the spore radius; canaliculate to striate,

Plate 4. Dispersed Spores

Figure

1, 2. *Trilobosporites trioreticulosus* Cookson and Dettman 1958
1, slide 5L-5 at 0.88-1.60; 72μ
1a, high focus; 1b, medium focus
2, slide 7-8 at 1.15-0.95; 77μ

3. *Concavissimisporites* cf. *C. punctatus* (Delcourt and Sprumont) Singh 1964
Slide 6-2 at 0.91-0.75; 75μ

4, 6. *Dictyophyllidites* sp.
4, slide 3C-4 at 1.71-1.29; 37μ
6, slide 3C (damaged); 34μ

5. *Verrucosisporites* sp. C
Slide 29-3 at 1.41-0.91; 48μ

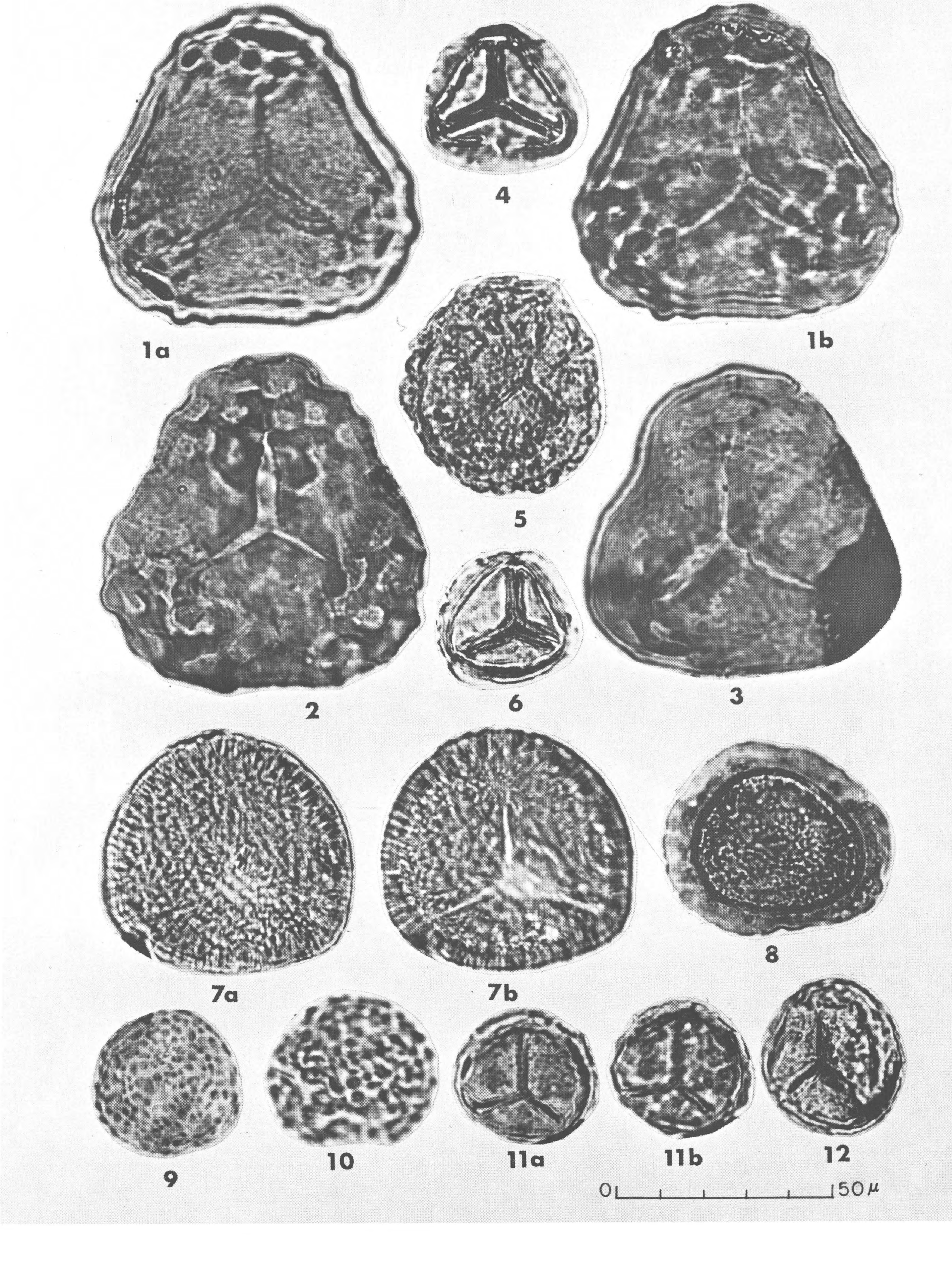
7. *Cirratriradites* sp.
Slide 3C-3 at 1.46-0.64; 59μ
7a, high focus; 7b, low focus

8. *Aequitriradites* sp.
Slide 29-3 at 3.22-1.73; 52 x 43μ

9, 10. *Verrucosisporites* sp. A
9, slide 2-8 at 1.99-0.78; 34μ
10, slide 2-8 at 1.75-1.40; 38μ

11, 12. *Verrucosisporites* sp. B
11, slide 13-1 at 1.25-1.05; 35μ
11a, high focus; 11b, low focus
12, slide 13-1 at 0.35-0.94; 34μ

PLATE 4



ridges subparallel to outline; lirae width 3μ, bifurcate; striae with 1-3μ; diameter 44-54μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent. One of the more common schizaeaceous species.

Cicatricosisporites hallei Delcourt and Sprumont, 1955. Plate 3, figure 9.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of Straight Cliffs Sandstone; rare to frequent.

DISTRIBUTION: Lower Cretaceous, Belgium, Maryland; Upper Cretaceous, Alabama. One of the more common schizaeaceous species in Straight Cliffs; very similar morphologically to *C. dorogensis* Potonié and Gelletich, but *C. hallei* has a smaller size range.

Cicatricosisporites sp. E. Plate 3, figure 10.

DESCRIPTION: Triapsidate, outline slightly crenulate; apical areas deeply "notched"; laesurae extend to equator; sculpture canaliculate, ridges parallel outline; lirae width 3μ, striae narrower than 1μ; diameter 51μ.

OCCURRENCE: Tropic Shale and lower member of Straight Cliffs Sandstone; rare.

Cicatricosisporites sp. F. Plate 3, figure 4.

DESCRIPTION: Triapsidate, angles rounded; laesurae simple, extend to margins; proximal exine smooth, distal sculptured with very fine lines about 1μ wide, which meet outline at large angle; diameter 38μ.

OCCURRENCE: Uppermost Tropic Shale and lower member of Straight Cliffs Sandstone; rare.

Genus APPENDICISPORITES Weyland and Krieger, 1953.

Appendicisporites tricornitatus Weyland and Greifeld, 1953. Plate 3, figure 11.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of Straight Cliffs Sandstone.

DISTRIBUTION: Top Berriasian, Europe; Lower Cretaceous, Alberta, Canada; Senonian, Germany.

Appendicisporites sp. A. Plate 3, figure 12.

DESCRIPTION: Triapsidate, slightly appendiculate; laesurae extend to equator; canaliculate, lirae width 2-3μ, striae 1-2μ; appendici conical, minute, about 3μ long; diameter 35-37μ.

OCCURRENCE: Middle member of Straight Cliffs Sandstone, and possibly in upper member; rare to frequent.

Appendicisporites sp. B. Plate 3, figure 13.

DESCRIPTION: Triangulate to triapsidate; laesurae extend to near angles; finely striate; lirae width about 1μ, striae narrower; appendici conical, minute; diameter 40μ.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare.

Appendicisporites sp. C. Plate 3, figure 14.

DESCRIPTION: Triangular to triapsidate; appendiculate; laesurae on prominent raised margo, 4μ wide, which extends to angles; canaliculate, lirae 2μ wide, striae slightly narrower; appendici conical, minute; diameter 37μ.

Plate 5. Dispersed Spores

Figure

1. *Microreticulatisporites* sp. A
Slide 3C-3 at 2.39-1.39; 41μ
1a, high focus; 1b, low focus

2. *Microreticulatisporites* sp. B
Slide 3C-4 at 0.96-0.42; 42μ
2a, high focus; 2b, low focus

3. *Osmundacites comaumensis* (Cookson) Cookson and Dettmen 1958
Slide 16-4 at 3.39-0.98; 41μ
3a, high focus; 3b, medium focus

4, 5. *Microreticulatisporites* sp. C
4, slide 10B-8 at 2.23-1.01; 36 x 31μ
5, slide 10B-8 at 1.01-0.63; 38 x 35μ

6. *Apiculatisporis* sp. A
Slide 3C-4 at 0.97-0.59; 24μ

7. *Apiculatisporis* sp. B
Slide 3C-4 at 1.42-1.19; 25μ

8. *Triplanosporites* sp. B
Slide 3C-5 at 2.20-0.88; 31 x 28μ

9, 10. *Triplanosporites* sp. A
9, slide 3C-5 at 0.89-1.54; 76μ
10, slide 3C-5 at 3.38-1.24; 92 x 76μ

11. *Todisporites minor* Couper 1958
Slide 10B-8 at 1.93-0.58; 35μ

12-14. *Laevigatosporites ovatus* Wilson and Webster 1946
12, slide 10B-8 at 2.31-1.44; tetrad
13, slide 6-3 at 1.33-1.63; 31 x 20μ
14, slide 5U-3 at 1.80-0.33; 24 x 18μ

15. *Reticuloidosporites* sp. B
Slide 29-4 at 1.12-1.27; 35 x 24μ

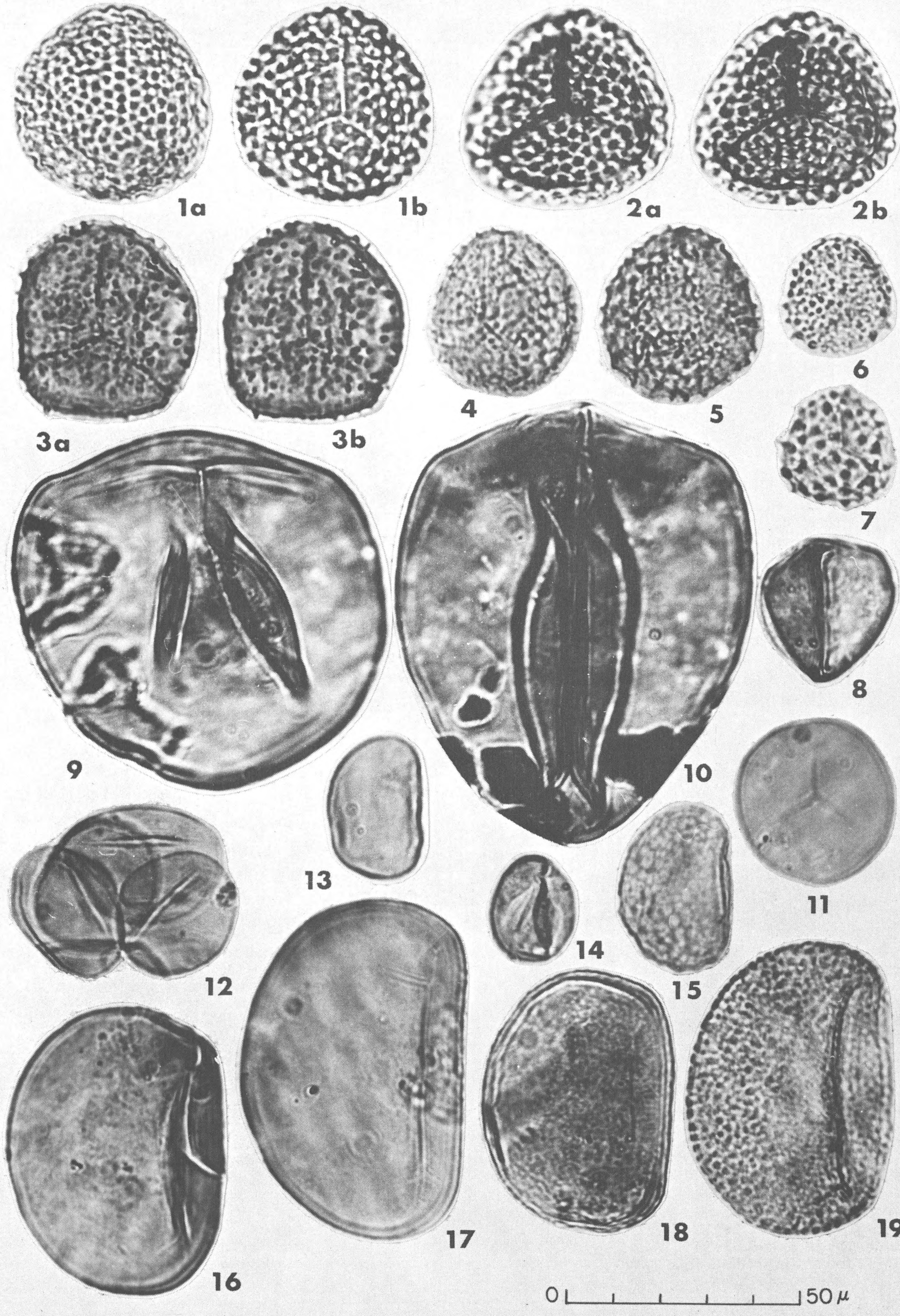
16. *Laevigatosporites* sp. A
Slide 16-2 at 2.35-1.37; 61 x 44μ

17. *Laevigatosporites* sp. B
Slide 10B-8 at 2.78-0.68; 73 x 47μ

18. *Laevigatosporites* sp. C
Slide 29-3 at 1.04-0.45; 44 x 39μ

19. *Reticuloidosporites* sp. A
Slide 10B-8 at 2.32-0.52; 61 x 43μ

PLATE 5



OCCURRENCE: Uppermost Tropic Shale and middle member of Straight Cliffs Sandstone; rare.

DESCRIPTION: Outline subrounded; prominent laesurae extend to inner edge of flange, of constant 5μ width; flange distinctly sculptured with 0.5μ-wide radial striae, which are characteristic; ornamentation granulate to verrucate; diameter 59μ.

OCCURRENCE: Lower member of Straight Cliffs Sandstone; rare.

Genus AEQUITRIRADITES Delcourt and Sprumont, 1955 emend. Cookson and Dettman, 1961.

Aequitriradites sp. Plate 4, figure 8.

DESCRIPTION: Central body distinct, oval, scabrate, exine 2μ thick, laesurae faintly or not represented, 38 x 32μ, zona irregular outline, thin, unsculptured, 5-7μ wide.

OCCURRENCE: Found only in upper member of Straight Cliffs Sandstone; rare.

Genus VERRUCOSISPORITES Ibrahim, 1933 emend. Potonié and Kremp, 1954.

Verrucosisporites sp. A. Plate 4, figures 9, 10.

DESCRIPTION: Outline circular; laesurae 1/2 to 3/4 radius, indistinct; exine thickly covered with verrucae 2-3μ wide and about 1μ high; in some specimens, verrucae are so close as to form a negative reticulum, in others warts are about 5μ apart; diameter 30-38μ.

OCCURRENCE: Scattered through lower and middle members of the Straight Cliffs Sandstone; rare to frequent.

Verrucosisporites sp. B. Plate 4, figures 11, 12.

DESCRIPTION: Outline circular to subcircular; laesurae prominent, raised, extend to or almost to equator; exine very thickly covered with subspherical verrucae about 2μ in diameter and 1.5μ high, and spaced about 0.5μ apart; diameter 30-39μ.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of Straight Cliffs Sandstone; in sample 10B, 10 specimens were found in clastic facies, none in coal.

Verrucosisporites sp. C. Plate 4, figure 5.

DESCRIPTION: Outline subcircular; laesurae indistinct, 1/2 to 2/3 radius; exine granulate to verrucate; in some specimens, a weakly to moderately developed cingulum; outline tends to be somewhat lobate.

OCCURRENCE: Upper member of Straight Cliffs Sandstone; rare.

Genus MICRORETULATISPORITES Knox, 1950 emend. Potonié and Kremp, 1954.

Microreticulatisporites sp. A. Plate 5, figure 1.

DESCRIPTION: Outline circular; laesurae extend about 2/3 to the periphery; lumina subcircular 1.5-2μ across; muri about 1μ thick; meshes are distinctly aligned over the laesurae; diameter 41-46μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Microreticulatisporites sp. B. Plate 5, figure 2.

DESCRIPTION: Outline triapsidate; laesurae extend to apparent crenate cingulum 5μ wide; lumina of reticulum 3/4μ to 2μ across; muri thinner than 1μ, about 1μ high; diameter 31-42μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Microreticulatisporites sp. C. Plate 5, figures 4, 5.

DESCRIPTION: Outline oval to elliptical; laesurae indistinct, extend to near periphery; irregular reticulum, lumina 2-5μ across, muri narrow, about 1μ high; diameter 31-38μ.

OCCURRENCE: Found in middle member of Straight Cliffs Sandstone; in sample 10B, occurs in clastic facies but not in coal; rare to frequent.

Plate 6. Inaperturate and Nonsaccate Gymnosperm Pollen

Figure

1-3. *Araucariacites australis* Cookson 1947
1, slide 29-3 at 1.69-120; 85 x 71μ
2, slide 10B-8 at 2.79-0.44; 65 x 55μ
3, slide 3C-4 at 0.68-1.82; 60μ

4. *Cycadopites fragilis* Singh 1964
Slide 3C-4 at 2.27-1.31; 31 x 20μ

5, 6. *Cycadopites* cf. *C. formosus* Singh 1964
5, slide 6-3 at 0.87-1.47; 35 x 26μ
6, slide 7-8 at 0.37-0.76; 43 x 27μ

7, 8. *Ephedripites* sp. A
7, slide 13-3 at 0.84-1.18; 55 x 34μ
8, slide 13-1 at 0.38-0.85; 54 x 37μ
8a, high focus; 8b, medium focus

9-11. *Ephedripites* sp. B
9, slide 17-1 at 0.71-1.74; 98 x 20μ
10, slide 17-1 at 2.30-0.50; 65 x 20μ
11, slide 17-1 at 1.04-1.20; 63 x 15μ

12, 13. *Ephedripites ovatus* (Pierce) 1961
12, slide 13-1 at 0.73-1.77; 38 x 21μ
13, slide 13-3 at 0.51-0.53; 34 x 25μ

14. *Ephedripites* sp. C
Slide 10B-8 at 2.78-1.43; 39 x 21μ

15-18. *Inaperturopollenites cenomanianus* (Agasie) 1969
15, slide 6-2 at 0.21-1.20; 32μ
16, slide 7-1 at 0.91-1.56; 39μ
17, slide 10A-2 at 2.34-1.52; 48μ
18, slide 13-1 at 1.77-0.45; 45μ

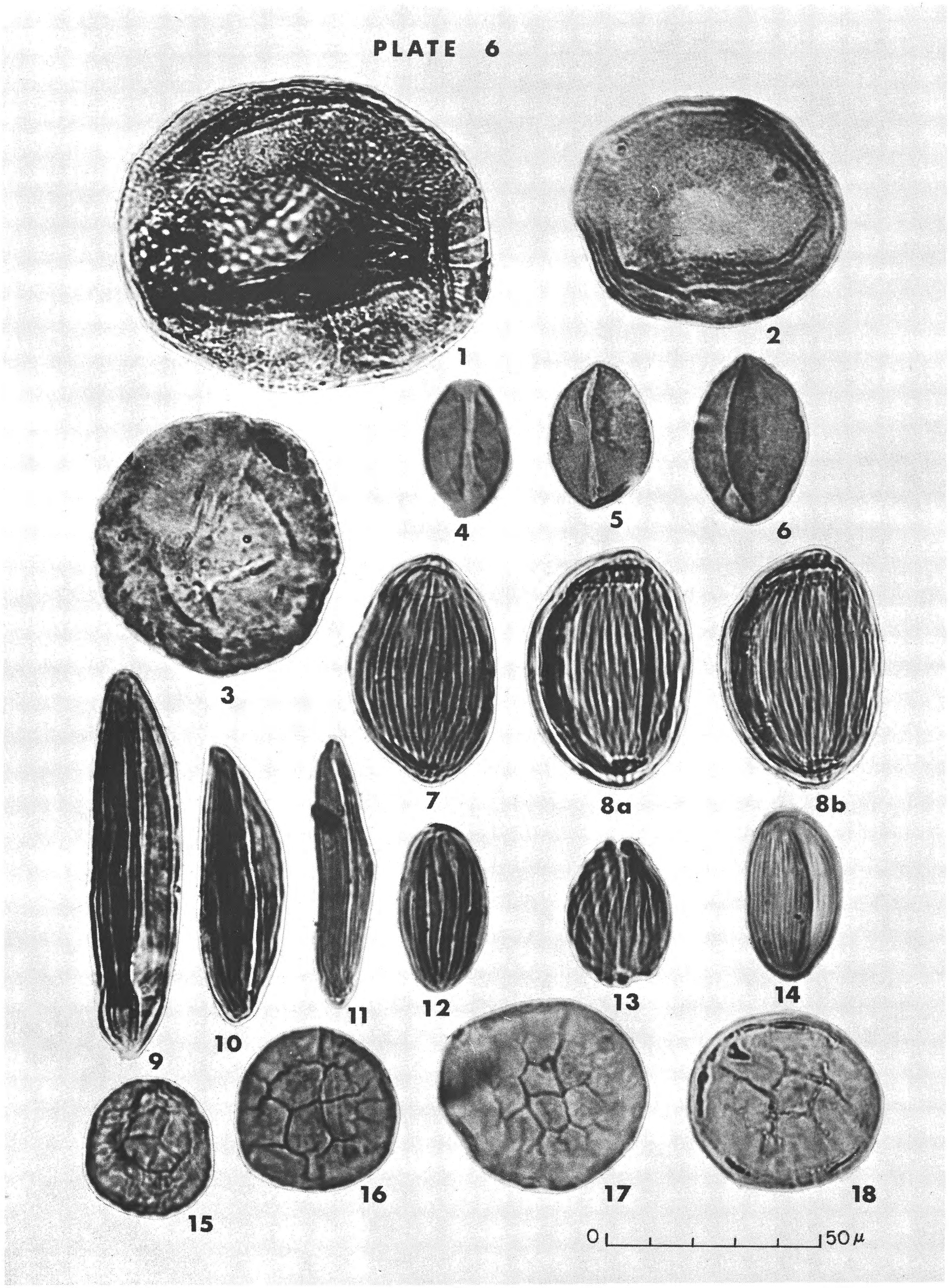


PLATE 6
1
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4
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6
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8a
8b
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10
11
12
13
14
15
16
17
18
0
50μ

Genus OSMUNDACIDITES Couper, 1953.

Osmundacidites comaumensis (Cookson) Cookson and Dettman, 1958. Plate 5, figure 3.

OCCURRENCE: Uppermost Tropic Shale and in middle member of Straight Cliffs Sandstone; rare to frequent.

Genus APICULATISPORIS Potonié and Kremp, 1956.

Apiculatisporis sp. A. Plate 5, figure 6.

DESCRIPTION: Equatorial outline oval to circular; laesurae indistinct, extend to equator; conical projections 1.5μ high and 1.5-2μ wide at base cover exine; diameter 24 x 22μ.

OCCURRENCE: Found only in sample 3C, lower member of Straight Cliffs Sandstone; frequent.

Apiculatisporis sp. B. Plate 5, figure 7.

DESCRIPTION: Outline subcircular; laesurae distinct, extend 3/4 distance to equator; subequilateral conical projections 2μ in size cover exine, bases 1-2μ apart; diameter 25μ.

OCCURRENCE: Found only in sample 3C, lower member of Straight Cliffs Sandstone; rare.

Genus TRIPLANOSPORITES Pflug, 1953.

Appendicisporites sp. D. Plate 3, figure 15.

DESCRIPTION: Appendiculate, sides convex; laesurae indistinct, extend almost to angle; canaliculate, lirae width 3μ, striae narrower than 1μ; appendici conical, prominent, about 10μ long; diameter 48-54μ.

OCCURRENCE: In lower and middle members of Straight Cliffs Sandstone; rare.

Genus TRILOBOSPORITES Pant, 1954, nom. nud. ex Potonié, 1956.

Trilobosporites trioreticulosus Cookson and Dettman, 1958. Plate 4, figures 1, 2.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of Straight Cliffs Sandstone; rare to frequent.

DISTRIBUTION: Aptian to Albanian in south Australia (Cookson and Dettman, 1958); Mannville Group, Alberta. The upper Turonian-lower Coniacian occurrence in Utah appears to extend the previous restricted range of this species. Although the possibility of recycling of these spores from Lower Cretaceous into the Upper Cretaceous strata should not be discounted, it is believed the spores and strata are contemporaneous. Straight Cliffs forms have been found at 8 levels, are among the largest of the spores found, and are very well preserved.

Genus CONCAVISSIMISPORITES Delcourt and Sprumont, 1955 emend. Delcourt and others, 1963.

Concavissimisporites cf. *C. punctatus* (Delcourt and Sprumont) Singh, 1964. Plate 4, figure 3.

OCCURRENCE: Lower and middle members of the Straight Cliffs Sandstone; rare.

DISTRIBUTION: In lowermost Cretaceous, England; Lower Cretaceous, Belgium, Alberta, Maryland (Singh, 1964).

Genus DICTYOPHYLLIDITES Couper, 1958 emend. Dettman, 1963.

Dictyophyllidites sp. Plate 4, figures 4, 6.

DESCRIPTION: Trilete spore; outline triangular, sides straight to convex; laesurae long, commissures raised; prominent margo 4-5μ wide; thin, narrow equatorial flange 2-4μ wide on some specimens, margin smooth to undulatory; exine to 2μ thick, diameter 32-38μ.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of Straight Cliffs Sandstone; rare.

Genus CIRRATRIRADITES Wilson and Coe, 1940.

Cirratriradites sp. Plate 4, figure 7.

Plate 7. Inaperturate and Nonsaccate Gymnosperm Pollen

Figure
1-4. *Classopollis classoides* (Pflug) Pocock and Jansonius 1961
1, slide 3C-4 at 2.65-1.51; tetrad
2, slide 3C-5 at 2.98-0.28; 28μ
3, slide 3C-4 at 1.30-0.29; 24μ
4, slide 3C-4 at 2.80-0.49; 24μ

5. *Monosulcites* cf. *M. glottus* Brenner 1963
Slide 7-5 at 1.18-0.71; 54 x 35μ

6. *Monosulcites spinosus* Brenner 1963
Slide 3C-5 at 1.15-0.58; 48 x 36μ

7. *Schizosporis* cf. *S. majusculus* Hedlund 1966
Slide 10A-2 at 1.79-1.42; 120 x 70μ

8. *Schizosporis* cf. *S. spriggi* Cookson and Dettman 1959
Slide 1-4 at 1.03-1.49; 75 x 56μ

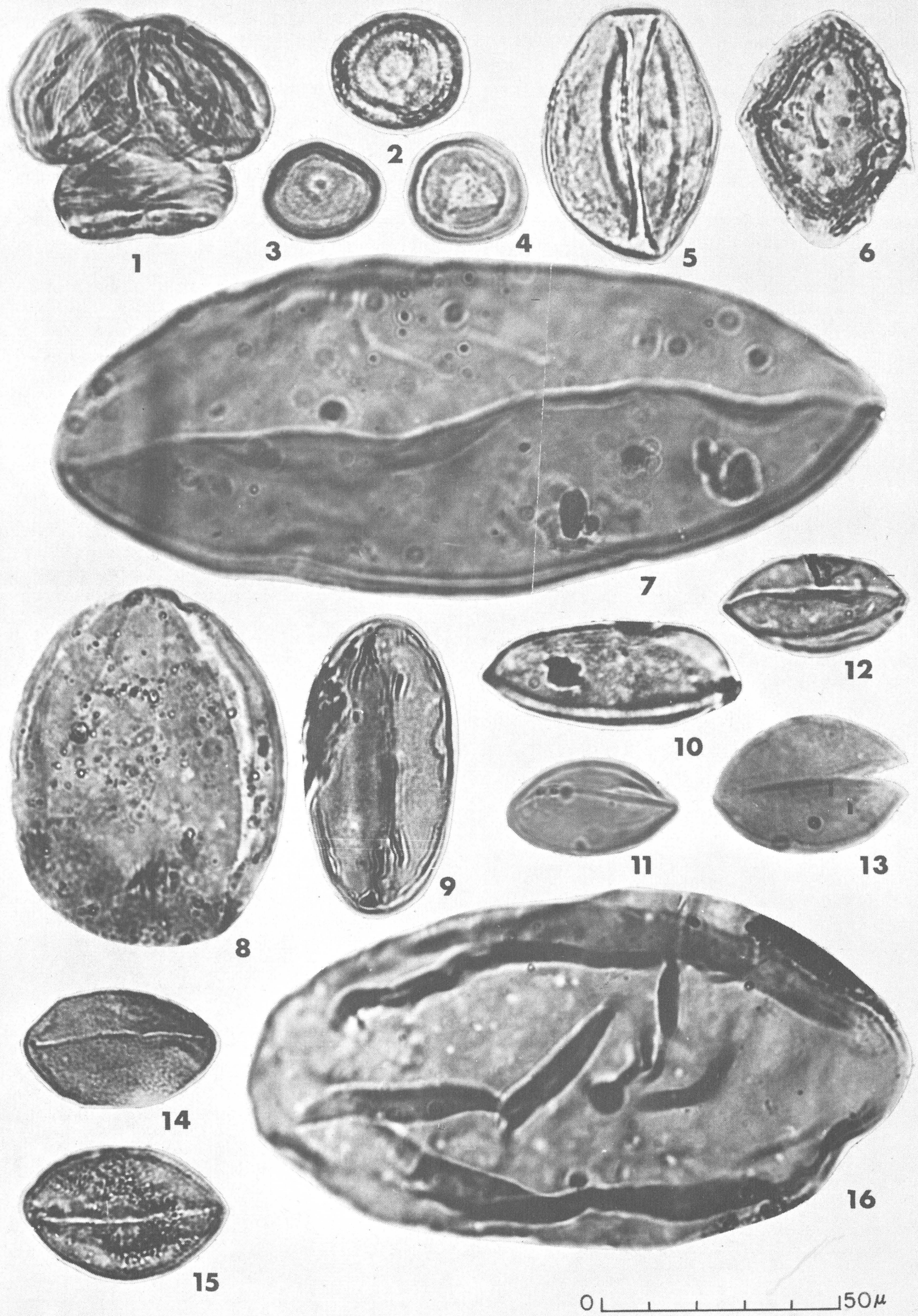
9. *Schizosporis* sp. A
Slide 3C-4 at 2.41-1.51; 61 x 30μ

10-12. *Schizosporis* sp. B
10, slide 3C-4 at 0.72-1.69; 58 x 22μ
11, slide 4-3 at 0.51-1.16; 34 x 17μ
12, slide 3C-5 at 2.60-0.36; 39 x 21μ

13-15. *Schizosporis* sp. C
13, slide 6-7 at 2.34-0.17; 42 x 30μ
14, slide 6-3 at 1.97-0.57; 41 x 26μ
15, slide 3C-5 at 0.65-1.40; 43 x 31μ

16. *Laricoidites gigantus* Brenner 1963
Slide 6-2 at 1.47-0.66; 145 x 75μ

PLATE 7



REMARKS: The long polar and shorter equatorial axes differentiate spores in this form-genus from most other trilete spores which have shorter polar than equatorial axes. In the "triplanes" the compacted outline is markedly asymmetrical. The proximal side containing the trilete mark is usually flattened, and the distal is very convex or pointed. Commonly, "leaflike" folds of exine are seen. It is difficult at times to place spores which have axes of equal length which have been compressed in a polar plane (compare plate 5, figure 9). Indeed, *Triplanosporites* may be a compaction phenomenon embracing spores from many similar psilate or weakly sculptured genera (compare discussion by Stanley, 1965, p. 263 and Deak, 1959). Generic assignment is much confused. For example, *Triplanosporites sinuosis* forms on Plate 3 of Leopold and Pakiser (1964) have *shorter polar* than *equatorial* axes.

Triplanosporites sp. A. Plate 5, figures 9, 10.

DESCRIPTION: Outline ovaloid, proximal end with laesurae is flattened, distal convex to pointed; "leaflike" folds of exine are common; exine smooth; polar length 76-92μ, equatorial diameter 76μ; polar measurements may be foreshortened should spore be compressed with polar axis at an angle to bedding.

OCCURRENCE: Lower member of Straight Cliffs Sandstone; rare.

Triplanosporites sp. B. Plate 5, figure 8.

DESCRIPTION: Outline ovaloid; proximal end flattened, distal pointed; leaflike folds of exine are common; exine smooth; polar length 23-36μ, equatorial 22-36μ.

OCCURRENCE: Scattered through Henrieville Creek section; rare to frequent.

Genus TODISPORITES Couper, 1958.

Todisporites minor Couper, 1958. Plate 5, figure 11.

OCCURRENCE: Scattered through entire Henrieville Creek section; rare to frequent.

DISTRIBUTION: *T. minor* was described from Jurassic Bajonian of England (Couper, 1958).

Genus LAEVIGATOSPORITES Ibrahim, 1933 emend. Schopf, Wilson and Bentall, 1944.

Laevigatosporites ovatus Wilson and Webster, 1946. Plate 5, figures 12-14.

OCCURRENCE: Ranges through Henrieville Creek section; rare to common; in sample 10B, it is more abundant in clastic facies than in coal.

DISTRIBUTION: Originally described from a Paleocene Fort Union coal in Montana; widespread in Cretaceous of North America and Australia (Hedlund, 1966).

Laevigatosporites sp. A. Plate 5, figure 16.

DESCRIPTION: Outline elliptical to bean-shaped; monolete mark extends about 3/4 of length on flattened side; exine psilate to weakly sculptured, moderately thin; length 44-61μ; width 28-44μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to common.

REMARKS: *Laevigatosporites* sp. A contains spores 44-61μ long; *L. ovatus* has smaller spores, and *L.* sp. B. has larger. Although the size groups are not strictly trimodal, these otherwise similar spores fall readily into these groups.

Laevigatosporites sp. B. Plate 5, figure 17.

DESCRIPTION: Outline bean-shaped; straight simple monolete mark is 2/3 to 3/4 length of spore; exine psilate, thin; length 63-99μ; width 41-50μ.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare to dominant; comprises 80 percent of sample 16, probably a local over-representation.

Laevigatosporites sp. C. Plate 5, figure 18.

DESCRIPTION: Bean-shaped or with flat proximal side; monolete mark 2/3 to 3/4 length; exine granu-

Plate 8. Inaperturate and Saccate Gymnosperm Pollen

Figure

1. *Laricoidites magnus* (Potonie) Potonie, Thomson and Thiergart 1950
   Slide 6-2 at 0.94-0.99; 85 x 78μ

2, 3. *Inaperturopollenites dubis* (Potonie and Venitz) Thomson and Pflug 1953
   2, slide 3C-4 at 0.50-1.21; 48μ
   3, slide 10B-8 at 2.10-0.41; 50μ

4. *Taxodiaeceaepollenites hiatus* (Potonie) Kremp 1949
   Slide 6-3 at 2.70-0.75; 30 x 25μ

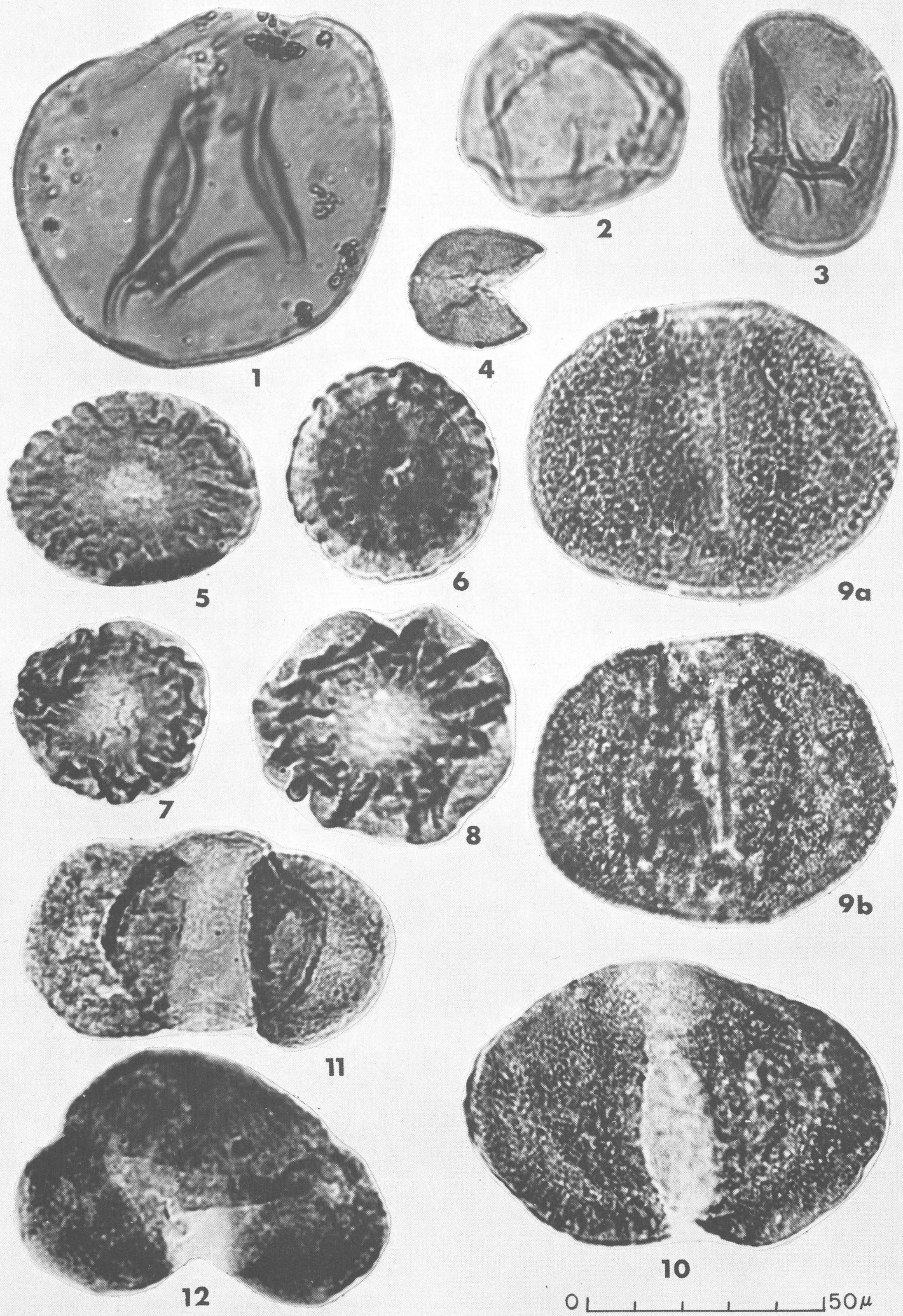
5, 6. *Zonalopollenites* sp. A
   5, slide 10B-2 at 3.22-1.00; 53 x 42μ
   6, slide 29-4 at 0.68-1.09; 47μ

7, 8. *Zonalapollenites dampieri* Balme 1957
   7, slide 6-2 at 0.61-0.59; 40μ
   8, slide 6-2 at 2.63-0.47; 50μ

9, 10. *Abietineaepollenites microreticulatus* Groot and Penny 1960
   9, slide 3C (damaged); 75 x 60μ
   9a, high focus; 9b, low focus
   10, slide 6-2 at 0.78-1.48; 89 x 60μ

11, 12. *Pinuspollenites* sp.
   11, slide 6-2 at 2.54-0.32; 76 x 53μ
   12, slide 6-6 at 3.75-1.17; 77 x 50μ

PLATE 8



late or microgranulate; length 43-60μ, width 27-38μ.

OCCURRENCE: Middle and upper members of Straight Cliffs Sandstone; rare to frequent.

Genus RETICULOIDOSPORITES Pflug, *in* Thomson and Pflug, 1953.

Reticuloidosporites sp. A. Plate 5, figure 19.

DESCRIPTION: Outline bean-shaped or with flat proximal side; monolete mark 2/3 to 3/4 length; sculpture or closely spaced subcircular to polygonal flat-topped verrucae 1-2μ across forming a negative reticulum; length 51-61μ, width 37-44μ.

OCCURRENCE: Scattered through lower and middle members of Straight Cliffs Sandstone; rare. An apparently conspecific larger form is in Upshaw (1964, figure 21), *Reticulosporis* sp., from Upper Cretaceous Frontier Formation in Wyoming.

Reticuloidosporites sp. B. Plate 5, figure 15.

DESCRIPTION: Outline generally with flat proximal side; monolete mark about 2/3, distinct, gaping; sculpture clearly reticulate, polygonal lumina 1-2μ across, muri narrow and low; size 35 x 24μ.

OCCURRENCE: Upper member of Straight Cliffs Sandstone, possibly in middle member; rare.

Inaperturate Grains and Gymnosperm Pollen

Genus ARAUCARIACITES Cookson ex Couper, 1953.

Araucariacites australis Cookson, 1947. Plate 6, figures 1-3.

OCCURRENCE: Uppermost Tropic Shale and in all members of the Straight Cliffs Sandstone; rare to common.

DISTRIBUTION: Jurassic and Cretaceous, Australia; Senonian, Germany; Potomac Group, Lower Cretaceous; Upper Cretaceous, Alabama.

Genus CYCADOPITES Wodehouse, 1933, ex Wilson and Webster, 1946.

Cycadopites fragilis Singh, 1964. Plate 6, figure 4.

OCCURRENCE: Scattered through entire Henrieville Creek section; rare to frequent.

DISTRIBUTION: Lower Cretaceous, Mannville Group, Alberta.

Cycadopites cf. *C. formosus* Singh, 1964. Plate 6, figures 5, 6.

OCCURRENCE: Scattered through entire Henrieville Creek section; rare to frequent.

DISTRIBUTION: Lower Cretaceous, Alberta.

Genus EPHEDRIPITES Bolkhovitina, 1953, ex Potonié, 1958.

Ephedripites sp. A. Plate 6, figures 7, 8.

DESCRIPTION: Outline elliptical, sculpture of about 30 coalescing ridges 1.5μ wide; furrows narrower; length 54-58μ; diameter of compressed forms 34-37μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent.

Ephedripites sp. B. Plate 6, figures 9-11.

DESCRIPTION: Outline elongate, fusiform; sculpture of 15-25 straight ridges 1-3μ wide, coalescing at ends; furrows narrower; length 63-98μ; diameter of compressed forms 15-20μ.

OCCURRENCE: Found only in sample 17, middle member of Straight Cliffs Sandstone; frequent.

Ephedripites ovatus (Pierce) n. comb. Plate 6, figures 12, 13.

OCCURRENCE: Middle and possibly in upper member of Straight Cliffs Sandstone; rare to frequent.

DISTRIBUTION: This form appears conspecific with the ephedraceous species, *Equisitosporites ovatus* (Pierce) Singh, and *Striainaperturites ovatus* Pierce; respectively from Mannville Group, Lower Cretaceous, Alberta and Dakota, Cenomanian, Minnesota.

Ephedripites sp. C. Plate 6, figure 14.

Plate 9. Saccate Gymnosperm Pollen and Inaperturate Grains

Figure

1, 2. *Piceapollenites* sp.
1, slide 29-3 at 2.73-0.65; 115 x 80μ
2, slide 29-3 at 0.32-0.52; 105 x 75μ

3, 4. *Parvisaccites* sp.
3, slide 5U-3 at 0.41-1.62; 51 x 40μ
4, slide 29-3 at 0.69-1.16; 44μ

5. *Podocarpidites* sp. A
Slide 3C-4 at 1.30-1.41; 75 x 54μ

6. *Podocarpidites* sp. B
Slide 29-4 at 0.30-0.78; 78 x 54μ

7. *Podocarpidites* sp. C
Slide 17-1 at 2.53-0.72; 120 x 78μ

8. *Foveoinaperturites* sp.
Slide 6-7 at 3.05-0.20; 41 x 32μ

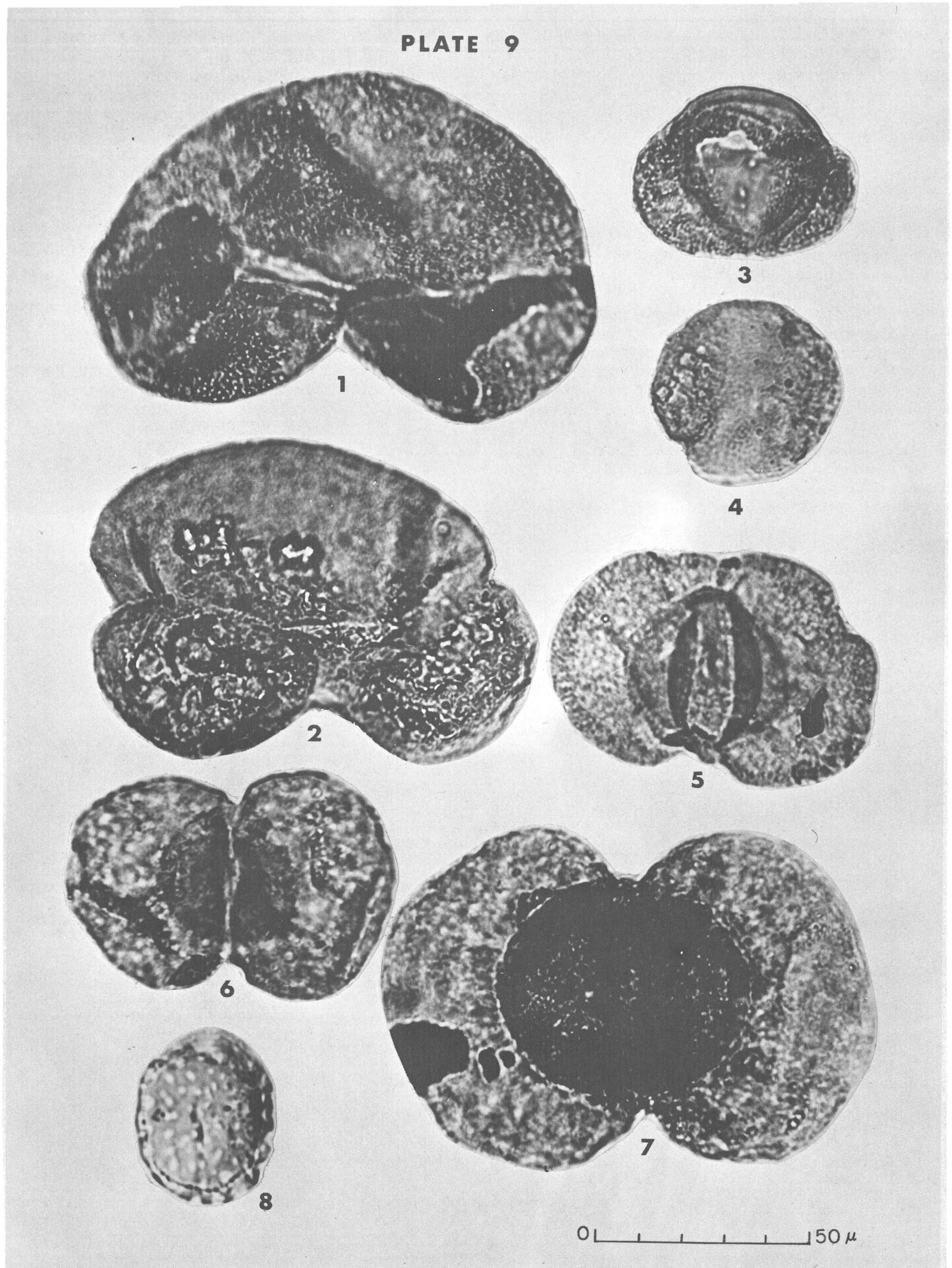


PLATE 9
1
2
3
4
5
6
7
8
0 50 μ

DESCRIPTION: Outline elliptical; sculpture of very fine, straight, coalescing ridges and furrows, about 1μ wide; length 27-39μ; diameter 15-21μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Genus INAPERTUROPOLLENITES Thomson and Pflug, 1953.

Inaperturopollenites cenomanianus (Agasie) n. comb. Plate 6, figures 15-18.

DESCRIPTION: Outline circular to subcircular; germinal apparatus is apparently lacking; a few superficially similar specimens show a faint trilete mark which extends to the periphery; the outstanding diagnostic feature is the prominent sculpturing pattern of an irregular reticulation near the grain center, and radiating lines and wrinkles which intersect the grain margin; the sculpture comprises elements which are generally neither raised above, or incised below the surface of the grain; rarely, a "zonate-like" structure is seen in some grains (plate 6, figure 18) but this is probably a compaction phenomenon; diameter range 32-50μ, but most are commonly about 44μ.

AFFINITY: Unknown, probably gymnospermous.

OCCURRENCE: Throughout entire Straight Cliffs Henrieville Creek section, but greatest numbers are found in and below the 345-foot level; this form is one of the more common and abundant palynomorphs; rare to dominant.

DISCUSSION: This and similar grains have been described under a multitude of names from Lower and Upper Cretaceous rocks in many areas. Stratigraphic value, therefore, is limited. Illustrations of the following species have been examined: *Inaperturopollenites pseudoreticulatus* Pierce, 1961 from the Dakota Formation, Minnesota, is similar to but larger than the Utah forms; *Retitriletes cenomanianus* Agasie, 1969 from the Dakota Sandstone, northeast Arizona, may be conspecific with the Straight Cliffs grains.*Hymenozonotriletes reticulatus* Bolkhovitina, 1953 from the USSR and from Alabama rocks (Leopold and Pakiser, 1964) has a faint but definite long trilete mark and a narrow membranous zona, in contrast to most of the Straight Cliffs grains which rarely may show either feature but not both.

Genus CLASSOPOLLIS Pflug, 1953 emend. Pocock and Jansonius, 1961.

Classopollis classoides Pflug, 1953 emend. Pocock and Jansonius, 1961. Plate 7, figures 1-4.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of the Straight Cliffs Sandstone; most common in the lower marine member, where it occurs with samples which also contain microplanktonic forms; rare to common. The occurrence of many grains of *Classopollis* in shallow water shale or

Plate 10. Angiosperm Pollen

Figure
1. *Liliacidites* sp.
Slide 6-3 at 0.68-1.25; 24 x 21μ
1a, high focus; 1b, low focus

2. *Tricolpites* sp. A
Slide 6-3 at 2.60-0.35; 18μ

3. *Tricolpites* sp. B
Slide 6-7 at 2.03-0.64; 26μ

4. *Tricolpites* sp. C
Slide 6-3 at 1.94-0.20; 27 x 19μ
4a, high focus; 4b, low focus

5. *Tricolpites* sp. D
Slide 6-3 at 0.74-1.73; 21 x 19μ

6. *Tricolpites* sp. E
Slide 3C-4 at 2.98-1.01; 21 x 16μ

7, 8. *Retitricolpites* sp. A
7, slide 7-5 at 3.39-1.27; 25 x 21μ
8, slide 5L-5 at 3.14-1.43; 27 x 24μ

9. *Tricolpites* sp. F
Slide 4-3 at 1.91-0.44; 39 x 28μ

10. *Tricolpites* sp. G
Slide 29-3 at 2.58-1.48; 27μ

11.-13. *Retitricolpites* sp. B
11, slide 13-1 at 1.65-0.59; 26 x 22μ
12, slide 3C-4 at 1.62-1.21; 24μ
13, slide 6-3 at 2.09-0.95; 20μ

14. *Retitricolpites* sp. C
Slide 6-2 at 0.63-0.57; 41μ
14a, high focus; 14b, low focus

15. *Retitricolpites* sp. D
Slide 3C-4 at 2.10-0.86; 41μ

16. *Retitricolpites* sp. E
Slide 3C-4 at 2.30-1.70; 45 x 27μ

17. *Retitricolpites* sp. F
Slide 4-3 at 2.49-1.13; 32 x 24μ
17a, high focus; 17b, medium focus

18-20. *Vitipites* sp.
18, slide 13-3 at 0.98-1.62; 20μ
19, slide 3C-4 at 3.33-0.42; 17μ
20, slide 3C-4 at 1.36-0.91; 17μ

21. *Nyssapollenites* sp.
Slide 29-3 at 2.50-0.33; 34μ

22, 23. *Tricolporites* sp. A
22, slide 17-1 at 1.94-1.70; 24μ
23, slide 13-1 at 1.06-1.90; 18μ

24. *Tricolporites* sp. B
Slide 3C-4 at 2.57-0.31; 17 x 13μ

25, 26. *Tricolporites* sp. C
25, slide 17-1 at 2.06-0.50; 20 x 17μ
26, slide 13-1 at 1.66-1.15; 24 x 19μ

27. *Tricolporites* sp. D
Slide 29-3 at 1.11-1.78; 31 x 29μ

28, 29. *Proteacidites* sp. A
28, slide 13-1 at 1.86-1.47; 33μ
29, slide 10B-8 at 1.83-0.92; 32μ

30. *Proteacidites* sp. B
Slide 29-2 at 2.67-0.98; 30μ

31, 32. *Sporopollis* sp.
31, slide 13-1 at 0.17-1.07; 27μ
32, slide 13-1 at 0.95-0.53; 27μ

33. *Triorites* cf. *T. fragilis* Couper 1953
Slide 13-1 at 2.49-1.27; 26μ

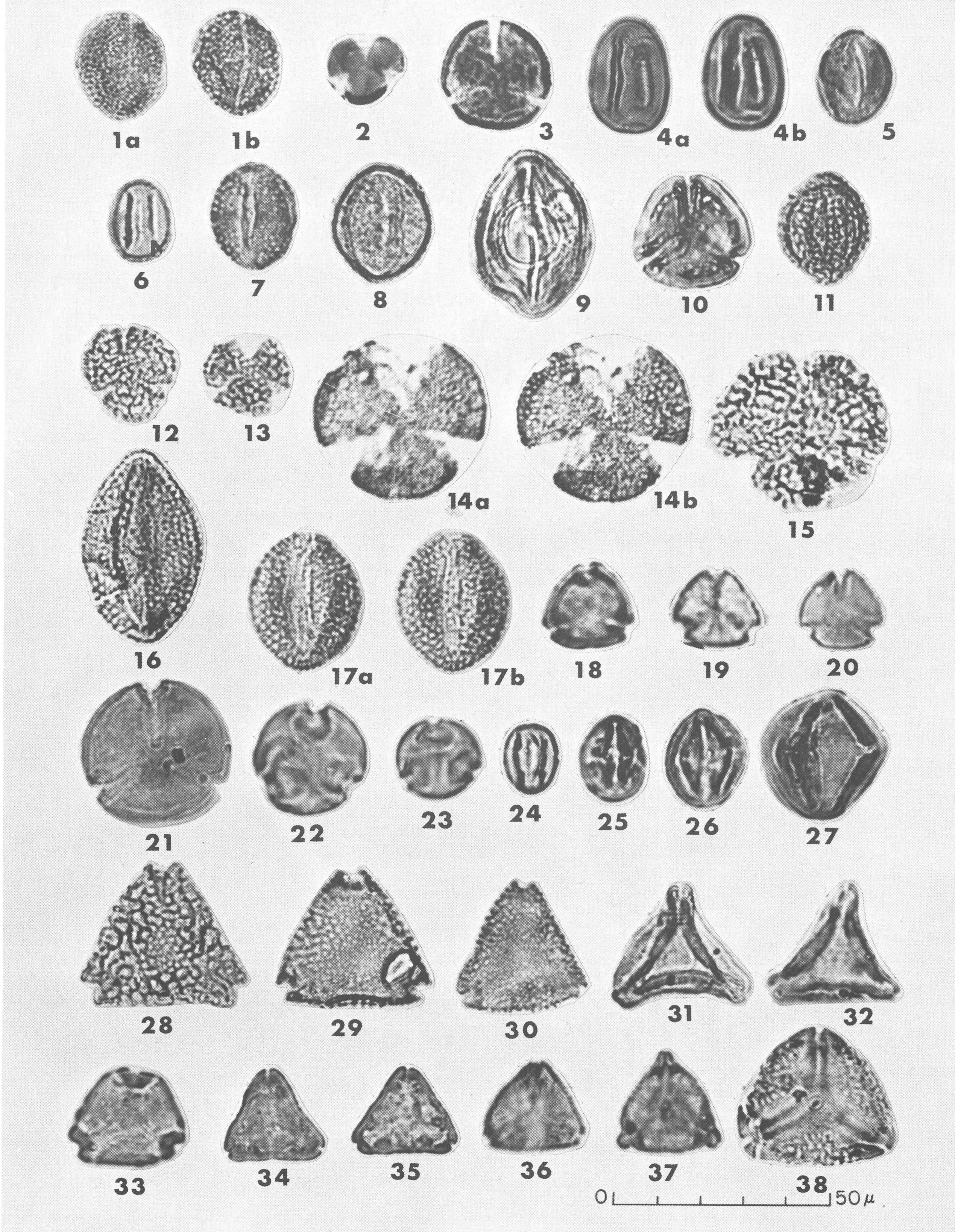
34, 35. *Tricolporites* sp. E
34, slide 29-3 at 2.35-1.43; 22μ
35, slide 29-3 at 1.25-0.35; 22μ

36. *Cupanieidites* sp. A
Slide 29-3 at 2.20-1.52; 22μ

37. *Cupanieidites* sp. B
Slide 13-1 at 0.98-1.88; 24μ

38. *Cupanieidites* sp. C
Slide 29-4 at 0.68-1.09; 34μ

PLATE 10


1a 1b 2 3 4a 4b 5
6 7 8 9 10 11
12 13 14a 14b 15
16 17a 17b 18 19 20
21 22 23 24 25 26 27
28 29 30 31 32
33 34 35 36 37 38
0 50 μ

mudstone which contains a marine microflora, suggests that the parent plants lived in a coastal environment to (Pocock and Jansonius, 1961, p. 446).

Genus MONOSULCITES Cookson, 1947, ex Couper, 1953.

Monosulcites cf. *M. glottus* Brenner, 1963. Plate 7, figure 5.

OCCURRENCE: Lower member of Henrieville Creek section; rare.

DISTRIBUTION: Potomac Group of Maryland.

Monosulcites spinosus Brenner, 1963. Plate 7, figure 6.

OCCURRENCE: Lower member Straight Cliffs Sandstone; rare.

Genus SCHIZOSPORIS Cookson and Dettman, 1959.

Schizosporis cf. *S. majusculus* Hedlund, 1966. Plate 7, figure 7.

OCCURRENCE: Middle and upper members of Straight Cliffs Sandstone; rare.

DISTRIBUTION: Cenomanian, Oklahoma.

Schizosporis cf. *S. spriggi* Cookson and Dettman, 1959. Plate 7, figure 8.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

DISTRIBUTION: Cretaceous, Australia; Cenomanian, Oklahoma; similar forms from Lower Cretaceous, Alberta.

Schizosporis sp. A. Plate 7, figure 9.

DESCRIPTION: Outline elliptical; exine thin, psilate; diameter 61-80 x 29-41μ.

OCCURRENCE: In uppermost Tropic Shale and in all members of Straight Cliffs Sandstone; rare.

Schizosporis sp. B. Plate 7, figures 10-12.

DESCRIPTION: Outline elliptical to lenticular; equatorial furrow extends diameter of grain, closed to partly open; exine smooth; diameter 34-58 x 17-24μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent.

Schizosporis sp. C. Plate 7, figures 13-15.

DESCRIPTION: Elliptical to lenticular; equatorial furrow closed to partly split; exine smooth, possibly faintly patterned; diameter 41-43 x 26-31μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent.

Genus LARICOIDITES Potonié, Thomson and Thiergart, 1950.

Laricoidites gigantus Brenner, 1963. Plate 7, figure 16.

OCCURRENCE: Entire Henrieville Creek section; rare most samples, occasionally frequent.

Laricoidites magnus (Potonié) Potonié, Thomson and Thiergart, 1950. Plate 8, figure 1.

OCCURRENCE: Entire Henrieville Creek section; rare to dominant.

DISTRIBUTION: *L. gigantus* and *L. magnus* are abundant and widespread; reported from Paleocene of South Dakota, Lower Cretaceous of Maryland, Upper Cretaceous of Oklahoma, and Cretaceous and Tertiary of Europe.

Genus INAPERTUROPOLLENITES Thomson and Pflug, 1953.

Inaperturopollenites dubius (Potonié and Venitz) Thomson and Pflug, 1953. Plate 8, figures 2, 3.

OCCURRENCE: Scattered through Henrieville Creek section; generally occurs together with *Laricoidites* forms but is less abundant than the larger forms.

Plate 11. Dinoflagellates and Hystrichosphaerids

Figure

1, 2. *Palaeoperidinium* sp.
1, slide 3C-4 at 1.92-0.47; 96 x 81μ
2, slide 3C-4 at 3.52-0.49; 98 x 92μ

3, 4. *Deflandrea* sp. A
3, slide 6-2 at 1.10-1.38; 55 x 48μ
4, slide 3C-4 at 2.70-0.37; 60 x 51μ

5-7. *Deflandrea* sp. B
5, slide 6-2 at 0.92-0.47; 65 x 45μ
6, slide 6-2 at 0.79-1.12; 62 x 47μ
7, slide 6-2 at 1.59-1.50; 79 x 52μ

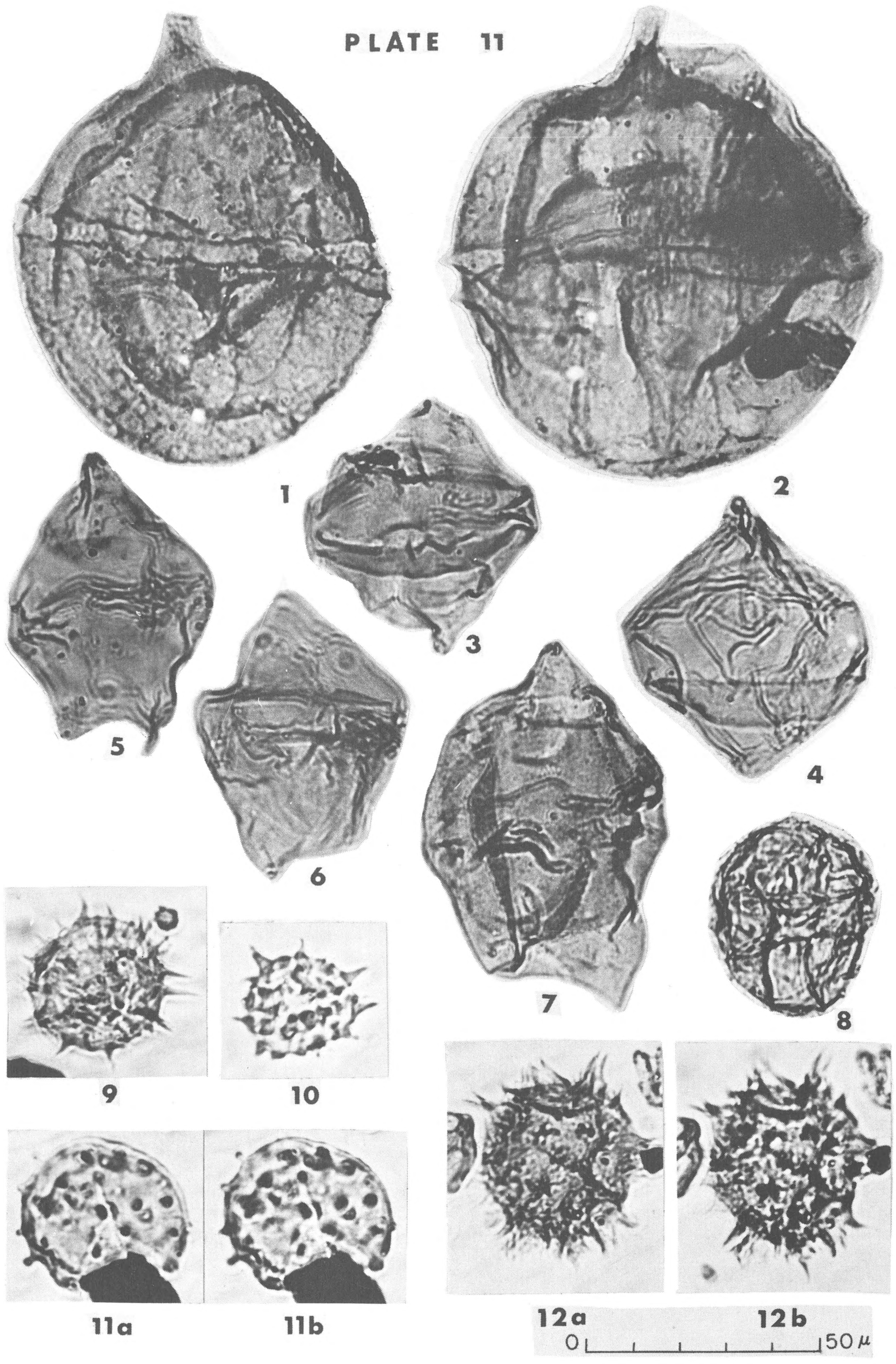
8. *Microdinium* sp.
Slide 7-5 at 1.63-1.26; 43 x 36μ

9, 12. *Baltisphaeridium* sp. A
9, slide 3C-5 at 0.73-1.44; 40μ
12, slide 3C-5 at 1.45-0.43; 48μ
12a, low focus; 12b, high focus

10. *Baltisphaeridium* sp. B
Slide 3C-4 at 3.61-1.21; 30μ

11. *Baltisphaeridium* sp. C
Slide 3C-4 at 3.02-1.43; 39 x 34μ
11a, high focus; 11b, low focus

PLATE 11



DISTRIBUTION: This and similar species under different names are widespread in Cretaceous and Tertiary deposits in Europe and North America.

Genus TAXODIACEAEPOLLENITES Kremp, 1949.

Taxodiaceaepollenites hiatus (Potonié) Kremp, 1949. Plate 8, figure 4.

OCCURRENCE: Not limited to any part of Henrieville Creek section; generally rare; unsplit grains of *Inaperturopollenites* are far more common.

DISTRIBUTION: Widespread, in Cretaceous of Oklahoma, Alabama, Maryland; Tertiary of Colorado, Utah, Germany, Hungary (Wodehouse, 1933).

Genus ZONALAPOLLENITES Pflug, 1953.

Zonalapollenites sp. A. Plate 8, figures 5, 6.

DESCRIPTION: Pollen grains mainly inaperturate; equatorial outline circular to subcircular; central body bordered by narrow fringe 8-10μ wide, regularly frilled; 47-53μ total diameter; vestigial trilete mark on one specimen.

OCCURRENCE: Middle and upper members of Straight Cliffs Sandstone; rare.

Zonalapollenites dampieri Balme, 1957. Plate 8, figures 7, 8.

OCCURRENCE: Entire Straight Cliffs Sandstone section; rare to frequent.

DISTRIBUTION: Lower Jurassic through Lower Cretaceous of western Australia; Lower Cretaceous of New Guinea (Balme, 1957), Potomac Group, Maryland.

Genus ABIETINEAEPOLLENITES Potonié, 1951.

Abietineaepollenites microreticulatus Groot and Penny, 1960. Plate 8, figures 9, 10.

Size range in total breadth of grain, 62-89μ; breadth of central body, about 35μ; length of central body, about 35μ; height of bladders, about 60μ.

OCCURRENCE: Ranges through Henrieville Creek section; rare.

Genus PINUSPOLLENITES Raatz, 1937.

Pinuspollenites sp. Plate 8, figures 11, 12.

DESCRIPTION: In most forms, bladders well separated by 15μ-wide zone on distal surface of central body; most specimens are of diploxylon type (bladders have reentrant angle); body subcircular.

Size range: total breadth of grain, 65-78μ; breadth of central body, about 45μ; length of central body, about 40μ; breadth of bladders, 28-33μ; length of bladders, 40-45μ; height of central body, 30-35μ.

OCCURRENCE: Throughout Henrieville Creek section; rare to very abundant; this is by far the most common saccate form in the Straight Cliffs Sandstone section; many oblique or equatorially oriented grains otherwise unassignable have been lumped in this organ-genus as well; not stratigraphically significant; rare or absent in coal samples.

Genus PICEAPOLLENITES Potonié, 1931.

Piceapollenites sp. Plate 9, figures 1, 2.

DESCRIPTION: Bisaccate pollen grain; body usually large, bladders small in comparison; in lateral view, a small reentrant angle visible between bladder and body; bladders nearly as long as body, and longer than broad; body texture granulate, bladders coarsely reticulate.

Size range: total breadth, 105-115μ; breadth of central body, 95-110μ; breadth of bladders, 36μ; height of central body, 45-55μ.

OCCURRENCE: Ranges through Henrieville Creek section, but is more common in middle and upper members; rare to frequent.

Genus PARVISACCITES Couper, 1958.

Parvisaccites sp. Plate 9, figures 3, 4.

DESCRIPTION: Bisaccate pollen grain; grain generally broader than long; bladders very small in comparison with central body; bladders sculptured with radial thickenings generally; bladders attached distally; proximal cap and crest well developed (terms illustrated in figure 4).

Size range: total breadth of grain, 42-62μ; breadth of central body, 35-55μ; length of central body, 38-51μ; breadth of bladders, 15-20μ; height of central body, about 38μ.

OCCURRENCE: Ranges through Henrieville Creek section; rare to frequent.

Genus PODOCARPIDITES Cookson, 1947, ex Cooper, 1953.

Pollen of this organ-genus resembles those of modern family Podocarpaceae, which is now restricted to the Southern Hemisphere (Leopold and Pakiser, 1964).

Podocarpidites sp. A. Plate 9, figure 5.

DESCRIPTION: Bisaccate pollen grains; outline of central body circular to polygonal; bladders usually large and distally pendant, often delicate; furrow distinct, often wide.

Size: total breadth of grain, 75μ; breadth of central body, 38μ; length of central body, 38μ; length of bladders, 52μ.

OCCURRENCE: One specimen was found in the lower member of Straight Cliffs Sandstone, and a few more in upper member; rare.

Podocarpidites sp. B. Plate 9, figure 6.

DESCRIPTION: Similar to sp. A. above.

Size: total breadth of grain, 75μ; breadth of central body, 30μ; length of central body, 31μ; breadth of bladders, 37μ; length of bladders, 49μ.

OCCURRENCE: Found only in upper member of Straight Cliffs Sandstone; rare.

Podocarpidites sp. C. Plate 9, figure 7.

DESCRIPTION: Similar to sp. A. above.

Size: total breadth of grain, 120μ; breadth of central body, 60μ; length of central body, 53μ; breadth of bladders, 57μ; length of bladders, 80μ.

OCCURRENCE: Found only in middle member of Straight Cliffs Sandstone; rare.

Genus FOVEOINAPERTURITES Pierce, 1961.

Foveoinaperturites sp. Plate 9, figure 8.

DESCRIPTION: Outline elliptical; germinal apparatus apparently lacking; exine covered by subrounded foveolae, 1-3μ in diameter, distributed in irregular rows; pits are 3-5μ apart; size 24-41 x 20-32μ in diameter.

OCCURRENCE: Lower member of Straight Cliffs Sandstone; rare.

Angiosperm Pollen

Genus LILIACIDITES Couper, 1953.

Liliacidites sp. Plate 10, figure 1.

DESCRIPTION: Outline subcircular; sulcus extends full length of grain; microreticulate, lumina diameter 1μ or less; 20-29μ long; 17-21μ wide.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Genus TRICOLPITES Cookson ex Couper, 1953.

This form-genus accommodates tricolpate grains lacking reticulate sculpture.

Tricolpites sp. A. Plate 10, figure 2.

DESCRIPTION: Polar outline "lobate"; colpi side gaping, extending 2/3 poles; exine thick, psilate; diameter 15-19μ.

OCCURRENCE: Uppermost Tropic Shale and lower and middle members of Straight Cliffs Sandstone; rare to frequent.

Tricolpites sp. B. Plate 10, figure 3.

DESCRIPTION: Polar outline circular; colpi long, narrow, extending 2/3 to 3/4 to poles; exine 1.5μ thick, smooth to punctate; diameter 19-26μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Tricolpites sp. C. Plate 10, figure 4.

DESCRIPTION: Equatorial outline oval to elliptical; colpi extend 2/3 to 3/4 to poles; exine thin, psilate; 27-31 x 19-20μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent.

Tricolpites sp. D. Plate 10, figure 5.

DESCRIPTION: Equatorial outline elliptical; colpi extend 3/4 to poles; exine thin, psilate to scabrate; 18-24 x 12-19μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Tricolpites sp. E. Plate 10, figure 6.

DESCRIPTION: Equatorial outline elliptical; colpi extend 2/3 to poles; sculpture baculate, elements 0.5μ high, closely packed; 16-21 x 14-16μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to common.

Tricolpites sp. F. Plate 10, figure 9.

DESCRIPTION: Equatorial outline elliptical, poles acute; colpi extend to near poles; exine 1μ thick, psilate to possibly scabrate; 32-43 x 25-28μ.

OCCURRENCE: Not restricted to any member of Straight Cliffs Sandstone; rare to frequent.

Tricolpites sp. G. Plate 10, figure 10.

DESCRIPTION: Polar outline subcircular to triapsidate; colpi narrow, tapering, extend almost to poles; exine smooth, about 3μ thick, 20-27μ diameter.

OCCURRENCE: Tropic Shale and middle and upper members of Straight Cliffs Sandstone; rare to frequent.

Genus RETITRICOLPITES Van der Hammen, 1956.

This form-genus accommodates tricolpate grains with reticulate sculpture.

Retitricolpites sp. A. Plate 10, figures 7, 8.

DESCRIPTION: Outline elliptical; colpi extend to near poles; sculpture scabrate to microreticulate, lumina 0.5-1μ across, muri narrow, to .75μ high; 23-29 x 17-24μ.

OCCURRENCE: Tropic Shale and lower and middle members of Straight Cliffs Sandstone; rare to frequent.

Retitricolpites sp. B. Plate 10, figures 11-13.

DESCRIPTION: Polar outline subcircular, equatorial outline elliptical; colpi narrow or widely gaping, depending on compression effects, extend to near poles; sculpture reticulate, lumina 1-2μ across, muri narrow, low; size range 15-27μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to frequent. This form-species is smaller than *Tricolpites bathyreticulatus* Stanley from the Paleocene but has similar sculpture; *T. reticulatus* Cookson is similar in size but its reticulation is finer than Straight Cliffs Sandstone forms.

Retitricolpites sp. C. Plate 10, figure 14.

DESCRIPTION: Polar outline circular; colpi unbordered, widely gaping, extend to near poles; exine thin, microreticulate, lumina circular to polygonal, 0.5-0.75μ across, muri narrow, low; 32-49μ diameter.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare.

Retitricolpites sp. D. Plate 10, figure 15.

DESCRIPTION: Polar outline subcircular; colpi widely gaping, extend about 1/2 to 2/3 to poles; exine thin, irregularly reticulate, lumina 1-4μ across, muri narrow, about 0.5μ high; 41μ diameter.

OCCURRENCE: Found only in sample 3C, in lower member of Straight Cliffs Sandstone; rare.

Retitricolpites sp. E. Plate 10, figure 16.

DESCRIPTION: Equatorial outline fusiform or elliptical with acute poles; colpi extend to near poles; evenly microreticulate, lumina 0.5-1μ across, about 1μ apart, muri low; 42-45 x 28-30μ.

OCCURRENCE: Tropic Shale and lower member of the Straight Cliffs Sandstone; rare.

Retitricolpites sp. F. Plate 10, figure 17.

DESCRIPTION: Equatorial outline elliptical; colpi extend to near poles; exine thin, microreticulate, lumina about 1μ across, muri narrow, low; 28-32 x 17-24μ.

OCCURRENCE: In all members of Straight Cliffs Sandstone; rare to frequent.

Genus VITIPITES Wodehouse, 1933.

Vitipites sp. Plate 10, figures 18-20.

DESCRIPTION: Pollen, tricolporate, outline in polar view subtriangular to subcircular; colpi sharply defined, long, tapering; pores round, usually indistinct; sculpture scabrate to finely reticulate; 14-20μ in diameter.

OCCURRENCE: In all members of Straight Cliffs Sandstone; rare to frequent.

Genus NYSSAPOLLENITES Thiergart ex Potonié, 1960.

Nyssapollenites sp. Plate 10, figure 21.

DESCRIPTION: Pollen, tricolporate, spherical to oblate; outline in polar view circular to subtriangular; pores large, distinct with annulus; colpi prominent, tapering, often extending almost to poles; sculpture weakly granulate; 33-37μ diameter.

OCCURRENCE: Middle and upper members of Straight Cliffs Sandstone, possibly in lower; rare to common.

Genus TRICOLPORITES Erdtman, 1947.

This form-genus encompasses tricolporate grains.

Tricolporites sp. A. Plate 10, figures 22, 23.

DESCRIPTION: Outline in polar view circular; pores prominent, colpi reduced; pores have subcircular vestibule underlying external pore, and endexinous thickening which is characteristic; exine thin, psilate; 18-24μ diameter.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare. This form is strongly suggestive of a *Tilia*-type pollen, but the Straight Cliffs form is smaller and lacks the pronounced reticulum structure which seems characteristic of *Tilia* (Traverse, 1955). *Tilia* has been described from Tertiary Brandon lignite and Paleocene of the San Juan Basin (Anderson, 1960).

Tricolporites sp. B. Plate 10, figure 24.

DESCRIPTION: Equatorial outline elliptical, poles broadly rounded; colpi extend to near poles, pores are an elongate widening in the middle of the colpi; exine thin, smooth; size 13-17 x 10-13μ.

OCCURRENCE: Lower and middle members of Straight Cliffs Sandstone; rare to common; absent in clastic facies of sample 10B, middle member.

Tricolporites sp. C. Plate 10, figures 25, 26.

DESCRIPTION: Equatorial outline elliptical, poles rounded to somewhat acute; colpi extend to near poles, pores equatorial, small, subcircular; exine smooth; 19-27 x 14-19μ.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare to frequent.

Tricolporites sp. D. Plate 10, figure 27.

DESCRIPTION: Equatorial outline subcircular to rhomboidal; colpi extend almost to poles, cut by prominent transverse furrow, or pore; colpi commonly gaping because of compression effects; exine thin, psilate; 29-32 x 27-29μ in compressed pollen.

OCCURRENCE: Upper member of Straight Cliffs Sandstone; frequent.

Tricolporites sp. E. Plate 10, figures 34, 35.

DESCRIPTION: Polar outline triangular, sides straight to slightly concave; pores small, colpi narrow, short, indistinct; exine thin, smooth; 17-22μ diameter.

OCCURRENCE: Middle and upper members of Straight Cliffs Sandstone; rare to frequent.

Genus CUPANIEIDITES Cookson and Pike, 1954.

Cupanieidites sp. A. Plate 10, figure 36.

DESCRIPTION: Pollen, syntricolporate; outline in polar view triangular with sides weakly convex or concave; arci enclosing polar islands common in some species; exine weakly microreticulate, becoming smoother toward poles; diameter 22μ.

OCCURRENCE: Upper member of Straight Cliffs Sandstone; rare.

Cupanieidites sp. B. Plate 10, figure 37.

DESCRIPTION: Polar outline triapsidate, angles slightly extended; tricolporate, arci triangular, enclose polar island; exine weakly microreticulate, becoming smoother toward poles; diameter 24μ.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare.

Cupanieidites sp. C. Plate 10, figure 38.

DESCRIPTION: Polar outline triapsidate; syntricolporate, colpi distinct; exine microreticulate, lumina becoming smaller toward poles; diameter 28-34μ.

OCCURRENCE: Upper member of Straight Cliffs Sandstone; frequent.

Genus PROTEACIDITES Cookson, 1950.

DISTRIBUTION: Upper Cretaceous and Eocene, United States. In the eastern United States *Proteacidites* was previously unknown from strata older than Campanian, but the genus has recently been described from the Pond Bank deposit of Pennsylvania, which may be as old as late Turonian (Tschudy, 1965). Therefore, finding *Proteacidites* in Straight Cliffs Sandstone strata dated as late Turonian and possibly early Coniacian is of interest, for it corroborates the dating of the Pond Bank deposit by Tschudy. Several species of *Proteacidites* occur in the Vermejo Formation (Maestrichtian) of Colorado (Clarke, 1963), Late Cretaceous and Paleocene formations, northwestern Colorado (Newman, 1961), and strata of Maestrichtian age in South Dakota.

Proteacidites sp. A. Plate 10, figures 28, 29.

DESCRIPTION: Polar outline triangular, sides straight; apical pores large, about 5μ across; exine thick, coarsely reticulate toward periphery, becoming finer toward poles, lumina 0.5-3μ across; muri thick, projecting about 0.5μ; 31-33μ diameter.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare to frequent.

Proteaciditites sp. B. Plate 10, figure 30.

DESCRIPTION: Polar outline triangular, sides straight to slightly convex; pores about 3μ across; microreticulate, lumina becoming smaller toward poles, range 1μ and smaller; diameter 22-30μ.

OCCURRENCE: Middle and upper members of Straight Cliffs Sandstone; rare to frequent.

REMARKS: *Proteacidites* species A and B are separated because they appear to be bimodal on size and sculpture character, based on a small sampling. Newman (1961, p. 46) has a larger number and finds intergrading of somewhat similar end-members; however, in the older Straight Cliffs, species A and B may be clearly distinguished and may have stratigraphic significance.

Genus SPOROPOLLIS Pflug, 1953.

Sporopollis sp. Plate 10, figures 31, 32.

DESCRIPTION: Pollen, triporate or possibly tricolporate; polar outline triquete; outstanding character a very strong torus close to and parallel to margin; pores about 1μ in diameter; if colpus present, it is very short; 27μ.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare. Very similar forms are figured in Leopold and Pakiser (plate 3, 1964); they occur in pre-Selma strata of Alabama (Cenomanian to Coniacian).

Genus TRIORITES Cookson ex Couper, 1953.

Triorites cf. *T. fragilis* Couper, 1953. Plate 10, figure 33.

OCCURRENCE: Middle member of Straight Cliffs Sandstone; rare.

DISTRIBUTION: *T. fragilis* from Upper Cretaceous of New Zealand is slightly larger than Straight Cliffs form but is otherwise very similar.

Dinoflagellates and Hystrichsphaerids
Order Dinoflagellata
Family Peridinidae

Genus PALAEOPERIDINIUM Deflandre, 1934.

Palaeoperidinium sp. Plate 11, figures 1, 2.

DESCRIPTION: Test subcircular, tapering more or less toward a point which bears a single tapering horn about 14μ long; theca smooth to weakly granulate; equatorial girdle in middle marked by a border of distinct raised lines about 5μ apart; diameter 80-100μ.

OCCURRENCE: Comprises about 15 percent of the microplanktonic forms in sample 3C in lower member of Straight Cliffs Sandstone. The described form somewhat resembles the more granulate species *P. granulatum* Singh from the Albian of Alberta.

Family Deflandreidae

Genus DEFLANDREA Eisenack, 1938.

Deflandrea sp. A. Plate 11, figures 3, 4.

DESCRIPTION: Outline subhexagonal; epitheca is triangular, tapering to twisted horn; girdle 15-20μ wide, sides straight; hypotheca subequal in size to epitheca, bears one prominent twisted horn, the other much less prominent; test appears unplated; archeopyle obscure or absent; characteristic are darkly stained bands 5-8μ wide which may mark borders of an internal cyst; size range 40-60 x 40-52μ.

OCCURRENCE: Constitutes about 10-20 percent of microplanktonic forms in uppermost Tropic Shale and lower member of Straight Cliffs Sandstone.

Deflandrea sp. B. Plate 11, figures 5-7.

DESCRIPTION: Outline subpentagonal, sides straight to rounded; epitheca triangular, tapering to blunt apical horn; girdle area indistinctly marked, sides convex; hypotheca tapers and carries two very unequal triangular horns; archeopyle obscure or absent; test commonly contains a subcircular cyst; size range including horns 63-92μ long, 48-70μ broad.

OCCURRENCE: Constitutes 60-85 percent of microplanktonic forms in uppermost Tropic Shale and lower member of Straight Cliffs Sandstone.

Incertae Familiae

Genus MICRODINIUM Cookson and Eisenack, 1960.

Microdinium sp. Plate 11, figure 8.

DESCRIPTION: Test small, more or less oval in outline; girdle circular, level with surface; lacks horns; theca clearly plated; prominent ridges between plates; surface pitted and wrinkled; broad girdle divides test unequally; size 42-48 x 33-44μ.

OCCURRENCE: Lower member of Straight Cliffs Sandstone only; rare to frequent.

Order Hystrichosphaeridea
Family Hystrichosphaeridae

Genus BALTISPHAERIDIUM Eisenack, 1958 emend. Downie and Sarjeant, 1963.

Baltisphaeridium sp. A. Plate 11, figures 9, 12.

DESCRIPTION: Vesicle outline circular, wall thin, thickly covered with long, tapering, unbranched spinelike processes to 8μ long; range total diameter 40-48μ.

OCCURRENCE: Found only in sample 3C; lower member of Straight Cliffs Sandstone; frequent.

Baltisphaeridium sp. B. Plate 11, figure 10.

DESCRIPTION: Vesicle outline circular, thin-walled, thickly covered with broad-based, tapering, unbranched spinelike processes 3-5μ long; total diameter 30μ.

OCCURRENCE: Found only in sample 3C; frequent.

Baltisphaeridium sp. C. Plate 11, figure 11.

DESCRIPTION: Vesicle outline circular to subcircular, fairly thin-walled, covered with short, cylindrical processes with rounded ends, about 3μ long, and 2μ wide; processes are spaced 3-6μ apart; total diameter 39 x 34μ.

OCCURRENCE: Found only in sample 3C; rare.

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