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Dinoflagellate and organic facies stratigraphy of the Twin Creek Limestone (Jurassic) in western Wyoming and northeastern Utah, USA

Van Pelt, Robert Scott, Ph.D.

City University of New York, 1990

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DINOFLAGELLATE AND ORGANIC FACIES STRATIGRAPHY OF THE TWIN CREEK LIMESTONE (JURASSIC) IN WESTERN WYOMING AND NORTHEASTERN UTAH, U.S.A.

by

ROBERT S. VAN PELT

A dissertation submitted to the Graduate Faculty in Earth and Environmental Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1990

This manuscript has been read and accepted for the Graduate Faculty in Earth and Environmental Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

Sept. 28, 1990
Date

Daniel Habib
Prof. Daniel Habib
Chair of Examining Committee

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Prof. Gerald M. Friedman

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Dr. Stephen R. Jacobson

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

ABSTRACT

DINOFLAGELLATE AND ORGANIC FACIES STRATIGRAPHY OF THE TWIN CREEK LIMESTONE (JURASSIC) IN WESTERN WYOMING AND NORTHEASTERN UTAH, U.S.A.

by

Robert S. Van Pelt

Advisor: Professor Daniel Habib

(Text of Abstract)

Palynological study of six sections of the Twin Creek Limestone (Jurassic) in the surface and subsurface of western Wyoming and northeastern Utah yielded 59 species and 32 genera of dinoflagellate cysts, many of which are biostratigraphically significant. In addition, 12 species and 7 genera of pollen and spores were recognized.

The dinoflagellate stratigraphy is dated by ammonite and pelecypod taxa, which in turn have been calibrated against ammonite assemblages from Arctic and western Canada, southern Alaska, and against European stratotype sections. However, where there is lack of resolution, ages (Late Bathonian - Callovian) assigned to dinoflagellate species from European stratotype and Arctic Canadian sections have been utilized. One new dinoflagellate species, _Mendicodinium_ _scrobiculatum_ sp.

nov. is described from Late Bajocian sediments. The last appearance of this species appears to coincide with the Bajocian/Bathonian boundary.

Three regional palynozones were established for the formation. They are from oldest to youngest:

I. Mendicodinium scrobiculatum Taxon Range Zone (Late Bajocian)

II. Atopodinium prostatum Interval Zone (late Middle/early Late Bathonian to Late Bathonian)

III. Gonyaulacysta centriconnata Interval Zone (Early Callovian).

The similarity of these zones with those published for Europe and Arctic Canada suggests that the Late Bajocian, Late Bathonian, and Early Callovian were times of cosmopolitan assemblages. Increase in the number of dinoflagellate species and the occurrence of abundant amorphous debris suggest an expanding marine environment. A decrease in the number of dinoflagellate species, coincident with an increase in terrigenous material (tracheal and cuticular tissue, pollen grains and spores), correlates with a change towards marine regression.

Two parasequences have been defined for the Twin Creek Limestone (Camp Davis section). A correlation exists between shallowing conditions, as evidenced by lithologic interpretations, and decreases in marine microplankton.

Conversely, initial deepening coincides with an increase in the number of marine microplankton taxa.

The studied sections (Twin Creek Limestone) lie within the oil window. The sediments in the Camp Davis section (northernmost section) lie within the early stage of maturation, with the remaining sections exhibiting a greater degree of maturation.

The kerogen content consists of amorphous debris, marine microplankton, tracheal and cuticular tissue, pollen grains, spores, and inertinite.

ACKNOWLEDGEMENTS

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In addition, Dr. Robert P. Wright and Dr. Warren Drugg of Chevron Oil Company, and Dr. Gerald Waanders of Waanders Palynology Consulting, provided helpful information and study material.

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INTRODUCTION

The purpose of this research was to :

I. establish a regional marine dinoflagellate stratigraphy, for correlation of the Jurassic Twin Creek Limestone, and to assess its global stratigraphic potential.

II. determine the total organic matter in residues in order to distinguish terrigenous (land plant detritus) intervals from marine (microplankton and fecal pellet detritus) intervals, and to investigate their relationship to the lithofacies evidence of relative sea-level change.

III. analyze thermal alteration of organic matter by the TAI method to determine its potential and petroleum generation history.

The Twin Creek Limestone lies within the Idaho-Wyoming-Utah Overthrust Belt of western North America (Figure 1). It was deposited in the Twin Creek trough during two episodes of marine transgression and regression, which occurred from ?Middle Bajocian through Early Callovian time (Imlay, 1967,1980). The formation is divided into seven members, each representing a specific shallow marine carbonate environment (Table 1). In ascending order, these are the Gypsum Spring (brecciated

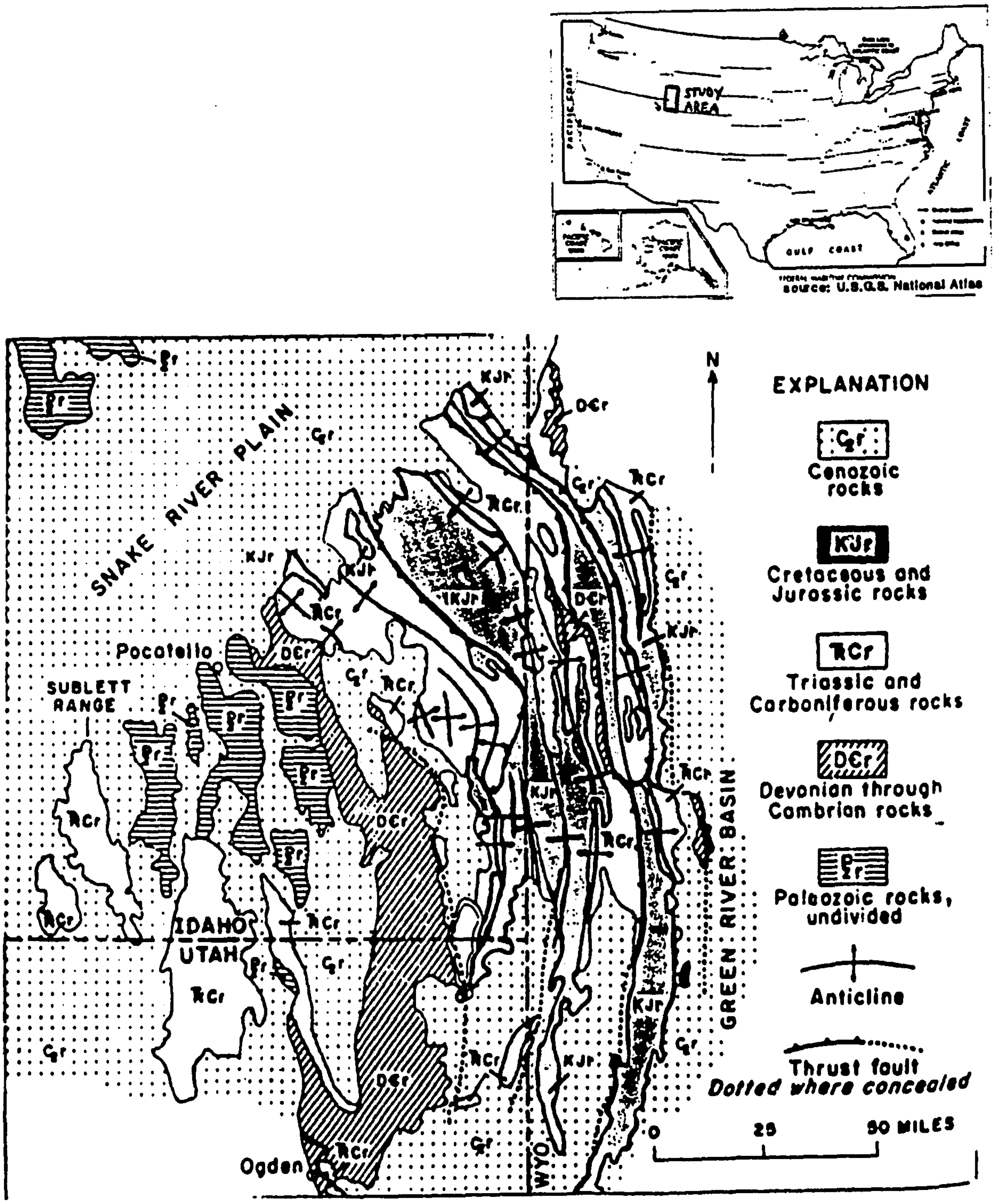


Figure 1. Generalized geologic map showing the distribution of the Idaho-Wyoming-Utah Overthrust Belt (After Armstrong and Oriel, 1967).

Table 1. Generalized statigraphic section and characteristics of the Twin Creek Limestone (MODIFIED FROM IMLAY,1967,1980)

Member	Lithologic features	Thickness(meters)	Contents	Characteristics Fossils	Age	Origin
Giraffe Creek	Mostly gray silty to sandy ripple-marked thin-bedded limestone and sandstone. Some thicker beds of oolitic sandy limestone. Becomes sandier and glauconitic westward. Forms ridges.	8-90 Thickens westward and southward irregularly.	Grades upward within a few meters into soft red beds at base of Preuss Sandstone.	Coquinas of crinoid, echinoid, and CAMPTONECTES fragments. OSTREA present locally.	EARLY CALLOVIAN	Shallow marine to littoral. Sea regressive westward. Sand derived from west. Much wave action.
Leeds Creek	Mostly light-gray soft dense shaly splintery limestone. Some oolitic silty or sandy ripplemarked limestone. Becomes clayey northeastward in Wyoming and southward in Utah. Forms valleys.	80-488. Thickens westward.	Grades upward evenly into silty to sandy thin-bedded limestone.	GRYPHAEA NEBRASCENSIS, PLAATYMYA ROCKYMONTANA, and CADOCERAS? sp. Megafossils uncommon.	LATE BATHONIAN	Shallow marine. Soft calcareous mud formed rapidly. Sand and silt derived mostly from east.
Watton Canyon	Mostly gray dense compact brittle even-bedded medium- to thin-bedded limestone. Basal bed generally massive and oolitic. Forms prominent cliffs and ridges.	18-122. Thickens westward.	Grades upward evenly into shaly limestone of the Leeds Creek Member.	GRYPHAEA sp. juv. cf. G. NEBRASCENSIS near top. MYOPHOLAS HARDYI Imlay near middle. Megafossils	?MIDDLE TO LATE BATHONIAN	Shallow sea transgressive eastward Shallower than during deposition of Leeds Creek Member.
Boundary Ridge	Red, green, and yellow soft siltsone interbedded with silty to sandy or oolitic limestone. Changes eastward into red siltstone and westward into limestone.	9-87. Thickens westward irregularly	Overlain sharply by cliff-forming limestone of Watton canyon Member.	ASTARTE(COELASTARTE) LIVINGSTONENSIS Imlay found near top. Megafossils rare.	BATHONIAN	Shallow marine to littoral or lagoonal. Sea regressive westward. Climate probably hot and dry.
Rich	Medium-gray shaly limestone, very soft basally; contains some thin beds near top. Becomes clayey and fossiliferous eastwrd. Forms ravines.	12-152. Thickens westward irregularly.	Grades upward within few meters into harder sandy limestone or softer red siltstone.	GRYPHAEA PLANOCONVEXA, GERVILLIA MONTANENSIS, SOHLITES SPINOSUS, and PARACHONDROCERAS spp.	LATE BAJOCIAN	Shallow sea transgressive eastward. Bottom probably muddier and deeper than during Sliderock time.
Sliderock	Grayish-black medium-to thin-bedded limestone. Basal beds in Wyoming are oolitic; in Idaho, sandy cross-bedded and pebbly; in Utah, sandy and oolitic. Sandiness increases westward. Forms low ridges.	6-87. Thickens westward.	Grades upward within few meters into soft shaly limestones of the Rich Member.	GRYPHAEA PLANOCONVEXA FRATERNA Imlay n. var., MEGASPHAEROCERAS spp., SPIROCERAS sp., STEMMATOCERAS spp., and STEPHANOCERAS spp. Fossils common.	LATE BAJOCIAN	Shallow warm sea transgressive eastward. Sand and pebbles derived from west.
Gypsum Spring	Mostly red soft siltstone and brecciated vuggy or chert-bearing limestone. Basal brecciated limestone passes eastward into thick gypsum mass. Chert-bearing limestone thickens westward. Forms ravines.	3-122. Thickens irregularly toward west and southwest.	Contacts sharp_ _ _	Crinoid and echinoid fragments. Fossils rare.	?MIDDLE BAJOCIAN	Shallow marine to lagoonal. Sea transgressive eastward. Climate probably hot and dry.

limestone and calcareous siltstone), Sliderock (oolitic limestone), Rich (shaly limestone), Boundary Ridge (calcareous siltstone), Watton Canyon (oolitic limestone), Leeds Creek (calcareous shale), and Giraffe Creek (sandy/silty limestone). The sequence is conformable, except for sharp contacts between the Gypsum Spring/Sliderock and the Boundary Ridge/Watton Canyon members.

The Twin Creek Limestone was first described by Veatch (1907) from exposures of marine limestone, shale, and sandstone along and near Twin Creek between Sage and Nugget in western Wyoming. Imlay (1950a, 1967) subsequently divided the formation into seven members based on lithologic and paleontologic criteria. A full description of the lithology, depositional environment, and paleontology is provided by Imlay (1967). He established a paleontologic framework which was based principally upon ammonite and pelecypod assemblages. His work provides the ages for this study. Peterson (1957) indicated that the Twin Creek Limestone is time equivalent in northeastern, central, and northern Wyoming. His paleogeographic reconstructions are shown in Figure 2. Wright (1973) described Jurassic marine sediments from parts of Wyoming and South Dakota, which include the Twin Creek Limestone and the time equivalent "Lower Sundance" formation. He provided paleoecologic and

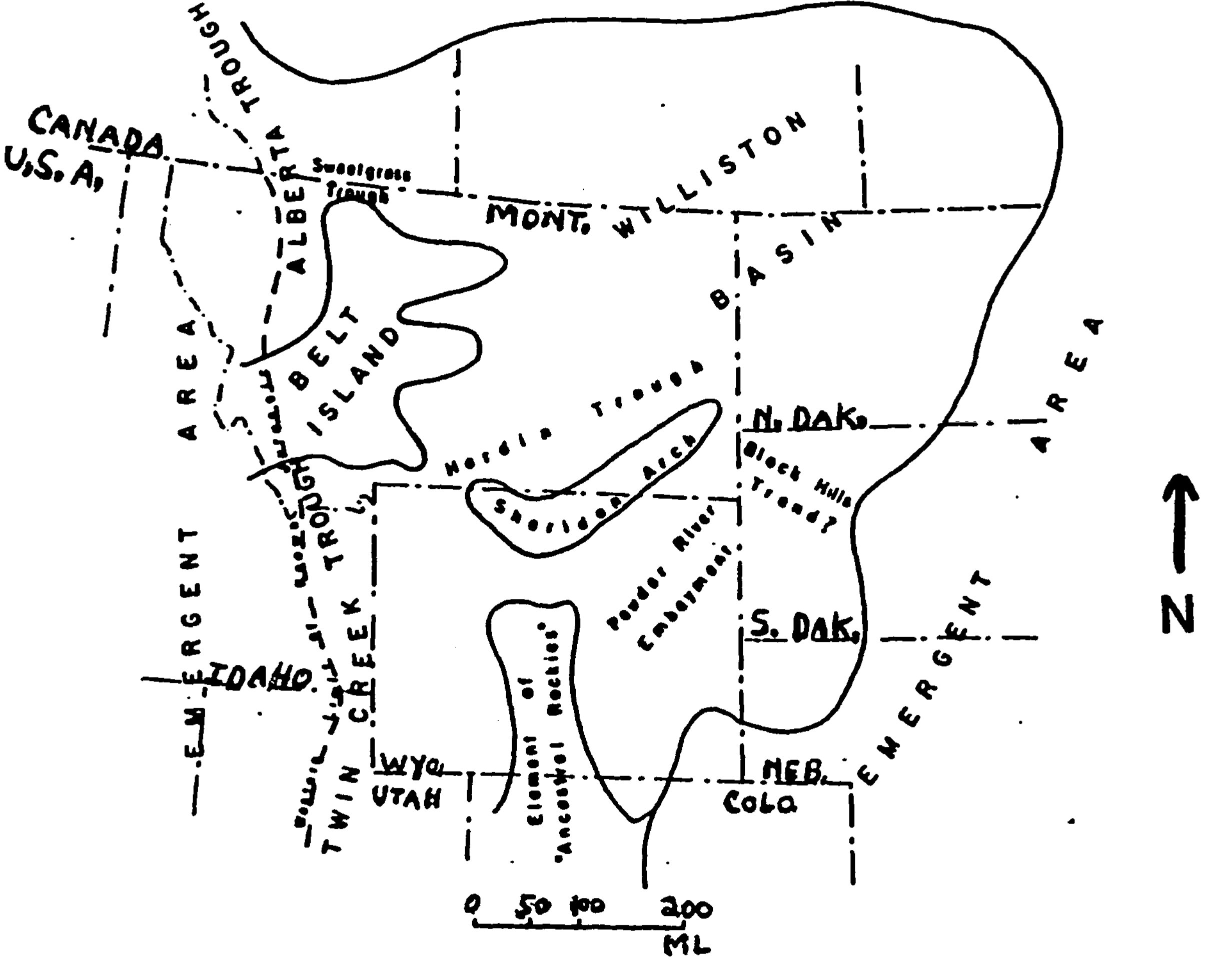


Figure 2. Paleogeography of the Twin Creek Trough (after Peterson, 1957).

paleobiogeographic reconstructions based on bivalves, foraminifera, and ostracodes (the latter two groups are restricted to the "Lower Sundance") and lithologic evidence. Wright (1973) used the geographic distribution of each member to produce a relative sea-level curve for the Twin Creek Limestone. He combined his results with those of Imlay (1950a, 1967) and Peterson (1957). Wright's sea-level curve (Figure 9) is referred to when comparing organic facies (Figure 10), changes in dinoflagellate species abundance (Figures 8 and 10), and parasequences (Figure 11).

Prior to this study, palynological research on the Twin Creek Limestone was conducted in oil companies and by professional consultants. Dr. Gerald Waanders (written commun., 1987) studied outcrop samples from western Wyoming and northeastern Utah, and described several species from the Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek members. His data are referred to in this study.

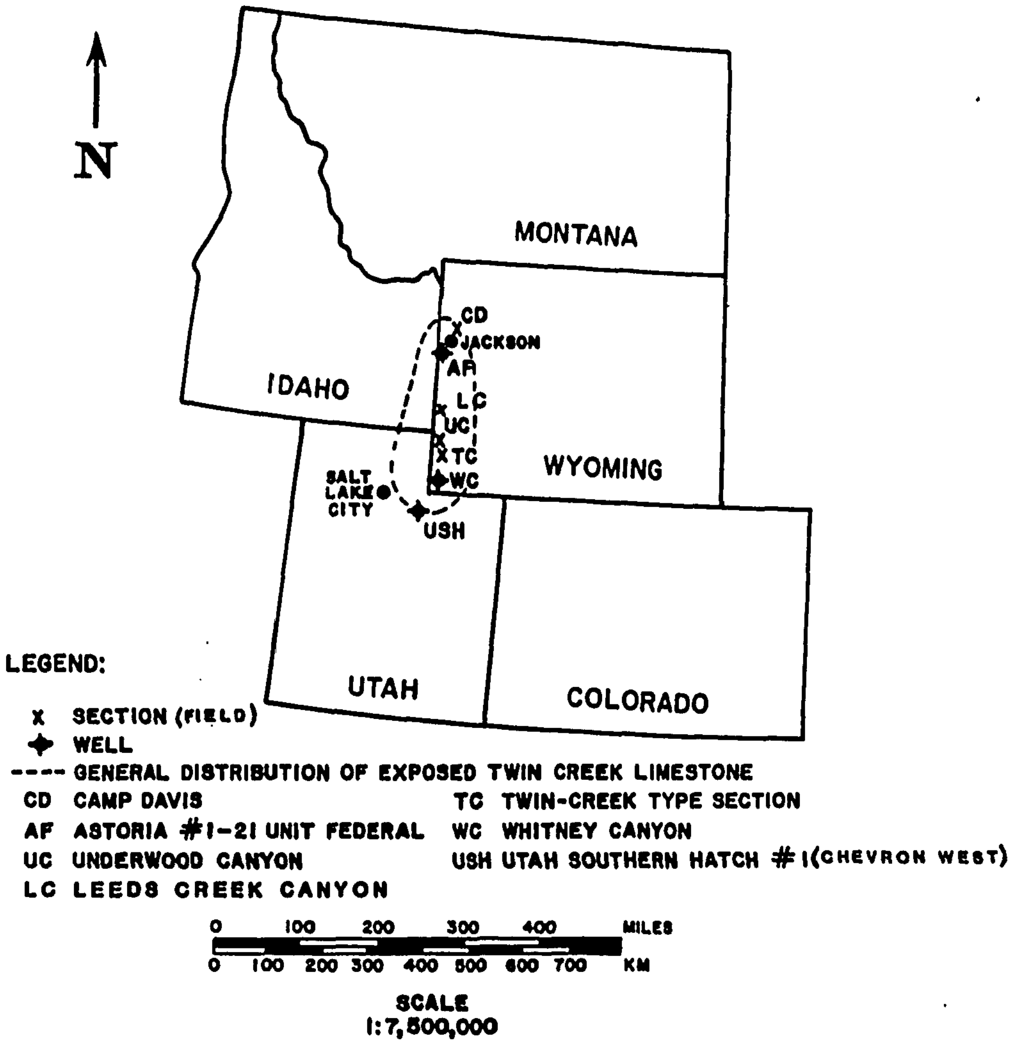
The total organic matter recovered from residues was used to distinguish episodes of marine transgression and regression. The study of palynologically-defined depositional organic facies was used in paleoenvironmental interpretations (Habib, 1979; Batten, 1982a&b; Habib, 1982; Jones, 1987; and Habib and Miller, 1989). The diagensis of organic matter (kerogen) was used in analyses of source potential for petroleum (Batten, 1982b).

Parasequences were established for the Twin Creek Limestone. These genetic units represent regional changes in relative sea-level (Van Wagoner et. al., 1988). Two shallowing upward sequences were recognized and related to the depositional organic facies and to the dinoflagellate stratigraphy.

The organic matter recovered from each studied section was analyzed by the TAI method. Several methods are available to determine thermal maturation and to evaluate source-rock potential (Tissot and Welte, 1978, 1984). The Thermal Alteration Index (TAI) method of Staplin (1969, 1975) utilizes the color of spores and pollen. It is rapid, efficient and inexpensive method for identifying the extent of maturation. Its application to samples in the study area has been conducted by oil company geologists for more than twenty years (S. Nelson, pers. commun.). Its advantage over other methods is the relatively rapid rate at which the stage of maturation is estimated. The disadvantage is that it provides fine resolution in only parts of the maturation scale, whereas vitrinite reflectance and pyrolysis resolve the entire scale from immature to overmature. However, both of the latter methods cannot provide information on age and depositional environment, and are more costly than the TAI method.

The investigated sections are located in northwestern, western, and southwestern Wyoming, and in northeastern Utah (Figure 3). They represent outcrop, core, and drill-cutting material.

Figure 3. STUDY AREA OF THE TWIN CREEK LIMESTONE



GEOLOGIC SETTING

The Twin Creek Limestone is situated within the Idaho-Wyoming-Utah Overthrust Belt of western North America. The belt is part of the Cordilleran Foreland Thrust Belt, which extends from Alaska to Mexico (Allmendinger and Jordan, 1981). It forms part of the Laramide deformation along the ancient western margin of the North American craton. The Idaho-Wyoming-Utah Overthrust Belt (Figure 1) rises from beneath the Snake River lava plain in eastern Idaho and trends east-southeastward into Wyoming and Utah (Grubbs and Van Der Voo, 1976). A series of continuous subparallel low angle thrusts and tight cylindrical folds are situated in a zone approximately 100km wide (Grubbs and Van Der Voo, 1976). Thrusting related to the Laramide Orogeny was episodic in the area from latest Jurassic to the Early Eocene (Armstrong and Oriel, 1965). In western Wyoming, southeastern Idaho and northeastern Utah, the overthrust belt forms a broad salient, which is convex towards the east. The region is cut by six or seven major thrusts, numerous minor thrusts, and late listric normal faults (Royse et al., 1975). The major thrusts become increasingly younger in an eastward direction (Armstrong and Oriel, 1965).

Initial thrusting is inferred for the Late Cretaceous. It continued episodically into Eocene time (Armstrong and Oriel, 1965; Lelek, 1982), and resulted in complex structures including repetitive and overturned strata, synorogenic deposits, and unconformities.

The Twin Creek Limestone was deposited in the Twin Creek trough (Figure 2). It extended from western Utah, northeastward into central Utah and then northward, through north-central Utah into southeastern Idaho and westernmost Wyoming (Peterson, 1957). The trough was part of the larger Rocky Mountain Geosyncline, which was bounded on the east by a broad shelf area extending across the plains of western Canada (Alberta shelf) continuing southward into the United States (Wyoming-Montana shelf) as far as northern Arizona and New Mexico (Peterson, 1957). Sedimentation was influenced significantly by several associated paleotectonic features: Alberta and Twin Creek troughs, Williston Basin (negative trending features), and Belt Island and Sheridan Arch (positive trending features) (Peterson, 1957). A major source for Jurassic siliciclastic sediments of this region is an inferred tectonically active, north-south trending landmass west of the Twin Creek trough (Peterson, 1957; Imlay, 1967). Deposition took place during two episodes of marine transgression and regression ranging in age from ?Middle Bajocian to the early Callovian (Imlay, 1967;

Wright, 1973).

The sediments deposited in the deeper part of the trough (southeastern Utah to southwestern Wyoming) are apparently uniform in thickness. Changes in thickness and facies are most noticeable in the northwesternmost extent of this formation, near the Snake River in southeastern Idaho (Imlay, 1967).

The Twin Creek limestone is predominantly a medium-light gray shaly limestone, which weathers into pencil-like splinters. The members and their respective characteristics are shown in Table 1. Paleontologic evidence is mostly responsible for stratigraphic correlations and age assignments. However, the formation is not very fossiliferous. The fauna are dominated by pelecypods, and then by ammonites, and gastropods, and few echinoid and crinoid fragments. Problems of preservation and of poor fossil recovery, are common.

The stratotype section, limited to the lower four members, occurs approximately 1 kilometer (Km) north of Twin Creek in Sage, Wyoming. The nearest complete section occurs approximately 13 km north of the type section. Here, on Leeds Creek, the upper three members are better exposed than the lower four. Therefore, this section is utilized as the reference section for the upper part of the Twin Creek Limestone (Imlay, 1967).

The members of the formation are described below:

Gypsum Spring Member. It was originally designated as member A by Imlay (1950a) and defined by Oriel (1963) for a basal unit consisting of red beds and associated brecciated limestone and chert-bearing limestone. It rests sharply on the Nugget Sandstone (Imlay, 1967). It is characterized by soft brownish-red to yellow calcareous siltstone and silty claystone containing interbeds of brecciated and chert-bearing limestone (Imlay, 1967). Brecciated limestone with interbeds of red calcareous siltstone occur in western Wyoming and easternmost Idaho. The lithofacies changes to gypsum in northwestern Wyoming and is dominant in Idaho (Imlay, 1967). Imlay (1967) inferred that the brecciated limestone represents the dissolution of interbedded gypsum. The Gypsum Spring characteristically thins or thickens within short distances. It thickens regionally southwestward from approximately 23 meters in western Wyoming to more than 122 meters in Idaho (Imlay, 1967).

The basal contact of this member on the underlying Nugget Sandstone is sharp. The upper contact is a sharp change from soft pink, red, or gray calcareous siltstone to the oolitic or sandy limestone of the overlying Sliderock Member (Imlay, 1967). Crinoid columnals and echinoid spines comprise the megafossil assemblage, indicating full marine salinity.

The age of this member is constrained by an ammonite assemblage (early Late Bajocian age) in the overlying Sliderock Member (Imlay, 1956b;1967;1980;1984). It is generally believed that the Gypsum Spring Member is earliest to late Middle Bajocian in age.

The Gypsum Spring Formation in north-central Wyoming and farther east in Wyoming has been correlated with the lower red bed of the Piper Formation in southern Montana and parts of the Sawtooth Formation in northwestern and southwestern Montana (Imlay, 1948;1954; Cobban, 1945).

The Gypsum Spring Member was initially deposited in a shallow sea which advanced from the west (Imlay, 1967). Abrupt lithologic changes, from red calcareous siltstone with minor amounts of gypsum and calcareous mud in the Gypsum Spring to the overlying fossiliferous oolitic limestone of the Sliderock member, suggest a trend towards increasing marine conditions (Imlay, 1967; Wright, 1973). The presence of gypsum and red beds suggest an oxidizing, warm arid climate.

Sliderock Member. It was first referred to as member B by Imlay (1950a), and defined as a dark fossiliferous, medium to thin-bedded, limestone ranging in thickness from 6 meters to more than 92 meters. It rests sharply on the Gypsum Spring member and is overlain gradationally by the basal shaly limestone of the Rich member (Imlay, 1967).

It is characterized as an indurated dark oolitic limestone grading up to a black to medium gray fossiliferous, thin to medium-bedded, limestone (Imlay, 1967). It is predominantly a medium to thin-bedded, grayish-black to brownish-gray, dense to granular limestone. There is a general thickening of the Sliderock westward and an increase in sand, silt and clay. Oolitic and fossil-rich sediments increase in an eastward and northern direction (Imlay, 1967; Wright, 1973).

Ammonite and pelecypod taxa dominate the fauna. Ammonites are abundant in the northernmost occurrence of the member. Gastropods, echinoid spines and crinoid columnals comprise the remaining megafossil assemblage. Age determinations are based upon the ammonite and pelecypod taxa. The ammonite assemblage is similar to that recovered from middle Jurassic sediments of Alaska(Imlay, 1964;1967), Canada (Frebold, 1963) and in northwestern Montana (Imlay, 1962a), all of which are known to be early to middle Late Bajocian age. Therefore, the Sliderock was assigned an early Late Bajocian age (Imlay, 1967). Deposition occurred in a normal saline, shallow marine environment. A varied and modest occurrence of ammonite and pelecypod taxa (upper part of member) suggests a trend towards increasing marine conditions during Late Bajocian time (Imlay, 1967).

<u>Rich</u> <u>member</u>. It was originally designated as member C by Imlay (1950; 1953a). It was defined as a mostly medium-gray shaly limestone. It becomes increasingly more indurated and thin-bedded towards the top. There is noticeable change in lithology toward the eastern (clay-rich and fossiliferous) and western (calcareous and poorly fossiliferous) limits of its distribution. The basal part is gradational with the underlying Sliderock. The top is marked by a conformable change from shaly limestone to red calcareous siltstone of the overlying Boundary Ridge Member (Imlay, 1967; Wright, 1973).

The fauna of the Rich includes ammonites, pelecypods, gastropods, crinoid columnals and echinoid spines. Ammonite and pelecypod taxa are similar to those recovered from Late Bajocian strata of British Columbia (Mclearn, 1929 in Imlay, 1967), Alaska, Canada, and northwestern Montana (Imlay, 1964;1967;1980). Therefore, the Rich is inferred to be Late Bajocian in age. Support for this age comes from regional lithologic and paleontologic similarities with the Sawtooth Formation in northwestern Montana. Deposition occurred in a shallow nearshore marine environment (Imlay,1967; Wright, 1973). An increase in ammonite and pelecypod abundance in easternmost Idaho and western Wyoming supports this inference (Wright, 1973). The member ranges in thickness from approximately 30 meters in western Wyoming to over 150 m in the Wasatch Range, Utah (Imlay,1967).

The Rich member correlates with the middle claystone and limestone unit of the Gypsum Spring Formation in northern Wyoming (Wright, 1973), and with the lower part of the Carmel Formation in central, southern, and southwestern Utah (Imlay, 1967).

Boundary Ridge Member. It was originally designated as member D by Imlay (1953a). It is defined as an interbedded soft red, maroon, green, or yellow calcareous siltstone; silty to finely sandy limestone; oolitic limestone and greenish-gray silty claystone (Imlay, 1967). The basal part grades down into the underlying Rich Member, with the top overlain sharply by the Watton Canyon Member (Imlay, 1967). The lithology is characterized by yellow silty, sandy and oolitic limestone interbedded with soft red calcareous siltstone which varies within short distances (e.g. miles) (Imlay, 1967). In contrast to the Sliderock and Rich Members, the Boundary Ridge contains a sparse and fragmented assemblage of megafossils. These include crinoid columnals and echinoid spines. In addition pellets, intraclasts and trace fossils (worm burrows) are common (Wright, 1973).

A probable Bathonian age is suggested, based on stratigraphic correlation with the lower part of the "Lower Sundance" and with the upper calcareous siltstone member of the Sawtooth Member in northwestern Montana (Imlay, 1967; Wright, 1973). Additional support comes from the overlying Watton Canyon which has been dated early Late Bathonian (Imlay, 1980;1984; Wright, 1973). Deposition occurred in a very shallow marine environment during decreasing marine conditions. This is indicated by the sparse and fragmented nature of the megafossil assemblages; by the red color of much of the calcareous claystone and siltstone; by the interbedding of oolitic limestone and calcareous siltstone; and by the stratigraphic position between the underlying and overlying marine limestone (Imlay, 1967; Wright, 1973).

The member ranges in thickness from approximately nine meters (easternmost limit) to 87 m (westernmost limit). The Boundary Ridge correlates lithologically with parts of the Piper Formation in south-central, central, and eastern Montana; lower part of the Arapien Shale; and parts of the Carmel Formation in southwestern Utah (Imlay, 1967).

Watton Canyon member. It was originally designated as member E by Imlay (1950a;1953a) and defined as a medium brownish-gray compact brittle medium to thin-bedded limestone ranging from about 18m (easternmost limit) to over 122m (westernmost extent). In most exposed areas, the lower part consists of massive oolitic limestone, whereas the upper part is mainly thin-bedded shaly limestone and calcareous shale (Imlay,1967). The upper part grades into the overlying Leeds Creek member, whereas the basal part sharply overlies the underlying Boundary Ridge Member.

The member is characterized by a poor assemblage of megafossil taxa, most of which have long stratigraphic ranges. An early Late Bathonian age is suggested on the basis of sparse ammonite and pelecypod fossils. These fossils are similar to those recovered from the Canyon Springs Sandstone Member of the "Lower Sundance" Formation (Imlay, 1967; Wright, 1973), of early Late Bathonian age. Lithologic and paleontologic evidence suggests that deposition occurred in a shallow marine environment. The abrupt change from reddish calcareous siltstone of the underlying Boundary Ridge to marine limestone at the base of the Watton Canyon indicates a trend towards increasing marine conditions (Imlay, 1967; Wright, 1973). Stratigraphic correlations are inferred with the Arapien Shale in central Utah and to parts of the Carmel Formation in south-central Utah.

<u>Leeds</u> <u>Creek</u> <u>Member</u>. It was first designated as member F by

Imlay (1950a;1953a). It is defined as a dense, light gray to dark gray shaly limestone and calcareous shale, with minor amounts of oolitic, silty, sandy, and rippled-marked limestone. The upper part grades continually to silty or sandy, ripple-marked limestone of the Giraffe Creek. The lower part is composed of indurated silty to oolitic, sandy, ripple-marked limestone. The member ranges in thickness from about 80 meters (easternmost extent) to more than 488 m (westernmost limit). Pelecypod and ammonite evidence suggests a latest Bathonian to early Callovian age. This is based on similar assemblage of megafossils in the Stockade Beaver Shale member of the "Lower Sundance" ; the upper part of the Rierdon Formation in Montana; middle Jurassic strata from Alaska (Imlay, 1964;1980) and Greenland (Imlay, 1980). Paleontologic and lithologic evidence suggests that deposition occurred in a shallow marine environment during increasing marine conditions (Imlay, 1967; Wright, 1973). Support comes from the observed westward increase in species abundance of pelagic fauna (Imlay, 1967; Wright, 1973). Stratigraphic correlations have been made with the upper part of the Twelve Mile Canyon Member of the Arapien Shale in the Wastach Range of Utah; Stockade Beaver Shale Member of the "Lower Sundance" in northern and central Wyoming; and the upper part of the Carmel Formation in the Uinta mountains of Utah (Imlay, 1967; Sprinkel, 1980; Wright, 1973).

Giraffe Creek Member. It was first designated as member G (Imlay, 1950a;1953a). It is defined as a yellowish to pinkish-gray, silty to sandy, ripple-marked, thin-bedded limestone with interbeds of sandstone, shaly and oolitic limestone (Imlay, 1967). The upper and lower boundaries are generally difficult to determine, due to a combination of indistinctive gradational changes in lithology (lower boundary) and regional faulting (upper boundary) (Imlay, 1967). The member ranges in thickness from approximately eight (8) meters (easternmost limit) to more than 90 m (westernmost extent). This is one of the most distinctive members of the Twin Creek in that it contrasts lithologically with the underlying Leeds Creek and the overlying Preuss Sandstone Formation.

The Giraffe Creek Member does not contain age-diagnostic megafossils. However, an Early Callovian age has been suggested based on its stratigraphic equivalence with the Hulett Sandstone Member of the "Lower Sundance" Formation in north-central and eastern Wyoming, western South Dakota, and in southern Montana (Peterson, 1957; Imlay, 1967; Wright, 1973). These units contain a pelecypod fauna of Early Callovian age. Both the Giraffe Creek and Hulett Sandstone were deposited in a very shallow marine environment during decreasing marine conditions (Imlay, 1967;1980; Wright, 1973). Support for shallowing marine conditions comes from sedimentary structures such as oscillation ripple marks, crossbedding, and oolites.

Regional Setting

The Twin Creek Limestone crops out in an area of extensive thrust faulting along the Idaho-Wyoming State line and in north-central Utah extending from the southern end of the Teton mountains west of Jackson, Wyoming, southward to near the southern end of the Wasatch Range a few kilometers south of Thistle, Utah (Imlay, 1967). The westernmost exposures occur a few kilometers east of Salt Lake City, Utah and in the Idaho Falls area, Idaho. Easternmost exposures occur near Kemmerer, Wyoming (Veatch, 1907; Imlay, 1967). Overall, the Twin Creek Limestone covers an area of approximately 272 km north to south, and 96 km east to west. The general distribution of exposed Twin Creek Limestone is shown in figure 3. The Twin Creek Limestone thickens westward to over 830m near Idaho Falls, Idaho and southwestward to approximately 870m in the Wasatch Range, southwestern Utah. The formation thins to 203m in northwestern Wyoming and to approximately 135m in the Uinta mountains of northern Utah (Imlay, 1967).

Geologic History

Lithologic and paleontologic evidence indicates that there were two discrete episodes of marine transgression, during the ?Middle to Late Bajocian and during the Late Bathonian to Early Callovian. Regression occurred during the Early to ?Middle Bathonian and again during the late Early to Middle Callovian. During ?Middle to early Late Bajocian time, the Jurassic sea spread southward from the Arctic region into western Canada, continuing into Montana, Idaho, Wyoming, and north-central and northeastern Utah. The first sediments were deposited in widespread hypersaline environments (Wright, 1973). These sediments form the Gypsum Spring member. They include gypsum and calcareous siltstone in western Wyoming. Similar sediments occur in the Gypsum Spring formation throughout north-central and eastern Wyoming and in the Black Hills of South Dakota (Wright, 1973). During this time, southeastern Wyoming was a source area for much of the fine siliciclastic sand and silt that was deposited (Wright, 1973).

Transgression continued within the Late Bajocian, which produced normal marine conditions in western and northern Wyoming. Gypsum was replaced by the limestone and shale of the Sliderock and Rich Members in western Wyoming, and by the limestone, shale, and claystone of the middle unit of the Gypsum Spring Formation in northern Wyoming (Wright, 1973). The predominance of lime mud sediment indicates that quiescent open-shelf conditions prevailed during the Late Bajocian (Wright, 1973).

Regression began in the latest Bajocian (uppermost Rich Member) and continued into the ?Middle Bathonian. This resulted in marginal marine conditions which deposited red to maroon calcareous siltstones, shales, and thin oolitic beds of the Boundary Ridge Member in western Wyoming (Wright, 1973). This is supported by the almost complete absence of a well-preserved marine megafauna. Only few shelly fossils occur in this member.

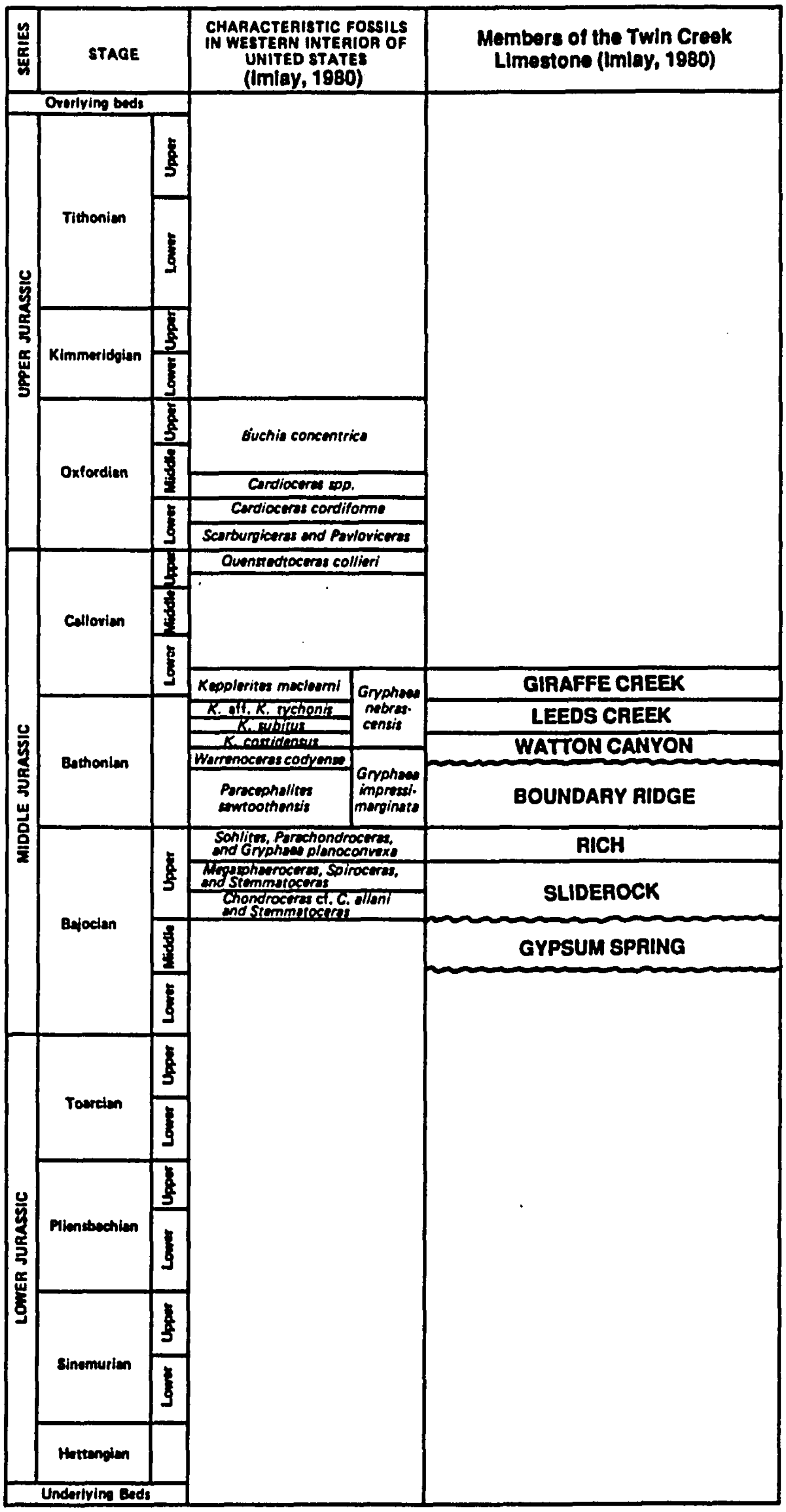
Sea-level rose in the Western Interior during Late Bathonian time. The Late Bajocian was a period of marked deepening across the Wyoming shelf as attested by oolitic limestone and calcareous shale of the Watton Canyon and Leeds Creek Members, respectively. It was followed by an increasing abundance of pelecypods and ammonites in the Leeds Creek Member. This is evident in the stratigraphically equivalent Canyon Springs and Stockade Beaver Shale Members of the "Lower Sundance" Formation. Both members exhibit increasing species abundance of benthic foraminifera, ostracodes, pelecypods, and ammonites (Wright, 1973). The Late Bathonian was also the time of rapid accumulation of lime mud and subsidence.

The maximum marine transgression occurred in the Early Callovian (Wright, 1973). A marine regression began possibly within the late Early Callovian. The regression continued into the Middle Callovian, as evidenced by the absence of marine megafauna of this age within the Western Interior Region (Wright 1973, Imlay, 1980). Sedimentological evidence for a marine regression is derived from the increasingly sandy (siliciclastic) nature of marine sediments within the uppermost part of the Leeds Creek Member, and occurrence of oolitic calcarenites, sandy limestone, and calcareous siltstone of the Giraffe Creek Member. Additional support comes from the stratigraphically equivalent Hulett Sandstone Member of the "Lower Sundance" Formation, which is characterized by crossbedding, ripple marks, shell fragments, and oolites (Wright, 1973). Gypsum and red beds of the overlying Lak Member ("Lower Sundance" Formation) follow deposition of the Hulett sands as hypersaline conditions existed throughout central and southeastern Wyoming and in the Black Hills of South Dakota (Wright, 1973). This episode of marine regression ended the time of Twin Creek Limestone deposition.

Paleontology

The general paleontologic framework for the Twin Creek Limestone is shown in figure 4 (Imlay 1952a,b,c,1962,1967,1980). Imlay (1967) thoroughly described the megafossil assemblages. Ages were obtained mainly by correlation with European stratotype ammonite assemblages, as follows: Sliderock and Rich = Late Bajocian; Watton Canyon = ?middle to Late Bathonian; lower Leeds Creek = Late Bathonian; middle Leeds Creek through Giraffe Creek = Early Callovian.

The Early Bathonian is represented by sediments of the Boundary Ridge Member. The age for this member is based on stratigraphic correlation with time equivalent strata (eg. Rierdon Formation) in southwestern Montana. In spite of these ages, faunal assemblages recovered from the Watton Canyon and Leeds Creek Members are only slightly pandemic, that is, not very similar to assemblages from European stratotype sections (Imlay, 1967,1980,1984). This limits the use of these fossils in assigning precise ages. This provincialism is further indicated by subsequent studies on Jurassic sediments within the Western Interior Region. It is generally agreed that until Late Bajocian time, the megafaunal distribution exhibited an overall Tethyan composition, with a minor Boreal and East Pacific component (Imlay,



SERIES	STAGE		CHARACTERISTIC FOSSILS IN WESTERN INTERIOR OF UNITED STATES (Imlay, 1980)		Members of the Twin Creek Limestone (Imlay, 1980)
Overlying beds					
UPPER JURASSIC	Tithonian	Upper			
		Lower			
	Kimmeridgian	Upper			
		Lower			
	Oxfordian	Upper	*Buchia concentrica*		
		Middle	*Cardioceras spp.*		
		Lower	*Cardioceras cordiforme*		
			Scarburgiceras and Pavloviceras		
MIDDLE JURASSIC	Callovian	Upper	*Quenstedtoceras collieri*		
		Middle			
		Lower	*Kepplerites maclearni*	*Gryphaea nebrascensis*	GIRAFFE CREEK
	Bathonian		*K. aff. K. tychonis*		LEEDS CREEK
			K. subitus		
			K. costidensus		WATTON CANYON
			Warrenoceras codyense	*Gryphaea impressimarginata*	BOUNDARY RIDGE
			Paracephalites sawtoothensis		
	Bajocian	Upper	*Sohlites, Parachondroceras, and Gryphaea planoconvexa*		RICH
			Megasphaeroceras, Spiroceras, and Stemmatoceras		SLIDEROCK
			Chondroceras cf. C. allani and Stemmatoceras		
		Middle			GYPSUM SPRING
		Lower			
LOWER JURASSIC	Toarcian	Upper			
		Lower			
	Pliensbachian	Upper			
		Lower			
	Sinemurian	Upper			
		Lower			
	Hettangian				
Underlying Beds					

FIGURE 4
THE FIGURE SHOWS THE CHARACTERISTIC MACROFOSSILS (AMMONITES AND PELECYPODS) FOR THE TWIN CREEK LIMESTONE. MODIFIED AFTER IMLAY, 1980.

1984; Callomon, 1984; Taylor et al, 1984). At some point during the Latest Bajocian, "Twin Creek" provincialism became acute, persisting until Early Cretaceous time (Imlay, 1984, Callomon, 1984, Imlay, 1984). During this time of provincialism, the area encompassing the Twin Creek Limestone exhibited a megafossil distribution of subboreal affinity. The distribution consisted of a mixture of boreal and endemic, and to a lesser extent East Pacific forms. Tethyan forms have not been recorded within this region in sediments of Latest Bajocian through to Early Cretaceous time (Imlay, 1984, Callomon, 1984). During this time interval, assemblages recovered from sediments in Alaska, western and Arctic Canada, and East Greenland exhibit an exclusive boreal affinity (Imlay, 1984;Callomon, 1984). Taylor et al (1984) further suggested that paleontologic provinces could be established (western United States, Alaska, western and Arctic Canada) on the basis of megafossil assemblages. For example, they named the area encompassing the Twin Creek Limestone as the subboreal Shoshonean province (Taylor et al, 1984). The reasons postulated for the latitudinal provincialism include: a) temperature difference of sea waters from north to south (Imlay, 1984, b) restriction of the seas in the boreal region at certain times (Imlay, 1984), or c) tectonic displacement of fault blocks (allochthonous terranes) in the Pacific coast region (Coney et al, 1980). In addition to the problem of endemism, a question of whether a partial Bathonian hiatus exists is discussed. Up until about the middle 1970's, it was generally believed that most of the Bathonian was missing from the Western Interior Region. This assumption was based on the ages inferred from pelecypod and ammonite evidence (Imlay, 1952a,b,c,1967; Wright, 1973). Subsequent studies on Jurassic ammonite and pelecypod assemblages recovered from sediments in Alaska (Imlay and Detterman, 1973; Imlay, 1975,1980) and western Canada (Hall and Westermann, 1980) have suggested that assemblages originally considered Callovian are Bathonian. These studies suggest that part of the Early and the entire Middle Callovian is absent, possibly implying marine regression (Imlay, 1980,1984).

RESULTS OF INVESTIGATION

Sampling

Six stratigraphic sections, represented by outcrop, core samples and drill cuttings, were selected for study (Figure 3; Appendices 1-13). Considering the size of the area (272 kilometer long X 96 km wide) and the purpose of study, these sections provide sufficient data for palynostratigraphic analysis.

The reasons for selecting the sections are : 1) the Camp Davis section represents one of the few relatively undeformed and complete outcrop sections. Useful paleontologic and lithologic information is available from the studies of Imlay (1967) and Wright (1973). 2) The Chevron West Utah Southern Hatch #1 well represents a cored section which lies within the southern limits of the Twin Creek. Both the Whitney Canyon and Astoria #1-21 Unit Federal wells represent relatively undeformed (Nelson, personal commun., 1987) subsurface sections which lie between the northern and southernmost limits of the Twin Creek. 3) The type section of the Twin Creek lies within the south-central limit of the formation. The upper three members (Watton Canyon, Leeds Creek and Giraffe Creek) are poorly represented in the type section (Imlay, 1967). Therefore, an attempt was made to sample the supplemental reference section at Leeds Creek located approximately 3 miles north of the type section. Because access to the Leeds Creek was not possible a section two miles to the north, Underwood Canyon, was sampled. The Leeds Creek and Giraffe Creek are the only members represented. These samples combined with data from studied sections by Waanders (written commun., 1987) provide a reliable palynostratigraphic framework for the Twin Creek Limestone.

The Twin Creek (type section) and Underwood Canyon sections were sampled by the author at intervals of about three meters in most places. The Twin Creek section represents a combination of two sites located approximately 6.4 kilometers apart. The first site occurs 0.5 km east of Sage, Wyoming and is represented by the Gypsum Spring and lowermost Sliderock members. Total thickness of this site is 33.5 m; 31.7 m of Gypsum Spring and 1.8 m of lowermost Sliderock. Eleven samples were collected. The second site is located 6.4 km to the east and represents the Rich, Boundary Ridge and lowermost Watton Canyon Members. The total thickness of this site is 79.3 m. Twenty-one samples were collected. Both sites combined total 112 m of outcrop referable as the Twin Creek - type section.

The Underwood Canyon section contains 167.7 m of measured section, which is represented by the Leeds Creek and Giraffe Creek Members. However, 74.7 m (Leeds Creek Member) was not sampled because of vegetation cover. Thirty-eight samples were collected. The remaining sections were prepared by Chevron U.S.A., Inc. Drill-cuttings of the Astoria #1-21 Unit Federal and Whitney Canyon wells were also provided by Chevron. Total thickness of both subsurface sections is 747 m and 518.3m, respectively. The Camp Davis and Chevron West Utah Southern Hatch #1 well represent 106.7 m (outcrop) and 582.3 m (core), respectively. The methodology used by Chevron in preparing samples for study is discussed in the following paragraphs.

Selected sections were sampled at intervals of approximately three meters (Camp Davis, Twin Creek - type section and Underwood Canyon sections), 30.5 m (Astoria #1-21 Unit Federal and Whitney Canyon wells), or at intervals of specific lithologies (Utah Southern Hatch #1 well).

Samples and their stratigraphic location are listed in Appendix 1.

Rock samples of 20 to 25 grams were selected from a variety of lithologies at approximately equally spaced intervals. However, some closely spaced samples were chosen because they represent facies changes (see Twin Creek and Underwood Canyon sections).

Rock was crushed into small pieces (approximately 3 millimeters) and then water - washed through a 250 micrometer sieve to eliminate contamination. Next the samples were prepared chemically, utilizing standard palynological preparation techniques(see Doher, 1980) in order to perform palynostratigraphic, organic facies and thermal maturation analyses on the same sample. Oxidizing agents were not utilized since these can destroy and induce color changes in some organic matter. The processed samples were treated chemically according to the following method (Figure 5).

A) treat with dilute (5 - 10%) hydrochloric acid (HCL) overnight for removal of carbonate; wash with distilled water.

B) treat remaining sample in concentrated (52%) hydrofluoric acid (HF) for 1 to 3 days to remove silicates; wash with distilled water.

The Camp Davis samples were prepared by Chevron U.S.A.(Western Region Exploration Lab) using the following method:

A) approximately 50 to 70 grams of crushed rock sample is placed in HCL, HF and then again in HCL to remove all carbonate and silicate material. Next, a slide

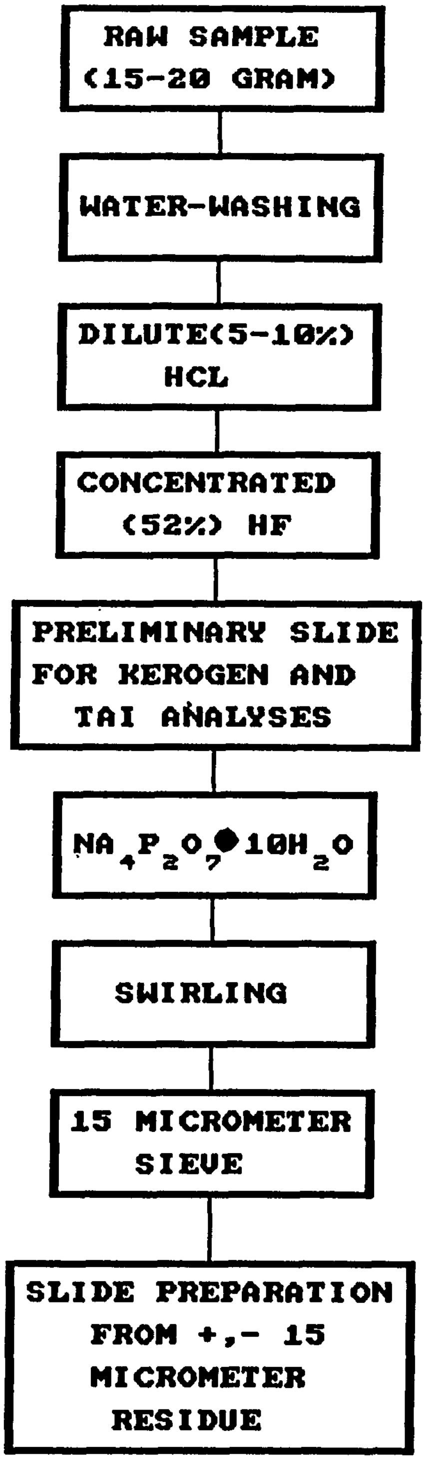


FIGURE 5. FLOWCHART OF PHYSICAL AND CHEMICAL STEPS IN SAMPLE TREATMENT UTILIIZED IN THIS STUDY.

is prepared for Microscopic Organic Analysis and thermal maturation analyses. Remaining organic residue is treated with nitric acid to remove small - sized (less than 15 micrometers) debris and pyrite in order to facilitate palynomorph identification. The remaining residue is sieved through a 15 micrometer sieve in order to concentrate palynomorphs. Two slides are constructed from the fraction greater than 15 micrometers.

One slide is prepared from the organic residue in order to perform MOA and thermal alteration analyses. If the slide contains abundant small - size (less than 15 micrometers) organic particles, the residue is then washed with 0.5 molar sodium pyrophosphate (Na4 P2 07 x 10 H20) in order to separate the fine debris from the coarse fraction (greater than 15 micrometers). The palynomorphs concentrate. Some samples contain significant mineral debris. These samples are swirled (see Doher, 1980).

The next step in slide preparation is to concentrate palynomorphs. Concentration is achieved by sieving residue through a 15 micrometer sieve. Three slides were prepared from the organic residue; two slides from the fraction greater than 15 micrometers and one slide from the fraction less than 15 micrometers. Palynomorphs are mounted in glycerin jelly. The remaining residue is stored in glass vials with a few drops of phenol added to prevent fungal growth.

The samples and slides are stored in the palynology laboratory of the Department of Geology, Queens College, City University of New York, Flushing, New York.

The slides were studied with a Zeiss transmitted light microscope. Palynomorph coordinates were recorded by the use of an England Finder. Photographs were taken with either a 40x objective, a 63x or 100x oil immersion lens using Panatomic X film.

The specimens were measured with a stage micrometer.

The study of each sample included the following:

A) Identification and documentation of palynomorphs.

B) Age determination.

C) Organic matter analysis for depositional facies.

D) Thermal alteration (TAI) analysis.

For each sample, the palynomorphs were counted in order to construct numeric and relative abundance charts. A key to the relative abundance of each group was given in each range chart. Three slides (one organic facies/MOA and two from the fraction greater than 15 micrometers) were used for counting specimens.

Scanning Electron Microscope (SEM) procedure: Some samples from the Camp Davis section were processed for SEM study. These are listed in Appendix 1. A drop of residue suspended in water was placed on a stub and allowed to dry. The specimen was then coated and examined under the SEM. Photographs were taken using polaroid PN55 film.

Regional Dinoflagellate Zonation

A zonation based on selected dinoflagellate taxa is presented for the Twin Creek Limestone. The zones are defined from the Camp Davis section. The Camp Davis section was chosen as a reference section because it is relatively undeformed, contains all members, was sampled at the smallest interval (~three meters) of all studied sections, and contains the best-preserved organic matter. The zonation is preliminary, subject to future revision as additional sections are studied. It encompasses the Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek Members. The Gypsum Spring and Boundary Ridge Members do not contain sufficient dinoflagellate taxa and are not included. They are characterized by terrigenous organic matter.

The zones are defined by first and last occurrences (interval zone) and by total ranges of specific species (taxon range zone). They are dated, for the most part, by ammonite and pelecypod taxa which have been calibrated against ammonite assemblages from Arctic and western Canada, from southern Alaska, and from European stratotype sections (Imlay, 1967, 1980, 1984). Where there is doubt or where there is lack of resolution, ages established by dinoflagellate zonations (Woollam and Riding, 1983) calibrated to European stratotype sections, and to zones established (Davies, 1983) for Arctic Canada were used.

Three zones are defined (Figure 6). Zones established at each studied section are shown in Appendices 1-13. They are described in ascending stratigraphic order.

1. Mendicodinium scrobiculatum Taxon Range zone. It is defined by the total range of the nominative species. Other stratigraphically useful species make their first appearance in this zone. They include Diacanthum filapicatum (Gocht, 1970) Stover and Evitt, 1978, ?Rynchodinopsis regalis (Gocht, 1970b) Stover and Evitt, 1978, Sentusidinium spp., Ctenidodinium norrisii (Pocock, 1972) Stover and Evitt, 1978, and Parvocysta sp.B of Bjaerke, 1982. Some of these species appear restricted to a particular area. For example, Apteodinium sp.1, Ctenidodinium sp.1, and ?Gonyaulacysta sp.1 have only been recovered from the section at Camp Davis.

In the Camp Davis section, the zone encompasses the uppermost Sliderock and entire Rich Member, ranging from 15m above base (Uppermost Sliderock) to the 37m interval (boundary between Rich and overlying Boundary Ridge Member). The interval is represented by approximately one meter of dark gray oolitic limestone, which is overlain by 21 m of medium gray fossiliferous shaly limestone. The megafossils recovered include abundant ammonites and

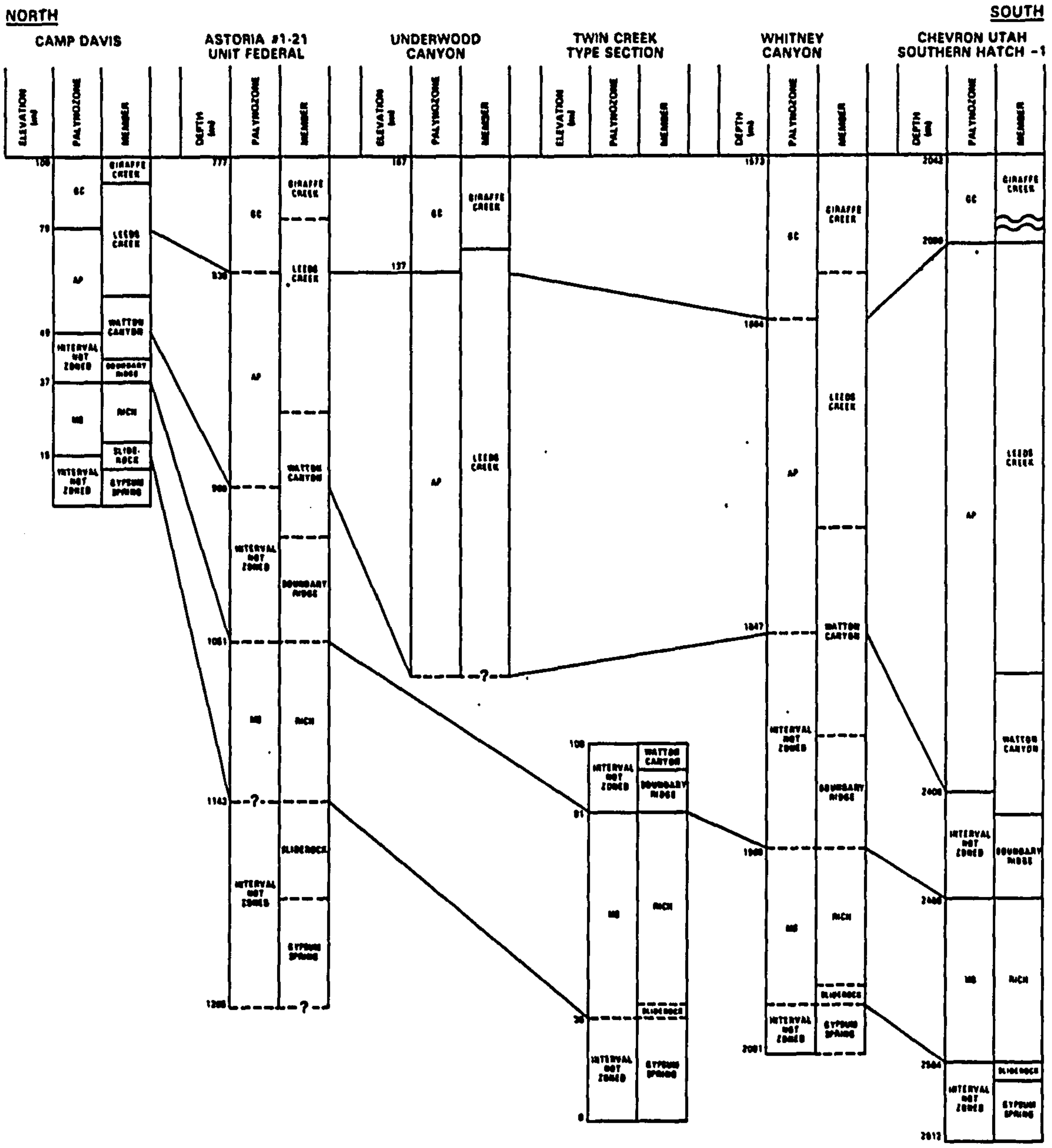


FIGURE 6
PALYNOZONE CORRELATION FOR THE TWIN CREEK LIMESTONE
(FOR COMPLETE DETAILS, SEE APPENDICES)

pelecypods of Late Bajocian age (Imlay, 1967, 1980). The uppermost part of the interval represents a gradational contact between a shaly limestone (Rich) and overlying maroon calcareous siltstone (Boundary Ridge). The zone is recognized in each studied section, except for that at Underwood Canyon. It is recognized in the Twin Creek - type section and Astoria #1-21 Unit Federal well by the association of the nominative species and Sentusidinium spp. In the type section, the zone ranges upward from 30.5 m above base of section to 85.4 m; the interval 30.5 to 36.6 m represented by gray oolitic limestone of the Sliderock, 36.6 m to 85.4 m composed of medium gray shaly limestone of the Rich Member.

The zone is represented in the Astoria #1-21 Unit Federal well by the interval 1143.3 m to 1051.5 m. The lithology is dominated by gray shaly limestone along with some gray oolitic limestone and maroon/red calcareous siltstone.

In the Whitney Canyon well, the zone comprises the entire Sliderock and Rich Members representing the interval 2061 m (Sliderock) to 1969.5 m (Rich). Oolitic limestone dominates the interval 2061 m to 2030.5 m, whereas gray shaly limestone prevails from 2030.5 m to 1969.5 m. The zone is recognized by the association of the nominative species, C. norrisii, D. filapicatum, and

Sentusidinium spp.

The interval 2564.3m to 2468m, dominated by shaly limestone, delimits the zone in the Utah Southern Hatch #1 well. It is recognized by the first appearances of *D. filapicatum*, *C. norrisii*, and *Sentusidinium* spp.

Characteristics: low (nine) species abundance represented by proximate and proximochorate cysts.

Age: early Late to Late Bajocian based on cosmopolitan ammonite and pelecypod assemblages (Imlay, 1967, 1980, 1984). The lower boundary coincides approximately with the middle of the *Stemmatoceras*, *Megasphaeroceras*, *Spiroceras*, and *Gryphaea planoconvexa fraterna* assemblage, whereas the remaining part of the zone correlates to the *Sohlites*, *Spinosus*, *Parachondroceras andrewsi*, and *G. planoconvexa* assemblage (Figure 6). Both ammonite and pelecypod assemblages are recognized from European stratotype sections.

2.*Atopodinium prostatum* (Ap) Interval Zone. It is defined from the first appearance of *Atopodinium prostatum* Drugg, 1978 to the first appearance of *Gonyaulacysta centriconnata* Riding, 1983. *A.prostatum* first appears in Upper Callovian (*P.athleta* Zone) strata of England (Drugg, 1978, p.63). *G.centriconnata* first appears in Middle Callovian (*Erymnoceras coronatum* Zone) strata of eastern

England (Riding, 1983, p.202). Species making their first appearance include *Rynchodiniopsis cladophora* (Deflandre, 1938b) Stover and Evitt, 1978, *Ellipsoidictyum cinctum* Klement, 1960, *E. reticulatum* (Valensi, 1953) Lentin and Williams, 1977b, *E. gochtii* Fensome, 1979, *Glomodinium evittii* (Pocock, 1972) Davies, 1983, *Pareodinia ceratophora* Deflandre, 1947c; emend. Gocht, 1970b, *P. groenlandica* Sarjeant, 1972, *P. brachythelis* Fensome, 1979, *Ctenidodinium sellwoodii* (Sarjeant, 1975a) Stover and Evitt, 1978, *Endoscrinium galeritum* (Deflandre, 1938b) Vozzhennikova, 1967, *Korystocysta gochtii* (Sarjeant, 1976a) Woollam, 1983, *Aldorfia aldorfensis* (Gocht, 1970b) Stover and Evitt, 1978, *Valensiella ovula* (Deflandre, 1947c) Eisenack, 1963a, *Ctenidodinium chondrum* Drugg, 1978, *Escharisphaeridia pocockii* (Sarjeant, 1968) Erkmen and Sarjeant, 1980, *Heslertonia teichophera* (Sarjeant, 1966a) Sarjeant, 1976c, *H.pellucida* Gitmez, 1970, *Chytroeisphaeridia chytroeides* (Sarjeant, 1962a) Downie and Sarjeant, 1965; emend. Davey, 1979d, *C.scabrata* Pocock, 1972, *Tubotuberella dangeardii* (Sarjeant, 1968) Stover and Evitt, 1978; emend. Sarjeant, 1982, *Lithodinia jurassica* Eisenack, 1935; emend. Gocht, 1975b, *Gonyaulacysta* sp.A of Pocock, 1972, *G. eisenackii* (Deflandre, 1938b) Dodekova, 1967; emend. Sarjeant, 1982, *G. jurassica* subsp. *adecta* Sarjeant, 1982, *Hystrichogonyaulax pectinigera* (Gocht, 1970b) Stover and

Evitt, 1978; emend. Fensome, 1979, Valensiella ampulla Gocht, 1970b, Meiourogonyaulax caytonensis group (Sarjeant, 1959) Sarjeant, 1969, Komewuia cf.stoveri Chen, 1978, and Occisucysta cf.balios Gitmez, 1970. Ctenidodinium norrisii last appears within the lower to middle part of the zone.

In the Camp Davis section, the zone encompasses the middle (approximately 41m interval) part of the Watton Canyon through the upper middle (79m interval) part of the Leeds Creek Member. The lithological sequence consists of a lowermost 6m of dark gray oolitic limestone overlain by 5m of gray calcareous, 6m of gray oolitic limestone, and 21m of gray calcareous shale for a total of 38m of sediment.

In the Utah Southern Hatch #1 well, the zone is represented by the interval 2408.5m to 2090.8m; 2408.5m to 2341.5m represented by gray silty to oolitic limestone of the Watton Canyon, 2341.5m to 2090.8m comprising gray calcareous silty shale of the Leeds Creek Member. However, this is not true with regard to the Astoria #1-21 Unit Federal, Whitney Canyon, and type section. It is recognized in the Astoria #1-21 Unit Federal well by the association of R. cladophora group, G. evittii, E. gochtii, Sentusidinium spp., and V. ovula. The zone corresponds to the interval 960.4m to 838.4m; 960.4m to

914.6m equivalent to gray oolitic limestone and calcareous siltstone of the Watton Canyon, 914.6m to 838.4m represented by gray shaly and oolitic limestone of the Leeds Creek Member.

The association of Sentusidinium spp. (abundant), E. gochtii, R.cladophora group, V.ovula, G.evittii, and M. caytonensis group identifies the zone in the Whitney Canyon well. It is represented in the interval from 1847.6m to 1664.6m. The interval from 1847.6m to 1786.6m consists of gray shaly and oolitic limestone with some calcareous siltstone of the Watton Canyon, 1786.6m to 1664.6m represented by gray limestone with some calcareous siltstone of the Leeds Creek Member.

Only the lowermost part of the Watton Canyon Member was recovered at the type section. Dinoflagellates were not recorded from the lowermost part of this member. Therefore, the zone is not recognized in this section. In the Leeds Creek Member of the Underwood Canyon section it is recognized by the presence of A.prostatum, R. cladophora group, Sentusidinium spp., E.reticulatum, and V.ovula. The zone ranges from the base of the section to 137.2m, and is represented by mostly gray shaly limestone with interbeds of oolitic to pelloidal limestone.

The variation in species abundance between sections may be related to several factors, such as the paleoenvironment (offshore versus nearshore setting; episodes of transgression) and/or postdepositional processes (microbial decay, thermal alteration).

The Astoria #1-21 Unit Federal, Whitney Canyon, and Utah Southern Hatch #1 sections exhibit some corrosion to the organics as well as thermal alteration (possibly mature to overmature).

Characteristics: the zone exhibits a rich and diverse (50 species) assemblage of dinoflagellates, which are represented by proximate, proximochorate, and chorate cysts.

Age: late Middle to early Late Bathonian based on the Twin Creek ammonite assemblage, which includes the upper part of the Warrenoceras codyense to the Kepplerites cf.K. tychonis/Kepplerites maclearni boundary.

3.Gonyaulacysta centriconnata Interval Zone. It is defined by the interval from the first appearance of the nominative species to the top of the section containing dinocysts. It is tentatively assigned as an interval zone until a palynologic investigation of the overlying Jurassic Preuss Sandstone Formation can be made. Other species making their first appearance include

?Korystocysta thulia (Davies, 1983); emend. Du Chene et al., 1986; Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978, Leptodinium subtile Klement, 1960, Sirmiodinium grossii Alberti, 1961; emend. Warren, 1973, Acanthaulax sp.1, Stephanelytron cf.redcliffense Sarjeant, 1961a; emend. Stover et al., 1977, and Cleistosphaeridium spp. The latter three are known only from the Camp Davis section. There is also an increase in abundance of M. caytonensis group, E. gochtii, V. ovula, G. evittii, R. cladophora group, and A. prostatum. The last appearance of G. jurassica and D. filapicatum occurs within the middle to upper part of the zone.

In the Camp Davis section, the zone encompasses the middle upper Leeds Creek and the Giraffe Creek Members, which includes the interval 79m to 100m; 79m to 97m consists of calcareous shale, 97m to 99m sandy limestone, and 99m to 100m calcareous sandy siltstone.

Recognition of the zone in the Astoria #1-21 Unit Federal well is by the association of L. subtile, M. caytonensis group, E.gochtii, and the last appearance of G. jurassica and D. filapicatum. It occurs within the interval 838.4m to 777.4m; 838.4m to 807.9m gray limestone with some oolitic limestone representative of the Leeds Creek, 807.9m to 777.4m consisting of oolitic and shaly limestone with some calcareous siltstone of the Giraffe

Creek Member.

The zone is recognized in the Whitney Canyon well by the association of M. caytonensis group, L. subtile, E. cinctum, and last appearance of A. prostatum and D. filapicatum. It is represented by the interval 1664.6m to 1573.2m. The interval from 1664.6m to 1634.1m consists of gray limestone with some calcareous siltstone of the Leeds Creek; the interval from 1634.1m to 1573.2m is composed of calcareous siltstone and oolitic limestone of the Giraffe Creek Member.

The association of M. caytonensis group, S.grossii, E. cinctum, E. gochtii, and A.prostatum identifies the zone in the Underwood Canyon Canyon section. It occurs within the interval 137.2m to 167.7m. The interval from 137.2m to 143.3m consists of gray limestone/calcareous shale with interbeds of oolitic and pelloidal limestone of the Leeds Creek member; the interval from 143.3m to 167.7m sandy shaly limestone of the Giraffe Creek Member.

In the Utah Southern Hatch #1 well, the zone is recognized by the same association as found in the Camp Davis. It occurs within the interval from 2090.8m to 2042.7m, which consists of calcareous sandy siltstone to sandy limestone of the Giraffe Creek Member.

Dinoflagellates disappear within either the uppermost part of the Leeds Creek, or in the Giraffe Creek Member. Furthermore, dinoflagellates have not been recovered from the upper part of the Giraffe Creek Member in the studied sections.

Deposition of the Giraffe Creek occurred during a time of decreasing marine conditions which may explain the apparent disappearance of dinoflagellates. However, dinoflagellates have been recovered in the Giraffe Creek Member from the Utah Southern Hatch #1 and Underwood Canyon sections. A possible explanation may lie in the paleoenvironment. For example, both sections are located in the southernmost extent of the Twin Creek trough, an area in which each member attains maximum thickness. Favorable marine conditions may have persisted to permit the existence of some dinoflagellates, even during a time of marine regression. In addition, there is a trend towards a decrease in abundance of dinoflagellate species in studied sections located to the north of the Utah Southern Hatch #1 and Underwood Canyon sections.

Characteristics: A rich and diverse (37 species) assemblage of dinoflagellates, which include proximate, proximochorate, and chorate cyst types.

Age: Early to late Early Callovian based on ages provided by dinoflagellate stratigraphy correlated against ammonite-dated European stratotype sections (Woollam and Riding, 1983; Riding, 1985), and by dinoflagellate assemblages recovered (Davies, 1983) from Jurassic age strata of Arctic Canada. Ammonites, as well as many dinoflagellate, recovered from Arctic Canada are similar specifically to those from European stratotype sections (Davies, 1983). Therefore, the zone ranges in age from the base of the Macrocephalus ammonite zone to possibly, the Coronatum/Jason boundary. However, the age of the upper boundary of the zone is in question because of an inconsistency between studied sections. For example, dinoflagellates range throughout most of the Giraffe Creek Member in the Utah Southern Hatch #1 and Underwood Canyon sections. However, they are rare to absent in the remaining sections. As a result the upper boundary is defined only in the Utah Southern Hatch #1 and Underwood Canyon sections (Giraffe Creek Member), which contain dinoflagellates of probable Early to late Early Callovian age.

The Twin Creek Limestone zonation has been compared to regional (unpublished) and worldwide (published) dinoflagellate stratigraphy for the purpose of determining its chronostratigraphic potential. Waanders (unpublished) has proposed that certain dinoflagellate species are useful for dating members of the Twin Creek Limestone. The study was centered on three sections located in northcentral Utah (Thistle) and in western Wyoming (Cottonwood Creek and South Piney Creek). Waanders noted that the Sliderock and Rich Members could be characterized by the species Leptodinium sp.R and Alga sp.A. This latter form is questioned as a dinoflagellate because it does not exhibit an archeopyle nor any other evidence of tabulation (Waanders, written commun.). It has been recovered from the Rich member of the Astoria #1-21 Unit Federal and Camp Davis sections, and possibly in the lower part of the Leeds Creek member in the latter section. Waanders has utilized the last occurrences of both Leptodinium sp.R and Alga sp.A to denote the boundary between the Rich and Boundary Ridge Members (Upper Bajocian/Bathonian boundary). The boundary corresponds to the top of the (Ms) zone in the present study. Similar to that observed in the present study, dinoflagellates are rare to absent within most of the Boundary Ridge sediments studied by Waanders.

Several dinoflagellate species are considered by Waanders to be characteristic of the overlying Watton Canyon, Leeds Creek and Giraffe Creek Members. Species Ellipsoidictyum reticulatum (formerely Dictyopyxidia reticulata), Valensiella ovula, and V. ampulla are considered characteristic of the Watton Canyon and Leeds

Creek Members, and suggest a Bathonian age (Waanders, written commun.)

In the present study, the species have been recovered from both members, included in both the Atopodinium prostatum and Gonyaulacysta centriconnata zones. Rynchodiniopsis cladophora, Ctenidodinium ornatum, Sentusidinium spp., and Gonyaulacysta pectinigera are considered characteristic of the upper Leeds Creek and Giraffe Creek Members (Waanders, written commun.). In the present study, both R.cladophora and Sentusidinium spp. are abundant within the middle to upper Watton Canyon and Leeds Creek Members. However, C. ornatum has not been observed in any of the studied sections. Both studies suggest that the interval from the middle part of the Leeds Creek through the Giraffe Creek represents Early to possibly late Early Callovian time.

In conclusion, a similarity exists between dinoflagellates identified in the present study and those recorded by Waanders (unpublished), and that there is agreement with respect to the position of the stage boundaries.

Several Jurassic dinoflagellate zonations have been published, covering various parts of the sequence studied (Figure 7). Some of the zonations were derived largely from compilation (Sarjeant, 1979) of world-wide data and

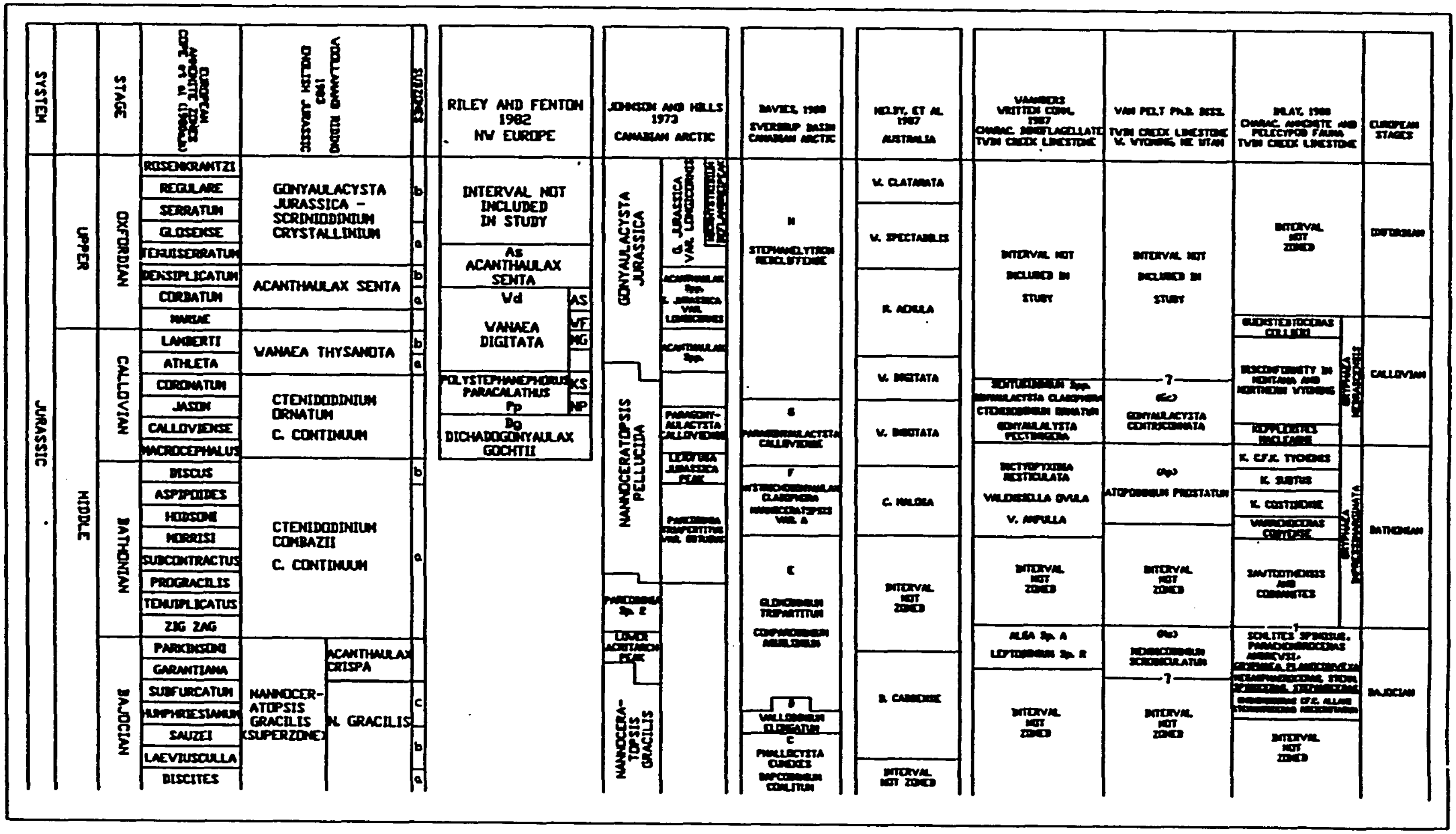


FIGURE 7. COMPARISONS OF REGIONAL PALYNOZONES TO SELECTED ESTABLISHED ZONATIONS.

difficult to apply to any given rock sequence. Others were derived from a single locality and lack resolution (see Woollam and Riding, 1983).

Beju (1971) established four zones (J1 to J4) for Toarcian through Tithonian sediments from the Carpathian Foreland of Roumania. However, they are broad-based and lack resolution (Woollam and Riding, 1983). For example, the *Nannoceratopsis gracilis* zone represents the Bajocian and Bathonian stages, whereas *Gonyaulacysta cladophora* zone spans the entire Callovian and Oxfordian time.

Pocock (1972) defined seven zones for parts of the Jurassic of western Canada. They were based on spore and pollen assemblages, with some data on dinoflagellate species. No direct comparisons can be made with his zonation. Johnson and Hills (1973) established a series of zones of Toarcian through Volgian (Kimmeridgian (pars) and Portlandian) age in the Canadian Arctic. Their zonation is based on three widespread localities with poor macrofossil control. The position of some stage boundaries is considered tentative and confusing (Woollam and Riding, 1983). There does not appear to be much in common with the Twin Creek Limestone, except for the following: the "Lower Acritarch Peak" of the Upper Bajocian correlates (in age) with the *Mendicodinium scrobiculatum* zone (Late Bajocian); acritarchs (*Micrhystridium*) are abundant within the lower part of the Mendicodinium scrobiculatum zone; the P. calloviense subzone (Early Callovian) contains some species, such as Endoscrinium galeritum and R. cladophora, which are also recorded in the present study. However, both species first appear within sediments of Bathonian age; the Acanthaulax spp. subzone (Upper Callovian) includes Acanthaulax sp.2, which is similar to Acanthaulax sp.1 found within the G.centriconnata zone (Early to late Early Callovian).

Riley and Fenton (1982) compiled four zones and five subzones based principally on unpublished data from northwest Europe (northwest Scotland, southern and eastern England, and northern France). The Dichadogonyaulax gochtii zone (Early Callovian) is dominated by species of Lithodinia and Dichadogonyaulax and associated with Sentusidinium and Nannoceratopsis. In addition, A. aldorfensis and H. pectinigera occur within the zone. Both latter species, as well as species of Lithodinia and Sentusidinium, are present in both the Atopodinium prostatum and Gonyaulacysta centriconnata zones.
The Polystephanephorus paracalathus zone (Early to Middle Callovian) contains the first appearance of the genus Stephanelytron (especially S. redcliffense) and Atopodinium prostatum (middle part of the zone). In the Twin Creek Limestone,S. cf.redcliffense first appears within the Gonyaulacysta centriconnata zone, whereas A.

prostatum first appears within the Atopodinium prostatum zone. There does not appear to be any other direct comparisons, however. For example, several species which first appear in the Bathonian to Early Callovian Twin Creek Limestone, first occur in sediments of Late Callovian to Early Oxfordian age in northwest Europe. They include Lithodinia jurassica, E. galeritum, G. jurassica, R. cladophora, E. pocockii, and L. subtile.

Woollam and Riding (1983) established four zones and five subzones for the English Jurassic, which were calibrated against (stratotype) ammonite fauna. However, because of spot sampling dinocyst boundaries may only approximate ammonite zonal boundaries. The Acanthaulax crispa subzone (Garantiana - Parkinsoni - Late Bajocian) exhibits slight similarity to the time equivalent Mendicodinium scrobiculatum zone. For example, D. filapicatum and species of Ctenidodinium first appear within the same time interval in both regions. However, unlike the Mendicodinium scrobiculatum zone, the Acanthaulax crispa subzone exhibits a rich and diverse assemblage of dinoflagellates, and includes the first appearances of the Ellipsoidictyum/Valensiella complex, H. pectinigera, Ctenidodinium spp. (ornate forms), Tubotuberella spp., A. aldorfensis, P. ceratophora, Escharisphaeridia spp., and the M. caytonensis group. In spite of this abundance of species, there appears to be a trend towards a decrease in species abundance to the north (northern England). The above species first appear in the Twin Creek Limestone within the ?Middle to Upper Bathonian (Ap) zone. There also appears to be a difference in the abundance of dinoflagellates. Unlike English sections, the interval is represented by a low abundance of species. The English Bathonian is represented by the C. combazii - C. continuum zone, which is characterized by the appearance of Ctenidodinioid (Woollam and Riding, 1983). The upper part of the zone includes the first appearances of S. grossii, Cleistosphaeridium spp., the local reduction in the number of C. sellwoodii, and last appearance of C. combazii (Woollam and Riding, 1983). In contrast, dinoflagellates have only been recovered from ?Middle to Upper Bathonian dated sediments (A.prostatum zone). Furthermore, there is not an abundance of ornate Ctenidodinioid cysts nor S.grossii or Cleistosphaeridium spp. Both species first appear within the G.centriconnata zone. The A.prostatum zone does, however, contain a rich and diverse assemblage of species, of which includes Ctenidodinium sellwoodii and C. chondrum.

The C. ornatum - C. continuum zone (lower Macrocephalus to top of Coronatum - Early to Middle Callovian) is characterized by the almost complete disappearance of Ctenidodinioid cysts at the base of the zone, along with an increase in abundance greater than that observed for the Bathonian (Woollam and Riding, 1983). The lower part of the zone contains species found within the lower to middle part of the *G.centriconnata* zone, which include *M. caytonensis* group, *Cleistosphaeridium* spp., *G. jurassica*, *Sentusidinium* spp., and *Stephanelytron* spp. The occurrence of the species together support an Early Callovian age for the *G.centriconnata* zone.

In summary, there are both similarities and differences between the Jurassic of Europe and that of the Western Interior Region of North America. Differences include a rich and diverse distribution of dinoflagellates during Late Bajocian time for European sections, whereas a low abundance characterizes the Twin Creek Limestone. Furthermore, species of the genus *Nannoceratopsis* range throughout the Jurassic of Europe. They have not been recovered from Twin Creek sediments. The Bathonian (middle to upper) of the Western Interior Region exhibits a rich and diverse assemblage of dinoflagellates. Counterwise, few new dinoflagellate species appeared within the European realm (Woollam and Riding, 1983).

There are also similarities between both regions. For example, both regions were subjected to a Late Bathonian marine transgression (continuing through into the Callovian), which resulted in an influx of dinoflagellates, as well as an introduction of new species.

Comparisons have also been made with established zonations for the Jurassic of Canada. For example, Davies (1983) proposed seventeen dinoflagellate zones for Upper Pleinsbachian through Hauterivian strata of Arctic Canada. The zones are dated principally by ammonites and characterized by low species abundance of dinoflagellates and long ranging species, which is typical of high latitude dinoflagellate assemblages (Davies, 1983). There is little comparison during Late Bajocian through to the Middle Bathonian time. Only Chytroeisphaeridia chytroeides appears in both regions. However, similar assemblages are apparent during the Late Bathonian and the Callovian. In Davies (1983), the Nannoceratopsis senex var.A (F) zone, dated Late Bathonian, contains the first appearances of R. cladophora, A. prostatum, Heslertonia teichophera, and E. cinctum. These species first appear also in the Twin Creek Limestone A.prostatum zone.

The Late Bathonian to Early Callovian of Arctic Canada is represented by the Paragonyaulacysta calloviense (G) zone. The zone includes the first appearances of E. pocockii, G.jurassica, L. jurassica, and S. grossii, along with the continuing occurrence of the previous species. The same species make their first appearance within the A.prostatum zone. The Stephanelytron redcliffense (H) zone (Early Callovian to Upper Oxfordian) contains the first appearances (near the base of the zone) of the nominative species, ?Occisucysta thulia, and E. galeritum. They first appear, excluding the latter species, within the G.centriconnata zone, and are used to support a Early to late Early Callovian age for it. In summary, a correlation between dinoflagellate species of both regions for the Late Bathonian through Early Callovian time is evident, which may be related to a Late Bathonian marine transgression inferred for both regions.

Other established Jurassic zones include the Oppel zonation (7 miospore and 7 dinoflagellate) erected by Davies (1985) for the Lias of Portugal. However, due to an apparent lack of marine sediments, zones based on dinoflagellate species have not been developed for Bajocian and younger strata. In fact, few species, represented by the genera Ellipsoidictyum, Lithodinia, and Sentusidinium, have been recovered from sediments dated Early to Late Bajocian. Species of the latter genus are represented in each of the three zones of the Twin Creek Limestone. There also appears to be a correlation between species of Late Bathonian age. For example, both regions experienced a sudden increase in the number of dinoflagellate species, including the first appearances of E. gochtii, Escharisphaeridia pocockii, G. jurassica, Glomodinium evittii, Gonyaulacysta eisenackii, Tubotuberella dangeardii, V. ampulla, R. cladophora, C.

chytroeides, *A. prostatum*, and *L. jurassica*. However, unlike the Western Interior Region, a decrease in dinoflagellate species abundance prevailed during the Late Bathonian and into the Callovian in Portugal. Dinoflagellate zones were also established for the Jurassic of Australia. Helby et al (1987) defined seven zones for Bajocian through Kimmeridgian sediments from various basins in Australia. The zones were dated by ammonites. When ammonites were absent, European dinoflagellate data was utilized. There does not appear to be any similarity between regions with respect to dinoflagelate assemblages. However, similar times of marine transgression and regression appeared to have occurred. Both regions exhibited a marine regression during the Latest Bajocian into the early Middle Bathonian, and increasing marine conditions during Late Bathonian time.

Dinoflagellate Species Abundance And Depositional Organic Facies

1. Stratigraphic change in number of dinoflagellate species

Dinoflagellate species and palynologically-defined depositional organic facies are useful for determining intervals of marine transgression and regression. An increase in the number of dinoflagellate species and of specimen abundance coincides with episodes of marine transgression. Multiple occurrences of dinoflagellate species coincide with the base of an interval indicating the beginning of marine transgression immediately above sediments representing marine regression. A decrease in the number of species and specimen abundance correlates with episodes of marine regression. Dinoflagellate taxa are poorly represented within intervals representing maximum marine regression.

Relatively few palynological studies have centered on the use of palynomorphs for distinguishing sedimentary cycles of marine transgression and regression. However, they have shown some interesting results. One of the first studies pertained to Early Tertiary sediments of the Gippsland Basin of southern Australia. Partridge (1976) recognized dinoflagellate "ingressions" (sudden introduction of numerous species) in sediments representing initial marine transgression as inferred by seismic and lithological evidence. Partridge noted that these "ingressions" occurred immediately above sediments indicating marine regression.

Habib and Miller (1989) recognized sudden multiple occurrences of dinoflagellate species in sediments considered on lithologic evidence to represent increasing marine conditions. This influx of dinoflagellate species occurred at the base of an interval indicating the beginning of marine transgression immediately above sediments representing a marine regression. Therefore, the multiple occurrence datum is considered to represent the first palynological evidence of marine transgression (Habib and Miller, 1989). The authors further suggest that the influx of species reflects the life mode of these marine algae. Dinoflagellates are considered to be "opportunistic species" which invade and immediately occupy niches made available during transgression (Habib and Miller, 1989). Changes in dinoflagellate species abundance were recorded. Increases in dinoflagellate species abundance occurred with a trend towards maximum marine transgression as defined by lithological evidence. Maximum dinoflagellate species abundance appears coincident with the time of maximum marine transgression.

As conditions changed towards marine regression, there was a decrease in the number of dinoflagellate species. This apparent correlation between dinoflagellate species abundance and intervals of marine transgression and regression may be related to the paleoenvironment. Habib and Miller (1989) noted that species abundance increased in an offshore direction, whereas few species were recovered from sediments representing a very shallow nearshore setting. This trend in species abundance was also observed in Tertiary sediments from the Atlantic coastal plain of Maryland by Goodman (1977), who recorded an increase in the number of dinoflagellate species in an offshore direction.

A study of surface sediments by Wall et al (1977) supports these findings. It does appear, therefore, that changes in dinoflagellate species abundance correlates with intervals of marine transgression and regression.

In this study, parameters such as dinoflagellate species abundance, multiple occurrence datum and organic facies, are used to detect sedimentary cycles of marine transgression and regression in the Twin Creek Limestone. Dinoflagellate species and specimen abundance were determined, for each sample, by counting all specimens from three palyniferous slides representing organic residue greater than 15 microns in diameter. Results for the Camp Davis section are shown in table 2.

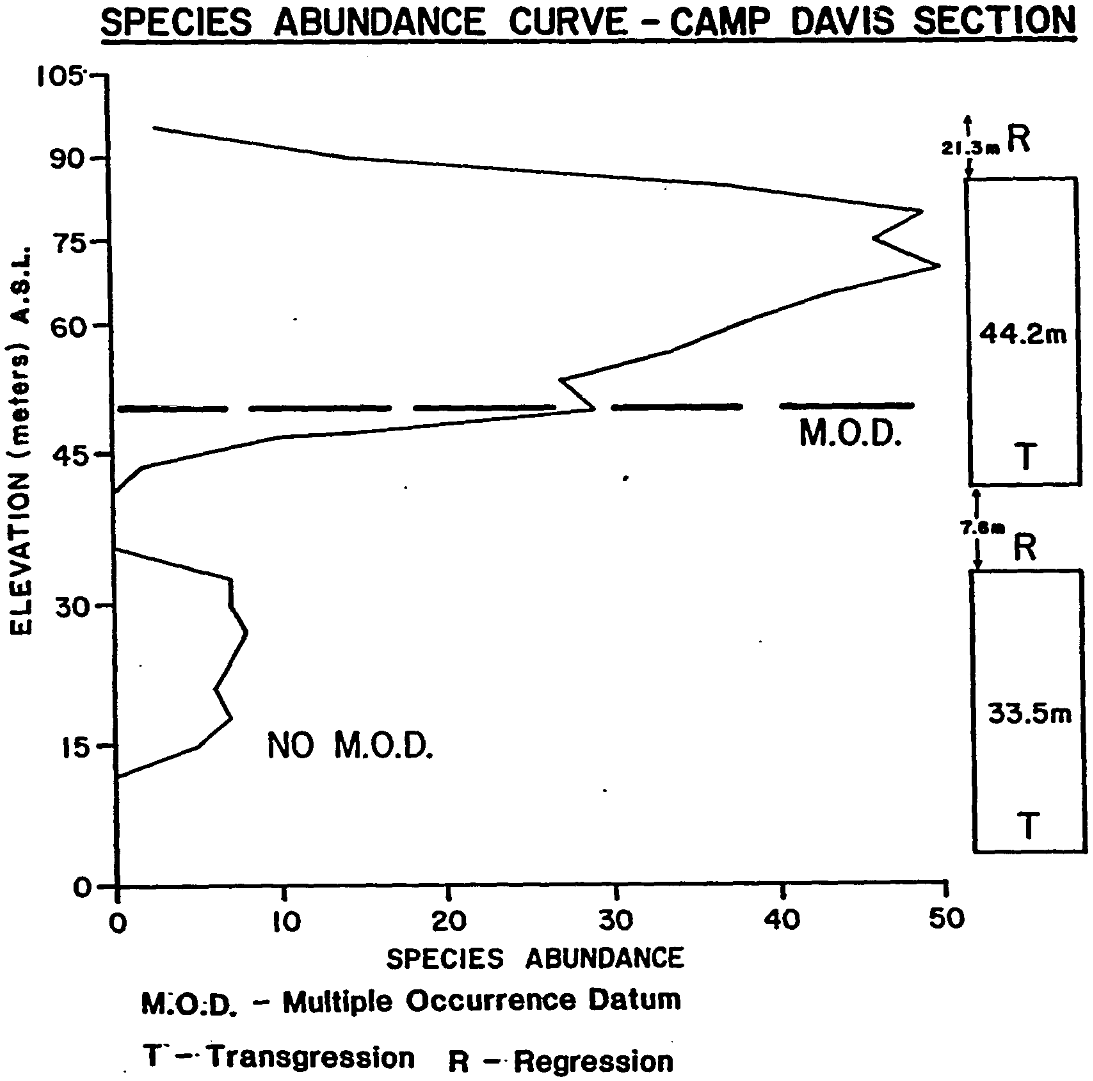
A graphic representation of dinoflagellate species and specimen abundance for the Camp Davis section is shown in Figure 8. Two intervals of dinoflagellate species are observed. The lower interval (basal part of the section) exhibits low species (six) and specimen (59) abundance and corresponds to the lowermost part of the Rich Member. This member represents an offshore muddy shelf facies deposited during an inferred Late Bajocian marine transgression (Figure 9). An overall low species abundance has also been recorded in the marine invertebrate distribution (Imlay, 1967). The upper interval corresponds to the Watton Canyon and Leeds Creek Members which represent a shoal and offshore muddy shelf facies, respectively. The upper interval is discussed in the following paragraphs.

Dinoflagellate species and specimen abundance increases slightly within the Rich Member to a maximum of eight species and specimen abundance of 100 (Figure 10). This observation coincides to the interval of maximum marine transgression as inferred by lithologic and paleontological evidence. Immediately above this interval there is a decrease in species and specimen abundance (7 and 33, respectively), which coincides to the beginning of a marine regression. Marine regression appears to reach a

MEMBERS	Sample #	Species Abundance	Specimen Abundance
GC	27	3	27
LC	26	14	159
	25	37	545
	24	49	1138
	23	46	1473
	22	50	1544
	21	43	1193
	20	38	610
	19	34	545
WC	18	27	396
	17	29	664
	16	10	131
	15	2	8
BR	14	0	0
	13	0	0
R	12	0	0
	11	7	33
	10	7	48
	9	8	107
	8	7	97
	7	6	24
	6	7	123
	5	5	59
S	4	0	0
GS	3	0	0
	2	0	0
	1	0	0

Table 2. Species and specimen abundance of dinoflagellates per sample for the Camp Davis section.

Figure 8- Dinoflagellate Species Abundance Curve for the Camp Davis section.



CAMP DAVIS SECTION

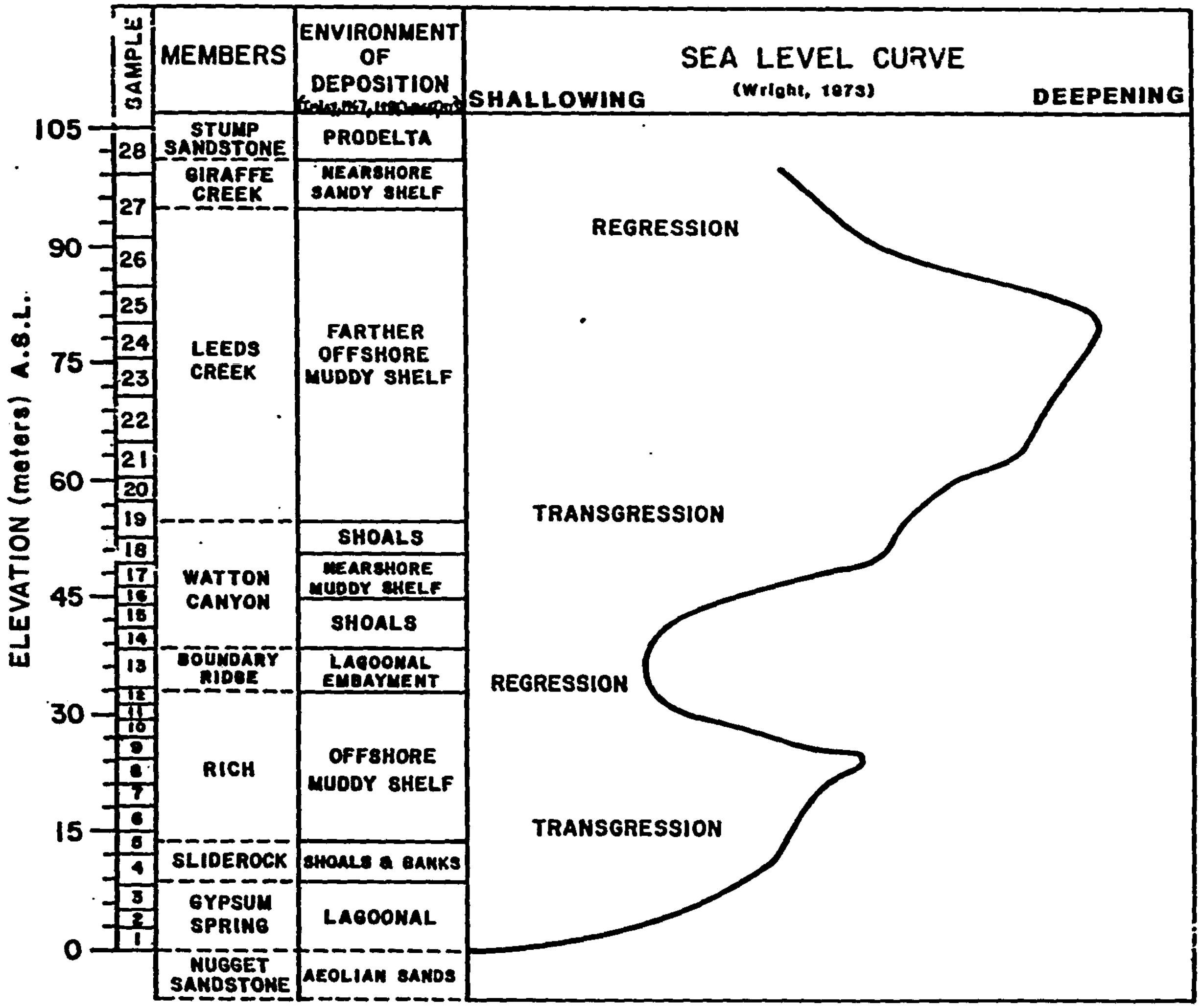


Figure 9. Comparison of Members, Depositional Environment, and Sea-Level Curve.

CAMP DAVIS SECTION

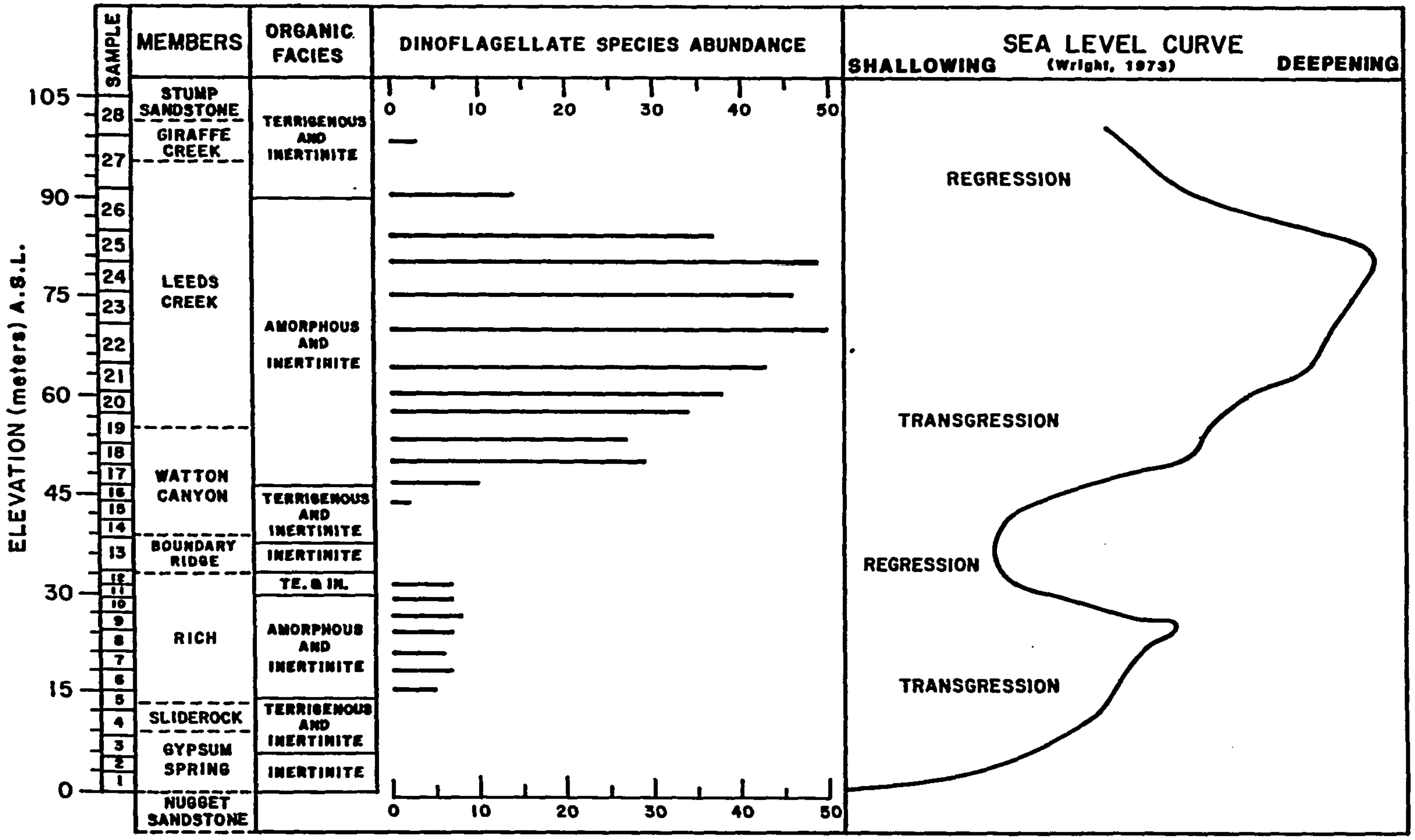


Figure 10. Comparison of Organic Facies, Species Abundance, and Sea-Level Curve.

maximum during the Early Bathonian and is represented by shallow marine sediments of the Boundary Ridge Member(see table 1). Dinoflagellate species are poorly represented in this member.

Marine conditions returned to the Western Interior Region during a late Middle to Late Bathonian marine transgression. This is represented by the basal part of the Watton Canyon Member, which is composed of oolitic sediments interpreted as a shoal facies. Dinoflagellate species appear within the basal part of this member. However, they constitute only two species in eight specimens. The number of species and specimens (11 and 100, respectively) of dinoflagellates increases immediately above this interval. A facies change (calcareous shale representing a nearshore muddy shelf setting) occurs near the middle of this member, which represents a continued rise in sea-level (Imlay, 1967; Wright, 1973). An influx in the number of dinoflagellate species (29 species, 664 specimens) occurs within the middle part of the Watton Canyon Member. This sudden appearance of species represents a multiple occurrence datum and is considered to be the first palynological evidence of marine transgression. Marine transgression continued throughout the upper part of the Watton canyon and into the Leeds Creek Member. Dinoflagellate species and specimen abundance continues to increase with increasing marine conditions, and reaches a maximum (50 species, ~1500 specimens) within the lower upper part of the Leeds Creek. This coincides with a time of maximum transgression as defined by lithological and paleontological evidence.

Dinoflagellate species and specimen abundance decreases (11 species, 159 specimens) within the uppermost part of the Leeds Creek Member, coinciding with a facies change towards a sandy (detrital and coarser carbonate particles) limestone. This facies change represents a change toward a marine regression, which continues throughout the uppermost part of the Leeds Creek and through the overlying Giraffe Creek Member. Dinoflagellate species and specimen abundance decreases to a minimum (three species, 27 specimens) within the middle part of the Giraffe Creek Member.

The trend in dinoflagellate species abundance has also been observed in studies concerning the megafossil distribution. Imlay (1953a, 1967, 1980) has remarked that a low species abundance of ammonites and pelecypods occurs in the Sliderock and Rich Members, whereas an increase in species abundance occurs within the Watton Canyon and Leeds Creek Members. He has also noted that a decrease in species abundance occurs within the Giraffe Creek Member.

A similar trend in species and specimen abundance was recorded within the bivalve, foraminifera (benthic), and ostracod distribution from the stratigraphically equivalent "Lower Sundance" Formation by Wright (1973). Wright (1973) has shown that these faunal groups exhibit low species and specimen abundance during times of marine regression (Hulett Sandstone Member) and increase in species abundance with marine transgression (Canyon Springs Sandstone and Stockade Beaver Shale Members). The Hulett Sandstone is equivalent to the Giraffe Creek, whereas the Canyon Springs Sandstone and Stockade Beaver Shale are corretable to the Watton Canyon and Leeds Creek Members, respectively.

Low dinoflagellate species abundance appears persistent during Bajocian time. In fact, only 25 genera and 29 species of dinoflagellates have been recorded worldwide from Bajocian sediments (Bujak and Williams, 1979). Species abundance increases during the Bathonian and Callovian from 43 genera and 78 species to 47 genera with 90 species, respectively (Bujak and Williams, 1979). This worldwide increase in dinoflagellate species abundance appears generally related to increasing marine conditions, which are inferred for this time period (Haq, 1973: in Bujak and Williams, 1979). According to Bujak and Williams (1979), other factors such as sediment supply and type, nutrient supply, basin circulation, seasonal fluctuations, biological interactions, and salinity changes need consideration when determining causes affecting species abundance patterns.

Overall, it appears that dinoflagellate species and specimen abundance are valuable palynological tools in detecting intervals of marine transgression and regression.

In addition to the use of species and specimen abundance, the total organic residue of the samples has been studied. This parameter also appears useful in recognizing intervals of marine transgression and regression.

2. Depositional Organic Matter.

Depositional organic facies is defined as the total amount of thermally immature organic matter in sediments which can be used to identify and distinguish environments of deposition (D. Habib, pers. commun., 1988). The concept of Organic Facies is generally attributed to Combaz (1964) who proposed the term "Palynofacies" as equal to the "microscopic organic constituents extracted from a rock after maceration" (Combaz, 1964, p. 205). Subsequent studies broadened the application of organic facies in the analysis of source potential (thermally mature organic matter as the result of diagenesis) for petroleum (Batten, 1982a,b) and in paleoenvironmental (thermally immature organic matter as the result of a particular depositional environment) interpretations (Habib, 1979; Batten, 1982a&b; Habib, 1982; Habib and Drugg, 1983;).

The organic facies established for the Camp Davis section is shown in Figure 10. It is established on the basis of the predominant constituents occurring in the residues. Three facies are distinguished in the Camp Davis stratigraphy based on the abundance of amorphous debris and marine microplankton, terrigenous material (including land plant tissue, pollen, and spores), and inertinite, respectively.

The <u>Amorphous</u> <u>Debris</u> <u>Facies</u> is defined by the dominance of well-preserved granular amorphous debris (Habib and Miller, 1989). Inertinite is common in the majority of the samples and is abundant in several. Tracheal and cuticular tissue, pollen and spores are considerably fewer in numbers than the marine microplankton. The origin of the granular amorphous debris is considered to be similar to that suggested for the Late Maestrichtian to Danian sediments of the Atlantic Coastal Plain. Habib and Miller (1989) consider this material to be largely the fecal remains of zooplankton which fed on phytoplankton and other organic particles. Evidence for their interpretation was based on studies of modern zooplankton which were fed a diet of dinoflagellates (Porter and Robbins, 1982). These zooplankton produced fecal pellets which are similar in size and form to the fossil fecal pellets observed by Habib and Miller (1989). However, the origin of amorphous debris cannot be considered entirely fecal in nature. Studies on Upper Jurassic to Lower Cretaceous sediments from Northwest Europe concur that amorphous debris is a largely a product of both marine and nonmarine environments (Batten, 1982a,b). Amorphous debris produced in marine environments appears mostly granular but can be also fairly massive or flakely, and commonly contains relict structures of pyrite (Batten, 1981: in Batten, 1982b). Nonmarine amorphous debris appears fibrous and is difficult to separate from other unstructured substances derived from land plants (Batten, 1982a). Additional support for a nonmarine origin are large numbers of Botryoccus algae associated with the amorphous debris (Batten, 1982a). Batten (1982a,b) considers organic facies dominated by granular amorphous debris to have been deposited under restricted marine (estuarine) conditions as shown by association with numerous tasmanitids, foraminiferal linings, and leiospheres. However, in both this study and in Habib and Miller (1989), amorphous debris dominates residues of sediments clearly marine (nearshore to offshore) in origin. In the Camp Davis section, the amorphous facies is represented in a calcareous shale/shaly limestone lithofacies.

The <u>Vascular Tissue Facies</u> is defined by the dominance of well-preserved vascular and cuticular tissue, and a large variey of pollen grains and spores. There is a decrease in the number of dinoflagellate species and specimen abundance, fewer acritarchs, and fewer foraminiferal linings and tasmanitids than in the amorphous facies. Granular amorphous debris is noticeably reduced in amount. The majority of the residues contain significant amounts of inertinite. The terrigenous facies occurs in the Camp Davis section in lithofacies interpreted as lagoonal, shoals and banks, and shallow marine sandy shelf settings.

The <u>Inertinite Facies</u> is defined by the dominance of non-structured carbonized debris in residues, which are for the most part barren or impoverished of palynomorphs. Granular amorphous debris occurs as a minor component. Palynomorphs (dinoflagellates, pollen, and spores) are poorly represented and poorly preserved. This condition may be attributed to diagenetic oxidation and/or recycling (Habib and Miller, 1989). The inertinite facies occurs in lithofacies interpreted as lagoonal.

Dinoflagellates show an increase in species and specimen abundance within the upper Sliderock, Rich, Watton Canyon, and Leeds Creek Members. This supports lithofacies evidence which indicates prevailing marine conditions during the deposition of these members. This trend is also in agreement with the distribution of organic facies, which indicates an upward change from inertinite and vascular tissue facies in the Gypsum Spring and Sliderock, respectively to development of amorphous and inertinite facies in the Rich Member. Dinoflagellate species also appear in the lowermost part of the Rich and increase with respect to species and specimens through to the upper part of the member. Vascular tissue and inertinite prevail within the uppermost part of the Rich coincident with a decrease in dinoflagellate species abundance (including total marine microplankton assemblage), and continue throughout the Boundary Ridge Member. The change in organic facies and species abundance suggests a trend towards shallowing marine conditions, which is corroborated by lithofacies and the sea-level curve. A change in organic facies is again apparent within the lower part of the Watton Canyon Member. Amorphous debris and inertinite facies, in conjunction with multiple occurrences of dinoflagellate species, occurs at the base of lithofacies (oolitic limestone and calcareous shale) deposited under increasing marine conditions. Marine conditions persist throughout the rest of the Watton Canyon and most of the overlying Leeds Creek. This is supported by the continued presence of the amorphous debris and inertinite facies along with an increase in dinoflagellate species and specimen abundance. Dinoflagellate species and specimen abundance reach a maximum within the lower upper Leeds Creek, which is coincident with a maximum marine transgression as indicated by the sea-level curve.

A decrease in the number of species and specimens occurs immediately above the interval along with a transition from amorphous debris to vascular tissue. This indicates a trend towards shallowing marine conditions, which is supported by the sea-level curve (beginning of a marine regression). Marine regression continued throughout the uppermost Leeds Creek and persisted through the Giraffe Creek Member. Vascular tissue and inertinite facies along with very few dinoflagellate species comprise organic assemblages extracted from Giraffe Creek sediments.

Overall, there is a relationship between total organic content and episodes of marine transgression and regression as defined by lithological and paleontological evidence. Intervals of shallowing marine conditons are represented by influxes of terrigenous material and carbonized debris along with reduced assemblages of marine microplankton. This possibly reflects the proximity to source of land vegetation as well as stressful environmental conditions characteristic of shallow nearshore settings. Episodes of increasing marine conditions are represented by influxes of amorphous debris, marine microplankton, and inertinite. Increasing abundance of marine microplankton could be related to a combination of factors such as availability of nutrients, niches, and equitable climatic conditions. Terrigenous material is considered a minor component of increasing marine conditions.

Parasequences

A parasequence is defined as a "relative conformable succession of genetically related beds bounded by marine flooding surfaces" (Van Wagoner et. al., 1988). The boundaries are usually transgressive as erosional surfaces. The sedimentary packages are considered to represent changes in sea level relative to the surface of deposition.

Parasequences are vertical in nature and classified into three types:

A) Shallowing upwards: where rate of subsidence is less than the sedimentation rate resulting in progradation, hence regression.

B) Deepening upwards: where rate of subsidence is greater than the sedimentation rate resulting in a transgression.

C) Aggradational: where rate of subsidence is equal to the sedimentation rate resulting in a stationary setting.

Two shallowing upwards (A) parasequences are presented for the Camp Davis section (Figure 11).

Parasequence 1 is represented by sediments of the Gypsum Spring, Sliderock, Rich, and Boundary Ridge Members. The lower boundary represents the unconformable contact between the underlying eolian (nonmarine)

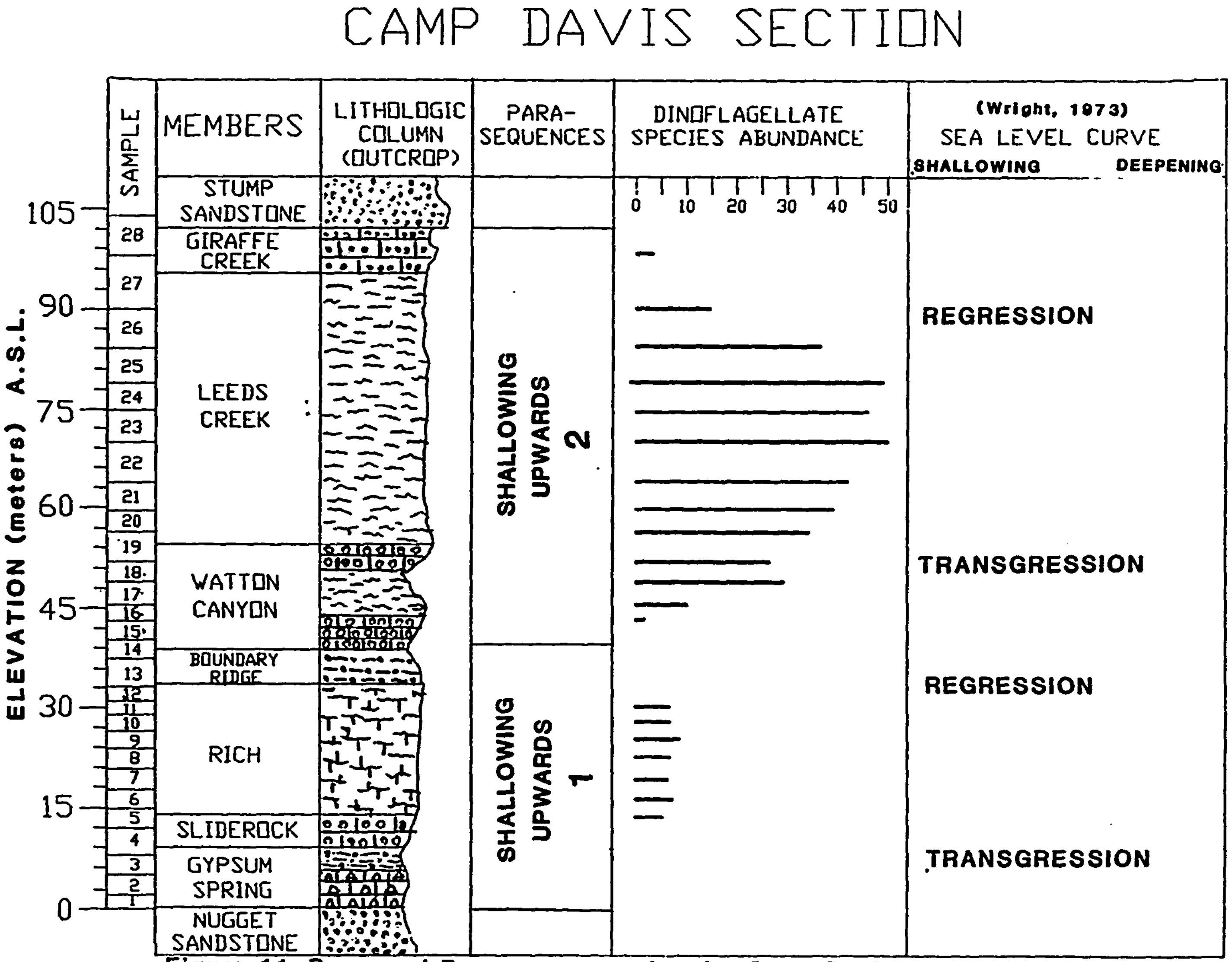


Figure 11. Proposed Parasequences for the Camp Davis section.

sandstone of the Nugget Sandstone Formation (Early Jurassic) and overlying brecciated limestone of the Gypsum Spring Member. The boundary is interpreted as denoting the beginning of marine transgressive (?Middle Bajocian age) conditions. The brecciated limestone is interpreted as forming in a nearshore very shallow marine, hypersaline setting (Imlay, 1967; Wright, 1973). The limestone is gradationally overlain by a calcareous siltstone of the Gypsum Spring Member. Few macrofossils, in the form of fragmented crinoid columnals and echinoid spines, are present in both the limestone and siltstone. However, the presence of the macrofossils indicates full marine salinity.

A study of the palynomorphs reveals the presence of inertinite, some amorphous debris, and varying amounts of pollen. The palynomorph distribution can be attributed to the environment (very shallow marine, hypersaline setting) in which the sediments were deposited. Supporting sedimentological evidence for the environment includes the oxidized appearance (maroon to red color) to the calcareous sediments (Gypsum Spring Member) and interbedded salt and gypsiferous sediments of the time equivalent Gypsum Spring Formation, occurring to the southeast in central Wyoming. Results from the palynological study support this inference. There is abundance of inertinite accompanied by a complete absence of marine microplankton, and dominance of Classopollis pollen. Classopollis pollen is interpreted as pollen produced by the conifer family Cheirolepidiaceac, which inhabited coastal marine hypersaline environments, during the Jurassic (Francis, 1984).

Immediately above the calcareous siltstone occurs an oolitic limestone unit representative of the Sliderock Member. Oolitic sediments of the Sliderock Member are interpreted as a continuation of marine transgressive conditions, and representing shoals formed in a nearshore shallow marine setting (Imlay, 1967; 1980; Wright, 1973). Macrofossils, mostly in the form of fragmented pelecypod and ammonite assemblages, are fairly well-represented. Fragments of crinoid columnals, echinoid spines, and gastropods have also been recovered. The echinoderms (crinoids, echinoids) indicate full marine salinity.

The palynomorph distribution includes amorphous debris, inertinite, and varying amounts of pollen, spores, foraminiferal linings, acritarchs (rare), and dinoflagellates (very rare fragments). Most of the distribution is fragmented owing to the nature (high energy) under which the sediments were deposited. Immediately above the oolites occurs a unit of shaly limestone representative of the Rich Member. The contact between both units appears conformable. It has been suggested (Imlay, 1967, 1980; Wright, 1973) that the unit of shaly limestone formed within an offshore shallow marine (subtidal) environment. It is based primarily upon the results from macrofossil studies of Imlay (1952a,1967, 1980) and Wright (1973). Results show well-preserved assemblages dominated by ammonite and pelecypod fauna, which indicate a trend towards increasing marine conditions. It is supported by results from this study, which show an abundance of amorphous debris, marine microplankton, such as dinoflagellates, acritarchs, foraminiferal linings, and tasmanitids, compared to lesser amounts of pollen, spores, tracheal and cuticular tissue, and inertinite. In fact, the number of species and specimens of dinoflagellates, as well as the number of specimens of foraminiferal linings, acritarchs, and tasmanitids increases upwards within the unit indicating a continued increase in marine conditions.

Results from this study support the contention that the Sliderock and most of the Rich Member were deposited during a Late Bajocian marine transgressive event. A lithological and paleontological change occurs within the upper middle to upper part of the shaly limestone unit (Rich Member). It is represented by a change towards an increasing silty and sandy component, an increase in inertinite, pollen, spores, tracheal and cuticular tissue, as well as a significant decrease in marine macrofossils and dinocysts (species and specimens), and has been interpreted as a change towards shallowing marine conditions.

The gradual change towards a calcareous siltstone/sandstone represents the boundary between the Rich and overlying Boundary Ridge Member. The Boundary Ridge Member is interpreted as being deposited within a shallow marine to littoral or lagoonal setting (Imlay, 1967; 1980). Supporting evidence for the environment are the presence of oscillation ripples, horizontal burrows, almost complete absence of dinocysts (except for very few fragmented specimens), and oxidized appearance (maroon to red color) to the sediments (Imlay, 1967, 1980). Results from the palynological study support this inference. There is an abundance of inertinite accompanied by a complete absence of marine microplankton, except for the rare appearance of the dinoflagellate Sentusidinium and rare fragmented foraminiferal linings. Immediately overlying the unit is a sharp contact with oolitic sediments representing the Watton Canyon Member. This boundary denotes the top of parasequence I.

Parasequence II is represented by sediments of the Watton Canyon, Leeds Creek, and Giraffe Creek Members. The base of the sequence represents the contact between the underlying Boundary Ridge and the Watton Canyon Member. The oolitic sediments of the Watton Canyon are interpreted as shoal deposits formed during the beginning stages of a ?Middle to Late Bathonian marine transgression (Imlay, 1967, 1980).

Marine macrofossils and dinocysts are well-represented and mostly fragmented (high-energy environment). Pelecypod and ammonite fauna dominate the macrofossils, whereas amorphous debris, dinoflagellates, acritarchs, foraminiferal linings, and tasmanitids comprise most of the palynomorph assemblage. Tracheal and cuticular tissue, pollen, and spores are less represented. Both the marine macrofossil and palynomorph assemblage increase with respect to the number of species and specimens throughout the member and into the overlying Leeds Creek.

In addition to oolitic sediments, the Watton Canyon contains a calcareous shale unit, which conformably overlies the oolites interpreted as the lower part of the transgression. It is within this unit that marine microplankton exhibit a dramatic increase in species and specimen abundance. In fact, there is a threefold (2 to 29) increase in the number of dinoflagellate species within 3 meters of sediment. The sudden increase in species coincides with the base of an interval sedimentologically-defined as representing initial marine conditions. The unit of calcareous shale is considered to represent a change towards an offshore shallow shelf setting based on the marine macro and microfossil evidence. There is a return to oolitic sediments (thin unit) immediately above the calcareous shale. These sediments comprise the upper part of the Watton Canyon Member and represent either a brief interval of shallowing or change in position of shoreline. There does not appear to be any significant change in the marine macrofossil or palynomorph assemblage. Therefore, a trend towards marine shallowing and/or regression is not supported by paleontological evidence. Furthermore, the change in lithology has not been observed in the remaining studied sections. It could be argued that the oolitic sediments reflect a local change in shoreline position. Immediately above the oolites lies a thick unit of calcareous shale representing the Leeds Creek Member. The contact between the two units is conformable and represents the boundary separating the Watton Canyon and overlying Leeds creek Member. The thick sequence of calcareous shale has been interpreted as representing an offshore shallow shelf (subtidal) setting (Imlay, 1967, 1980). It was deposited during a continuation of marine transgressive conditions which began during the Late Bathonian.

Marine macrofossils and palynomorphs are well-represented and occurr throughout the entire unit. Pelecypods dominate followed by ammonites and few gastropods. Amorphous debris and dinoflagellates are abundant followed by acritarchs, foraminiferal linings, and tasmanitids. Terrestrial-derived pollen and spores are also represented. However, they comprise a much smaller percentage than the marine microplankton. Maximum marine transgression is inferred for the upper Middle to lower Upper part of the member based upon the geographical extent of the marine calcareous shale deposits, and supplemented by macrofossil (Wright, 1973) and microfossil (this study) evidence. For example, there is a trend towards increasing species and specimen abundance with respect to dinoflagellates throughout most of the Leeds Creek Member. In fact, maximum species (50) and specimen abundance (1544) coincides with the time of maximum marine transgression as defined by sedimentological and paleontological evidence.

A change in lithology in the form of a sandy/silty shale occurs within the upper part of the Leeds Creek Member. It is interpreted as representing a trend towards shallowing conditions, which is supported by paleontological evidence (decrease in the macrofossil and palynomorph assemblage). The macrofossil assemblage is mostly fragmented and dominated by pelecypods to the absence of ammonites (Imlay, 1967, 1980; Wright, 1973). Terrestrial-derived pollen, spores, and plant tissue become increasingly dominant over marine microplankton accompanied by an increase inertinite and decrease in amorphous debris. Immediately above the sandy/silty calcareous shale, occurs a gradational change to a crossbedded, ripple-marked sandy/silty limestone representing the Giraffe Creek Member. This member represents a change towards a very shallow marine environment, possibly an intertidal setting, which is supported by paleontological evidence. Marine macrofossils are poorly represented with only very few indeterminable fragments recovered (Imlay, 1967, 1980). The palynomorph assemblage is dominated by inertinite, plant tissue, pollen and spores accompanied by little amorphous debris and very few specimens of marine microplankton. As a result, the combined lithological and paleontological evidence support the contention that the Giraffe Creek Member was deposited during a marine regressive event.

The Giraffe Creek Member represents the final period of deposition with respect to the Twin Creek Limestone. It is unconformably overlain by the Preuss Sandstone Formation, which was deposited during another episode (?Middle - Late Callovian) of marine transgression unrelated to the time of the Twin Creek Limestone. The boundary between the Giraffe Creek Member and the overlying Preuss Sandstone represents the top of parasequence II.

Thermal Maturation

It is now well-established that the thermal alteration of organic matter leads to formation of petroleum (Staplin, 1969,1977; Tissot and Welte, 1978,1984). Therefore, a study of organic material extracted from sedimentary rocks is of value to the petroleum industry. In the Overthrust Belt, successful petroleum ventures commenced in 1975 with the discovery of petroleum in the Idaho-Wyoming-Utah Overthrust Belt (Dixon, 1982). Intensive exploration ensued and resulted in the discovery of 19 fields (Warner, 1982).

The source rock for much of the discovered petroleum is generally believed to be organic-rich shales of Cretaceous and Permian age (Lamerson, 1982; Warner, 1982). Minor reserves of petroleum have been found locally in subsurface Twin Creek Limestone within part of the Absaroka Thrust Belt (Figure 1), which lies in southwestern Wyoming (Lamerson, 1982). It is within this region that the Twin Creek Limestone is considered by Dixon (1982) a potential source rock.

Samples prepared for palynological study were also evaluated as to the level of thermal maturation and potential for petroleum formation.

There are several methods available for thermal maturation analyses. For example, Vitrinite Reflectance, Rock Eval Pyrolysis, Mass Spectrometry, Gas Chromatography, Flourescence, and Thermal Alteration Index are considered useful methods either independently or in combination with one another (Tissot and Welte, 1978,1984). However, the method utilized in this study is the Thermal Alteration Index of Staplin (1969,1977). This method is considered time efficient, inexpensive and an relatively accurate for determining maturation levels and petroleum source facies (Batten, 1982a).

Staplin (1969,1977), Tissot and Welte (1978,1984) and Gray and Boucot (1975) have shown in nature and experiment that the breakdown of organic matter is affilated with temperature increase as related to rock overburden. In addition to overburden, thermal maturation is influenced by tectonic activity, such as overthrusting of strata (Edman and Surdam, 1984). This type of tectonic activity resulted in the formation of the Idaho-Wyoming-Utah Overthrust Belt. The effects of thrusting have been shown in many thermal models (eg. Edman and Surdam, 1984). The effect is to cool the overriding sheet and warm sediments being overridden (Edman and Surdam, 1984). The overriding sheet transfers heat into the sediments below and causes the overridden sheet to be more deeply buried (Edman and Surdam, 1984). Therefore, thermal maturation of Twin

Creek sediments was probably the result of combined overthrusting and overburden. The thermal alteration of organic matter includes darkening of color, decrease in light transmissibility, and loss of fine structural detail (Staplin, 1977). The organic material studied by Staplin (1969, 1977) included spores, pollen, non-woody cuticle, and amorphous sapropelic debris. This material is seen as most sensitive to heat with respect to the total organic material recoverable in a rock. Furthermore, their alteration progresses at roughly the same rate (Staplin, 1969). The thermal alteration of organics results in gradual changes of their color from transparent pale yellow through deep red brown and brown to opaque black. Numeric values based on vitrinite reflectance equivalents are assigned to each color change, thus enabling a correlation between color of organics and rank in terms of maturity (Staplin, 1977). This correlation then leads to the definition of an oil window (Staplin, 1969, 1977). During the 1960's, Staplin (1969,1977) applied this method to samples from wells located in western Canada, and was able to define the oil window in several studied sections.

The color index chart used in the study is adapted from Pearson (1981). It is a modification of the Staplin method with minor differences in the munsell color standards used.

Figure 12 shows a collation of organic thermal maturity, thermal alteration index and studied sections. Thermal maturation results indicate that to the north, in the Camp Davis section, organic matter has reached a low level (TAI = greater than or equal to (>/=) 2+) of maturity. Towards the south, maturation levels increase from a TAI value of </= 3 in the Astoria #1-21 Unit Federal and Utah Southern Hatch #1 wells, to a value of </= 3+ in the Whitney Canyon well, Twin Creek and Underwood Canyon sections. Variations in color values of spores and pollen within a sample are not uncommon. Plausible causes are differences in spore and pollen wall thickness, composition and epigenetic processes such as corrosion and degradation (Gray and Boucot, 1975).

Tissot and Welte (1978,1984) have shown experimentally that specific types of kerogen (organic material insoluble in organic acids - Tissot and Welte, 1978) have the potential for petroleum formation. Briefly, the types of kerogen are:

A) Type I - represented by algal matter such as Botrycoccus, mostly deposited in a lacustrine environment; characterized by high atomic H/C ratio and low atomic O/C ratio.

B) Type II - represented by mostly microplankton and other material more or less extensively reworked by

ORGANIC THERMAL MATURITY (FROM PEARSON, 1984)	TAI	VIT. REF.	FOSSIL COLOR	STUDIED SECTIONS					
				CAMP DAVIS	ASTORIA #1-21 UNIT FEDERAL	UNDERWOOD CANYON	TWIN CREEK	WHITNEY CANYON	UTAH SOUTHERN NATCH #1
IMMATURE	1		PALE YELLOW						
	1+		LIGHT YELLOW						
	2-		LIGHT YELLOW						
MATURE MAIN PHASE OF LIQUID PETROLEUM GENERATION AND PRESERVATION	2	0.5%	MEDIUM YELLOW	▨					
	2+		AMBER YELLOW	▨					
	3-		LIGHT BROWN		▨				
	3		BROWN		▨	▨	▨	▨	▨
DRY GAS OR BARREN	3+	1.3%	DARK BROWN			▨	▨	▨	▨
	4-		DARK BROWN/BLACK						
	4		BLACK						

FIGURE 12. COLLATION OF ORGANIC THERMAL MATURITY, THERMAL ALTERATION INDEX(TAI), Vitrinite Reflectance AND STUDIED SECTIONS. SHADED AREAS INDICATE APPROXIMATE STATE OF MATURATION.

microorganisms living in the sediment (Demaison and Moore, 1980), and generally related to marine reducing environments; characterized by moderately high atomic H/C ratio and low O/C ratio.

C) Type III - derived mainly from terrestrial plants and transported to a marine or nonmarine environment, which undergoes only a moderate level of degradation before burial; characterized by lower atomic H/C ratio than in types I and II, although associated with a higher atomic O/C ratio than previous types.

D) Type IV - represented by residual organic matter which may be recycled from older sediments by erosion, deeply altered by subaerial weathering, combustion, or biological oxidation in swamps and soils prior to redeposition; characterized by abnormally high atomic O/C ratio and very low atomic H/C ratio.

Tissot (1984) also noted the common occurrence of intermediate kerogens, particularly between types II and III. Intermediate kerogens possibly result from an admixture of marine and terrestrially derived organic matter (Tissot, 1984). Due to their high atomic H/C ratio, kerogen types I and II are considered hydrocarbon rich, and most likely to form petroleum. Type III, with a lower atomic H/C ratio and associated higher O/C ratio, has a lower potential for petroleum formation. The abnormally high O/C ratio and associated very low H/C ratio of type IV precludes any potential for petroleum formation.

Figure 13 shows kerogen type(s) per member for each studied section. Based exclusively on microscopy, each member appears to contain an admixture of kerogen types I - IV. The Gypsum Spring Member is dominated by kerogen type IV with minor inclusion of type III; the Camp Davis and Astoria #1-21 Unit Federal sections exhibit only a trace of type III. The Sliderock Member contains an admixture of kerogen types II, III and IV; types III and IV dominate with minor inclusion of type II; the Twin Creek and Whitney Canyon sections are dominated by types IV and II. The Rich Member is dominated by kerogen types II and IV with minor inclusion of type III; however, a general increase in amount of type III occurs towards the upper part of the member in each section. The Boundary Ridge Member is dominated by kerogen type IV with minor inclusion of type III and trace of type II. The Watton Canyon Member is represented by kerogen types II, III and IV; types IV and III dominate at the base of the member, whereas type II becomes increasingly dominant towards the middle and upper part of the member. The Leeds Creek Member is represented by kerogen types II, III and IV; a dominance of types II and IV followed by type III prevails in the Astoria #1-21 Unit Federal, Underwood Canyon,

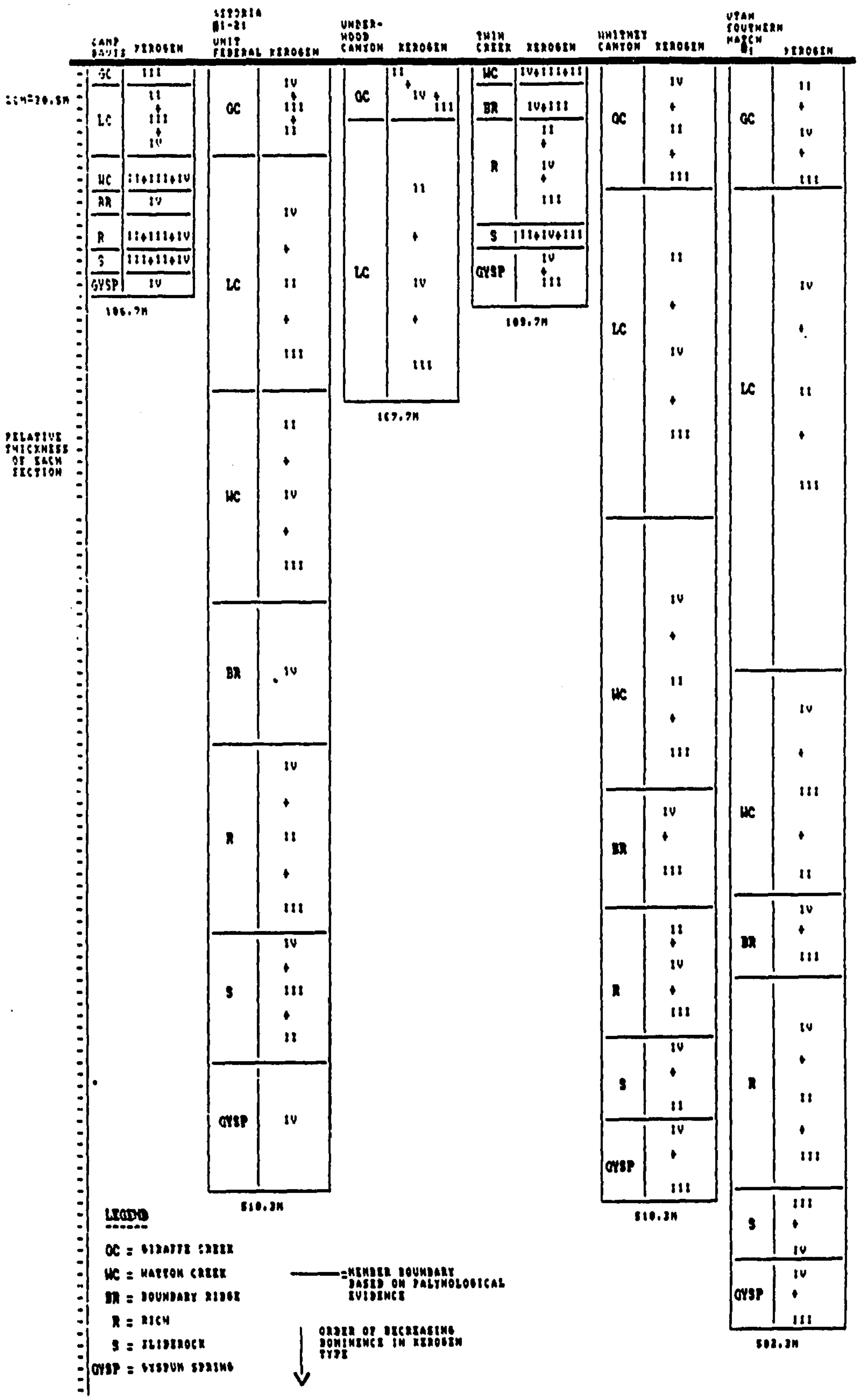


Figure 13. Kerogen types established for the Twin Creek Limestone.

Whitney Canyon, and Utah Southern Hatch #1 sections; dominance of type II followed by types III and IV occurs in the Camp Davis section; each section, excluding the Underwood Canyon and Utah Southern Hatch #1 sections, shows a marked decrease in type II and an increase in types III and IV towards the upper part of the member; a slight increase of type II occurs in the upper part of the member at Underwood Canyon and Utah Southern Hatch #1 sections. The Giraffe Creek Member contains kerogen types II, III and IV; type III with a trace of type IV prevails in the Camp Davis section; types IV and III dominate with minor inclusion of type II in the Astoria #1-21 Unit Federal well; type IV dominates followed by types II and III in the Whitney Canyon well; types II and IV dominate followed by type III in the Underwood Canyon and Utah Southern Hatch #1 sections.

The variability in kerogen type within a particular member, and between studied sections, might be explained either in combination or independently, by the following:

A) Depositional environment: during episodes of marine transgression and regression; sediments deposited under shallowing conditions (figure 9) would exhibit a greater concentration of terrestrially derived (type III) organic material, whereas an increase in marine-derived (type II) material would be expected under transgressive conditions.

The type of paleogeographic setting need also be considered. For example, deposition of the Twin Creek Limestone occurred within a shallow trough during fluctuations of an epicontinental sea. This type of setting would not be conducive for distinct differentation of kerogen types as might be encountered in an oceanic environment (Habib, 1979; Habib and Miller, in press).

B) Reworking: during times of marine transgression and regression, it is possibile that reworked material could be deposited contemporaneously with in situ organics.

C) Thermal alteration: as organic matter reaches maturity, degradation and darkening of color commences which could result in the destruction of part of the kerogen content, therefore, inhibit precise identification of the total kerogen composition.

Summary and Conclusions

The Twin Creek Limestone represents a carbonate sequence formed within the Twin Creek trough. The environments of deposition include the shallow marine (subtidal), offshore shallow marine (subtidal), and marginal marine (intertidal) settings. The sequence represents sedimentary cycles deposited during two episodes of marine transgression and regression. The top and the base of the formation are distinguished by erosional unconformities.

Three regional dinoflagellate zones were distinguished.

I. Mendicodinium scrobiculatum Taxon Range Zone (Late Bajocian), defined by the stratigraphic range of the nominative species. Other useful species making their first appearance include D. filapicatum, ?R.regalis, C. norrisii, and Parvocysta sp.B, Bjaerke, 1982, which first appear generally within the same time interval in European sections. However, unlike European assemblages, the interval is characterized by a low abundance of dinoflagellate species. The zone is recognized in each studied section except for the Underwood Canyon, which represents sediments of the Leeds Creek and Giraffe Creek Members. It ranges from the upper Sliderock to the uppermost part of the Rich Member. Sediments representative of the Gypsum Spring Member do not appear to contain dinoflagellates. Therefore, this member has not been included in the proposed dinoflagellate zones.

II. Atopodinium prostatum Interval Zone (?late Middle/early Late Bathonian to Latest Bathonian), defined by the first appearance of A. prostatum to the first appearance of Gonyaulacysta centriconnata. Other useful species making their first appearance include R. cladophora E.gochtii, E.reticulatum, E.cinctum, G. evittii, E.galeritum, C.sellwoodii group, A. aldorfensis, K.gochtii, M.caytonensis group, V.ovula, P.brachythelis, T.dangeardii, G.jurassica, and K. cf. stoveri. The last appearance of C.norrisii occurs within the zone. Overall, the zone exhibits a rich and diverse assemblage of dinoflagellates. These species generally first appear within the same time interval in European and Arctic Canadian sections. The zone ranges from approximately the middle part of the Watton Canyon to the upper middle part of the Leeds Creek Member. It is recognized in each studied section except for the type section, which contains only the lowermost part of the Watton Canyon Member. This part is apparently devoid of dinocysts. The Boundary Ridge Member is considered to be Early Bathonian in age based on stratigraphic position (Imlay,1967). Dinoflagellates have not been recovered from this member. As a result, the Early Bathonian has not been included in the proposed dinoflagellate zones for the Twin Creek

Limestone.

III. Gonyaulacysta centriconnata Interval Zone (Early Callovian). It is defined by the first appearance of the nominative species to the top of the sequence containing dinocysts. Other useful species making their first appearance include C.whitei, L.subtile, S.grossii, ?K. thulia, S.cf.redcliffense, and Cleistosphaeridium spp. The latter two species were found only in the Camp Davis section. This zone is recognized in each studied section except for the type section. The type section represents sediments of the Gypsum Spring, Sliderock, Rich. and Boundary Ridge Members. The nominative species and the species listed above, first appear generally within the same time interval or younger in European and Arctic Canadian sections. A rich and diverse assemblage characterizes the lower to middle parts of the zone, with a significant decrease in abundance towards the upper boundary. The zone ranges from the upper middle Leeds Creek to the lower/?middle part of the Giraffe Creek Member. The zones established for the Twin Creek Limestone generally compare with established zonations proposed for the Middle Jurassic of Europe (Riley and Fenton, 1982; Woollam and Riding, 1983) and Arctic Canada (Johnson and Hills, 1973; Davies, 1983).

The Twin Creek dinoflagellate assemblages are similar generally to European species during Late Bajocian time. For example, species *D.filapicatum*, *C.norrisii*, and *?R.regalis* first appear within the Late Bajocian in both regions.

A similarity between dinoflagellate assemblages is evident also in sediments of Late Bathonian to Early Callovian age, and includes the first appearances of *A. prostatum*, *C.sellwoodii* group, and *M.caytonensis* group. Species which first appear in the Twin Creek Limestone during ?late Middle/early Late Bathonian time occur earlier (Late Bajocian) in European sections. They include *A.aldorfensis*, *E.gochtii*, *E.cinctum*, *P. ceratophora*, and *H.pectinigera*. However, some species first occurring in the Twin Creek during Late Bathonian to Early Callovian time, appear later (Late Callovian to Oxfordian) in European sections, and include *C. chondrum*, *L. jurassica*, *E. galeritum*, and *L. subtile*.

A comparison with Arctic Canadian zonations shows a good similarity between dinoflagellate assemblages. For example, similar first occurrences during the Late Bathonian include *A.prostatum*, *R.cladophora*, *H. teichophera*, *E.cinctum*, *E.pocockii*, *G.jurassica*, *L. jurassica*, and *S.grossii*. Species *S.redcliffense* first appears in the Early Callovian of Arctic Canada, whereas S.cf.redcliffense first occurs within an interval considered Early Callovian in the Twin Creek. In addition, species ?K.thulia is known to first appear within late Early to early Middle Callovian in Arctic Canada. It appears jointly with S.cf.redcliffense and G.centriconnata in the Twin Creek. Conversely, dinoflagellate assemblages are dissimilar during the Late Bajocian.

A similarity also exists with respect to assemblages identified from the Lias of Portugal. Davies (1985) recorded an abundance of dinoflagellate species for the early Late Bathonian, which include the first appearance of A.prostatum, E.gochtii, E.pocockii, G.jurassica, G. evittii, T.eisenackii (NOW G.eisenackii), T.dangeardii, V.ampulla, H.cladophora, and L.jurassica. These species first appear with the same time interval in the Twin Creek Limestone. However, unlike the Twin Creek Limestone, a decrease in species abundance occurs during the Latest Bathonian into the Early Callovian of Portugal.

A comparison between unpublished data (Waanders, written commun.) on the Twin Creek Limestone suggests a good similarity between dinoflagellate assemblages. However, a greater number of species have been recorded in this study. Both studies show an absence/paucity of dinoflagellate species in sediments representing the Boundary Ridge Member. Furthermore, both studies are in agreement with respect to placement of the stage boundaries for the members of the Twin Creek Limestone.

Overall, there is a similarity between dinoflagellate assemblages identified from the Twin Creek Limestone, Western Interior Region, U.S.A. and those from Europe for the Late Bajocian, a time of postulated worldwide marine transgression.

Provincialism is common to assemblages from the Twin Creek Limestone and to those from European stratotype sections during the Early to Middle Bathonian, a time of marine regression within the Western Interior Region and northwest Europe.

Similarity between assemblages is worldwide during the Late Bathonian to Early Callovian time. Marine transgressive conditions appear to have persisted throughout much of the world during this time (Hallam, 1984).

The stratigraphic fluctuation of depositional organic facies and dinoflagellate species abundance correlate with lithofacies evidence of marine transgression and regression. Increase in the numerical abundance of dinoflagellate species and abundant amorphous debris coincide with marine transgression (shown by relative sea-level curve, figures 9 and 10). An interval dominated by tracheal and cuticular tissue, pollen and spores, with few dinoflagellates and lesser amorphous debris, correlates with a change towards marine regression. Maximum marine regression correlates with abundant inertinite (carbonized debris) and a paucity of palynomorphs.

Parasequences (two shallowing upwards parasequences) are established for the Twin Creek Limestone (Camp Davis section). These genetic units are considered to represent changes in relative sea-level and support episodes of marine transgression and regression postulated for the Twin Creek Limestone.

Parasequence I represents sediments of the Gypsum Spring, Sliderock, Rich, and Boundary Ridge Members. The lower boundary represents a brecciated limestone with marine fossils (echinoderms) unconformably underlain by eolian (nonmarine) sediments of the Nugget Sandstone Formation (Early Jurassic). The brecciated limestone unit (very shallow marine) denotes the beginning of marine transgressive conditions, which continue through to the oolitic subtidal shoals of the Sliderock Member overlain by the Rich Member. The Rich Member represents a shaly limestone formed in an shallow offshore setting (subtidal). Dinoflagellate species first appear within the lowermost Rich and attain maximum species abundance in the middle part of the member. A significant decrease in species abundance occurs within the interval, and continues throughout the upper Rich into the Boundary Ridge Member. The change in dinoflagellate species coincides with a lithological change to a silty limestone. This interval is considered as representing the initial change towards marine regressive conditions. Gradationally overlying the Rich is a calcareous siltstone (lagoonal setting) representative of the Boundary Ridge Member. The unit is characterized by a paucity of marine microplankton, further evidence that supports the increasing shallowing conditions. The upper boundary of parasequence I is denoted by the sharp contact between the Boundary Ridge and the overlying oolitic limestone unit of the Watton Canyon Member.

Parasequence II represents sediments of the Watton Canyon, Leeds Creek, and Giraffe Creek Members. The lower boundary represents the contact between the oolitic limestone (shoals - subtidal setting) unit and the underlying calcareous siltstone of the Boundary Ridge Member. The oolitic unit denotes the return of marine transgressive conditions, which continued into the middle part of the overlying Leeds Creek Member. Dinoflagellate species suddenly increase within the upper middle part of the Watton Canyon and represent the first palynological evidence of a marine transgression. Marine conditions increase into the Leeds Creek as denoted by a lithological change towards a calcareous shale (offshore - subtidal) and increase in abundance of dinoflagellate species. However, a change towards shallowing conditions is evident within the upper part of the Leeds Creek. Evidence comes from a lithological change towards a silty/sandy calcareous shale along with a dramatic decrease in dinoflagellate species. Shallowing conditions continue throughout the gradationally overlain Giraffe Creek Member based on a lithological change to a crossbedded sandy limestone (very shallow marine - marginal subtidal), and a further reduction in dinoflagellate species abundance. The upper boundary of parasequence II represents the unconformable contact with the overlying Preuss Sandstone Formation.

Overall, there is a good correlation between the established parasequences and changes in species abundance of dinoflagellates in recognizing changes in relative sea-level within the Twin Creek Limestone (Camp Davis section).

The organic matter content for each studied section was analyzed (modification of Thermal Alteration Index of Staplin, 1969; 1975) in order to determine its thermal maturation. This method uses the changes in color of spores and pollen to determine degree of thermal maturation. Results indicate that to the north, in the Camp Davis section, organic matter has reached a low level of maturity (TAI = >/= 2+), borderline oil window. Towards the south, maturation levels increase from TAI values of </= 3 in Astoria #1-21 Unit Federal and Utah Southern Hatch #1 wells, to a value of </= 3+ in the Whitney Canyon well, type section, and Underwood Canyon section, each section within the oil window.

The total organic matter content analyzed for potential of petroleum formation follows the method of Tissot and Welte (1978, 1984). In this method, organic matter is separated into Kerogen (organic material insoluble in organic acids) types I - IV, which represent variations of marine and nonmarine-derived material. Results indicate that the members identified from each studied section contains an admixture of kerogen types II (marine), III (terrestrial), and IV (oxidized matter). This may be the result of depositional environment, that is members deposited under shallowing conditions (ie. Giraffe Creek) exhibit a greater concentration of terrestrial-derived material, whereas an increase in type II (ie. Rich and Leeds Creek) reflects deposition under increasing marine conditions. A time of maximum shallowing (ie. Boundary Ridge) would favor concentration of type IV organic material.

Other possible explanations include reworking and thermal maturation. Times of fluctuating sea-level could enhance reworking from underlying units. This may help to explain the significant concentration of type IV material within the lower part of the Watton Canyon member observed in most of the studied sections.

As organic matter reaches maturity, it degrades, destroying original features and inhibiting precise identification. Included in this process, is a change in color of organics towards a darker appearance, further preventing an accurate identification.

APPENDICES

CAMP DAVIS	ASTORIA #1-21 UNIT FEDERAL	UNDERWOOD CANYON
ELEV./NO./MEMBER	DEPTH /NO./MEMBER	ELEV./NO./MEMBER
100m /27/GIR.CK	777.4m/2550/GIR.CK	167.7m/LC33/GIR.CK
91m/26/LDS CK	807.9m/2650/GIR.CK	161.6m/LC31/GIR.CK
85m/25/LDS CK	838.4m/2750/LDS CK	155.5m/LC29/GIR.CK
79m/24/LDS CK	868.9m/2850/LDS CK	149.4m/LC27/GIR.CK
76m/23/LDS CK	899.4m/2950/LDS CK	143.3m/LC25/GIR.CK
70m/22/LDS CK	914.6m/3000/LDS CK	137.2m/LC23/LDS CK
64m/21/LDS CK	929.9m/3050/WAT.CN	131.1m/LC21/LDS CK
61m/20/LDS CK	960.4m/3150/WAT.CN	125.0m/LC19/LDS CK
58m/19/LDS CK	990.8m/3250/WAT.CN	118.9m/LC17/LDS CK
55m/18/WAT.CN	1021.3m/3350/B.RDGE	94.5m/LC15/LDS CK
52m/17/WAT.CN	1051.8m/3450/B.RDGE	88.4m/LC13/LDS CK
49m/16/WAT.CN	1082.3m/3550/RICH	82.3m/LC11/LDS CK
46m/15/WAT.CN	1112.8m/3650/RICH	57.9m/LC09/LDS CK
43m/14/WAT.CN	1143.3m/3750/RICH	51.8m/LC07/LDS CK
40m/13/WAT.CN	1173.8m/3850/SLDRCK	45.7m/LC05/LDS CK
37m/12/B.RDGE	1204.3m/3950/SLDRCK	39.6m/LC03/LDS CK
34m/11/RICH	1234.7m/4050/GY.SPG	33.5m/LC01/LDS CK
31m/10/RICH	1265.2m/4150/GY.SPG	
28m/09/RICH	1295.7m/4250/ ?	
25m/08/RICH	1326.2m/4350/ ?	
22m/07/RICH	1356.7m/4450/ ?	
19m/06/RICH	1417.7m/4550/ ?	
16m/05/RICH	1448.2m/4650/ ?	
13m/04/SLDRCK	1478.6m/4750/ ?	
10m/03/SLDRCK	1509.1m/4850/ ?	
07m/02/GY.SPG	1524.4m/4950/ ?	
04m/01/GY.SPG		

LEGEND: NO. = sample number
GIR.CK = Giraffe Creek
LDS CK = Leeds Creek
WAT.CN = Watton Canyon
B.RDGE = Boundary Ridge
SLDRCK = Sliderock
GY.SPG = Gypsum Spring

Appendix 1. All samples studied and their litho - stratigraphy.

		UTAH
WHITNEY CANYON	TWIN CREEK	SOUTHERN HATCH #1
DEPTH/NO./MEMBER	ELEV./NO./MEMBER	DEPTH/NO./MEMBER
1573.2m/5160/GIR.CK	109.7m/TC37/WAT.CN	2073.2m/2068/GIR.CK
1603.6m/5260/GIR.CK	103.6m/TC35/WAT.CN	2103.6m/2116/LDS CK
1634.1m/5360/GIR.CK	97.6m/TC33/B.RDGE	2195.1m/2205/LDS CK
1664.6m/5460/LDS CK	91.5m/TC31/B.RDGE	2256.1m/2275/LDS CK
1695.1m/5560/LDS CK	85.4m/TC29/RICH	2408.5m/2436/WAT.CN
1725.6m/5660/LDS CK	79.3m/TC27/RICH	2469.5m/2473/RICH
1756.1m/5760/LDS CK	73.2m/TC25/RICH	2500m/2512/RICH
1786.6m/5860/LDS CK	67.1m/TC23/RICH	2530.5m/2533/RICH
1817.1m/5960/WAT.CN	61.0m/TC21/RICH	2564.3m/2590/RICH
1847.6m/6060/WAT.CN	54.9m/TC19/RICH	2591.5m/2599/GY.SPG
1878m/6160/WAT.CN	48.8m/TC17/RICH	2622m/2611/GY.SPG
1908.5m/6260/WAT.CN	42.7m/TC15/RICH	
1939m/6360/B.RDGE	36.6m/TC13/RICH	
1969.5m/6460/B.RDGE	30.5m/TC12/SLDRCK	
2000m/6560/RICH	24.4m/TC10/GY.SPG	
2030.5m/6660/RICH	18.3m/TC08/GY.SPG	
2061m/6760/SLDRCK	12.2m/TC06/GY.SPG	
2091.5m/6860/GY.SPG	6.1m/TC04/GY.SPG	
	0.0m/TC01/GY.SPG	

LEGEND:

NO. = sample number
GIR.CK = Giraffe Creek
LDS CK = Leeds Creek
WAT.CN = Watton Canyon
B.RDGE = Boundary Ridge
SLDRCK = Sliderock
GY.SPG = Gypsum Spring

Appendix 1 cont. All samples studied and their litho - stratigraphy.

ELEVATION(m)	SAMPLE	LITHOLOGY	MEMBER	PALYNOZONE	AGE
100	27	CALCAREOUS SANDY SILTSTONE	GIRAFFE CREEK	Gc	EARLY CALLOVIAN
97		SANDY LIMESTONE			
94		CALCAREOUS SHALE			
91	26		LEEDS CREEK		
88					
85	25				
82					
79	24				
76	23			Ap	LATE BATHONIAN
73					
70	22				
67					
64	21				
61	20				
58	19				
55	18	OOLITIC LIMESTONE	WATTON CANYON		
52	17				
49	16	CALCAREOUS SHALE			
46	15			INTERVAL NOT ZONED	?MIDDLE BATHONIAN
43	14	OOLITIC LIMESTONE			
40	13				
37	12	CALCAREOUS SILTSTONE	BOUNDARY RIDGE		EARLY BATHONIAN
34	11	SHALY LIMESTONE	RICH	Ms	LATE BAJOCIAN
31	10				
28	9				
25	8				
22	7				
19	6				
16	5				
13	4	OOLITIC LIMESTONE	SLIDEROCK		
10	3			INTERVAL NOT ZONED	
7	2	CALCAREOUS SILTSTONE	GYPSUM SPRING		?MIDDLE TO LATE BAJOCIAN
4	1	BRECCIATED LIMESTONE			
0		NUGGET SANDSTONE FORMATION			

APPENDIX 2. LITHOSTRATIGRAPHY AND PALYNOSTRATIGRAPHY OF THE CAMP DAVIS SECTION.

No.	Taxon
1	BOTRYCOCCUS
2	UNDIFFERENTIATED BISACCATES
3	UNDIFFERENTIATED FUNGAL SPORES
4	CLASSOPOLLIS SPP.
5	MICRHYSTRIDIUM COMPLEX
6	UNDIFFERENTIATED TRILETE SPORES
7	CALLIASPORITES DAMPIERI
8	CALLIASPORITES TRILOBATUS
9	CEREBROPOLLENITES SPP.
10	CTENIDODINIUM NORRISII
11	CYATHIDITES SPP.
12	DELTOIDOSPORA SPP.
13	DIACANTHUM FILAPICATUM
14	EXESIPOLLENITES TUMULUS
15	FORAMINIFERAL LININGS
16	MENDICODINIUM SCROBICULATUM
17	PARVOCYSTA SP.B
18	SENTUSIDINIUM SPP.
19	TASMANACEAE
20	CTENIDODINIUM SP.1
21	GONYAULACYSTA SP.1
22	RHYNCHODINIOPSIS REGALIS
23	APTEODINIUM SP.1
24	ARAUCARIACITES AUSTRALIS
25	CHYTROEISPHAERIDIA CHYTROEIDES
26	DINOFLAGELLATE SP.A
27	ELLIPSOIDICTYUM CINCTUM
28	ELLIPSOIDICTYUM RETICULATUM
29	GLOMODINIUM EVITTII
30	HYSTRICHOGONYAULAX PECTINIGERA
31	PAREODINIA CERATOPHORA
32	PAREODINIA GROENLANDICA
33	ELLIPSOIDINIUM SP.1
34	ATOPODINIUM PROSTATUM
35	CTENIDODINIUM SELLWOODII GROUP
36	DINOFLAGELLATE SP.B
37	DISSILIODINIUM SP.1
38	ELLIPSOIDICTYUM GOCHTII
39	ENDOSCRINIUM CF.SUBVALLARE
40	ENDOSCRINIUM GALERITUM
41	GONYAULACYSTA SP.2
42	GONYAULACYSTA SP.A POCOCK, 1972
43	HESLERTONIA PELLUCIDA
44	RHYNCHODINIOPSIS CLADOPHORA GROUP
45	KORYSTOCYSTA GOCHTII
46	LITHODINIA SP.1
47	MEIOUROGONYAULAX CAYTONENSIS GROUP
48	OCCISUCYSTA CF.MONOHEURISKA
49	ENDOSCRINIUM SP.1
50	PAREODINIA BRACHYTHELIS
51	VALENSIELLA OVULA
52	ALDORFIA ALDORFENSIS
53	ALGA SP.A
54	CHYTROEISPHAERIDIA SCABRATA
55	CTENIDODINIUM CHONDRUM
56	ESCHARISPHAERIDIA POCOCKII
57	HESLERTONIA TEICHOPHERA
58	LITHODINIA JURASSICA
59	GONYAULACYSTA HELICOIDEA
60	LEPTODINIUM SP.1
61	TUBOTUBERELLA DANGEARDII
62	KORYSTOCYSTA THULIA
63	GONYAULACYSTA EISENACKII
64	VALENSIELLA AMPULLA
65	COMETODINIUM WHITEI
66	DINOFLAGELLATE SP.C
67	ENDOSCRINIUM SP.2
68	GONYAULACYSTA CENTRICONNATA
69	GONYAULACYSTA JURASSICA
70	KOMEWUIA CF. STOVERI
71	OCCISUCYSTA CF.BALIOS
72	ACANTHAULAX SP.1
73	CLEISTOSPHAERIDIUM SPP.
74	LEPTODINIUM SUBTILE
75	SIRMIODINIUM GROSSII
76	STEPHANELYTRON CF.REDCLIFFENSE

—8–14–6——4—3—1—3——22——4——

9 173 8 1 2 7 2 6 3 5 5 4 78 3 3 3 10 8 12 4 2 9 11 8 GC ZONE 1 (EARLY CALLOVIAN) 1 8 2

90 12 127 18 29 41 16 36 37 58 28 24 2 100 67 6 64 27 12 3 11 11 10 3 4 38 34 4 3 9 22 18 54 2 1 41 12 8 10 1 12 9 3 14 1 4 3 12 2 7 8

62 26 78 18 34 33 10 42 21 24 28 23 135 100 57 7 59 88 10 8 29 41 36 17 14 46 3 4 29 3 7 28 11 15 32 11 18 41 8 29 43 3 8 31 28 11 16 7 38 27 2 9 7 36 27 11 28 21 9 3 32 9 3

86 91 21 8 36 11 61 6 9 44 36 197 4 150 29 19 31 187 47 28 38 34 24 27 13 48 13 8 29 100 7 22 34 14 26 61 15 12 51 18 38 10 1 12 34 17 14 18 2 36 31 3 19 9 84 24 13 18 19

67 6 33 27 9 21 6 26 4 7 47 8 218 218 36 18 31 163 41 58 48 38 13 7 15 24 19 18 22 44 18 24 33 1 17 138 22 6 28 12 54 24 57 8 2 3 6 42 21 1 24 8 48 38 5 18 9 4 58 14 8 28 11

21 29 37 6 9 2 19 10 8 11 31 18 136 6 366 18 28 18 117 17 64 23 19 34 15 27 15 14 13 12 9 17 10 1 12 88 4 5 10 11 73 21 24 11 3 5 21 17 10 1 15 1 18 3 2 11

54 81 17 9 12 4 30 1 18 24 6 41 60 29 26 21 6 42 21 13 14 23 16 10 18 12 18 15 19 4 25 20 1 13 29 6 7 30 18 37 18 2 14 4 6 30 18 1 16 6 41

51 64 45 12 19 3 12 1 19 28 32 47 80 3 127 43 1 17 27 18 4 12 12 10 11 12 30 4 13 18 6 12 19 4 12 19 14 28 19 27 4 8 5 4 18 16 5

34 17 38 34 14 17 4 30 1 21 28 28 18 19 79 15 5 14 30 18 11 17 14 15 13 5 6 18 3 8 7 18 23 8 13 16 11 33 15 5

37 18 87 7 17 2 11 14 72 18 48 6 156 8 17 5 36 7 19 7 24 16 31 5 14 34 18 8 8 31 7 16 12 11 15 25 9 18 24 16 AP ZONE (LATE BATHONIAN)

81 24 69 17 28 4 11 5 22 27 24 22 58 32 9 13 8 5 12 4 17 9 11 4

14 2 5 1 2 2 2 8

48 6 3 4 5 2 2

2 2 3 1

1 3 2 3 2

78 4 102 27 28 28 12 30 12 16 8 30 14 3 12 5 1 4 2 3 11 MS ZONE (LATE BAJOCIAN)

9 18 16 4 5 3 1 3 4 9 5 117 8 11 2 6 8 8

14 14 5 11 5 1 5 6 9 12 37 8 12 22 9 3 6 9 6 12

24 11 3 9 2 18 46 5 28 19 18 2 3 3 7

6 36 4 4 15 2 3 5 3 6 3 4 191 9 3 2 2 2

13 24 26 4 4 8 3 5 48 16 57 36 12 6 4 7 8

18 10 75 11 8 3 4 9 11 12 11 11 27 21 4 11 5

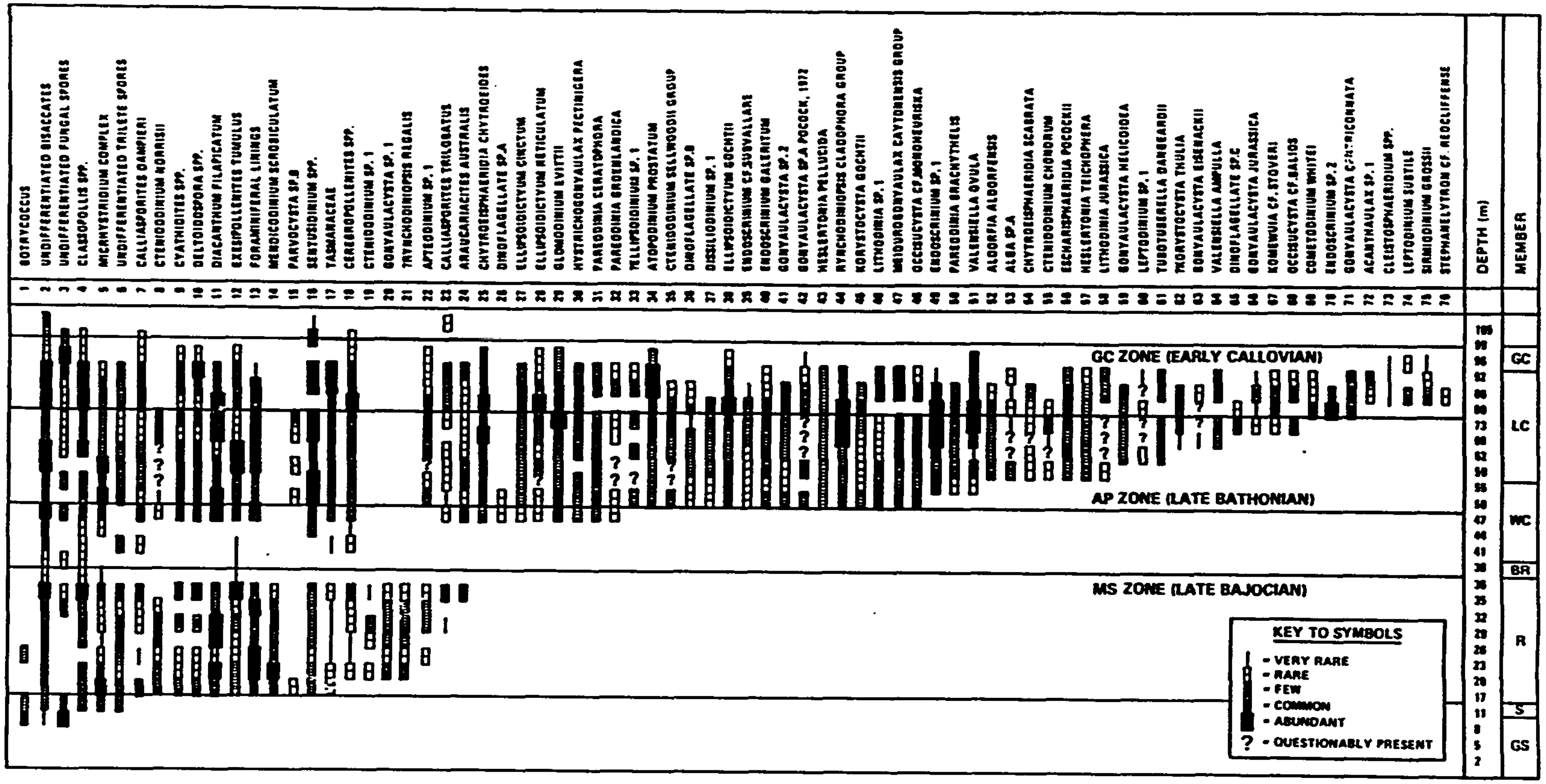
7 7 26 9 11 8

16 2 158

DEPTH (m): 105, 99, 96, 92, 86, 80, 73, 68, 62, 59, 55, 50, 47, 44, 41, 38, 36, 35, 32, 29, 26, 23, 20, 17, 11, 8, 5, 2

MEMBER: GC, LC, WC, BR, R, S, GS

PALYNOSTRATIGRAPHY OF CAMP DAVIS SECTION: TETON CO., WYO.
RANGE CHART OF NUMERIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 3



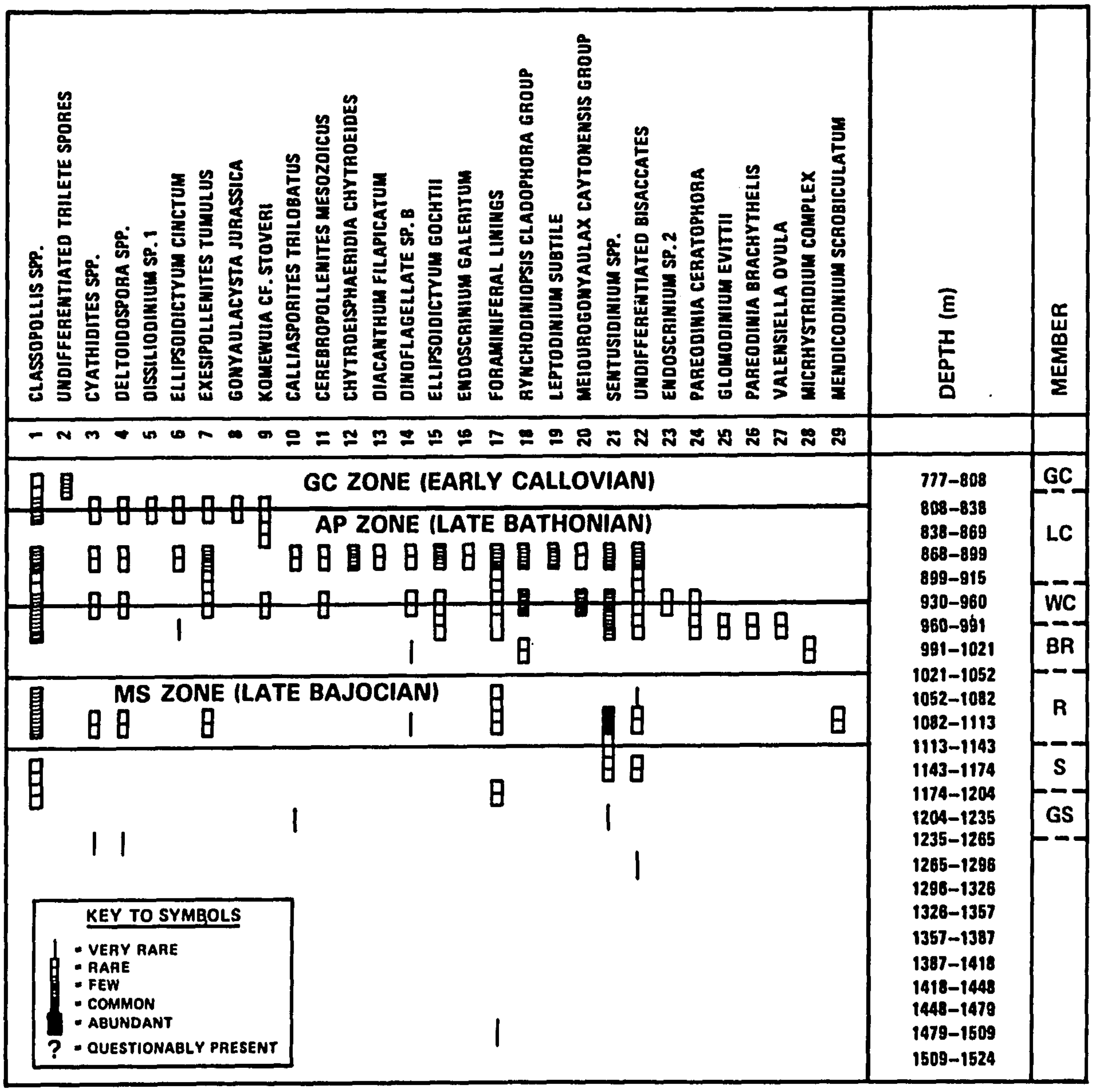
PALYNOSTRATIGRAPHY OF CAMP DAVIS SECTION: TETON CO., WYO.
RANGE CHART OF GRAPHIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 4

DEPTH(m)	SAMPLE	LITHOLOGY	MEMBER	PALYNOZONE	AGE
777.4	2550	OOLITIC AND SHALY LIMESTONE; MINOR CALCAREOUS SILTSTONE	GIRAFFE CREEK	Gc	EARLY CALLOVIAN
807.9	2650				
838.4	2750	SHALY LIMESTONE; SOME OOLITES; MINOR CALCAREOUS SILTSTONE	LEEDS CREEK		
868.9	2850			Ap	LATE BATHONIAN
899.4	2950				
914.6	3000				
929.9	3050	SHALY LIMESTONE; MINOR OOLITES AND CALCAREOUS SILTSTONE	WATTON CANYON		
960.4	3150				
990.8	3250			INTERVAL NOT ZONED	?MIDDLE BATHONIAN
1021.3	3350	SILTY LIMESTONE; MINOR OOLITES, CALCAREOUS SILTSTONE AND GYPSUM	BOUNDARY RIDGE		EARLY BATHONIAN
1051.8	3450				
1082.3	3550	SHALY LIMESTONE; MINOR OOLITES AND CALCAREOUS SILTSTONE	RICH	Ms	LATE BAJOCIAN
1112.8	3650				
1143.3	3750				
1173.8	3850	SHALY LIMESTONE AND CALCAREOUS SILTSTONE	SLIDEROCK	INTERVAL NOT ZONED	
1204.3	3850				
1234.7	4050	GYPSIFEROUS SILTSTONE; MINOR SANDSTONE AND LIMESTONE	GYPSUM SPRING		? MIDDLE TO LATE BAJOCIAN
1265.2	4150				
1295.7	4250	SANDSTONE MINOR GYPSUM AND LIMESTONE	?	INTERVAL NOT ZONED	?
1326.2	4350				
1356.7	4450				
1417.7	4550				
1448.2	4650				
1478.6	4750				
1509.1	4850				
1524.4	4950				

APPENDIX 5. LITHOSTRATIGRAPHY AND PALYNOSTRATIGRAPHY OF THE ASTORIA # 1-21 UNIT FEDERAL WELL.

CLASSOPOLLIS SPP. 1	UNDIFFERENTIATED TRILETE SPORES 2	CYATHIDITES SPP. 3	DELTOIDOSPORA SPP. 4	DISSILIODINIUM SP.1 5	ELLIPSOIDICTYUM CINCTUM 6	EXESIPOLLENITES TUMULUS 7	GONYAULACYSTA JURASSICA 8	KOMEWUIA CF. STOVERI 9	CALLIASPORITES TRILOBATUS 10	CEREBROPOLLENITES MESOZOICUS 11	CHYTROEISPHAERIDIA CHYTROEIDES 12	DIACANTHUM FILAPICATUM 13	DINOFLAGELLATE SP.B 14	ELLIPSOIDICTYUM GOCHTII 15	ENDOSCRINIUM GALERITUM 16	FORAMINIFERAL LININGS 17	RYNCHODINIOPSIS CLADOPHORA GROUP 18	LEPTODINIUM SUBTILE 19	MEIOUROGONYAULAX CAYTONENSIS GROUP 20	SENTUSIDINIUM SPP. 21	UNDIFFERENTIATED BISACCATES 22	ENDOSCRINIUM SP.2 23	PAREODINIA CERATOPHORA 24	GLOMODINIUM EVITTII 25	PAREODINIA BRACHYTHELIS 26	VALENSIELLA OVULA 27	MICRHYSTRIDIUM COMPLEX 28	MENDICODINIUM SCROBICULATUM 29	DEPTH (m)	MEMBER
GC ZONE (EARLY CALLOVIAN)																														
3	6																												777–808	GC
8		3	4	3	3	3	3	2																					808–838	
AP ZONE (LATE BATHONIAN)																														
								3																					838–869	LC
7		4	3		4	7			2	2	7	2	3	6	4	8	9	9	3	7	8								868–899	
4						3										4					5								899–915	
9		4	3			4		2		3			3	2		3	8		6	9	3	4	3						930–960	WC
6					2									3		7				9	3		3	4	3	4			960–991	
													1				4										3		991–1021	BR
MS ZONE (LATE BAJOCIAN)																														
																													1021–1052	
7																2													1052–1082	
8		3	3			3							2			4				4	4							3	1082–1113	R
																				5									1113–1143	
4																				4	3								1143–1174	S
4																4													1174–1204	
									1											2									1204–1235	GS
		1	1																										1235–1265	
																					1								1265–1296	
																													1296–1326	
																													1326–1357	
																													1357–1387	
																													1387–1418	
																													1418–1448	
																													1448–1479	
															1														1479–1509	
																													1509–1524	

PALYNOSTRATIGRAPHY OF ASTORIA #1-21 UNIT FEDERAL WELL
RANGE CHART OF NUMERIC ABUNDANCES BY HIGHEST APPEARANCE
APPENDIX 6



PALYNOSTRATIGRAPHY OF ASTORIA #1-21 UNIT FEDERAL WELL
RANGE CHART OF GRAPHIC ABUNDANCES BY HIGHEST APPEARANCE
APPENDIX 7

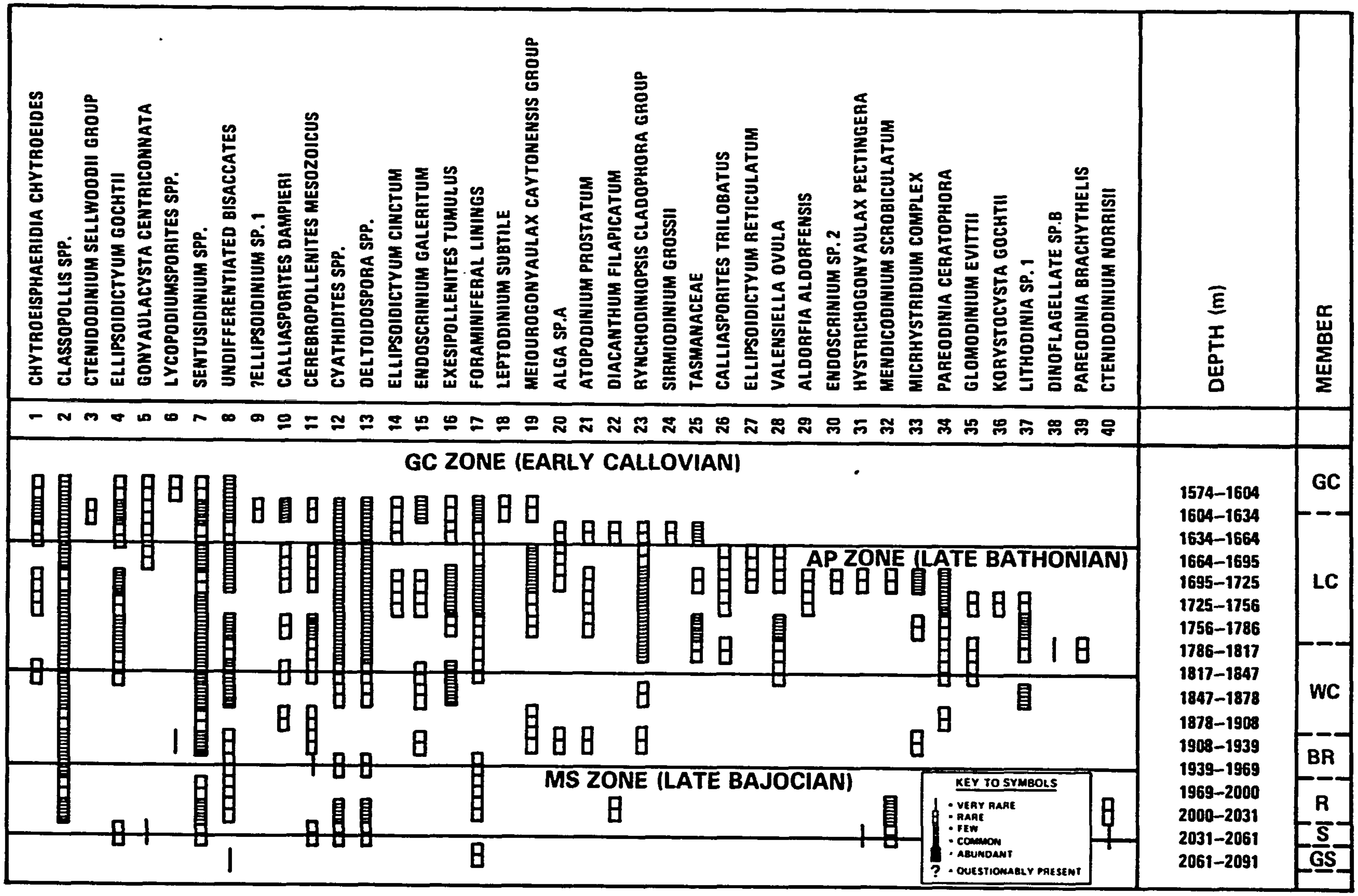
DEPTH(m)	SAMPLE	LITHOLOGY	MEMBER	PALYNOZONE	AGE
1573.2	5160	CALCAREOUS SILTSTONE, LIMESTONE AND OOLITIC LIMESTONE	GIRAFFE CREEK	Gc	EARLY CALLOVIAN
1603.6	5260				
1634.1	5360				
1664.6	5460	LIMESTONE; MINOR CALCAREOUS SILTSTONE	LEEDS CREEK		
1695.1	5560			Ap	LATE BATHONIAN
1725.6	5660				
1756.1	5760				
1786.6	5860				
1817.1	5960	LIMESTONE, OOLITIC LIMESTONE; MINOR CALCAREOUS SILTSTONE	WATTON CANYON		
1847.6	6060				
1878.0	6160			INTERVAL NOT ZONED	?MIDDLE BATHONIAN
1908.5	6260				
1939.0	6360	LIMESTONE,OOLITIC LIMESTONE; MINOR CALCAREOUS SILTSTONE	BOUNDRY RIDGE		EARLY BATHONIAN
1969.5	6460				
2000.0	6560	LIMESTONE; MINOR CALCAREOUS SILTSTONE	RICH	Ms	LATE BAJOCIAN
2030.5	6660				
2061.0	6760	OOLITIC LIMESTONE;MINOR CALCEREOUS SILTSTONE	SLIDEROCK		
2091.5	6860	GYPSUM,CALCAREOUS SILTSTONE; LIMESTONE	GYPSUM SPRING	INTERVAL NOT ZONED	?MIDDLE TO EARLY BAJOCIAN

APPENDIX 8. LITHOSTRATIGRAPHY AND PALYNOSTRATIGRAPHY OF THE WHITNEY CANYON WELL.

ZONE	DEPTH (m)	1 CHYTROEISPHAERIDIA CHYTROEIDES	2 CLASSOPOLLIS SPP.	3 CTENIDODINIUM SELLWOODII GROUP	4 ELLIPSOIDICTYUM GOCHTII	5 GONYAULACYSTA CENTRICONNATA	6 LYCOPODIUMSPORITES SPP.	7 SENTUSIDINIUM SPP.	8 UNDIFFERENTIATED BISACCATES	9 ?ELLIPSOIDINIUM SP. 1	10 CALLIASPORITES DAMPIERI	11 CEREBROPOLLENITES MESOZOICUS	12 CYATHIDITES SPP.	13 DELTOIDOSPORA SPP.	14 ELLIPSOIDICTYUM CINCTUM	15 ENDOSCRINIUM GALERITUM	16 EXESIPOLLENITES TUMULUS	17 FORAMINIFERAL LININGS	18 LEPTODINIUM SUBTILE	19 MEIDUROGONYAULAX CAYTONENSIS GROUP	20 ALGA SP.A	MEMBER
GC ZONE (EARLY CALLOVIAN)	1574–1604	3	8	1	4	2	2	5	6													GC
	1604–1634	7	9	3	6	3		6	7	2	6	2	9	8	2	6	4	8	3	2		
	1634–1664	3	7		2	3		5	2				8	7	2		3	4			2	
AP ZONE (LATE BATHONIAN)	1664–1695		8			4		7	6		3	2	9	6				4		6	2	
	1695–1725	3	3		7			5	9		3	2	6	8	2	6	9	9		8	2	LC
	1725–1756	4	10		3			9					7	6	3	4	8	9		4		
	1756–1786		18		7			10	11		3	6	7	6			4	5		4		
	1786–1817		13		3			9	4			4	8	7				2				
	1817–1847	4	7		4			7	8		4	3	4	4		4	7	4				
	1847–1878		8					8	3				3	4		3	6					WC
	1878–1908		4					5			3	4								3		
	1908–1939		7				1	6	4			3				2				2	3	
	1939–1969		9						3			1	4	3				4				BR
MS ZONE (LATE BAJOCIAN)	1969–2000		3					3	5									5				R
	2000–2031		9					6	4				6	9				4				
	2031–2061				2	1		2				2	3	3								S
	2061–2091		1						1									3				GS

ZONE	DEPTH (m)	21 ATOPODINIUM PROSTATUM	22 DIACANTHUM FILAPICATUM	23 RYNCHODINIOPSIS CLADOPHORA GROUP	24 SIRMIODINIUM GROSSII	25 TASMANACEAE	26 CALLIASPORITES TRILOBATUS	27 ELLIPSOIDICTYUM RETICULATUM	28 VALENSIELLA OVULA	29 ALDORFIA ALDORFENSIS	30 ENDOSCRINIUM SP. 2	31 HYSTRICHOGONYAULAX PECTINGERA	32 MENDICODINIUM SCROBICULATUM	33 MICRHYSTRIDIUM COMPLEX	34 PAREODINIA CERATOPHORA	35 GLOMODINIUM EVITTII	36 KORYSTOCYSTA GOCHTII	37 LITHODINIA SP. 1	38 DINOFLAGELLATE SP.B	39 PAREODINIA BRACHYTHELIS	40 CTENIDODINIUM NORRISII	MEMBER
GC ZONE (EARLY CALLOVIAN)	1574–1604																					GC
	1604–1634																					
	1634–1664	2	2	3	2	6																
AP ZONE (LATE BATHONIAN)	1664–1695			4			2	3	2													
	1695–1725	3		11		3	2	4	3	2	3	2	2	7	8							LC
	1725–1756	4		9			3			2					9	2	2	4				
	1756–1786	4		6		6			8					4	5			8				
	1786–1817			7		4	2		3						3	3		4	1	2		
	1817–1847								3						3	2						
	1847–1878			4														6				WC
	1878–1908														2							
	1908–1939	2		3										3								
	1939–1969																					BR
MS ZONE (LATE BAJOCIAN)	1969–2000																					R
	2000–2031		3										6								2	
	2031–2061											1	4								1	S
	2061–2091																					GS

PALYNOSTRATIGRAPHY OF WHIT CANYON WELL, UNITA CO., WYOMING
RANGE CHART OF NUMERIC ABUNDANCES BY HIGHEST APPEARANCE
APPENDIX 9



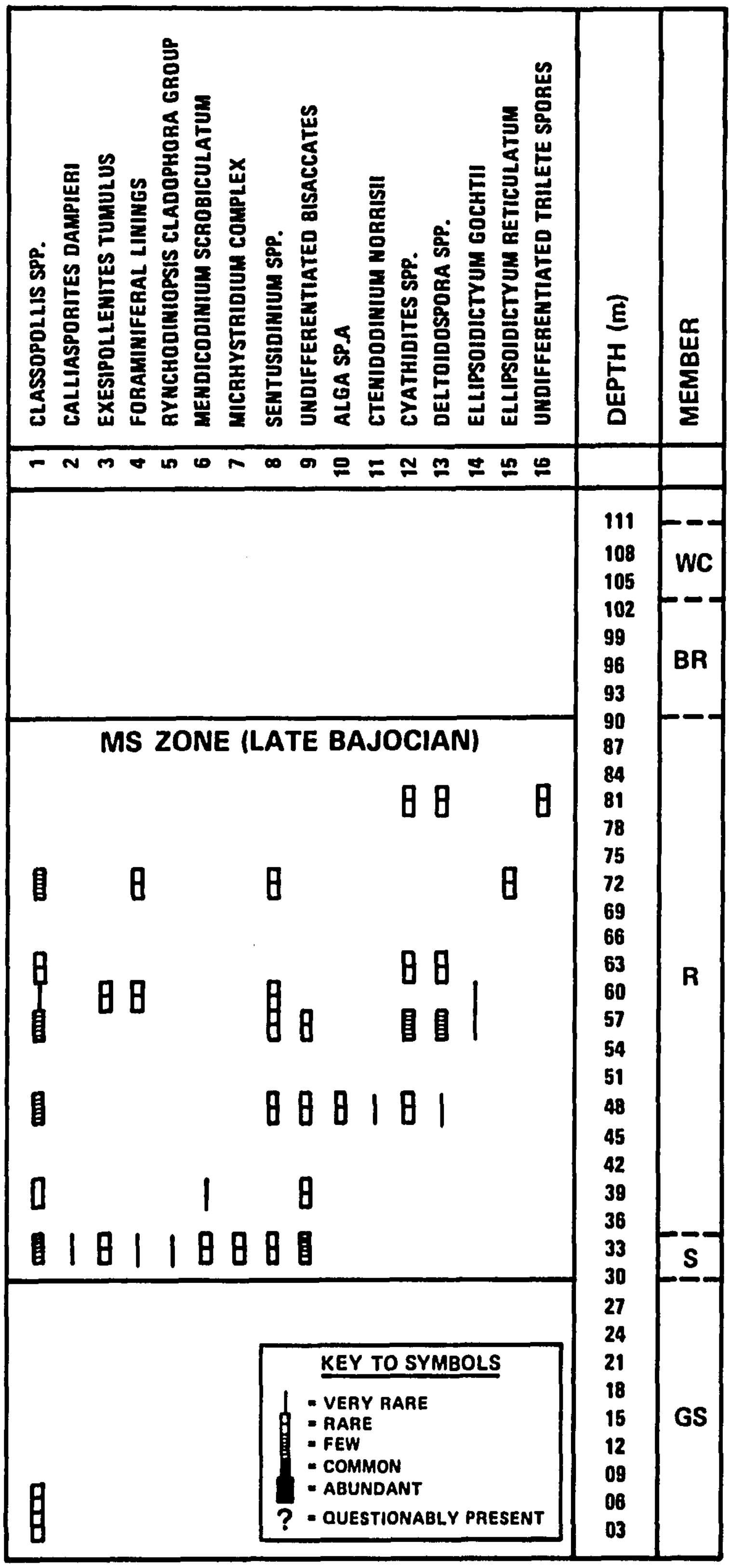
PALYNOSTRATIGRAPHY OF WHIT CANYON WELL, UNITA CO., WYOMING
RANGE CHART OF GRAPHIC ABUNDANCES BY HIGHEST APPEARANCE
APPENDIX 10

ELEVATION(m)	SAMPLE	LITHOLOGY	MEMBER	PALYNOZONE	AGE
109.7	TC 37	OOLITIC LIMESTONE	WATTON CANYON	INTERVAL NOT ZONED	?MIDDLE BATHONIAN
103.6	TC 35				
97.6	TC 33	CALCAREOUS SILTSTONE	BOUNDARY RIDGE		EARLY BATHONIAN
91.5	TC 31				
85.4	TC 29	SHALY LIMESTONE	RICH	Ms	LATE BAJOCIAN
79.3	TC 27				
73.2	TC 25				
67.1	TC 23				
61.0	TC 21				
54.9	TC 19				
48.8	TC 17				
42.7	TC 15				
36.6	TC 13				
30.5	TC 12	OOLITIC LIMESTONE	SLIDEROCK		
24.4	TC 10	CALCAREOUS SILTSTONE	GYPSUM SPRING	INTERVAL NOT ZONED	?MIDDLE TO LATE BAJOCIAN
18.3	TC 8				
12.2	TC 6				
6.1	TC 4	GYPSIFEROUS SILTSTONE			
0.0	TC 1				

APPENDIX II. LITHOSTRATIGRAPHY AND PALYNOSTRATIGRAPHY OF THE TWIN CREEK - TYPE SECTION.

1 CLASSOPOLLIS SPP.	2 CALLIASPORITES DAMPIERI	3 EXESIPOLLENITES TUMULUS	4 FORAMINIFERAL LININGS	5 RYNCHODINIOPSIS CLADOPHORA GROUP	6 MENDICODINIUM SCROBICULATUM	7 MICRHYSTRIDIUM COMPLEX	8 SENTUSIDINIUM SPP.	9 UNDIFFERENTIATED BISACCATES	10 ALGA SP.A	11 CTENIDODINIUM NORRISII	12 CYATHIDITES SPP.	13 DELTOIDOSPORA SPP.	14 ELLIPSOIDICTYUM GOCHTII	15 ELLIPSOIDICTYUM RETICULATUM	16 UNDIFFERENTIATED TRILETE SPORES	DEPTH (m).	MEMBER
																111	
																108	WC
																105	
																102	
																99	BR
																96	
																93	
																90	
MS ZONE (LATE BAJOCIAN)																87	R
																84	
												2			2	81	
																78	
																75	
9			3				4							2		72	
																69	
																66	
3												3				63	
		3	4				6						1			60	
9							4	3		2		8	1			57	
																54	
																51	
8							3	2	2	1	1					48	
																45	
																42	
5	1							5								39	
																36	
18	4	1	6	1	1	7	6	9								33	S
																30	
																27	GS
																24	
																21	
																18	
																15	
																12	
																09	
5																06	
4																03	

PALYNOSTRATIGRAPHY OF TYPE SECTION: TWIN CREEK LS.
RANGE CHART OF NUMERIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 1.2



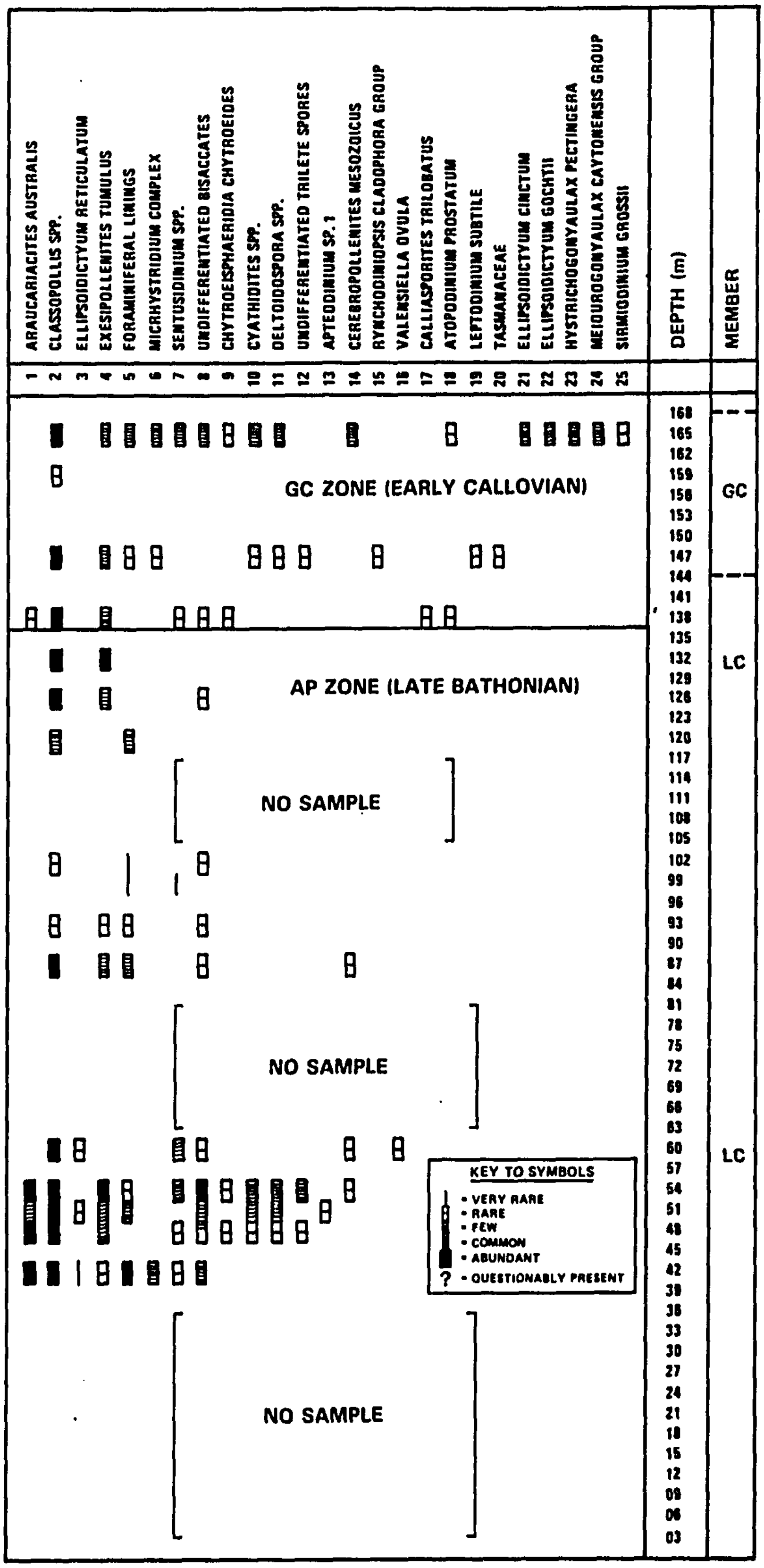
PALYNOSTRATIGRAPHY OF TYPE SECTION: TWIN CREEK LS.
RANGE CHART OF GRAPHIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 13

ELEVATION(m)	SAMPLE	LITHOLOGY	MEMBER	PALYNOZONE	AGE
167.7	LC 33	SANDY LIMESTONE	GIRAFFE CREEK	Gc	EARLY CALLOVIAN
161.6	LC 31				
155.5	LC 29				
149.4	LC 27				
143.3	LC 25				
137.2	LC 23	CALCAREOUS SHALE/SHALY LIMESTONE INTERBEDDED WITH OOLITIC/PELLITIC LIMESTONE	LEEDS CREEK		
131.1	LC 21			Ap	LATE BATHONIAN
125.1	LC 19				
118.9	LC 17				
112.8	NO SAMPLE				
106.7					
100.6					
94.5	LC 15	CALCAREOUS SHALE/ SHALY LIMESTONE INTERBEDDED WITH OOLITIC/PELLITIC LIMESTONE	LEEDS CREEK	Ap	
88.4	LC 13				
82.3	LC 11				
76.2	NO SAMPLE				
70.1					
64.0					
57.9	LC 9	CALCAREOUS SHALE/ SHALY LIMESTONE INTERBEDDED WITH OOLITIC/PELLITIC LIMESTONE	LEEDS CREEK	Ap	
51.8	LC 7				
45.7	LC 5				
39.6	LC 3				
33.5	LC 1				
27.4	NO SAMPLE				
21.3					
15.2					
9.1					
3.1					
0.0					

APPENDIX 14. LITHOSTRATIGRAPHY AND PALYNOSTRATIGRAPHY OF THE UNDERWOOD CANYON SECTION.

ARAUCARIACITES AUSTRALIS	CLASSOPOLLIS SPP.	ELLIPSOIDICTYUM RETICULATUM	EXESIPOLLENITES TUMULUS	FORAMINIFERAL LININGS	MICRHYSTRIDIUM COMPLEX	SENTUSIDINIUM SPP.	UNDIFFERENTIATED BISACCATES	CHYTROEISPHAERIDIA CHYTROEIDES	CYATHIDITES SPP.	DELTOIDOSPORA SPP.	UNDIFFERENTIATED TRILETE SPORES	APTEODINIUM SP. 1	CEREBROPOLLENITES MESOZOICUS	RYNCHODINIOPSIS CLADOPHORA GROUP	VALENSIELLA OVULA	CALLIASPORITES TRILOBATUS	ATOPODINIUM PROSTATUM	LEPTODINIUM SUBTILE	TASMANACEAE	ELLIPSOIDICTYUM CINCTUM	ELLIPSOIDICTYUM GOCHTII	HYSTRICHOGONYAULAX PECTINGERA	MEIOUROGONYAULAX CAYTONENSIS GROUP	SIRMIODINIUM GROSSII	DEPTH (m)	MEMBER
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25		
																									168	
	2	3	8	8		7	6	7	2	8			7				3			7	8	7	9	2	165	
																									162	
	4																								159	
											GC ZONE (EARLY CALLOVIAN)														156	GC
														1											153	
																									150	
	25		1	5	3					3	4			3				2	3						147	
																									144	
																									141	
3			9			7	3	2								2	3								138	
																									135	
	21		10									↑													132	LC
											AP ZONE (LATE BATHONIAN)														129	
	23		14				5																		126	
																									123	
	11			15												1									120	
																									117	
																									114	
										NO SAMPLE															111	
																									108	
																									105	
	4			1			2																		102	
				1		1																			99	
																									96	
	6		3	2			3																		93	
																									90	
	20		7	7			2						2												87	
																									84	
																									81	
																									78	
																									75	
										NO SAMPLE															72	
																									69	
																									66	
																									63	
	21	2				9							3		2										60	LC
																									57	
11	34		17	6		9	13	2	9	4		2	2	1											54	
9	27	4	9	8			9		7		2														51	
12	20		9			7	8	2	2	3															48	
																									45	
11	21		6	17	9	6	8																		42	
																									39	
																									36	
																									33	
																									30	
																									27	
																									24	
										NO SAMPLE															21	
																									18	
																									15	
																									12	
																									09	
																									06	
																									03	

PALYNOSTRATIGRAPHY OF UNDERWOOD CANYON, LINCOLN CO., WYO.
RANGE CHART OF NUMERIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 15



PALYNOSTRATIGRAPHY OF UNDERWOOD CANYON, LINCOLN CO., WYO.
RANGE CHART OF GRAPHIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 16

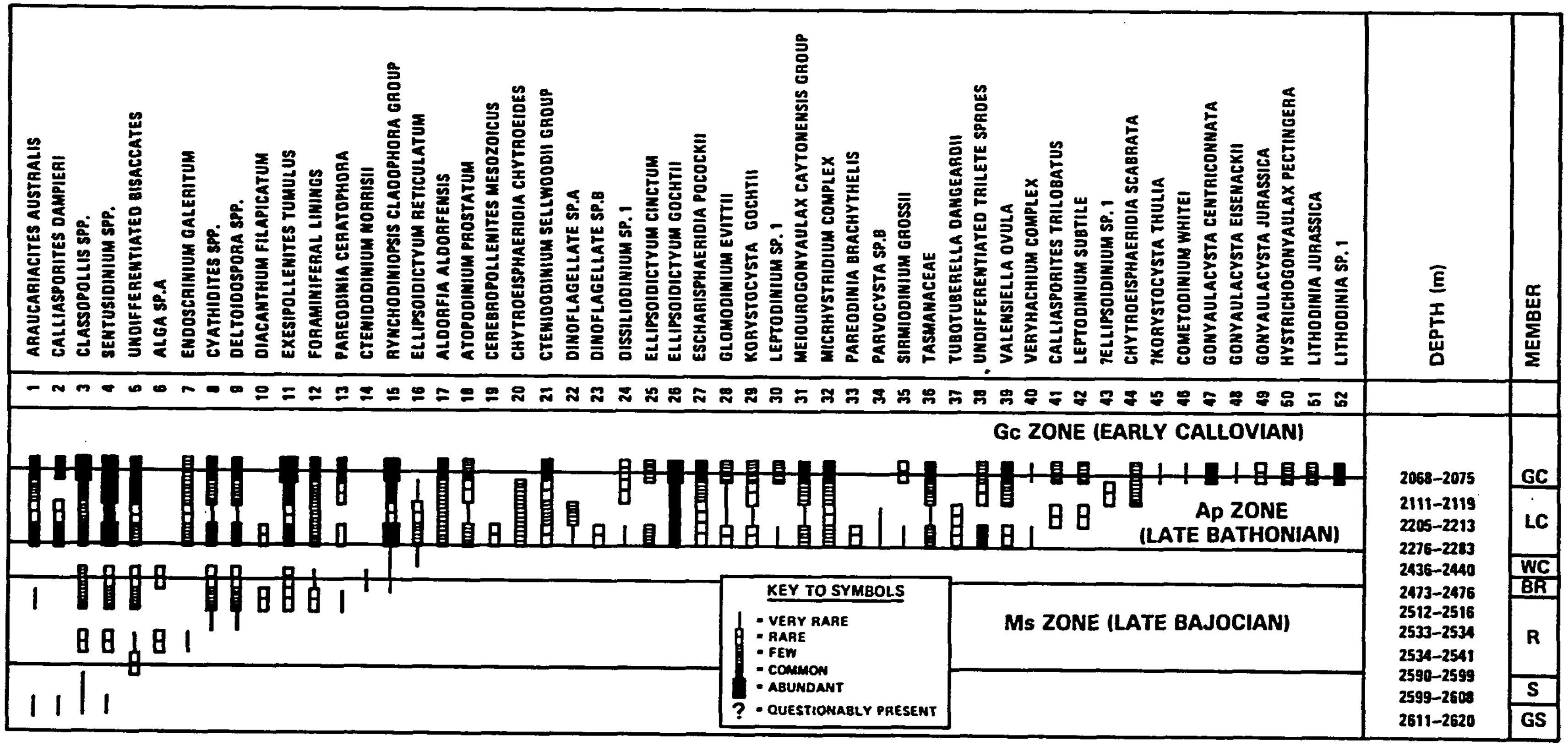
DEPTH(m)	SAMPLE	LITHOLOGY	MEMBER	PALYNOZONE	AGE
2042.7		CALCAREOUS SANDY SILTSTONE	GIRAFFE		EARLY
2073:2	2068-2075.6	TO SANDY LIMESTONE	CREEK	Gc	CALLOVIAN
2090.8					
2103.6	2116.6-2119.2				
2134.1					
2164.6		CALCAREOUS			
2195.1	2205.2-2213.4	SHALE	LEEDS		LATE
2225.6		TO	CREEK		BATHONIAN
2256.1	2275.9-2283.5	CALCAREOUS		Ap	
2286.6		SILTY SHALE			
2317.1					
2341.5					
2347.6					
2378		SILTY TO OOLITIC	WATTON		
2408.5	2436-2440.5	LIMESTONE	CANYON		
2422.8				INTERVAL	?MIDDLE BATHONIAN
2439		SILTY LIMESTONE	BOUNDARY	NOT	
2468		TO CALCAREOUS SILTSTONE	RIDGE	ZONED	EARLY BATHONIAN
2469.5	2473.5-2476.5				
2500	2512.2-2516.3	SHALY	RICH	Ms	
2530.5	2533-2541.1	LIMESTONE			
2561					
2564.3	2590-2599				
2576.8		SILTY TO OOLITIC LIMESTONE	SLIDE ROCK	INTERVAL	
2591.5	2599-2608.2	CALCAREOUS SILTSTONE	GYPSUM	NOT	? MIDDLE TO LATE
2612.8		TO SILTY ANHYDRITE	SPRING	ZONED	BAJOCIAN
2622	2611.6-2619.8				

APPENDIX 17. LITHOSTRATIGRAPHY AND PALYNOSTRATIGRAPHY
OF THE UTAH SOUTHERN HATCH #1 WELL.

DEPTH (m)	MEMBER	1 ARAUCARIACITES AUSTRALIS	2 CALLIASPORITES DAMPIERI	3 CLASSOPOLLIS SPP.	4 SENTUSIDINIUM SPP.	5 UNDIFFERENTIATED BISACCATES	6 ALGA SP.A	7 ENDOSCRINIUM GALERITUM	8 CYATHIDITES SPP.	9 DELTOIDOSPORA SPP.	10 DIACANTHUM FILAPICATUM	11 EXESIPOLLENITES TUMULUS	12 FORAMINIFERAL LININGS	13 PAREODINIA CERATOPHORA	14 CTENIDODINIUM NORRISII	15 RYNCHODINIOPSIS CLADOPHORA GROUP	16 ELLIPSOIDICTYUM RETICULATUM	17 ALDORFIA ALDORFENSIS	18 ATOPODINIUM PROSTATUM	19 CEREBROPOLLENITES MESOZOICUS	20 CHYTROEISPHAERIDIA CHYTROEIDES	21 CTENIDODINIUM SELLWOODII GROUP	22 DINOFLAGELLATE SP.A	23 DINOFLAGELLATE SP.B	24 DISSILIODINIUM SP. 1	25 ELLIPSOIDICTYUM CINCTUM	26 ELLIPSOIDICTYUM GOCHTII
GC ZONE (EARLY CALLOVIAN)																											
2068–2075	GC	23	18	57	64	22		8	21	24		54	28	24		56		17	9			24			3	10	68
AP ZONE (LATE BATHONIAN)																											
2111–2119	LC	8		34	51	28		7	12	16		29	10	6		37	1	8	4		9	5			2	41	10
2205–2213		5	5	7	29	6		5	1	1		6	8			6	2	7	1		7	8	6				
2276–2283		13	17	21	54	9		3	18	14	4	24	9	9		51	6	7	5	3	8	2		2	1	6	12
2436–2440	WC			1												1	1										
2473–2476	BR			7	4	3	2		5	3		6	1		1	1											
MS ZONE (LATE BAJOCIAN)																											
2512–2516	R	1		8	7	9			9	7	2	2	2	1													
2533–2534									1	1																	
2534–2541				3	2	1	3	1																			
2590–2599	S					2																					
2599–2608				1																							
2611–2620	GS	1	1	1	1	•																					

DEPTH (m)	MEMBER	27 ESCHARISPHAERIDIA POCOCKII	28 GLOMODINIUM EVITTII	29 KORYSTOCYSTA GOCHTII	30 LEPTODINIUM SP. 1	31 MEIOUROGONYAULAX CAYTONENSIS GROUP	32 MICRHYSTRIDIUM COMPLEX	33 PAREODINIA BRACHYTHELIS	34 PARVOCYSTA SP.B	35 SIRMIODINIUM GROSSII	36 TASMANACEAE	37 TUBOTUBERELLA DANGEARDII	38 UNDIFFERENTIATED TRILETE SPROES	39 VALENSIELLA OVULA	40 VERYHACHIUM COMPLEX	41 CALLIASPORITES TRILOBATUS	42 LEPTODINIUM SUBTILE	43 ?ELLIPSOIDINIUM SP. 1	44 CHYTROEISPHAERIDIA SCABRATA	45 ?KORYSTOCYSTA THULIA	46 COMETODINIUM WHITEI	47 GONYAULACYSTA CENTRICONNATA	48 GONYAULACYSTA EISENACKII	49 GONYAULACYSTA JURASSICA	50 HYSTRICHOGONYAULAX PECTINGERA	51 LITHODINIA JURASSICA	52 LITHODINIA SP. 1
GC ZONE (EARLY CALLOVIAN)																											
2068–2075	GC	21	9	7	6	31	28			5	14		10	2	1	8	7		6	1	1	18	1	2	5	6	14
AP ZONE (LATE BATHONIAN)																											
2111–2119	LC	8	1	4		7	10				9		3	8				2	5								
2205–2213		4	1	1		1	3		1		1	2				3	4										
2276–2283			2	2	1	8	8	2	1	1	8	4	17	5	1												
2436–2440	WC																										
2473–2476	BR																										
MS ZONE (LATE BAJOCIAN)																											
2512–2516	R																										
2533–2534																											
2534–2541																											
2590–2599	S																										
2599–2608																											
2611–2620	GS																										

PALYNOSTRATIGRAPHY OF UTAH HATCH #1 WELL: SUMMIT CO., UTAH
RANGE OF NUMERIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 18



PALYNOSTRATIGRAPHY OF UTAH HATCH #1 WELL: SUMMIT CO., UTAH
RANGE OF GRAPHIC ABUNDANCES BY LOWEST APPEARANCE
APPENDIX 19

APPENDIX 20. Taxonomic list of species of dinoflagellates, acritarchs, tasmanitids, spores, and pollen recorded in the study.

Species are arranged in alphabetical order.

Acanthaulax sp.1

Aldorfia aldorfensis (Gocht, 1970b) Stover and Evitt, 1978

Apteodinium sp.1

Atopodinium prostatum Drugg, 1978

Chytroeisphaeridia chytroeides (Sarjeant, 1962a) Downie and Sarjeant, 1965; emend. Davey, 1979d

Chytroeisphaeridia scabrata Pocock, 1972

Cleistosphaeridium spp.

Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978

Ctenidodinium chondrum Drugg, 1978

Ctenidodinium norrisii (Pocock, 1972) Stover and Evitt, 1978

Ctenidodinium sellwoodii (Sarjeant, 1975a) Stover and Evitt, 1978

Ctenidodinium sp.1

Diacanthum filapicatum (Gocht, 1970) Stover and Evitt, 1978

Dissiliodinium sp.1

Ellipsoidictyum cinctum Klement, 1960

Ellipsoidictyum gochtii Fensome, 1979

Ellipsoidictyum reticulatum (Valensi, 1953) Lentin and Williams, 1977b

?Ellipsoidinium sp.1

Endoscrinium galeritum (Deflandre, 1938b) Vozzhennikova, 1967

Endoscrinium cf. subvallare (Sarjeant, 1962) Lentin and Williams, 1973

Endoscrinium sp.1

Endoscrinium sp.2

Escharisphaeridia pocockii (Sarjeant, 1968) Erkmen and Sarjeant, 1980

Glomodinium evittii (Pocock, 1972) Davies, 1983

Gonyaulacysta centriconnata Riding, 1983

Gonyaulacysta eisenackii (Deflandre, 1938b) Dodekova, 1967; emend. Sarjeant, 1982

Gonyaulacysta helicoidea (Eisenack and Cookson, 1960) Sarjeant, 1966b

Gonyaulacysta jurassica subsp. adecta Sarjeant, 1982

Gonyaulacysta sp. A Pocock, 1972

Gonyaulacysta sp.1

Heslertonia pellucida Gitmez, 1970

Heslertonia teichophera (Sarjeant, 1966a) Sarjeant, 1976c

Hystrichogonyaulax cladophora (Deflandre, 1938b) Stover and Evitt, 1978

Hystrichogonyaulax pectinigera (Gocht, 1970b) Stover and Evitt, 1978; emend. Fensome, 1979

Hystrichogonyaulax regalis (Gocht, 1970b) Stover and Evitt, 1978

Komewuia cf. *stoveri* Chen, 1978

Korystocysta gochtii (Sarjeant, 1976a) Woollam, 1983

?*Korystocysta thulia* (Davies, 1983); emend. Du Che'ne et al., 1986; emend. Van Pelt, In Press

Leptodinium subtile Klement, 1960

Leptodinium sp.1

Lithodinia jurassica Eisenack, 1935; emend. Gocht, 1975b

Lithodinia sp.1

Meiourogonyaulax caytonensis (Sarjeant, 1959) Sarjeant, 1969

Mendicodinium scrobiculatum sp. nov.

Occisucysta cf. *balia* Gitmez, 1970

Occisucysta cf. *monoheuriska* Gitmez and Sarjeant, 1972

Pareodinia brachythelis Fensome, 1979

Pareodinia ceratophora Deflandre, 1947c; emend. Gocht, 1970b

Pareodinia groelandica Sarjeant, 1972

Parvocysta sp.B Bjaerke, 1982

Sentusidinium spp.

Sirmiodinium grossii Alberti, 1961; emend. Warren, 1973

Stephanelytron cf. *redcliffense* Sarjeant, 1961a; emend. Stover et al., 1977

Tubotuberella dangeardii (Sarjeant, 1968) Stover and Evitt, 1978; emend. Sarjeant, 1982

Valensiella ampulla Gocht, 1970b

Valensiella ovula (Deflandre, 1947c) Eisenack, 1963a

MISCELLANEOUS MARINE MICROPLANKTON

Alga sp.A Waanders (unpublished)

Dinoflagellate sp.A

Dinoflagellate sp.B

Dinoflagellate sp.C

Tasmanites complex

Micrhystridium complex

Veryhachium complex

TERRESTRIAL PALYNOMORPHS

Araucariacites australis Cookson, 1947

Calliasporites dampieri (Balme, 1957) Sukh Dev, 1961

Calliasporites trilobatus (Balme) Sukh Dev, 1961

Cerebropollenites mesozoicus (Couper) Nilsson, 1958

Classopollis spp.

Exesipollenites tumulus Balme, 1957

Cyathidites spp.

Deltoidospora spp.

Lycopodiumsporites spp.

Undifferentiated bisaccate pollen

Undifferentiated trilete spores

SYSTEMATIC PALYNOLOGY

Where appropriate, plates are numbered and discussed utilizing traditional kofoidian nomenclature.

Genera are arranged alphabetically within the order Peridiniales.

The format is a modification of Stover and Evitt (1978) and Stover and Williams (1987).

Pollen and spores are arranged alphabetically.

Full descriptions are provided only for previously undescribed taxa or taxa in which the original description was inadequate, or requires some modification.

Overall dimensions are given for each dinoflagellate species. Remaining palynomorphs are listed in terms of relative dimensions (small, intermediate, and large).

A question mark before a generic name denotes that the assigment to that genus is tentative.

The local occurrence denotes the biostratigraphic range of a species within the Twin Creek Limestone. Occurrences outside the Twin Creek Limestone are included in known distribution, utilizing data from published sources. This section is intended only to give a general representation of the species stratigraphic range and not a comprehensive listing.

Division PYRRHOPHYTA Pascher, 1914
Class DINOPHYCEAE Fritsch, 1929
Order PERIDINIALES Haeckel, 1894

Genus Acanthaulax Sarjeant, 1968; emend. Sarjeant, 1982

Type Species A. venusta (Klement, 1960) Sarjeant, 1968

Acanthaulax sp.1
(plate 8, figure 7)

SYNOPSIS: cysts are proximochorate, acavate, subellipsoidal, with an apical protrusion; tabulation gonyaulacacean, indicated by low sutural ridges surmounted by spinate features; spinate features present within intratabular areas; archeopyle precingular, type P.

DESCRIPTION:

Shape. subellipsoidal, with a transparent apical protrusion apparently formed by a coalescence of granule-like features emerging from the apical series, and tapering distally.

Wall Relationships. autophragm only; thin in nature.

Wall Features. sutural features appear as low ridges surmounted spinate crests; densely distributed, nontabular spines and granules are present within intratabular areas; a reduction in size and density of ornamentation occurs towards the apex.

Tabulation. faintly indicated by sutural features surmounted by spinate crests; gonyaulacacean; formula: 4', 0a, 6", XC, 6'", 1P, 1"".

Archeopyle. precingular, type P (3"); operculum free or infrequently attached adcingular.

Cingulum. indicated by a transverse parallel alignment of sutural ridges and by an undetermined number of subrectangular plates.

Sulcus. area incompletely expressed; probable area indicated by a longitudinal alignment of sutural ridges; reduction in ornamentation occurs in sulcal area.

DIMENSIONS: overall length 81.8um; width 60.9um; 7 specimens measured. Apical protrusion 9.2um length X 5um width.

REMARKS: the species is somewhat similar to *Acanthaulax* sp.1 (p.205, pl.1, fig.15, 20, 21) of Johnson and Hills (1973), with respect to the apical protrusion and faintly indicated tabulation. However, their species exhibit a reticulate pattern on the autophragm formed by spines arising from ridges; a narrow sulcus that extends from the apical protrusion to the antapical area; and an outline that is subcircular to ovoidal, and ranges from the Callovian through to the Lower Oxfordian in Arctic Canada. The species *A. senta* Drugg, 1978 (p.62, pl.3, fig.13, pl.4, fig. 1-3) is highly spinate and lacks intratabular granules.

LOCAL OCCURRENCE: the species is restricted to the upper Leeds Creek and lowermost Giraffe Creek members of the Camp Davis section.

Genus Aldorfia Stover and Evitt, 1978

Type Species A. aldorfensis (Gocht, 1970b) Stover and Evitt, 1978

Aldorfia aldorfensis

DIMENSIONS: overall length 77.5um X width 64.2um; 7 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek member; Whitney Canyon - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Late Bajocian - Early Callovian in northwest Europe and Germany.

Genus Apteodinium Eisenack, 1958

Type Species A. granulatum Eisenack, 1958

Apteodinium sp.1

(plate 3, figure 4)

SYNOPSIS: cysts proximate, acavate, ovoidal to subspherical body, with a short apical protrusion; tabulation gonyaulacacean, indicated by faint sutural boundaries composed of aligned granulate to verrucate features; intratabular area composed of densely arranged granulate and verrucate features; archeopyle precingular, type P.

DESCRIPTION:

Shape. subspherical to ovoidal in outline, with a short, rounded apical protrusion.

Wall Relationships. autophragm only

Wall Features. sutural features indicated by alignment of granules and verrucae, which appear mostly fused together; these features are best developed on the hypocyst; intratabular areas densely arranged with granules and verrucae.

Tabulation. obscure on the epicyst; best developed on the hypocyst; indicated by sutural features of low relief; gonyaulacacean; formula: ?', ?", XC, 6"', 1P, 1"", ?3S.

Archeopyle. precingular, type P (middorsal); operculum free.

Cingulum. indicated by transverse parallel alignment of sutural features and by undistinguished number of subrectangular plates.

Sulcus. expressed mostly on the hypocyst, slightly extended onto the epicyst; elongate shape, delimited by alignment of sutural features, consisting of a subquadrate right anterior sulcal (ras), and possible subquadrate right sulcal (rs) plate.

DIMENSIONS: overall length 72.9um X width 66.3um; 11 specimens measured.

REMARKS: compressional folds are common to specimens;

this species is slightly similar to Apteodinium sp.1 (fig.24, nos.67-73) of Chen (Ph. D. dissertation, 1978); however, his specimens exhibit a curved acute horn, two-layered wall, periphragm giving rise to densely vermiculate surface ornamentation, and obscure tabulation; the species ranges from the Bajocian to Oxfordian in Madagascar.

LOCAL OCCURRENCE: Camp Davis - Rich, Watton Canyon, and Leeds Creek members; Underwood Canyon - Leeds Creek.

Genus Atopodinium Drugg, 1978

Type Species A. prostatum Drugg, 1978

Atopodinium prostatum Drugg, 1978

(plate 4, figures 8 and 9)

DIMENSIONS: overall length 55.7um X width 51.1um; 16 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek members; Whitney Canyon - Boundary Ridge, Watton Canyon, and Leeds Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN OCCURRENCE: ?Middle/Upper Bathonian through to the Lower Oxfordian in northwest Europe, Germany, France, Portugal, and Arctic Canada.

Genus Chytroeisphaeridia (Sarjeant, 1962a) Downie and Sarjeant,1965; emend. Pocock, 1972; emend. Davey, 1979d

Type Species C. chytroeides (Sarjeant, 1962a) Downie and Sarjeant, 1965; emend. Davey, 1979d

Chytroeisphaeridia chytroeides (Sarjeant, 1962a) Downie and Sarjeant, 1965; emend. Davey, 1979d

(plate 8, figure 8)

DIMENSIONS: overall length 55.3um X width 45um; 26 specimens measured

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek members; Astoria #1-21 Unit Federal - Leeds Creek; Whitney Canyon - Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek

KNOWN OCCURRENCE: Bajocian through Kimmeridgian of northwest Europe, Netherlands, East Greenland, Arctic Canada, Portugal, and Australia

Chytroeisphaeridia scabrata Pocock, 1972

DIMENSIONS: overall length 47.9um X width 40.8um; 4 specimens measured

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek

KNOWN DISTRIBUTION: Callovian of western Canada

Genus *Cleistosphaeridium* Davey et al., 1966

Type Species *C. diversispinosum* Davey et al., 1966

Cleistosphaeridium spp.

SYNOPSIS: cysts skolochorate, acavate, subspherical to spherical body, exhibiting numerous (~>50) nontabular processes of similar size and shape; tabulation indicated by archeopyle only; archeopyle apical, type t(A).

DESCRIPTION:

Shape. subspherical to spherical in outline.

Wall Relationships. autophragm only.

Wall Features. numerous (~>50) nontabular processes of similar size and shape, slightly enlarged at the base with trumphet-shaped tips; autophragm between processes smooth.

Tabulation. indicated by archeopyle only.

Archeopyle. apical, type t(A); operculum free.

Cingulum. not indicated.

Sulcus. not indicated.

DIMENSIONS: orientation of specimens (apical/antapical) prohibits precise measurements; relative size - intermediate.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

Genus *Cometodinium* Deflandre and Courteville, 1939

Type Species *C. obscurum* Deflandre and Courteville, 1939

Cometodinium whitei (Deflandre and Courteville, 1939) Stover and Evitt, 1978

(plate 4, figure 1)

DIMENSIONS: overall length 45.9um X width 44um; 4 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Giraffe Creek.

KNOWN DISTRIBUTION: Kimmeridgian through Senonian of the western North Atlantic.

Genus Ctenidodinium Deflandre, 1938b; emend. Sarjeant, 1966b; emend. Sarjeant, 1975a; emend. Woollam, 1983; emend. Benson, 1985

Type Species C. ornatum (Eisenack, 1935) Deflandre, 1938b

Ctenidodinium chondrum Drugg, 1978

DIMENSIONS: overall length 75.3um X width 70.6um; 11 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

KNOWN OCCURRENCE: Early Kimmeridgian of France and western North Atlantic.

Ctenidodinium norrisii (Pocock, 1972) Stover and Evitt, 1978

REMARKS: Lentin and Williams (1985, p.82) place this species in the genus Korystocysta. However, according to Benson (1985, p.147 and 154), an apical horn must be present for assignment to the genus. The species does not exhibit an apical horn, therefore, is better suited to the genus Ctenidodinium.

DIMENSIONS: overall length 67um X width 67.5um; 6 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Rich, Watton Canyon, and Leeds Creek members; Whitney Canyon - Sliderock and Rich; Type section - Rich; Utah Southern Hatch #1 - Boundary Ridge.

KNOWN DISTRIBUTION: Late Bajocian through Callovian of northwest Europe and Germany.

Ctenidodinium _sellwoodii_ ,(Sarjeant, 1975a) Stover and Evitt, 1978 group

REMARKS: Lentin and Williams (1985, p.106) place this species in the genus _Dichadogonyaulax_. I concure with Benson's (1985, p.147 and 150) placement of the species in the genus _Ctenidodinium_ based on the observation that the 2' and 4' apical plates are separated at the apex by preapical plate(s) and presence of anterior intercalary plate(s).

DIMENSIONS: overall length 62.5um X width 75um; 5 specimens measured; all specimens appear somewhat compressed, therefore, restricting precise measurements.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Whitney Canyon - Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: lower Middle Bathonian through Middle Callovian of England.

Ctenidodinium sp.1

SYNOPSIS: cysts proximochorate, acavate, subspherical to subovoidal body,; tabulation indicated by sutural septa surmounted by spinate crests; archeopyle combination epicystal, type (tA&P).

DESCRIPTION:

Shape. subspherical to subovoidal in outline.

Wall Relationships. autophragm only.

Wall Features. sutural septa, commonly perforate at the base, surmounted by spinate crests; spinate features generally exhibit acuminate tips, rarely bifid, which are equally developed on both the epi and hypocyst. Nontabular granulate features occur within the intratabular areas; some of the granules appear fused, expressing an imperfect microreticulate pattern.

Tabulation. indicated by sutural septa; gonyaulacacean, formula: 1pr, 4', 1a, 6", XC, 6"', 1P, 1"", XS.

Archeopyle. combination epicystal, type (tA&P); operculum free; archeopyle not developed in one specimen.

Cingulum. indicated by transverse parallel alignment of sutural septa and by indistinct number of subrectangular plates.

Sulcus. expressed as an elongate area, mostly developed on the hypocyst, slightly extended onto the epicyst; tabulation not evident.

REMARKS: the species is slightly similar to C. continuum, first identified by Gocht (1970, p.141-142, pl.26, fig.3, pl.27, fig.5) in overall shape and equal development of spinate features on both epi and hypocyst. However, the Twin Creek specimens exhibit a distinct granulate surface ornamentation, which in places appears microreticulate.

DIMENSIONS: overall length 77.8um X width 73.9um; 4 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Rich member

Genus Diacanthum Habib, 1972

Type Species D. hollisteri Habib, 1972

Diacanthum filapicatum (Gocht, 1970) Stover and Evitt, 1978

(plate 2, figures 1a&b and 2)

REMARKS: In addition to the mode of archeopyle formation discussed by Habib and Drugg (1987, p. 762-764), few specimens recorded from the Camp Davis section exhibit a type 5P (loss of precingular plates 1', 2", 3", 4", and 5").

LOCAL OCCURRENCE: Camp Davis - Rich, Watton Canyon, and Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek; Whitney Canyon - Rich and Leeds Creek; Utah Southern Hatch #1 - Rich and Leeds Creek.

KNOWN DISTRIBUTION: Late Bajocian through Middle Callovian of northwest Europe, Germany, western Portugal, and western North Atlantic.

Genus Dissiliodinium Drugg, 1978

Type Species D. globulum Drugg, 1978 (monotypic)

Dissiliodinium sp.1

(plate 6, figure 1 and 2)

SYNOPSIS: cysts proximate, acavate, subovoidal to subspherical body; tabulation indicated by archeopyle and cingulum only; archeopyle precingular compound, type 5P.

DESCRIPTION:

Shape. subovoidal to subspherical in outline.

Wall Relationships. autophragm only.

Wall Features. no sutural features; autophragm smooth.

Tabulation. indicated by archeopyle and cingulum only, however, in few specimens, precingular plates are faintly indicated by accessory archeopyle sutures developed within the operculum.

Archeopyle. precingular compound, type 5P, formed by loss of precingular plates 1" through 5"; operculum dominantly free, however, few specimens exhibit a partially attached operculum; in several specimens, partial operculum is observed within the cyst.

Cingulum. indicated by a slight depression within the mid area of the cyst.

Sulcus. not indicated.

DIMENSIONS: overall length 56.4um X width 61.5um; 8 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

Genus *Ellipsoidictyum* Klement, 1960

Type Species *E. cinctum* Klement, 1960

Ellipsoidictyum cinctum Klement, 1960

DIMENSIONS: overall length 48.1um X width 47.2um; 9 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon and Leeds Creek; Whitney Canyon - Leeds Creek and Giraffe Creek; Underwood Canyon - Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Bajocian through Kimmeridgian of northwest Europe, Germany, Netherlands, and East Greenland.

Ellipsoidictyum gochtii Fensome, 1979

(plate 5, figure 2)

DIMENSIONS: overall length 54.3um X width 50um; 13 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon and Leeds Creek; Whitney Canyon - Sliderock, Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Giraffe Creek; Type section - Rich; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Late Bajocian through Callovian of northwest Europe, Germany, western Portugal, and East Greenland.

Ellipsoidictyum reticulatum (Valensi, 1953) Lentin and Williams, 1977b (plate 5, figure 3)

DIMENSIONS: overall length 50um X width 46um; 10 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Whitney Canyon - Leeds Creek; Underwood Canyon - Leeds Creek; Type section - Rich; Utah Southern Hatch #1 - Leeds Creek.

KNOWN DISTRIBUTION: Bajocian through Upper Bathonian (C. discus) of northwest Europe and Germany.

Genus Ellipsoidinium Clarke and Verdier, 1967

Type Species E. rugulosum Clarke and Verdier, 1967

?Ellipsoidinium sp.1

(plate 6, figure 3)

SYNOPSIS: cysts proximate, acavate, ellipsoidal body, with nontabular low, commonly longitudinal, sometimes oblique, discontinuous to rarely continuous ridges; tabulation indicated by archeopyle and cingulum only; archeopyle dominantly precingular, type P, however, rarely combination epicystal, type (tA&1P).

DESCRIPTION:

Shape. ellipsoidal in outline.

Wall Relationships. autophragm only.

Wall Features. no sutural features present; surface exhibits multiple, low, discontinuous to rarely continuous ridges that are commonly longitudinal, sometimes oblique; surface between ridges appears scabrate to smooth.

Tabulation. indicated by archeopyle and cingulum only.

Archeopyle. dominantly precingular, type P; operculum free; however few specimens exhibit an epicystal combination, type (tA&1P), formed by the apparent loss of the entire apical series and one precingular plate; operculum free.

Cingulum. indicated by apparent interruption of ridges in the equitorial area.

Sulcus. not indicated.

REMARKS: the species is questionably assigned to Ellipsoidinium because of the rare occurrences continuous ridges on the autophragm and rare archeopyle epicystal combination, type (tA&1P), features not consistent with the description of the genus by Stover and Evitt (1978, p.153).

DIMENSIONS: overall length 45um X width 36.5um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Whitney Canyon - Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek.

Genus Endoscrinium (Klement, 1960) Vozzhennikova, 1967

Type Species E. galeritum (Deflandre, 1938b) Vozzhennikova, 1967

Endoscrinium galeritum (Deflandre, 1938b) Vozzhennikova, 1967

(plate 5, figure 5)

DIMENSIONS: overall length - 75.3um X width 66.7um; 8 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton and Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek; Whitney Canyon - Boundary Ridge, Leeds Creek, and Giraffe Creek; Utah Southern Hatch #1 - Rich, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Middle Bajocian through ?Upper Kimmeridgian of Arctic Canada, East Greenland, Poland, Roumania, and northwest Europe.

Endoscrinium cf. subvallare (Sarjeant, 1962) Lentin and Williams, 1973

REMARKS: the species is very similar to that described by Pocock (1972, p.92, text-fig.8, pl.23, fig.4). The specimens, as well as in Pocock, differ from E. subvallare in lacking well-developed sutural crests denoting plate boundaries, as shown in Sarjeant (1962, pp. 202-203, pl.1, fig.10).

DIMENSIONS: overall length 76um X width 69.8um; 6 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek.

KNOWN DISTRIBUTION: Oxfordian of western Canada; E. subvallare is known to range from the Callovian through Oxfordian of Roumania and northwest Europe.

Endoscrinium sp.1

(plate 6, figure 7 and 8)

SYNOPSIS: cysts proximate, circumcavate, ellipsoidal to subellipsoidal body, with a small apical bulge; tabulation indicated by low sutural septa surmounted by spinate to denticulate crests; archeopyle precingular, type P.

DESCRIPTION:

Shape. ellipsoidal to subellipsoidal in outline, with a small rounded apical bulge.

Wall Relationships. cysts circumcavate, endophragm and periphragm in contact locally along the lateral margins; sutural features are expressed as low septa, commonly perforate basally and surmounted by denticulate to spinate crests; Spinate features are acuminate distally and decrease in size towards the apex; intratabular areas are varably scabrate to punctate.

Tabulation. indicated by sutural septa developed on periphragm, gonyaulacacean, formula: 4', 6", 4-5C, 6"', 1P, 1"", ?3S.

Archeopyle. precingular, type P, formed by loss of middorsal precingular plate 3"; operculum free.

Cingulum. indicated by transverse parallel alignment of sutural septa and by four or five rectangular to quadrate plates.

Sulcus. expressed as a broad, elongate longitudinally area, positioned mostly on the hypocyst; tabulation evident and includes a posterior sulcal plate, immediately anterior, a faintly indicated small subquadrate appears.

DIMENSIONS: overall length 58.4um X width 47.8um; 22 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek member.

Endoscrinium sp.2

(plate 6, figure 5)

SYNOPSIS: cysts proximate, circumcavate, spherical to ovoidal body; tabulation indicated by archeopyle and cingulum only; archeopyle precingular, type P.

DESCRIPTION:

Shape. spherical to ovoidal in outline.

Wall Relationships. circumcavate, endophragm and periphragm in contact along lateral margins.

Wall Features. no sutural features; periphragm is thin, finely granulate, occasionally perforate, and containing compressional folds; endophragm is thicker, granulate to verrucae, which sometimes coalesce to give an impression of an imperfect reticulate pattern.

Tabulation. indicated by archeopyle and cingulum only.

Archeopyle. precingular, type P; operculum free

Cingulum. indicated by a narrow equatorial depression.

Sulcus. not indicated.

REMARKS: specimens appear poorly preserved in all sections except the Camp Davis.

DIMENSIONS: overall length 48.9um X width 43.7um; 7 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon; Whitney Canyon - Leeds Creek.

Genus Escharisphaeridia Erkmen and Sarjeant, 1980

Type Species E. pocockii (Sarjeant, 1968) Erkmen and Sarjeant, 1980

Escharisphaeridia pocockii (Sarjeant, 1968) Erkmen and Sarjeant, 1980

DIMENSIONS: overall length 51.3um (without operculum) X width 57.5um; 8 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN OCCURRENCE: Late Bajocian through Kimmeridgian of northwest Europe, western Portugal, East Greenland, Arctic Canada, and Australia.

Genus Glomodinium Dodekova, 1975

Type Species G. reticulopilosum Dodekova, 1975

Glomodinium evittii (Pocock, 1972) Davies, 1983

(plate 4, figure 6)

DIMENSIONS: overall length 60.2um X width 43.8um; 12 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon; Whitney Canyon - Watton Canyon and Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Bajocian through Callovian of East Greenland, Arctic Canada, and western North Atlantic.

Genus Gonyaulacysta Deflandre, 1964; emend. Sarjeant, 1969; emend. Stover and Evitt, 1978; emend. Sarjeant, 1982

Type Species G. jurassica (Deflandre, 1938b) Norris and Sarjeant, 1965; emend. Sarjeant, 1982

Gonyaulacysta centriconnata Riding, 1983
(plate 8, figures 1 and 2)

DIMENSIONS: overall length 56.4um X width 51.9um; 12 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Whitney Canyon - Leeds Creek and Giraffe Creek; Utah Southern Hatch #1 - Giraffe Creek.

KNOWN DISTRIBUTION: Middle Callovian through Early Oxfordian of England.

Gonyaulacysta eisenackii (Deflandre, 1938b) Dodekova, 1967; emend. Sarjeant, 1982 (plate 7, figure 1)

DIMENSIONS: overall length 60um X width 46.3um; 3 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Giraffe Creek.

KNOWN DISTRIBUTION: Middle Bathonian through Lower Kimmeridgian of northwest Europe, East Greenland, and Arctic Canada.

<u>Gonyaulacysta</u> <u>helicoidea</u> (Eisenack and Cookson, 1960) Sarjeant, 1966b

DIMENSIONS: overall length 50um X width 47.2; 9 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

KNOWN OCCURRENCE: Early Kimmeridgian through Aptian of the western North Atlantic; Middle Callovian through Aptian of Arctic Canada.

<u>Gonyaulacysta</u> <u>jurassica</u> <u>subsp.</u> <u>adecta</u> Sarjeant, 1982

DIMENSIONS: overall length 63.5um X width 50.5um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek; Utah Southern Hatch #1 - Giraffe Creek.

KNOWN DISTRIBUTION: Middle Callovian to Early Oxfordian of western Scotland.

<u>Gonyaulacysta</u> sp.A Pocock, 1972

(plate 5, figures 7a&b)

REMARKS: Pocock's (1972, p.89-90, pl.23, fig 5; text-fig.5) description of the species is based on one specimen. Conversely, numerous specimens are recorded from the Twin Creek Limestone.

DIMENSIONS: overall length 56.9um X width 45.8um; 9 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek members.

KNOWN OCCURRENCE: Oxfordian to Kimmeridgian of western Canada.

Gonyaulacysta sp.1

(plate 7, figures 4a&b)

SYNOPSIS: cysts proximate, bicavate, ovoidal to subspherical body, with a small apical horn; tabulation indicated by sutural ridges surmounted by spinate features of low relief; intratabular areas expressed by granulate features; archeopyle precingular, type P.

DESCRIPTION:

Shape. ovoidal to subspherical in outline, with a small, subpolygonal, transparent apical horn that is open distally.

Wall Relationships. cysts bicavate, although development of the hypopericoel is lacking.

Wall Features. low continuous sutural ridges surmounted by spinate features of low relief; spinate features appear acuminate distally; intratabular areas expressed by granules that range from small to intermediate, sometimes fused to form verrucae-like features.

Tabulation. indicated by sutural ridges; gonyaulacacean, formula: 1pr, 4', 1a, 6", XC, 5-6"', 1P, 1"", 3-4S; orientation and generally poor preservation prevent precise identification of the postcingular series, cingulum and sulcal areas.

Archeopyle. precingular, type P, formed through the loss of middorsal plate 3"; operculum free.

Cingulum. indicated by transverse parallel alignment of sutural ridges and indistinct number of subrectangular plates.

Sulcus. expressed as a broad, elongate longitudinally, area delimited by sutural ridges; tabulation evident and includes a posterior sulcal (ps) plate, right anterior sulcal (ras), and a poorly developed left anterior (las) sulcal plate, the latter plate not always distinguishable on all specimens; very few specimens exhibit a flagellar pore scar.

REMARKS: Specimens are generall poorly preserved.

DIMENSIONS: overall length 59.4um X width 52.8um; 8 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Rich member.

Genus Heslertonia Sarjeant, 1966b; emend. Duxbury, 1980

Type Species H. heslertonensis (Neale and Sarjeant, 1962) Sarjeant, 1966b; emend. Duxbury, 1980

Heslertonia pellucida Gitmez, 1970

(plate 3, figure 3)

DIMENSIONS: overall length 42.5um X width 35um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek.

KNOWN DISTRIBUTION: Early Kimmeridgian to Early Tithonian of northwest Europe.

Heslertonia teichophera (Sarjeant, 1966a) Sarjeant, 1976c

(plate 3, figure 2)

DIMENSIONS: overall length 42.1um X width 42.9um; 6 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

KNOWN DISTRIBUTION: Upper Callovian through Lower Oxfordian of northwest Europe.

Genus Hystrichogonyaulax Sarjeant, 1969

Type Species H. cornigera (Valensi, 1953) Sarjeant, 1969

Hystrichogonyaulax pectinigera (Gocht, 1970b) Stover and Evitt, 1978; emend. Fensome, 1979

DIMENSIONS: overall length 51.5um X width 44um; 14 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Whitney Canyon - Sliderock (?reworked), Leeds Creek; Underwood Canyon - Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Late Bajocian through Early Callovian of northwest Europe, Germany, Netherlands, and East Greenland.

Genus Komewuia Cookson and Eisenack, 1960b; emend. Dorhofer and Davies, 1980; emend. Chen, 1982
Type Species K. glabra Cookson and Eisenack, 1960b; emend. Chen, 1982

Komewuia cf. stoveri Chen, 1978
(plate 4, figures 2 & 3)

REMARKS: specimens observed are similar to K. stoveri Chen, 1978 (pp.39-40, pl.3, figs. 22, 24-29b) with the exception of the antapical horn, cingulum, and size. Chen's specimens often exhibit a much reduced antapical horn, lack or faint indication of a cingulum, and overall size of 120-130um length X 100-120um width; The Twin Creek specimens all exhibit a reduced antapical horn, well-expressed cingulum indicated by transverse parallel alignment of granulate features, and much smaller size.
DIMENSIONS: overall length 60.4um X width 50.4um; 6 specimens measured.
LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek and Giraffe Creek.
KNOWN DISTRIBUTION: K. stoveri is known from the Kimmeridgian of Madagascar.

Genus Korystocysta Woollam, 1983; emend. Benson, 1985

Type Species K. gochtii (Sarjeant, 1976a) Woollam, 1983

Korystocysta gochtii (Sarjeant, 1976a) Woollam, 1983
(plate 5, figure 4)

DIMENSIONS: overall length 72um X width 71um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Whitney Canyon - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: lower Middle Bathonian to the Lower Callovian of England.

?Korystocysta thulia (Davies, 1983); emend. Du Che'ne et al., 1986; comb. nov. (=Occisucysta thulia Davies, 1983, p.19-20; pl.5, figs.1-8, 10-12; fig.14; = Ctenidodinium (?) thulia (Davies, 1983) Du Che'ne et al., 1986 (Appendix A, p.32, pl.27, figs. 13-15)
(plate 8, figures 4a&b, 5, and 6)

REMARKS: originally assigned to the genus Occisucysta by Davies (1983). A questioning of the generic assignment by Du Che'ne et al. (1986), based on mode of archeopyle and tabulation, led Davies (In Du Che'ne et al., 1986, p.32 of Appendix A) to suggest provisional placement in the genus Ctenidodinium. The assignment was concurred by Du Che'ne et al. (1986, Appendix, p.32).

However, specimens identified from the study, as well as those described by Davies (1983, p.20, text-fig.14, pl. 5, fig. 4&5) and Du Che'ne et al. (1986, Appendix, p.32, pl.27, fig. 13&15) exhibit morphologic features inconsistent with the genus Ctenidodinium.

Features include the presence of an apical horn and apparent penitabular arrangement of hair-like spines. The presence of these features, according to Benson (1985, p.154), are characteristic of the genus Korystocysta. In addition, a marked elongation of the posterior intercalary plate is common to the genus. This feature has not been observed in specimens of this study, nor has it been described from the studies of Davies (1983) and Du Che'ne et al. (1986), therefore the reason for the provisional assignment to Korystocysta.

DIMENSIONS: overall length 80.1um X width 73.8um; 11 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Giraffe Creek.

KNOWN DISTRIBUTION: Middle Callovian to Oxfordian of Arctic Canada.

Genus Leptodinium Klement, 1960; emend. Sarjeant, 1966b; emend. Wall, 1967; emend. Sarjeant, 1969; emend. Stover and Evitt, 1978; emend. Sarjeant, 1982

Type Species Leptodinium subtile Klement, 1960

Leptodinium subtile

DIMENSIONS: overall length 57.8um X width 60.6um; 8 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek; Whitney Canyon - Giraffe Creek; Underwood Canyon - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Early Bathonian to Middle Kimmeridgian of East Greenland; Lower Oxfordian to Upper Kimmeridgian of northwest Europe.

Leptodinium sp.1

(plate 6, figures 4a&b)

SYNOPSIS: cysts proximochorate, acavate, subovoidal to subpolygonal body, with an apical protrusion; tabulation indicated by sutural septa surmounted by denticulate to finely spinate crests; archeopyle precingular, type P.

DESCRIPTION:

Shape. subovoidal to subpolygonal in outline, with a small rounded apical protrusion.

Wall Relationships. autophragm only.

Wall Features. sutural septa continuous, smooth and surmounted by denticulate to finely spinate crests; spinate features are acuminate distally; intratabular areas are expressed mostly by granulate features of equal size, and slightly punctate.

Tabulation. indicated by sutural septa; gonyaulacacean, formula: 4', 2a, 6", 6C, ?5"', 1P, 1"", XS; septum is present between apical plates 1' and 4', the latter plate shorter than the former; line of contact substantial between plates 4' and five-sided 6"; two anterior intercalary plates present.

Archeopyle. precingular, type P, formed by loss of middorsal 3" plate; operculum free.

Cingulum. indicated by transverse parallel alignment of sutural septa and by six rectangular plates.

Sulcus. delimited by sutural septa; positioned mostly on the hypocyst, which broadens towards the antapex; possible posterior sulcal (ps) plate, however, unclear.

DIMENSIONS: overall length 76.5um X width 72.7um; 6 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

Genus *Lithodinia* Eisenack, 1935; emend. Gocht, 1975b

Type Species *L. jurassica* Eisenack, 1935; emend. Gocht, 1975b

Lithodinia jurassica Eisenack, 1935; emend. Gocht, 1975b

DIMENSIONS: overall length 43.1um (without operculum) X width 44.4um; 6 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Utah Southern Hatch #1 - Giraffe Creek.

KNOWN DISTRIBUTION: Lower Bathonian through Callovian of northwest Europe, Germany, and Poland.

Lithodinia sp.1

(plate 6, figure 6a&b)

SYNOPSIS: cysts proximate, acavate, subspherical to ovoidal body; tabulation indicated by discontinuous sutural features surmounted by small spinate features; archeopyle apical, type 4a

DESCRIPTION:

Shape. subspherical to ovoidal in outline.

Wall Relationships. autophragm only.

Wall Features. discontinuous sutural features composed of granules, some of which are fused together; base of granules appear slightly perforated; isolated small spines arise from sutural boundaries; spines are acuminate distally; intratabular areas densely microgranulate, occasionally micropunctate.

Tabulation. indicated by sutural boundaries; gonyaulacacean, formula: 4', 6", ?5C, 1P, 1"", XS; tabulation figured from two complete specimens.

Archeopyle. apical, type 4A, exhibiting a zigzag principal archeopyle suture with a deep sulcal notch; operculum free.

Cingulum. indicated by transverse parallel alignment of sutural features; possible 5 subrectangular plates.

Sulcus. expressed as a broad, elongate longitudinally area, indicated by sutural boundaries, and positioned mostly on the hypocyst; tabulation unclear, however, a possible small quadrate right anterior sulcal (ras) plate occurs immediately adjacient to the cingulum; ras plate delimited by apparent alignment of fused granules.

DIMENSIONS: overall length 46.1um (without operculum) X width 48.6um; 8 specimens measured; two complete specimens = overall length 52.5um X width 43.75um.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Whitney Canyon - Watton Canyon and Leeds Creek; Utah Southern Hatch #1 - Giraffe Creek.

Genus Meiourogonyaulax Sarjeant, 1966b

Type Species M. valensii Sarjeant, 1966b

Meiourogonyaulax caytonensis (Sarjeant, 1959) Sarjeant, 1969 group (plate 4, figure 10)

REMARKS: Riding (1987, p.262) remarked "the members of his (Sarjeant) plexus of forms are difficult to consistently differentiate, the group comprises the following species.

M. callomonii Sarjeant, 1972
M. caytonensis (Sarjeant, 1959) Sarjeant, 1969
M. cristulata (Sarjeant, 1959) Sarjeant, 1969
M. deflandrei Sarjeant, 1968

In concurrence, I have followed Riding's (1987) assignation of group to this species.

DIMENSIONS: overall length 48.1um (without operculum) X width 46.8um; 9 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek; Whitney Canyon - Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Upper Bathonian through Lower Oxfordian of northwest Europe and Germany.

Genus <u>Mendicodinium</u> Morgenroth, 1970

Type Species <u>M. reticulatum</u> Morgenroth, 1970

<u>Mendicodinium scrobiculatum</u> sp. nov.

(plate 1, figures 1-5)

SYNOPSIS: cysts proximate, acavate, subellipsoidal to subovoidal body, with a small apical bulge; tabulation indicated by archeopyle, cingulum, operculum, and vaguely by possible sutural boundaries, formed by thickening of surface ornamentation; formula: ?', 6", XC, ?6"', 1P, ?1"", XS; archeopyle combination epicystal, type (tA&tP)a or (tA&tP).

DESCRIPTION:

<u>Shape</u>. subellipsoidal to subspherical in outline, with a small bulge at the apex; epicyst slightly smaller than hypocyst.

<u>Wall Relationships</u>. autophragm only; thick-walled, which at the apex appears as an apical bulge; thickening of wall evident under Scanning Electron Microscope (SEM).

<u>Wall Features</u>. surface delimited by densely distributed, nontabular ditch-like to furrowed features of variable size and shape, which exhibit raised and thickened edges; under transmitted light these features appear as an imperfect reticulate pattern, however, under SEM, the features discussed above are observed; vaguely indicated sutural boundaries are observed on the epicyst and hypocyst, which are formed by apparent coalescence of

surface thickenings of ditch-like and furrowed features; area between these features appears smooth to scabrate.

Tabulation. indicated by archeopyle, operculum, cingulum, and vaguely expressed sutural boundaries; accessory precingular sutures are developed on the operculum, which indicate the presence of six generally trapezoidal-shaped precingular plates; apical series is not indicated; six probable posterior plates are indicated on the hypocyst along with a elongate longitudinally posterior intercalary plate, and probable antapical plate; formula: ?', 6", XC, ?6"', 1P, ?1"", XS.

Archeopyle. combination, epicystal, type (tA&tP)a or (tA&tP); operculum commonly attached ventrally.

Cingulum. indicated by a transverse alignment of surface thickenings, possibly giving the impression of ridge-like features; ditch-like and furrowed features appear reduced or absent within this equitorial area.

Sulcus. vaguely indicated under SEM; appears as an elongate longitudinal area apparently devoid of surface ornamentation and bordered by surface thickenings; positioned mostly on the hypocyst; tabulation not evident.

REMARKS: the exact nature of the surface ornamentation is difficult to discern under transmitted light; this demonstrates the need for SEM study when conducting morphologic investigations; compressional folds are very common to this species.

HOLOTYPE: slide 6s - TCCD - England Finder Coor. R 29

HOLOTYPE LOCALITY AND AGE: Camp Davis section - Rich Member - elevation 19m (60'); early Late to Late Bajocian based on ammonite assemblage of *Stemmatoceras*, *Megasphaeroceras*, *Spiroceras*, *Sohlites*, *Spinosus*, and *Parachondroceras andrewsii*.

DERIVATION OF NAME: the specific epithet, *scrobiculatum*, is derived from the Latin *scrobis*, meaning ditch-like, pitted, or furrowed.

DIMENSIONS: overall length 84.1um X width 80.2um; 7 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Rich; Astoria #1-21 Unit Federal - Rich; Whitney Canyon - Sliderock; Type section - Sliderock and Rich.

Genus *Occisucysta* Gitmez, 1970

Type Species *O. balia* Gitmez, 1970

Occisucysta cf. balia Gitmez, 1970

(plate 8, figure 10)

REMARKS: the species differs from the type species, as described by Gitmez (1970, p.268), by lacking distally deep denticulate or fenestrate membraneous crests on sutural boundaries, not as densely tuberculate, and questionable presence of an anterior intercalary plate.

DIMENSIONS: overall length 58.9um X width 56um; 13 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

KNOWN DISTRIBUTION: the type species is known from the Oxfordian to Early Kimmeridgian of northwest Europe and Netherlands.

<u>Occisucysta</u> <u>cf.</u> <u>monoheuriska</u> Gitmez and Sarjeant, 1972

REMARKS: the species differs from <u>O.</u> <u>monoheuriska</u> of Gitmez and Sarjeant, 1972 (p.221-223, pl.17, fig.10-11; text-fig.21) by the following: a hollow (Twin Creek specimens) versus solid apical horn; Twin Creek specimens exhibit a longer sulcus which terminates near the antapical portion of the hypocyst versus a shorter sulcus restricted to the medial area of both the epi and hypocyst; a subspherical to subovoidal outline to the Twin Creek specimens versus a subellipsoidal to subpolygonal body in the latter species; indistinct number of plates comprising the cingulum in species of this study versus 7 cingulum plates in the latter species; and in the Twin Creek specimens an elongate subpolygonal to polygonal posterior intercalary plate versus a shorter subquadrate to subpolygonal plate in the latter species.

DIMENSIONS: overall length 60.8um X width 58.5um; 15 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek members.

KNOWN DISTRIBUTION: O. monoheuriska is known from the Early Kimmeridgian of the Netherlands.

Genus Pareodinia Deflandre, 1947c; emend. Gocht, 1970b; emend. Johnson and Hills, 1973; emend. Wiggins, 1975; emend. Stover and Evitt, 1978

Type Species P. ceratophora Deflandre, 1947c; emend. Gocht, 1970b

Pareodinia brachythelis Fensome, 1979

(plate 3, figure 1)

DIMENSIONS: overall length 53.1um X width 43.8um; 6 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon; Whitney Canyon - Watton Canyon; Utah Southern Hatch #1 - Leeds Creek.

KNOWN DISTRIBUTION: Bathonian through Callovian of East Greenland.

Pareodinia ceratophora Deflandre, 1947c; emend. Gocht, 1970b

(plate 5, figure 1)

DIMENSIONS: overall length 61um X width 41um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon; Whitney Canyon - Watton Canyon and Leeds Creek; Utah Southern Hatch #1 - Rich, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: ?Aalenian through Cretaceous of northwest Europe, Germany, Netherlands, Arctic Canada, East Greenland, and Australia.

Pareodinia groelandica Sarjeant, 1972

DIMENSIONS: overall length 60.5um X width 43um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek.

KNOWN DISTRIBUTION: Middle Callovian through Lower Cretaceous of Arctic Canada; Upper Bathonian through Lower Cretaceous of northwest Europe.

Genus *Parvocysta* Bjaerke, 1980

Type Species *P. bullula* Bjaerke, 1980

Parvocysta sp.B Bjaerke, 1982

(plate 4, figures 4&5)

REMARKS: Twin Creek specimens appear well-preserved, therefore, are not considered reworked.

DIMENSIONS: overall length 41.3um X width 35um; 3 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Rich, Watton Canyon, and Leeds Creek; Utah Southern Hatch #1 - Leeds Creek.

KNOWN DISTRIBUTION: Toarcian of East Greenland and Svalbard.

Genus Rynchodiniopsis Deflandre,1935; emend.
Sarjeant, 1982b; emend. Jan du Chene et al., 1985b.
Type Species R. aptiana Deflandre, 1935; emend.
Sarjeant, 1982b.

Rynchodiniopsis cladophora (Deflandre, 1938b)
Below, 1981a group (plate 3, figures 5, 6a and b)

REMARKS: variability in size, shape, and density of spinate ornamentation facilitated assignment of this species as a group.

DIMENSIONS: overall length 83.5um X width 78.5um; 27 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon and Leeds Creek; Whitney Canyon - Boundary Ridge, Watton Canyon, and Leeds Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Sliderock; Utah Southern Hatch #1 - Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Middle Bajocian through Lower Kimmeridgian of northwest Europe, Germany, Netherlands, western Portugal, Poland, East Greenland, and Arctic

Canada.

?Rynchodiniopsis regalis (Gocht, 1970b) Jan du Chene et al., 1985b (plate 2, figures 3a - c)

DIMENSIONS: overall length 60.3um X width 54.4um; four specimens measured.
LOCAL OCCURRENCE: Camp Davis - Rich member.
KNOWN DISTRIBUTION: Upper Bajocian to Middle Bathonian of northwest Europe and Germany.

Genus Sentusidinium Sarjeant and Stover, 1978

Type Species S. rioulti (Sarjeant, 1968) Sarjeant and Stover, 1978

Sentusidinium spp.

(plate 7, figures 2, 3, and 5)

REMARKS: no attempt has been made to assign Twin Creek specimens to the specific level; this is due to the difficulty in distinguishing species that exhibit such a variable ornamentation; however, the Twin Creek specimens represent a plexus of forms described by Sarjeant and Stover (1978) and Erkmen and Sarjeant (1980) that include:
S. rioulti (Sarjeant, 1968) Sarjeant and Stover, 1978
S. sparsibarbatum Erkmen and Sarjeant, 1980
S. verrucosum (Sarjeant, 1968) Sarjeant and Stover, 1978
S. villersense (Sarjeant, 1968) Sarjeant and Stover, 1978

DIMENSIONS: overall length 34.5um (without operculum) X width 38um; 9 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Sliderock, Rich, Watton Canyon, and Leeds Creek; Whitney Canyon - Sliderock, Rich, Watton Canyon, and Leeds Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Sliderock and Rich; Utah Southern Hatch #1 - Gypsum Spring, Sliderock, Rich, Boundary Ridge, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Bajocian through Cretaceous of northwest Europe, Germany, Arctic Canada, and East Greenland.

Genus _Sirmiodinium_ Alberti, 1961; emend. Warren, 1973

Type Species _S._ _grossii_ Alberti, 1961; emend. Warren, 1973

Sirmiodinium _grossii_ Alberti, 1961; emend. Warren, 1973

(plate 8, figure 9)

REMARKS: pentagonal form of species.

DIMENSIONS: overall length 49um X width 47.8um; 5 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Whitney Canyon - Leeds Creek; Underwood Canyon - Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.
KNOWN DISTRIBUTION: Late Bathonian through Lower Cretaceous of northwest Europe, Germany, East Greenland, and California, U.S.A.

Genus Stephanelytron Sarjeant, 1961a; emend. Stover et al., 1977

Type Species S. redcliffense Sarjeant, 1961a; emend. Stover et al., 1977

Stephanelytron cf. redcliffense Sarjeant, 1961a; emend. stover et al., 1977 (plate 8, figure 3)

REMARKS: the species differs from the type species in shape and size of tubiform processes; Twin Creek specimens appear to exhibit larger processes which appear more subcylindrical than tubiform, as noted in type species; the corona in Twin Creek specimens appears scabrate and lacks a thickening at the distal margin, whereas in the type species, it is smooth and thickened distally; Twin Creek specimens are difficult to interpret due to compressional folds.

DIMENSIONS: overall length 41.7um (without operculum) X width 42.5um; 3 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

KNOWN OCCURRENCE: the type species is known from the late Early Callovian through Lower Kimmeridgian of northwest

Europe and Arctic Canada.

Genus Tubotuberella Vozzhennikova, 1967; emend. Brideaux, 1977; emend. Sarjeant, 1982

Type Species T. rhombiformis Vozzhennikova, 1967; emend. Brideaux, 1977

Tubotuberella dangeardii (Sarjeant, 1968) Stover and Evitt, 1978; emend. Sarjeant, 1982 (plate 5, figure 6)

DIMENSIONS: overall length 68.4um X width 51.8um; 20 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek and Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek.

KNOWN DISTRIBUTION: lower Middle Bathonian through Upper Kimmeridgian of southwest England.

Genus Valensiella Eisenack, 1963a

Type Species V. ovula (Deflandre, 1947c) Eisenack, 1963a

Valensiella ovula (Deflandre, 1947c) Eisenack, 1963a

DIMENSIONS: overall length 45.6um (without operculum) X width 44.4um; 4 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Watton Canyon; Whitney Canyon - Watton Canyon and Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Aalenian through Upper Kimmeridgian of Germany; Bajocian through Early Oxfordian of East

Greenland.

Valensiella ampulla Gocht, 1970b

DIMENSIONS: overall length 45um (without operculum) X width 42.5um; 2 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

KNOWN DISTRIBUTION: Early Bathonian through Middle Bathonian of England and western Portugal.

MISCELLANEOUS MARINE MICROPLANKTON

Alga sp.A Waanders (unpublished)

REMARKS: Waanders (written commun.) recorded the species from the Sliderock and Rich members of the South Piney Creek and Cottonwood Creek sections of western Wyoming. Although Waanders has questioned its affinity, he has suggested that it may be a dinoflagellate. Specimens do not exhibit any evidence of tabulation nor development of an archeopyle. I agree with Waanders description and tentative assignment; specimens representative of the species have been recorded in this study.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek; Whitney Canyon - Boundary Ridge and Leeds Creek; Type section - Rich; Utah Southern Hatch #1 - Rich and Boundary Ridge.

Dinoflagellate sp.A

(plate 7, figure 6)

SYNOPSIS: cysts proximate, acavate, subellipsoidal body, with a long apical horn; tabulation indicated by archeopyle and cingulum only; archeopyle precingular, type P.

DESCRIPTION:

Shape. subellipsoidal in outline, with a long apical horn.

Wall Relationships. autophragm only.

Wall Features. no sutural features; surface characterized by nontabular granulate to verrucate-like features, which are densely distributed.

Tabulation. indicated by archeopyle and cingulum only.

Archeopyle. precingular, type P; operculum free.

Cingulum. indicated by transverse parallel alignment of granulate to verrucate features.

Sulcus. not indicated.

REMARKS: the species is similar to Pareodinia except for mode of archeopyle formation (intercalary in the latter); different from Kalyptea in lacking an antapical horn and exhibiting a precingular instead of an intercalary archeopyle.

DIMENSIONS: overall length 72.1um X width 38.4um; length of apical horn 9.2um; 3 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon; Whitney Canyon - Watton Canyon; Utah Southern Hatch #1 - Leeds Creek.

Dinoflagellate sp.B

SYNOPSIS: cysts proximate, acavate, subspherical to subovoidal body; tabulation gonyaulacacean, indicated by sutural ridges surmounted by low striate septa with denticulate crests; archeopyle apical, type (tA).

DESCRIPTION:

Shape. subspherical to subovoidal in outline.

Wall Relationships. autophragm only; thin-walled <1um thick.

Wall Features. sutural ridges continuous and smooth, surmounted by low striate septa with denticulate crests; intratabular areas delimited by nontabular granulate to foveolate features.

Tabulation. indicated by sutural ridges surmounted by low septa; formula not figured.

Archeopyle. apical, type (tA); operculum free.

Cingulum. indicated by transverse parallel alignment of sutural features offset ventrally by about one cingulum width; no evidence of tabulation.

Sulcus. delimited by sutural ridges as an elongate longitudinally, modestly broad area positioned mostly on the hypocyst; tabulation indistinct.

REMARKS: similar to Meiourogonyaulax with respect to continuous sutural features, however, tabulation distinct in the latter genus; similar to Microdinium sp. of Chen (1978 Ph.D. dissertation, p.451, fig. 56), although, species of the genus exhibit a two-layered wall and definite tabulation.

DIMENSIONS: overall length 37.7um (without operculum) X width 36.8um; 18 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Watton Canyon and Leeds Creek; Astoria #1-21 Unit Federal - Rich, Watton Canyon, and Leeds Creek; Whitney Canyon - Watton Canyon; Utah Southern Hatch #1 - Leeds Creek.

Dinoflagellate sp.C

(plate 7, figure 7)

SYNOPSIS: cysts proximate, acavate, subellipsoidal body, autophragm and ectophragm; tabulation indicated by archeopyle and cingulum only; archeopyle precingular, type P.

DESCRIPTION:

Shape. subellipsoidal in outline.

Wall Relationships. Autophragm and ectophragm; autophragm exhibits rod-like features which appear to connect distally to a thinner ectophragm.

Wall Features. autophragm appears densely granulate to verrucate, and slightly foveolate; ectophragm is thinner, slightly enlarged at the apex and appressed at the antapex, and exhibits an imperfect reticulate pattern.

Tabulation. indicated by archeopyle and cingulum only.

Archeopyle. precingular, type P; operculum free.

Cingulum. faintly indicated by transverse parallel alignment of granules; tabulation not evident.

Sulcus. not indicated.

REMARKS: few specimens observed and restricted to the Camp Davis section.

DIMENSIONS: overall length 50.9um X width 41.6um; 7 specimens measured.

LOCAL OCCURRENCE: Camp Davis - Leeds Creek.

Genus Tasmanites Newton, 1875

Type Species T. punctatus Newton, 1875

Tasmanites complex

(plate 9, figure 6)

REMARKS: no attempt to differentiate on the specific level; specimens grouped together as a complex of forms.

DIMENSIONS: relative size - large.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Whitney Canyon - Watton Canyon and Leeds Creek; Underwood Canyon - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN OCCURRENCE: species of this genus are abundantly represented throughout the Jurassic and Lower Cretaceous.

Group Acritarcha Evitt, 1963

Genus Micrhystridium Deflandre, 1937

Type Species M. inconspicuum (Deflandre) Deflandre, 1937

Micrhystridium complex

(plate 9, figures 1-3)

REMARKS: specimens belonging to the genus have been grouped together as a complex of forms; no attempt to assign at the specific level.

DIMENSIONS: relative size - small.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Watton Canyon; Whitney Canyon - Boundary Ridge and Leeds Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Sliderock; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: the genus is known to range from the Cambrian through the Tertiary.

Genus <u>Veryhachium</u> Deunff, 1958

Type Species <u>V.</u> <u>trisulcum</u> Deunff, 1958

<u>Veryhachium</u> complex

REMARKS: no attempt to differentiate on specific level; grouped as a complex of forms.

DIMENSIONS: relative size - small.

LOCAL OCCURRENCE: Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: the genus is know to range from the Cambrian through the Tertiary.

TERRESTRIAL PALYNOMORPHS

<u>Pollen</u>

Genus <u>Araucariacites</u> Cookson ex Couper, 1953

Type Species <u>A.</u> <u>australis</u> Cookson, 1947

<u>Araucariacites</u> <u>australis</u> Cookson, 1947

(plate 9, figure 7)

DIMENSIONS: relative size - large.

LOCAL OCCURRENCE: Camp Davis - Rich. Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Leeds Creek; Type section - Rich; Utah Southern Hatch #1 - Gypsum Spring, Rich, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Jurassic through Cretaceous of northwest Europe, Arctic Canada, Portugal, and Australia.

Genus Calliasporites Sukh Dev, 1961

Type Species C. trilobatus (Balme) Sukh Dev, 1961

Calliasporites dampieri (Balme, 1957) Sukh Dev, 1961

(plate 10, figure 8)

DIMENSIONS: relative size - large.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Whitney Canyon - Watton Canyon, Leeds Creek, and Giraffe Creek; Type section - Sliderock; Utah Southern Hatch #1 - Gypsum Spring, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Jurassic through Lower Cretaceous of Australia, northwest Europe, Arctic Canada, and Portugal.

Calliasporites trilobatus (Balme) Sukh Dev, 1961

(plate 10, figure 10)

DIMENSIONS: relative size - large.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Rich and Leeds Creek; Whitney Canyon - Watton Canyon and Leeds Creek; Underwood Canyon - Leeds Creek; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

KNOWN DISTRIBUTION: Jurassic through Lower Cretaceous of northwest Europe, Arctic Canada, Portugal, and Australia.

Genus Cerebropollenites Nilsson

Type Species Cerebropollenites mesozoicus (Couper) Nilsson, 1958

(plate 10, figure 6)

DIMENSIONS: relative size - intermediate.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Leeds Creek; Whitney Canyon - Sliderock, Rich, Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Utah Southern Hatch #1 - Leeds Creek.

KNOWN DISTRIBUTION: Jurassic through Lower Cretaceous of northwest Europe, Arctic Canada, and Australia.

Genus Classopollis Pflug, 1953; emend. Reyre, 1970

Type Species C. kieseri Reyre, 1970

Classopollis spp.

(plate 10, figure 1)

REMARKS: no attempt to assign at the specific level.

DIMENSIONS: relative size - small to intermediate.

LOCAL OCCURRENCE: Camp Davis - Gypsum Spring, Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Whitney Canyon - Gypsum Spring, Sliderock, Rich, Boundary Ridge, Watton

Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Gypsum Spring, Sliderock, and Rich; Utah southern Hatch #1 - Gypsum Spring, Rich, Boundary Ridge, Watton canyon, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Triassic through Cretaceous of northwest Europe, Arctic canada, East Greenland, Portugal, Roumania, Australia.

Genus Exesipollenites Balme, 1957

Type Species E. tumulus Balme, 1957

Exesipollenites tumulus Balme, 1957

(plate 10, figure 5)

DIMENSIONS: relative size - small.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, and Leeds Creek; Astoria #1-21 Unit Federal - Leeds Creek and Giraffe Creek; Whitney Canyon - Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Sliderock and Rich; Utah Southern Hatch #1 - Rich, Boundary Ridge, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: Jurassic through Cretaceous of western Europe, Madagascar, and Australia.

Spores

Genus *Cyathidites* Couper, 1953

Type species *C. australus* Couper, 1953

Cyathidites spp.

(plate 10, figure 9)

REMARKS: no attempt to assign at the specific level.

DIMENSIONS: relative size - intermediate to large.

LOCAL OCCURRENCE: Camp Davis - Sliderock, rich, Watton Canyon, and Leeds Creek; Astoria #1-21 Unit Federal - Gypsum Spring, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Whitney Canyon - Sliderock and Rich; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Rich; Utah Southern Hatch #1 - Rich, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: the genus is known from the Jurassic through Cretaceous throughout the world.

Genus *Deltoidospora* (Miner, 1935); emend. Potonie', 1956

Type Species *D. hallii* Miner, 1935

Deltoidospora spp.

REMARKS: no attempt to assign at the specific level.

DIMENSIONS: relative size - intermediate to large.

LOCAL OCCURRENCE: Camp Davis - Sliderock, Rich, Watton Canyon, and Leeds Creek; Astoria #1-21 Unit Federal - Gypsum Spring, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Whitney Canyon - Sliderock and Rich; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Rich; Utah Southern Hatch #1 - Rich, Leeds Creek, and Giraffe Creek.

KNOWN DISTRIBUTION: the genus is known from the Jurassic through Cretaceous of Canada.

Genus Lycopodiumsporites Thiergart ex Delcourt and Sprumont, 1955

Type Species L. agathoecus (Potonie') Delcourt and Sprumont, 1955

Lycopodiumsporites spp.

REMARKS: no attempt to assign at the specific level.

DIMENSIONS: relative size - small.

LOCAL OCCURRENCE: Whitney Canyon - Leeds Creek.

KNOWN DISTRIBUTION: the genus is known from the Triassic through Cretaceous throughout the world.

Miscellaneous pollen and spore groups

Undifferentiated bisaccate pollen

(plate 10, figures 4 and 7)

REMARKS: no attempt to assign to generic or specific level.

DIMENSIONS: relative size - small to large.

LOCAL OCCURRENCE: Camp Davis - Gypsum Spring, Sliderock, rich, Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Gypsum Spring, Sliderock, Rich, Watton Canyon, and Leeds Creek; Whitney Canyon - Gypsum Spring, Sliderock, Rich, Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek; Underwood Canyon - Leeds Creek and Giraffe Creek; Type section - Sliderock and Rich; Utah Southern Hatch #1 - Sliderock, Rich, Boundary Ridge, Leeds Creek, and Giraffe Creek.

Undifferentiated trilete spores

(plate 10, figures 2 and 3)

REMARKS: no attempt to assign at the generic or specific level.

DIMENSIONS: relative size - small.

LOCAL OCCURRENCE: Camp Davis - Gypsum Spring, Sliderock, Rich, Watton Canyon, Leeds Creek, and Giraffe Creek; Astoria #1-21 Unit Federal - Giraffe Creek; Underwood Canyon - Leeds Creek; Type section - Rich; Utah Southern Hatch #1 - Leeds Creek and Giraffe Creek.

PLATES

Explanation of Plate 1

Magnifications of figures 1, 3 & 4 approximately X 787.5. Figure 2 X 1.00K. Dimensions of specimens indicated in micrometers. Location of dinoflagellates indicated by England Finder Coordinates.

1 - 4. Mendicodinium scrobiculatum sp. nov. Camp Davis, 19m, sample 6.

1. sample 6s, Q49. Specimen of epicyst (operculum); note accessory sutures delimiting precingular series. ~37.5um in width.

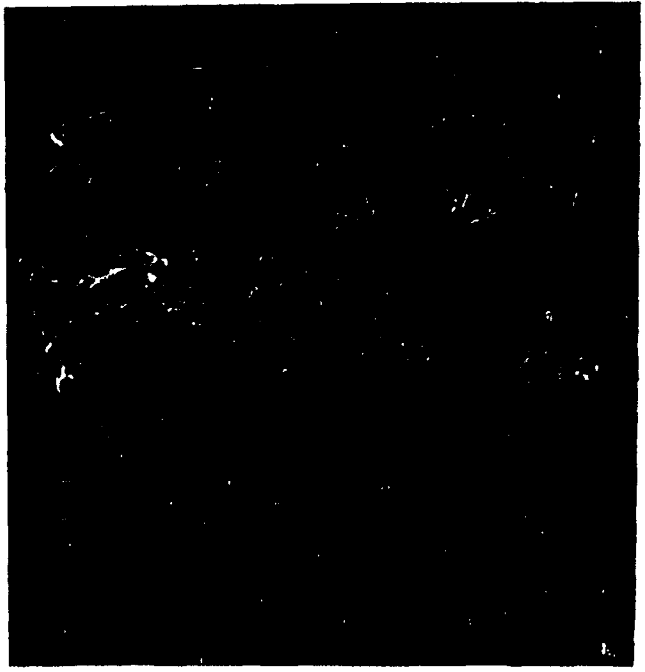
2. sample 6', SEM stub A, 270y X 498x. ventral view; specimen with epicyst attached adcingular; note variability in size and shape of ditch-like and furrowed surface features; suggested presence of a slightly sinuous sulcus developed mostly on the hypocyst.

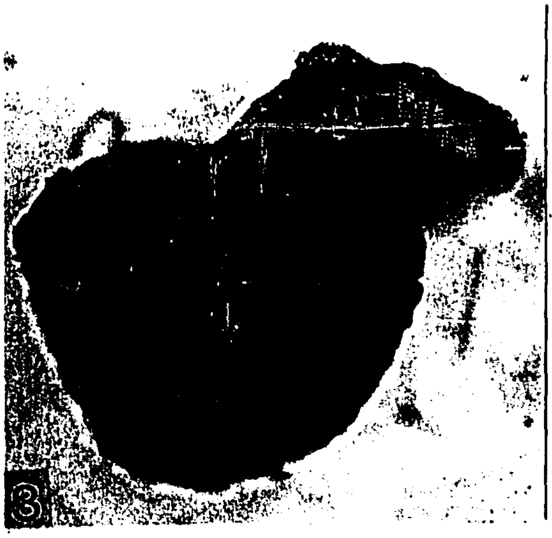
3. sample 6s, T36(4). Specimen with epicyst partially adherent adcingular. 75.0um length X 67.5um width.

4. sample 6s, R29. Specimen with epicyst attached adcingular; note hypocyst appears slightly larger than epicyst. 90.0um length X 83.8um width.

PLATE 1


1

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Explanation of Plate 2

Magnifications approximately X 787.5. Dimensions of specimens indicated in micrometers. Location of dinoflagellates indicated by England Finder Coordinates.

1 - 2. Diacanthum filapicatum. Camp Davis, 19m, sample 6.

1a. sample 6', K56(2); dorsal view delimiting operculum (consisting of two precingular plates) inside cyst. 80.0um length X 72.5um width.

1b. sample 6', T25(4); ventral view showing archeopyle formed by apparent loss of precingular plates 3", 4", and 5". 75.0um length X 72.5um width.

3a - c. ?Rynchodiniopsis regalis Camp Davis, 19m, sample 6uns, X25. 61.3um length X 52.5um width.

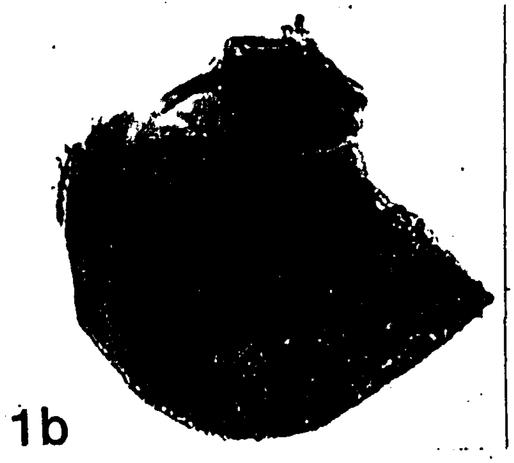
3a. oblique dorsal view; note precingular archeopyle and presence of few small processes concentrated within the center of the postcingular plate in view.

3b. oblique dorsal view.

3c. oblique dorsal view; note trabeculate septa.

PLATE 2

1a



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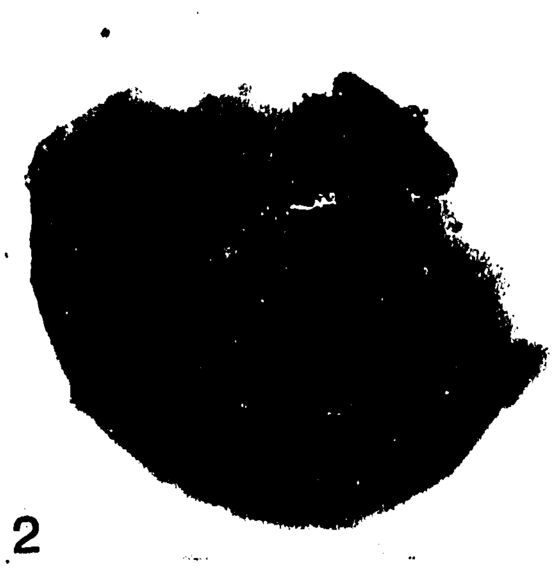

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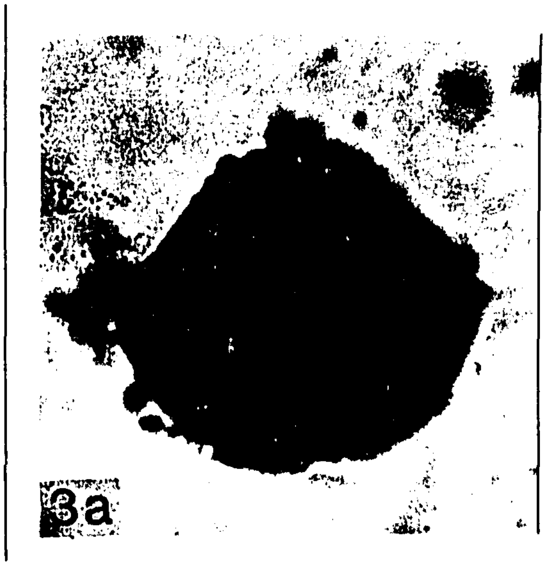

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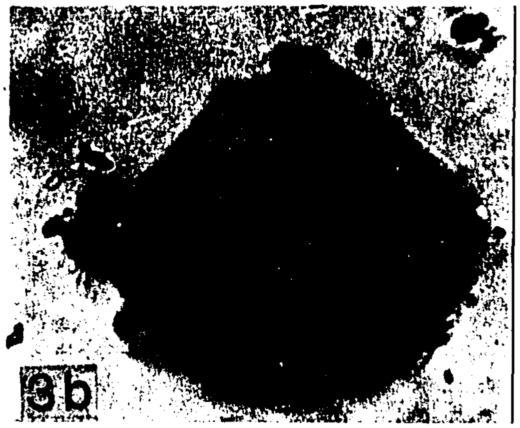


3b

Explanation of Plate 3

Magnifications approximately X 787.5. Dimensions of specimens indicated in micrometers. Location of dinoflagellates indicated by England Finder coordinates.

1. Pareodinia brachythelis. Camp Davis, 49m, sample 16', M31. Dorsal view. 53.0um length X 43.0um width.

2. Heslertonia teichophera. Camp Davis, 58m, sample 19uns, O31. Probably dorsal view; note striated septa. 42.5um length X 42.5um width.

3. Heslertonia pellucida. Camp Davis, 70m, sample 22s, Q25. Probably antapical view; note thin, transparent septa. 35.0um length X 32.0um width.

4. Apteodinium sp.1. Camp Davis, 61m, sample 20+, Q29. Ventral view; note faint indication if ventral tabulation; imperfect reticulate appearance to autophragm. 72.9um length X 66.3um width.

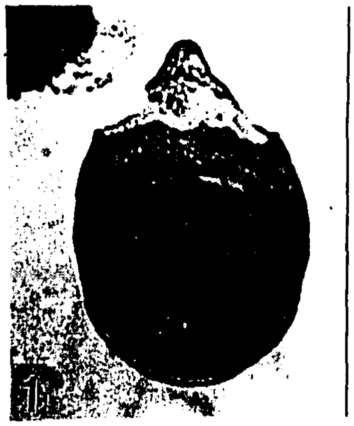
5 - 6. Rynchodiniopsis cladophora group. Camp Davis, 52m and 70m, respectively.

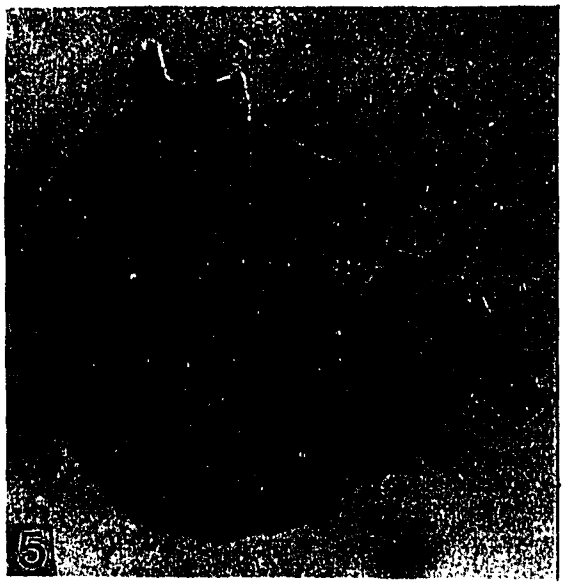
5. sample 17', 52m, X42(1). Ventral view; note apparent reduction in sutural ornamentation. 72.0um length X 55.0um width.

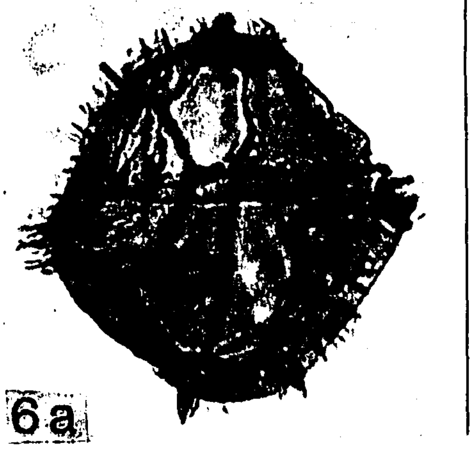
6a. sample 22s, 70m, J32. Oblique dorsal view; note precingular archeopyle and prominent sutural ornamentation. 100.0um length X 102.5um width.

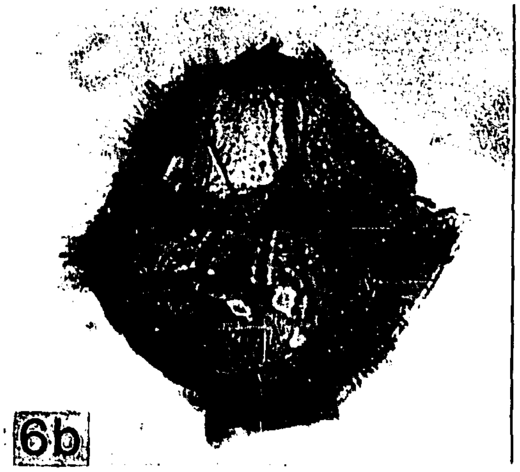
6b. oblique ventral view.

PLATE 3









Explanation of Plate 4

Magnifications approximately X 787.5. Dimensions indicated in micrometers. Locations are indicated by England Finder coordinates.

1. Cometodinium whitei. Camp Davis, 76m, sample 23/1, T34(4). 45.9um length X 44.0um width.

2. Komewuia cf. stoveri. Camp Davis, 76m, sample 23/1, M22. Dorsal view; note alignment of granulate ornamentation delimiting cingulum. 60.0um length X 52.0um width.

3. Komewuia cf. stoveri. Camp Davis, 76m, sample 23s, L24. Dorsal view; note reduced antapical horn. 61.0um length X 50.0um width.

4. Atopodinium prostatum. Camp Davis, 85m, sample 25 moa, Z28(4). Probable ventral view; note antapical lobate features. 55.7um length X 51.1um width.

5. Ctenidodinium chondrum. Camp Davis, 70m, sample 22', M34. Oblique dorsal view. 75.3um length X 70.6um width.

6. Atopodinium prostatum. Camp Davis, 76m, sample 23 uns, Q48; note reduced antapical lobate features and lack of archeopyle development. 62.5um length X 61.3um width.

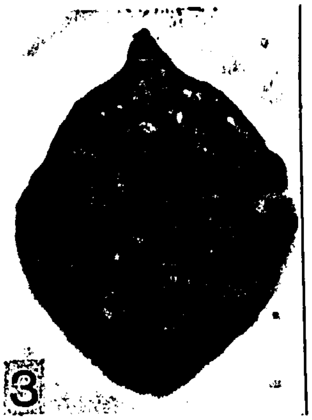
7. Glomodinium evittii. Camp Davis, 52m, sample 22', M34. Oblique dorsal view; note reduction in size of ornamentation towards apex. 60.0um length X 42.0um width.

8. <u>Meiourogonyaulax</u> <u>caytonensis</u> group. Camp Davis, 52m, sample 17', U46. Oblique ventral view; note attached operculum. 52.5um length X 50.0um width.

PLATE 4


1


2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Explanation of Plate 5

Magnifications approximately X 787.5. Dimensions indicated in micrometers. Locations indicated by England Finder coordinates.

1. *Pareodinia ceratophora*. Camp Davis, 79m, sample 24', T25. Dorsal view; note attached operculum. 58.0um length X 40.0um width.

2. *Ellipsoidictyum gochtii*. Camp Davis, 70m, sample 22s, Q25(2). Probable dorsal view; note attached operculum. 53.8um length X 50.0um width.

3. *Ellipsoidictyum reticulatum*. Camp Davis, 76m, sample 23 moa, H22. Probable dorsal view. 63.8um length X 52.5um width.

4. *Endoscrinium galeritum*. Camp Davis, 61m, sample 20+, M17. Probable ventral view. 87.5um length X 75.0um width.

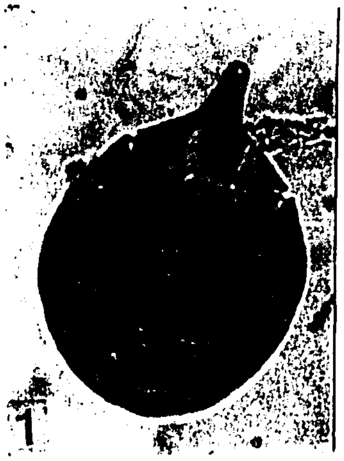
5. *Korystocysta gochtii*. Camp Davis, 76m, sample 23s, F41. Dorsal view. 72.0um length X 70.0um width.

6a. *Gonyaulacysta* sp.A Pocock, 1972. Camp Davis, 52m, sample 17+, N38. Ventral view. 60.0um length X 52.5um width.

6b. *Gonyaulacysta* sp.A Pocock, 1972. Camp Davis, 52m, sample 17+, N38. Dorsal view.

7. *Tubotuberella dangeardii*. Camp Davis, 85m, sample 25', G46. Dorsal view. 73.8um length X 52.5um width.

PLATE 5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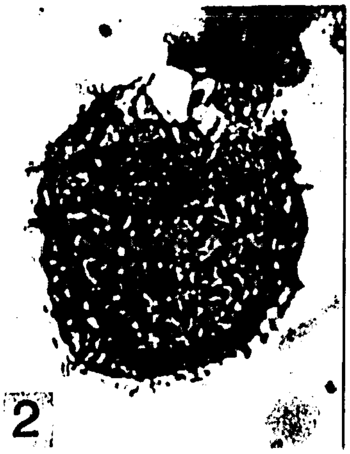
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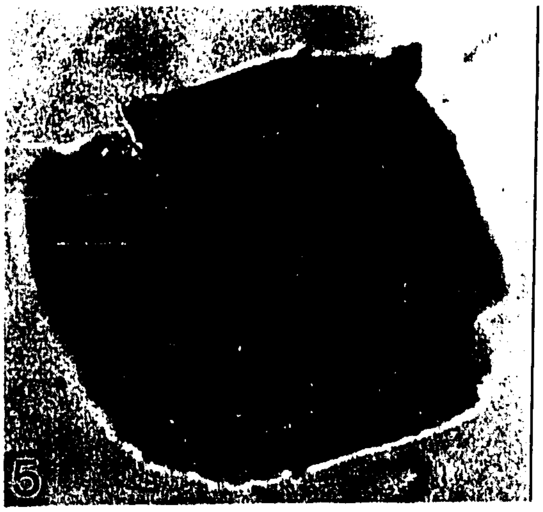
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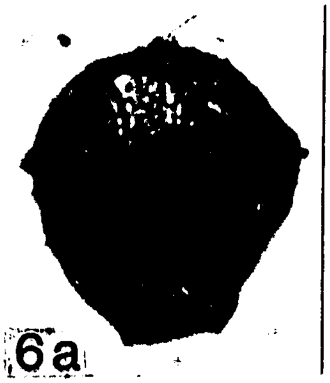
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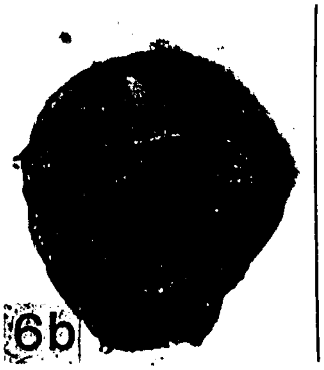
6b


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Explanation of Plate 6

Magnifications approximately X 787.5. Dimensions indicated in micrometers. Locations indicated by England Finder coordinates.

1 - 2. Dissiliodinium sp.1. Camp Davis, 64m, sample 21' and 76m, sample 23', respectively.

1. Sample 21', T35(4). Dorsal view; note smooth autophragm. 63.8um length X 67.5um width.

2. Sample 23s, E17(4). Oblique ventral view; note subpolygonal sulcal tongue; operculum inside cyst appears to consist of two precingular plates. 32.5um length X 58.8um width.

3. ?Ellipsoidinium sp.1. Camp Davis, 55m, sample 18s, M18(2). Possible dorsal view; note reduction in ornamentation within area of cingulum. 45.0um length X 36.5um width.

4a. Leptodinium sp.1. Camp Davis, 76m, sample 23 moa, Z45(4). Ventral view. 88.0um length X 79.0um width.

4b. Leptodinium sp.1. sample 23 moa, Z45(4). Dorsal view.

5. Endoscrinium sp.2. Camp Davis, 76m, sample 23s, W24(3). Oblique dorsal view; note narrow cingulum clearly expressed along lateral margin. 50.0um length X 45.0um width.

6a. Lithodinia sp.1. Camp Davis, 52m, sample 17uns, J34. Oblique dorsal view; note granulate ornamentation. 40.0um length X 40.0um width.

6b. Lithodinia sp.1. sample 17uns, J34. Oblique ventral view.

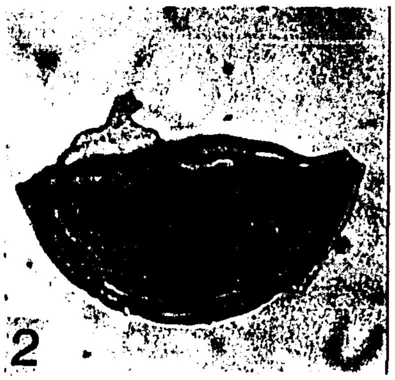
7. Parvocysta sp.B Bjaerke, 1982. Camp Davis, 52m, sample 17', Y30(2). Specimen exhibiting fingerlike processes extending from the lateral horns. 43.8um length X 40.0um width.

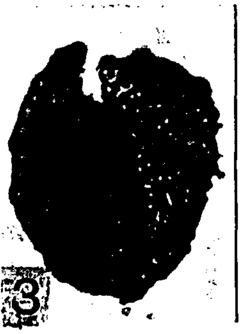
8 - 9. Endoscrinium sp.1. Camp Davis, 64m, sample 21'.

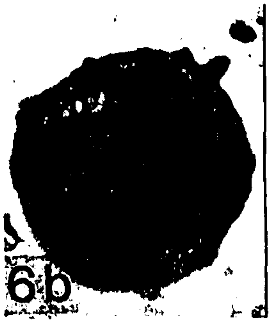
8. Sample 21', S21(2). Oblique dorsal view; note well-developed cavation. 66.3um length X 47.5um width.

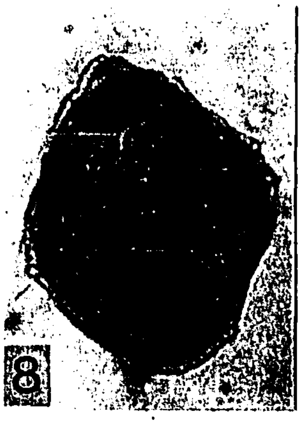
9. Sample 21', Y44(3). Ventral view. 55.0um length X 42.5um width.

PLATE 6









Explanation of Plate 7

Magnifications approximately X 787.5. Dimensions indicated in micrometers. Locations indicated by England Finder coordinates.

1. Gonyaulacysta eisenackii. Camp Davis, 79m, sample 24s, X37(3). Dorsal view. 60.0um length X 46.3um width.

2, and 3. Sentusidinium spp. Camp Davis, 76m sample 23 and 61m sample 20.

2. Sample 23/1, Z26. Specimen exhibiting densely arranged broad trumphet-shaped ornamentation. 42.5um length X 37.5um width.

3. Sample 20uns, X29(4). Specimen exhibiting variable ornamentation, which includes: small trumphet-shaped, spinate, and granulate features. 45.0um length X 40.0um width.

4a. Gonyaulacysta sp.1. Camp Davis, 28m, sample 9+, V20. Ventral view with antapical region in focus; note sparsely arranged granules within intratabular areas.

4b. Gonyaulacysta sp.1. sample 9+, V20. Ventral view with epicyst in focus; note small apical horn, which appears open distally. 67.5um length X 62.5um width.

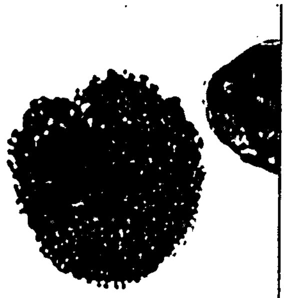
5. Escharisphaeridia spp. Camp Davis, 52m, sample 17', Y45. Specimen exhibiting scabrate to smooth autophragm; note large size, moderately deep precingular sutures, and faintly indicated cingulum. 51.3um length X 57.5um width.

6. Dinoflagellate sp.A. Camp Davis, 49m, sample 16', G44(2). Oblique dorsal view; note operculum inside cyst; moderately broad cingulum delimited by alignment of granulate features. 73.7um length X 35.2um width.

7. Dinoflagellate sp.C. Camp Davis, 70m, sample 22', Q25(2). Oblique dorsal view; note precingular archeopyle; subovoidal outline; imperfect reticulate ornamentation. 51.3um length X 42.5um width.

PLATE 7


1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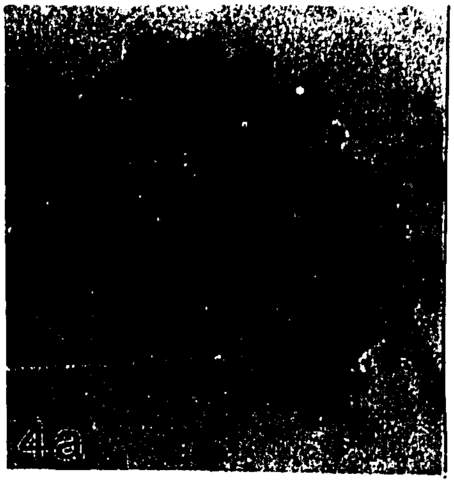
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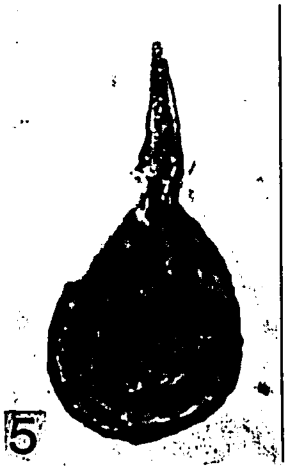
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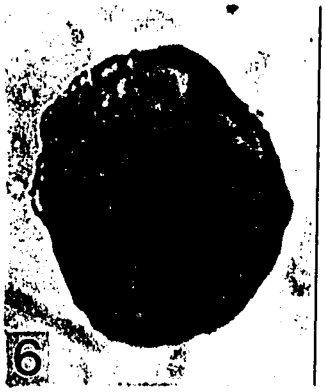
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4b


7

Explanation of Plate 8

Magnifications approximately X 787.5. Dimensions indicated in micrometers. Locations indicated by England Finder coordinates.

1. Gonyaulacysta centriconnata Camp Davis, 85m, sample 25uns, Z40. Ventral view; note flagellar pore scar and pandasuturate precingular and postcingular plates. 56.0um length X 52.0um width.

2. Occisucysta cf. balia. Camp Davis, 76m, sample 23/1, Y22(1). Lateral view; note adherent operculum (two precingular plates), tuberculate ornamentation, and compressed apical horn. 65.0um length X 55.0um width.

3. Sirmiodinium grossii. Camp Davis, 85m, sample 25', Z32(4). Ventral view with epicyst in focus. 52.5um length X 57.5um width.

4 - 6. ?Korystocysta thulia. Camp Davis, 79m, sample 24.

4. Sample 24', P38. Ventral view not in focus; note apparent sulcal tongue not in focus. 37.5um length X 77.5um width.

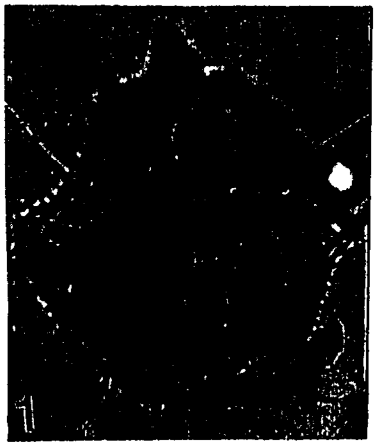
5. Sample 24', X34. Apical view of epicyst (operculum); note development of accessory precingular sutures. ~77.0um width.

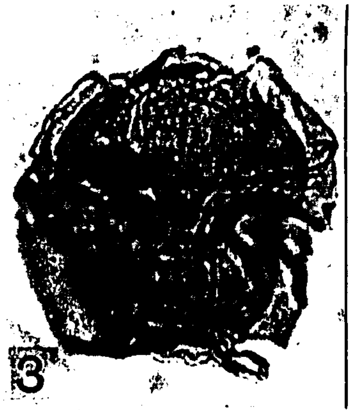
6. Sample 24', U39. Probable oblique dorsal view; note apical horn. 82.5um length X 72.5um width.

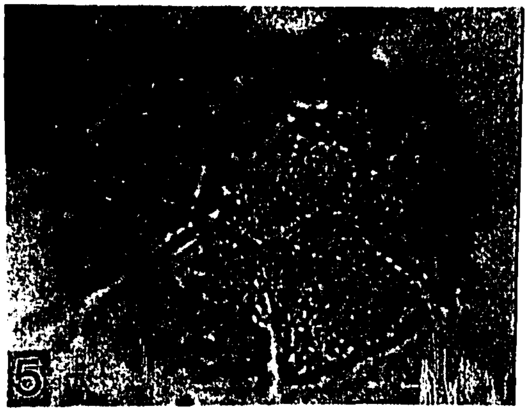
7. Acanthaulax sp.1. Camp Davis, 85m, sample 25 moa, Z38(3). Probable lateral view; note apparent apical protrusion composed of granulate features. 80.0um length X 55.0um width.

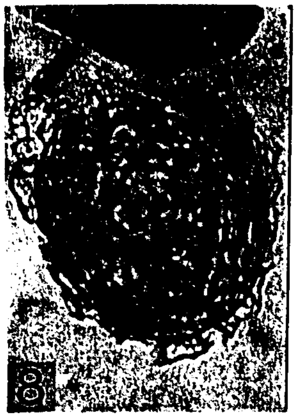
8. Stephanelytron cf. redcliffense. Camp Davis, 79m, sample 24s, M42. Dorsal view not in focus; note antapical corona. 50.0um length X 45.0um width.

PLATE 8









Explanation of Plate 9

Magnifications indicated for each specimen. Locations indicated by England Finder coordinates.

1. Micrhystridium complex. Camp Davis, 58m, sample 19', V26. Specimen exhibiting at least 20 processes, some of which are enlarged or bifid distally; X 787.5.

2. Micrhystridium complex. Camp Davis, 52m, sample 17uns, J34(2). Specimen exhibiting approximately 15 to 20 processes; X 787.5.

3. Micrhystridium complex. Camp Davis, 19m, sample 6 moa, Y46; note enlarged bases of processes; X 787.5.

4. Scoledont. Camp Davis, 76m, sample 23/1, N26; X 787.5.

5. Microforaminifer lining. Camp Davis, 22m, sample 7', R36(3); X312.5.

6. Tasmanites spp. Camp Davis, 58m, sample 19', W32; X 500.

7. Araucariacites australis. Camp Davis, 58m, sample 19', W31(4); X 787.5

PLATE 9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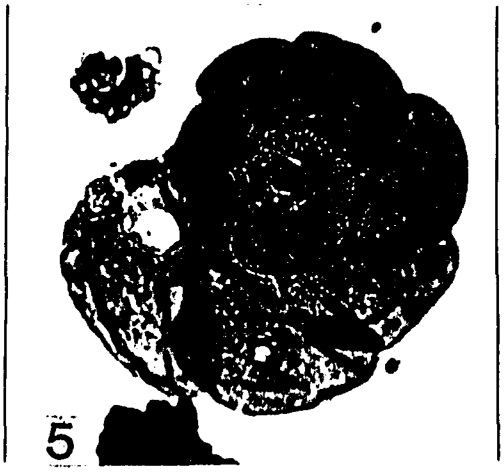
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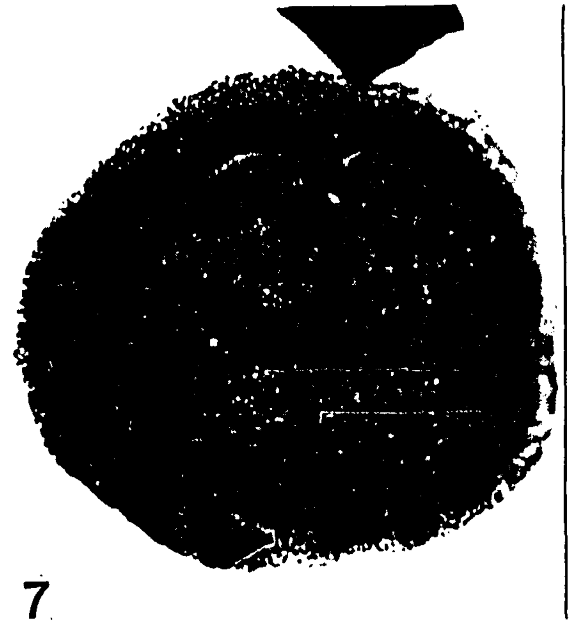

7

Explanation of Plate 10

Magnifications indicated for each specimen. Locations indicated by England Finder coordinates.

1. Classopollis spp. Camp Davis, 49m, sample 16', P41(2), X 787.5; specimen of a tetrad.

2. Undifferentiated trilete spore. Camp Davis, 79m, sample 24', K36(4), X 787.5; proximal view.

3. Undifferentiated trilete spore. Camp Davis, 79m, sample 24', R53(2), X 787.5; proximal view.

4. Undifferentiated bisaccate pollen. Camp Davis, 85m, sample 25 moa, V41(4), X 787.5; proximal view.

5. Exeispollenites tumulus. Camp Davis, 61m, sample 20', W48, X 787.5; polar view.

6. Cerebropollenites mesozoicus. Camp Davis, 55m, sample 18', Q53, X 787.5; polar view.

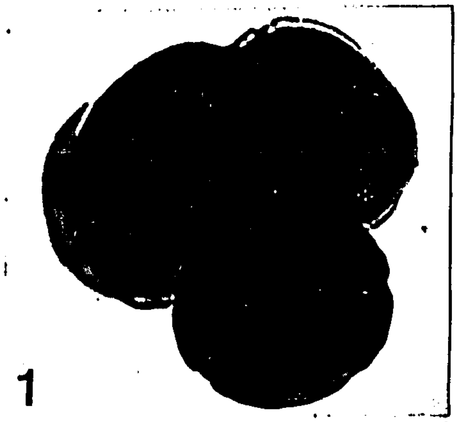
7. Undifferentiated bisaccate pollen. Camp Davis, 49m, sample 16', D45(3), X 787.5; distal view.

8. Calliasporites dampieri. Camp Davis, 85m, sample 25', U31(4), X 787.5; proximal view.

9. Cyathidites spp. Camp Davis, 49m, sample 16', M34, X 787.5; proximal view.

10. Calliasporites trilobatus. Camp Davis, 49m, sample 16', R43(3), X 787.5; proximal view.

PLATE 10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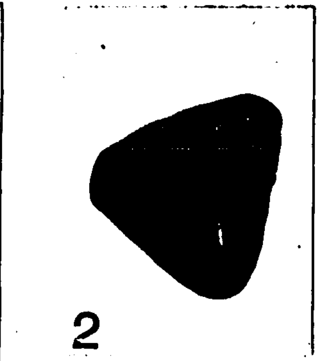
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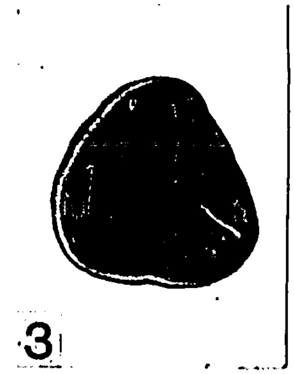
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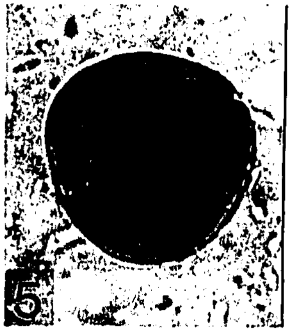
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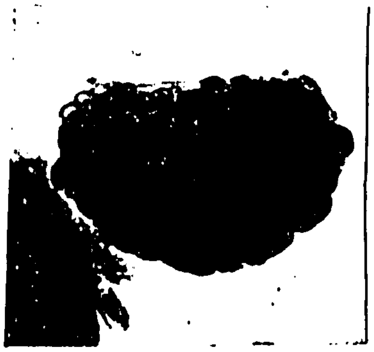

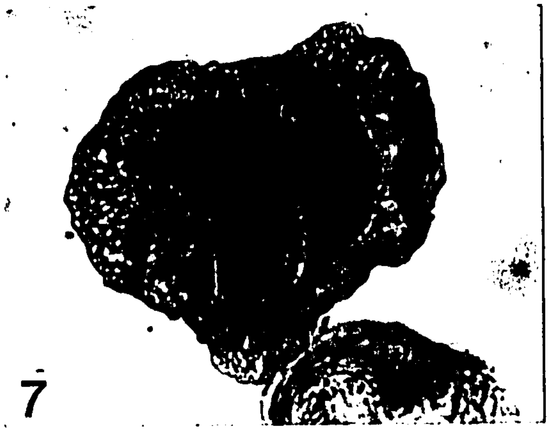
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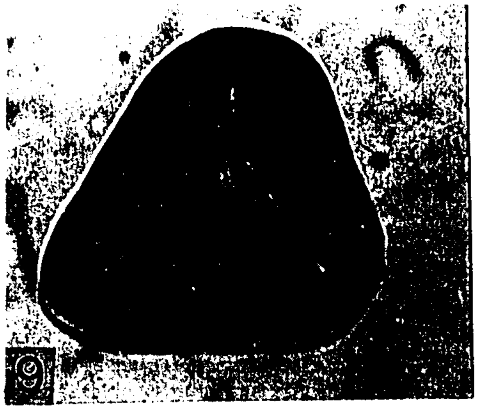
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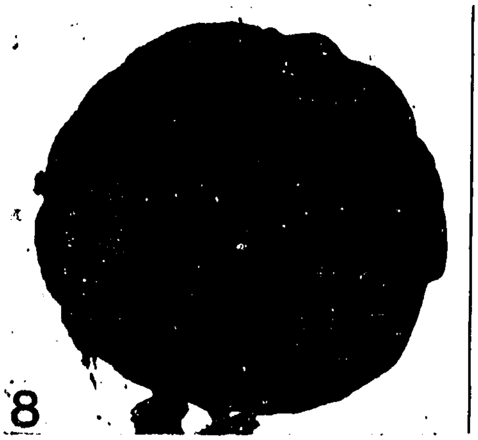
8

Explanation of Plate 11

Magnifications approximately X 200. Locations indicated by England Finder coordinates.

1. Inertinite Facies. Camp Davis, 46m, sample 15 moa, N25(3).
2. Terrigenous Facies. Camp Davis, 40m, sample 13 moa, N40.
3. Amorphous Facies. Camp Davis, 37m, sample 12 moa, K50(3).
4. Amorphous Facies, Multiple Occurrence Datum. Camp Davis, 52m, sample 17 moa, X46.

PLATE 11


1


2


3

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