# Palynological Evaluation of Cedar Mountain and Burro Canyon Formations, Colorado Plateau

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1281

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*By* R. H. TSCHUDY, B. D. TSCHUDY, *and* L. C. CRAIG

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# PALYNOLOGICAL EVALUATION OF CEDAR MOUNTAIN AND BURRO CANYON FORMATIONS, COLORADO PLATEAU

By R. H. TSCHUDY, B. D. TSCHUDY, and L. C. CRAIG

ABSTRACT

By lithologic facies change the Cedar Mountain Formation of eastern Utah passes laterally into the Burro Canyon Formation of western Colorado. Both formations lie between the Dakota Sandstone and Morrison Formation. Few fossils have been found in the Cedar Mountain and Burro Canyon Formations, and consequently the age span attributed to these formations has been uncertain.

The overlying Dakota Sandstone in these two areas is palynologically of early Cenomanian age. The first occurrence of the angiosperm fossil pollen, *Nyssapollenites albertensis* Singh, found in the basal Dakota, is proposed as the palynological indicator of the Early-Late Cretaceous boundary in the Western Interior. Palynomorphs found in the upper parts of both the Cedar Mountain and Burro Canyon Formations are more advanced than are those found in the upper part of the Morrison Formation in the same general area. Consequently, the upper parts of the Cedar Mountain and Burro Canyon Formations that yielded palynomorphs are palynologically of Early Cretaceous age.

The palynomorph assemblage found in the upper part of the Cedar Mountain Formation date this horizon as late Albian. The Burro Canyon assemblages were somewhat less distinctive, exhibiting evidence of sequential biofacies changes, and one sample exhibited an unusual lithotype somewhat suggestive of algal origin. Nevertheless, the palynological age of the upper part of the Burro Canyon Formation is clearly older than that of the Cedar Mountain sample. The age of the Burro Canyon sample is estimated to be Aptian to early Albian with the possibility of being as old as Barremian (latest Neocomian). Thus, samples from the upper parts of these two physically equivalent formations show a difference in age. We speculate that pre-Dakota erosion may have removed beds equivalent to the upper Cedar Mountain at the Burro Canyon locality, and that the Neocomian may be represented in the still undated lower parts of the Cedar Mountain and Burro Canyon Formations.

## INTRODUCTION

The Burro Canyon Formation of western Colorado and the physically equivalent Cedar Mountain Formation of eastern Utah, both of Early Cretaceous age, have received considerable geologic attention since their definition by Stokes and Phoenix (1948) and Stokes (1944, p. 965–967). Both formations have proved valid as mappable units, yet concern remains about the age and detailed relations of these formations, both to the underlying Morrison Formation of supposed Late Jurassic age and to the overlying Dakota Sandstone of earliest Late Cretaceous age. All students of the Burro Canyon and Cedar Mountain Formations agree that, at least in part, the formations pass laterally by lithologic change into each other.

Upper parts of the Burro Canyon and Cedar Mountain have been interpreted as passing laterally into the overlying Dakota Sandstone (Young, 1960, p. 158) and as separated from it by an erosional disconformity (Craig and others, 1955, p. 161; Carter, 1957, p. 313). The Burro Canyon has also been interpreted as intertonguing with the underlying Brushy Basin Member of the Morrison Formation (Craig and others, 1961, p. 1583) and as separated from the Morrison by a disconformity (Young, 1960, p. 169). These differences of interpretation serve to emphasize the importance of age determinations from either the Cedar Mountain or Burro Canyon Formations and adjoining beds. Unfortunately, both the Cedar Mountain and Burro Canyon Formations contain few fossils. Young (1960, p. 180–181) summarized the knowledge of the limited invertebrate fauna and megaflora. The Aptian or Albian Age (table 1) determined for these fossils accounts for the assignment of the Burro Canyon and Cedar Mountain to the Early Cretaceous.

The recognition of palynomorphs in samples from the Burro Canyon led to the hope that more could be learned from the plant microfossils about the ages of the Burro Canyon and Cedar Mountain Formations and adjacent beds. Considerable search for likely fossiliferous beds resulted in the collection of numerous samples, most of which proved to be barren of palynomorphs. A few samples, however, contained suites of palynomorphs, and these new data and the interpreted ages are presented in this report.

*Acknowledgments.*—We thank Sharon Van Loenen for her assistance in the preparation of illustrations, the photography of specimens, and other aspects of the preparation of this manuscript.

## ROCK UNITS

A summary of the characteristics of the Cedar Mountain and Burro Canyon Formations near the fossil sites follows; figure 1 shows the stratigraphic position of the productive palynomorph collections discussed in this paper.

TABLE 1.—*Relation of geochronologic terms used in this report and age estimate of boundaries in millions of years before present, based on Lanphere and Jones (1978)*

| PERIOD | EPOCH | AGE | | AGE ESTIMATE |
|---|---|---|---|---|
| Cretaceous (part) | Late Cretaceous (part) | Cenomanian (part) | | |
| | | | | 96 |
| | Early Cretaceous | Albian | | |
| | | Aptian | | |
| | | Neocomian | Barremian | |
| | | | Hauterivian | |
| | | | | 136 |
| | | | Valanginian | |
| | | | Berriasian | |
| | | | | 138 |
| Jurassic (part) | Late Jurassic (part) | Portlandian | | |

## CEDAR MOUNTAIN FORMATION

The Cedar Mountain consists of a relatively thin basal conglomeratic sandstone unit, the Buckhorn Conglomerate Member, and a relatively thick upper shale unit, the shale member. The shale member consists of silty to sandy swelling mudstones that show relatively thick color zones of pastel shades. Some of the mudstone units contain abundant limestone nodules that cover the weathered slopes of the member. Minor constituents of the member are thin, broadly lenticular limestone beds, and a few sandstone units, which are generally cross bedded, may contain lenticles of granule to pebble conglomerate, and appear fluvial in origin. The carbonaceous mudstone from which the palynomorphs were collected is almost unique in the Cedar Mountain.

The Cedar Mountain differs from the Burro Canyon in that the shale member consists dominantly of pastel-colored claystone, including purples and reds, as well as green; it is composed of swelling clays and it generally contains an abundance of limestone nodules that cover the weathered slopes. The Cedar Mountain Formation differs from the underlying Brushy Basin Member of the Morrison Formation in that it lacks the brilliant colors of the Brushy Basin, it lacks the distinct color banding, and it has abundant limestone nodules. The Cedar Mountain is distinguished from the Dakota Sandstone by the general absence of carbonaceous layers in the mudstone of the Cedar Mountain and the presence of carbonaceous shale and plant remains in the sandstone beds of the Dakota.

The palynomorph collections reported here come from a single carbonaceous unit near the top of the formation (fig. 1) in the SE¼SW¼, sec. 17, T. 19 S., R. 9 E., Emery County, Utah. The locality is about 16 km southwest of the type locality of the Cedar Mountain Formation (Stokes, 1952, p. 1773). This carbonaceous unit also has provided a small invertebrate and megaflora suite reported by Katich (1951, p. 2093–2094).

## BURRO CANYON FORMATION

The Burro Canyon is a sequence of alternating lenticular conglomeratic sandstone beds and variegated, mostly greenish-gray, nonswelling mudstone beds. The sandstone units generally dominate in the lower part of the formation, whereas the mudstone is more abundant in the upper part of the formation. Minor rock components are limestone and chert beds.

The formation is distinguished from the underlying Brushy Basin Member in that it consists of coarse, generally conglomeratic, sandstone and interbedded dominantly greenish-gray mudstone, composed of nonswelling clay. The Brushy Basin contains only a few conglomeratic sandstone beds, particularly in its upper part, and is composed dominantly of alternating red, green, and gray mudstone that contains swelling clay, and forms distinctly color-banded outcrops. The Burro Canyon Formation is distinguished from the overlying Dakota Sandstone by the greenish mudstone and by the absence of carbonaceous material and organic-rich shale, lignite, or coal. The Dakota consists of interbedded sandstone and carbonaceous shale; the sandstone is in part conglomeratic and generally contains much carbonaceous debris and common impressions of twigs, stems, and branches.

The collections of palynomorphs reported here came from two carbonaceous shale units (fig. 1) in the upper shaly part of the Burro Canyon exposed in a small tributary of Disappointment Creek in the NE¼, sec. 11, T. 43 N., R. 18 W. The fossil locality is 6.2 km southeast of the type locality of the Burro Canyon Formation (in Burro Canyon, sec. 29, T. 44 N., R. 18 W., San Miguel County, Colo.). Neither of the carbonaceous units have been recognized at the type locality. The upper carbonaceous unit is the same unit that has pro-

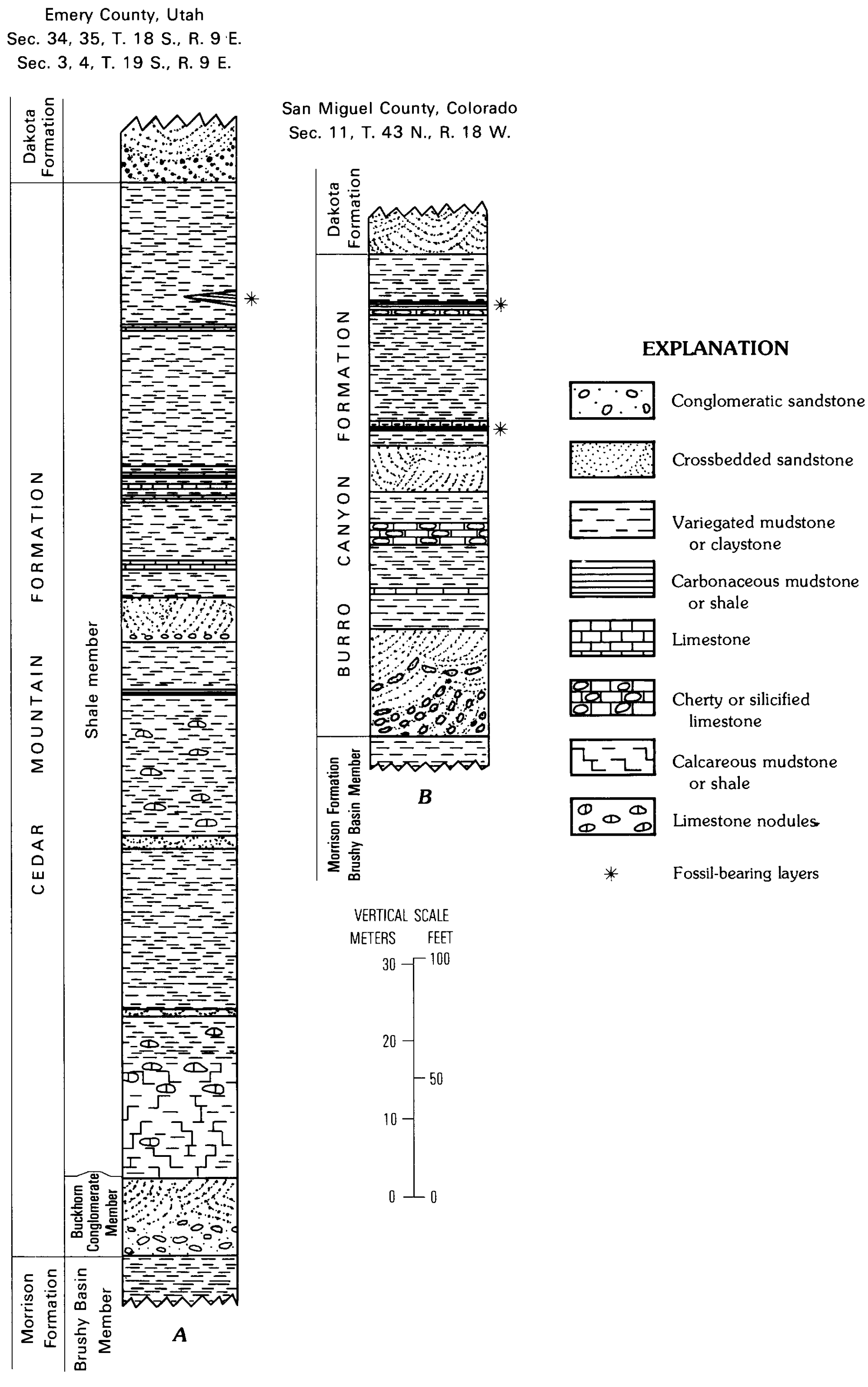



FIGURE 1.—Graphic sections showing stratigraphic positions of palynomorph collections. *A*, Section of Cedar Mountain Formation near type locality of formation; fossil-bearing carbonaceous lens sketched on basis of position beneath the Dakota Sandstone at fossil locality. *B*, composite section of Burro Canyon Formation measured at fossil localities.

duced a small invertebrate fauna and megaflora reported by Simmons (1957, p. 2525–2526).

## DISTRIBUTION, STRATIGRAPHIC RELATIONS, AND INTERPRETATION

The Burro Canyon formation is recognized over a broad area in southeastern Utah and western Colorado (fig. 2), and recently the name has been extended to similar rocks occupying a similar stratigraphic position in the Chama basin of north-central New Mexico (Saucier, 1974).

The southern limit of the Burro Canyon is an erosional limit where the Burro Canyon is cut out by the regional unconformity at the base of the overlying Dakota Sandstone. This limit is along a northwest-trending line that passes near the Four Corners. South of this limit, the pre-Dakota unconformity progressively bevels the Morrison Formation and older formations southward.

To the east, beds equivalent to the Burro Canyon are believed to be present in central and eastern Colorado (Lytle Formation of Dakota Group along the Front Range foothills and Lytle Sandstone Member of Purgatoire Formation in southeast Colorado). The Burro Canyon itself reaches a poorly known pinchout along an irregular north-south line extending from northwestern Colorado to northwestern New Mexico (fig. 2). The nature of this pinchout is uncertain. In part it is probably the result of pre-Dakota erosion, but in part it also may be due to depositional thinning of the formation. In the poor exposures along the few outcrop belts that cross the pinchout, the sandstone beds in the Burro Canyon appear to thin as the pinchout is approached. However, pre-Dakota erosion seems the most important factor in the pinchout of the formation.

The Cedar Mountain Formation is recognized over much of south-central and northeastern Utah and northwestern Colorado. The southern limit is south of the Henry Mountains and is an erosional limit along which the Cedar Mountain is cut out by the erosional unconformity at the base of the Dakota. The western limit is poorly known but it extends beneath the high plateaus of central Utah. To the north, the formation is identified to the Wyoming State line in both northeastern Utah and northwestern Colorado. Equivalent beds in Wyoming are included in the Cloverly Formation.

The arbitrary lateral limit between the Burro Canyon Formation and the Cedar Mountain Formation is placed along the Colorado River in Utah (Stokes, 1952, p. 1774), although for a distance of about 40 km west of the river the characteristics of the two formations intermingle.

To the north in Colorado, the Burro Canyon Formation passes laterally into the Cedar Mountain Formation. In this area north of the Colorado River, the line of demarcation between the Burro Canyon and Cedar Mountain is placed where Burro Canyon characteristics give way to Cedar Mountain characteristics in the subsurface as interpreted from drillhole logs.

Based on thickness, percentage of sandstone, pebble size, and limited current-direction studies, the Burro Canyon and Cedar Mountain are interpreted as sediments from two alluvial systems deposited across a broad even surface on top of the Morrison Formation; in many respects they appear to represent a continuation of Morrison deposition. The major source for the Burro Canyon was southwest of the Four Corners, perhaps in southern Arizona. Burro Canyon deposits were spread northward and eastward from a major depositional axis along the southern part of the Utah-Colorado State line. The source for the Cedar Mountain Formation was somewhere west of the high plateaus in central Utah, and Cedar Mountain deposits were spread eastward.

## METHODS OF SAMPLE TREATMENT

Samples were first cleaned, then broken into fragments about 1–5 mm (millimeters) in diameter. 10–20 g (grams) of broken rock were placed in plastic beakers and tested for the presence of carbonates. If carbonates were present, the samples were then treated with 10-percent HCl to remove carbonates; otherwise they were treated directly with hydrofluoric acid to disaggregate and partly dissolve the inorganic matrix. After thorough washing, the centrifuged residue was treated with the oxidizing Schulze[1] solution ($HNO_3 + NaCl)O_3$). After washing, the acid humates were solubilized and removed by a short treatment with 10-percent NaOH solution. Pollen and spores (and insoluble organic matter) were concentrated from the residue by flotation in zinc bromide solution (specific gravity about 2.0) and then "panned" by means of the technique suggested by Funkhouser and Evitt (1959). The palynomorphs were then stained with Bismark Brown, if necessary, and then mixed with Vinylite AYAF in 90-percent alcohol (polyvinyl acetate plastic, refractive index 1.466).

Several drops of the palynomorph-plastic mixture were placed on a 22×40 mm cover glass and another cover glass was placed on the mixture, thus making a "sandwich." After the plastic had spread evenly to the margins, the cover glasses were separated by sliding them in opposite directions lengthwise in much the

[1]Trade names used in this paper are for descriptive purposes only and do not constitute endorsement by the U.S. Geological Survey.

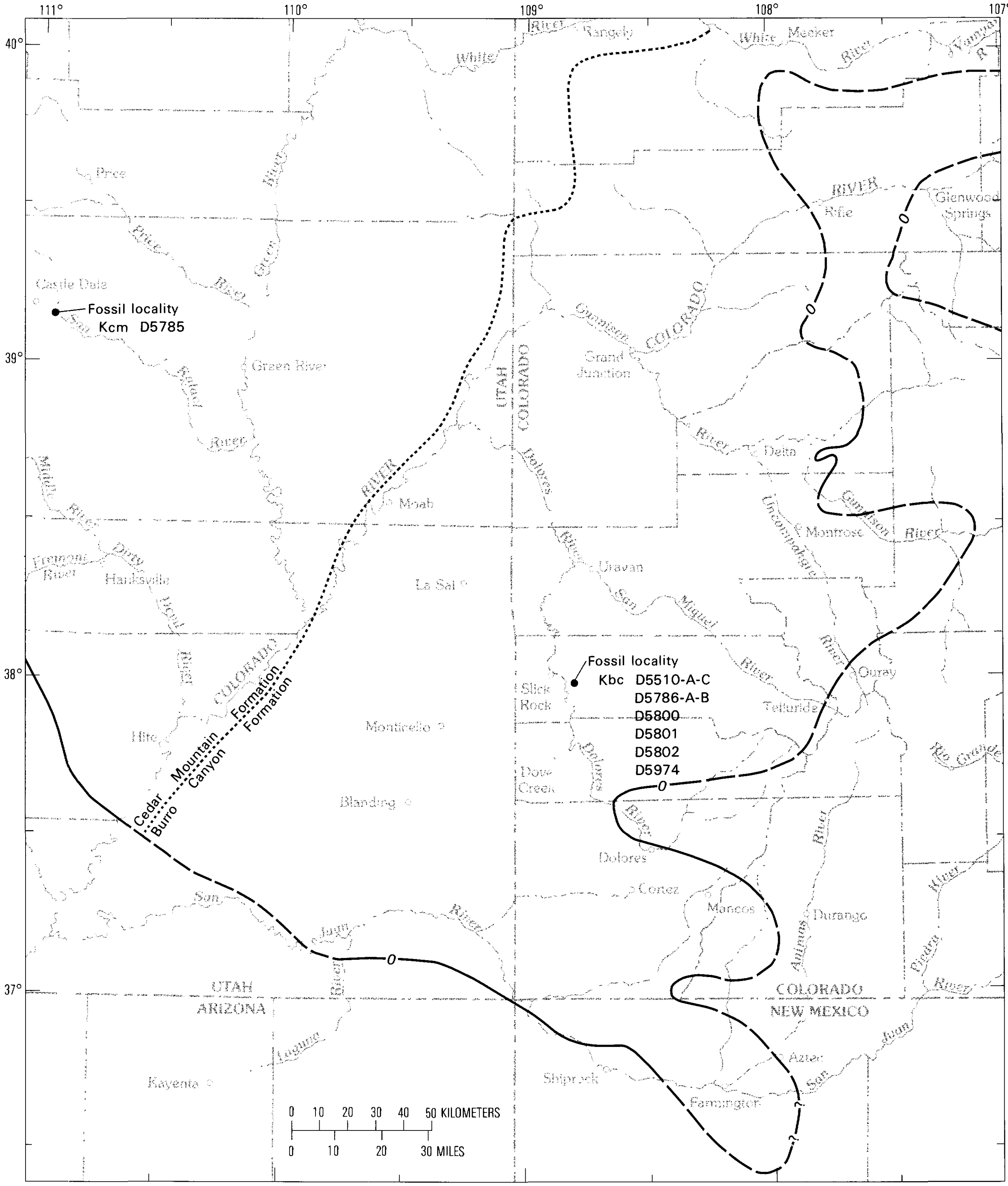



FIGURE 2.—Map of Colorado Plateau area showing fossil sample localities, sample numbers, and distribution of Cedar Mountain (Kcm) and Burro Canyon (Kbc) Formations. Zero line marks pinchout of Burro Canyon and Cedar Mountain Formations (dashed where uncertain). Dotted line is arbitrary line separating areas in which Burro Canyon and Cedar Mountain are recognized.

same manner as a blood smear is made. After the film on the cover glasses had dried for a few minutes on a warming plate, the cover glasses were inverted and mounted on slides using Histoclad resin. This method provides a thin, evenly dispersed film of pollen and spores in a mountant of favorable refractive index. It serves to anchor the fossils close to the cover glass so that they can be examined conveniently even under high-power oil-immersion lenses.

Slides are identified by locality number (D5510–A), and slide number D5510–A (1) or D5510–A (2); and on occasion processing sequence is also included as preparation 1 (prep. 1, prep. 2) and fraction—heavy fractions, fine fraction (Hvs; fines.): for example, D5785–A, prep. 4, Hvs., slide 5.

Minor modifications of oxidation time, cleaning procedures, and staining were tried with some success in efforts to improve the quality of some preparations.

## LOCATION OF PRODUCTIVE SAMPLES

### CEDAR MOUNTAIN FORMATION

Two Cedar Mountain samples were obtained from the locality known as the Stokes-Katich locality (Simmons, 1957, p. 2527). Samples were taken from a 1.5-m-thick, dark-gray calcareous shale outcrop in a cliff. The outcrop was about 13.9 m below the Dakota contact. The lower sample, consisting of gray calcareous siltstone interspersed with small calcite crystals, was barren of palynomorphs. The upper sample, consisting of dark-gray laminated shale and black claystone, was productive and was assigned a USGS paleobotany locality number as indicated below:

| USGS paleobotany loc. No. | Field No. | Locality |
|---|---|---|
| D5785 | 3RT–77–7 | SE¼SW¼ sec. 17, T. 19 S., R. 9 E., ¼ mi west of the junction of Rock Canyon Creek and Cottonwood Creek, Emery County, Utah. (Stokes-Katich locality in Simmons, 1957, p. 2527). |

### BURRO CANYON FORMATION

#### UPPER HORIZON

Productive samples were obtained from two horizons. The upper horizon consisted of a 1.5-m-thick layer of black fissile shale located 7.3 m below the base of the Dakota Sandstone and immediately above a prominent limestone ledge. This is the same general locality from which fossils were collected by Stokes (1952) and the identical locality visited by G. C. Simmons and D. R. Shawe, and later revisited by L. C. Craig and others (Simmons, 1957, p. 2525). Several collections for palynological examination were taken from this locality during the summer of 1976. The yield of palynomorphs from these samples was so poor that resampling was conducted at the same site and along the lateral extent of the outcrop in the summer of 1977 and again in 1978. Sample number and localities for the upper horizon of the Burro Canyon Formation are listed below:

| USGS paleobotany loc. No. | Field No. | Locality |
|---|---|---|
| D5510–A | RT–76–6 | ¼NW¼NE¼ sec. 11, T. 43 N., R. 18 W., in northwest wall of an intermittent stream bed about 330 m south of its junction with Disappointment Creek, Hamm Canyon quadrangle, San Miguel County, Colo. Approximately 1.5-m-thick ledge of black fissile shale, 7.3 m below Burro Canyon-Dakota contact. Sample 25 cm above limestone ledge at base of shale. |
| D5510–B | RT–76–7 | Same locality as D5510–A, 31 cm above limestone ledge. |
| D5510–C | RT–76–8 | Same locality as D5510–A, 61 cm above limestone ledge. |
| D5786–A | RT–77–15 | Same locality as D5510–A, top part of limestone ledge. |
| D5786–B | RT–77–16 | 90 m S. 5° E., from locality of D5510–A, along strike of black fissile shale. 1-cm-thick basal siltstone layer immediately above limestone ledge. |
| D5800 | RT–77–17 | Same locality as D5786–B. Black, wet mudstone, 60 cm above limestone ledge. |
| D5801 | RT–77–18 | Same locality as D5786–B. Black fissile shale with limestone concretions 18 cm above limestone ledge. |
| D5802 | RT–77–19 | S. 60° W., 200 m from sample D5801; sample from northwest side of drainage. Composite sample from 1.5-m-thick black fissile shale. |
| D5974 | RT–78–18 | NW corner sec. 13, T. 43 N., R. 18 W., along unimproved road, Hamm Canyon quadrangle, San Miguel County, Colo. About 1.5-m-thick black fissile shale. Same horizon as previous Burro Canyon samples, but only 3 m below the Dakota contact. |

The upper horizon of black fissile shale has been traced several kilometers to the northwest and to the southeast of the original locality, but is apparently absent from the type locality of the Burro Canyon Formation in Burro Canyon near the village of Slick Rock, Colo., sec. 29, T. 44 N., R. 18 W., San Miguel County, Colo.

### LOWER HORIZON

In 1976 during the course of recollecting samples from the localities just described, a black limy shale horizon was found about 10.4 m below the base of the 1.5-m-thick black fissile upper-shale horizon. This sample yielded a much better assemblage of palynomorphs than was obtained from the upper fissile-shale horizon. The sample consisted of two lithotypes—a fine-grained, hard, calcareous black shale, and a black, soft, friable shale containing small calcite crystals. Palynomorph yield from the two lithotypes was distinctly different, suggesting that biofacies near the site of deposition had changed. The site was recollected in 1978. Six samples were collected from an 87-cm interval (fig. 8). Four of these samples were productive and were given USGS paleobotany locality numbers as indicated below:

| USGS paleobotany loc. No. | Field No. | Locality |
|---|---|---|
| D5803 | RT–77–20 | SW¼NE¼ sec. 11, T. 43 N., R. 18 W., at approximate location of bench mark 5641, Hamm Canyon quadrangle, 1960, 10.4 m below base of upper fissile-shale horizon. Sample included two lithotypes; soft, black friable shale with small calcite crystals, and hard, dark-gray calcareous shale. |
| D5972–A,B, C,D | RT–77–20 | Same locality as D5803. See figure 8. |
| D5973 | RT–78–16 | Same locality as D5803 but 10.2 m north along strike of dark-gray and black outcrop. Sample from bentonite zone, friable black shale that grades upward into dark-gray to black limestone. Composite sample from 30-cm interval. |

The lower horizon was traced about 150 m along the wash, but apparently is not present or is covered elsewhere.

## PALYNOLOGICAL ANALYSIS—CEDAR MOUNTAIN FORMATION

Reports of fossils from the Cedar Mountain Formation are exceedingly sparse. The pertinent information concerning those few fossils found is presented by Simmons (1957) who listed fossils from two localities. The first locality, the socalled Stokes-Katich locality, is the same locality mentioned previously that yielded the palynomorphs in the present study. Fossils found include *Eupera onestae* McLearn, a fresh-water pelecypod of Aptian Age, *Tempskya minor* Reed and Brown, a tree fern trunk, known from the Aspen Shale (Albian Age) Wyoming and Idaho, ostracods, and ganoid fish scales. "The second locality is in sec. 22, T. 22 S., R. 20 E., on the southwest flank of the Salt Valley anticline, Grand County, Utah" (Simmons, 1957, p. 2527). This locality yielded ostracods, gastropods, microfossil material, and the charophyte *Clavator harrisi* Peck.

The microfossil material was examined by R. E. Peck who stated: "All of these are common fossils in the Gannett Group, the Cloverly of northwestern Wyoming, and the limestones in the upper Kootenai of Montana. *Clavator harrisi* Peck is common in the Trinity of the Gulf Coast. None of these species occurs in the Morrison of the Front Range of Colorado, in eastern Wyoming or in the Black Hills. Their occurrence is an excellent indication of the Lower Cretaceous age of the formation" (*in* Simmons, 1957, p. 2527). The purported age of the Gannett Group is Early Cretaceous, of the Cloverly and Kootenai Formations is Aptian, and of the Trinity Group of the Gulf Coast, is Aptian to early Albian. "In view of the identifications, an Early Cretaceous age seems assured for the shale member of the Cedar Mountain Formation" (Simmons, 1957, p. 2527).

Angiosperm wood was collected from the Cedar Mountain Formation near Castle Dale and Ferron, Utah by Thayn (1973). Genera found were *Icacinoxylon*, previously known only from the Tertiary of Europe, and *Paraphyllanthoxylon*, known from the Cretaceous of Arizona, Idaho, and Alabama. However, these fossils shed no additional light upon the age of the Cedar Mountain Formation.

The samples collected for our study were examined palynologically in an attempt to obtain a more definite age determination and to verify the reported correlations of the Cedar Mountain and Burro Canyon Formations (Simmons, 1957; Craig and others, 1955).

Palynomorphs were poorly preserved and somewhat sparse, requiring the intensive examination of many slides in order to obtain a significant assemblage. The palynomorph assemblage consisted of tricolpate angiosperm pollen, bisaccate conifer pollen, monosulcate pollen, *Corollina* and minor representations of *Liliacidites*, trilete spores and taxodiaceous pollen (fig. 3). The high percentage of unidentified palynomorphs (averaging 32 percent of the assemblage) attests to the generally poor condition of the palynomorphs present. Figure 3 includes counts of palynomorph types in four separate preparations. Modification of preparation procedures were tried in attempts to obtain better recovery from this sample. That some of the preparations were better than others is evident upon examination of the graph. For example, preparation C (D5758-B, prep. 2) yielded

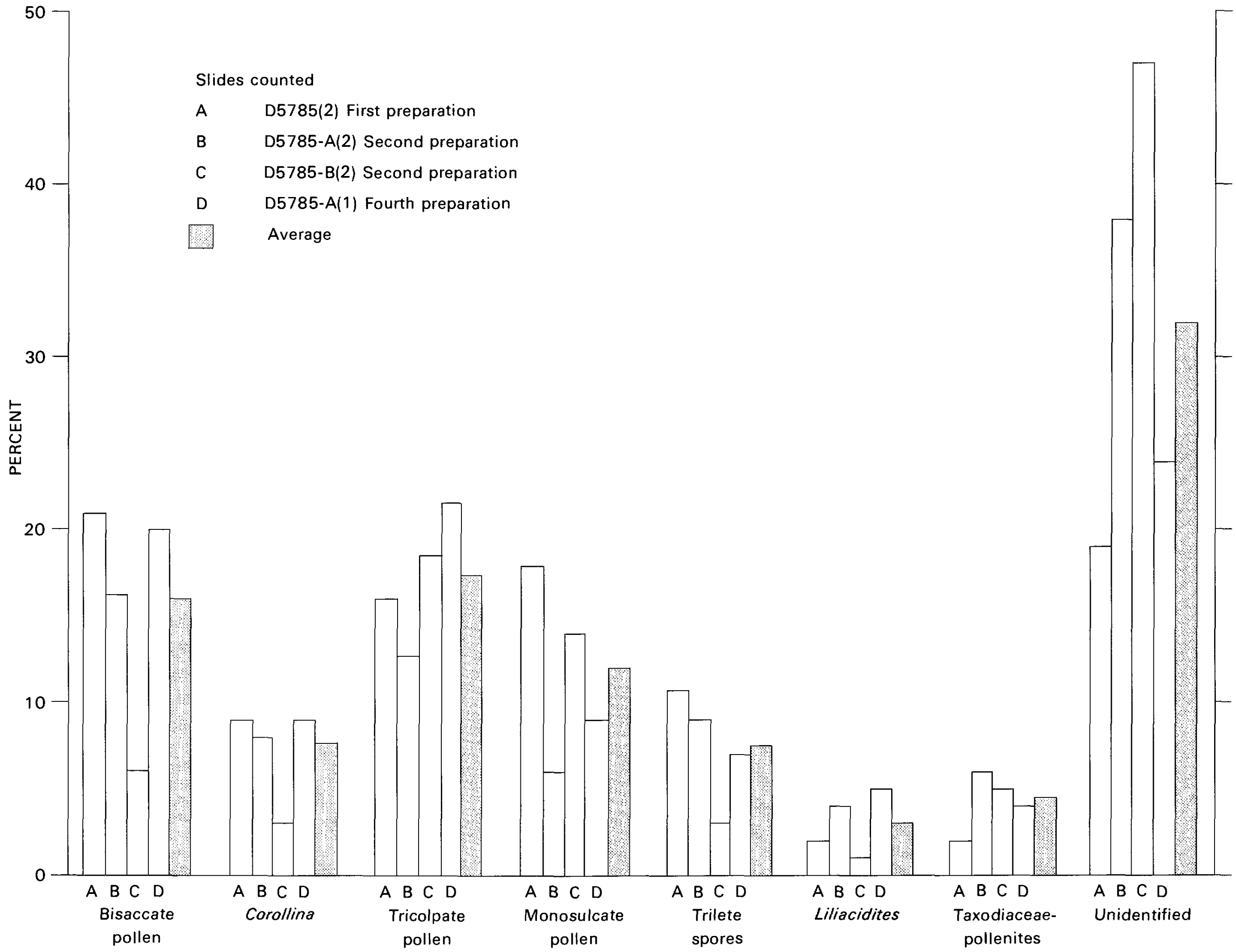



FIGURE 3.—Percentage distribution of major plant microfossil groups from several preparations of the productive Cedar Mountain sample.

only 6 percent bisaccate conifer pollen, and the unidentified palynomorphs accounted for 47 percent of the assemblage. In contrast, preparation A (D5758, prep. 1) yielded 21 percent bisaccate conifer pollen and only 19 percent unidentified palynomorphs. Except for discrepancies accounted for by the varied preparation procedures, the recovery of the several palynomorph groups shows a remarkable consistency.

The following genera and species have been identified from the preparations, and the taxa are shown on plates 1–4.

*Laevigatosporites* cf. L. *belfordii* Burger 1976
*Laevigatosporites gracilis* Wilson and Webster 1946
*Cyathidites australis* Couper 1953
*Todisporites* sp.
*Todisporites minor* Couper 1958
*Gleicheniidites senonicus* Ross 1949
*Lygodiumsporites* sp.
*Deltoidospora hallii* Miner 1935
*Cyathidites minor* Couper 1953
*Dictyotriletes granulatus* Pocock 1962
*Foraminisporis* sp.
*Foraminisporis* cf. *F. wonthaggiensis* (Cookson and Dettman) Dettmann 1963
*Concavissimisporites variverrucatus* (Couper) Singh 1964
*Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner 1963
*Leptolepidites* sp.
*Baculatisporites comaumensis* (Cookson) Potonié 1956
*Pilosisporites trichopapillosus* (Thiergart) Delcourt & Sprumont 1955
*Echinatisporis varispinosus* (Pocock) Srivastava 1975
*Cicatricosisporites hughesii* Dettmann 1963
*Cicatricosisporites* sp.
*Cicatricosisporites* cf. *C. minutaestriatus* (Bolkhovitina) Pocock 1964

*Cicatricosisporites venustus* Deák 1963
*Distaltriangulisporites* cf. *D. irregularis* Singh 1971
*Costatoperforosporites* sp.
*Psilatriletes circumundulatus* Brenner 1963
*Densoisporites microrugulatus* Brenner 1963
*Densoisporites velatus* Weyland and Krieger 1953
cf. *Schizosporis* sp.
*Alisporites grandis* (Cookson) Dettmann 1963
*Pityosporites granulatus* Phillips and Felix 1971
*Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970b
*Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
*Cedripites* cf. *C. cretaceus* Pocock 1962
*Cedripites canadensis* Pocock 1962
*Podocarpidites multesimus* (Bolkhovitina) Pocock 1962
*Podocarpidites* cf. *P. minisculus* Singh 1964
*Podocarpidites* sp.
*Vitreisporites pallidus* (Reissinger) Nilsson 1958
*Cycadopites carpentieri* (Delcourt and Sprumont) Singh 1964
*Monocolpopollenites* sp.
*Ginkgocycadophytus* cf. *G. nitidus* (Balme) de Jersey 1962
*Equisetosporites multicostatus* (Brenner) Norris 1967
*Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949
*Eucommiidites* sp.
*Corollina torosa* (Reissinger) Cornet and Traverse 1975
*Exesipollenites tumulus* Balme 1957
*Asteropollis asteroides* Hedlund & Norris 1968
*Clavatipollenites hughesii* (Couper) Kemp 1968
*Liliacidites* sp.
*Liliacidites* cf. *L. peroreticulatus* (Brenner) Singh 1971
*Tricolpites crassimurus* (Groot and Penny) Singh 1971
*Retitricolpites* cf. *R. virgeus* (Groot, Penny and Groot) Brenner 1963
*Retitricolpites vulgaris* Pierce 1961
*Retitricolpites vermimurus* Brenner 1963
*Striatopollis paraneus* (Norris) Singh 1971
*Rousea georgensis* (Brenner) Dettman 1973
*Cupuliferoidaepollenites parvulus* (Groot and Penny) Dettmann 1973
*Cupuliferoidaepollenites minutus* (Brenner) Singh 1971
*Tricolpites* cf. *T. wilsonii* Kimyai 1966
*Tricolpites* cf. *T.* sp. 1 of Kemp (1968)
*Tricolpites micromunus* (Groot and Penny) Singh 1971
*Tetracolpites* cf. *T. pulcher* Srivastava 1969
*Tetracolpites* sp.

## LANDMARK EVOLUTIONARY EVENTS IN THE DEVELOPMENT OF ANGIOSPERM POLLEN

The earliest records of angiosperm pollen include some of the same taxa that were recovered from the Cedar Mountain Formation. The first occurrences of angiosperm pollen in the stratigraphic record and the subsequent diversification of angiosperm pollen is pertinent to the age determinations and conclusions derived from Cedar Mountain samples.

The stratigraphic record has provided the basis for several outlines of the developmental history of angiosperm pollen, particularly in North America (Singh, 1971, 1975; Doyle, 1969; Jarzen and Norris 1975; Norris, Jarzen, and Awai-Thorne, 1975; Muller, 1970; and others). These outlines present data concerning the earliest record of angiosperm pollen, followed successively by the first appearance of tricolpate pollen, tricolporate pollen, triporate pollen; and in the Cenomanian and later stages, the times of origin of evolutionarily more advanced pollen types.

There are no substantiated pre-Cretaceous records of angiosperm pollen. The most primitive putative angiosperm pollen type is a monosulcate grain with pilate or retipilate sculpture, represented by the genus *Clavatipollenites* Couper. Couper (1958), in describing the type species *C. hughesii* from the Barremian of England, pointed out that although the monosulcate aperture condition is prevalent in gymnosperms, pilate or retipilate sculpture is not known outside the angiosperms. Pollen grains of the *Clavatipollenites* type are now considered by the vast majority of palynologists to be of probable angiosperm origin. *Clavatipollenites* pollen has been widely reported in rocks of Aptian-Albian Age from diverse parts of the world: Hughes (1958) and Kemp (1968) from England, Couper (1964) from Central America and Australia, Kemp (1968) and Norris (1967) from western Canada, and Brenner (1963) from eastern United States. Chlonova (1977) reported the first find of *Clavatipollenites* in ?Albian-Cenomanian rocks of Western Siberia. She discussed the pre-Barremian (Jurassic) records of identifications of *Clavatipollenites* (from central Europe and Asia) and rejected them as not being completely reliable. Birkelund, and others (1978) and Vigran and Thusu (1975) reported *Clavatipollenites* from Jurassic and pre-Jurassic rocks of Norway. Perhaps significantly, Birkelund and others (1978) found *Clavatipollenites* in their assemblage 1 (Middle Jurassic) but not in younger assemblages—assemblage 2 (Kimmeridgian), assemblage 3 (Kimmeridgian-Volgian), and assemblage 4 (early Neocomian).

In North America, the oldest record of *Clavatipollenites* is from the upper part of the Barremian (Doyle, 1969; Doyle and Robbins, 1977). In western Canada, the entrance level of *Clavatipollenites* coincides in Alberta with the entrance level of reticulate tricolpate forms (middle Albian). *Clavatipollenites* was not found in Canada in the Loon River Formation, lower mid-Albian (Singh, 1975), nor in the Mannville Group (Singh, 1964; Norris, 1967) of Aptian to early middle Albian age and no older than late Barremian (Singh, 1964). Thus, in western North America there are no records of *Clavatipollenites* earlier than mid-Albian time. The presence of specimens of *Clavatipollenites* in Cedar Mountain rocks therefore suggests an Albian or younger age.

Tricolpate pollen first appears, apparently worldwide, in the Albian. "The appearance of tricolpate pollen seems to have been a major world-wide event, and in all areas which have been carefully studied there is a zone with small reticulate tricolpates but without triporates or typical tricolporates (cf. Krutzsch, 1963; Muller, 1968). This appearance generally may be dated as early or middle Albian, but refinement is needed in most areas." (Doyle, 1969, p. 11). Singh (1971, p. 25) has summarized these data as follows: "The entrance of tricolpate dicotyledonous pollen in Albian strata of North America has been well documented by Brenner (1963), Davis (1963), Pannella (1966), Norris (1967), and Hedlund and Norris (1968). In other parts of the world, the first definite dicotyledonous pollen has been reported from Albian strata of central Russia (Bolkhovitina, 1953), New Zealand (Couper, 1960), Portugal (Groot and Groot, 1962), Central America and Africa (Couper, 1964), Peru (Brenner, 1968), Australia (Dettmann and Playford, 1968) and England (Kemp, 1968). Thus the entrance of tricolpate dicolyledonous pollen in the Lower Cretaceous succession of the Peace River area supports the middle to late Albian age assigned to these beds on faunal evidence (Wickenden, 1951, Stelck, *et al.*, 1956)."

The angiosperm pollen succession in eastern Australia was discussed by Dettmann (1973). She reported that the earliest occurrence of tricolpate pollen was found in the middle Albian of the Great Artesian Basin, whereas tricolpate pollen first appears a little later, in the upper Albian, in the more southerly Otway Basin. The first occurrence of tricolpate angiosperm pollen in Australia appears to coincide in time with its first appearance in Western North American rocks.

Tricolporate pollen first appears in latest? Albian time in western Canada and western United States and in the early Cenomanian in eastern United States (Singh, 1975). Tricolporate pollen has a widespread distribution throughout the Cenomanian of the Western Interior. Singh (1975, p. 377) concluded "It is evident from the above discussion that the Albian-Cenomanian boundary in North America is marked by the appearance of smooth, triangular tricolporates (Table II, III) and angiosperm tetrads."

The tricolporate pollen mentioned by Singh (1975) is the species *Nyssapollenites albertensis* Singh. It appears just below the fish scale member in the Shaftesbury Formation of Alberta (uppermost Albian). The same species identified as *Tricolporopollenites aliquantulus* Hedlund was found in the Red Branch Member of the Woodbine Formation of Oklahoma (Cenomanian) (Hedlund, 1966). Pannella (1966) reported the same species (as *Tricolporites dakotensis*) from the upper part of the Dakota Sandstone and the Huntsman Shale of MacKenzie (1965) (upper Albian-Cenomanian) of the Denver basin, Colorado. The same species (as *Tricolporopollenites aliquantulus* Hedlund) was found in the Dakota Sandstone of Arizona (Cenomanian) by Agasie (1969). We have found pollen of *Nyssapollenites albertensis* Singh to be a common constituent of Cenomanian rocks of Colorado and Utah. In the Front Range near Denver, Colo., the entrance level of this species is in the middle part of the Kassler Sandstone Member of the South Platte Formation (Dakota Group) about 30.5 m below the base of the Benton Formation (Mowry Shale to the north). The Mowry Shale is characterized by abundant fish scales, and is found at approximately the same stratigraphic position as the "fish scale marker bed" ("The traditional Lower-Upper Cretaceous boundary***" (Norris and others, 1975) in the Shaftesbury Formation of Alberta Canada. Significantly, Singh (1971, p. 28) found the entrance level of *Nyssapollenites albertensis* at about 35.0 m below the "fish scale marker bed." With the exceptions of the latest Albian report by Singh (1971) and the late Albian (Dakota) report by Pannella (1966), all other records of tricolporate pollen from western North America are from Cenomanian and younger rocks. The consistent first occurrence of *Nyssapollenites albertensis* at or very near the Albian-Cenomanian boundary provides a reliable indicator in western North America of the palynological boundary between the Early and Late Cretaceous. This palynological marker species coincides with or is close to the Early-Late Cretaceous boundary based on other types of evidence.

## AGE OF THE UPPER PART OF THE CEDAR MOUNTAIN FORMATION

The absence of any tricolporate pollen eliminates the possibility of a Cenomanian Age. The presence of small tricolpate pollen indicates an age range from middle to late Albian. The presence of at least 11 identified species of tricolpate pollen suggests that a significant amount of time must have elapsed since the origin of tricolpates in the mid Albian, until the plants had evolved to produce the diverse tricolpate flora including such large forms as *Tetracolpites pulcher* Srivastava.

Thus, this assemblage is clearly of late or latest Albian age.

## PALYNOLOGICAL ANALYSIS—BURRO CANYON FORMATION

The Burro Canyon Formation also has yielded few fossils. Fossil evidence for the age of the Burro Canyon Formation was presented by Stokes (1952) and Simmons (1957). The fossils were obtained from the NE¼NW¼NE¼ sec. 11, T. 43 N., R. 18 W., San Miguel County, Colo. This locality is the identical locality that yielded palynomorphs from the upper Burro Canyon horizon mentioned previously. The following fossils of possible age significance were reported:

Plant—*Frenelopsis varians* Fontaine (Aptian-early Albian)

Molluscs—*Protelliptio douglassi* Stanton (Aptian)
"*Unio*" *farri* Stanton (Aptian)
*Nipponaia asinaria* Reeside (Early Cretaceous)

No other reports of fossils from the Burro Canyon Formation have come to our attention.

A second locality that yielded palynomorphs, about 10.4 m below the base of the upper Burro Canyon horizon, has been mentioned previously. No other types of fossils are known from this second locality.

As with the Cedar Mountain Formation, the Burro Canyon Formation samples were examined palynologically in an attempt to obtain a more refined age determination, to address the question raised by reported intertonguing of the basal part of the Burro Canyon and upper part of the Morrison Formations (Simmons, 1957, p. 2523), and to attempt to determine whether or not the Burro Canyon and Cedar Mountain Formations are correlative palynologically.

The overlying Dakota Sandstone in this area is palynologically of early Cenomanian age (it has yielded *Nyssapollenites albertensis* Singh). The Burro Canyon Formation lies between the Dakota and the Morrison. In some places, evidence exists of apparent continuous deposition from the Morrison into the basal part of the Burro Canyon. Samples obtained from the upper or Brushy Basin Member of the Morrison Formation in this general area have yielded a palynological suite of fossils indicative of a Late Jurassic age. Theoretically, the Burro Canyon Formation could represent an age ranging from Late Jurassic to Cenomanian—that is, the entire Early Cretaceous spanning a time interval of some 40 million years.

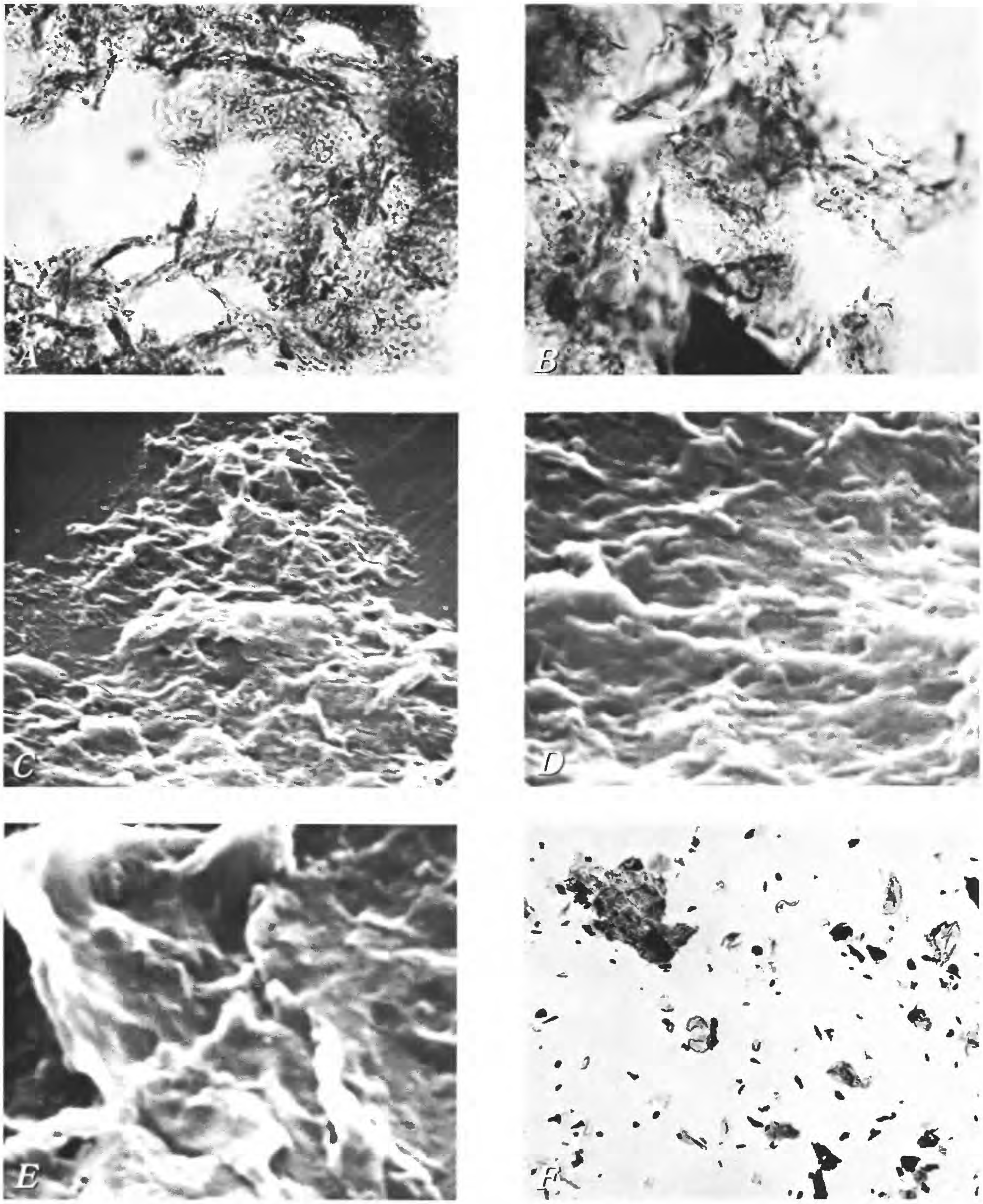
### UPPER HORIZON

As has been indicated, two palynologically productive horizons were found in the upper part of the Burro Canyon Formation. The upper horizon sample, from a 1.5-m-thick layer of black fissile shale about 7.3 m below the base of the Dakota Sandstone, yielded sparse assemblages of palynomorphs. The great majority of the organic matter consisted of what appeared to be short filaments (fig. 4*A*). On closer examination these filaments proved to be aggregates of amorphous material. At higher magnification, the apparent strands lose their continuity and appear as small strands with somewhat indefinite margins (fig. 4*B*). In the lower part of the photomicrograph (fig. 4*B*) a fragment of black woody tissue can be seen. Near the center a palynomorph is obscured by this organic material. At succeedingly higher magnifications (fig. 4*C*, *D*, and *E* scanning electron micrographs), the organic material exhibits its amorphous character, and the filamentous attribute effectively disappears. Contrast between upper-horizon preparations containing an abundance of amorphous organic material and more nearly normal preparations is shown on a photomicrograph of a preparation from the lower horizon (fig. 4*F*). Wood fragments, bits of epidermal and cuticular tissue, and easily recognizable palynomorphs are visible. This preparation is virtually devoid of organic material of the kind found in upper horizon samples. The great abundance of amorphous organic material present in upper horizon samples could not be removed from the samples by oxidation without destroying the accompanying palynomorphs. Thus, the few spores and pollen grains present were commonly obscured by this material. Samples from the upper horizon are unique in this respect in our experience. We have never found samples that reacted in the same manner. The closest observed similarity is to samples of oil shale from the Green River Formation, yet the organic material in the Green River oil shale appears visually to be distinctly different.

Two samples of black fissile shale from the upper horizon were submitted to L. G. Schultz, U. S. Geological Survey, Denver, Colo. for X-ray analysis. He reported that the nonorganic part of the black shale contained 2–10 percent calcite, 1 to 2 percent quartz, and a large percentage of mixed-layer illite-smectite, a swelling clay that could be an altered tuff.

Thin sections made from this upper horizon shale show the abundance and bedded nature of the unaltered organic material but give no hint of its original composition (fig. 5). These thin sections, plus macerated sample material from the upper horizon were sent to the late Dr. J. M. Schopf, USGS Coal Geology Laboratory at Columbus, Ohio. He remarked (written commun., Dec. 13, 1977) "The thin sections are excellent . . . I wish I could suggest how such a rock could reasonably be deposited. My next suggestion is that it must be an unusual local occurrence."

This abundant amorphous organic material possibly could be the residue from some, as yet unidentified,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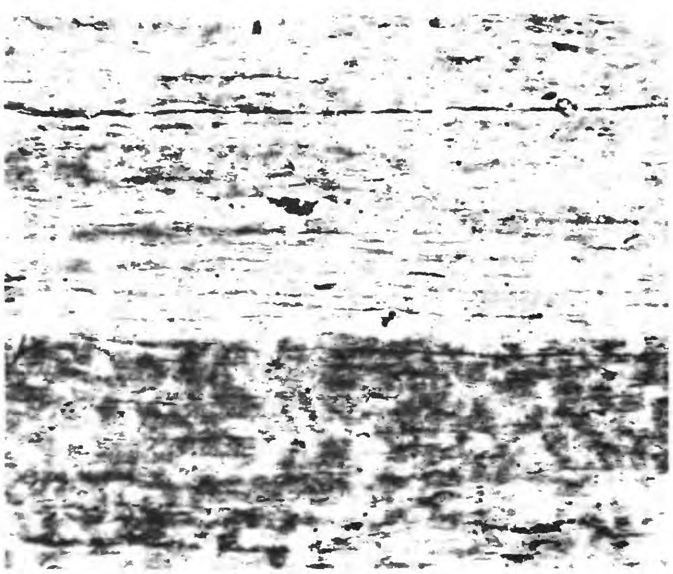


FIGURE 5.—Burro Canyon-upper horizon sample D5510–A. Thin section of whole rock showing bedded nature of organic material. × 100.

alga. *Botryococcus*, a common lacustrine alga, has been found in all upper horizon samples.

### PALYNOMORPH RECOVERY FROM UPPER HORIZON SAMPLES

The palynomorph recovery from upper horizon samples was sparse. The abundant organic matter and the comparatively poor state of preservation made identification extremely difficult. Gross palynomorph recovery from representative upper horizon samples is shown in figure 6. The average number of unidentified forms was 48 percent, attesting to the difficulty posed by the amorphous organic material.

The following identified taxa were obtained from an examination of more than 60 slides.

Burro Canyon *upper horizon*
*Undulatisporites* cf. *U. fossulatus* Singh 1971
*Cyathidites minor* Couper 1953
*Todisporites minor* Couper 1958
*Dictyotriletes pseudoreticulatus* (Couper) Pocock 1962
*Cadargasporites reticulatus* de Jersey and Paten 1964
*Staplinisporites caminus* (Balme) Pocock 1962
*Matthesisporites tumulosus* Döring 1964
aff. *Cicatricosisporites phaseolus* (Delcourt and Sprumont) Krutzsch 1959
*Converrucosisporites* cf. *C. proxigranulatus* Brenner 1963
*Cicatricosisporites* cf. *C. minor* (Bolkhovitina) Pocock 1964
*Cicatricosisporites* cf. *C. cuneiformis* Pocock 1964
*Cicatricosisporites augustus* Singh 1971
*Cicatricosisporites* cf. *C. potomacensis* Brenner 1963
*Cicatricosisporites* cf. *C. mediostriatus* (Bolkhovitina) Pocock 1964
*Cicatricosisporites* sp.
*Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
*Cicatricosisporites apiteretus* Phillips and Felix 1971
*Cicatricosisporites* cf. *C. subrotundus* Brenner 1963
*Cicatricosisporites* cf. *C. crassistriatus* Burger 1966
*Distaltriangulisporis* sp.
*Appendicisporites bilateralis* Singh 1971
*Appendicisporites jansonii* Pocock 1962
*Corollina torosa* (Reissinger) Cornet and Traverse 1975
*Equisetosporites* spp.
*Araucariacites* sp.
*Callialasporites* sp.
*Vitreisporites pallidus* (Reissinger) Nilsson 1958
*Alisporites thomasii* (Couper) Pocock 1962
*Alisporites grandis* (Cookson) Dettmann 1963
*Cedripites* cf. *C. canadensis* Pocock 1962
*Cedripites cretaceus* Pocock 1962
*Podocarpidites ornatus* Pocock 1962

Burro Canyon taxa are shown on plates 5–9.

## LOWER HORIZON

This locality was found about 10.4 m below the upper fissile shale horizon. The recovery of palynomorphs was much better than from upper horizon samples even though preservation quality was not the best. The difference in appearance of the slides from the two horizons is shown on figure 4. In figure 4*F* fusainized wood fragments are prevalent in the photograph, and epidermal tissue and palynomorphs make up the lighter, more translucent material. The appearance of the organic material from the lower horizon is normal, in contrast to

FIGURE 4 (facing page).—Burro Canyon-upper horizon sample. *A*, After HF treatment and flotation in $ZnBr_2$ water mount. × 500. *B*, Standard treatment. Mounted in AYAF and histoclad. × 1000. Note wood fragment at center lower margin, and palynomorph at center, obscured by organic material. *C*, Electron micrograph × 5000. *D*, Electron micrograph × 16000. *E*, Electron micrograph × 20,000. *F*, Lower horizon sample showing more normal appearance of material on slide; ×100. Note epidermal tissue at upper left corner and several palynomorphs.

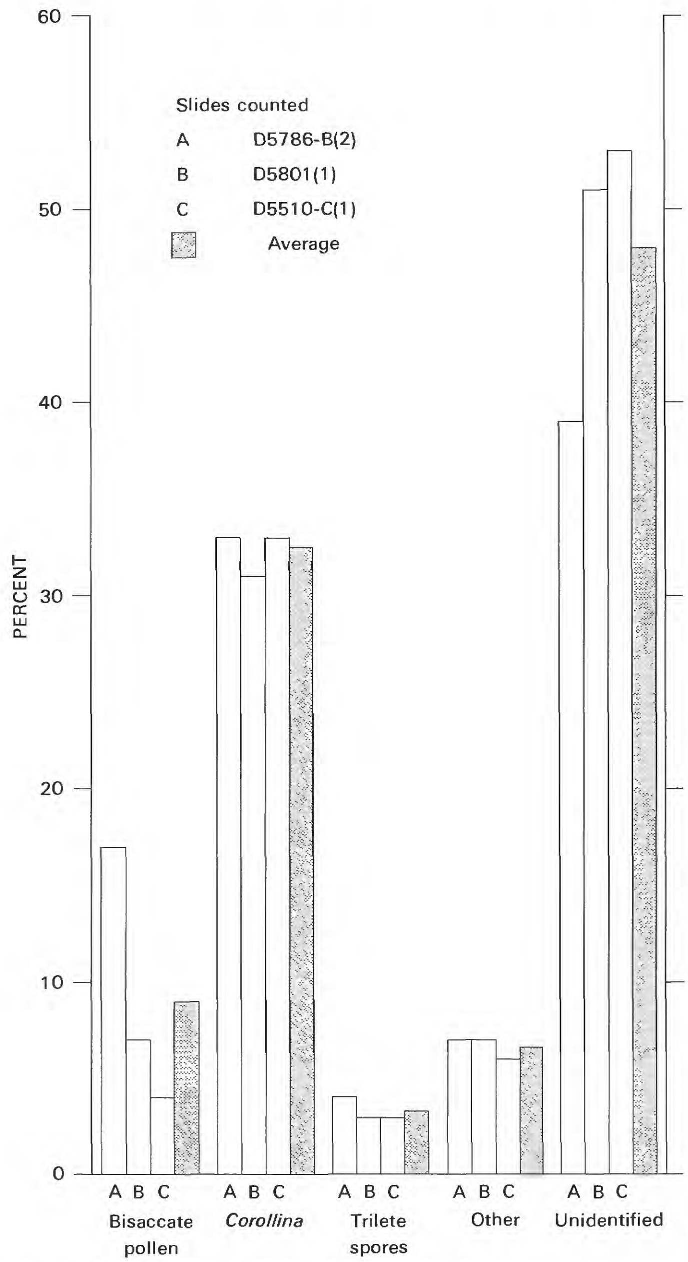



FIGURE 6.—Gross palynomorph recovery from some upper horizon Burro Canyon samples.

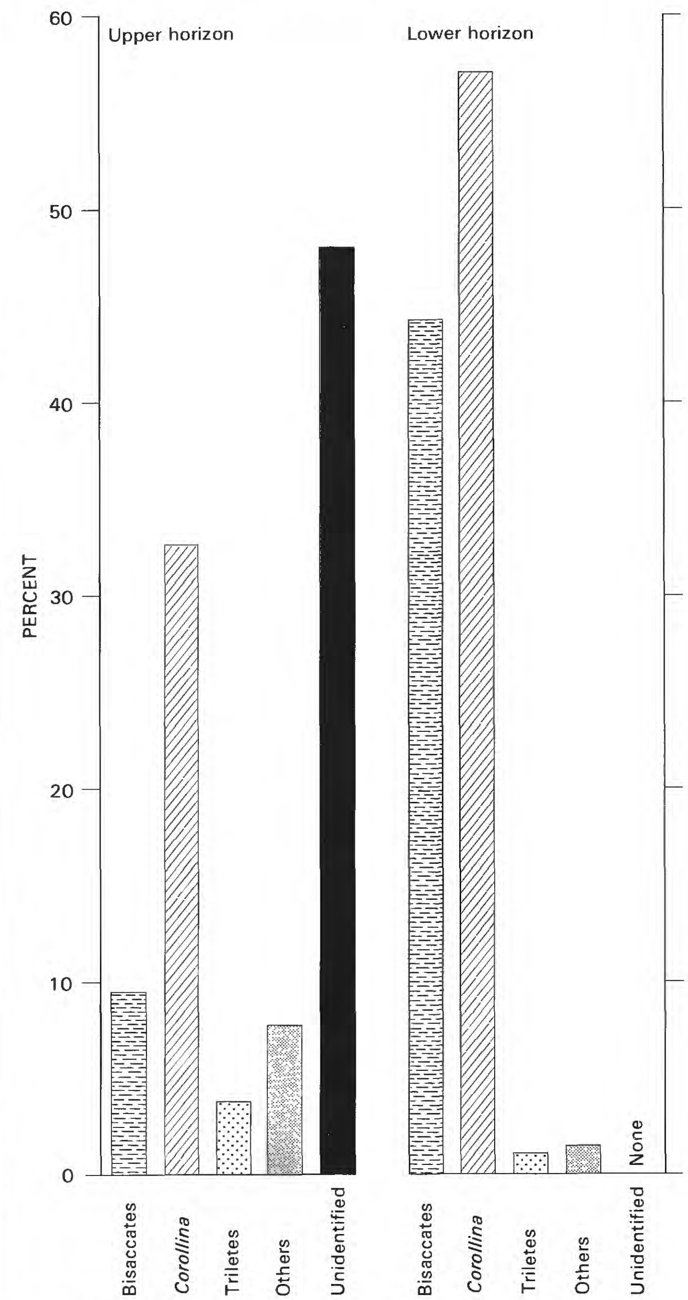



FIGURE 7.—Comparison of gross palynomorph recovery from Burro Canyon upper and lower horizons. Average recovery data for upper horizon taken from figure 5. Average recovery data from lower horizon taken from figure 8. Unidentified fossils may consist of *Corollina*, and possibly unidentified algae. *Botryococcus* is present in all samples but commonly is not abundant.

the appearance of the organic material from the upper horizon.

A comparison of the gross palynomorph recovery from the upper and lower horizons is shown in figure 7. The contrast is shown vividly by the absence of unidentified forms from the lower horizon. The lower horizon assemblage is dominated by bisaccate conifer pollen and *Corollina*. The residue of palynomorphs makes up less than 3 percent of the total assemblage.

The first samples collected from the lower horizon showed a marked difference in recovery from hard dark-gray shale and from black friable shale containing small calcite crystals. The hard dark-gray shale (interval C, fig. 8) was dominated by bisaccate conifer pollen and the black friable shale (interval D, fig. 8) by *Corollina* pollen. The lower horizon was therefore recollected the following year in an attempt to verify these data. The possibly productive interval consisted of 87 cm of alternating shale, calcareous shale, and limestone capped by 40 cm of blocky gray limestone. Six samples were taken from the 87-cm interval as shown on figure 8.

### PALYNOMORPH RECOVERY FROM LOWER HORIZON SAMPLES

The upper two samples were barren. The gross palynomorph recovery of the four lower samples is shown in figure 8. The sample D5972–D yielded 97 percent bisaccate conifer pollen and only 1 percent *Corollina*, whereas samples D5972–C, D5972–B and D5972–A yielded 20, 23, and 35 percent bisaccate conifer pollen, respectively, and the assemblages were dominated by abundant *Corollina* specimens. Bisaccate pollen and pollen of *Corollina* were produced by conifers. *Corollina* pollen was produced by the fossil tree genus *Cheirolepis*. The prominent change in abundance of these two pollen groups in a comparatively short stratigraphic interval indicates a prominent floral change and suggests a prominent biofacies difference between the two groups of samples.

The following taxa were identified from the lower horizon:

*Gleicheniidites senonicus* (Ross) Skarby 1964
*Cyathidites minor* Couper 1953
*Deltoidospora* cf. *D. psilostoma* Rouse 1959
*Tigrisporites reticulatus* Singh 1971
*Interulobites triangularis* (Brenner) Phillips and Felix 1971
*Staplinisporites caminus* (Balme) Pocock 1962
*Lycopodiumsporites* sp.
*Matthesisporites tumulosus* Döring 1964
*Leptolepidites verrucatus* Couper 1953
*Verrucosisporites* cf. *V. densus* (Bolkhovitina) Pocock 1970a
*Cicatricosisporites* sp.
*Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
*Distaltriangulisporis perplexus* (Singh) Singh 1971
*Corollina torosa* (Reissinger) Cornet and Traverse 1975
*Cycadopites* spp.
*Equisetosporites* spp.
*Araucariacites* sp.
*Exesipollenites tumulus* Balme 1957
*Cerebropollenites mesozoicus* (Couper) Nilsson 1958
*Callialasporites segmentatus* (Balme) Sukh-Dev 1961
*Vitreisporites pallidus* (Reissinger) Nilsson 1958
*Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
*Clavatipollenites hughesii* (Couper) Kemp 1968
*Paleoconiferus asaccatus* Bolkhovitina 1956
*Pityosporites* cf. *P. divulgatus* (Bolkhovitina) Pocock 1970b
*Alisporites grandis* (Cookson) Dettmann 1963
*Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970b
*Cedripites* cf. *C. canadensis* Pocock 1962
*Cedripites cretaceus* Pocock 1962
*Podocarpidites ornatus* Pocock 1962
*Podocarpidites* cf. *P. ellipticus* Cookson 1947
*Podocarpidites* cf. *P. multesimus* (Bolkhovitina) Pocock 1962
*Podocarpidites radiatus* Brenner 1963
Burro Canyon taxa are shown on plates 5–9

The chief distinction between the assemblages from the upper and lower horizons of the Burro Canyon is that many species and specimens of *Cicatricosisporites* were found in the upper horizon assemblages and very few *Cicatricosisporites* specimens were found in the lower horizon assemblages.

## AGE OF THE UPPER PART OF THE BURRO CANYON FORMATION

Both upper and lower horizon assemblages were from the upper part of the Burro Canyon Formation, so for the purpose of this discussion they will be considered as a unit even though the discrepancies in recovery may appear significant. These discrepancies may be due in part to variations in biofacies existing at the times of deposition, giving rise to the distinctly different organic content of the two groups of samples. It may also be due, in part, to the low frequency of recovery of individual taxa. With the exception of bisaccate conifer pollen and *Corollina*, many of the remaining taxa were found only as single specimens, or generally as only a few specimens of any single taxon.

Bisaccate conifer pollen is difficult to segregate into generic units. Futhermore, most genera and species are long-ranging and are of little value in age determinations. *Corollina* pollen is almost omnipresent in Upper Jurassic and Lower Cretaceous continental palynomorph-bearing rocks of North America. Consequently the remaining taxa, even though present in extremely low frequency in the samples, are the significant taxa for the estimation of the ages of the samples.

The palynomorphs recovered failed to reveal even a single specimen of tricolpate pollen. The apparent first record of tricolpate (tricolporate) pollen is from the Berriasian-Valanginian of the Netherlands (Burger, 1966). But well-documented tricolpates first appear in the Aptian-Albian worldwide (Doyle, 1969; Muller, 1970; Chlonova, 1977). In North America, tricolpates enter the stratigraphic record no earlier than mid-Albian time

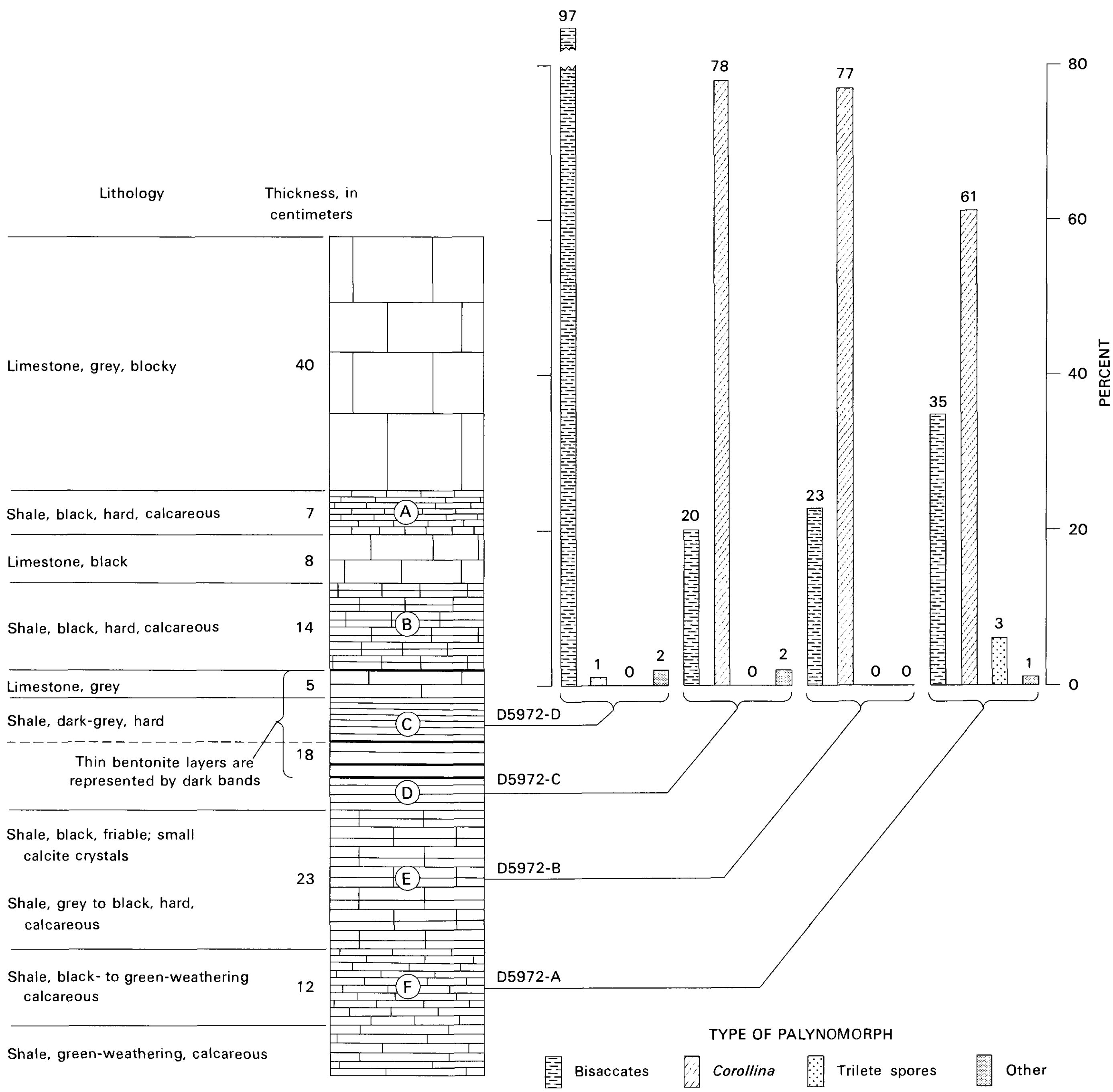



FIGURE 8.—Gross palynomorph recovery from selected intervals in lower horizon Burro Canyon. A–F, Intervals from which samples (D-numbers) were taken. Samples from intervals A and B were barren of palynomorphs. Numbers at top of bars indicate percentage of each type of palynomorph.

(Singh, 1975). Consequently, palynomorph assemblages lacking tricolpate pollen may be assumed to be no younger than mid-Albian.

Because of the purported interfingering of the Jurassic Brushy Basin Member of the Morrison with the lower part of the Burro Canyon Formation, comparisons of Burro Canyon assemblages with Jurassic and early Early Cretaceous assemblages were made. The Burro Canyon palynomorph assemblages are distinctly more advanced than are Late Jurassic assemblages from the Colorado Plateau, or from Western Canada (Pocock, 1962; 1970a,b). For example, two species of *Appendicisporites* were isolated from the Burro Canyon Formation. This taxon is not present in the Jurassic; it first appears worldwide in the Valanginian (Pocock, 1967; Vakhrameev and others, 1973). Further, many species of *Cicatricosisporites* are present in the Burro Canyon, and although a few species have been reported from the Upper Jurassic of Europe and Asia, none have been found in the Jurassic of western Canada (Pocock, 1970a), nor have we found any specimens of *Cicatricosisporites* in any of the assemblages from the Brushy Basin, Westwater Canyon, or Recapture Members of the Morrison Formation (Upper Jurassic) of the Colorado Plateau region. Consequently, it is safe to assume that the age of the Burro Canyon Formation is Neocomian to early Albian.

Assemblages from near the Jurassic-Cretaceous boundary in northwest Europe (Döring, 1965; Burger, 1966; Norris, 1969; Dörhöfer and Norris, 1977; Dörhöfer, 1977) were compared with those from the Burro Canyon Formation. Little similarity was evident. In fact, little similarity between assemblages of similar age from England and from continental northwest Europe was evident. "Of the 109 trilete spore types described by Döring (1965) from the German Jurassic-Cretaceous sediments, only about 10 species are known in the southern England succession" (Norris, 1973, p. 99). Furthermore, the assemblage from the German Bückeberg Formation (Dörhöfer, 1977) (Berriasian-Valanginian) correlative with the English upper Purbeck and lower Wealden (Dörhöfer and Norris, 1977) yielded no bisaccate conifer pollen. Most other Neocomian assemblages yielded significant proportions of bisaccate pollen. Consequently, the differing biofacies conditions in the two European localities and in the Burro Canyon Formation make comparisons more difficult.

The precise position of Lower Cretaceous samples cited in the literature is often not known. Reports refer in general terms to Lower Cretaceous, or to Neocomian rather than to the formal subdivisions. This usage is true of most reports from Australia and Russia. For example, Burger (1973) and Dettmann (1963) referred to the Lower Cretaceous or Neocomian, and Orlova-Turchina (1966) reported on the Hauterivian-Barremian Russian complexes in general terms only.

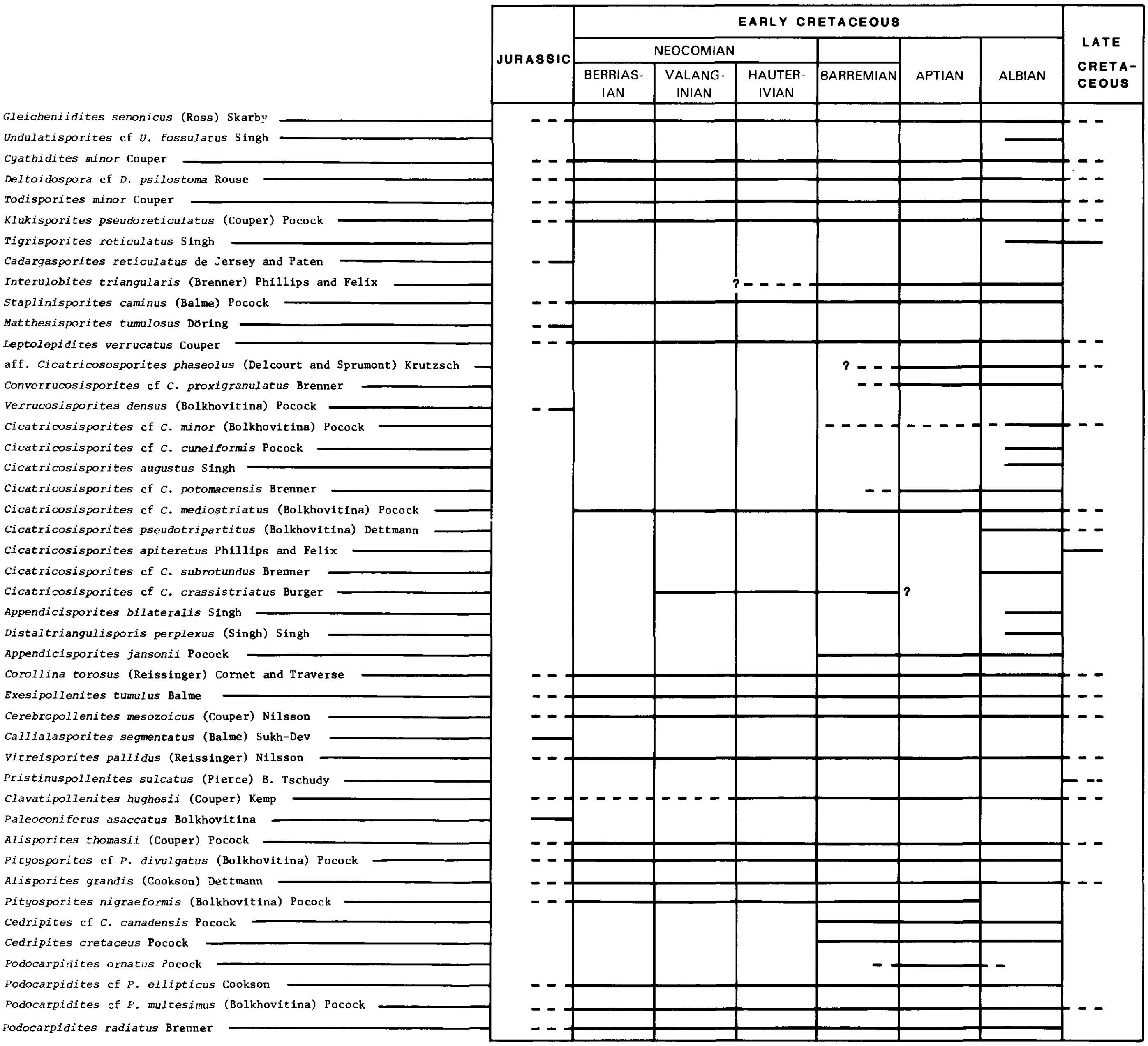
Another fact that hinders direct correlation is the yield of palynomorphs from the Burro Canyon Formation. The yield of taxa of potential usefulness was minimal. Aside from conifer pollen—mostly long-ranging species and *Corollina*, the remainder of the assemblage as a whole was sparse (see fig. 6). Generally, only a few specimens of any one taxon were found. Many of the genera and species commonly used to subdivide the Neocomian in other regions failed to appear in Burro Canyon samples. These genera include *Concavissimisporites*, *Trilobosporites*, *Impardecispora*, *Contignisporites*, *Januasporites*, and *Schizosporis*.

Comparison of the Burro Canyon assemblages with Jurassic and Early Cretaceous assemblages from western Canada failed to present evidence for direct correlation. This lack of evidence may be due to the fact that the Lower Cretaceous rocks of western Canada are commonly no older than Barremian (Singh, 1971). Only one report of upper Neocomian palynomorph assemblages from Canada is available. Hopkins (1971) reported an assemblage from the Isachsen Formation, bounded below by upper Valanginian rocks and above by Albian rocks. Hopkins (1971, p. 110) concluded that "The Isachsen Formation is therefore entirely Lower Cretaceous, ranging from Upper Valanginian, including probably Hauterivian and Barremian; possibly also Aptian***". Hopkins also observed "There appears to be no significant variation of the flora from the top to bottom of the Isachsen Formation suggesting that environmental conditions did not vary greatly during the time represented by Isachsen deposition, ***the flora is remarkably uniform over a comparatively long period of time (about 10 million years)." The palynomorph assemblage from the Isachsen Formation bears the closest resemblance to assemblages from the Burro Canyon Formation yet observed, even though most of the species mentioned did not appear in the Burro Canyon assemblages.

Adequate data are not yet available representing the age-ranges of taxa found in the Burro Canyon Formation owing to the comparatively few reliable reports on Lower Cretaceous rocks, particularly from North America. The currently known ranges of all species figured on plates 5–9 are recorded in table 2.

As shown on table 2, many of the identified species have long ranges, and offer no aid in narrowing down the age of the Burro Canyon Formation. Some of the other species, *Verrucosisporites densus* (Bolkhovitina) Pocock, *Matthesisporites tumulosus* Döring, *Callialasporites segmentatus* (Balme) Sukh-Dev, *Paleoconiferus asaccatus* Bolkhovitina, and *Cadargasporites reticulatus* de Jersey and Paten are limited, as understood at present, to the Jurassic. *Cicatricosisporites apiteretus* Phillips and Felix, is limited to the Cenomanian. The ranges of the Jurassic species in our samples possibly may be attributed to redeposition into Lower Cretaceous rocks, although no visual difference in the appearance of the fossils was observed. On the other hand, both the limited ranges of the Jurassic and Cenomanian species may be due to the limited amount of work that has been done on Lower Cretaceous rocks in North America. The true ranges may not yet be evident. For example, the genus *Cadargasporites* and the species *Cadargasporites reticulatus* de Jersey and Paten, have been reported previously, to our knowledge, only from the Early Jurassic of the Surat Basin, Australia (de Jersey and Paten, 1964). Yet the two

TABLE 2.—*Stratigraphic ranges of Burro Canyon palynomorph species*




specimens from the Burro Canyon Formation with their distinctive distal labyrinthine reticulum, and smooth proximal contact area, appear to be conspecific with the Australian species.

The data presented on table 2 suggest to us a late Neocomian to Aptian-Albian age. A few taxa from table 2 merit further discussion.

*Tigrisporites reticulatus* Singh.—This species was first reported by Singh (1971) from the middle Albian of Alberta, Canada. Its presently known range is from the mid-Albian to early Cenomanian. Although several specimens of this species were found, the species was not represented in all preparations. This species is not as yet known from anywhere in the world except from western North America. A closely allied species, *Tigrisporites scurrandus* Norris with an almost identical known range (mid- and late Albian) also appears to be confined to western North America. We have found both species in formations of Albian Age from Colorado and Idaho.

*Interulobites triangularis* (Brenner) Phillips and Felix.—This species was observed sporadically in Burro Canyon assemblages. It has been reported previously only by Brenner (1963) (as *Lycopodiacidites trian-*

*gularis)* from the Albian-Aptian, possibly Barremian, Patapsco, Arundel and Patuxent Formations of Maryland, by Phillips and Felix (1971) from the Albian Paluxy Formation of Louisiana, and by Scott (1976) from the Neocomian(?) Sundays River and Kirkwood Formations of South Africa.

*Appendicisporites jansonii* Pocock.—The range of this species according to Singh (1971) is Barremian to Albian. Outside of Canada it has been reported by Hedlund and Norris (1968) from the Albian of Oklahoma. Singh (1971) claimed that *Appendicisporites* sp. reported by Lantz (1958) from the Albian of England is conspecific with *A. jansonii* Pocock. The presence of *Appendicisporites* species suggests that the age of the Burro Canyon samples can be no older than Valanginian. "It is important to note the appearance, in the Valanginian of the genus *Appendicisporites* also. This genus is unknown in older deposits of Europe and Asia." (Vakrameev and others, 1973 p. 214). "No species of this genus have been recorded from strata older than this [Valanginian] anywhere in the world." (Pocock, 1967 p. 135).

*Clavatipollenites hughesii* (Couper) Kemp.—A single specimen of *Clavatipollenites hughesii* (Couper) Kemp was found on one of the slides of a sample from the lower horizon. Although literature reports of Triassic and Jurassic occurrences from several parts of the world have appeared (see previous discussion), this species has not been reported from North American rocks older than Barremian and from western North American rocks older than Albian (Singh, 1975). Its earlier appearance elsewhere may mean that the parent plant had not migrated to North America earlier, or palynological investigations have not yet uncovered the data. The plant may have existed for a long time in extremely low frequency and in limited ecological environments, before it expanded its habitat and abundance sufficiently to be represented commonly in Albian and younger rocks.

The taxa discussed, combined with the absence of tricolpate pollen all point to an Aptian-early Albian age, with the remote possiblity of a late Barremian age, for the upper part of the Burro Canyon Formation.

## CONCLUSIONS

Although all students of these beds are agreed that Burro Canyon and Cedar Mountain beds are physically continuous in large part, the results of the present study of palynomorphs shows a difference in age: the upper part of the Cedar Mountain is younger (late or latest Albian) than the upper part of the Burro Canyon (Aptian to early Albian and perhaps as old as Barremian). We suggest that the thick lower part of the Cedar Mountain, which is undated by fossils, may contain beds that are age equivalent to the older Burro Canyon beds. The beds equivalent to the uppermost Cedar Mountain beds of late or latest Albian age may have been removed by pre-Dakota (pre-earliest Late Cretaceous) erosion at the Burro Canyon locality or are represented in the 6 m of green mudstones (nonproductive of palynomorphs) at the top of the Burro Canyon at the collection locality. A further speculation that may be warranted is that the Neocomian (early Early Cretaceous) may be represented in a still-undated lower part of the Burro Canyon and Cedar Mountain—perhaps even including an upper part of the Brushy Basin Member of the Morrison. The recognition of a fossil (*Clavatipollenites hughesii* (Couper) Kemp) known to occur as early as the Barremian (latest Neocomian) suggests that the undated older beds of these formations might contain beds of this age, a stage that is almost unrecorded in western North America.

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# INDEX

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# PLATES 1–9

# PLATE 1

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Laevigatosporites* cf. *L. belfordii* Burger 1976
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 99.0×21.6.

2. *Laevigatosporites gracilis* Wilson and Webster 1946
Sample D5785, slide 1, coordinates 81.0×13.7.

3. *Cyathidites australis* Couper 1953
Sample D5785–A, prep. 4, floated first, hvs, slide 5, coordinates 112.5×8.2.

4. *Todisporites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 89.3×14.8.

5. *Todisporites minor* Couper 1958
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 106.2×6.7.

6. *Gleicheniidites senonicus* Ross 1949
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 100.8×17.3.

7. *Lygodiumsporites sp.*
*Sample D5785, slide 2, coordinates 76.7*×10.1.

8. *Deltoidospora hallii* Miner 1935
Sample D5785–A, prep. 2, slide 1, coordinates 91.6×6.0.

9. *Cyathidites minor* Couper 1953
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 101.6×2.0.

10. *Concavissimisporites variverrucatus* (Couper) Singh 1964
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 110.2×18.4.

11. *Foraminisporis* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 96.8×6.7.

12. *Concavissimisporites variverrucatus* (Couper) Singh 1964
Sample D5785–A, prep. 4, floated first, hvs, slide 6, coordinates 112.5×8.2.

13. *Dictyotriletes granulatus* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 97.4×21.1.

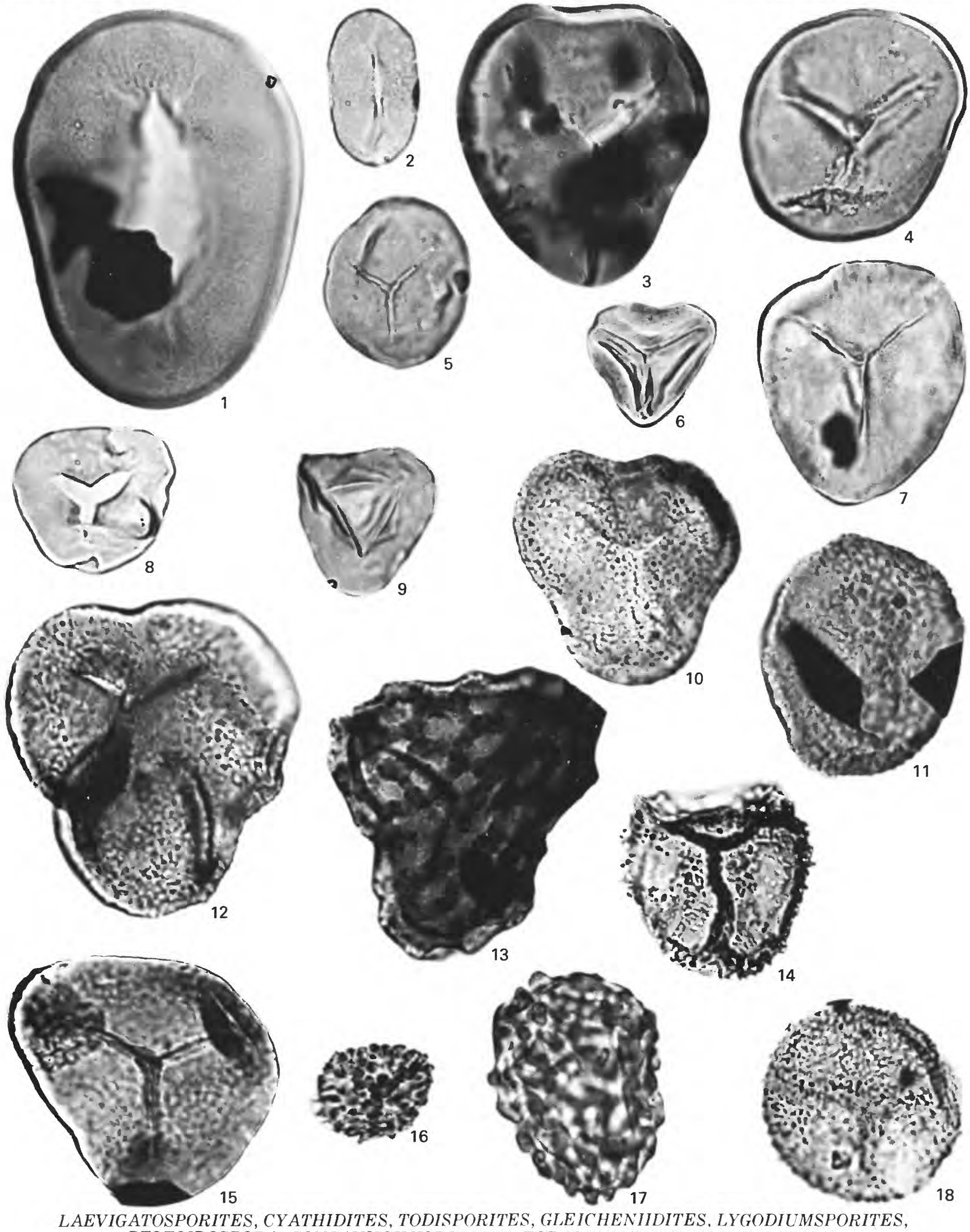
14. *Foraminisporis* cf. *F. wonthaggiensis* (Cookson and Dettmann) Dettmann 1963
Sample D5785–A, prep. 2, slide 1, coordinates 112.1×19.8.

15. *Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 81.9×3.1.

16. Trilete spore undetermined.
Sample D5785–A, prep. 2, slide 1, coordinates 104.2×10.4. Ornamented with short blunt verrucae as well as short spines.

17. *Leptolepidites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 87.6×5.1.

18. *Baculatisporites comaumensis* (Cookson) Potonie 1956
Sample D5785–A, prep. 2, slide 1, coordinates 110.5×11.1.




*LAEVIGATOSPORITES, CYATHIDITES, TODISPORITES, GLEICHENIIDITES, LYGODIUMSPORITES, DELTOIDOSPORA, CONCAVISSIMISPORITES, FORAMINISPORIS*, TRILETE SPORE, *LEPTOLEPIDITES*, AND *BACULATISPORITES*

# PLATE 2

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Pilosisporites trichopapillosus* (Thiergart) Delcourt and Sprumont 1955
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 77.7×5.4.

2–4. *Echinatisporis varispinosus* (Pocock) Srivastava 1975
2. Sample D5785–A, prep.4, floated first, fines, slide 2, coordinates 87.3×5.9.
3. Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 73.9×13.0.
4. Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 107.6×4.8.

5. *Cicatricosisporites hughesii* Dettmann 1963
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 108.4×13.3.

6. *Cicatricosisporites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 74.0×7.5.

7. *Cicatricosisporites* cf. *C. minutaestriatus* (Bolkhovitina) Pocock 1964.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 98.6×9.9.

8. *Cicatricosisporites venustus* Deak 1963
Sample D5785–A, prep. 2, slide 1, coordinates 110.0×6.2.

9. *Cicatricosisporites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 95.1×21.1.

10. *Distaltriangulisporites* cf. *D. irregularis* Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 88.0×14.5.

11. *Costatoperforosporites* sp.
Sample D5785–A, prep. 4, hvs., slide 6, coordinates 76.8×8.0.

12. Trilete spore, undetermined.
Sample D5785, slide 2, coordinates 91.1×19.3.

13. *Densoisporites microrugulatus Brenner 1963*
*Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 75.4*×8.0.

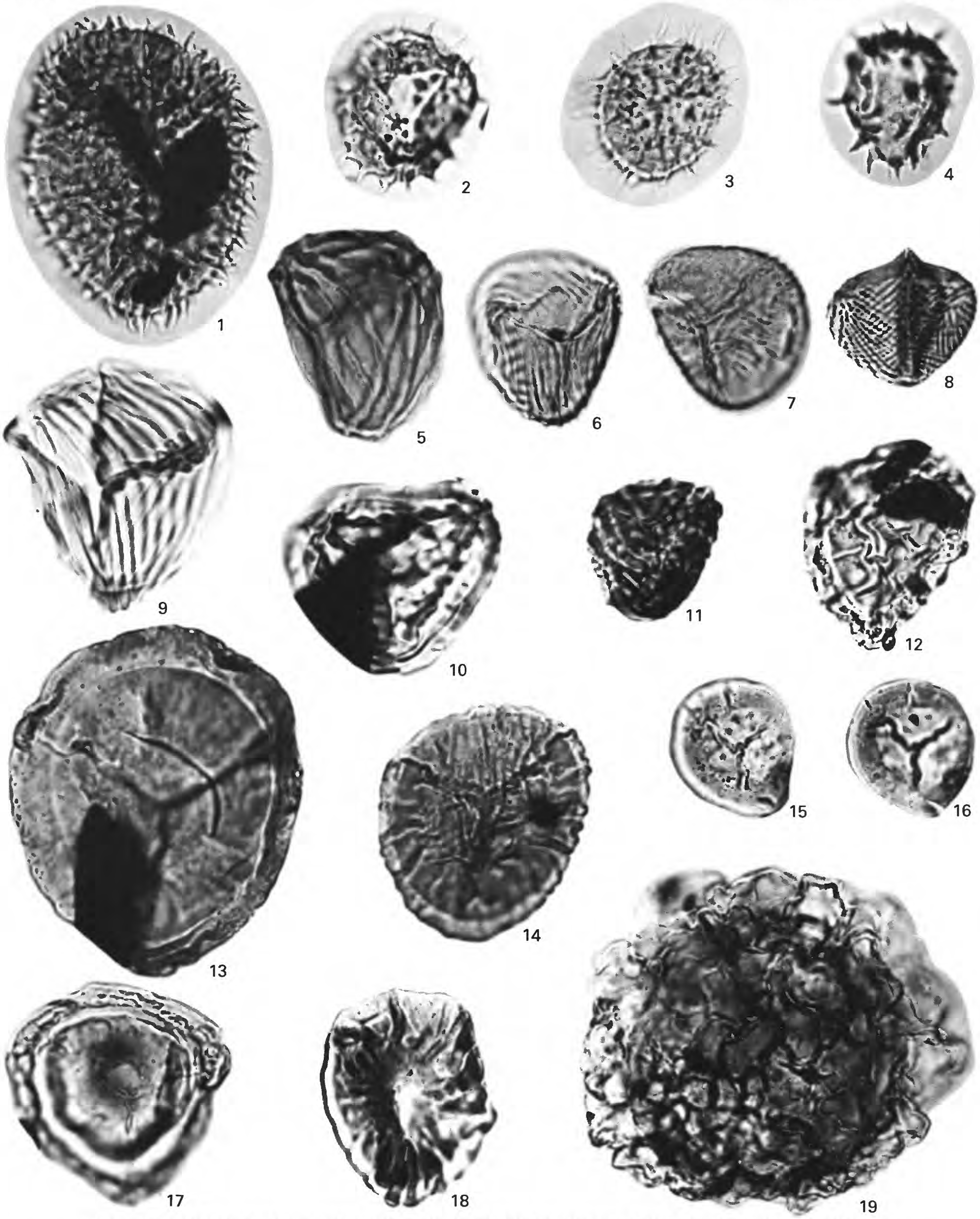
14. *Psilatriletes circumundulatus* Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 84.2×20.4.

15–16. Trilete spore, undetermined.
Sample D5785–A, prep. 2, slide 1, coordinates 90.5×19.4.
15. Proximal view.
16. Distal view.

17. *Densoisporites velatus* Weyland and Krieger 1953
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 83.5×12.4.

18. Undetermined.
Sample D5785–A, prep. 2, slide 1, coordinates 102.9×15.6.

19. cf. *Schizosporis* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 103.5×16.2




*PILOSISPORITES, ECHINATISPORIS, CICATRICOSISPORITES, DISTALTRIANGULISPORITES, COSTATOPERFOROSPORITES, DENSOISPORITES, PSILATRILETES,* cf. *SCHIZOSPORIS,* AND TRILETE SPORE

# PLATE 3

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Alisporites grandis* (Cookson) Dettmann 1963
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 88.2×4.0.

2. *Pityosporites granulatus* Phillips and Felix 1971
Sample D5785–A, prep. 4, floated first, hvs., slide 5, coordinates 95.2×17.6.

3. *Cedripites* cf. C. *cretaceus* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 77.8×5.2.

4. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 97.1×10.1.

5. *Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 83.2×22.3.

6. *Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 104.8×4.1.

7. *Cedripites canadensis* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 87.7×5.4.

8. *Podocarpidites* cf. *P. minisculus* Singh 1964
Sample D5785–A, prep. 4, floated first, hvs., slide 5, coordinates 99.1×19.4.

9. *Podocarpidites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 112.2×2.4.

10. *Cedripites* cf. *C. canadensis* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 74.8×11.9.

11. *Vitreisporites pallidus* (Reissinger) Nilsson 1958
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 110.3×18.0.


*ALISPORITES, PITYOSPORITES, CEDRIPITES, PODOCARPIDITES, PRISTINUSPOLLENITES,* AND *VITREISPORITES*

# PLATE 4

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany location numbers (text fig. 2)]

FIGURE 1. *Cycadopites carpentieri* (Del court and Sprumont) Singh 1964
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 110.9×12.1.

2. *Cycadopites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 99.0×13.0.

3. *Monocolpopollenites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 96.0×4.0.

4. *Monocolpopollenites* sp.
Sample D5785–B, slide 3, coordinates 101.6×14.2.

5. *Ginkgocycadophytus* cf. *G. nitidus* (Balme) de Jersey 1962
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 81.4×4.6.

6. *Equisetosporites multicostatus* (Brenner) Norris 1967
Sample D5785–A, prep. 2, coordinates 106.1×22.5.

7. *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 92.8×1.6.

8. *Eucommiidites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 102.7×21.5.

9. *Corollina torosa* (Reissinger) Cornet and Traverse 1975.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 80.7×5.7.

10. *Exesipollenites tumulus* Balme 1957
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 78.3×2.1.

11–12. *Asteropollis asteroides* Hedlund & Norris 1968
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 104.4×9.4.
- 11. Low focus showing baculae near equator.
- 12. High focus.

13. *Clavatipollenites hughesii* (Couper) Kemp 1968
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 112.0×21.0.
The size of this specimen is on the borderline between *C. hughesii* (Couper) Kemp and *C. minutus* Brenner.

14. *Liliacidites* sp.
Sample D5785–B, prep. 2, slide 2, coordinates 112.3×14.5.

15. *Liliacidites* cf. *L. peroreticulatus* (Brenner) Singh 1971
Sample D5785–B, slide 3, coordinates 106.5×5.7.

16. *Tricolpites crassimurus* (Groot and Penny) Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 94.1×7.5.

17. *Tricolpites* cf. *T. crassimurus* (Groot and Penny) Singh 1971
Sample D5785–A, prep. 4, floated first, Hvs., slide 5, coordinates 88.2×9.1.

18. *Cupuliferoidaepollenites parvulus* (Groot and Penny) Dettmann 1973
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 90.5×2.1.

19. *Retitricolpites* cf. *R. virgeus* (Groot, Penny and Groot) Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 83.0×11.8.

20. *Retitricolpites vulgaris* Pierce 1961
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 104.3×20.0.

21. *Retitricolpites vulgaris* Pierce 1961
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 111.4×17.0.

22. *Tricolpites* cf. *T. wilsonii* Kimyai 1966
Sample 5785–A, prep. 4, floated first, fines, slide 4, coordinates 88.0×16.2.

23. *Striatopollis paraneus* (Norris) Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 106.4×5.4.

24. *Striatopollis paraneus* (Norris) Singh 1971
Sample D5785, slide 2, coordinates 105.5×13.3.

25. *Retitricolpites vermimurus* Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 97.5×19.8.

26. *Rousea georgensis* (Brenner) Dettman 1973
Sample D5785–A, prep. 4, floated first, Hvs., slide 5, coordinates 112.1×11.0.

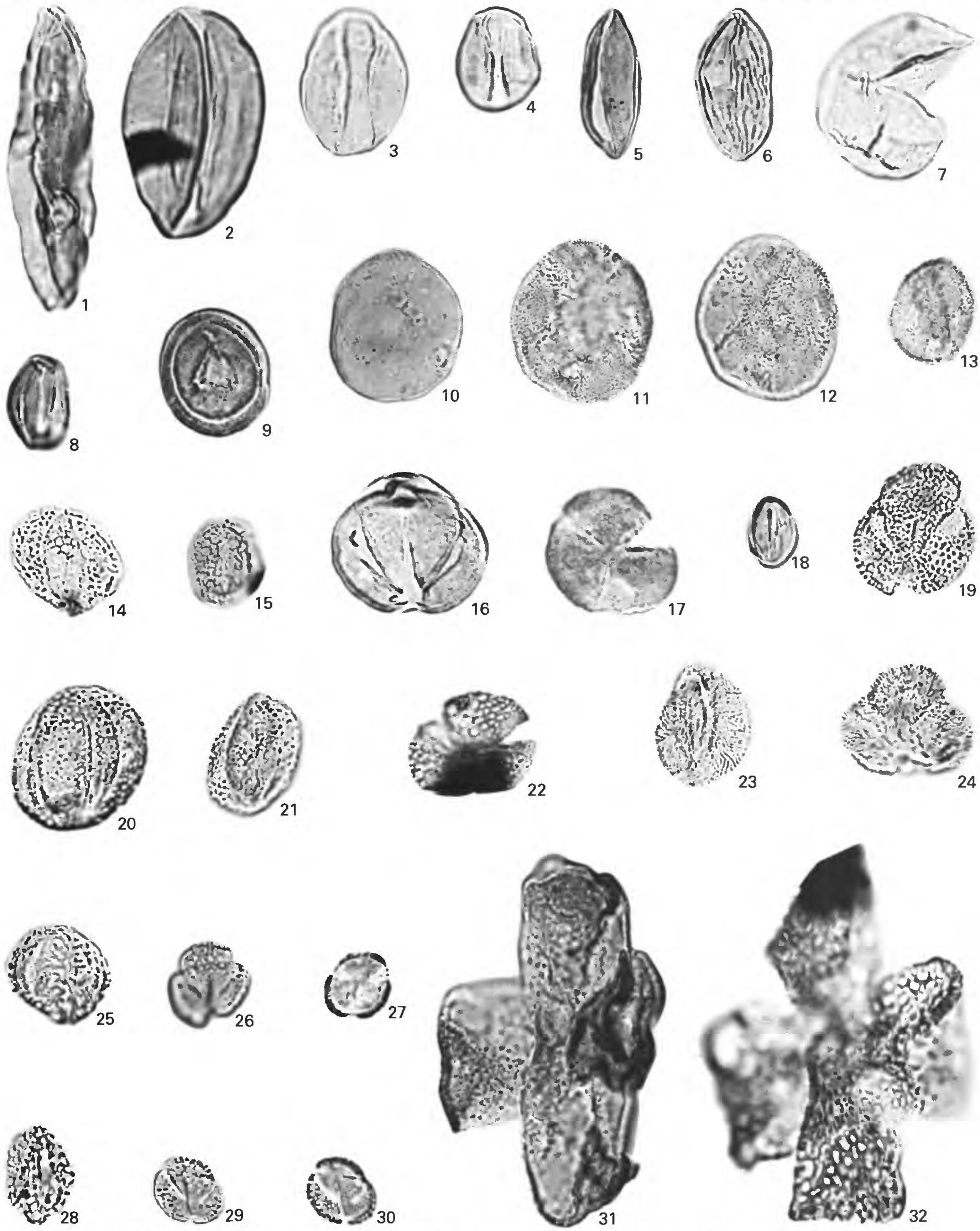
27. *Cupuliferoidaepollenites minutus* (Brenner) Singh 1971
Sample D5785–B, prep. 2, slide 2, coordinates 111.5×8.6.

28. *Tricolpites* cf. *T.* sp. 1 of Kemp 1968
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 104.1×14.5

29–30. *Tricolpites micromunus* (Groot and Penny) Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 110.7×2.0. (Sensu Groot and Penny. This specimen is small and may not be the same species as figured by Singh 1971).
- 29. High focus.
- 30. Low focus.

31. *Tetracolpites* cf. *T. pulcher* Srivasteva 1969
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 105.5×8.0.

32. *Tetracolpites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 89.8×17.9.



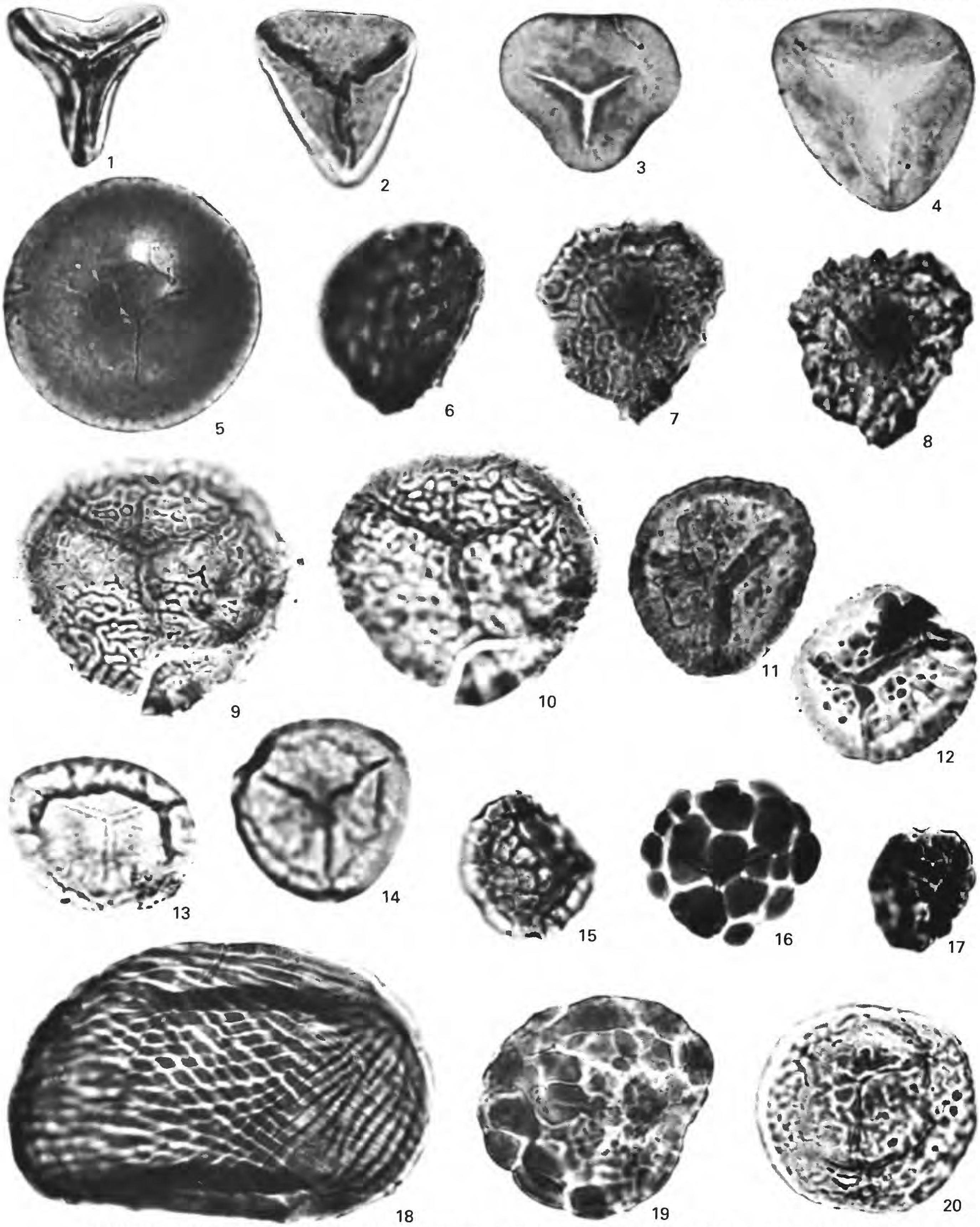

*CYCADOPITES, MONOCOLPOPOLLENITES, GINKGOCYCADOPHYTUS, EQUISETOSPORITES, TAXODIACEAEPOLLENITES, EUCOMMIIDITES, COROLLINA, EXESIPOLLENITES, ASTEROPOLLIS, CLAVATIPOLLENITES, LILIACIDITES, TRICOLPITES, CUPULIFEROIDAEPOLLENITES, RETITRICOLPITES, STRIATOPOLLIS, ROUSEA,* AND *TETRACOLPITES*

# PLATE 5

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers. (text fig. 2)]

FIGURE 1. *Gleicheniidites senonicus* Ross 1949
Sample D5803, slide 22, coordinates 111.6×13.8.
2. *Undulatisporites* cf. *U. fossulatus* Singh 1971
Sample D5510–B, slide 1, coordinates 103.6×10.5.
3. *Cyathidites minor* Couper 1953
Sample D5510–C, slide 4, coordinates 105.9×6.8.
4. *Deltoidospora* cf. *D. psilostoma* Rouse 1959
Sample D5803, slide 12, coordinates 91.0×17.8.
5. *Todisporites minor* Couper 1958
Sample D5801, prep. 2, slide 4, coordinates 78.1×20.9.
6. *Dictyotriletes pseudoreticulatus* (Couper) Pocock 1962
Sample D5801, slide 2, coordinates 107.2×9.8.
7–8. *Tigrisporites reticulatus* Singh 1971
Sample D5973, slide 2, coordinates 75.2×14.3.
9–10. *Cadargasporites reticulatus* de Jersey and Paten 1964
Sample D5510–B, slide 2, coordinates 93.8×3.0.
11. *Interulobites triangularis* (Brenner) Phillips and Felix 1971
Sample D5803, slide 4, coordinates 107.6×21.7.
12. *Interulobites triangularis* (Brenner) Phillips and Felix 1971
Sample D5973, slide 2, coordinates 81.2×15.6.
13. *Staplinisporites caminus* (Balme) Pocock 1962
Sample D5803, slide 6, coordinates 96.4×4.4.
14. *Staplinisporites caminus* (Balme) Pocock 1962
Sample D5803, slide 11, coordinates 82.4×19.8.
15. *Lycopodiumsporites* sp.
Sample D5803, slide 22, coordinates 74.7×1.2.
16. *Matthesisporites tumulosus* Döring 1964
Sample D5803, slide 12, coordinates 81.7×21.1.
17. *Leptolepidites* cf. *L. verrucatus* Couper 1953
Sample D5803, slide 8, coordinates 90.0×2.2.
18. aff. *Cicatricososporites phaseolus* (Delcourt and Sprumont) Krutzsch 1959
Sample D5801, slide 2, coordinates 76.0×15.5.
19. *Converrucosisporites* cf. *C. proxigranulatus* Brenner 1963
Sample D5510–C, slide 2, coordinates 98.4×15.4.
20. *Verrucosisporites densus* (Bolkhovitina) Pocock 1970
Sample D5803, slide 6, coordinates 106.1×4.7.




*GLEICHENIIDITES, UNDULATISPORITES, CYATHIDITES, DELTOIDOSPORA, TODISPORITES, DICTYOTRILETES, TIGRISPORITES, CADARGASPORITES, INTERULOBITES, STAPLINISPORITES, LYCOPODIUMSPORITES, MATTHESISPORITES, LEPTOLEPIDITES, CICATRICOSOSPORITES, CONVERRUCOSISPORITES,* AND *VERRUCOSISPORITES*

# PLATE 6

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers. (text fig. 2)]

FIGURE 1. *Cicatricosisporites* cf. *C. minor* (Bolkhovitina) Pocock 1964
Sample D5510–C, slide 1, coordinates 109.4×11.1.

2. *Cicatricosisporites* cf. *C. cuneiformis* Pocock 1964
Sample D5510–C, slide 4, coordinates 100.3×10.0.

3. *Cicatricosisporites augustus* Singh 1971
Sample D5510–B, slide 1, coordinates 99.0×4.5.

4. *Cicatricosisporites* cf. *C. potomacensis* Brenner 1963
Sample D5510–C, slide 2, coordinates 87.0×5.5.

5. *Cicatricosisporites* cf. *C. mediostriatus* (Bolkhovitina) Pocock 1964
Sample D5510–C, slide 1, coordinates 88.8×5.4.

6. *Cicatricosisporites* sp.
Sample D5510–A, slide 2, coordinates 92.6×14.7.

7. *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
Sample D5801, prep. 2, slide 4, coordinates 105.9×20.8.

8. *Cicatricosisporites* cf. *C. pseudotripartitus* (Bolkhovitina) Dettmann 1963
Sample D5510–B, slide 1, coordinates 99.5×16.6.

9. *Cicatricosisporites apiteretus* Phillips and Felix 1971
Sample D5510–C, slide 2, coordinates 89.7×10.5.

10. *Cicatricosisporites* cf. *C. subrotundus* Brenner 1963
Sample D5510–B, slide 1, coordinates 107.2×13.3.

11–12. *Cicatricosisporites* cf. *C. crassistriatus* Burger 1966
Sample D5801, prep. 2, slide 2, coordinates 110.3×1.0.

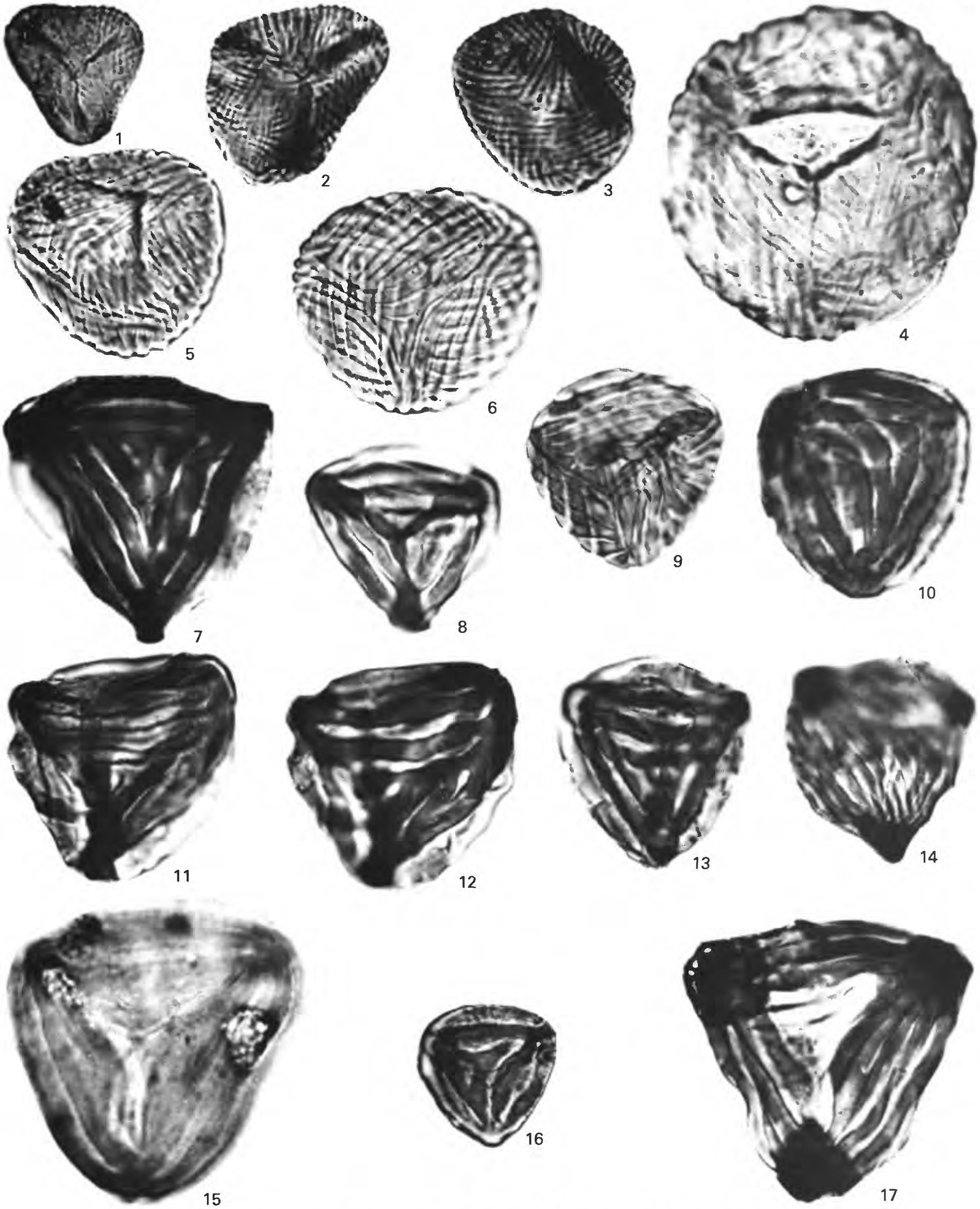
13. *Cicatricosisporites* cf. *C. pseudotripartitus* (Bolkhovitina) Dettmann 1963
Sample D5510–C, slide 4, cordinates 108.5×13.0.

14. *Appendicisporites bilateralis* Singh 1971
Sample D5801, prep. 2, slide 4, coordinates 88.3×10.5.

15. *Distaltriangulisporites perplexus* (Singh) Singh 1971
Sample D5803, slide 6, coordinates 75.9×10.0.

16. *Distaltriangulisporites* sp.
Sample D5510–B, slide 1, coordinates 73.0×9.0.

17. *Appendicisporites jansonii* Pocock 1962
Sample D5801, prep. 2, slide 2, coordinates 109.4×14.1.



CICATRICOSISPORITES, APPENDICISPORITES, AND DISTALTRIANGULISPORITES

# PLATE 7

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers. (text fig. 2)]

FIGURE 1. *Corollina torosa* (Reissinger) Cornet and Traverse 1975 (two specimens)
Sample D5803, slide 19, coordinates 79.0×20.1.

2. *Equisetosporites* sp.
Sample D5803, slide 12, coordinates 91.8×11.0.

3. *Equisetosporites* sp.
Sample D5803, slide 8, coordinates 80.4×12.9.

4. *Cycadopites* sp.
Sample D5803, slide 4, coordinates 90.8×20.2.

5. *Cycadopites* sp.
Sample D5803, slide 5, coordinates 105.3×13.6.

6. *Cycadopites* sp.
Sample D5803, slide 6, coordinates 108.8×12.4.

7. *Exesipollenites tumulus* Balme 1957
Sample D5803, slide 10, coordinates 76.6×6.1.

8. *Araucariacites* sp.
Sample D5510–C, slide 1, coordinates 72.2×1.1.

9. *Cerebropollenites mesozoicus* (Couper) Nilsson 1958
Sample D5803, slide 3, coordinates 84.2×20.5.

10. *Callialasporites segmentatus* (Balme) Sukh-Dev 1961
Sample D5803, slide 8, coordinates 93.2×16.0.

11. *Callialasporites* sp.
Sample D5510–C, slide 1, coordinates 76.9×18.0.

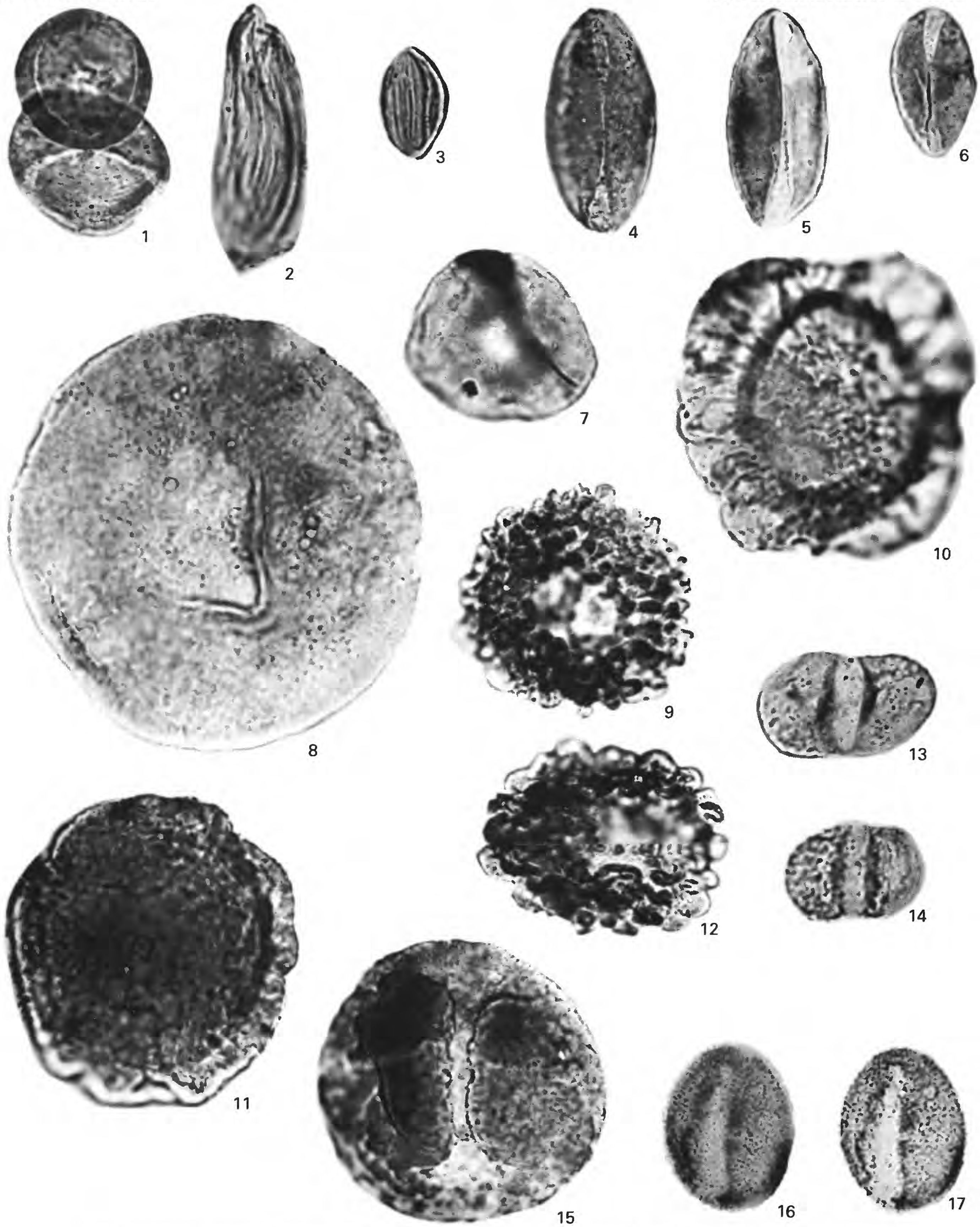
12. *Cerebropollenites mesozoicus* (Couper) Nilsson 1958
Sample D5803, slide 22, coordinates 99.8×13.4.

13. *Vitreisporites pallidus* (Reissinger) Nilsson 1958
Sample D5803, slide 21, coordinates 96.5×15.0.

14. *Vitreisporites pallidus* (Reissinger) Nilsson 1958
Sample D5510–C, slide 4, coordinates 105.4×4.3.

15. *Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
Sample D5803, slide 3, coordinates 110.8×20.7.

16–17. *Clavatipollenites hughesii* (Couper) Kemp 1968
Sample D5803, slide 12, coordinates 80.0×23.0.



*COROLLINA, EQUISETOSPORITES, CYCADOPITES, EXESIPOLLENITES, ARAUCARIACITES, CEREBROPOLLENITES, CALLIALASPORITES, VITREISPORITES, PRISTINUSPOLLENITES,* AND *CLAVATIPOLLENITES*

# PLATE 8

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Paleoconiferus asaccatus* Bolkhovitina 1956
Sample D5803, slide 21, coordinates 108.1×17.8.

2. *Alisporites thomasii* (Couper) Pocock 1962
Sample D5510–C, slide 2, coordinates 99.6×1.6.

3. *Pityosporites* cf. *P. divulgatus* (Bolkhovitina) Pocock 1970
Sample D5803, slide 21, coordinates 76.2×13.9.

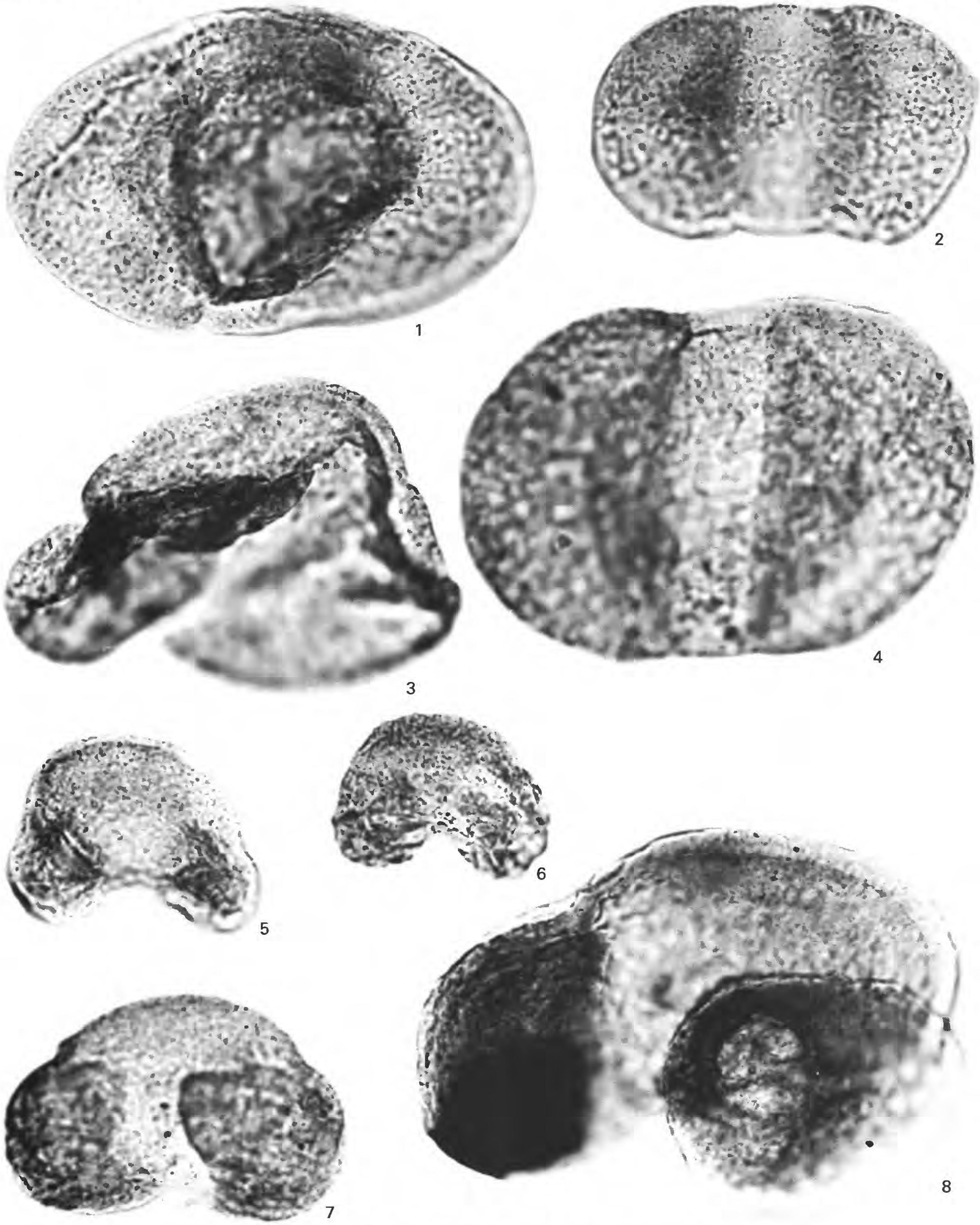
4. *Alisporites grandis* (Cookson) Dettmann 1963
Sample D5803, slide 5, coordinates 85.4×8.2.

5. *Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970
Sample D5803, slide 22, coordinates 89.8×21.6.

6. *Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970
Sample D5803, slide 22, coordinates 95.1×12.8.

7. *Cedripites* cf. *C. canadensis* Pocock 1962
Sample D5803, slide 21, coordinates 80.8×17.5.

8. *Cedripites cretaceus* Pocock 1962
Sample D5803, slide 21, coordinates 109.7×17.6



*PALEOCONIFERUS*, *ALISPORITES*, *PITYOSPORITES*, AND *CEDRIPITES*

# PLATE 9

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Podocarpidites ornatus* Pocock 1962
Sample D5803, slide 16, coordinates 110.0×10.1.

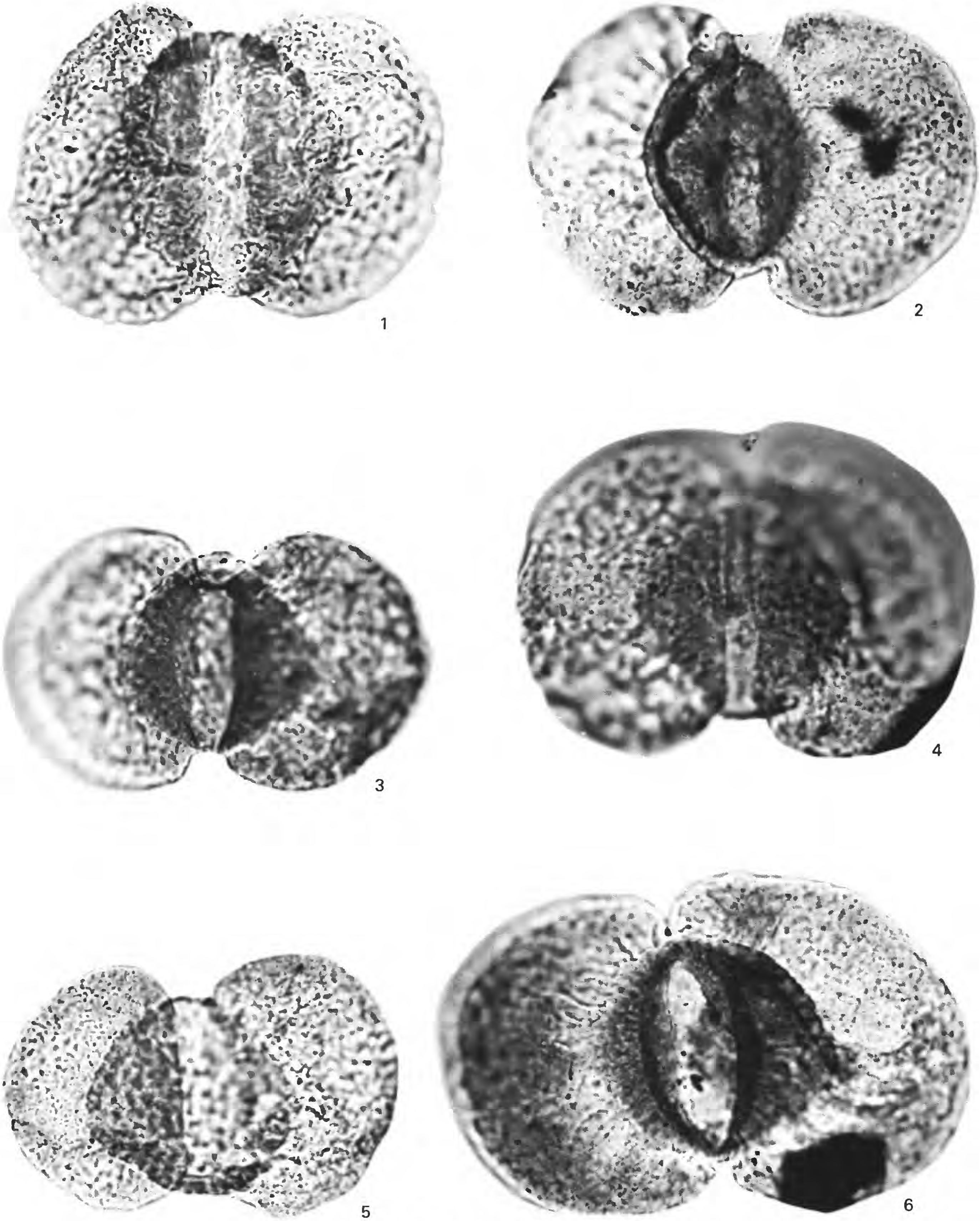
2. *Podocarpidites* cf. *P. ellipticus* Cookson 1947
Sample D5803, slide 5, coordinates 98.7×19.1.

3. *Podocarpidites* cf. *P. ornatus* Pocock 1962
Sample D5803, slide 4, coordinates 89.3×11.4.

4. *Podocarpidites* cf. *P. multesimus* (Bolkhovitina) Pocock 1962
Sample D5803, slide 21, coordinates 102.3×20.4.

5. *Podocarpidites* cf. *P. ornatus* Pocock 1962
Sample D5803, slide 21, coordinates 109.3×17.5.

6. *Podocarpidites radiatus* Brenner 1963
Sample D5803, slide 5, coordinates 111.5×9.7.




*PODOCARPIDITES*

# Palynological Evaluation of Cedar Mountain and Burro Canyon Formations, Colorado Plateau

*By* R. H. TSCHUDY, B. D. TSCHUDY, *and* L. C. CRAIG

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# TABLES

# PALYNOLOGICAL EVALUATION OF CEDAR MOUNTAIN AND BURRO CANYON FORMATIONS, COLORADO PLATEAU

By R. H. Tschudy, B. D. Tschudy, and L. C. Craig

ABSTRACT

By lithologic facies change the Cedar Mountain Formation of eastern Utah passes laterally into the Burro Canyon Formation of western Colorado. Both formations lie between the Dakota Sandstone and Morrison Formation. Few fossils have been found in the Cedar Mountain and Burro Canyon Formations, and consequently the age span attributed to these formations has been uncertain.

The overlying Dakota Sandstone in these two areas is palynologically of early Cenomanian age. The first occurrence of the angiosperm fossil pollen, *Nyssapollenites albertensis* Singh, found in the basal Dakota, is proposed as the palynological indicator of the Early-Late Cretaceous boundary in the Western Interior. Palynomorphs found in the upper parts of both the Cedar Mountain and Burro Canyon Formations are more advanced than are those found in the upper part of the Morrison Formation in the same general area. Consequently, the upper parts of the Cedar Mountain and Burro Canyon Formations that yielded palynomorphs are palynologically of Early Cretaceous age.

The palynomorph assemblage found in the upper part of the Cedar Mountain Formation date this horizon as late Albian. The Burro Canyon assemblages were somewhat less distinctive, exhibiting evidence of sequential biofacies changes, and one sample exhibited an unusual lithotype somewhat suggestive of algal origin. Nevertheless, the palynological age of the upper part of the Burro Canyon Formation is clearly older than that of the Cedar Mountain sample. The age of the Burro Canyon sample is estimated to be Aptian to early Albian with the possibility of being as old as Barremian (latest Neocomian). Thus, samples from the upper parts of these two physically equivalent formations show a difference in age. We speculate that pre-Dakota erosion may have removed beds equivalent to the upper Cedar Mountain at the Burro Canyon locality, and that the Neocomian may be represented in the still undated lower parts of the Cedar Mountain and Burro Canyon Formations.

## INTRODUCTION

The Burro Canyon Formation of western Colorado and the physically equivalent Cedar Mountain Formation of eastern Utah, both of Early Cretaceous age, have received considerable geologic attention since their definition by Stokes and Phoenix (1948) and Stokes (1944, p. 965–967). Both formations have proved valid as mappable units, yet concern remains about the age and detailed relations of these formations, both to the underlying Morrison Formation of supposed Late Jurassic age and to the overlying Dakota Sandstone of earliest Late Cretaceous age. All students of the Burro Canyon and Cedar Mountain Formations agree that, at least in part, the formations pass laterally by lithologic change into each other.

Upper parts of the Burro Canyon and Cedar Mountain have been interpreted as passing laterally into the overlying Dakota Sandstone (Young, 1960, p. 158) and as separated from it by an erosional disconformity (Craig and others, 1955, p. 161; Carter, 1957, p. 313). The Burro Canyon has also been interpreted as intertonguing with the underlying Brushy Basin Member of the Morrison Formation (Craig and others, 1961, p. 1583) and as separated from the Morrison by a disconformity (Young, 1960, p. 169). These differences of interpretation serve to emphasize the importance of age determinations from either the Cedar Mountain or Burro Canyon Formations and adjoining beds. Unfortunately, both the Cedar Mountain and Burro Canyon Formations contain few fossils. Young (1960, p. 180–181) summarized the knowledge of the limited invertebrate fauna and megaflora. The Aptian or Albian Age (table 1) determined for these fossils accounts for the assignment of the Burro Canyon and Cedar Mountain to the Early Cretaceous.

The recognition of palynomorphs in samples from the Burro Canyon led to the hope that more could be learned from the plant microfossils about the ages of the Burro Canyon and Cedar Mountain Formations and adjacent beds. Considerable search for likely fossiliferous beds resulted in the collection of numerous samples, most of which proved to be barren of palynomorphs. A few samples, however, contained suites of palynomorphs, and these new data and the interpreted ages are presented in this report.

*Acknowledgments.*—We thank Sharon Van Loenen for her assistance in the preparation of illustrations, the photography of specimens, and other aspects of the preparation of this manuscript.

## ROCK UNITS

A summary of the characteristics of the Cedar Mountain and Burro Canyon Formations near the fossil sites follows; figure 1 shows the stratigraphic position of the productive palynomorph collections discussed in this paper.

TABLE 1.—*Relation of geochronologic terms used in this report and age estimate of boundaries in millions of years before present, based on Lanphere and Jones (1978)*

| PERIOD | EPOCH | AGE | | AGE ESTIMATE |
|---|---|---|---|---|
| Cretaceous (part) | Late Cretaceous (part) | Cenomanian (part) | | |
| | | | | 96 |
| | Early Cretaceous | Albian | | |
| | | Aptian | | |
| | | Neocomian | Barremian | |
| | | | Hauterivian | |
| | | | | 136 |
| | | | Valanginian | |
| | | | Berriasian | |
| | | | | 138 |
| Jurassic (part) | Late Jurassic (part) | Portlandian | | |

## CEDAR MOUNTAIN FORMATION

The Cedar Mountain consists of a relatively thin basal conglomeratic sandstone unit, the Buckhorn Conglomerate Member, and a relatively thick upper shale unit, the shale member. The shale member consists of silty to sandy swelling mudstones that show relatively thick color zones of pastel shades. Some of the mudstone units contain abundant limestone nodules that cover the weathered slopes of the member. Minor constituents of the member are thin, broadly lenticular limestone beds, and a few sandstone units, which are generally cross bedded, may contain lenticles of granule to pebble conglomerate, and appear fluvial in origin. The carbonaceous mudstone from which the palynomorphs were collected is almost unique in the Cedar Mountain.

The Cedar Mountain differs from the Burro Canyon in that the shale member consists dominantly of pastel-colored claystone, including purples and reds, as well as green; it is composed of swelling clays and it generally contains an abundance of limestone nodules that cover the weathered slopes. The Cedar Mountain Formation differs from the underlying Brushy Basin Member of the Morrison Formation in that it lacks the brilliant colors of the Brushy Basin, it lacks the distinct color banding, and it has abundant limestone nodules. The Cedar Mountain is distinguished from the Dakota Sandstone by the general absence of carbonaceous layers in the mudstone of the Cedar Mountain and the presence of carbonaceous shale and plant remains in the sandstone beds of the Dakota.

The palynomorph collections reported here come from a single carbonaceous unit near the top of the formation (fig. 1) in the SE¼SW¼, sec. 17, T. 19 S., R. 9 E., Emery County, Utah. The locality is about 16 km southwest of the type locality of the Cedar Mountain Formation (Stokes, 1952, p. 1773). This carbonaceous unit also has provided a small invertebrate and megaflora suite reported by Katich (1951, p. 2093–2094).

## BURRO CANYON FORMATION

The Burro Canyon is a sequence of alternating lenticular conglomeratic sandstone beds and variegated, mostly greenish-gray, nonswelling mudstone beds. The sandstone units generally dominate in the lower part of the formation, whereas the mudstone is more abundant in the upper part of the formation. Minor rock components are limestone and chert beds.

The formation is distinguished from the underlying Brushy Basin Member in that it consists of coarse, generally conglomeratic, sandstone and interbedded dominantly greenish-gray mudstone, composed of nonswelling clay. The Brushy Basin contains only a few conglomeratic sandstone beds, particularly in its upper part, and is composed dominantly of alternating red, green, and gray mudstone that contains swelling clay, and forms distinctly color-banded outcrops. The Burro Canyon Formation is distinguished from the overlying Dakota Sandstone by the greenish mudstone and by the absence of carbonaceous material and organic-rich shale, lignite, or coal. The Dakota consists of interbedded sandstone and carbonaceous shale; the sandstone is in part conglomeratic and generally contains much carbonaceous debris and common impressions of twigs, stems, and branches.

The collections of palynomorphs reported here came from two carbonaceous shale units (fig. 1) in the upper shaly part of the Burro Canyon exposed in a small tributary of Disappointment Creek in the NE¼, sec. 11, T. 43 N., R. 18 W. The fossil locality is 6.2 km southeast of the type locality of the Burro Canyon Formation (in Burro Canyon, sec. 29, T. 44 N., R. 18 W., San Miguel County, Colo.). Neither of the carbonaceous units have been recognized at the type locality. The upper carbonaceous unit is the same unit that has pro-

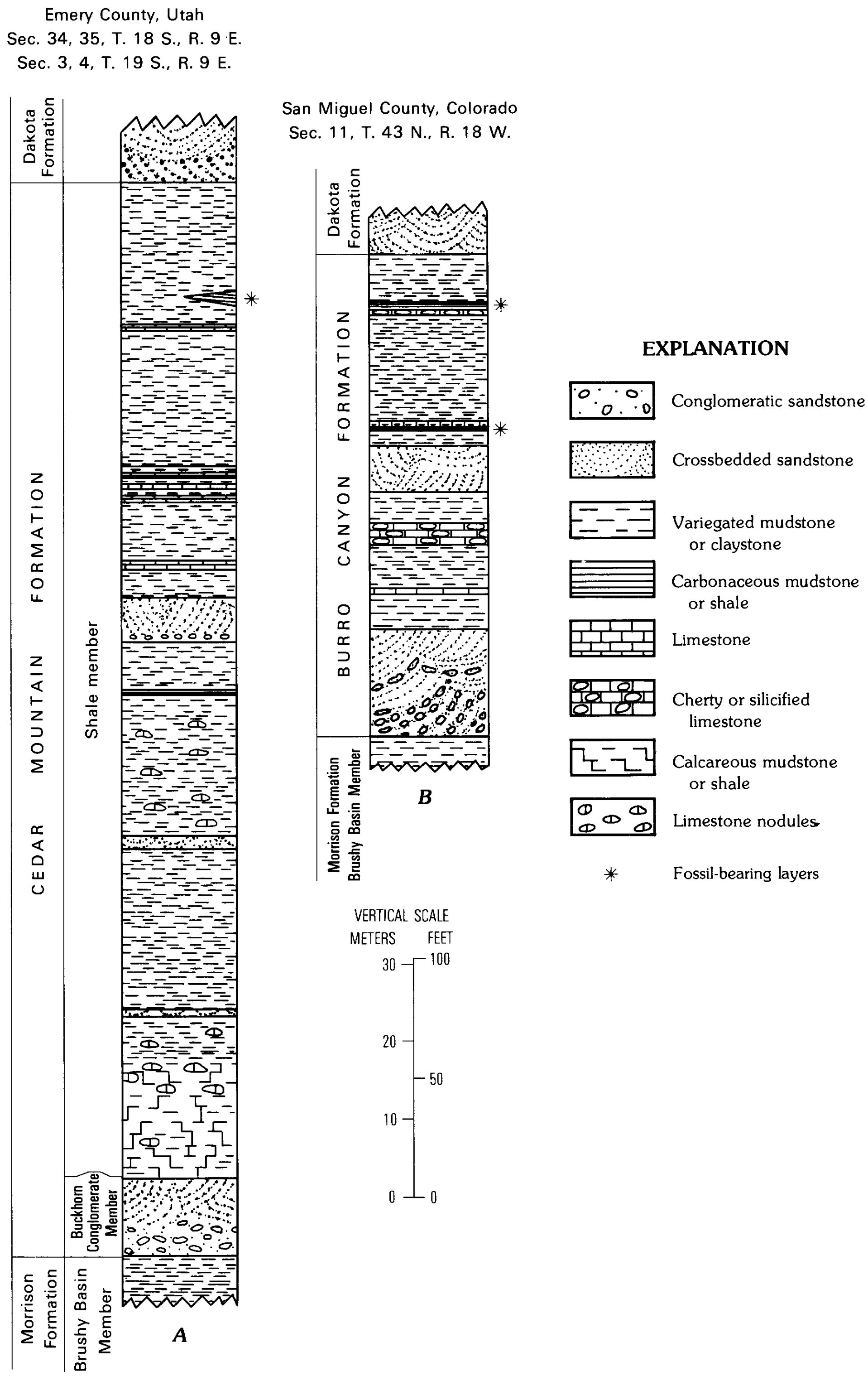



FIGURE 1.—Graphic sections showing stratigraphic positions of palynomorph collections. *A*, Section of Cedar Mountain Formation near type locality of formation; fossil-bearing carbonaceous lens sketched on basis of position beneath the Dakota Sandstone at fossil locality. *B*, composite section of Burro Canyon Formation measured at fossil localities.

duced a small invertebrate fauna and megaflora reported by Simmons (1957, p. 2525–2526).

## DISTRIBUTION, STRATIGRAPHIC RELATIONS, AND INTERPRETATION

The Burro Canyon formation is recognized over a broad area in southeastern Utah and western Colorado (fig. 2), and recently the name has been extended to similar rocks occupying a similar stratigraphic position in the Chama basin of north-central New Mexico (Saucier, 1974).

The southern limit of the Burro Canyon is an erosional limit where the Burro Canyon is cut out by the regional unconformity at the base of the overlying Dakota Sandstone. This limit is along a northwest-trending line that passes near the Four Corners. South of this limit, the pre-Dakota unconformity progressively bevels the Morrison Formation and older formations southward.

To the east, beds equivalent to the Burro Canyon are believed to be present in central and eastern Colorado (Lytle Formation of Dakota Group along the Front Range foothills and Lytle Sandstone Member of Purgatoire Formation in southeast Colorado). The Burro Canyon itself reaches a poorly known pinchout along an irregular north-south line extending from northwestern Colorado to northwestern New Mexico (fig. 2). The nature of this pinchout is uncertain. In part it is probably the result of pre-Dakota erosion, but in part it also may be due to depositional thinning of the formation. In the poor exposures along the few outcrop belts that cross the pinchout, the sandstone beds in the Burro Canyon appear to thin as the pinchout is approached. However, pre-Dakota erosion seems the most important factor in the pinchout of the formation.

The Cedar Mountain Formation is recognized over much of south-central and northeastern Utah and northwestern Colorado. The southern limit is south of the Henry Mountains and is an erosional limit along which the Cedar Mountain is cut out by the erosional unconformity at the base of the Dakota. The western limit is poorly known but it extends beneath the high plateaus of central Utah. To the north, the formation is identified to the Wyoming State line in both northeastern Utah and northwestern Colorado. Equivalent beds in Wyoming are included in the Cloverly Formation.

The arbitrary lateral limit between the Burro Canyon Formation and the Cedar Mountain Formation is placed along the Colorado River in Utah (Stokes, 1952, p. 1774), although for a distance of about 40 km west of the river the characteristics of the two formations intermingle.

To the north in Colorado, the Burro Canyon Formation passes laterally into the Cedar Mountain Formation. In this area north of the Colorado River, the line of demarcation between the Burro Canyon and Cedar Mountain is placed where Burro Canyon characteristics give way to Cedar Mountain characteristics in the subsurface as interpreted from drillhole logs.

Based on thickness, percentage of sandstone, pebble size, and limited current-direction studies, the Burro Canyon and Cedar Mountain are interpreted as sediments from two alluvial systems deposited across a broad even surface on top of the Morrison Formation; in many respects they appear to represent a continuation of Morrison deposition. The major source for the Burro Canyon was southwest of the Four Corners, perhaps in southern Arizona. Burro Canyon deposits were spread northward and eastward from a major depositional axis along the southern part of the Utah-Colorado State line. The source for the Cedar Mountain Formation was somewhere west of the high plateaus in central Utah, and Cedar Mountain deposits were spread eastward.

## METHODS OF SAMPLE TREATMENT

Samples were first cleaned, then broken into fragments about 1–5 mm (millimeters) in diameter. 10–20 g (grams) of broken rock were placed in plastic beakers and tested for the presence of carbonates. If carbonates were present, the samples were then treated with 10-percent HCl to remove carbonates; otherwise they were treated directly with hydrofluoric acid to disaggregate and partly dissolve the inorganic matrix. After thorough washing, the centrifuged residue was treated with the oxidizing Schulze[1] solution ($HNO_3 + NaCl)O_3$). After washing, the acid humates were solubilized and removed by a short treatment with 10-percent NaOH solution. Pollen and spores (and insoluble organic matter) were concentrated from the residue by flotation in zinc bromide solution (specific gravity about 2.0) and then "panned" by means of the technique suggested by Funkhouser and Evitt (1959). The palynomorphs were then stained with Bismark Brown, if necessary, and then mixed with Vinylite AYAF in 90-percent alcohol (polyvinyl acetate plastic, refractive index 1.466).

Several drops of the palynomorph-plastic mixture were placed on a 22×40 mm cover glass and another cover glass was placed on the mixture, thus making a "sandwich." After the plastic had spread evenly to the margins, the cover glasses were separated by sliding them in opposite directions lengthwise in much the

[1]Trade names used in this paper are for descriptive purposes only and do not constitute endorsement by the U.S. Geological Survey.

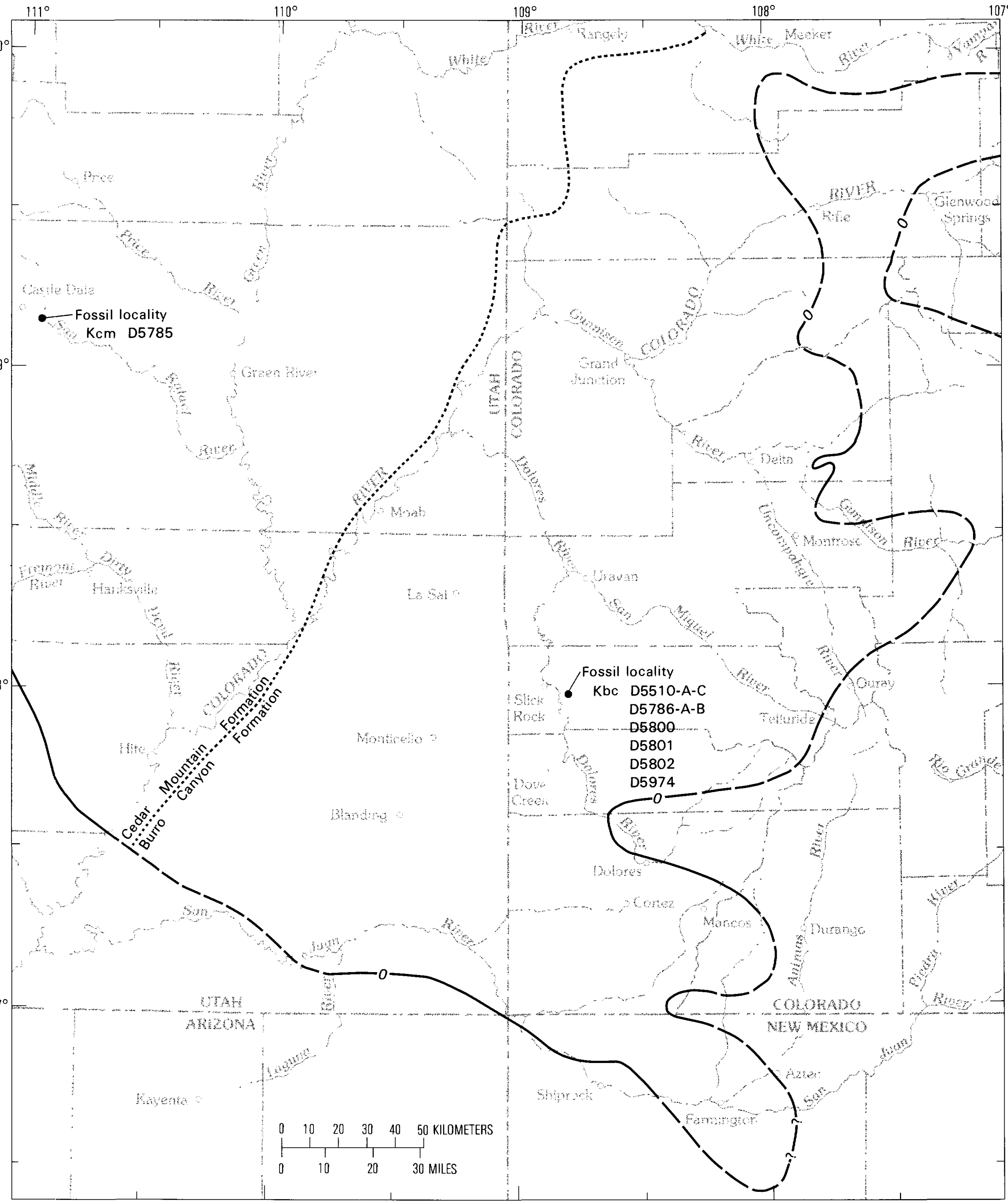



FIGURE 2.—Map of Colorado Plateau area showing fossil sample localities, sample numbers, and distribution of Cedar Mountain (Kcm) and Burro Canyon (Kbc) Formations. Zero line marks pinchout of Burro Canyon and Cedar Mountain Formations (dashed where uncertain). Dotted line is arbitrary line separating areas in which Burro Canyon and Cedar Mountain are recognized.

same manner as a blood smear is made. After the film on the cover glasses had dried for a few minutes on a warming plate, the cover glasses were inverted and mounted on slides using Histoclad resin. This method provides a thin, evenly dispersed film of pollen and spores in a mountant of favorable refractive index. It serves to anchor the fossils close to the cover glass so that they can be examined conveniently even under high-power oil-immersion lenses.

Slides are identified by locality number (D5510–A), and slide number D5510–A (1) or D5510–A (2); and on occasion processing sequence is also included as preparation 1 (prep. 1, prep. 2) and fraction—heavy fractions, fine fraction (Hvs; fines.): for example, D5785–A, prep. 4, Hvs., slide 5.

Minor modifications of oxidation time, cleaning procedures, and staining were tried with some success in efforts to improve the quality of some preparations.

# LOCATION OF PRODUCTIVE SAMPLES

## CEDAR MOUNTAIN FORMATION

Two Cedar Mountain samples were obtained from the locality known as the Stokes-Katich locality (Simmons, 1957, p. 2527). Samples were taken from a 1.5-m-thick, dark-gray calcareous shale outcrop in a cliff. The outcrop was about 13.9 m below the Dakota contact. The lower sample, consisting of gray calcareous siltstone interspersed with small calcite crystals, was barren of palynomorphs. The upper sample, consisting of dark-gray laminated shale and black claystone, was productive and was assigned a USGS paleobotany locality number as indicated below:

| USGS paleobotany loc. No. | Field No. | Locality |
|---|---|---|
| D5785 | 3RT–77–7 | SE¼SW¼ sec. 17, T. 19 S., R. 9 E., ¼ mi west of the junction of Rock Canyon Creek and Cottonwood Creek, Emery County, Utah. (Stokes-Katich locality in Simmons, 1957, p. 2527). |

## BURRO CANYON FORMATION

### UPPER HORIZON

Productive samples were obtained from two horizons. The upper horizon consisted of a 1.5-m-thick layer of black fissile shale located 7.3 m below the base of the Dakota Sandstone and immediately above a prominent limestone ledge. This is the same general locality from which fossils were collected by Stokes (1952) and the identical locality visited by G. C. Simmons and D. R. Shawe, and later revisited by L. C. Craig and others (Simmons, 1957, p. 2525). Several collections for palynological examination were taken from this locality during the summer of 1976. The yield of palynomorphs from these samples was so poor that resampling was conducted at the same site and along the lateral extent of the outcrop in the summer of 1977 and again in 1978. Sample number and localities for the upper horizon of the Burro Canyon Formation are listed below:

| USGS paleobotany loc. No. | Field No. | Locality |
|---|---|---|
| D5510–A | RT–76–6 | ¼NW¼NE¼ sec. 11, T. 43 N., R. 18 W., in northwest wall of an intermittent stream bed about 330 m south of its junction with Disappointment Creek, Hamm Canyon quadrangle, San Miguel County, Colo. Approximately 1.5-m-thick ledge of black fissile shale, 7.3 m below Burro Canyon-Dakota contact. Sample 25 cm above limestone ledge at base of shale. |
| D5510–B | RT–76–7 | Same locality as D5510–A, 31 cm above limestone ledge. |
| D5510–C | RT–76–8 | Same locality as D5510–A, 61 cm above limestone ledge. |
| D5786–A | RT–77–15 | Same locality as D5510–A, top part of limestone ledge. |
| D5786–B | RT–77–16 | 90 m S. 5° E., from locality of D5510–A, along strike of black fissile shale. 1-cm-thick basal siltstone layer immediately above limestone ledge. |
| D5800 | RT–77–17 | Same locality as D5786–B. Black, wet mudstone, 60 cm above limestone ledge. |
| D5801 | RT–77–18 | Same locality as D5786–B. Black fissile shale with limestone concretions 18 cm above limestone ledge. |
| D5802 | RT–77–19 | S. 60° W., 200 m from sample D5801; sample from northwest side of drainage. Composite sample from 1.5-m-thick black fissile shale. |
| D5974 | RT–78–18 | NW corner sec. 13, T. 43 N., R. 18 W., along unimproved road, Hamm Canyon quadrangle, San Miguel County, Colo. About 1.5-m-thick black fissile shale. Same horizon as previous Burro Canyon samples, but only 3 m below the Dakota contact. |

The upper horizon of black fissile shale has been traced several kilometers to the northwest and to the southeast of the original locality, but is apparently absent from the type locality of the Burro Canyon Formation in Burro Canyon near the village of Slick Rock, Colo., sec. 29, T. 44 N., R. 18 W., San Miguel County, Colo.

### LOWER HORIZON

In 1976 during the course of recollecting samples from the localities just described, a black limy shale horizon was found about 10.4 m below the base of the 1.5-m-thick black fissile upper-shale horizon. This sample yielded a much better assemblage of palynomorphs than was obtained from the upper fissile-shale horizon. The sample consisted of two lithotypes—a fine-grained, hard, calcareous black shale, and a black, soft, friable shale containing small calcite crystals. Palynomorph yield from the two lithotypes was distinctly different, suggesting that biofacies near the site of deposition had changed. The site was recollected in 1978. Six samples were collected from an 87-cm interval (fig. 8). Four of these samples were productive and were given USGS paleobotany locality numbers as indicated below:

| USGS paleobotany loc. No. | Field No. | Locality |
|---|---|---|
| D5803 | RT–77–20 | SW¼NE¼ sec. 11, T. 43 N., R. 18 W., at approximate location of bench mark 5641, Hamm Canyon quadrangle, 1960, 10.4 m below base of upper fissile-shale horizon. Sample included two lithotypes; soft, black friable shale with small calcite crystals, and hard, dark-gray calcareous shale. |
| D5972–A,B, C,D | RT–77–20 | Same locality as D5803. See figure 8. |
| D5973 | RT–78–16 | Same locality as D5803 but 10.2 m north along strike of dark-gray and black outcrop. Sample from bentonite zone, friable black shale that grades upward into dark-gray to black limestone. Composite sample from 30-cm interval. |

The lower horizon was traced about 150 m along the wash, but apparently is not present or is covered elsewhere.

## PALYNOLOGICAL ANALYSIS—CEDAR MOUNTAIN FORMATION

Reports of fossils from the Cedar Mountain Formation are exceedingly sparse. The pertinent information concerning those few fossils found is presented by Simmons (1957) who listed fossils from two localities. The first locality, the socalled Stokes-Katich locality, is the same locality mentioned previously that yielded the palynomorphs in the present study. Fossils found include *Eupera onestae* McLearn, a fresh-water pelecypod of Aptian Age, *Tempskya minor* Reed and Brown, a tree fern trunk, known from the Aspen Shale (Albian Age) Wyoming and Idaho, ostracods, and ganoid fish scales. "The second locality is in sec. 22, T. 22 S., R. 20 E., on the southwest flank of the Salt Valley anticline, Grand County, Utah" (Simmons, 1957, p. 2527). This locality yielded ostracods, gastropods, microfossil material, and the charophyte *Clavator harrisi* Peck.

The microfossil material was examined by R. E. Peck who stated: "All of these are common fossils in the Gannett Group, the Cloverly of northwestern Wyoming, and the limestones in the upper Kootenai of Montana. *Clavator harrisi* Peck is common in the Trinity of the Gulf Coast. None of these species occurs in the Morrison of the Front Range of Colorado, in eastern Wyoming or in the Black Hills. Their occurrence is an excellent indication of the Lower Cretaceous age of the formation" (*in* Simmons, 1957, p. 2527). The purported age of the Gannett Group is Early Cretaceous, of the Cloverly and Kootenai Formations is Aptian, and of the Trinity Group of the Gulf Coast, is Aptian to early Albian. "In view of the identifications, an Early Cretaceous age seems assured for the shale member of the Cedar Mountain Formation" (Simmons, 1957, p. 2527).

Angiosperm wood was collected from the Cedar Mountain Formation near Castle Dale and Ferron, Utah by Thayn (1973). Genera found were *Icacinoxylon*, previously known only from the Tertiary of Europe, and *Paraphyllanthoxylon*, known from the Cretaceous of Arizona, Idaho, and Alabama. However, these fossils shed no additional light upon the age of the Cedar Mountain Formation.

The samples collected for our study were examined palynologically in an attempt to obtain a more definite age determination and to verify the reported correlations of the Cedar Mountain and Burro Canyon Formations (Simmons, 1957; Craig and others, 1955).

Palynomorphs were poorly preserved and somewhat sparse, requiring the intensive examination of many slides in order to obtain a significant assemblage. The palynomorph assemblage consisted of tricolpate angiosperm pollen, bisaccate conifer pollen, monosulcate pollen, *Corollina* and minor representations of *Liliacidites*, trilete spores and taxodiaceous pollen (fig. 3). The high percentage of unidentified palynomorphs (averaging 32 percent of the assemblage) attests to the generally poor condition of the palynomorphs present. Figure 3 includes counts of palynomorph types in four separate preparations. Modification of preparation procedures were tried in attempts to obtain better recovery from this sample. That some of the preparations were better than others is evident upon examination of the graph. For example, preparation C (D5758-B, prep. 2) yielded

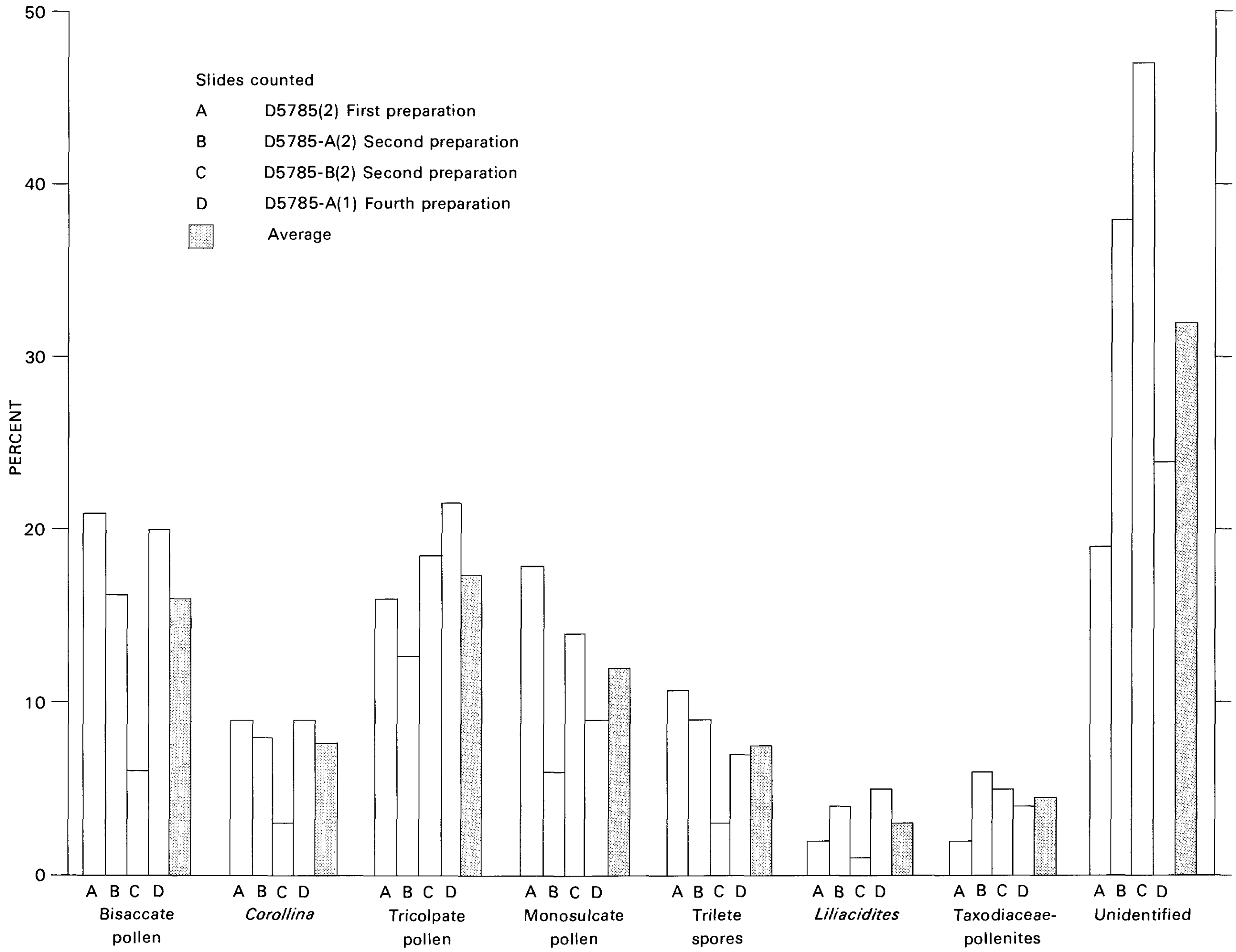



FIGURE 3.—Percentage distribution of major plant microfossil groups from several preparations of the productive Cedar Mountain sample.

only 6 percent bisaccate conifer pollen, and the unidentified palynomorphs accounted for 47 percent of the assemblage. In contrast, preparation A (D5758, prep. 1) yielded 21 percent bisaccate conifer pollen and only 19 percent unidentified palynomorphs. Except for discrepancies accounted for by the varied preparation procedures, the recovery of the several palynomorph groups shows a remarkable consistency.

The following genera and species have been identified from the preparations, and the taxa are shown on plates 1–4.

*Laevigatosporites* cf. L. *belfordii* Burger 1976
*Laevigatosporites gracilis* Wilson and Webster 1946
*Cyathidites australis* Couper 1953
*Todisporites* sp.
*Todisporites minor* Couper 1958
*Gleicheniidites senonicus* Ross 1949
*Lygodiumsporites* sp.
*Deltoidospora hallii* Miner 1935
*Cyathidites minor* Couper 1953
*Dictyotriletes granulatus* Pocock 1962
*Foraminisporis* sp.
*Foraminisporis* cf. *F. wonthaggiensis* (Cookson and Dettman) Dettmann 1963
*Concavissimisporites variverrucatus* (Couper) Singh 1964
*Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner 1963
*Leptolepidites* sp.
*Baculatisporites comaumensis* (Cookson) Potonié 1956
*Pilosisporites trichopapillosus* (Thiergart) Delcourt & Sprumont 1955
*Echinatisporis varispinosus* (Pocock) Srivastava 1975
*Cicatricosisporites hughesii* Dettmann 1963
*Cicatricosisporites* sp.
*Cicatricosisporites* cf. *C. minutaestriatus* (Bolkhovitina) Pocock 1964

*Cicatricosisporites venustus* Deák 1963
*Distaltriangulisporites* cf. *D. irregularis* Singh 1971
*Costatoperforosporites* sp.
*Psilatriletes circumundulatus* Brenner 1963
*Densoisporites microrugulatus* Brenner 1963
*Densoisporites velatus* Weyland and Krieger 1953
cf. *Schizosporis* sp.
*Alisporites grandis* (Cookson) Dettmann 1963
*Pityosporites granulatus* Phillips and Felix 1971
*Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970b
*Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
*Cedripites* cf. *C. cretaceus* Pocock 1962
*Cedripites canadensis* Pocock 1962
*Podocarpidites multesimus* (Bolkhovitina) Pocock 1962
*Podocarpidites* cf. *P. minisculus* Singh 1964
*Podocarpidites* sp.
*Vitreisporites pallidus* (Reissinger) Nilsson 1958
*Cycadopites carpentieri* (Delcourt and Sprumont) Singh 1964
*Monocolpopollenites* sp.
*Ginkgocycadophytus* cf. *G. nitidus* (Balme) de Jersey 1962
*Equisetosporites multicostatus* (Brenner) Norris 1967
*Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949
*Eucommiidites* sp.
*Corollina torosa* (Reissinger) Cornet and Traverse 1975
*Exesipollenites tumulus* Balme 1957
*Asteropollis asteroides* Hedlund & Norris 1968
*Clavatipollenites hughesii* (Couper) Kemp 1968
*Liliacidites* sp.
*Liliacidites* cf. *L. peroreticulatus* (Brenner) Singh 1971
*Tricolpites crassimurus* (Groot and Penny) Singh 1971
*Retitricolpites* cf. *R. virgeus* (Groot, Penny and Groot) Brenner 1963
*Retitricolpites vulgaris* Pierce 1961
*Retitricolpites vermimurus* Brenner 1963
*Striatopollis paraneus* (Norris) Singh 1971
*Rousea georgensis* (Brenner) Dettman 1973
*Cupuliferoidaepollenites parvulus* (Groot and Penny) Dettmann 1973
*Cupuliferoidaepollenites minutus* (Brenner) Singh 1971
*Tricolpites* cf. *T. wilsonii* Kimyai 1966
*Tricolpites* cf. *T.* sp. 1 of Kemp (1968)
*Tricolpites micromunus* (Groot and Penny) Singh 1971
*Tetracolpites* cf. *T. pulcher* Srivastava 1969
*Tetracolpites* sp.

## LANDMARK EVOLUTIONARY EVENTS IN THE DEVELOPMENT OF ANGIOSPERM POLLEN

The earliest records of angiosperm pollen include some of the same taxa that were recovered from the Cedar Mountain Formation. The first occurrences of angiosperm pollen in the stratigraphic record and the subsequent diversification of angiosperm pollen is pertinent to the age determinations and conclusions derived from Cedar Mountain samples.

The stratigraphic record has provided the basis for several outlines of the developmental history of angiosperm pollen, particularly in North America (Singh, 1971, 1975; Doyle, 1969; Jarzen and Norris 1975; Norris, Jarzen, and Awai-Thorne, 1975; Muller, 1970; and others). These outlines present data concerning the earliest record of angiosperm pollen, followed successively by the first appearance of tricolpate pollen, tricolporate pollen, triporate pollen; and in the Cenomanian and later stages, the times of origin of evolutionarily more advanced pollen types.

There are no substantiated pre-Cretaceous records of angiosperm pollen. The most primitive putative angiosperm pollen type is a monosulcate grain with pilate or retipilate sculpture, represented by the genus *Clavatipollenites* Couper. Couper (1958), in describing the type species *C. hughesii* from the Barremian of England, pointed out that although the monosulcate aperture condition is prevalent in gymnosperms, pilate or retipilate sculpture is not known outside the angiosperms. Pollen grains of the *Clavatipollenites* type are now considered by the vast majority of palynologists to be of probable angiosperm origin. *Clavatipollenites* pollen has been widely reported in rocks of Aptian-Albian Age from diverse parts of the world: Hughes (1958) and Kemp (1968) from England, Couper (1964) from Central America and Australia, Kemp (1968) and Norris (1967) from western Canada, and Brenner (1963) from eastern United States. Chlonova (1977) reported the first find of *Clavatipollenites* in ?Albian-Cenomanian rocks of Western Siberia. She discussed the pre-Barremian (Jurassic) records of identifications of *Clavatipollenites* (from central Europe and Asia) and rejected them as not being completely reliable. Birkelund, and others (1978) and Vigran and Thusu (1975) reported *Clavatipollenites* from Jurassic and pre-Jurassic rocks of Norway. Perhaps significantly, Birkelund and others (1978) found *Clavatipollenites* in their assemblage 1 (Middle Jurassic) but not in younger assemblages—assemblage 2 (Kimmeridgian), assemblage 3 (Kimmeridgian-Volgian), and assemblage 4 (early Neocomian).

In North America, the oldest record of *Clavatipollenites* is from the upper part of the Barremian (Doyle, 1969; Doyle and Robbins, 1977). In western Canada, the entrance level of *Clavatipollenites* coincides in Alberta with the entrance level of reticulate tricolpate forms (middle Albian). *Clavatipollenites* was not found in Canada in the Loon River Formation, lower mid-Albian (Singh, 1975), nor in the Mannville Group (Singh, 1964; Norris, 1967) of Aptian to early middle Albian age and no older than late Barremian (Singh, 1964). Thus, in western North America there are no records of *Clavatipollenites* earlier than mid-Albian time. The presence of specimens of *Clavatipollenites* in Cedar Mountain rocks therefore suggests an Albian or younger age.

Tricolpate pollen first appears, apparently worldwide, in the Albian. "The appearance of tricolpate pollen seems to have been a major world-wide event, and in all areas which have been carefully studied there is a zone with small reticulate tricolpates but without triporates or typical tricolporates (cf. Krutzsch, 1963; Muller, 1968). This appearance generally may be dated as early or middle Albian, but refinement is needed in most areas." (Doyle, 1969, p. 11). Singh (1971, p. 25) has summarized these data as follows: "The entrance of tricolpate dicotyledonous pollen in Albian strata of North America has been well documented by Brenner (1963), Davis (1963), Pannella (1966), Norris (1967), and Hedlund and Norris (1968). In other parts of the world, the first definite dicotyledonous pollen has been reported from Albian strata of central Russia (Bolkhovitina, 1953), New Zealand (Couper, 1960), Portugal (Groot and Groot, 1962), Central America and Africa (Couper, 1964), Peru (Brenner, 1968), Australia (Dettmann and Playford, 1968) and England (Kemp, 1968). Thus the entrance of tricolpate dicolyledonous pollen in the Lower Cretaceous succession of the Peace River area supports the middle to late Albian age assigned to these beds on faunal evidence (Wickenden, 1951, Stelck, *et al.*, 1956)."

The angiosperm pollen succession in eastern Australia was discussed by Dettmann (1973). She reported that the earliest occurrence of tricolpate pollen was found in the middle Albian of the Great Artesian Basin, whereas tricolpate pollen first appears a little later, in the upper Albian, in the more southerly Otway Basin. The first occurrence of tricolpate angiosperm pollen in Australia appears to coincide in time with its first appearance in Western North American rocks.

Tricolporate pollen first appears in latest? Albian time in western Canada and western United States and in the early Cenomanian in eastern United States (Singh, 1975). Tricolporate pollen has a widespread distribution throughout the Cenomanian of the Western Interior. Singh (1975, p. 377) concluded "It is evident from the above discussion that the Albian-Cenomanian boundary in North America is marked by the appearance of smooth, triangular tricolporates (Table II, III) and angiosperm tetrads."

The tricolporate pollen mentioned by Singh (1975) is the species *Nyssapollenites albertensis* Singh. It appears just below the fish scale member in the Shaftesbury Formation of Alberta (uppermost Albian). The same species identified as *Tricolporopollenites aliquantulus* Hedlund was found in the Red Branch Member of the Woodbine Formation of Oklahoma (Cenomanian) (Hedlund, 1966). Pannella (1966) reported the same species (as *Tricolporites dakotensis*) from the upper part of the Dakota Sandstone and the Huntsman Shale of MacKenzie (1965) (upper Albian-Cenomanian) of the Denver basin, Colorado. The same species (as *Tricolporopollenites aliquantulus* Hedlund) was found in the Dakota Sandstone of Arizona (Cenomanian) by Agasie (1969). We have found pollen of *Nyssapollenites albertensis* Singh to be a common constituent of Cenomanian rocks of Colorado and Utah. In the Front Range near Denver, Colo., the entrance level of this species is in the middle part of the Kassler Sandstone Member of the South Platte Formation (Dakota Group) about 30.5 m below the base of the Benton Formation (Mowry Shale to the north). The Mowry Shale is characterized by abundant fish scales, and is found at approximately the same stratigraphic position as the "fish scale marker bed" ("The traditional Lower-Upper Cretaceous boundary***" (Norris and others, 1975) in the Shaftesbury Formation of Alberta Canada. Significantly, Singh (1971, p. 28) found the entrance level of *Nyssapollenites albertensis* at about 35.0 m below the "fish scale marker bed." With the exceptions of the latest Albian report by Singh (1971) and the late Albian (Dakota) report by Pannella (1966), all other records of tricolporate pollen from western North America are from Cenomanian and younger rocks. The consistent first occurrence of *Nyssapollenites albertensis* at or very near the Albian-Cenomanian boundary provides a reliable indicator in western North America of the palynological boundary between the Early and Late Cretaceous. This palynological marker species coincides with or is close to the Early-Late Cretaceous boundary based on other types of evidence.

## AGE OF THE UPPER PART OF THE CEDAR MOUNTAIN FORMATION

The absence of any tricolporate pollen eliminates the possibility of a Cenomanian Age. The presence of small tricolpate pollen indicates an age range from middle to late Albian. The presence of at least 11 identified species of tricolpate pollen suggests that a significant amount of time must have elapsed since the origin of tricolpates in the mid Albian, until the plants had evolved to produce the diverse tricolpate flora including such large forms as *Tetracolpites pulcher* Srivastava.

Thus, this assemblage is clearly of late or latest Albian age.

## PALYNOLOGICAL ANALYSIS—BURRO CANYON FORMATION

The Burro Canyon Formation also has yielded few fossils. Fossil evidence for the age of the Burro Canyon Formation was presented by Stokes (1952) and Simmons (1957). The fossils were obtained from the NE¼NW¼NE¼ sec. 11, T. 43 N., R. 18 W., San Miguel County, Colo. This locality is the identical locality that yielded palynomorphs from the upper Burro Canyon horizon mentioned previously. The following fossils of possible age significance were reported:

Plant—*Frenelopsis varians* Fontaine (Aptian-early Albian)
Molluscs—*Protelliptio douglassi* Stanton (Aptian)
"*Unio*" *farri* Stanton (Aptian)
*Nipponaia asinaria* Reeside (Early Cretaceous)

No other reports of fossils from the Burro Canyon Formation have come to our attention.

A second locality that yielded palynomorphs, about 10.4 m below the base of the upper Burro Canyon horizon, has been mentioned previously. No other types of fossils are known from this second locality.

As with the Cedar Mountain Formation, the Burro Canyon Formation samples were examined palynologically in an attempt to obtain a more refined age determination, to address the question raised by reported intertonguing of the basal part of the Burro Canyon and upper part of the Morrison Formations (Simmons, 1957, p. 2523), and to attempt to determine whether or not the Burro Canyon and Cedar Mountain Formations are correlative palynologically.

The overlying Dakota Sandstone in this area is palynologically of early Cenomanian age (it has yielded *Nyssapollenites albertensis* Singh). The Burro Canyon Formation lies between the Dakota and the Morrison. In some places, evidence exists of apparent continuous deposition from the Morrison into the basal part of the Burro Canyon. Samples obtained from the upper or Brushy Basin Member of the Morrison Formation in this general area have yielded a palynological suite of fossils indicative of a Late Jurassic age. Theoretically, the Burro Canyon Formation could represent an age ranging from Late Jurassic to Cenomanian—that is, the entire Early Cretaceous spanning a time interval of some 40 million years.

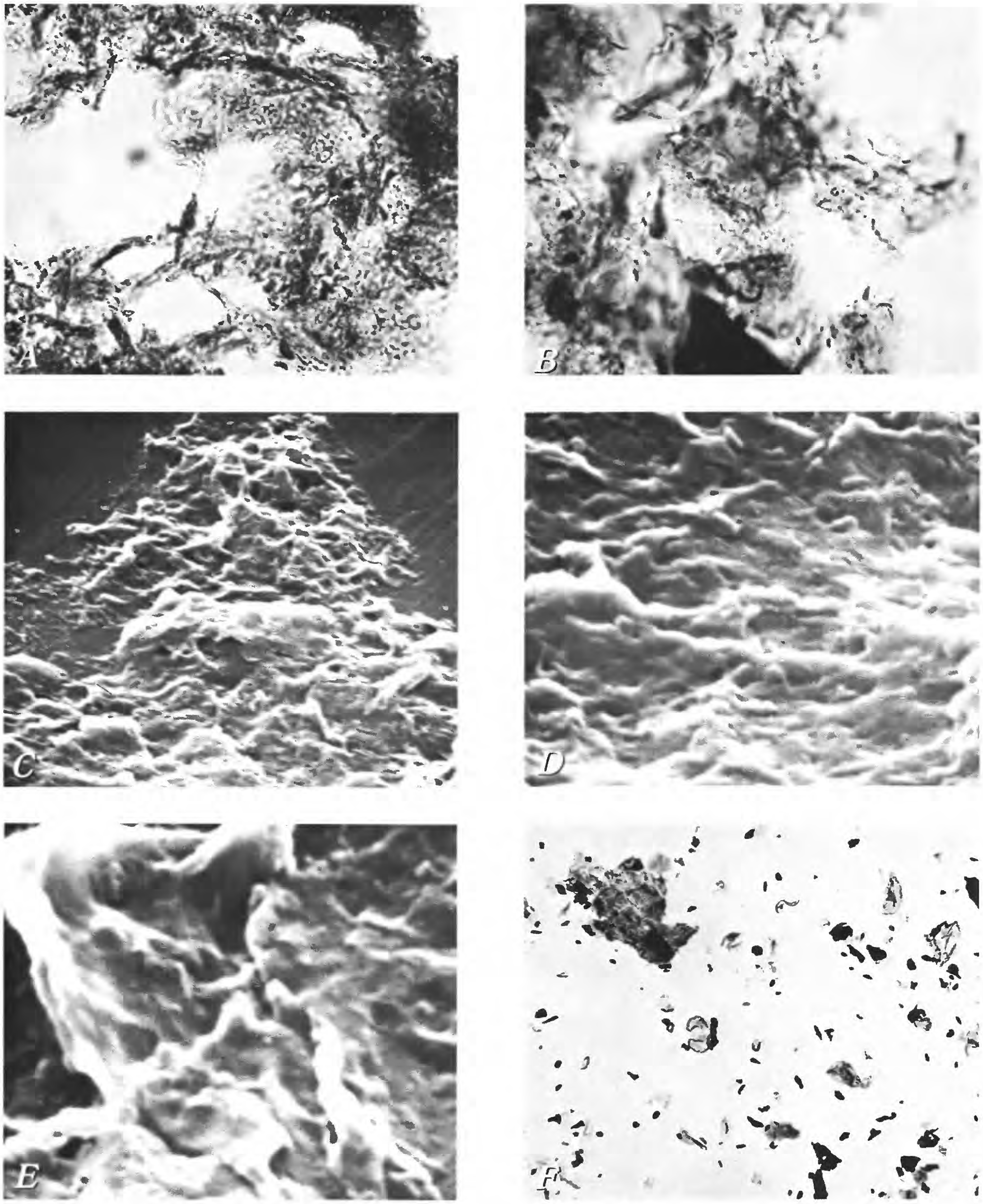
### UPPER HORIZON

As has been indicated, two palynologically productive horizons were found in the upper part of the Burro Canyon Formation. The upper horizon sample, from a 1.5-m-thick layer of black fissile shale about 7.3 m below the base of the Dakota Sandstone, yielded sparse assemblages of palynomorphs. The great majority of the organic matter consisted of what appeared to be short filaments (fig. 4*A*). On closer examination these filaments proved to be aggregates of amorphous material. At higher magnification, the apparent strands lose their continuity and appear as small strands with somewhat indefinite margins (fig. 4*B*). In the lower part of the photomicrograph (fig. 4*B*) a fragment of black woody tissue can be seen. Near the center a palynomorph is obscured by this organic material. At succeedingly higher magnifications (fig. 4*C*, *D*, and *E* scanning electron micrographs), the organic material exhibits its amorphous character, and the filamentous attribute effectively disappears. Contrast between upper-horizon preparations containing an abundance of amorphous organic material and more nearly normal preparations is shown on a photomicrograph of a preparation from the lower horizon (fig. 4*F*). Wood fragments, bits of epidermal and cuticular tissue, and easily recognizable palynomorphs are visible. This preparation is virtually devoid of organic material of the kind found in upper horizon samples. The great abundance of amorphous organic material present in upper horizon samples could not be removed from the samples by oxidation without destroying the accompanying palynomorphs. Thus, the few spores and pollen grains present were commonly obscured by this material. Samples from the upper horizon are unique in this respect in our experience. We have never found samples that reacted in the same manner. The closest observed similarity is to samples of oil shale from the Green River Formation, yet the organic material in the Green River oil shale appears visually to be distinctly different.

Two samples of black fissile shale from the upper horizon were submitted to L. G. Schultz, U. S. Geological Survey, Denver, Colo. for X-ray analysis. He reported that the nonorganic part of the black shale contained 2–10 percent calcite, 1 to 2 percent quartz, and a large percentage of mixed-layer illite-smectite, a swelling clay that could be an altered tuff.

Thin sections made from this upper horizon shale show the abundance and bedded nature of the unaltered organic material but give no hint of its original composition (fig. 5). These thin sections, plus macerated sample material from the upper horizon were sent to the late Dr. J. M. Schopf, USGS Coal Geology Laboratory at Columbus, Ohio. He remarked (written commun., Dec. 13, 1977) "The thin sections are excellent . . . I wish I could suggest how such a rock could reasonably be deposited. My next suggestion is that it must be an unusual local occurrence."

This abundant amorphous organic material possibly could be the residue from some, as yet unidentified,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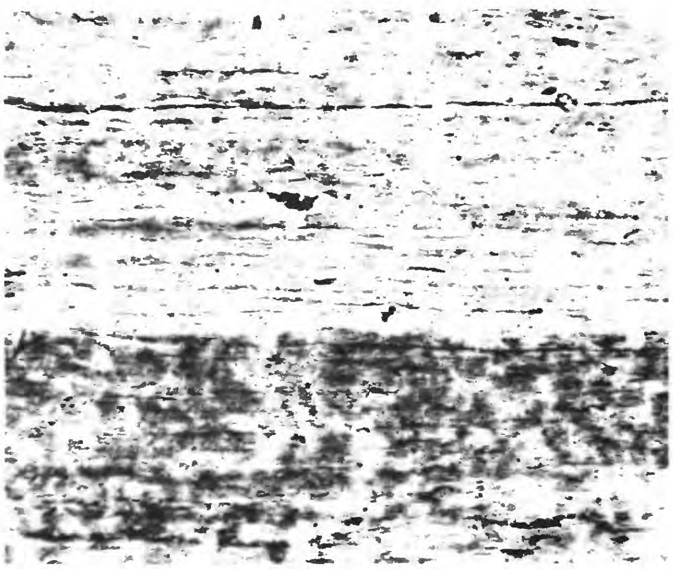

FIGURE 5.—Burro Canyon-upper horizon sample D5510–A. Thin section of whole rock showing bedded nature of organic material. × 100.

alga. *Botryococcus*, a common lacustrine alga, has been found in all upper horizon samples.

### PALYNOMORPH RECOVERY FROM UPPER HORIZON SAMPLES

The palynomorph recovery from upper horizon samples was sparse. The abundant organic matter and the comparatively poor state of preservation made identification extremely difficult. Gross palynomorph recovery from representative upper horizon samples is shown in figure 6. The average number of unidentified forms was 48 percent, attesting to the difficulty posed by the amorphous organic material.

The following identified taxa were obtained from an examination of more than 60 slides.

Burro Canyon *upper horizon*

- *Undulatisporites* cf. *U. fossulatus* Singh 1971
- *Cyathidites minor* Couper 1953
- *Todisporites minor* Couper 1958
- *Dictyotriletes pseudoreticulatus* (Couper) Pocock 1962
- *Cadargasporites reticulatus* de Jersey and Paten 1964
- *Staplinisporites caminus* (Balme) Pocock 1962
- *Matthesisporites tumulosus* Döring 1964
- aff. *Cicatricosisporites phaseolus* (Delcourt and Sprumont) Krutzsch 1959
- *Converrucosisporites* cf. *C. proxigranulatus* Brenner 1963
- *Cicatricosisporites* cf. *C. minor* (Bolkhovitina) Pocock 1964
- *Cicatricosisporites* cf. *C. cuneiformis* Pocock 1964
- *Cicatricosisporites augustus* Singh 1971
- *Cicatricosisporites* cf. *C. potomacensis* Brenner 1963
- *Cicatricosisporites* cf. *C. mediostriatus* (Bolkhovitina) Pocock 1964
- *Cicatricosisporites* sp.
- *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
- *Cicatricosisporites apiteretus* Phillips and Felix 1971
- *Cicatricosisporites* cf. *C. subrotundus* Brenner 1963
- *Cicatricosisporites* cf. *C. crassistriatus* Burger 1966
- *Distaltriangulisporis* sp.
- *Appendicisporites bilateralis* Singh 1971
- *Appendicisporites jansonii* Pocock 1962
- *Corollina torosa* (Reissinger) Cornet and Traverse 1975
- *Equisetosporites* spp.
- *Araucariacites* sp.
- *Callialasporites* sp.
- *Vitreisporites pallidus* (Reissinger) Nilsson 1958
- *Alisporites thomasii* (Couper) Pocock 1962
- *Alisporites grandis* (Cookson) Dettmann 1963
- *Cedripites* cf. *C. canadensis* Pocock 1962
- *Cedripites cretaceus* Pocock 1962
- *Podocarpidites ornatus* Pocock 1962

Burro Canyon taxa are shown on plates 5–9.

## LOWER HORIZON

This locality was found about 10.4 m below the upper fissile shale horizon. The recovery of palynomorphs was much better than from upper horizon samples even though preservation quality was not the best. The difference in appearance of the slides from the two horizons is shown on figure 4. In figure 4*F* fusainized wood fragments are prevalent in the photograph, and epidermal tissue and palynomorphs make up the lighter, more translucent material. The appearance of the organic material from the lower horizon is normal, in contrast to

FIGURE 4 (facing page).—Burro Canyon-upper horizon sample. *A*, After HF treatment and flotation in $ZnBr_2$ water mount. × 500. *B*, Standard treatment. Mounted in AYAF and histoclad. × 1000. Note wood fragment at center lower margin, and palynomorph at center, obscured by organic material. *C*, Electron micrograph × 5000. *D*, Electron micrograph × 16000. *E*, Electron micrograph × 20,000. *F*, Lower horizon sample showing more normal appearance of material on slide; ×100. Note epidermal tissue at upper left corner and several palynomorphs.

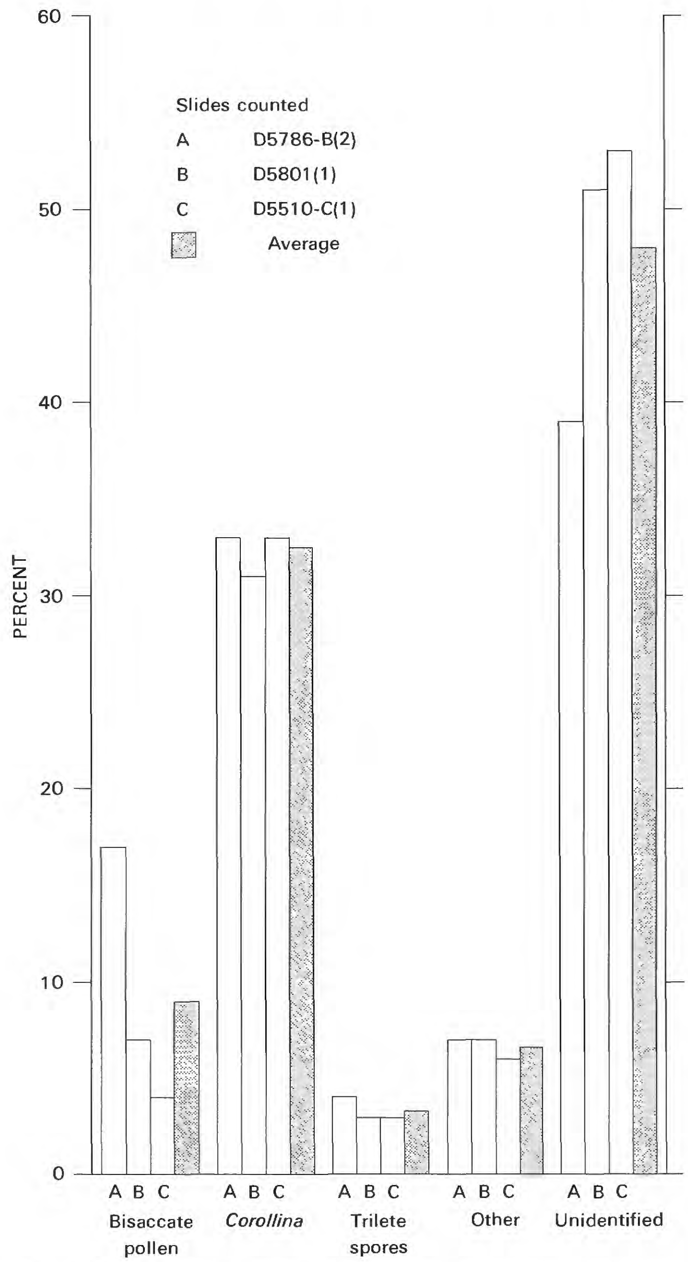


FIGURE 6.—Gross palynomorph recovery from some upper horizon Burro Canyon samples.

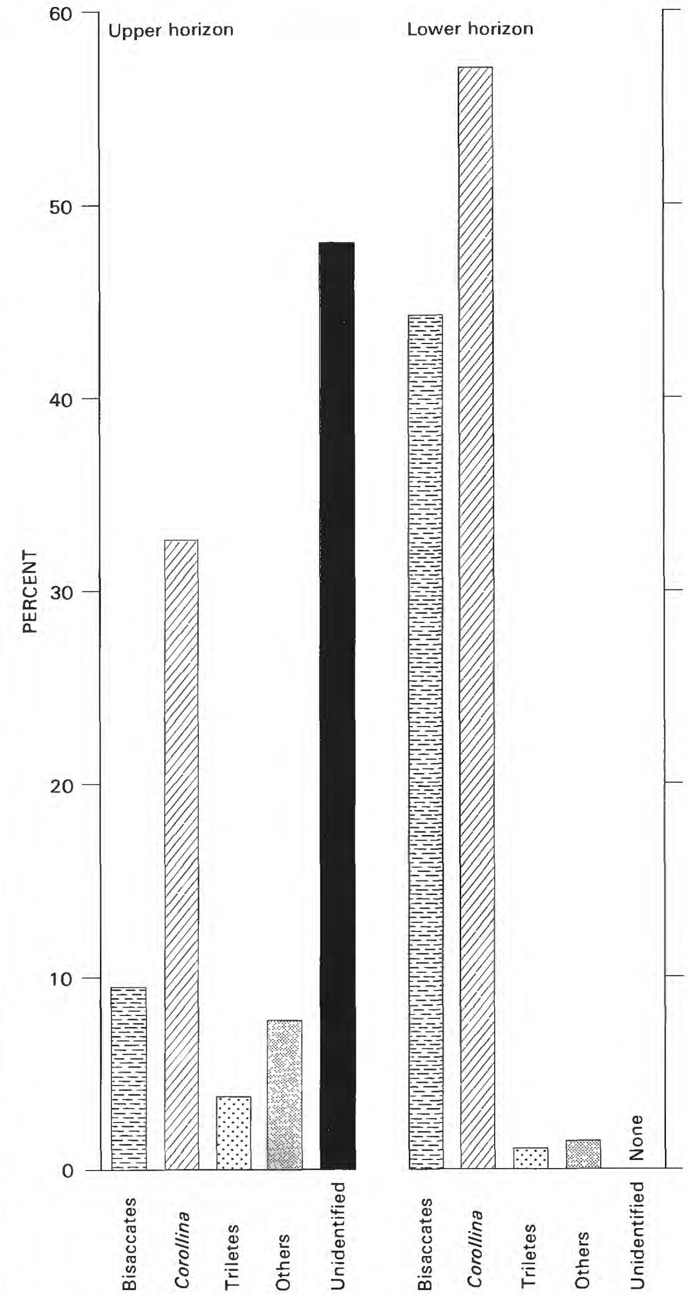


FIGURE 7.—Comparison of gross palynomorph recovery from Burro Canyon upper and lower horizons. Average recovery data for upper horizon taken from figure 5. Average recovery data from lower horizon taken from figure 8. Unidentified fossils may consist of *Corollina*, and possibly unidentified algae. *Botryococcus* is present in all samples but commonly is not abundant.

the appearance of the organic material from the upper horizon.

A comparison of the gross palynomorph recovery from the upper and lower horizons is shown in figure 7. The contrast is shown vividly by the absence of unidentified forms from the lower horizon. The lower horizon assemblage is dominated by bisaccate conifer pollen and *Corollina*. The residue of palynomorphs makes up less than 3 percent of the total assemblage.

The first samples collected from the lower horizon showed a marked difference in recovery from hard dark-gray shale and from black friable shale containing small calcite crystals. The hard dark-gray shale (interval C, fig. 8) was dominated by bisaccate conifer pollen and the black friable shale (interval D, fig. 8) by *Corollina* pollen. The lower horizon was therefore recollected the following year in an attempt to verify these data. The possibly productive interval consisted of 87 cm of alternating shale, calcareous shale, and limestone capped by 40 cm of blocky gray limestone. Six samples were taken from the 87-cm interval as shown on figure 8.

### PALYNOMORPH RECOVERY FROM LOWER HORIZON SAMPLES

The upper two samples were barren. The gross palynomorph recovery of the four lower samples is shown in figure 8. The sample D5972–D yielded 97 percent bisaccate conifer pollen and only 1 percent *Corollina*, whereas samples D5972–C, D5972–B and D5972–A yielded 20, 23, and 35 percent bisaccate conifer pollen, respectively, and the assemblages were dominated by abundant *Corollina* specimens. Bisaccate pollen and pollen of *Corollina* were produced by conifers. *Corollina* pollen was produced by the fossil tree genus *Cheirolepis*. The prominent change in abundance of these two pollen groups in a comparatively short stratigraphic interval indicates a prominent floral change and suggests a prominent biofacies difference between the two groups of samples.

The following taxa were identified from the lower horizon:

*Gleicheniidites senonicus* (Ross) Skarby 1964
*Cyathidites minor* Couper 1953
*Deltoidospora* cf. *D. psilostoma* Rouse 1959
*Tigrisporites reticulatus* Singh 1971
*Interulobites triangularis* (Brenner) Phillips and Felix 1971
*Staplinisporites caminus* (Balme) Pocock 1962
*Lycopodiumsporites* sp.
*Matthesisporites tumulosus* Döring 1964
*Leptolepidites verrucatus* Couper 1953
*Verrucosisporites* cf. *V. densus* (Bolkhovitina) Pocock 1970a
*Cicatricosisporites* sp.
*Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
*Distaltriangulisporis perplexus* (Singh) Singh 1971
*Corollina torosa* (Reissinger) Cornet and Traverse 1975
*Cycadopites* spp.
*Equisetosporites* spp.
*Araucariacites* sp.
*Exesipollenites tumulus* Balme 1957
*Cerebropollenites mesozoicus* (Couper) Nilsson 1958
*Callialasporites segmentatus* (Balme) Sukh-Dev 1961
*Vitreisporites pallidus* (Reissinger) Nilsson 1958
*Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
*Clavatipollenites hughesii* (Couper) Kemp 1968
*Paleoconiferus asaccatus* Bolkhovitina 1956
*Pityosporites* cf. *P. divulgatus* (Bolkhovitina) Pocock 1970b
*Alisporites grandis* (Cookson) Dettmann 1963
*Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970b
*Cedripites* cf. *C. canadensis* Pocock 1962
*Cedripites cretaceus* Pocock 1962
*Podocarpidites ornatus* Pocock 1962
*Podocarpidites* cf. *P. ellipticus* Cookson 1947
*Podocarpidites* cf. *P. multesimus* (Bolkhovitina) Pocock 1962
*Podocarpidites radiatus* Brenner 1963
Burro Canyon taxa are shown on plates 5–9

The chief distinction between the assemblages from the upper and lower horizons of the Burro Canyon is that many species and specimens of *Cicatricosisporites* were found in the upper horizon assemblages and very few *Cicatricosisporites* specimens were found in the lower horizon assemblages.

## AGE OF THE UPPER PART OF THE BURRO CANYON FORMATION

Both upper and lower horizon assemblages were from the upper part of the Burro Canyon Formation, so for the purpose of this discussion they will be considered as a unit even though the discrepancies in recovery may appear significant. These discrepancies may be due in part to variations in biofacies existing at the times of deposition, giving rise to the distinctly different organic content of the two groups of samples. It may also be due, in part, to the low frequency of recovery of individual taxa. With the exception of bisaccate conifer pollen and *Corollina*, many of the remaining taxa were found only as single specimens, or generally as only a few specimens of any single taxon.

Bisaccate conifer pollen is difficult to segregate into generic units. Futhermore, most genera and species are long-ranging and are of little value in age determinations. *Corollina* pollen is almost omnipresent in Upper Jurassic and Lower Cretaceous continental palynomorph-bearing rocks of North America. Consequently the remaining taxa, even though present in extremely low frequency in the samples, are the significant taxa for the estimation of the ages of the samples.

The palynomorphs recovered failed to reveal even a single specimen of tricolpate pollen. The apparent first record of tricolpate (tricolporate) pollen is from the Berriasian-Valanginian of the Netherlands (Burger, 1966). But well-documented tricolpates first appear in the Aptian-Albian worldwide (Doyle, 1969; Muller, 1970; Chlonova, 1977). In North America, tricolpates enter the stratigraphic record no earlier than mid-Albian time

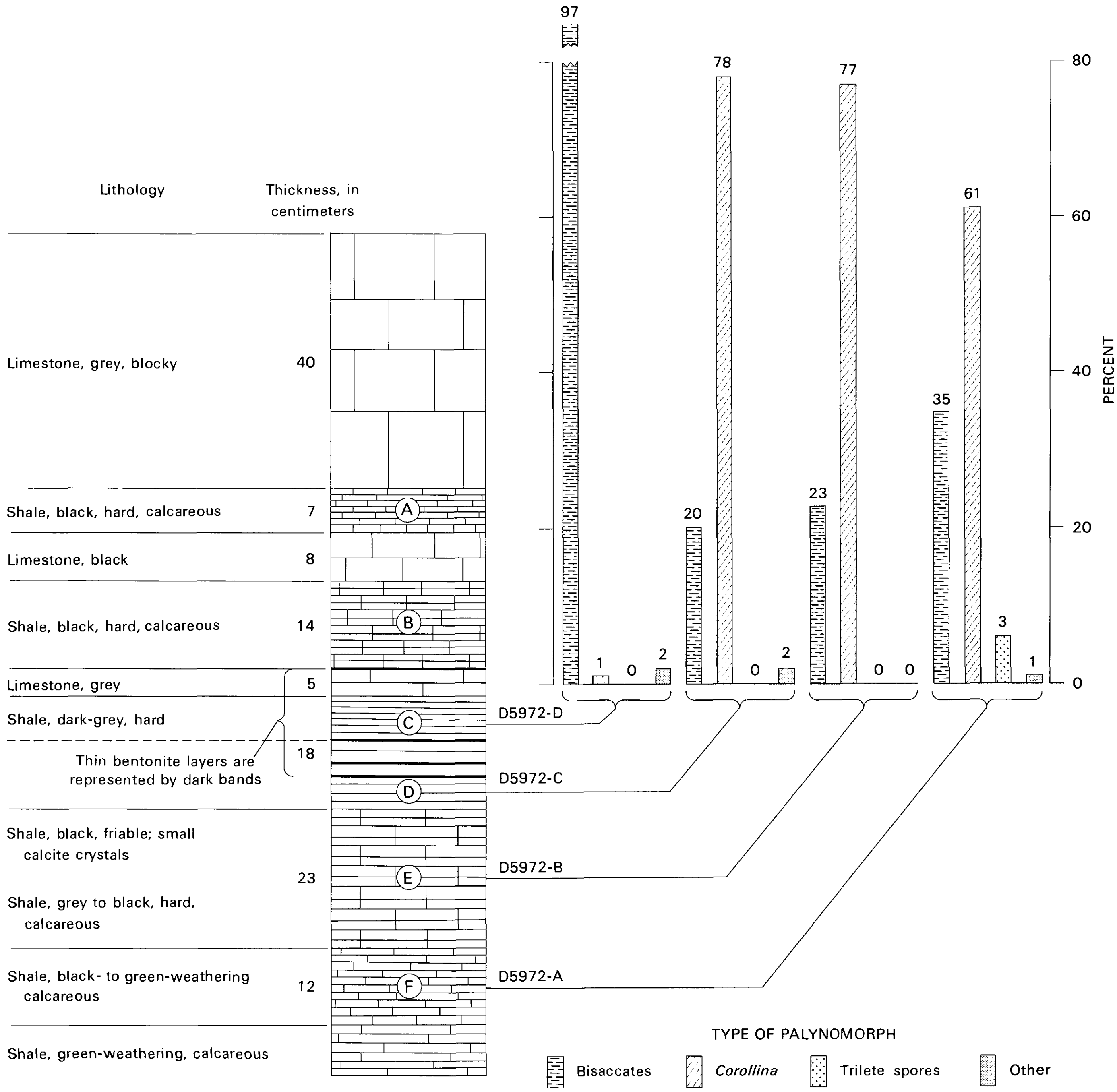


FIGURE 8.—Gross palynomorph recovery from selected intervals in lower horizon Burro Canyon. A–F, Intervals from which samples (D-numbers) were taken. Samples from intervals A and B were barren of palynomorphs. Numbers at top of bars indicate percentage of each type of palynomorph.

(Singh, 1975). Consequently, palynomorph assemblages lacking tricolpate pollen may be assumed to be no younger than mid-Albian.

Because of the purported interfingering of the Jurassic Brushy Basin Member of the Morrison with the lower part of the Burro Canyon Formation, comparisons of Burro Canyon assemblages with Jurassic and early Early Cretaceous assemblages were made. The Burro Canyon palynomorph assemblages are distinctly more advanced than are Late Jurassic assemblages from the Colorado Plateau, or from Western Canada (Pocock, 1962; 1970a,b). For example, two species of *Appendicisporites* were isolated from the Burro Canyon Formation. This taxon is not present in the Jurassic; it first appears worldwide in the Valanginian (Pocock, 1967; Vakhrameev and others, 1973). Further, many species of *Cicatricosisporites* are present in the Burro Canyon, and although a few species have been reported from the Upper Jurassic of Europe and Asia, none have been found in the Jurassic of western Canada (Pocock, 1970a), nor have we found any specimens of *Cicatricosisporites* in any of the assemblages from the Brushy Basin, Westwater Canyon, or Recapture Members of the Morrison Formation (Upper Jurassic) of the Colorado Plateau region. Consequently, it is safe to assume that the age of the Burro Canyon Formation is Neocomian to early Albian.

Assemblages from near the Jurassic-Cretaceous boundary in northwest Europe (Döring, 1965; Burger, 1966; Norris, 1969; Dörhöfer and Norris, 1977; Dörhöfer, 1977) were compared with those from the Burro Canyon Formation. Little similarity was evident. In fact, little similarity between assemblages of similar age from England and from continental northwest Europe was evident. "Of the 109 trilete spore types described by Döring (1965) from the German Jurassic-Cretaceous sediments, only about 10 species are known in the southern England succession" (Norris, 1973, p. 99). Furthermore, the assemblage from the German Bückeberg Formation (Dörhöfer, 1977) (Berriasian-Valanginian) correlative with the English upper Purbeck and lower Wealden (Dörhöfer and Norris, 1977) yielded no bisaccate conifer pollen. Most other Neocomian assemblages yielded significant proportions of bisaccate pollen. Consequently, the differing biofacies conditions in the two European localities and in the Burro Canyon Formation make comparisons more difficult.

The precise position of Lower Cretaceous samples cited in the literature is often not known. Reports refer in general terms to Lower Cretaceous, or to Neocomian rather than to the formal subdivisions. This usage is true of most reports from Australia and Russia. For example, Burger (1973) and Dettmann (1963) referred to the Lower Cretaceous or Neocomian, and Orlova-Turchina (1966) reported on the Hauterivian-Barremian Russian complexes in general terms only.

Another fact that hinders direct correlation is the yield of palynomorphs from the Burro Canyon Formation. The yield of taxa of potential usefulness was minimal. Aside from conifer pollen—mostly long-ranging species and *Corollina*, the remainder of the assemblage as a whole was sparse (see fig. 6). Generally, only a few specimens of any one taxon were found. Many of the genera and species commonly used to subdivide the Neocomian in other regions failed to appear in Burro Canyon samples. These genera include *Concavissimisporites*, *Trilobosporites*, *Impardecispora*, *Contignisporites*, *Januasporites*, and *Schizosporis*.

Comparison of the Burro Canyon assemblages with Jurassic and Early Cretaceous assemblages from western Canada failed to present evidence for direct correlation. This lack of evidence may be due to the fact that the Lower Cretaceous rocks of western Canada are commonly no older than Barremian (Singh, 1971). Only one report of upper Neocomian palynomorph assemblages from Canada is available. Hopkins (1971) reported an assemblage from the Isachsen Formation, bounded below by upper Valanginian rocks and above by Albian rocks. Hopkins (1971, p. 110) concluded that "The Isachsen Formation is therefore entirely Lower Cretaceous, ranging from Upper Valanginian, including probably Hauterivian and Barremian; possibly also Aptian***". Hopkins also observed "There appears to be no significant variation of the flora from the top to bottom of the Isachsen Formation suggesting that environmental conditions did not vary greatly during the time represented by Isachsen deposition, ***the flora is remarkably uniform over a comparatively long period of time (about 10 million years)." The palynomorph assemblage from the Isachsen Formation bears the closest resemblance to assemblages from the Burro Canyon Formation yet observed, even though most of the species mentioned did not appear in the Burro Canyon assemblages.

Adequate data are not yet available representing the age-ranges of taxa found in the Burro Canyon Formation owing to the comparatively few reliable reports on Lower Cretaceous rocks, particularly from North America. The currently known ranges of all species figured on plates 5–9 are recorded in table 2.

As shown on table 2, many of the identified species have long ranges, and offer no aid in narrowing down the age of the Burro Canyon Formation. Some of the other species, *Verrucosisporites densus* (Bolkhovitina) Pocock, *Matthesisporites tumulosus* Döring, *Callialasporites segmentatus* (Balme) Sukh-Dev, *Paleoconiferus asaccatus* Bolkhovitina, and *Cadargasporites reticulatus* de Jersey and Paten are limited, as understood at present, to the Jurassic. *Cicatricosisporites apiteretus* Phillips and Felix, is limited to the Cenomanian. The ranges of the Jurassic species in our samples possibly may be attributed to redeposition into Lower Cretaceous rocks, although no visual difference in the appearance of the fossils was observed. On the other hand, both the limited ranges of the Jurassic and Cenomanian species may be due to the limited amount of work that has been done on Lower Cretaceous rocks in North America. The true ranges may not yet be evident. For example, the genus *Cadargasporites* and the species *Cadargasporites reticulatus* de Jersey and Paten, have been reported previously, to our knowledge, only from the Early Jurassic of the Surat Basin, Australia (de Jersey and Paten, 1964). Yet the two

TABLE 2.—*Stratigraphic ranges of Burro Canyon palynomorph species*

| | JURASSIC | EARLY CRETACEOUS | | | | | | LATE CRETACEOUS |
|---|---|---|---|---|---|---|---|---|
| | | NEOCOMIAN | | | | | | |
| | | BERRIASIAN | VALANGINIAN | HAUTERIVIAN | BARREMIAN | APTIAN | ALBIAN | |
| *Gleicheniidites senonicus* (Ross) Skarby | - - | — | — | — | — | — | — | - - |
| *Undulatisporites* cf *U. fossulatus* Singh | | | | | | | — | |
| *Cyathidites minor* Couper | - - | — | — | — | — | — | — | - - |
| *Deltoidospora* cf *D. psilostoma* Rouse | - - | — | — | — | — | — | — | - - |
| *Todisporites minor* Couper | - - | — | — | — | — | — | — | - - |
| *Klukisporites pseudoreticulatus* (Couper) Pocock | - - | — | — | — | — | — | — | - - |
| *Tigrisporites reticulatus* Singh | | | | | | | — | — |
| *Cadargasporites reticulatus* de Jersey and Paten | - — | | | | | | | |
| *Interulobites triangularis* (Brenner) Phillips and Felix | | | | ? - - - | — | — | — | |
| *Staplinisporites caminus* (Balme) Pocock | - - | — | — | — | — | — | — | |
| *Matthesisporites tumulosus* Döring | - — | | | | | | | |
| *Leptolepidites verrucatus* Couper | - - | — | — | — | — | — | — | - - |
| aff. *Cicatricososporites phaseolus* (Delcourt and Sprumont) Krutzsch | | | | | ? - - | — | — | - - |
| *Converrucosisporites* cf *C. proxigranulatus* Brenner | | | | | - - | — | — | |
| *Verrucosisporites densus* (Bolkhovitina) Pocock | - — | | | | | | | |
| *Cicatricosisporites* cf *C. minor* (Bolkhovitina) Pocock | | | | | - - | - - | - — | - - |
| *Cicatricosisporites* cf *C. cuneiformis* Pocock | | | | | | | — | |
| *Cicatricosisporites augustus* Singh | | | | | | | — | |
| *Cicatricosisporites* cf *C. potomacensis* Brenner | | | | | - - | — | — | |
| *Cicatricosisporites* cf *C. mediostriatus* (Bolkhovitina) Pocock | | — | — | — | — | — | — | - - |
| *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann | | | | | | | — | - - |
| *Cicatricosisporites apiteretus* Phillips and Felix | | | | | | | | — |
| *Cicatricosisporites* cf *C. subrotundus* Brenner | | | | | | | — | |
| *Cicatricosisporites* cf *C. crassistriatus* Burger | | | — | — | — | ? | | |
| *Appendicisporites bilateralis* Singh | | | | | | | — | |
| *Distaltriangulisporis perplexus* (Singh) Singh | | | | | | | — | |
| *Appendicisporites jansonii* Pocock | | | | | — | — | — | |
| *Corollina torosus* (Reissinger) Cornet and Traverse | - - | — | — | — | — | — | — | - - |
| *Exesipollenites tumulus* Balme | - - | — | — | — | — | — | — | - - |
| *Cerebropollenites mesozoicus* (Couper) Nilsson | - - | — | — | — | — | — | — | - - |
| *Callialasporites segmentatus* (Balme) Sukh-Dev | — | | | | | | | |
| *Vitreisporites pallidus* (Reissinger) Nilsson | - - | — | — | — | — | — | — | - - |
| *Pristinuspollenites sulcatus* (Pierce) B. Tschudy | | | | | | | | — - - |
| *Clavatipollenites hughesii* (Couper) Kemp | - - | - - | - - | — | — | — | — | - - |
| *Paleoconiferus asaccatus* Bolkhovitina | — | | | | | | | |
| *Alisporites thomasii* (Couper) Pocock | - - | — | — | — | — | — | — | - - |
| *Pityosporites* cf *P. divulgatus* (Bolkhovitina) Pocock | - - | — | — | — | — | — | — | |
| *Alisporites grandis* (Cookson) Dettmann | - - | — | — | — | — | — | — | - - |
| *Pityosporites nigraeformis* (Bolkhovitina) Pocock | - - | — | — | — | — | — | | |
| *Cedripites* cf *C. canadensis* Pocock | | | | | — | — | — | |
| *Cedripites cretaceus* Pocock | | | | | — | — | — | |
| *Podocarpidites ornatus* Pocock | | | | | - - | — | - - | |
| *Podocarpidites* cf *P. ellipticus* Cookson | - - | — | — | — | — | — | — | |
| *Podocarpidites* cf *P. multesimus* (Bolkhovitina) Pocock | - - | — | — | — | — | — | — | - - |
| *Podocarpidites radiatus* Brenner | - - | — | — | — | — | — | — | |

specimens from the Burro Canyon Formation with their distinctive distal labyrinthine reticulum, and smooth proximal contact area, appear to be conspecific with the Australian species.

The data presented on table 2 suggest to us a late Neocomian to Aptian-Albian age. A few taxa from table 2 merit further discussion.

*Tigrisporites reticulatus* Singh.—This species was first reported by Singh (1971) from the middle Albian of Alberta, Canada. Its presently known range is from the mid-Albian to early Cenomanian. Although several specimens of this species were found, the species was not represented in all preparations. This species is not as yet known from anywhere in the world except from western North America. A closely allied species, *Tigrisporites scurrandus* Norris with an almost identical known range (mid- and late Albian) also appears to be confined to western North America. We have found both species in formations of Albian Age from Colorado and Idaho.

*Interulobites triangularis* (Brenner) Phillips and Felix.—This species was observed sporadically in Burro Canyon assemblages. It has been reported previously only by Brenner (1963) (as *Lycopodiacidites trian-*

*gularis)* from the Albian-Aptian, possibly Barremian, Patapsco, Arundel and Patuxent Formations of Maryland, by Phillips and Felix (1971) from the Albian Paluxy Formation of Louisiana, and by Scott (1976) from the Neocomian(?) Sundays River and Kirkwood Formations of South Africa.

*Appendicisporites jansonii* Pocock.—The range of this species according to Singh (1971) is Barremian to Albian. Outside of Canada it has been reported by Hedlund and Norris (1968) from the Albian of Oklahoma. Singh (1971) claimed that *Appendicisporites* sp. reported by Lantz (1958) from the Albian of England is conspecific with *A. jansonii* Pocock. The presence of *Appendicisporites* species suggests that the age of the Burro Canyon samples can be no older than Valanginian. "It is important to note the appearance, in the Valanginian of the genus *Appendicisporites* also. This genus is unknown in older deposits of Europe and Asia." (Vakrameev and others, 1973 p. 214). "No species of this genus have been recorded from strata older than this [Valanginian] anywhere in the world." (Pocock, 1967 p. 135).

*Clavatipollenites hughesii* (Couper) Kemp.—A single specimen of *Clavatipollenites hughesii* (Couper) Kemp was found on one of the slides of a sample from the lower horizon. Although literature reports of Triassic and Jurassic occurrences from several parts of the world have appeared (see previous discussion), this species has not been reported from North American rocks older than Barremian and from western North American rocks older than Albian (Singh, 1975). Its earlier appearance elsewhere may mean that the parent plant had not migrated to North America earlier, or palynological investigations have not yet uncovered the data. The plant may have existed for a long time in extremely low frequency and in limited ecological environments, before it expanded its habitat and abundance sufficiently to be represented commonly in Albian and younger rocks.

The taxa discussed, combined with the absence of tricolpate pollen all point to an Aptian-early Albian age, with the remote possiblity of a late Barremian age, for the upper part of the Burro Canyon Formation.

## CONCLUSIONS

Although all students of these beds are agreed that Burro Canyon and Cedar Mountain beds are physically continuous in large part, the results of the present study of palynomorphs shows a difference in age: the upper part of the Cedar Mountain is younger (late or latest Albian) than the upper part of the Burro Canyon (Aptian to early Albian and perhaps as old as Barremian). We suggest that the thick lower part of the Cedar Mountain, which is undated by fossils, may contain beds that are age equivalent to the older Burro Canyon beds. The beds equivalent to the uppermost Cedar Mountain beds of late or latest Albian age may have been removed by pre-Dakota (pre-earliest Late Cretaceous) erosion at the Burro Canyon locality or are represented in the 6 m of green mudstones (nonproductive of palynomorphs) at the top of the Burro Canyon at the collection locality. A further speculation that may be warranted is that the Neocomian (early Early Cretaceous) may be represented in a still-undated lower part of the Burro Canyon and Cedar Mountain—perhaps even including an upper part of the Brushy Basin Member of the Morrison. The recognition of a fossil (*Clavatipollenites hughesii* (Couper) Kemp) known to occur as early as the Barremian (latest Neocomian) suggests that the undated older beds of these formations might contain beds of this age, a stage that is almost unrecorded in western North America.

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# INDEX

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# PLATES 1–9

# PLATE 1

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Laevigatosporites* cf. *L. belfordii* Burger 1976
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 99.0×21.6.

2. *Laevigatosporites gracilis* Wilson and Webster 1946
Sample D5785, slide 1, coordinates 81.0×13.7.

3. *Cyathidites australis* Couper 1953
Sample D5785–A, prep. 4, floated first, hvs, slide 5, coordinates 112.5×8.2.

4. *Todisporites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 89.3×14.8.

5. *Todisporites minor* Couper 1958
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 106.2×6.7.

6. *Gleicheniidites senonicus* Ross 1949
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 100.8×17.3.

7. *Lygodiumsporites sp.*
*Sample D5785, slide 2, coordinates 76.7*×10.1.

8. *Deltoidospora hallii* Miner 1935
Sample D5785–A, prep. 2, slide 1, coordinates 91.6×6.0.

9. *Cyathidites minor* Couper 1953
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 101.6×2.0.

10. *Concavissimisporites variverrucatus* (Couper) Singh 1964
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 110.2×18.4.

11. *Foraminisporis* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 96.8×6.7.

12. *Concavissimisporites variverrucatus* (Couper) Singh 1964
Sample D5785–A, prep. 4, floated first, hvs, slide 6, coordinates 112.5×8.2.

13. *Dictyotriletes granulatus* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 97.4×21.1.

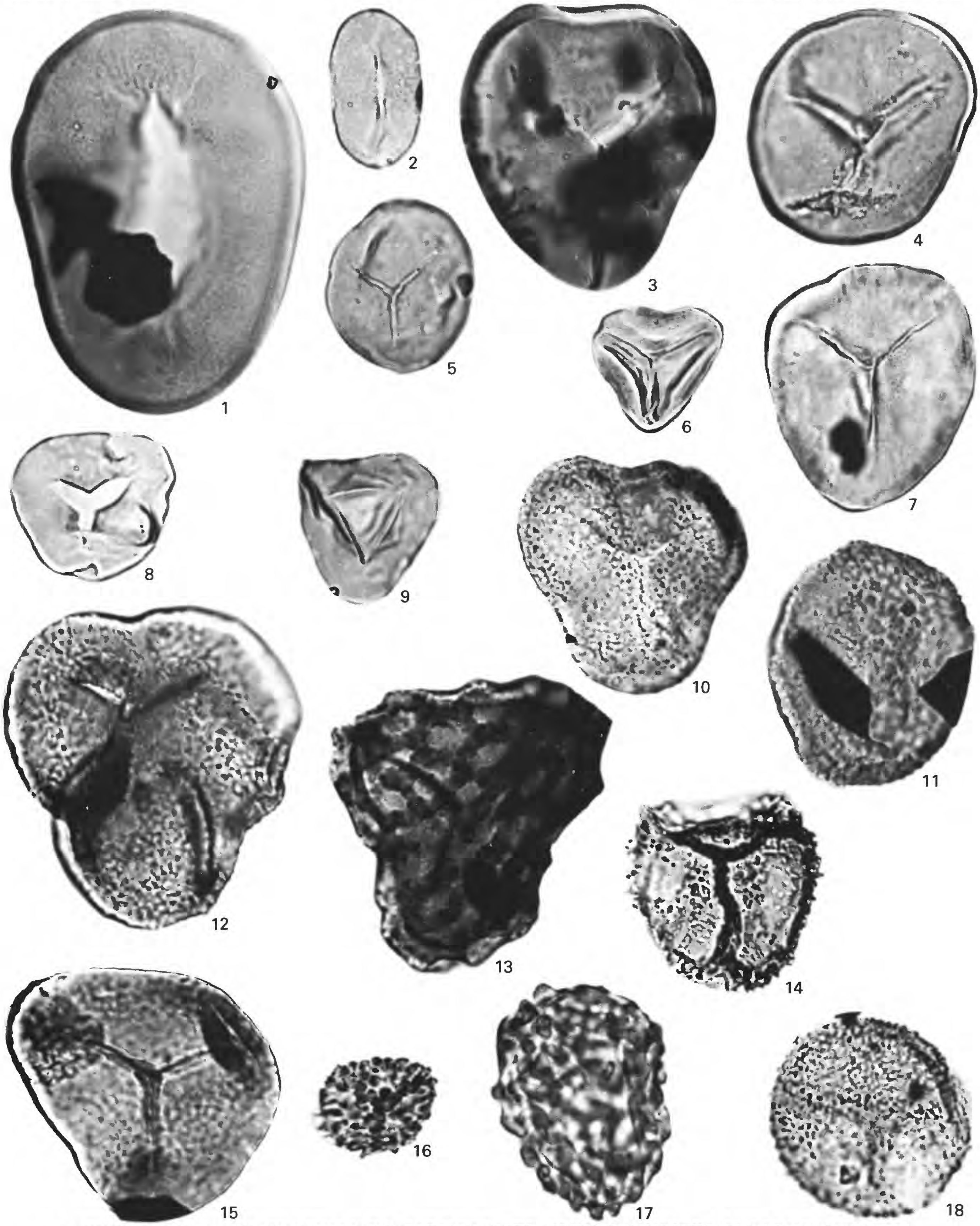
14. *Foraminisporis* cf. *F. wonthaggiensis* (Cookson and Dettmann) Dettmann 1963
Sample D5785–A, prep. 2, slide 1, coordinates 112.1×19.8.

15. *Concavissimisporites punctatus* (Delcourt and Sprumont) Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 81.9×3.1.

16. Trilete spore undetermined.
Sample D5785–A, prep. 2, slide 1, coordinates 104.2×10.4. Ornamented with short blunt verrucae as well as short spines.

17. *Leptolepidites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 87.6×5.1.

18. *Baculatisporites comaumensis* (Cookson) Potonie 1956
Sample D5785–A, prep. 2, slide 1, coordinates 110.5×11.1.




*LAEVIGATOSPORITES*, *CYATHIDITES*, *TODISPORITES*, *GLEICHENIIDITES*, *LYGODIUMSPORITES*, *DELTOIDOSPORA*, *CONCAVISSIMISPORITES*, *FORAMINISPORIS*, TRILETE SPORE, *LEPTOLEPIDITES*, AND *BACULATISPORITES*

# PLATE 2

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Pilosisporites trichopapillosus* (Thiergart) Delcourt and Sprumont 1955
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 77.7×5.4.

2–4. *Echinatisporis varispinosus* (Pocock) Srivastava 1975
2. Sample D5785–A, prep.4, floated first, fines, slide 2, coordinates 87.3×5.9.
3. Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 73.9×13.0.
4. Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 107.6×4.8.

5. *Cicatricosisporites hughesii* Dettmann 1963
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 108.4×13.3.

6. *Cicatricosisporites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 74.0×7.5.

7. *Cicatricosisporites* cf. *C. minutaestriatus* (Bolkhovitina) Pocock 1964.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 98.6×9.9.

8. *Cicatricosisporites venustus* Deak 1963
Sample D5785–A, prep. 2, slide 1, coordinates 110.0×6.2.

9. *Cicatricosisporites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 95.1×21.1.

10. *Distaltriangulisporites* cf. *D. irregularis* Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 88.0×14.5.

11. *Costatoperforosporites* sp.
Sample D5785–A, prep. 4, hvs., slide 6, coordinates 76.8×8.0.

12. Trilete spore, undetermined.
Sample D5785, slide 2, coordinates 91.1×19.3.

13. *Densoisporites microrugulatus Brenner 1963*
*Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 75.4*×8.0.

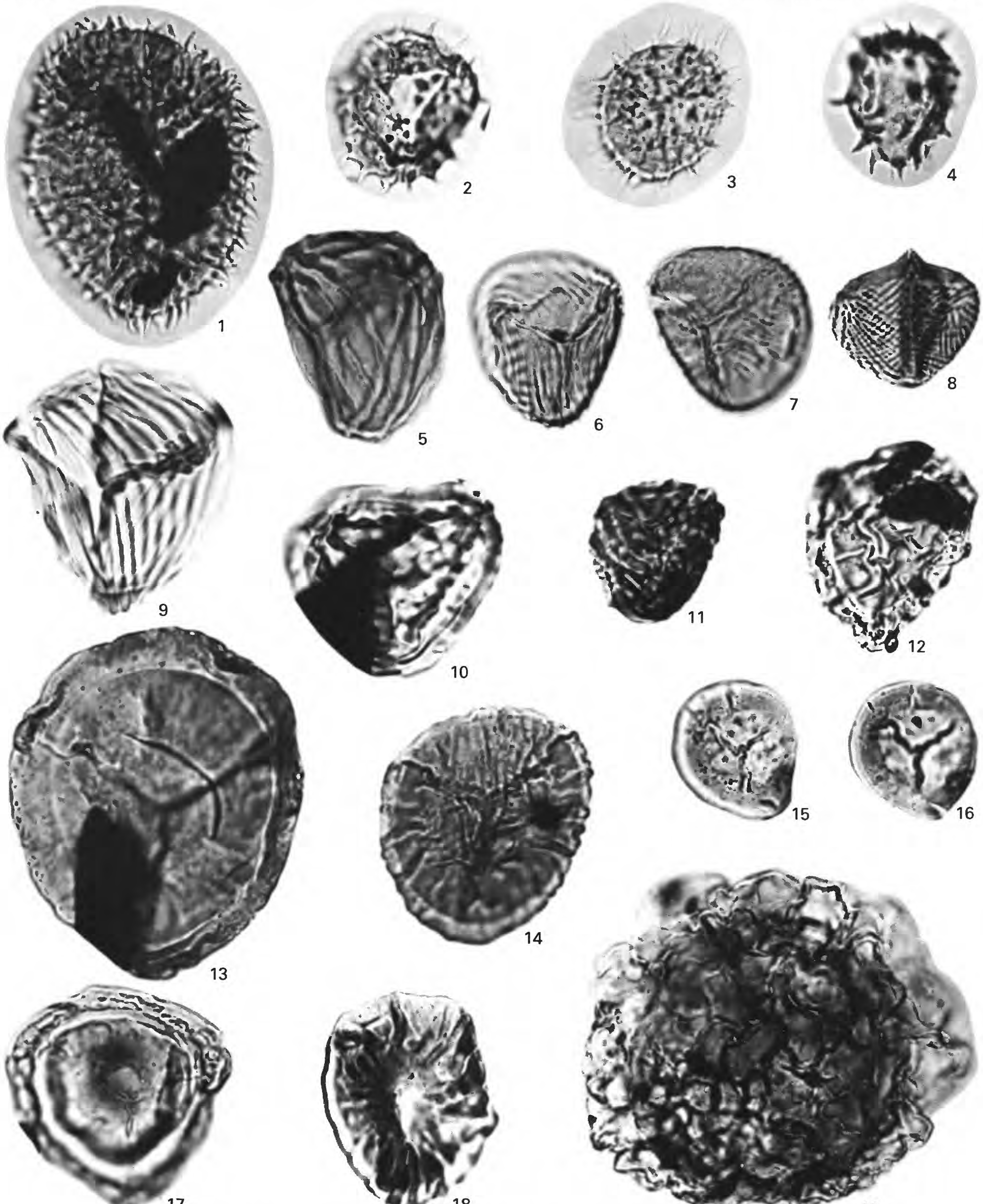
14. *Psilatriletes circumundulatus* Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 84.2×20.4.

15–16. Trilete spore, undetermined.
Sample D5785–A, prep. 2, slide 1, coordinates 90.5×19.4.
15. Proximal view.
16. Distal view.

17. *Densoisporites velatus* Weyland and Krieger 1953
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 83.5×12.4.

18. Undetermined.
Sample D5785–A, prep. 2, slide 1, coordinates 102.9×15.6.

19. cf. *Schizosporis* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 103.5×16.2




*PILOSISPORITES, ECHINATISPORIS, CICATRICOSISPORITES, DISTALTRIANGULISPORITES, COSTATOPERFOROSPORITES, DENSOISPORITES, PSILATRILETES,* cf. *SCHIZOSPORIS,* AND TRILETE SPORE

# PLATE 3

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Alisporites grandis* (Cookson) Dettmann 1963
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 88.2×4.0.

2. *Pityosporites granulatus* Phillips and Felix 1971
Sample D5785–A, prep. 4, floated first, hvs., slide 5, coordinates 95.2×17.6.

3. *Cedripites* cf. C. *cretaceus* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 77.8×5.2.

4. *Podocarpidites multesimus* (Bolkhovitina) Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 97.1×10.1.

5. *Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 83.2×22.3.

6. *Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
Sample D5785–A, prep. 4, floated first, fines, slide 1, coordinates 104.8×4.1.

7. *Cedripites canadensis* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 87.7×5.4.

8. *Podocarpidites* cf. *P. minisculus* Singh 1964
Sample D5785–A, prep. 4, floated first, hvs., slide 5, coordinates 99.1×19.4.

9. *Podocarpidites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 112.2×2.4.

10. *Cedripites* cf. *C. canadensis* Pocock 1962
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 74.8×11.9.

11. *Vitreisporites pallidus* (Reissinger) Nilsson 1958
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 110.3×18.0.


*ALISPORITES*, *PITYOSPORITES*, *CEDRIPITES*, *PODOCARPIDITES*, *PRISTINUSPOLLENITES*, AND *VITREISPORITES*

# PLATE 4

## Cedar Mountain Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany location numbers (text fig. 2)]

FIGURE 1. *Cycadopites carpentieri* (Del court and Sprumont) Singh 1964
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 110.9×12.1.

2. *Cycadopites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 99.0×13.0.

3. *Monocolpopollenites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 96.0×4.0.

4. *Monocolpopollenites* sp.
Sample D5785–B, slide 3, coordinates 101.6×14.2.

5. *Ginkgocycadophytus* cf. *G. nitidus* (Balme) de Jersey 1962
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 81.4×4.6.

6. *Equisetosporites multicostatus* (Brenner) Norris 1967
Sample D5785–A, prep. 2, coordinates 106.1×22.5.

7. *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 92.8×1.6.

8. *Eucommiidites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 102.7×21.5.

9. *Corollina torosa* (Reissinger) Cornet and Traverse 1975.
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 80.7×5.7.

10. *Exesipollenites tumulus* Balme 1957
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 78.3×2.1.

11–12. *Asteropollis asteroides* Hedlund & Norris 1968
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 104.4×9.4.
11. Low focus showing baculae near equator.
12. High focus.

13. *Clavatipollenites hughesii* (Couper) Kemp 1968
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 112.0×21.0.
The size of this specimen is on the borderline between *C. hughesii* (Couper) Kemp and *C. minutus* Brenner.

14. *Liliacidites* sp.
Sample D5785–B, prep. 2, slide 2, coordinates 112.3×14.5.

15. *Liliacidites* cf. *L. peroreticulatus* (Brenner) Singh 1971
Sample D5785–B, slide 3, coordinates 106.5×5.7.

16. *Tricolpites crassimurus* (Groot and Penny) Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 94.1×7.5.

17. *Tricolpites* cf. *T. crassimurus* (Groot and Penny) Singh 1971
Sample D5785–A, prep. 4, floated first, Hvs., slide 5, coordinates 88.2×9.1.

18. *Cupuliferoidaepollenites parvulus* (Groot and Penny) Dettmann 1973
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 90.5×2.1.

19. *Retitricolpites* cf. *R. virgeus* (Groot, Penny and Groot) Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 83.0×11.8.

20. *Retitricolpites vulgaris* Pierce 1961
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 104.3×20.0.

21. *Retitricolpites vulgaris* Pierce 1961
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 111.4×17.0.

22. *Tricolpites* cf. *T. wilsonii* Kimyai 1966
Sample 5785–A, prep. 4, floated first, fines, slide 4, coordinates 88.0×16.2.

23. *Striatopollis paraneus* (Norris) Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 106.4×5.4.

24. *Striatopollis paraneus* (Norris) Singh 1971
Sample D5785, slide 2, coordinates 105.5×13.3.

25. *Retitricolpites vermimurus* Brenner 1963
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 97.5×19.8.

26. *Rousea georgensis* (Brenner) Dettman 1973
Sample D5785–A, prep. 4, floated first, Hvs., slide 5, coordinates 112.1×11.0.

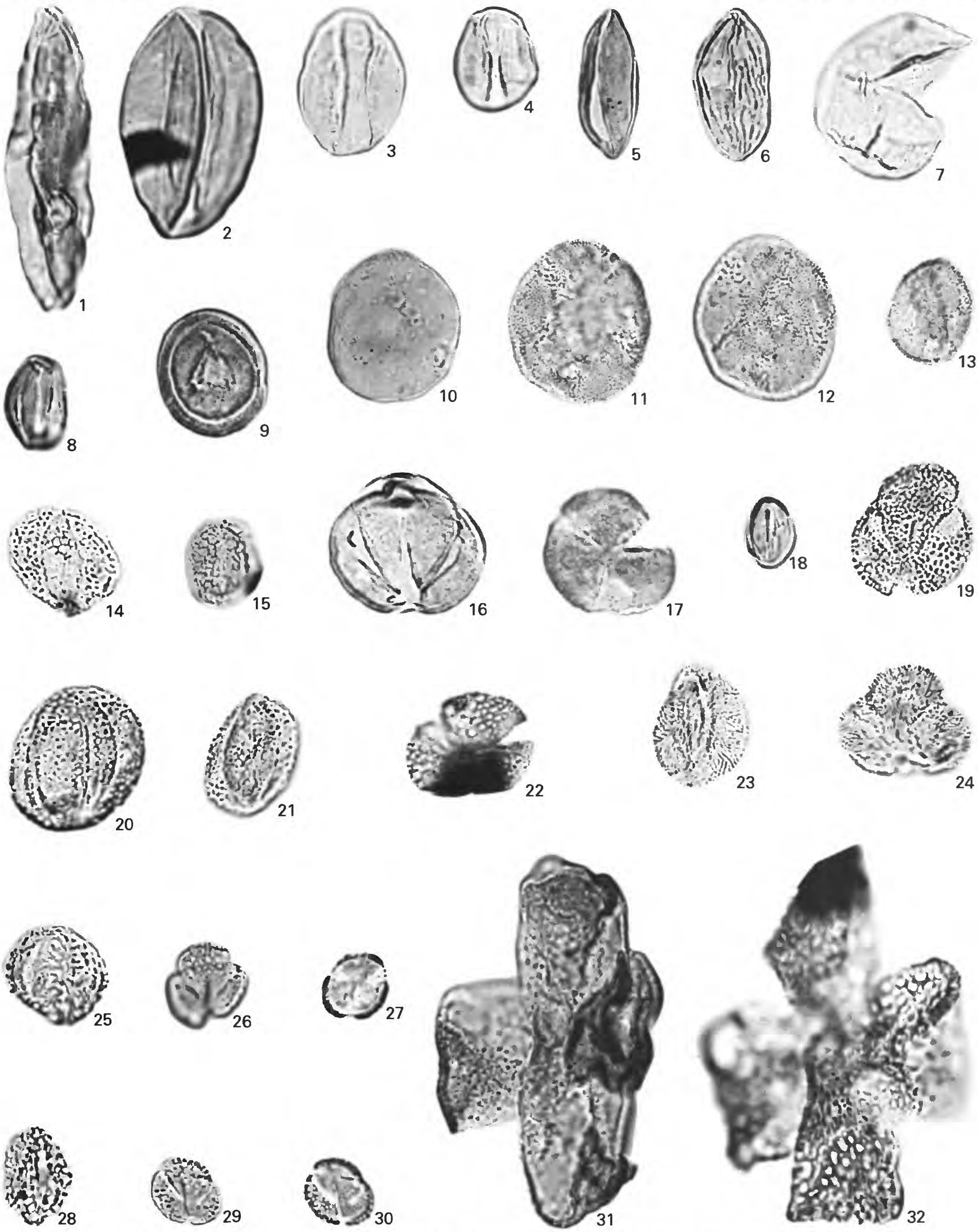
27. *Cupuliferoidaepollenites minutus* (Brenner) Singh 1971
Sample D5785–B, prep. 2, slide 2, coordinates 111.5×8.6.

28. *Tricolpites* cf. *T.* sp. 1 of Kemp 1968
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 104.1×14.5

29–30. *Tricolpites micromunus* (Groot and Penny) Singh 1971
Sample D5785–A, prep. 4, floated first, fines, slide 2, coordinates 110.7×2.0. (Sensu Groot and Penny. This specimen is small and may not be the same species as figured by Singh 1971).
29. High focus.
30. Low focus.

31. *Tetracolpites* cf. *T. pulcher* Srivasteva 1969
Sample D5785–A, prep. 4, floated first, fines, slide 3, coordinates 105.5×8.0.

32. *Tetracolpites* sp.
Sample D5785–A, prep. 4, floated first, fines, slide 4, coordinates 89.8×17.9.



*CYCADOPITES, MONOCOLPOPOLLENITES, GINKGOCYCADOPHYTUS, EQUISETOSPORITES, TAXODIACEAEPOLLENITES, EUCOMMIIDITES, COROLLINA, EXESIPOLLENITES, ASTEROPOLLIS, CLAVATIPOLLENITES, LILIACIDITES, TRICOLPITES, CUPULIFEROIDAEPOLLENITES, RETITRICOLPITES, STRIATOPOLLIS, ROUSEA,* AND *TETRACOLPITES*

# PLATE 5

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers. (text fig. 2)]

FIGURE 1. *Gleicheniidites senonicus* Ross 1949
Sample D5803, slide 22, coordinates 111.6×13.8.

2. *Undulatisporites* cf. *U. fossulatus* Singh 1971
Sample D5510–B, slide 1, coordinates 103.6×10.5.

3. *Cyathidites minor* Couper 1953
Sample D5510–C, slide 4, coordinates 105.9×6.8.

4. *Deltoidospora* cf. *D. psilostoma* Rouse 1959
Sample D5803, slide 12, coordinates 91.0×17.8.

5. *Todisporites minor* Couper 1958
Sample D5801, prep. 2, slide 4, coordinates 78.1×20.9.

6. *Dictyotriletes pseudoreticulatus* (Couper) Pocock 1962
Sample D5801, slide 2, coordinates 107.2×9.8.

7–8. *Tigrisporites reticulatus* Singh 1971
Sample D5973, slide 2, coordinates 75.2×14.3.

9–10. *Cadargasporites reticulatus* de Jersey and Paten 1964
Sample D5510–B, slide 2, coordinates 93.8×3.0.

11. *Interulobites triangularis* (Brenner) Phillips and Felix 1971
Sample D5803, slide 4, coordinates 107.6×21.7.

12. *Interulobites triangularis* (Brenner) Phillips and Felix 1971
Sample D5973, slide 2, coordinates 81.2×15.6.

13. *Staplinisporites caminus* (Balme) Pocock 1962
Sample D5803, slide 6, coordinates 96.4×4.4.

14. *Staplinisporites caminus* (Balme) Pocock 1962
Sample D5803, slide 11, coordinates 82.4×19.8.

15. *Lycopodiumsporites* sp.
Sample D5803, slide 22, coordinates 74.7×1.2.

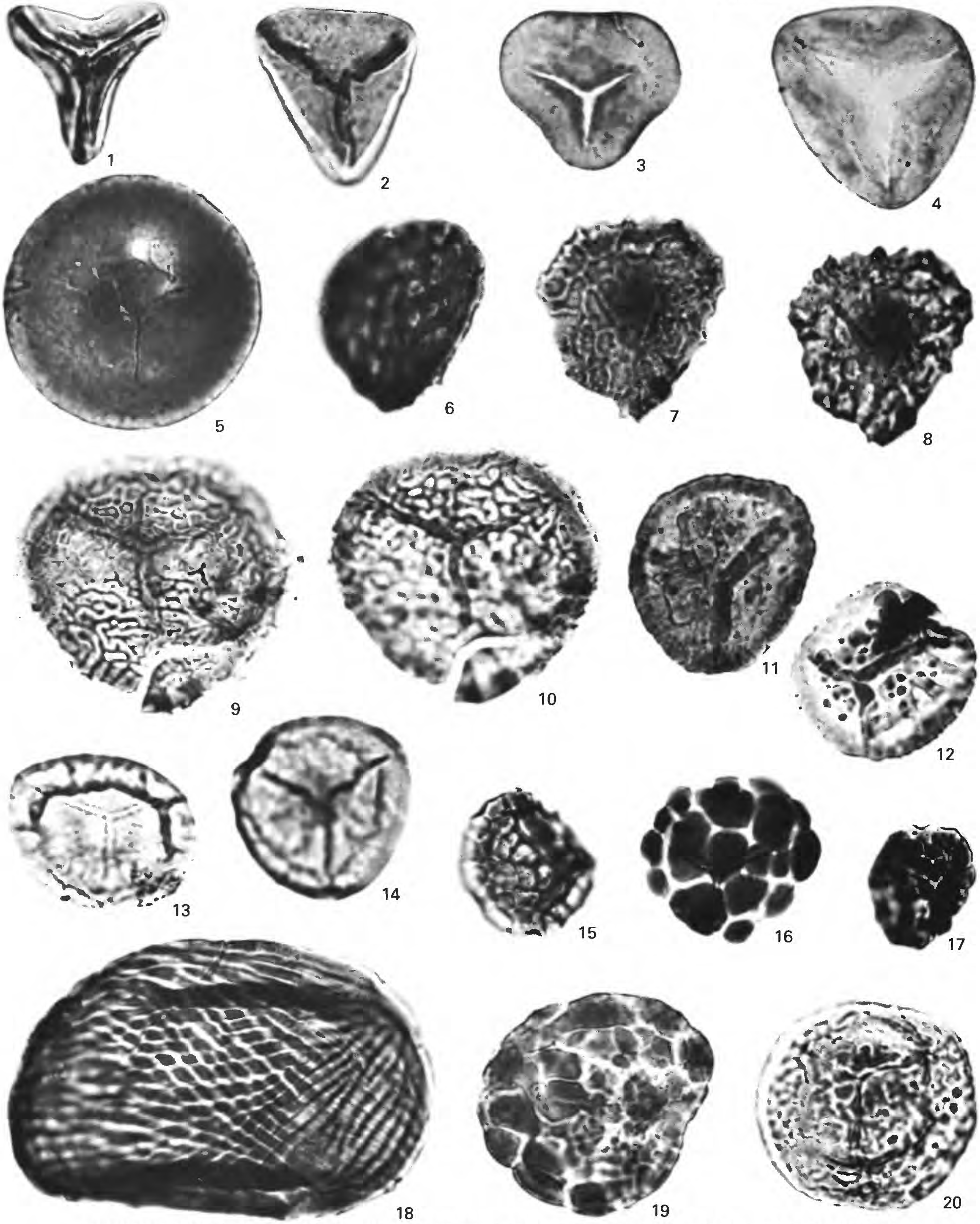
16. *Matthesisporites tumulosus* Döring 1964
Sample D5803, slide 12, coordinates 81.7×21.1.

17. *Leptolepidites* cf. *L. verrucatus* Couper 1953
Sample D5803, slide 8, coordinates 90.0×2.2.

18. aff. *Cicatricososporites phaseolus* (Delcourt and Sprumont) Krutzsch 1959
Sample D5801, slide 2, coordinates 76.0×15.5.

19. *Converrucosisporites* cf. *C. proxigranulatus* Brenner 1963
Sample D5510–C, slide 2, coordinates 98.4×15.4.

20. *Verrucosisporites densus* (Bolkhovitina) Pocock 1970
Sample D5803, slide 6, coordinates 106.1×4.7.




*GLEICHENIIDITES, UNDULATISPORITES, CYATHIDITES, DELTOIDOSPORA, TODISPORITES, DICTYOTRILETES, TIGRISPORITES, CADARGASPORITES, INTERULOBITES, STAPLINISPORITES, LYCOPODIUMSPORITES, MATTHESISPORITES, LEPTOLEPIDITES, CICATRICOSOSPORITES, CONVERRUCOSISPORITES,* AND *VERRUCOSISPORITES*

# PLATE 6

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers. (text fig. 2)]

FIGURE 1. *Cicatricosisporites* cf. *C. minor* (Bolkhovitina) Pocock 1964
Sample D5510–C, slide 1, coordinates 109.4×11.1.

2. *Cicatricosisporites* cf. *C. cuneiformis* Pocock 1964
Sample D5510–C, slide 4, coordinates 100.3×10.0.

3. *Cicatricosisporites augustus* Singh 1971
Sample D5510–B, slide 1, coordinates 99.0×4.5.

4. *Cicatricosisporites* cf. *C. potomacensis* Brenner 1963
Sample D5510–C, slide 2, coordinates 87.0×5.5.

5. *Cicatricosisporites* cf. *C. mediostriatus* (Bolkhovitina) Pocock 1964
Sample D5510–C, slide 1, coordinates 88.8×5.4.

6. *Cicatricosisporites* sp.
Sample D5510–A, slide 2, coordinates 92.6×14.7.

7. *Cicatricosisporites pseudotripartitus* (Bolkhovitina) Dettmann 1963
Sample D5801, prep. 2, slide 4, coordinates 105.9×20.8.

8. *Cicatricosisporites* cf. *C. pseudotripartitus* (Bolkhovitina) Dettmann 1963
Sample D5510–B, slide 1, coordinates 99.5×16.6.

9. *Cicatricosisporites apiteretus* Phillips and Felix 1971
Sample D5510–C, slide 2, coordinates 89.7×10.5.

10. *Cicatricosisporites* cf. *C. subrotundus* Brenner 1963
Sample D5510–B, slide 1, coordinates 107.2×13.3.

11–12. *Cicatricosisporites* cf. *C. crassistriatus* Burger 1966
Sample D5801, prep. 2, slide 2, coordinates 110.3×1.0.

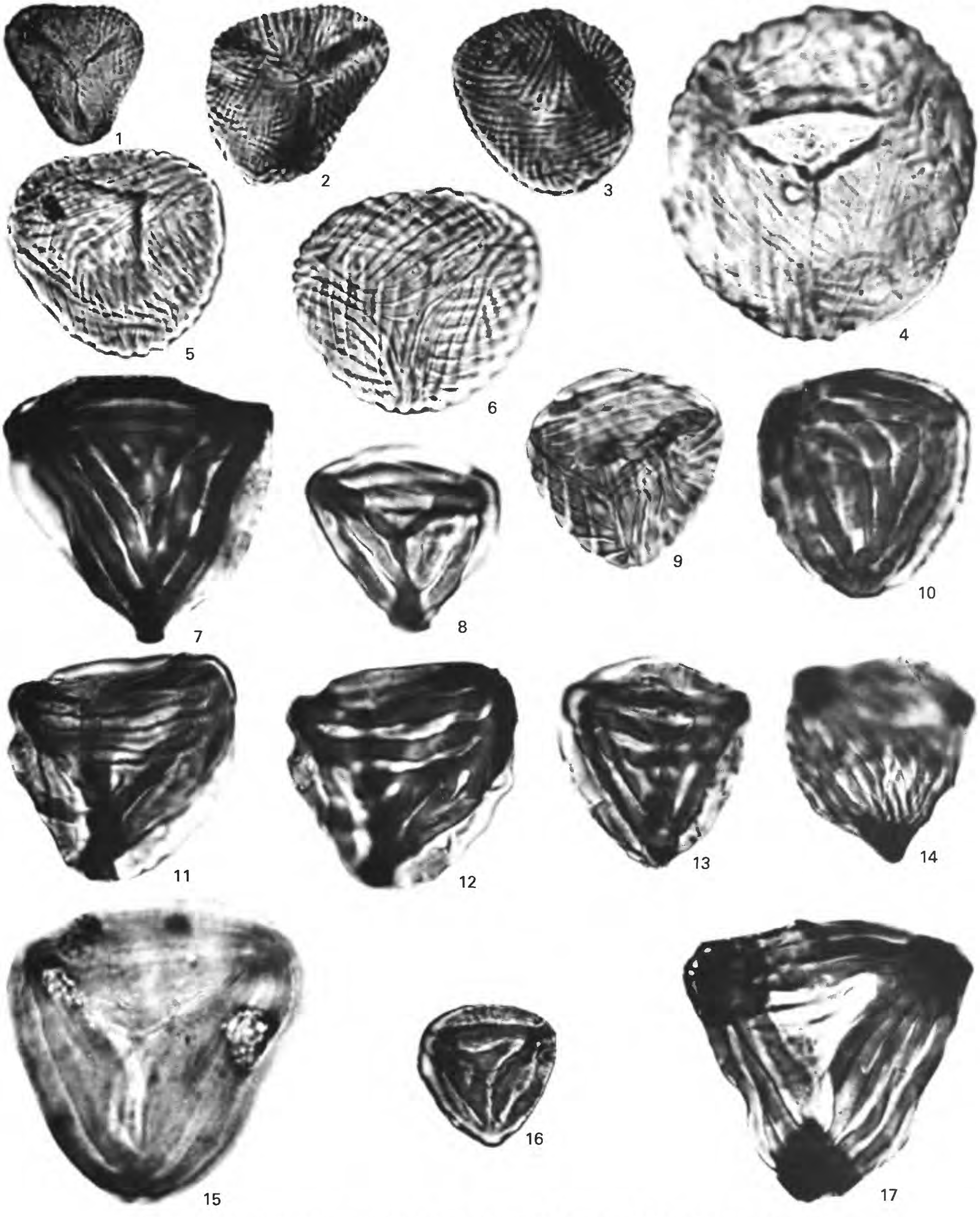
13. *Cicatricosisporites* cf. *C. pseudotripartitus* (Bolkhovitina) Dettmann 1963
Sample D5510–C, slide 4, cordinates 108.5×13.0.

14. *Appendicisporites bilateralis* Singh 1971
Sample D5801, prep. 2, slide 4, coordinates 88.3×10.5.

15. *Distaltriangulisporites perplexus* (Singh) Singh 1971
Sample D5803, slide 6, coordinates 75.9×10.0.

16. *Distaltriangulisporites* sp.
Sample D5510–B, slide 1, coordinates 73.0×9.0.

17. *Appendicisporites jansonii* Pocock 1962
Sample D5801, prep. 2, slide 2, coordinates 109.4×14.1.




*CICATRICOSISPORITES, APPENDICISPORITES*, AND *DISTALTRIANGULISPORITES*

# PLATE 7

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers. (text fig. 2)]

FIGURE 1. *Corollina torosa* (Reissinger) Cornet and Traverse 1975 (two specimens)
Sample D5803, slide 19, coordinates 79.0×20.1.

2. *Equisetosporites* sp.
Sample D5803, slide 12, coordinates 91.8×11.0.

3. *Equisetosporites* sp.
Sample D5803, slide 8, coordinates 80.4×12.9.

4. *Cycadopites* sp.
Sample D5803, slide 4, coordinates 90.8×20.2.

5. *Cycadopites* sp.
Sample D5803, slide 5, coordinates 105.3×13.6.

6. *Cycadopites* sp.
Sample D5803, slide 6, coordinates 108.8×12.4.

7. *Exesipollenites tumulus* Balme 1957
Sample D5803, slide 10, coordinates 76.6×6.1.

8. *Araucariacites* sp.
Sample D5510–C, slide 1, coordinates 72.2×1.1.

9. *Cerebropollenites mesozoicus* (Couper) Nilsson 1958
Sample D5803, slide 3, coordinates 84.2×20.5.

10. *Callialasporites segmentatus* (Balme) Sukh-Dev 1961
Sample D5803, slide 8, coordinates 93.2×16.0.

11. *Callialasporites* sp.
Sample D5510–C, slide 1, coordinates 76.9×18.0.

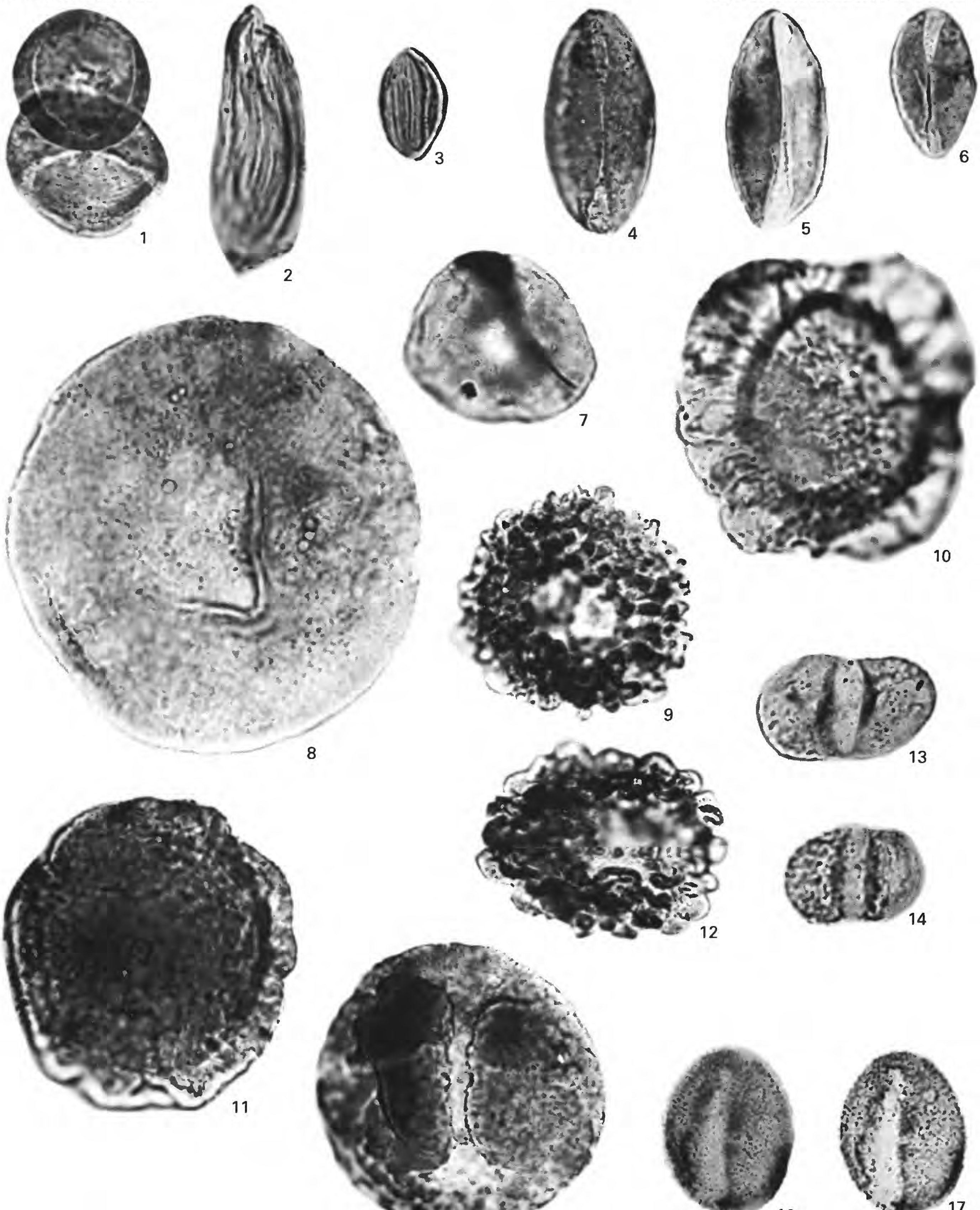
12. *Cerebropollenites mesozoicus* (Couper) Nilsson 1958
Sample D5803, slide 22, coordinates 99.8×13.4.

13. *Vitreisporites pallidus* (Reissinger) Nilsson 1958
Sample D5803, slide 21, coordinates 96.5×15.0.

14. *Vitreisporites pallidus* (Reissinger) Nilsson 1958
Sample D5510–C, slide 4, coordinates 105.4×4.3.

15. *Pristinuspollenites sulcatus* (Pierce) B. Tschudy 1973
Sample D5803, slide 3, coordinates 110.8×20.7.

16–17. *Clavatipollenites hughesii* (Couper) Kemp 1968
Sample D5803, slide 12, coordinates 80.0×23.0.



*COROLLINA, EQUISETOSPORITES, CYCADOPITES, EXESIPOLLENITES, ARAUCARIACITES, CEREBROPOLLENITES, CALLIALASPORITES, VITREISPORITES, PRISTINUSPOLLENITES,* AND *CLAVATIPOLLENITES*

# PLATE 8

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Paleoconiferus asaccatus* Bolkhovitina 1956
Sample D5803, slide 21, coordinates 108.1×17.8.

2. *Alisporites thomasii* (Couper) Pocock 1962
Sample D5510–C, slide 2, coordinates 99.6×1.6.

3. *Pityosporites* cf. *P. divulgatus* (Bolkhovitina) Pocock 1970
Sample D5803, slide 21, coordinates 76.2×13.9.

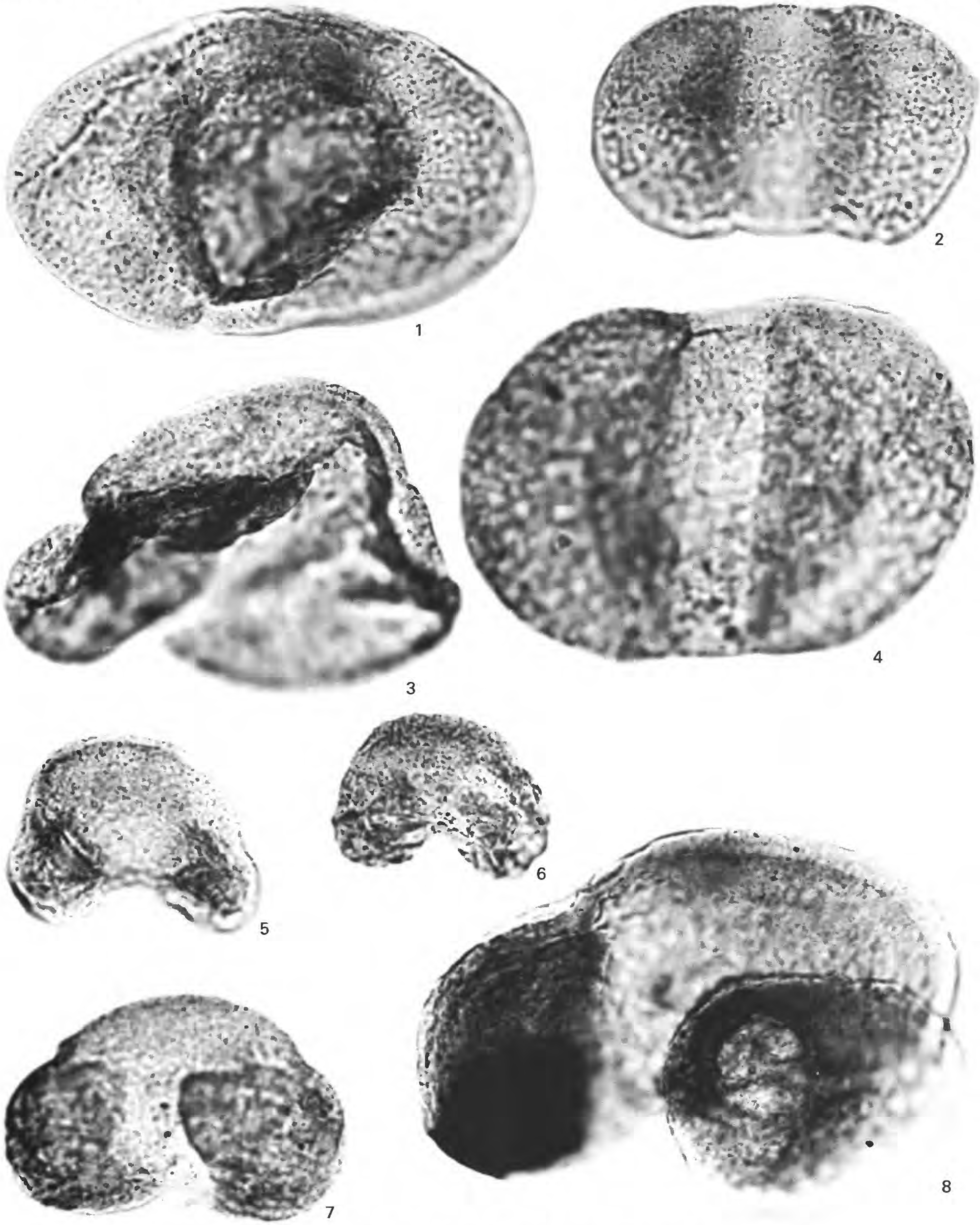
4. *Alisporites grandis* (Cookson) Dettmann 1963
Sample D5803, slide 5, coordinates 85.4×8.2.

5. *Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970
Sample D5803, slide 22, coordinates 89.8×21.6.

6. *Pityosporites nigraeformis* (Bolkhovitina) Pocock 1970
Sample D5803, slide 22, coordinates 95.1×12.8.

7. *Cedripites* cf. *C. canadensis* Pocock 1962
Sample D5803, slide 21, coordinates 80.8×17.5.

8. *Cedripites cretaceus* Pocock 1962
Sample D5803, slide 21, coordinates 109.7×17.6




*PALEOCONIFERUS*, *ALISPORITES*, *PITYOSPORITES*, AND *CEDRIPITES*

# PLATE 9

## Burro Canyon Formation

[Magnification × 1000. Sample numbers are those of USGS Paleobotany locality numbers (text fig. 2)]

FIGURE 1. *Podocarpidites ornatus* Pocock 1962
Sample D5803, slide 16, coordinates 110.0×10.1.

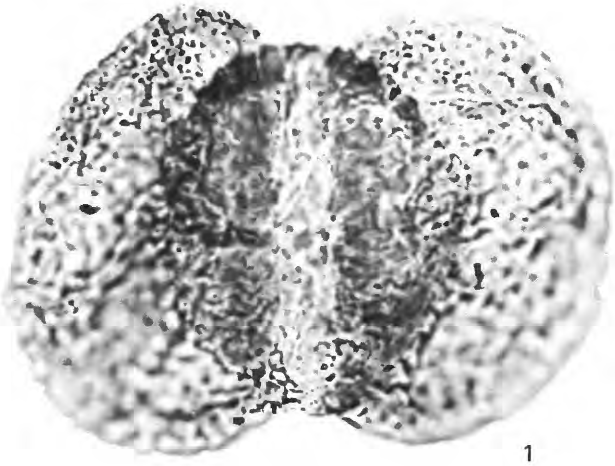
2. *Podocarpidites* cf. *P. ellipticus* Cookson 1947
Sample D5803, slide 5, coordinates 98.7×19.1.

3. *Podocarpidites* cf. *P. ornatus* Pocock 1962
Sample D5803, slide 4, coordinates 89.3×11.4.

4. *Podocarpidites* cf. *P. multesimus* (Bolkhovitina) Pocock 1962
Sample D5803, slide 21, coordinates 102.3×20.4.

5. *Podocarpidites* cf. *P. ornatus* Pocock 1962
Sample D5803, slide 21, coordinates 109.3×17.5.

6. *Podocarpidites radiatus* Brenner 1963
Sample D5803, slide 5, coordinates 111.5×9.7.



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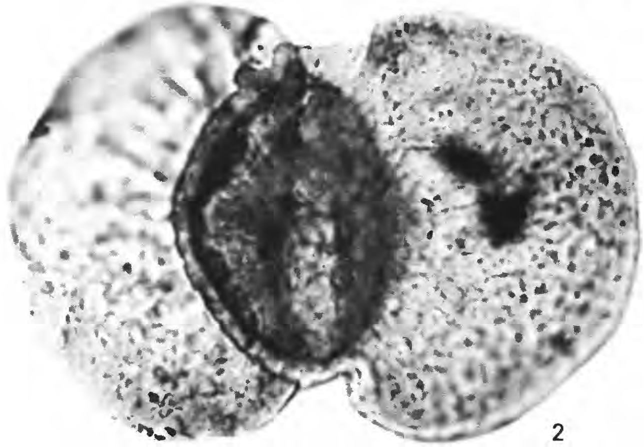

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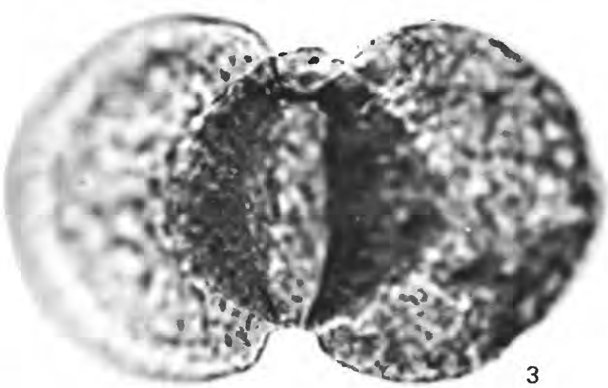

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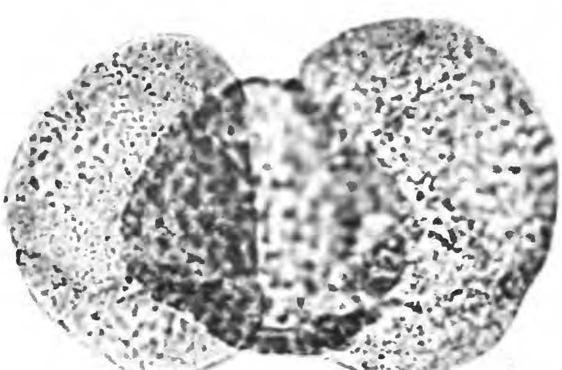
4



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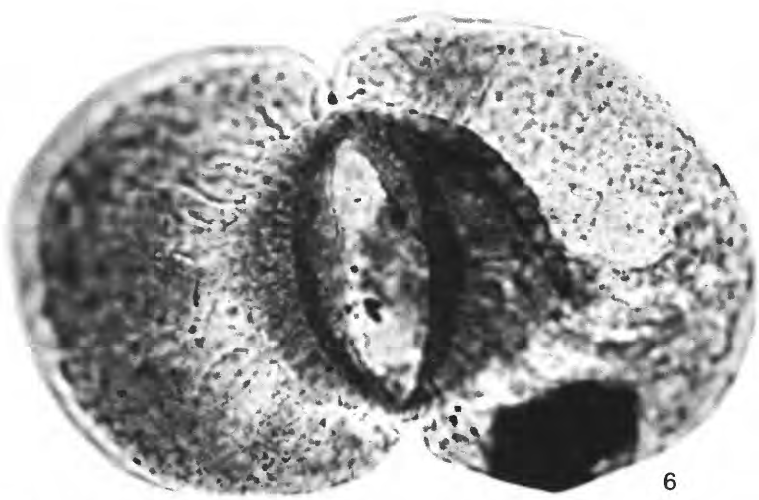

6

*PODOCARPIDITES*