Dinoflagellate cysts from the Upper Jurassic and Lower Cretaceous sedimentary rocks of Grassy Island, British Columbia, Canada

by

Clio J.M. Bonnett
BSc., University of Victoria, 2008

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTERS OF SCIENCE

in the Department of Earth and Ocean Sciences

Supervisory Committee

Dinoflagellate cysts from the Upper Jurassic and Lower Cretaceous sedimentary rocks of Grassy Island, British Columbia, Canada

by

Clio J.M. Bonnett
BSc., University of Victoria, 2008

Supervisory Committee

Dr. Vera Pospelova, (Department of Earth and Ocean Sciences)
Supervisor

Dr. Stephen Johnston, (Department of Earth and Ocean Sciences)
Departmental Member

Dr. Richard Hebda, (Department of Earth and Ocean Sciences)
Departmental Member

Abstract

Supervisory Committee
Dr. Vera Pospelova, (Department of Earth and Ocean Sciences)
Supervisor
Dr. Stephen Johnston, (Department of Earth and Ocean Sciences)
Departmental Member
Dr. Richard Hebda, (Department of Earth and Ocean Sciences)
Departmental Member

This is the first study of the Upper Jurassic and Lower Cretaceous dinoflagellate cysts of the Kyuquot Group on Grassy Island, British Columbia. Thirty nine dinoflagellate cyst taxa were identified in 85 samples collected from the Upper Tithonian Kapoose and Berriasian to Middle Valanginian One Tree formations. Cyst recovery, concentrations and diversity are relatively high in the samples from of the Kapoose Formation, whereas samples from One Tree Formation had poor dinoflagellate cyst recovery. Four dinoflagellate cyst zones were identified. Three cyst zones (*Cometodinium habibii-Endoscrinium campanula-Oligosphaeridium* sp.-*Pareodinia* spp.-*Gonyaulacysta jurassica* zone; Cyst Type P zone; and *Circulodinium* spp.-Cyst Type P zone) correspond to the *Buchia columbiana* zone from of the Kapoose Formation and the fourth cyst zone (Cyst Type D-Cyst Type Q-*Circulodinium* spp.-*Gonyaulacysta* spp. zone) is identified from the One Tree Formation, where four *Buchia* zones are recognised. The change in the ratio of marine to terrestrial palynomorphs indicates that the basin went through progressive shallowing and/or the shore came closer to the site of deposition beginning in the Upper Tithonian and continuous through to the Valanginian.

The zones resemble established Siberian dinoflagellate cyst zones of the same age. This correlation suggests that the two regions were a part of the Boreal Realm during the interval.

Table of Contents

List of Tables

List of Figures

Acknowledgments

The Geological Survey of Canada is thanked for providing samples required for this project. Special thanks is due to Dr. J. Haggart for sharing his data, providing samples for this project and taking the time to provide helpful, insightful suggestions to improve this work. Dr. N. Lebedeva and Dr. J. Riding are thanked for their invaluable assistance in taxonomic dinoflagellate cyst identification. The British Columbia Ministry of Energy and Mines is acknowledged for its financial support in this project. Some financial assistance was also provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) through Discovery Grant to Dr. Vera Pospelova. Dr. S. Johnston and Dr. R. Hebda are thanked for their contributions as part of the committee for this thesis and their time to review and edit this work.

Dr. Chris Barnes is acknowledged for his support of paleontology at the University of Victoria and personally to the author for the last six years.

Finally, and most importantly, I would like to thank Dr. Vera Pospelova for her unmatched guidance, unfaltering support and her exceptional patience during the course of this project.

Dedication

For my Mum and Dad, who gave me unconditional love and support throughout the course of this thesis, and everything else I have ever done. This is also dedicated to my brothers who have probably heard more about paleobiology than they ever would have liked but never complained.

I would also like to dedicate this to Dr. Chris Barnes and Marji Johns who first sparked and encouraged my interest in paleontology and have supported me through the very best and the very worst of times. Their passion has been inspiring and I cannot thank them enough for the opportunities they have given me over the years.

Chapter 1

Introduction

Paleontologists are interested in the Jurassic - Cretaceous boundary in order to understand changes in faunal and floral composition as well as the changing environmental conditions between the periods. In the western Canadian Cordillera, sedimentary outcrops that preserve the Jurassic - Cretaceous boundary are rare (Muller *et al.*, 1981). While macrofossils within the western Canadian Cordillera have been studied (e.g. Haggart *et al.*, 2009; Grey *et al.*, 2008; Haggart, 1991; Jeletzky, 1965; Poulton *et al*., 1991) the microfossils have not been studied as extensively (e.g. Kottachchi *et al.*, 2002; Carter and Haggart, 2006; Schröder-Adams and Haggart, 2006; Dalby *et al.*, 2008; Patterson *et al.*, 2010). Microfossils are a useful tool for biostratigraphy because they can be recovered in high numbers from small sediment samples and may be found where macrofossils have been destroyed or were not present. Where macrofossils may be indistinct, the accompanying microfossils may be specific and useful for biostratigraphic studies.

Dinoflagellates, one of the principal groups of marine phytoplankton, have a life cycle that includes a cyst stage. Cysts have resistant organic walls that preserve well in marine sediments and have therefore left a rich fossil record beginning in the Late Triassic (e.g. Dale, 1996; Fensome *et al.*, 1996a). Small size, large abundance, wide geographic distribution, rapid pace of evolution, as well as sensitivity to environmental change make this group of great importance for biostratigraphy and paleoenvironmental reconstructions (e.g. Fensome *et al.*, 1996b; Stover and Williams, 1987; Poulsen, 1996; Riding *et al*., 1999; Evitt, 1985).

This study utilises dinoflagellate cysts to help constrain Upper Jurassic and Lower Cretaceous biostratigraphy of the western Canadian Cordillera. An outcrop of sedimentary strata which preserves the Jurassic - Cretaceous boundary is located on Grassy Island (Figure 1B), off Vancouver Island's northwest coast (Jeletzky, 1950, 1965; Muller *et al.*, 1981; Grey *et al.*, 2007, 2008). This particular locality has been used to establish *Buchia* (bivalve) biostratigraphy (Jeletzky, 1950, 1965). Other fossil groups, such as ammonites and foraminifera, have provided little useful biostratigraphic information for the Upper Jurassic - Lower Cretaceous boundary interval of western Canada (Jeletzky, 1965; Haggart, *pers. comm.*). The primary purpose of this study is to provide the first dinoflagellate cyst zonation for the Jurassic - Cretaceous boundary of the western Canadian Cordillera.

1.1. Previous Dinoflagellate Cyst Studies from the Jurassic - Cretaceous Boundary - Canada

Work on Mesozoic dinoflagellate cysts in Canada has focused on northern, central and eastern Canadian study sites (Pocock, 1976; McIntyre and Brideaux, 1980; Davies, 1983; Van Helden, 1986). Van Helden (1986) studied dinoflagellate cysts across the Jurassic - Cretaceous boundary from offshore Newfoundland based on material recovered during oil exploration. He identified zones for eastern Canada and linked them to established European zones of the same age. These are not applicable to western Canada as during this time period western and eastern Canada faced separate ocean basins that had little interaction (Blakey, 2011).

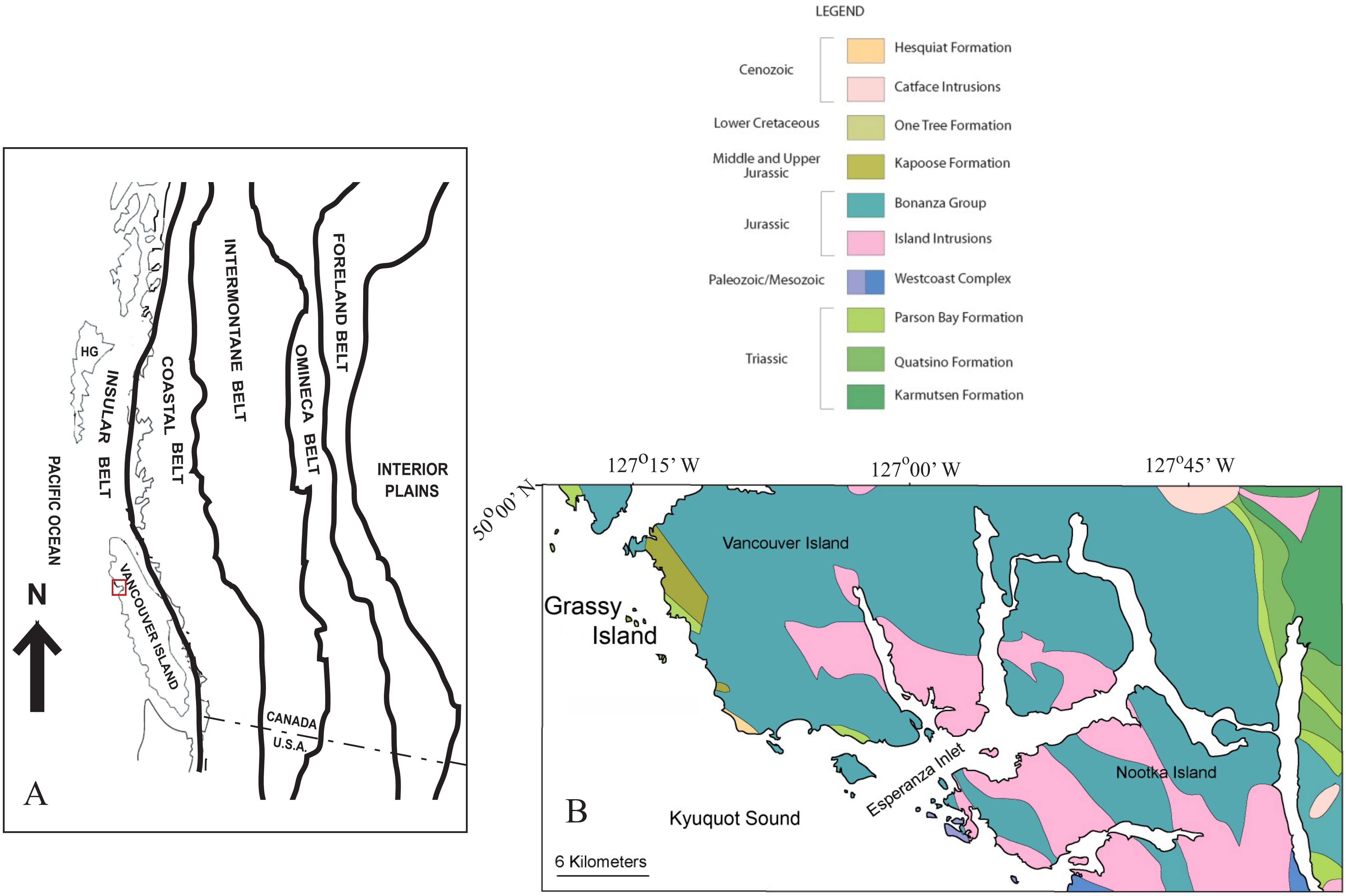

Figure 1. A. Morphogeological belts of the Canadian Cordillera. HG = Haida Gwaii (After Haggart *et al*., 2009). Red square represents inset figure 1B. B. Geology of Kyuquot Sound and Grassy Island (after Muller *et al*., 1981).

Pocock (1962, 1972, 1976) used dinoflagellate cysts to correlate a variety of sites across western Canada and to constrain the location of the Jurassic - Cretaceous boundary, principally in the northern Arctic and Alberta. Of particular interest to British Columbia are the Fernie and Kootenay formations, which outcrop in eastern British Columbia and are of Kimmeridgian and Tithonian age, respectively (Pocock, 1976). A series of dinoflagellate cyst zones were established ranging from the upper Middle Jurassic to the mid-Cretaceous (Pocock, 1976). Pocock’s dinoflagellate cyst zones were correlated to ammonite zones established in Europe, as well as key Canadian faunal groups, including *Buchia* (Pockock, 1976).

McIntyre and Brideaux (1980) studied miospores and microplankton, including dinoflagellate cysts, predominately of Valanginian age from the Mackenzie region in northern Canada. From this region, McIntyre and Brideaux (1980) were able to establish distinct assemblages for the Upper Jurassic and Lower Cretaceous. No particular zones were formally defined. Davies (1983) described multiple dinoflagellate cyst zones across the Jurassic – Cretaceous boundary, although, this study was specific to the Sverdrup Basin in northern Canada and Davies (1983) did not indicate to what extent the zones may be applied outside of that region.

1.2. Geological Setting of Study Area

The Canadian Cordillera is composed of five morphogeological belts, the most westerly of which, the Insular Belt, includes Vancouver Island (Figure 1A) and Haida Gwaii (formerly Queen Charlotte Islands). Vancouver Island is comprised of three distinct geologic terranes: Wrangellia, Pacific Rim, and Crescent (Bally, 1989). Wrangellia underlies ~90% of Vancouver Island (Bally, 1989) and is the terrane dominant in northern Vancouver Island (Bally, 1989;

Haggart *et al.*, 2009). The rocks of Wrangellia range from Devonian to Jurassic in age (Bally *et al.*, 1989); however, Kyuquot Sound, on the northwest coast of Vancouver Island (Figure 1B), is unique as it is the only place on Vancouver Island where the Jurassic - Cretaceous boundary is preserved within the Kyuquot Group (Middle Jurassic - Lower Cretaceous) (Muller *et al.*, 1981).

The Kyuquot Group consists of three units: the Kapoose Formation, One Tree Formation and strata informally assigned to the Longarm Formation (Jeletzky, 1965; Muller *et al.*, 1981; Grey *et al.*, 2007, 2008). The Longarm formation (Upper Valanginian - Barremian) does not conclusively outcrop on Vancouver Island but is present on the Haida Gwaii (Muller *et al.*, 1981; Haggart, 1991, 1993). The Upper Jurassic Kapoose (Tithonian) and Lower Cretaceous One Tree (Berriasian - Lower Valanginian) formations outcrop together on Grassy Island (Muller *et al.*, 1981; Grey *et al.*, 2007).

1.3. Grassy Island

The section analysed for this study is located on Grassy Island which is composed of several low islets located south of Kyuquot Sound (Figure 1B), just off the west coast of Vancouver Island (Grey *et al*., 2007). The base of the section is located at Lat. 49d 5.48' N, Long. 127d 15.18' W; UTM Zone 9U, 625400E, 5531500N; NTS 92E/14. The studied outcrop (Figure 2; Appendix 1) spans the Upper Jurassic (Tithonian) to the Lower Cretaceous (Lower Valanginian) and is nearly complete although there is a disconformity separating the Upper Jurassic and Lower Cretaceous rocks resulting in the uppermost Tithonian being absent (Jeletzky, 1965; Grey *et al*., 2007, 2008). The Tithonian Kapoose Formation (Muller *et al.*, 1981) is dominantly mudstone and shale with common calcareous concretions and interbedded fine-grained sandstone (Grey *et al*., 2007,

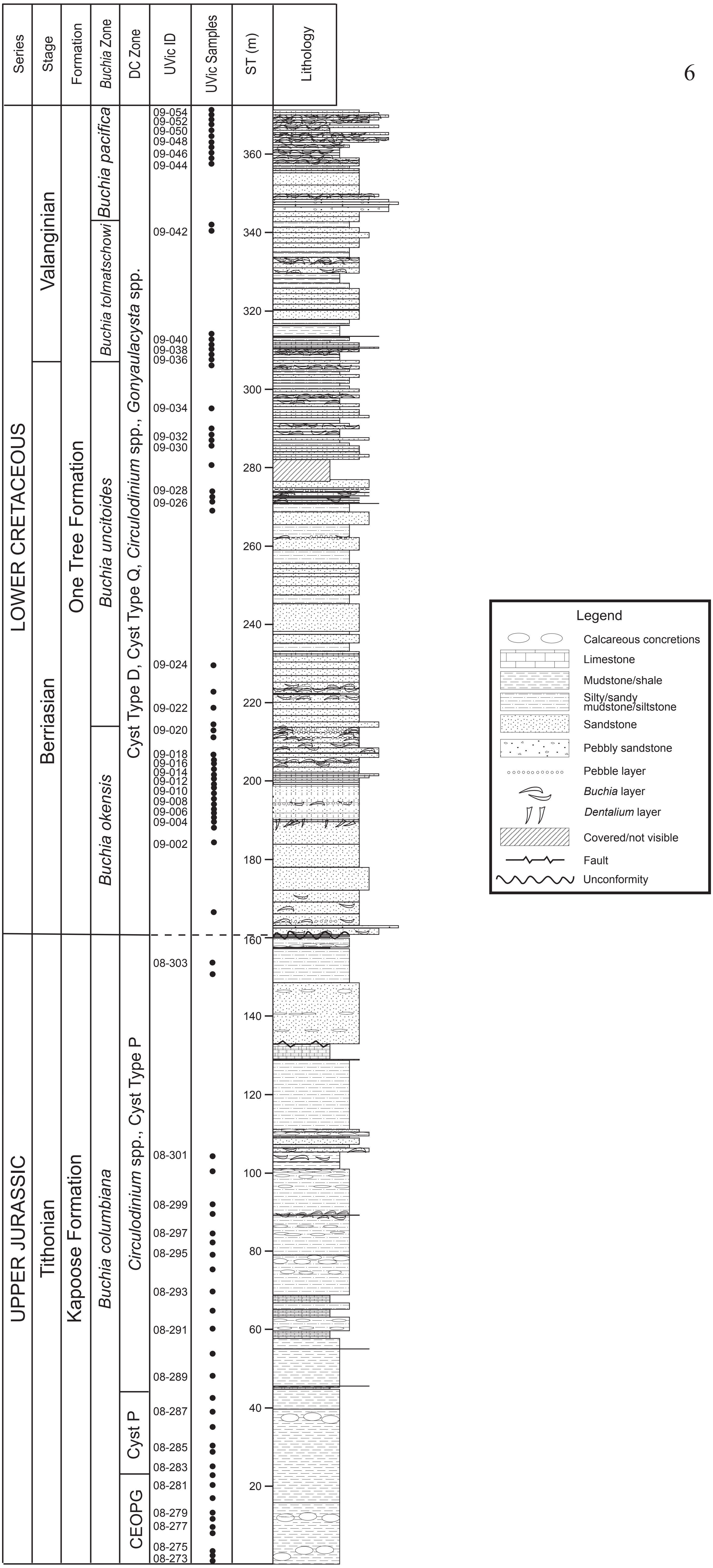

Figure 2. Measured section of the Tithonian to Valanginian (Upper Jurassic - Lower Cretaceous) sedimentary strata from Grassy Island. Position of all analysed samples is provided. UVic identification numbers are shown for every second sample. DC = Dinoflagellate cyst zones. CEOPG = *Cometodinium habibii*, *Endoscrinium campanula*, *Oligosphaeridium* spp., *Pareodinia* spp., *Gonyaulacysta jurassica* Zone. Cyst P = Cyst Type P Zone. ST = Sratigraphic level above base of section. Modified from Haggart, 2009, *pers. comm.* Original Geological Survey of Canada Locality numbers can be found in Table 1.

2008). The Berriasian - Lower Valanginian One Tree Formation (Bancroft, 1937; Jeletzky, 1950, 1965) is mostly medium- to coarse-grained sandstone with lesser interbedded siltstone and sandy shale (Grey *et al.*, 2007, 2008).

1.4. Biostratigraphy of the Kapoose and One Tree Formations on Grassy Island

Ammonites are some of the most common zonal index fossils used for Mesozoic sedimentary rocks. Unfortunately, however, ammonites are relatively rare in the Upper Jurassic – Lowermost Cretaceous strata of the Boreal realm (Jeletzky, 1965). Of the ammonites recovered from Grassy Island, 90% are phylloceratids and lytoceratids, which have long stratigraphic ranges and do not display enough distinct morphological characteristics to be useful zonal fossils (Jeletzky, 1965). In fact, ammonites other than phylloceratids or lytoceratids are so rare in Upper Jurassic – Lower Cretaceous strata of the Insular Belt that they are difficult to use for dating or correlation of the strata (Jeletzky, 1965). Belemnites (cephalopods) and trigoniids (bivalves), useful in correlation of other localities in the Boreal region, are also rare and poorly preserved on the Insular Belt (Jeletzky, 1965).

In distinct contrast, *Buchia*, a bivalve with distinct shell morphological characteristics and a mode of life similar to *Mytilus* (mussel), are abundant and well preserved throughout the Grassy Island section making them a useful group for biostratigraphy (Jeletzky, 1950, 1965; Grey *et al.*, 2008). Jeletzky (1965) defined *Buchia* zones for the Kapoose and One Tree formations which have been applied in correlation of Upper Jurassic – Lower Cretaceous strata across much of the Cordilleran region of Canada. This *Buchia* zonation has subsequenty been revised slightly by Grey *et al.* (2008). Five *Buchia* zones are recognised on Grassy Island: one in the Upper Jurassic

(Kapoose Formation) and four in the Lower Cretaceous (One Tree Formation) (Figure 2). These zones have been correlated globally to other established zonations of this particular genus over the same time interval (Grey *et al*., 2008).

Of the established *Buchia* zones, *B. okensis* is distributed widely throughout the Boreal realm (Zakharov, 1987). It has been demonstrated that the first appearance of *B. okensis* is at the very base of the Cretaceous and the taxon is thus used as an indicator to locate the Jurassic - Cretaceous boundary (Zakharov, 1987; Sha *et al.*, 2006). Based on the location of the *B. okensis* zone on Grassy Island, it is possible to directly place the Jurassic - Cretaceous boundary in the stratigraphic section analysed in this study and constrain the age of the strata (Figure 2) (Grey *et al.,* 2008).

1.5. Objectives

We extracted and identified dinoflagellate cysts from the Upper Tithonian to Lower Valanginian sedimentary rocks exposed on Grassy Island. The main objectives of this work are to:

1. Extract and identify dinoflagellate cysts;
2. Evaluate the abundance, composition and diversity of the dinoflagellate cyst assemblages;
3. Determine dinoflagellate cyst zones for the Upper Jurassic and Lower Cretaceous of Grassy Island and correlate to previously established dinoflagellate cyst zones of this age in the Northern Hemisphere;
4. Correlate dinoflagellate cyst zones to established *Buchia* zones; and
5. Reconstruct paleoenvironmental conditions.

Chapter 2

Methods

2.1. Sample Collection

For the analysis of dinoflagellate cysts from Grassy Island, 85 samples were obtained from the Geological Survey of Canada (GSC) in Vancouver, British Columbia. These samples were collected by J.A. Jeletzky in 1949, 1951, and 1952, as well as by J.W. Haggart in 2005 and 2006. The complete suite of samples was initially used by Jeletzky (1965) to create zones for *Buchia,* which were subsequently refined by Grey *et al.* (2008). All samples were labelled with University of Victoria identification numbers (UVic 08-273 to UVic 08-303 for Jurassic and UVic 09-001 to UVic 09-054 for Cretaceous samples) (Table 1; Figure 2). Correlation of UVic sample numbers with original GSC Locality numbers is provided in Table 1. Most of the samples were removed directly from the surrounding matrix of identified *Buchia* belonging to specific established zones (Figure 2). All samples were first studied for lithological characteristics using standard grain size charts (Table 1).

2.2. Palynological Preparation

The samples were crushed into pieces no larger than $1cm^3$ and then placed into a 50 mL polypropylene tube for palynological preparation. Dry weight of each sample was recorded in order to calculate palynmorph (i.e., spores, pollen and dinoflagellate cysts) concentration after counting.

Table 1. Samples processed for dinoflagellate cysts from Grassy Island with corresponding University of Victoria (Uvic ID) identification numbers, name of the collector (JWH = J.W. Haggart; JAJ = J.A. Jeletzky), Geological Survey of Canada (GSC) locality identification, the unit the sample was taken from, the Formation, stratigraphic level above the base of the section, the general lithology of the sample.

Uvic ID	Collector	GSC Locality	Formation	Unit	Level Above Base (m)	Lithology
08-273	JWH	V-002553	Kapoose	1	2.4	Shale
08-274	JWH	V-002554	Kapoose	1	4.8	Shale
08-275	JWH	V-002555	Kapoose	1	7.2	Shale
08-276	JWH	V-002556	Kapoose	1	9.6	Shale
08-277	JWH	V-002557	Kapoose	1	12.0	Shale
08-278	JWH	V-002558	Kapoose	1	14.5	Shale
08-279	JWH	V-002559	Kapoose	2	15.9	Shale
08-280	JWH	V-002560	Kapoose	2	18.3	Shale
08-281	JWH	V-002561	Kapoose	2	20.7	Shale
08-282	JWH	V-002562	Kapoose	2	23.1	Shale
08-283	JWH	V-002563	Kapoose	2	25.5	Shale
08-284	JWH	V-002564	Kapoose	2	28.7	Shale
08-285	JWH	V-002565	Kapoose	2	32.7	Shale
08-286	JWH	V-002566	Kapoose	2	35.9	Shale
08-287	JWH	V-002567	Kapoose	3	39.9	Shale
08-288	JWH	V-002568	Kapoose	3	43.9	Shale
08-289	JWH	V-002569	Kapoose	3	47.9	Siltstone
08-290	JWH	V-002570	Kapoose	3	55.9	Siltstone
08-291	JWH	V-002571	Kapoose	4	61.3	Siltstone
08-292	JWH	V-002572	Kapoose	4	64.8	Siltstone
08-293	JWH	V-002573	Kapoose	4	68.2	Siltstone
08-294	JWH	V-002574	Kapoose	5	75.5	Siltstone
08-295	JWH	V-002575	Kapoose	5	79.1	Siltstone
08-296	JWH	V-002576	Kapoose	6	82.8	Siltstone
08-297	JWH	V-002577	Kapoose	6	86.5	Siltstone
08-298	JWH	V-002578	Kapoose	6	89.8	Siltstone
08-299	JWH	V-002579	Kapoose	6	93.8	Siltstone
08-300	JWH	V-002580	Kapoose	8	101.4	Siltstone
08-301	JWH	V-002581	Kapoose	8	105.0	Siltstone
08-302	JWH	V-002582	Kapoose	11	152.0	Siltstone
08-303	JWH	V-002583	Kapoose	11	156.1	Shale

Table 1. Continued

Uvic ID	Collector	GSC Locality	Formation	Unit	Level Above Base (m)	Lithology
09-001	JAJ	19349	One Tree	19	167.2	Fine sandstone
09-002	JAJ	19289	One Tree	23	187.7	Fine sandstone
09-003	JAJ	19309	One Tree	24	189.5	Fine sandstone
09-004	JAJ	19314	One Tree	27	191.3	Fine sandstone
09-005	JAJ	19274	One Tree	28	192.3	Fine sandstone
09-006	JAJ	19333	One Tree	29	192.8	Fine sandstone
09-007	JAJ	19353	One Tree	30	193.1	Fine sandstone
09-008	JAJ	19348	One Tree	32	193.8	Fine sandstone
09-009	JAJ	19325	One Tree	33	194.6	Fine sandstone
09-010	JAJ	19329	One Tree	36	196.4	Fine sandstone
09-011	JAJ	19355	One Tree	40	198.0	Fine sandstone
09-012	JAJ	19288	One Tree	41	199.5	Fine sandstone
09-013	JAJ	19345	One Tree	42	200.5	Fine sandstone
09-014	JAJ	19290	One Tree	43	201.0	Fine sandstone
09-015	JAJ	19310	One Tree	45	201.3	Fine sandstone
09-016	JAJ	19294	One Tree	46	202.8	Medium sandstone
09-017	JAJ	19336	One Tree	47	203.3	Medium sandstone
09-018	JAJ	19332	One Tree	49	205.1	Medium sandstone
09-019	JAJ	19287	One Tree	54	211.0	Medium sandstone
09-020	JAJ	19328	One Tree	55	213.1	Medium sandstone
09-021	JAJ	19304	One Tree	56	214.4	Medium sandstone
09-022	JAJ	19317	One Tree	57	216.2	Medium sandstone
09-023	JAJ	19344	One Tree	59	219.5	Medium sandstone
09-024	JAJ	19301	One Tree	61	223.1	Medium sandstone
09-025	JAJ	18380	One Tree	65	230.8	Medium sandstone
09-026	JAJ	20656	One Tree	94	270.5	Medium sandstone
09-027	JAJ	20692	One Tree	96	273.8	Medium sandstone
09-028	JAJ	20673	One Tree	97	274.4	Medium sandstone
09-029	JAJ	20654	One Tree	98	275.1	Medium sandstone
09-030	JAJ	20574	One Tree	100	282.3	Medium sandstone
09-031	JAJ	20027	One Tree	106	286.7	Medium sandstone
09-032	JAJ	20632	One Tree	107	287.4	Medium sandstone
09-033	JAJ	20048	One Tree	110	289.2	Medium sandstone
09-034	JAJ	20034	One Tree	113	291.3	Medium sandstone

Table 1. Continued

Uvic ID	Collector	GSC Locality	Formation	Unit	Level Above Base (m)	Lithology
09-035	JAJ	20706	One Tree	119	295.6	Medium sandstone
09-036	JAJ	20168	One Tree	132	305.6	Medium sandstone
09-037	JAJ	20575	One Tree	136	308.7	Medium sandstone
09-038	JAJ	20564	One Tree	137	309.2	Medium sandstone
09-039	JAJ	20021	One Tree	141	311.0	Medium sandstone
09-040	JAJ	20717	One Tree	142	311.8	Medium sandstone
09-041	JAJ	20022	One Tree	143	312.3	Medium sandstone
09-042	JAJ	20603	One Tree	145	313.3	Medium sandstone
09-043	JAJ	20638	One Tree	168	341.5	Medium sandstone
09-044	JAJ	20020	One Tree	169	342.6	Medium sandstone
09-045	JAJ	20024	One Tree	185	358.5	Medium sandstone
09-046	JAJ	20700	One Tree	186	359.5	Medium sandstone
09-047	JAJ	20720	One Tree	187	360.0	Medium sandstone
09-048	JAJ	20046	One Tree	190	362.0	Medium sandstone
09-049	JAJ	20055	One Tree	191	362.6	Medium sandstone
09-050	JAJ	18372	One Tree	194	364.6	Medium sandstone
09-051	JAJ	20701	One Tree	195	365.6	Medium sandstone
09-052	JAJ	20553	One Tree	197	366.7	Medium sandstone
09-053	JAJ	20025	One Tree	201	369.2	Medium sandstone
09-054	JAJ	20709	One Tree	202	369.8	Medium sandstone

One tablet containing ~18 583 (batch #483216) *Lycopodium clavatum* grains was added to each sample so that dinoflagellate cyst concentrations could be calculated based on the total number of *L. clavatum* grains added compared to the number of grains counted and the dry weight of the processed sample (Stockmarr, 1971; Mertens *et al*., 2009). Samples were processed following the general method of Pospelova *et al.* (2005). Each sample had 10% HCl added and was left for approximately seven minutes to remove any carbonates. The samples were then centrifuged and decanted, after which 48% HF was added to each sample. Each sample was stirred and heated to 40^{o}C for ~30 minutes. After heating, the samples were left to cool and remained at room temperature 48% HF for three days. At this time, the fully reacted HF was removed and replaced with fresh 48% HF at room temperature. Samples then sat for three more days and were regularly stirred. After this step, the samples were rinsed with distilled water and sieved through 120μm and 15μm Nytex nylon mesh sieves. Material in the 15μm sieve was retained for final sample processing. Material that was greater than 120μm was returned to fresh 48% HF and treatment was repeated from the heating step. After a second sieving, any remaining material larger than 120μm was rinsed, dried, weighed, and placed in storage.

All material concentrated on the 15μm mesh sieves was treated again with 10% HCl for approximately seven minutes to remove precipitated silicofluorides. The remaining fraction was then rinsed with distilled water and sieved through a 15μm mesh sieve in order to remove residual fine silt particles. Samples were sonicated for no more than 30 seconds to assist in breaking down agglutinated particles at the bottom of the sieve.

Samples were transferred to 5mL tubes from which small aliquots of each sample were taken and mounted onto glass microscope slides using glycerine gel. Slides were viewed and counted under 400X magnification using a Nikon Eclipse 80i microscope. Dinoflagellate cysts were identified using magnifications between 400 and 1000X under the oil objectives. Photographs were taken using a Nikon Digital Sight DS-5M camera and edited in Adobe Photoshop version 9.0.2.

2.3. Dinoflagellate Cyst Analysis

A total of 200 dinoflagellate cysts is considered to be the ideal number of specimens to be counted for each sample. This was achieved for only two samples (UVic 08-288 and UVic 08-301). In most of the samples, material was sparse, and only 100 dinoflagellate cysts per sample were counted (Appendix 3). In some instances, a total of 100 dinoflagellate cysts per sample was not obtained, so as many as possible were counted within two or more complete slides (20 by 40mm). In order to estimate the degree of terrestrial input and infer proximity to shore, the total sums of pollen and spores was counted. The ratio of marine to terrestrial palynmorphs was calculated for each sample.

Dinoflagellate cyst concentrations were calculated by comparing the number of added *Lycopodium clavatum* marker grains to the counted number of *L. clavatum* and number of dinoflagellate cysts counted. Species richness was calculated with Microsoft Excel 2003 software using total cyst taxa that were identified. It should be noted that this is a modified type of species richness as not all taxa were identified to the species level. Therefore, it is a measure of taxa richness, but is referred to as species richness for simplicity. Simpson's Diversity Index ($D = \frac{\sum n(n-1)}{N(N-1)}$, where n is the total number of dinoflagellate cysts of a particular taxon, N is the total number of cysts of all taxa, and D is the Simpson’s Diversity Index) was calculated for each sample to determine species diversity. A D value of zero indicates infinite diversity, while a D value of one indicates no diversity, i.e., a unitaxial assemblage. Again, this is a modification of Simpson's Diversity Index, as all taxa recorded could not be identified to species level. This measure is therefore based on number of taxa, but is still referred to as Simpson's Diversity Index. Psimpoll software (version 4.27; http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html) was used to calculate the squared Euclidian dissimilarity values in order to support identification of dinoflagellate cyst zones. Further statistical analyses were not performed as an insufficient number of specimens were recovered and would not produce significant results.

Palynomorph colours were visually assessed in order to determine thermal alteration or colour alteration index (CAI) (e.g. Batten, 1996; Pross *et al.*, 2007). This parameter is commonly used to estimate maturity of palynomorph bearing sediments by comparing the colour of palynmorphs to Munsell colour standards which have been calibrated to corresponding temperature ranges (e.g. Batten, 1996; Pross *et al.*, 2007). By referring to the colour of palynmorphs recovered in a sample it is possible to determine to what maximum temperature the palynmorphs were exposed and thus the degree of alteration (e.g. Batten, 1996; Pross *et al.*, 2007).

Chapter 3
Results

3.1. Recovery and Preservation

The Jurassic suite of samples (UVic 08-273 to UVic 08-303) exhibited a range of poor to good recovery of dinoflagellate cysts, with 23 out of 30 samples reaching final counts above 100 cysts per sample. There were no completely barren samples (Appendix 2). The dinoflagellate cysts recovered from these samples (UVic 08-273 to UVic 08-303) were moderately corroded by pyrite. Cyst colour in this set of samples ranges between a medium yellow to light-medium brown suggesting exposure to temperatures no higher than 80^{o}C and thus low alteration (Batten, 1996). Spores were well represented in this suite of samples, pollen were uncommon (Appendix 2).

The Cretaceous suite of samples (UVic 09-001 to UVic 09-054) saw very poor recovery of dinoflagellate cysts in comparison to the Jurassic suite. Final counts of 100 cysts per sample were only reached in four samples near the upper part of the Cretaceous section (UVic 09-031, 09-032, 09-034, 09-041) (Appendix 2). Twenty-two samples were barren of dinoflagellate cysts, but showed poor to good preservation of pollen and spores. There is noticeably less pyritisation in these samples than those in the Upper Jurassic. Cysts in this suite were slightly darker, reaching a light yellow to medium brown range. The temperature exposure was still likely no higher than 80^{o}C (Batten, 1996). Silicofluoride precipitates in some samples could not be removed, making the samples difficult to analyse and obscuring cyst features required for identification to species level.

3.2. Palynomorph Abundance

Both relative abundances (%) (Figure 3) and concentrations of dinoflagellate cysts as well as pollen and spores were calculated (Appendix 2, 2, 3). The total dinoflagellate cyst concentration ranges from 0 to 7560 cysts g^{-1}, with an average of 315 cysts g^{-1} (Figure 4, Appendix 5). The average concentration of pollen and spores was 1532 grains g^{-1}, with a minimum of 54 grains $g^{-1}$and a maximum of 6735 grains g^{-1} (Figure 4).

The ratio of dinoflagellate cysts to pollen and spores was calculated for each sample (Figure 4). Dinoflagellate cysts dominate the Jurassic of the studied section, with pollen and spores playing a minor role. In the Cretaceous section, pollen and spores are more abundant than in the Jurassic while dinoflagellate cysts decline in number (Figure 4). It is important to note that while there are samples that do not have any dinoflagellate cysts recovered, there was still abundant pollen and spores recovered from all of these samples from the Lower Cretaceous.

3.3. Dinoflagellate Cyst Species Richness and Diversity

Excluding samples in which there were no dinoflagellate cysts recovered, the maximum number of dinoflagellate cyst taxa recorded was 13 taxa per sample (Figure 4), the minimum one taxon. The average recovery was four taxa. The highest species richness is observed in the Upper Jurassic, with an average of six taxa per sample, while the average richness in the Lower Cretaceous is only two taxa per sample. Thus, there is higher species richness in the Upper Jurassic than the Lower Cretaceous of Grassy Island. These results were supported by Simpson's Diversity Index that ranges from a D value of 0.06 in the Upper Jurassic to a D value of 1 in the Lower Cretaceous samples (Appendix 2).

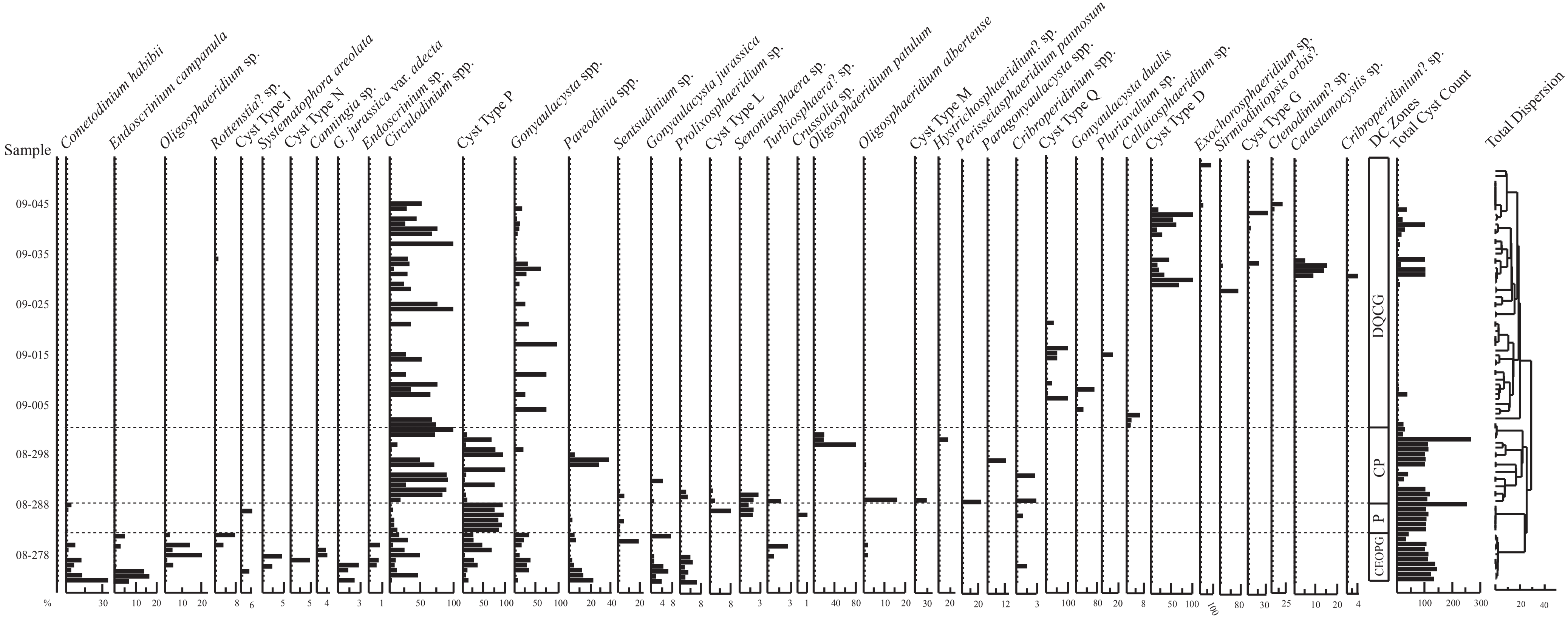

Figure 3. Relative abundance (%) of dinoflagellate cyst taxa, identified zones, and total cyst count. Total dispersion from CONISS results. DC Zones = Dinoflagellate cyst zones; CEOPG = *Cometodinium habibii*, *Endoscrinium campanula*, *Oligosphaeridium* sp., *Gonyaulacysta jurassica*; P = Cyst Type P; CP = *Circulodinium* spp., Cyst Type P; DQCG = Cyst Type D, Cyst Type Q, *Circulodinium* spp., *Gonyaulacysta* spp.

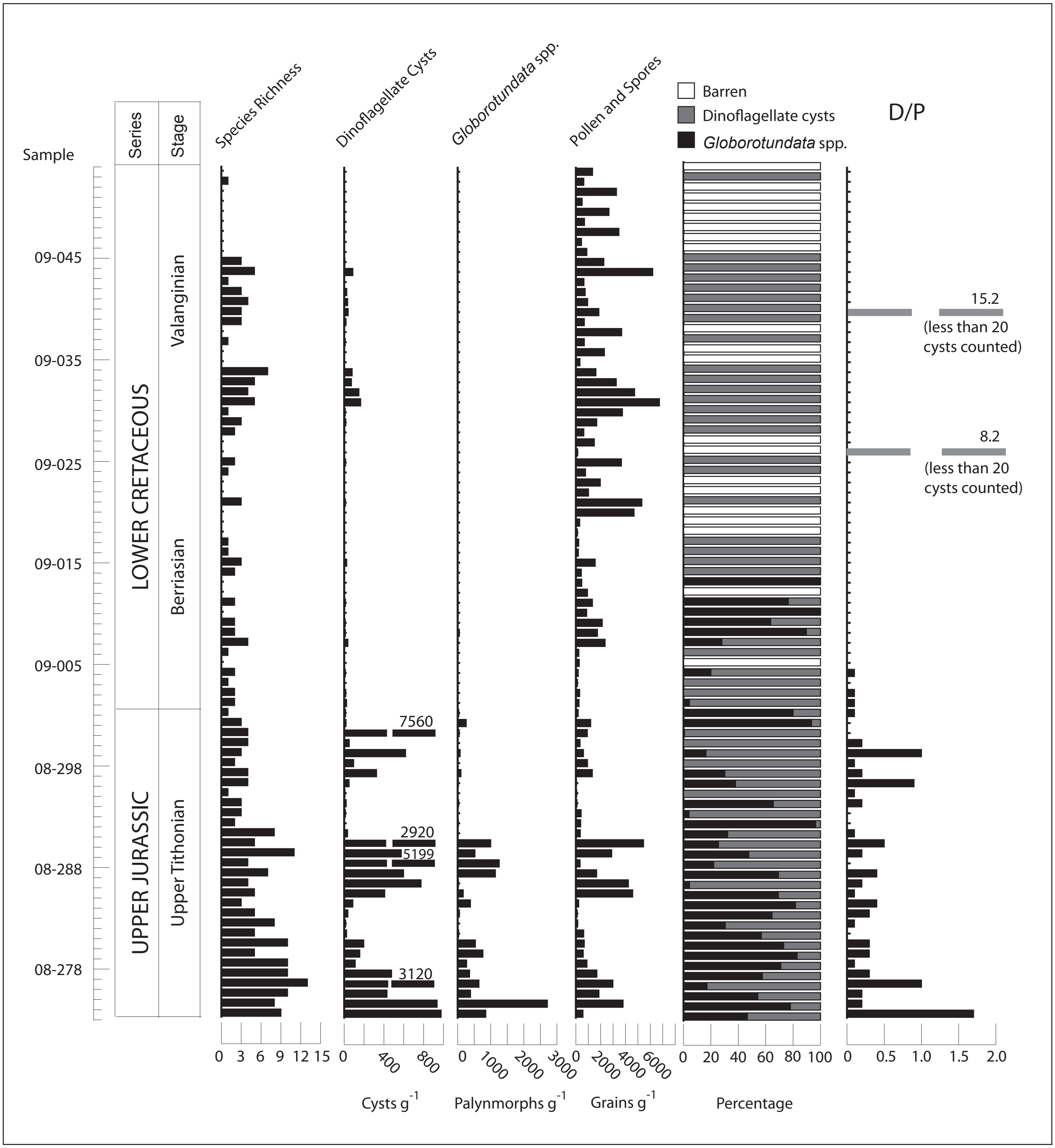

Figure 4. Dinoflagellate cyst species richness, concentration of dinoflagellate cysts, *Globorotundata* spp., pollen and spores, number of dinoflagellate cysts compared to *Globorotundata* spp., and the ratio of dinoflagellate cysts to pollen and spores (D/P).

3.4. Systematic Palynology and Stratigraphic Occurrence

Dinoflagellate cyst taxa were identified by referring to published original descriptions. Morphological terms used to describe dinoflagellate cyst taxa are those described by Williams *et al.* (2000). The synonomy lists have been kept to a minimum, because identified species listed have been previously described in their respective publications. The reader is referred to the Index of Fossil Dinoflagellates (Fensome and Williams, 2004) in which all the references listed are in agreement with the current taxonomic assignment. Some taxa differ slightly from their original description and/or require additional information and therefore warrant a remarks section. All identified dinoflagellate cyst taxa are illustrated on Plates 1 – 7.

Callaiosphaeridium sp. (Davey and Williams 1966)

Plate 1, Figure A

Description. Cysts are chorate with a spherical body. Acavate. Walls appear smooth. Tubular, wide processes, 5 – 10 μm long on the hypotheca. The processes elsewhere are more slender and less distinct. Archeopyle is not distinguishable.

Remarks. Preservation is good to poor. As a result of corrosion it was not possible to view all features necessary to make a species identification.

Stratigraphic Range. Upper Jurassic - Lower Berriasian

Samples. UVic 08-301; 09-001 to 09-003

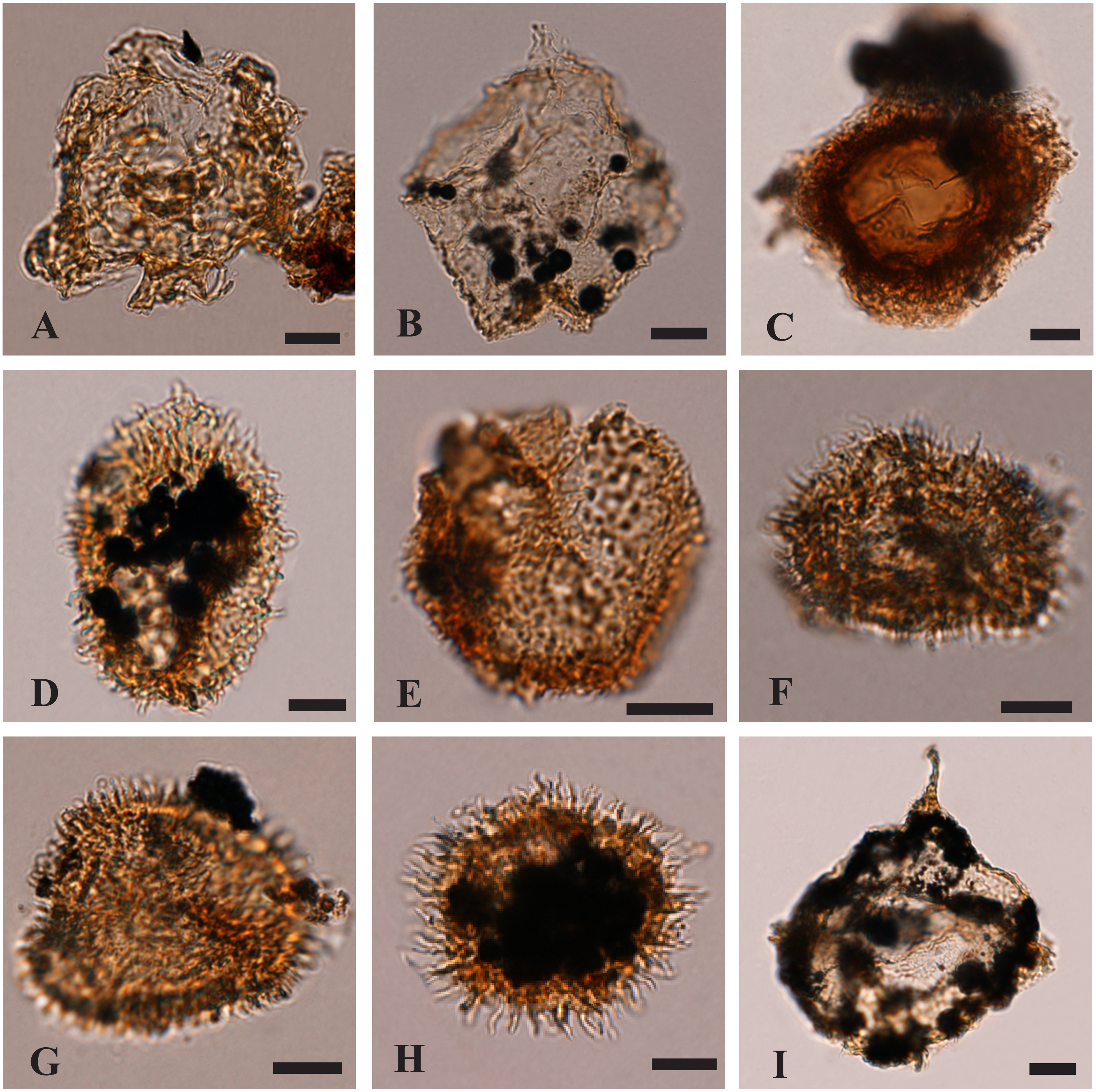

PLATE 1

All photomicrographs are brightfield images, scale bar represents 10 μm.
A. *Callaiosphaeridium* sp., Sample UVic 08-301, slide 1, England Finder coordinates X33/1
B. *Canningia* sp., Sample UVic 08-277, slide 3, England Finder coordinates W38/4
C. *Catastamocystis* sp., Sample UVic 09-032, slide 1, England Finder coordinates L39/2
D. *Circulodinium* sp., Sample UVic 08-273, slide 1, England Finder coordinates X40/1
E. *Circulodinium* sp., Sample UVic 08-276, slide 3, England Finder coordinates X38/2
F. *Circulodinium* sp., Sample UVic 08-290, slide 1, England Finder coordinates X45/0
G. *Circulodinium* sp., Sample UVic 08-300, slide 1, England Finder coordinates Y50/0
H. *Cometodinium habibii,* Sample UVic 08-273, slide 1, England Finder coordinates S45/1
I. *Cribroperidinium* sp., Sample UVic 08-273, slide 1, England Finder coordinates R44/0

Canningia sp. (Cookson and Eisenack 1960)

Plate 1, Figure B

Description. Cysts are subpentagonal with one apical and two antapical horns. Holocavate. Archeopyle apical.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-277 to 08-279

Catastamocystis sp. (Singh 1983)

Plate 1, Figure C

Description. Proximate cysts, camocavate with a spherical outline. Endocyst slightly larger in width than in length. It is smooth, pericyst is membranous and granular. Archeopyle intercalary, operculum free.

Remarks. These specimens were only found in one set of samples in the Lower Cretaceous interval and are relatively well preserved.

Stratigraphic Range. Upper Berriasian

Samples. UVic 09-032 to 09-035

Circulodinium spp. (Alberti 1961)

Plate 1, Figures D - G

Description. Cysts subspherical to ovoid, proximate to slightly proximochorate. Episomes and hyposomes tend to have more width than lengths. Surface verrucate, irregular. No expression of paracingulum observed. Archeopyle apical.

Remarks. Multiple forms of this genus were identified, however, specimens could not be placed in particular species as the majority were heavily pyritised, thus obscuring key features to identify the specimens at species level.

Stratigraphic Range. Upper Tithonian to Middle Valanginian

Samples. UVic 08-273 to 09-045

Cometodinium (Deflandre and Courteville 1939)

Cometodinium habibii (Monteil 1991)

Plate 1, Figure H

Description. Chorate cysts with subspherical body. Acavate. Processes thin, numerous, flexible, non-tabular, cylindrical, distally closed; similar in length and shape. Apical archeopyle, adherent operculum.

Remarks. Process length and shape is consistent with that described by Monteil (1991) and stratigraphic range is comparable. This species is a significant component of the mid Upper Tithonian assemblage on Grassy Island.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273 to 08-280; 08-284; 08-287 to 08-288

Cribroperidinium spp. (Neale and Sarjeant 1962)

Plate 1, Figure I; Plate 2, Figures A - C

Description. Cysts proximate, subspherical with a prominent, asymmetrical apical horn, 12 – 14 μm long, with a truncated to rounded tip. The wall is mildly to heavily pitted. Precingular archeopyle. Operculum free.

Remarks. Some specimens were difficult to identify as they were heavily pyritised and thus plate configurations and archeopyles were not always possible to see. Where an archeopyle is present, the tabulation is too heavily corroded to confidently place the specimen in a species.

Stratigraphic Range. Upper Tithonian; Upper Berriasian

Samples. UVic 08-273; 08-276; 08-286; 08-289; 08-294; 09-031

Crussolia sp. (Wolfard and Van Erve 1981)

Plate 2, Figure D

Description. Cyst proximate, ellipsoidal in shape with one apical horn, rounded tip. Holocavate. Wall smooth. No arechopyle visible. Medium brown in colour.

Remarks. Only one specimen was recovered.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-286

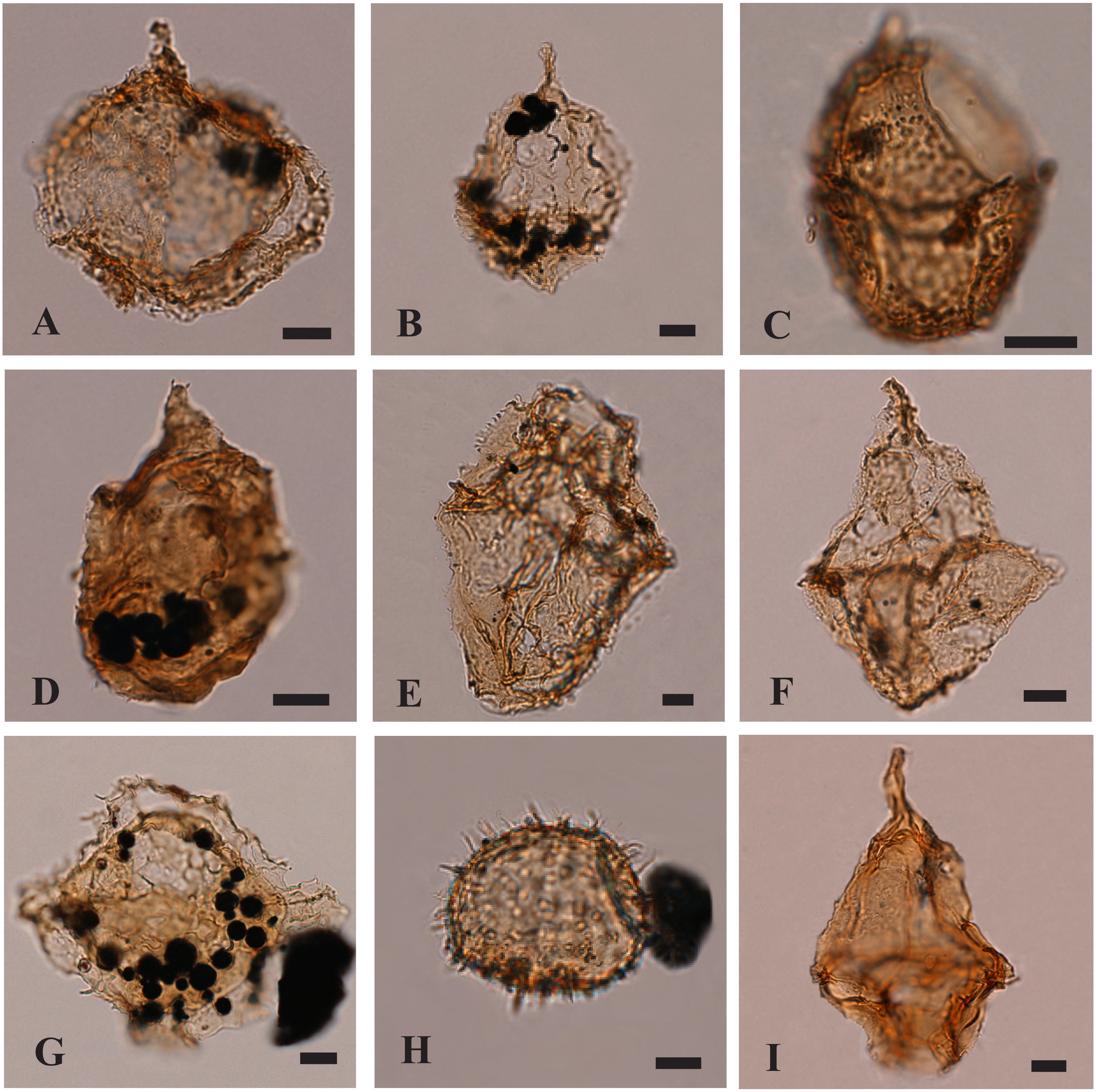

PLATE 2

All photomicrographs are brightfield images, scale bars represent 10 μm.
A. *Cribroperidinium* sp., Sample UVic 08-276, slide 3, England Finder coordinates W45/3
B. *Cribroperidinium* sp., Sample UVic 08-289, slide 2, England Finder coordinates W42/3
C. *Cribroperidinium*? sp., Sample UVic 09-031, slide 1
D. *Crussolia* sp., Sample UVic 08-286, slide 1, England Finder coordinates Y41/1
E. *Ctenodinium*? sp., Sample UVic 09-044, slide 1, England Finder coordinates L36/3
F. *Endoscrinium campanula,* Sample UVic 08-280, slide 3, England Finder coordinates Y38/2
G. *Endoscrinium* sp., Sample UVic 08-277, slide 3, England Finder coordinates V34/4
H. *Exochorosphaeridium* sp., Sample UVic 09-045, slide 1, England Finder coordinates S43/1
I. *Gonyaulacysta dualis*, Sample UVic 09-004, slide 1, England Finder coordinates N30/0

Ctenodinium? sp. (Deflandre 1939)

Plate 2, Figure E

Description. Cysts proximochorate, only autophragm. Body ellipsoidal, wall regulate. Crest septa denticulate. Hypocyst about twice the length of the epicyst. Archeopyle not visible.

Remarks. These specimens are moderately to poorly preserved and thus difficult to identify reliably. Plate configurations were not possible to see, but the overall shape and general appearance of the cysts place it within this genus, although placement is tentative.

Stratigraphic Range. Lower Valanginian

Samples. UVic 09-044 to 09-045

Endoscrinium sp. (Klement, 1960) Vozzhennikova, 1967

Plate 2, Figure G

Description. Cysts are circumcavate, proximate. Endocyst is roundly quadrate, smooth; the pericyst tends to follow the same outline of the endocyst, smooth with a few short, thin spines with rounded tips. Precingular archeopyle; operculum free.

Remarks. Archeopyle is precingular however, plate tabulation is not clear. There is a distinct outer layer compared to ovoid shaped inner body. Short spines are present on the outer edges of the cyst, however corrosion has resulted in only a few being preserved. In general, the specimens are relatively well preserved, but very rare. This specimen may be confused with *E. attadalense* which has a similar profile, but lacks spines on its outer edges and has an internal body much rounder than the specimens recovered from Grassy Island which are nearly square in shape. As a result of the spines and body shape, the *Endoscrinium* specimens cannot be classified within *E. attadalense.*

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-276 to 08-277; 08-280

Endoscrinium campanula (Gotcht, 1959) Vozzhennikova, 1967

Plate 2, Figure F

Description. Cysts compressed, tabulate, fairly straight cingulum. Apical horn is short and truncated; the overall shape displays a helmet to bell outline with one side of the cyst distinctly more bulging out that the other. Archeopyle not visible.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273 to 08-276; 08-280; 08-282

Exochorosphaeridium sp. (Davey *et al.* 1966)

Plate 2, Figure H

Description. Proximochorate cysts, subspherical central body; wall granular. Acavate. Processes numerous, solid, approximately 5 μm long, tips evexate. No archeopyle visible.

Remarks. Two specimens were recovered, however their preservation is very good. The specimens are found in the uppermost Valanginian.

Stratigraphic Range. Lower – Middle Valanginian

Samples. UVic 09-045; 09-053

Gonyaulacysta dualis (Brideaux and Fisher 1976)

Plate 2, Figure I

Description. Proximate cysts, elongate, twice as long as wide, tapering into an apical horn that is truncated; wall is smooth. Distinct cingulum. Archeopyle precingular.

Remarks. Identified based upon smooth body walls which distinguishes it from *Gonyaulacysta jurassica*. Specimens are rare to uncommon but are preserved exceptionally well compared to other members within the genus. Specimens were recovered from samples just above the Jurassic - Cretaceous boundary and this is their only occurrence through the entire section.

Stratigraphic Range. Lower Berriasian

Samples. UVic 09-004; 09-007 to 09-008

Gonyaulacysta jurassica (Deflandre 1939) Norris and Sarjeant 1965

Plate 3, Figure A

Description. Cysts epicavate, hexagonally rounded, tapering apically into a short horn, truncated at the tip; Flanks fairly planar. Hypocyst approximately the same size as the epicyst. Wall corroded. Precingular archeopyle.

Remarks. The majority of specimens are highly corroded and plate configurations are difficult to discern.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273 to 08-278; 08-282; 08-289; 08-293

Gonyaulacysta jurassica var. *adecta* (Sarjeant 1982)

Plate 3, Figure B

Description. Epicavate cyst, irregularly hexagonal, tapering apically into a horn, rounded at the tip; flanks slightly concave. No hypocystal cavation. Wall is scabrate. No arecheopyle visible.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273; 08-275 to 08-276; 08-293

Gonyaulacysta spp. (Deflandre 1964)

Plate 3, Figures C - I

Description. Cysts ovoid to quadrate, proximate, cavate, wall smooth to scabrate. Apical horn well developed, truncated to rounded tip. Some specimens display one or two antapical horns. Precingular archeopyle.

Remarks. Several types of this genus were recovered. These cysts were pyritised which destroyed plate configurations and if any archeopyles were present, they were too degraded to be diagnostic. Eventually these may be separated into particular species.

Stratigraphic Range. Upper Tithonian to Lower Valanginian

Samples. UVic 08-273 to 08-278; 08-280 to 08-282; 08-285; 08-287; 08-291; 08-294; 08-296; 08-299 to 08-300; 09-001; 09-004; 09-007; 09-011; 09-017; 09-021; 09-025; 09-029; 09-031 to 09-034; 09-039 to 09-042; 09-044

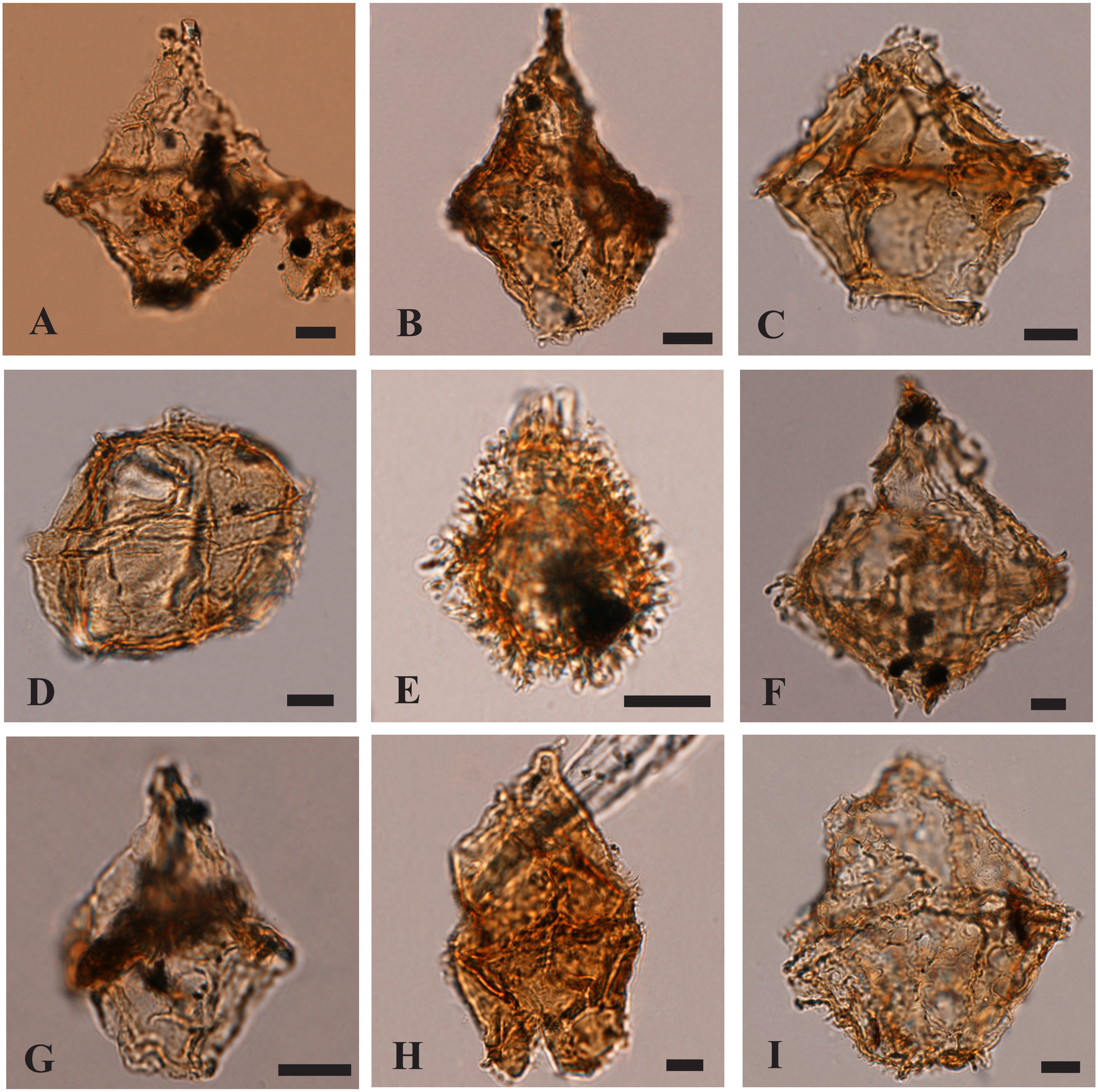

PLATE 3

All photomicrographs are brightfield images, scale bars represent 10 µm.

A. *Gonyaulacysta jurassica*, Sample UVic 08-273, slide 1, England Finder coordinates Y38/3

B. *Gonyaulacysta jurassica* var. *adecta*, Sample UVic 08-293, England Finder coordinates Y39/0

C. *Gonyaulacysta* sp., Sample UVic 08-276, slide 3

D. *Gonyaulacysta* sp., Sample UVic 09-025, slide 1, England Finder coordinates O33/1

E. *Gonyaulacysta* sp., Sample UVic 08-299, slide 1, England Finder coordinates Y49/3

F. *Gonyaulacysta* sp., Sample UVic 08-276, slide 3, England Finder coordinates W39/0

G. *Gonyaulacysta* sp., Sample UVic 08-294, slide 1, England Finder coordinates V44/0

H. *Gonyaulacysta* sp., Sample UVic 08-296, slide 1, England Finder coordinates Z48/1

I. *Gonyaulacysta* sp., Sample UVic 09-011, slide 1, England Finder coordinates T38/2

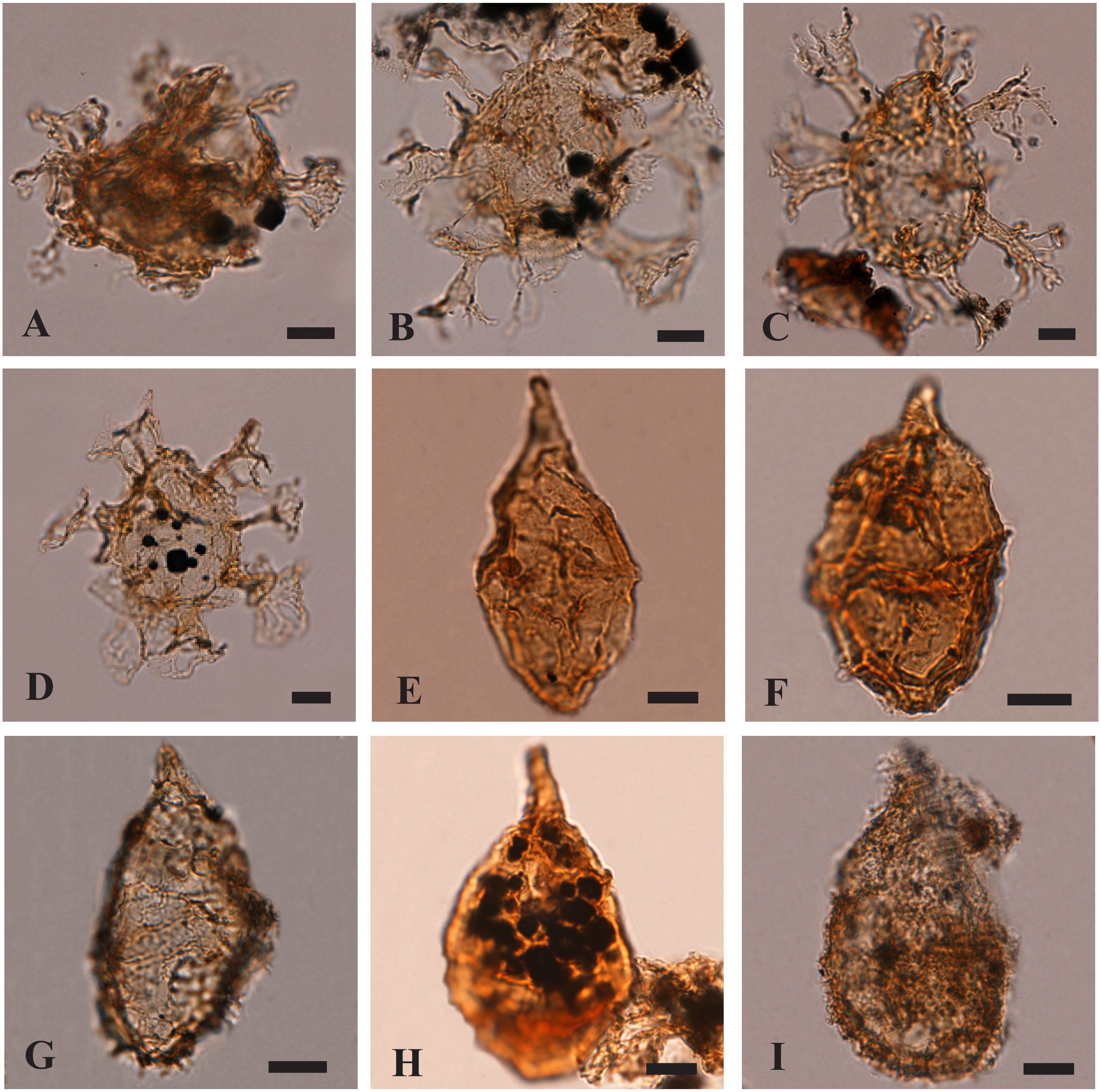

PLATE 4

All photomicrographs are brightfield images, scale bars represent 10 μm.

A. *Hystrichosphaeridium*? sp., Sample UVic 08-280, slide 3, England Finder coordinates X47/0

B. *Oligosphaeridium albertense*, Sample UVic 08-289, slide 2, England Finder coordinates W49/3

C. *Oligosphaeridium patulum*, Sample UVic 08-300, slide 1, England Finder coordinates Y37/0

D. *Oligosphaeridium* sp., Sample UVic 08-276, slide 3, England Finder coordinates V45/1

E. *Paragonyaulacysta* sp., Sample UVic 08-273, slide 1, England Finder coordinates X38/0

F. *Paragonyaulacysta* sp., Sample UVic 08-297, slide 1, England Finder coordinates Z48/0

G. *Paragonyaulacysta* sp., Sample UVic 09-029, slide 1, England Finder coordinates L39/0

H. *Pareodinia* sp., Sample UVic 08-273, slide 1, England Finder coordinates R36/3

I. *Pareodinia* sp., Sample UVic 08-281, slide 1, England Finder coordinates V39/3

Hystrichosphaeridium? sp. (Deflandre 1937)

Plate 4, Figure A

Descritpion. Chorate cyst with spherical central body. Acavate. Processes thick, proximally multifurcate with interconnecting trabeculae. Apical archeopyle, operculum free.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-280; 08-291; 08-301

Oligosphaeridium sp. (Davey and Williams 1966) Davey 1982

Plate 4, Figure D

Description. Chorate cyst with a subspherical central body, pronounced apical bosse. Acavate. Wall smooth. Processes hollow, open, strongly flaring distally in the last half of the process tips; the outer margin of the process tips have scalloped margins, processes similar in size, length and shape. Archeopyle apical, operculum free.

Remarks. In future, this particular specimen might warrant placement within *Stiphrosphaeridium* as the process tips are quite similar; However, the apical bosse on the Grassy Island specimens is quite pronounced, whereas it does not appear to be a significant feature in *Stiphrosphaeridium*. For this reason, the specimens analysed from Grassy Island are classified as *Oligosphaeridium*.

Stratigraphic Range. Upper Tithonian.

Samples. UVic 08-276 to 08-280; 08-282

Oligosphaeridium albertense (Pocock 1962) Davey and Williams 1969

Plate 4, Figure B

Description. Cysts chorate with spherical central body. There are 13 processes, between 17 – 25 μm long; cylindrical at their bases, widening distally with the distal half flaring; tips of processes somewhat scalloped, many fine, slender spines. The opening somewhat offset from the centre, is not the archeopyle but a tear created when the paraplate carrying the process pointing in this direction disengaged.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-278; 08-280; 08-289; 08-296

Oligosphaeridium patulum (Riding and Thomas 1988)

Plate 4, Figure C

Description. Skolochorate cysts, central body subspherical. Wall finely granulate. Processes tubiform, open, widely flaring; Tips deeply multifurcate, irregular, digitate distal opening. Apical processes slightly more slender than the others in most cases. No archeopyle visible.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-300 to 08-303

Paragonyaulacysta spp. (Johnson and Hills 1973) Dorhofer and Davies 1980

Plate 4, Figures E - G

Description. Proximate cysts with elongated, ellipsoidal outline. Apical horn present, maybe long or short, antapex rounded. There is a marked sutural crest. Wall ranges from smooth to very finely granulate to reticulate. Archeopyle not visible.

Remarks. Three members within this genus share these characteristics.

Stratigraphic Range. Upper Tithonian; Upper Berriasian

Samples. UVic 08-273; 08-297; 09-029

Pareodinia spp. (Deflandre 1947) Gocht 1970

Plate 4, Figures H – I; Plate 5, Figure A

Description. Proximate cysts, elongate ellipsoidal, tapering into an apical horn, long or short, with a rounded antapex. Wall smooth to granulate. No distinct indications of tabulation. Intercalcary archeopyle.

Remarks. There are three members within this group. Specimens are found only in the Jurassic section and are relatively well preserved. Studies of contemporaneous material (eg. Nikitenko *et al.*, 2008; Pocock, 1976) recovered *Pareodinia* in the Cretaceous section, unlike the Jurassic occurrence in this study.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273 to 08-277; 08-281 to 08-283; 08-285 to 08-286; 08-289; 08-291; 08-296 to 08-298

Perisseiasphaeridium (Davey and Williams 1966)

Perisseiasphaeridium pannosum (Davey and Williams 1966)

Plate 5, Figure B

Description. Chorate cyst, subspherical to spherical in shape. Wall smooth. Two types of processes are present and inequally spread over the cyst; some processes are tubular, flared proximally, the margins of the tips are spinose; The other processes are thinner, acuminate and multifurcate. No archeopyle was visible.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-289

Pluriavalium sp. (Sarjeant, 1962)

Plate 5, Figure C

Description. Proximate cyst, quite elongate ovoid, tapering into an apical horn, moderate in length, rounded antapex. Wall smooth, single layered. No distinct indications of tabulation. No noted archeopyle.

Remarks. Some authors (Fensome and Williams, 2004) suggest that *Pluriavalium* may be a taxonomic junior of *Pareodinia,* in which case, *Pareodinia* would extend into the Cretaceous of Grassy Island.

Stratigraphic Range. Middle Berriasian

Samples. UVic 09-015

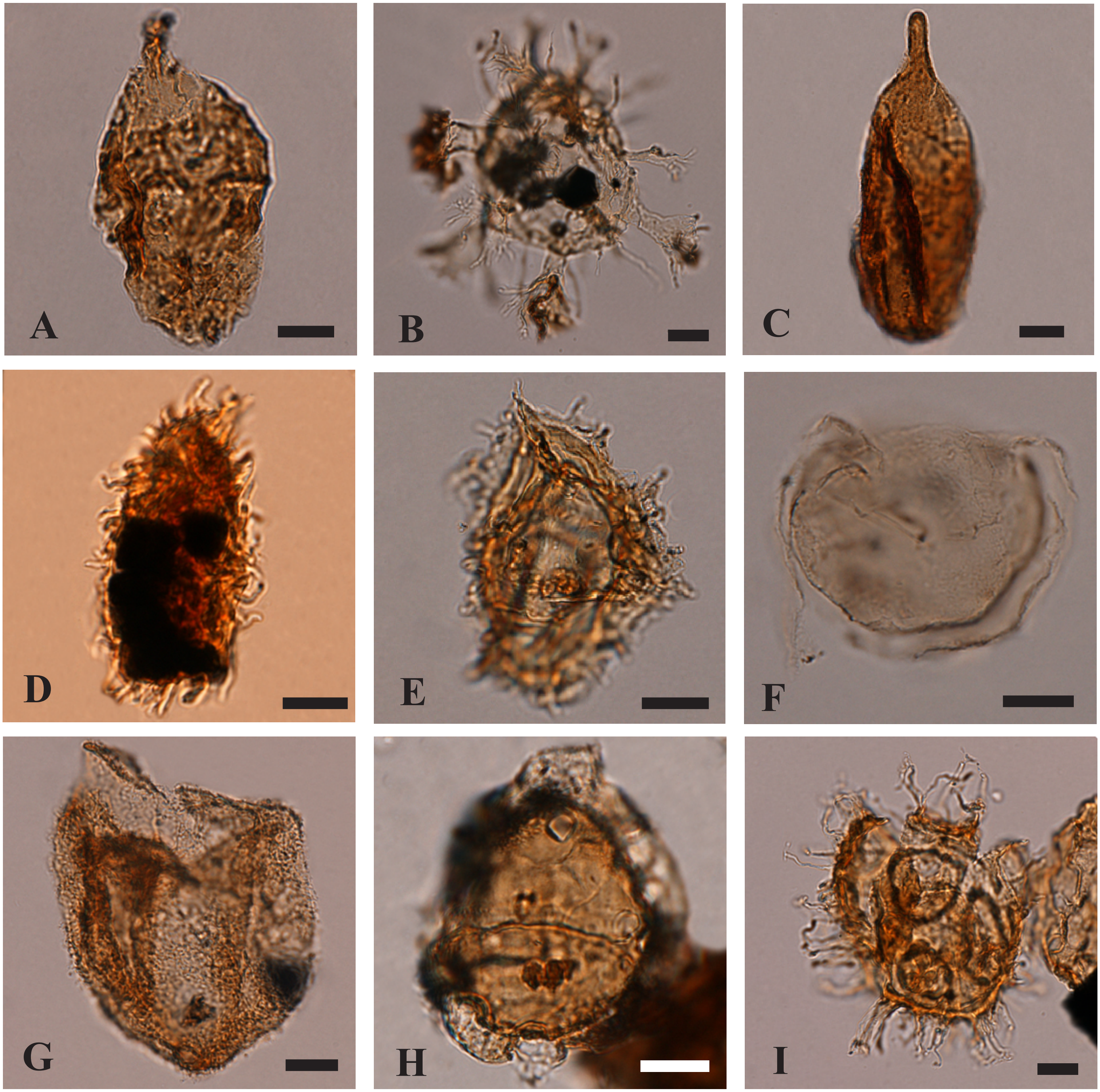

PLATE 5

All photomicrographs are brightfield images, scale bars represent 10 μm.
A. *Pareodinia* sp., Sample UVic 08-285, slide 1, England Finder coordinates W31/0
B. *Perisseiasphaerdium pannosum*, Sample UVic 08-289, slide 2, England Finder coordinates W44/4
C. *Pluriavalium* sp., Sample UVic 09-015, slide 1, England Finder coodinates U43/1
D. *Prolixosphaeridium* sp., Sample UVic 08-273, slide 1, England Finder coordinates Y43/3
E. *Rottensia*? sp., Sample UVic 09-034, slide 1, England Finder coordinates O50/1
F. *Senoniasphaera* sp., Sample UVic 08-286, slide 1, England Finder coordinates Z31/2
G. *Sentsudinium* sp., Sample UVic 08-293, slide 1, England Finder coordinates Z45/0
H. *Sirmiodiniopsis orbis*?, Sample UVic 09-028, slide 1, England Finder coordinates M52/4
I. *Systematophora areolata*, Sample UVic 08-276, slide 3, England Finder coordinates U35/0

Prolixosphaeridium sp. (Davey *et al.* 1966) Davey 1969

Plate 5, Figure D

Description. Cysts proximochorate, ellipsoidal. Wall appears smooth to granular. Relatively short processes, numerous, cover the whole cyst, they are simple evexate between 3 – 5 μm in length, appear flexible. Paratabulation is not evident. Archeopyle apical.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273 to 08-278; 08-290 to 08-291

Rottenstia? sp. (Cookson and Eisenack 1961)

Plate 5, Figure E

Description. Proximochorate cysts, slightly elongate, subpolyhedral with a avery small, pointed apical horn. Bicavate. Processes are simple, evexate, 4 to 6 μm in length, appear to be sutural. No arecheopyle is visible.

Stratigraphic Range. Upper Tithonian to Upper Berriasian

Samples. UVic 08-280; 08-282; 09-034

Senoniasphaera sp. (Clarke and Verdier 1967)

Plate 5, Figure F

Description. Proximate cysts, subpenagonal in outline. Circumcavate. Endophragm slightly granulate; periphragm smooth with one antapical horn offset to one side, tapering into a point. Archeopyle apical, operculum free.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-286 to 08-290

Sentsudinium sp. (Sarjeant and Stover 1978) Courtinant 1989

Plate 5, Figure G

Description. Proximate cyst, ellipsoidal. Wall coarsely granulate. Many very short and thin processes, several hundred cover the surface. Apical archeopyle with a distinct zigzag suture.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-281; 08-283 to 08-285; 08-290 to 08-291

Sirmiodiniopsis (Drugg 1978)

Sirmiodiniopsis orbis? (Drugg 1978)

Plate 5, Figure H

Description. Cyst proximate, subcircular outline. Endophragm and periphragm are in contact on the dorsal and ventral sides, periocels developed laterally, apically and antapically, approximately 7 μm thick. Endocyst surface shagreen; periphragm smooth. Paracingulum is visible on the periphragm, has low narrow crests, slightly concave. Apical archeopyle.

Stratigraphic Range. Upper Berriasian

Samples. UVic 09-028; 09-033

Systematophora (Klement 1960)

Systematophora areolata (Klement 1960)

Plate 5, Figure I

Description. Phragmochorate cyst, ovoid, with reticulate surface. 14 groups of processes are arranged around subcircular fields, widely spaced. Processes are thin, tips bifurcate and branching in some specimens with noticeable trabeculae.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-276; 08-278

Turbiosphaera? sp. (Archangelsky 1969)

Plate 6, Figure A

Description. Chorate cysts, subsperical in outline. Cavate. Endophragm and periphragm smooth to shagreenate. Processes thin and difficult to distinguish on epicyst; hypocyst has thick, tubular processes with entire tips open. The periphragm is well developed on these processes and appear to cover them along their lengths, attached at the tips of the processes. Archeopyle appears to be apical.

Stratigraphic Range. Upper Tithonian.

Samples. UVic 08-278; 08-280; 08-289

Cyst Type D

Plate 6, Figure B

Description. Chorate cysts, subcircular to ovoid in shape; slightly longer in length than width. Single walled, smooth. Processes are abundant, thin, moderate in length, similar in shape and size, simple with acuminate to evexate tips. There is no visible cingulum, tabulation or archeopyle. The specimens are colourless to a light yellow.

Dimensions (μm)

Height of cyst body	20.33(22.35)24.47	
Width of cyst body	19.03(20.66)22.48	
Length of processes	3.81(4.07)6.43	N=36

Number of specimens measured: 12

Stratigraphic Range. Upper Berriasian to Lower Valanginian

Samples. UVic 09-029 to 09-034; 09-039 to 09-044

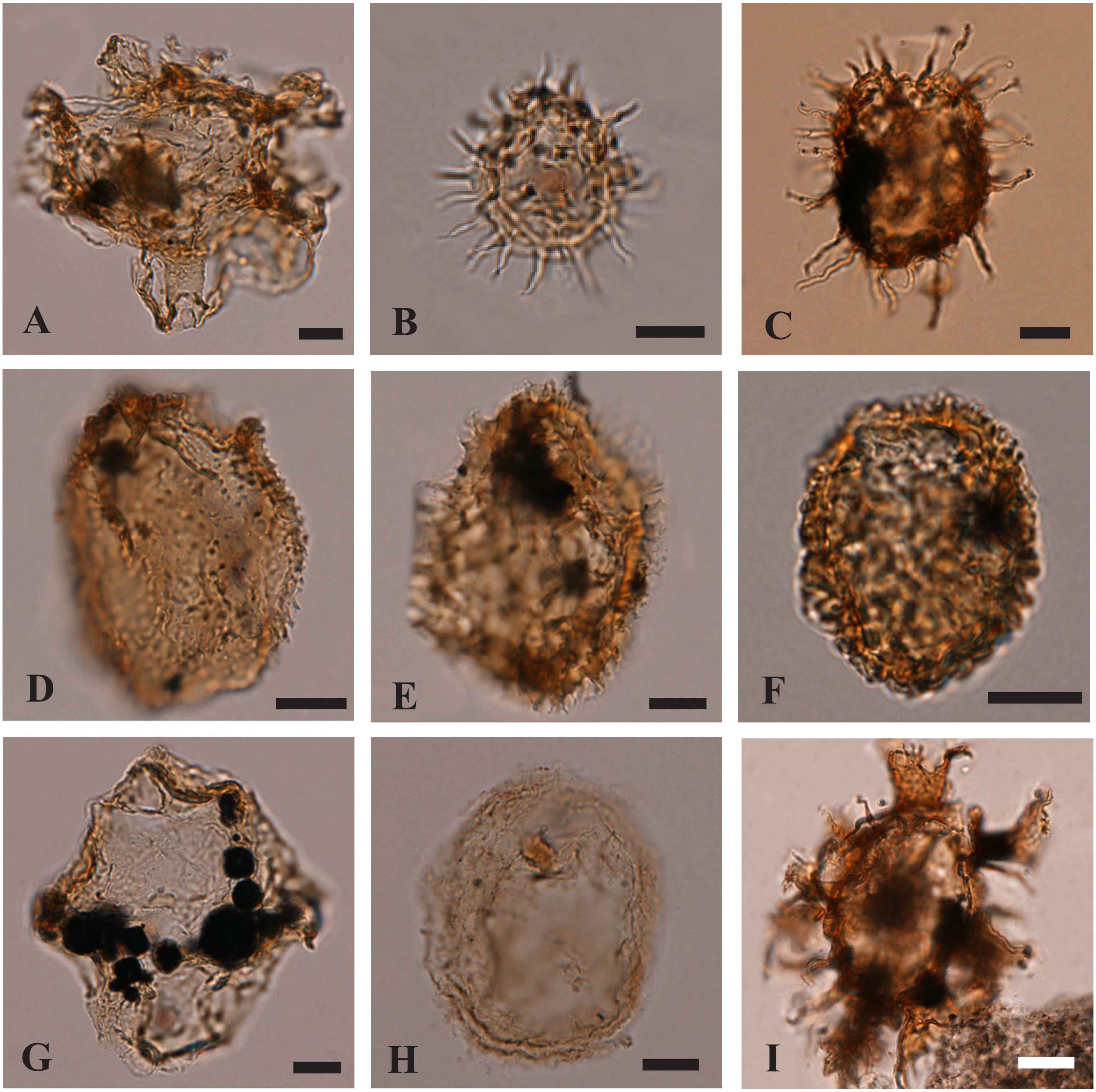

PLATE 6

All photomicrographs are brightfield images, scale bars represent 10 μm.

A. *Turbiosphaera*? sp., Sample UVic 08-289, slide 2, England Finder coordinates W45/4

B. Cyst Type D, Sample UVic 09-032, slide 1, England Finder coordinates U45/2

C. Cyst Type G, Sample UVic 09-031, slide 1, England Finder corodinates P48/0

D. Cyst Type J, Sample UVic 08-287, slide 1, England Finder coordinates Y43/4

E. Cyst Type L, Sample UVic 08-287, slide 1

F. Cyst Type M, Sample UVic 08-289, slide 2, England Finder coordinates W46/0

G. Cyst Type N, Sample UVic 08-277, slide 3, England Finder coordinates W44/0

H. Cyst Type P, Sample UVic 08-287, slide 1, England Finder coordinates Y32/2

I. Cyst Type Q, Sample UVic 09-006, slide 1

Cyst Type G

Plate 6, Figure C

Description. Chorate cysts, ovoid in shape. Single walled, smooth to shagreenate. Processes numerous, thin, long, flexible, capitate, similar in size and shape. No visible cingulum or tabulation. Archeopyle appears to be apical. Specimens are medium to dark brown.

Stratigraphic Range. Upper Berriasian to Lower Valanginian

Samples. UVic 09-031; 09-034; 09-041; 09-044

Cyst Type J

Plate 6, Figure D

Description. Proximate cysts, subpentagonal, rounded in outline. Possibly acavate. Surface tuberculate. Short, stout spines extend over the surface. Possibly two slight antapical horns, asymmetric. No distinct cingulum or notable tabulation. Archeopyle is likely apical. Medium yellow to brown.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-275; 08-287

Cyst Type L

Plate 6, Figure E

Description. Proximate cysts, subspherical to ellipsoidal. Wall smooth to scabrate. Processes short, hairlike, evexate tips, numerous, similar in size and shape. No visible tabulation, cingulum or archeopyle. Medium yellow to brown.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-287; 08-289; 08-291

Cyst Type M

Plate 6, Figure F

Description. Proximate cysts, ovoidal in shape. The hypocyst tapers into a wide, blunt point. Autophragm is highly baculate. Tabulation and cingulum not aparent. Archeopyle appears intercalary, operculum free. Medium to dark brown.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-289

Cyst Type N

Plate 6, Figure G

Description. Proximate cysts, subpolyhedral in shape. Epicyst terminates in two asymmetric apical horns, hypocyst tapers into a point. Epicyst is one and a half times larger than the hypocyst. Autophragm slightly reticulate. Cingulum highly distinct. Tabulation and archeopyle not visible. Light to medium yellow.

Stratigraphic Range. Upper Tithonian

Samples. UVsic 08-277

Cyst Type P

Plate 6, Figure H

Description. Proximate cysts, subspherical to slightly ovoid in shape. Periphragmn has very short, thin hairlike processes. Both periphragm and endophragmn are finely granulate. There is a pore on the epicyst just off centre. Epicystal archeopyle, operculum attached. Colourless to very light brown.

Dimensions (μm)

Length	41.15(46.86)58.94
Width	38.25(40.63)49.38

Number of Specimens measured: 25

Stratigraphic Range. Upper Tithonian.

Samples. UVic 08-273 to 08-295; 08-297 to 08-302

Cyst Type Q

Plate 6, Figure I

Description. Chorate cysts, subspherical in outline. Autophragm shagreenate. Processes are both thin, hollow, flexible with evexate tips as well as other thick, wide processes flaring distally, margins of tips are spinose. Tabulation, cingulum and archeopyle not visible. Medium to dark brown.

Remarks. Cysts are very dark with long chorate processes with flaring tips. The specimens could tentatively be *Achilleodinium*; However, cysts were surrounded by thick precipitates and could not be properly or clearly identified to fit within the genus. Specimens were found only in the Cretaceous section.

Stratigraphic Range. Berriasian

Samples. UVic 09-006 to 09-07; 09-014 to 09-016; 0-021; 09-034

INCERTAE SEDIS

Globorotundata spp. (Duane 1997)

Globorotundata Type A

Plate 7, Figure A - B

Description. Spherical to subspherical, single walled palynmorph. Wall smooth. Numerous bulbous protrusions covering the whole surface, possibly processes. Additionally, there are thin, short processes with evexate tips interspersed amongst the bulbous protrusions. No tabulation, cingulum or archeopyle visible.

Remarks. This genus is of unknown affinity and was not included in final dinoflagellate cyst counts.

Stratigraphic Range. Upper Tithonian

Samples. UVic 08-273 to 08-275; 08-277 to 08-280; 08-284; 08-287; 08-299

Globorotundata Type B

Plate 7, Figure C - D

Description. Spherical to subspherical single walled palynmorph. Wall smooth. Numerous bulbous protrusions cover the whole surface, possibly processes. No tabulation or cingulum was noted, however, some specimens show a tear in the wall which, if a cyst, may be the archeopyle.

Remarks. This genus is of unknown affinity and was not included in final dinoflagellate cyst counts.

Stratigraphic Range. Upper Tithonian to Lower Berriasian

Samples. UVic 08-273 to 08-294; 08-296 to 08-297; 08-299; 08-301 to 09-001; 09-004; 09-007 to 09-011

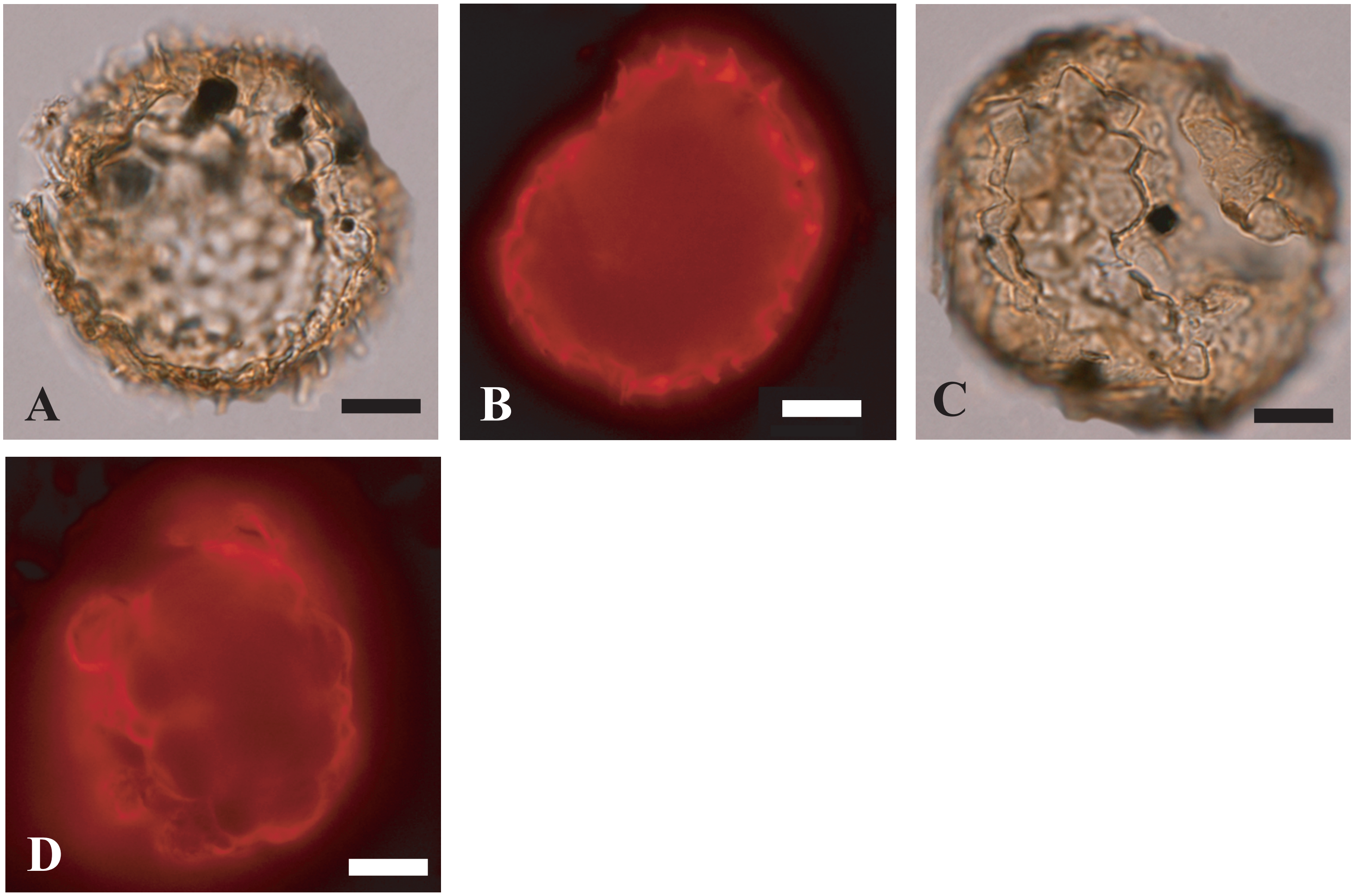

PLATE 7

Scale bar represents 10µm.

A. *Globorotundata* Type A, Sample UVic 08-274, slide 8, image is brightfield.

B. *Globorotundata* Type A, Sample UVic 08-274, slide 8, image is epifluoresencent.

C. *Globorotundata* Type B, Sample UVic 08-274, slide 8, England Finder coordinates U40/0, image is brightfield

D. *Globorotundata* Type B, Sample UVic 08-274, slide 8, image is epifluoresencent.

3.5. Dinoflagellate Cyst Zonation

Dinoflagellate cyst zones for Grassy Island were established using Psimpoll software (version 4.27; http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html) as well as by visual inspection. The Tithonian of Grassy Island was subdivided into three dinoflagellate cyst zones. The Cretaceous portion of the section is grouped as one zone. As a result there are very spotty representations of the dinoflagellate cyst taxa that were recovered from samples UVic 09-001 to UVic 09-054 (Figure 3), the Lower Cretaceous. The reader is encouraged to be aware of the number of cysts counted when using the dinoflagellate cyst zonation, particularly in the Lower Cretaceous.

***Cometodinium habibii*, *Endoscrinium campanula*, *Oligosphaeridium* sp., *Pareodinia* spp., *Gonyaulacysta jurassica* Zone (CEOPG Zone)**

Lower to middle Upper Tithonian - Samples UVic 08-273 to 08-282

This zone is characterised by the only occurrences of *Endoscrinium* sp., *E. campanula*, *Gonyaulacysta jurassica* var. *adecta*, *Oligosphaeridium* sp., and *Systematophora areolata*. *Cometodinium habibii* is consistently present in moderate numbers, up to a maximum of 35%. *Gonyaulacysta* spp., *Circulodinium* spp., and Cyst Type P are common, reaching maximum abundances of 40%. *Pareodinia* spp. reaches an abundance of ~20% and proceeds to decrease throughout this zone. Other minor components of this zone include *Gonyaulacysta jurassica*, *Oligosphaeridium albertense*, *Prolixosphaeridium* sp., *Canningia* sp., *Cribroperidinium* spp., *Sentsudinium* sp., and *Turbiosphaera* sp. At the base of the zone, *Pareodinia* spp. reaches an abundance of just over 20% (sample UVic 08-273) then decreases through the zone to 4% (sample UVic 08-292).

Cyst Type P Zone

Middle Upper Tithonian - Samples UVic 08-283 to 08-288

This zone is dominated by Cyst Type P, which consistently displays high abundances, maintaining relative abundances of 80%. Notably, *Gonyaulacysta jurassica* var. *adecta*, *G. jurassica*, and all species of *Oligosphaeridium* are absent. *Gonyaulacysta* spp. is present in much lower abundances than in the CEOPG Zone, approximately 10%. *Circulodinium* spp. abundances are relatively low as well, seeing a maximum abundance of 20%. *Cometodinium habibii* is also represented in low abundances, reaching a maximum of 5%; its final appearance is at the top of this zone. *Senoniasphaera* sp. appears for the first time in this zone in very low numbers, no higher than 4%. *Sentsudinium* sp. is also present in very low numbers.

Circulodinium spp., Cyst Type P Zone (CP Zone)

Uppermost Upper Tithonian - Samples UVic 08-289 to 08-303

This zone is characterised by high abundances of *Circulodinium* spp., up to 80% for most of the zone. Cyst Type P continues to play an important role, ranging between 80% and 2%, but remains above 50% for most of the zone; its final appearance is at the top of this zone. *Gonyaulacysta* spp. is present consistently, but maintains numbers as low as the previous zone, rarely above 10%. *Oligosphaeridium albertense* reappears in this zone and *O. patulum* appears in this zone only. *O. patulum* is present in much higher abundances than any other members within the genus, reaching 60% as a maximum, while *O. albertense* never appears in abundances higher than 10%. Futhermore, *O. albertense* appears closer to the base of this zone while *O. patulum* is present near the top of the zone and the two taxa are not present together in the same samples.

There is the reappearance of *Gonayaulacysta jurassica, Prolixosphaeridium* sp. and *Pareodinia* spp. which reaches a maximum of 35%; this is significantly higher than in the previous two zones. This zone has the only occurrence of *Hystrichosphaeridium*? sp. in low numbers, appearing only twice with an abundance of 2% and then 8% on its second appearance. Several taxa have their final appearances in this zone including *O. albertense, O. patulum, G. jurassica*, *Senoniasphaera* sp., and *Sentsudinium* sp.

Cyst Type D, Cyst Type Q, *Circulodinium* spp., *Gonyaulacysta* spp. Zone (DQCG Zone)

Lower Cretaceous (Berriasian – Valanginian) - Samples UVic 09-001 to 09-054

This zone is characterised by a distinct domination of Cyst Type Q in the lower portion of this zone which is then replaced by the dominance of Cyst Type D in the middle to upper portion of the zone. There are moderate, consistent numbers of *Circulodinium* spp., reaching maximum values of about 85%; its last appearance is just before the top of the zone. *Gonyaulacysta* spp. is present in low, but relatively consistent numbers reaching on average of approximately 35%, and disappearing at approximately the same level as *Circulodinium* spp., near the top of the zone. There are also some taxa, such as *Callaiosphaeridium* sp., *Catastamocystis* sp., *Cribroperidinium*? spp., *Ctenodinium*? sp., *Exochorosphaeridium* sp., *Gonyaulacysta dualis, Pluriarvalium* sp., and *Sirmiodiniopsis orbis*, which make a brief appearance at different levels throughout the zone.

3.6. ***Globorotundata*** **spp.**

Throughout most of the analysed Jurassic samples there are large numbers of a palynmorph called *Globorotundata* spp. (Figure 4). This taxon, of unknown affinity, was initially described from Lower Cretaceous sediments of the Antarctic Peninsula (Duane, 1997) and is characterized by numerous bulbous protrusions which could be interpreted as processes. Duane (1997) has suggested that it is possible that examples of *Globorotundata* spp. may originally have been a smooth palynmorph but as a result of intense pyritisation within the palynmorph the walls become extended outwards. The bulbous processes of *Globorotundata* spp. from Grassy Island may reflect this transformation. On the other hand, the absence of thinning of the walls, rounded shape of the processes, and no indication of pyritisation on any other palynomorphs in the samples presents evidence against *Globorotundata* spp. being the product of pyritisation (Duane, 1997).

In samples from Grassy Island (UVic 08-273 – UVic 09-012), *Globorotundata* spp. reaches concentrations of 2674 palynmorphs g^{-1}, with the highest concentrations in the Upper Tithonian (UVic 08-273 – UVic 08-290) after which it decreases in concentration before disappearing in the Lower Berriasian (Figure 4, Appendix 4). Note that this is an earlier appearance of *Globorotundata* spp. than previously reported by Duane (1997), thus extending the stratigraphic range of this taxon from the Upper Cenomanian down to the Upper Tithonian.

Globorotundata spp. specimens from Grassy Island are luminescent in the cholorphyll *a* band, when studied under an epifluorescent microscope (Plate 7, Figures B and D). These palynomorphs bear no indicative features of pollen and spores; Neither has any specimen with a clear archeopyle yet been observed in the Grassy Island samples. *Globorotundata* spp. is associated with anoxia (Duane, 1997) and is relevant in the Grassy Island section showing distinct abundances that do not appear to be random (Figure 4). While this taxon is important to Grassy Island, because of its questionable taxonomic affinity, *Globortundata* spp. was not included in the total dinoflagellate cyst or pollen and spore counts. Concentrations and the ratio of *Globorotundata* spp. to dinoflagellate cyst taxa was calculated (Figure 4, Appendix 4).

As pyritisation in other specimens tapers off, up-section, so do the numbers of *Globorotundata* spp. Immediately above the Jurassic - Cretaceous boundary, there is still minor pyritisation and the numbers of *Globorotundata* spp. are moderate. By the middle of the Cretaceous section, pyritised cysts, while still present, decrease significantly and *Globorotundata* spp. is no longer present. While this may be interpreted in favour of a link between pyritisation and *Globorotundata* spp., it may also be coincidental.

Chapter 4

Discussion

By analysing dinoflagellate cyst preservation, abundance, richness and diversity it is possible to assess the degree of alteration of the cysts as well as to determine the components of the dinoflagellate cyst assemblages throughout the studied section. By comparing the Grassy Island dinoflagellate cyst zones to other established cyst zones elsewhere in the world, we attempt to determine how closely related the Grassy Island zones are to other locations and how these areas may have been linked geographically in the past. In order to refine the biostratigraphy of the Grassy Island section it is necessary to compare dinoflagellate cyst zones to the established *Buchia* zones. Finally, the cyst assemblages are used to reconstruct the paleoenvironment of Grassy Island at the time of deposition.

4.1. Preservation, Cyst Abundance, Richness and Diversity

Preservation of dinoflagellate cysts ranges from very poor to good. The preservation in the Jurassic interval (UVic 08-273 to UVic 08-303) is moderately better than that in the Cretaceous interval (UVic 09-001 to UVic 09-054). Jurassic (Kapoose Formation) samples suffer from pyritisation, but show good recovery. The Lower Cretaceous (One Tree Formation) samples exhibit less corrosion, however, there is poor recovery of dinoflagellate cysts. This could be because of a change in sedimentation rate, diluting cyst concentrations, or the environment at the time of deposition may not have been conducive to dinoflagellate cyst production (e.g. Fensome *et al.*, 1996b; Stover and Williams, 1987; Poulsen, 1996; Riding *et al*., 1999; Evitt, 1985).

Dinoflagellate cyst concentrations vary over a wide range (Figure 4, Appendix 4), which may be a consequence of both changes in paleoenvironmental factors and/or diagenetic processes. Species richness is higher in the Kapoose Formation, reaching a maximum of 13 different taxa in a sample. In the One Tree Formation, species richness is lower throughout the suite of samples, reaching a maximum of seven taxa in a sample (Appendix 2). The same is true of taxonomic diversity: while it reaches its maximum in the Jurassic, the Lower Cretaceous of Grassy Island sees diversity decrease to a value of D=1, which indicates very low diversity (Appendix 2). These three measurements, abundance, richness, and diversity, follow the same trend, all being significantly higher in the Upper Jurassic than in the Lower Cretaceous parts of the section.

Globorotundata spp., while not included in final counts, does display an interesting pattern (Figure 4), showing higher numbers, both in Type A and B, in the Upper Tithonian and then disappearing completely by the upper part of the Berriasian. These trends are consistent with those for recognised dinoflagellate cysts, having higher numbers in the Upper Jurassic and then tapering off to almost nothing in the Lower Cretaceous. When found in high concentrations, *Globorotundata* spp. is indicative of high primary productivity, leading to formation of anoxia in the bottom waters (Duane, 1997). On Grassy Island, the *Globorotundata* spp. are consistently represented in greater numbers than the dinoflagellate cysts (Figure 4, Appendix 4), suggesting higher primary productivity in the Upper Jurassic.

4.2. Taxonomic Remarks

Of the 39 taxa recovered, 10 were identified to species level, 21 were identified to genus level and eight taxa could not be identified based on any known previously described taxa. Despite preservation issues, it is possible to recognize that these eight taxa are unique and they were therefore labelled as Cyst Types. Of these eight cyst types, four are dominant within established zones; three Cyst Types are used as zonal indicators (Cyst Type P, D, and Q).

The eight Cyst Types recovered from Grassy Island are not described anywhere else. As these Cyst Types have their first recorded presence within the strata on Grassy Island, it is necessary that further taxonomic analysis be carried out. Complete descriptions must be established in order for other studies to begin to recognize these taxa when they appear and draw comparisons to Grassy Island.

4.3. Comparison to Established Dinoflagellate Cyst Zones

Within Canada, Pocock (1976), McIntyre and Brideaux (1980), and Davies (1983) all analysed Upper Jurassic and Lower Cretaceous dinoflagellate cysts from the Western Canada Basin and the Arctic. Pocock (1976) is the only one of who established zones applicable to western Canada; McIntyre and Brideaux (1980) never firmly distinguished zonal boundaries, but did note assemblages within each stage; Davies (1983) established seven zones, which ranged from the lower Upper Tithonian to the Upper Valanginian to the Hauterivian, but the zones are only applicable locally. Pocock's (1976) zones are included in Figure 5 for comparison of various zones from different regions within the Boreal Realm of the Upper Jurassic - Lower Cretaceous.

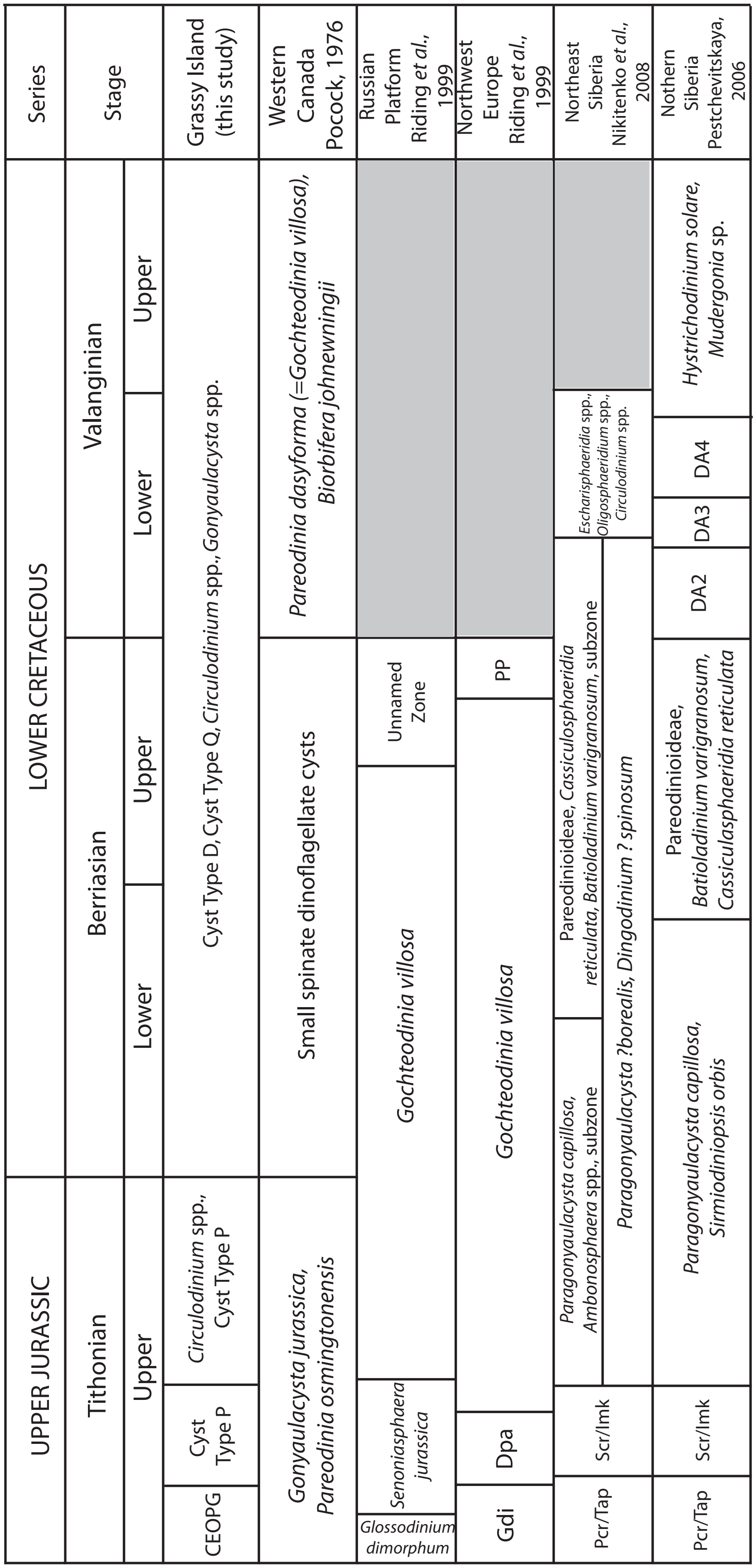

Figure 5. Summary chart showing correlation between Grassy Island dinoflagellate cyst zones and other localities in the Boreal Realm of the Northern Hemisphere. CEOPG = *Cometodinium habibii*, *Endoscrinium campanula*, *Oligosphaeridium* sp., *Pareodinia* spp., *Gonyaulacysta jurassica;* PP = *Pseudoceratium pelliferum*; Dpa = *Dichadogonyaulax*? *pannea*; Gdi = *Glossodinium dimorphum*; Scr/Imk = *Scriniodinium* sp., *Imbatodinium kondratjevii*; Pcr/Tap = *Pareodinia ceratophora*, *Tubotuberella apatella*; DA2 = *Escharisphaeridia* sp., *Oligosphaeridium* sp., *Circulodinium* spp.; DA3 = *Oligosphaeridium complex*, *Dingodinium cerviculum*; DA4 = *Aldorfia sibrica*, *Aprobolocysta galeata*.

Among the Canadian sites, including Grassy Island, there are several dinoflagellate cyst taxa that are recognised in all the different areas, so these taxa have a wide geographical range. Pocock (1976) has one zone for the Tithonian, the *Pareodinia osmingtonensis* - *Gonyaulacysta jurassica* zone. In contrast, the Grassy Island section displays three zones across Pocock's (1976) one zone. Pocock (1976) states that based on the range of *G. jurassica* it would appear that the upper limit of this species is the uppermost Tithonian. This is consistent with Grassy Island in that *G. jurassica* and *G. jurassica* var. *longicornis* do not extend beyond the Jurassic. Additionally, Pocock (1976) notes numerous species of *Pareodinia* in the zone which is consistent with this genus' distribution in samples from Grassy Island.

McIntyre and Brideaux (1980) note that in the Tithonian there is *Pareodinia ceratophora, Oligosphaeridium asterigerum,* and *Paragonyaulacysta borealis*. These genera (*Pareodinia*, *Oligosphaeridium*, and *Paragonyaulacysta*) are all observed within the Tithonian of Grassy Island. Davies (1983) noted *Cribroperidinium* sp., *Gonyaulacysta* sp., *Paragonyaulacysta* sp., and *Pareodinia* sp., in the lower Upper Tithonian to upper Upper Tithonian - Lower Berriasian; these four genera were all identified in the Tithonian of Grassy Island. Despite Pocock's (1976) single zone in the Upper Jurassic, there are variations within the zone. Noticeably missing in the Arctic and Western Canada Basin sites is *Circulodinium* sp.; it contributes a sizable fraction to the overall cyst abundance for the Tithonian of Grassy Island. This genus is not noted in any of the other Canadian sites.

When dinoflagellate cyst assemblages from the Tithonian of Grassy Island are compared to Siberian and European cyst zones (Figure 5), there are some similarities. Riding *et al.* (1999)

compares a section from the dinoflagellate cyst zonation of the Russian Platform to Northwest Europe. There are few similarities to European zones, with the European zonal indices absent in the Grassy Island section. The Russian Platform has four zones ranging from the Tithonian to the Valanginian (Riding *et al.*, 1999). The Jurassic zones of the Russian Platform are characterised by a dinoflagellate cyst assemblage that consists of *Circulodinium* sp., *Cribroperidinium* sp., *Gonyaulacysta* sp., *Endoscrinium* sp., *Oligosphaeridium* sp., *Perrisseiasphaeridium pannosum, Prolixosphaeridium* sp., *Senoniasphaera* sp., and *Systematophora areolata*, all of which are represented in the studied Jurassic section of Grassy Island.

Three dinoflagellate cyst zones are established for the Middle to Upper Tithonian in northeast (Nikitenko *et al.*, 2008) and northern (Pestcheviyskaya, 2006) Siberia. These zones have strong similarities to the three zones identified in the Upper Tithonian of Grassy Island. The first Siberian zone from the mid- Upper Tithonian includes taxa such as *Pareodinia* sp., *Cribroperidinium* sp., *Gonyaulacysta* sp., *Paragonyaulacysta* sp., and *Sentsudinium* sp. All these taxa are represented in CEOPG Zone of Grassy Island. However, there are two differences: Nikitenko *et al*. (2008) and Pestcheviyskaya (2006) observed *Sirmiodiniopsis orbis* and *Gonyaulacysta dualis* in their first zone. On Grassy Island, *G. dualis* is not found until immediately after the Jurassic - Cretaceous boundary and is only present for a relatively short time. *S. orbis* is also not present until the Upper Berriasian - Lower Valanginian, which is Grassy Island's DQCG Zone, in the Lower Cretaceous.

The second dinoflagellate cyst zone from Siberia spans from the lower Upper Tithonian to the middle Upper Tithonian has no taxa in common with the samples from Grassy Island, apart from

Pareodinia sp. The Cyst Type P Zone on Grassy Island is characterized by a fairly low abundance of cyst taxa, still with *Cribroperidinium* spp. and *Pareodinia* spp. present. The dinoflagellate cysts from Siberian *Scriniodinium* sp., *Imbatodinium kondratjevii* Zone appear to be quite diverse and well represented, which is not the case for the Cyst Type P Zone on Grassy Island.

The Siberian sections have a third zone that extends from the Upper Tithonian across the Jurassic - Cretaceous boundary into the Lower Berriasian (Nikitenko *et al.*, 2008; Pestcheviyskaya, 2006). The CP Zone from Grassy Island stops at the Jurassic - Cretaceous boundary. Nikitenko *et al.* (2008) described that this third zone is actually the *Paragonyaulacysta capillosa, Ambonosphaera* sp. subzone, part of the larger *Paragonyaulacysta ?borealis, Dingodinium ?spinosum* zone. Of note in this subzone are *Paragonyaulacysta, Pareodinia* sp., *Sirmiodiniopsis orbis, Sentsudinium* sp., and *Cribroperidinium*. The CP Zone from Grassy Island shares all these genera except *S. orbis*, which, as noted previously, does not appear until the Upper Beriasian - Lower Valanginian in the DQCG Zone on Grassy Island.

.

Previous studies of dinoflagellate cysts in Canada and Russia do not report two species that play a particularly important role in the Tithonian time of Grassy Island: *Cometodinium habibii* and Cyst Type P. *C. habibii* comprises up to 40% of the assemblage in CEOPG Zone and approximately 10% in the Cyst Type P Zone. Absent from the Grassy Island section is *Gochteodinia villosa* which is used by Pocock (1976) and Riding *et al.* (1999) to define cyst zones in the Lower Cretaceous of the Western Canada Basin and Europe.

The Lower Cretaceous of Grassy Island is poorly represented as a result of little to no dinoflagellate cyst recovery, resulting in placement of the Berriasian and Valanginian all into one zone, the DQCG Zone. The Arctic and Western Canada Basin studies (Pocock, 1976; McIntyre and Brideaux, 1980; Davies, 1983) have at least one zone for the Berriasian and one for the Valanginian. These studies find *Oligosphaeridium* sp., *Pareodinia* sp., and *Paragonyaulacysta* sp. in the Lower Cretaceous; on Grassy Island, however, none of these taxa range beyond the Jurassic. In the unnamed Lower Cretaceous interval on the Russian Platform (Riding *et al.*, 1999) there is *Circulodinium* spp., *Gonyaulacysta* spp., *Sentsudinium* sp., and *Oligosphaeridium complex* (Figure 5); the two former are noted and reasonably well represented in the long ranging DQCG Zone on Grassy Island, whereas the latter two do not extend beyond the Jurassic. Northern Siberia (Pestcheviyskaya, 2006) has five zones identified through the Berriasian and Valanginian. Taxa recovered here, which are also present on Grassy Island in the DQCG Zone, include *Circulodinium* sp., *Sirmiodiniopsis orbis*, *Gonyaulacysta* sp., and *Pluriarvalium*. There are a number of dinoflagellate cyst taxa found in northern Siberia that were not recovered from Grassy Island samples. Northern Siberia also sees *Oligosphaeridium* sp. ranging through the Lower Cretaceous (Nikitenko *et al.*, 2008; Pestcheviyskaya, 2006), but this is not the case on Grassy Island.

Cyst Type D and G make up to 80% and 20% respectively of the dinoflagellate cyst assemblages in the DQCG Zone on Grassy Island. Neither of these cyst types were recorded in the Pocock (1976), McIntyre and Brideaux (1980), Davies (1983), Riding *et al*. (1999), Pestchevitskaya (2006), and Nikitenko *et al*. (2008) studies. Despite this, Pocock (1976) has a zone that ranges from the base of the Cretaceous to the base of the Valanginian and is identified as the "small spinate dinoflagellate cysts" zone. Unfortunately, these specimens were not illustrated, so it is unknown if they are indeed similar to Cyst Type D, which are fairly small and spinose. If, indeed, these are they same types of cysts, then there is additional correlation between Arctic Canada and Grassy Island for the Valanginian.

Based on previously established zones for the Upper Jurassic and Lower Cretaceous, it seems as though Grassy Island is more clearly related to the Russian Platform and Siberian zones, sharing more dinoflagellate cyst taxa in comparison to the other Canadian sites. The Berriasian and Valanginian from the other Canadian studies lack the abundant *Circulodinium* spp. and *Gonyaulacysta* spp. present consistently through the Lower Cretaceous of Grassy Island. The Russian Platform and Siberian taxa in the Lower Cretaceous are much more representative of what was recovered from Grassy Island including *Circulodinium* sp. and *Gonyaulacysta* sp. Also, the Siberian zonation has three zones in the mid-Upper Tithonian, which is comparable with the number of zones recovered on Grassy Island during the same interval. It may appear that the zones in both regions have similar boundaries; unfortunately, there are no ammonites recovered from Grassy Island with high resolution biostratigraphic information (Jeletzky, 1965) to test this hypothesis. Accordingly, it is difficult to determine the exact timing of the boundaries on the Siberian zones compared to the Grassy Island zones. As a consequence, Figure 5 should be loosely interpreted, particularly around the boundaries of zones.

4.4. Paleogeography

The movements of Wrangellia during the Late Jurassic and Early Cretaceous are of great debate (e.g. Irving and Wynne, 1991; Johnston, 2001). It has been hypothesised that the terranes (including Wrangellia) were accreted perpendicularly to the western North American margin by the Jurassic (Monger *et al.*, 1982). Another theory is the well known Baja B.C. hypothesis, in which an allochthonous terrane was displaced northward along the western edge of North America by north-oblique convergence, reaching its present location (Irving and Wynne, 1991) in the Late Cretaceous or Tertiary. Finally, Johnston (2001) proposes that a ribbon continent, comprising most of the Canadian Cordillera, was translated several thousand kilometers north, respective to North America, and during the Late Cretaceous, was bent and collided, forming a series of oroclines. Thus, it is difficult to discern the precise paleogeographic positions of Wrangellia and, as well, Grassy Island, during the Late Jurassic and Early Cretaceous.

Despite not knowing the precise location of Wrangellia (or the Grassy Island site) during the Late Jurassic - Early Cretaceous, the similarity of the Grassy Island dinoflagellate cysts to the Siberian cysts is comparable to Jeletzky's (1965) interpretation of the *Buchia* zones from Grassy Island. Jeletzky (1965) determined his *Buchia* zones to be valid for regions adjacent to the Pacific slope of North America, ranging from California to Alaska. These zones, however, are not valid for northeastern British Columbia or Arctic Canada as those *Buchia* species belong to another faunal subprovince (Jeletzky, 1965). This suggests that there was some geographic barrier between the waters of the Grassy Island site from those of northeastern British Columbia and Arctic Canada, presumably the ancestral Cordilleran mountain belt. Conversely, the Grassy Island locality was more closely connected biogeograpically to the northeastern Siberia region during the Late Jurassic - Early Cretaceous.

Using dinoflagellate cysts, foraminifera, and ammonites Shulgina *et al.* (1994) established a correlation between northern the West Siberian Arctic basin, north East European Plain, Arctic Canada, Svalbard, the Barents Sea and north Central Siberia (deemed the Arctic Boreal by Shulgina *et al.*, 1994), based on the *Pareodinia borealis* assemblage noted throughout these sites. Portions of northern (Pestchevitskaya, 2006) and northeastern Siberia (Nikitenko *et al*., 2008) do not correlate to the Shulgina *et al.* (1994) sub-realm, but show the most similarity to Grassy Island. This confirms that northeastern Siberia and Grassy Island were somewhat isolated from the Arctic Boreal during the Late Jurassic - Early Cretaceous.

Recent work by Zakharov and Shurygin (2010) have inferred an Early Jurassic marine connection between the Arctic and paleo-North Pacific (Figure 6). During the Jurassic, however, there would have been open connections between the Arctic and paleo North-Pacific which were gradually reduced until the end of the Jurassic, when there would have been much less water-mass exchange (Zakharov and Shurygin, 2010). By the Early Cretaceous, the final separation between the two basins would have been complete, however, there were still deep-water troughs connecting the paleo North-Pacific and the Arctic in the Early Valanginian (Zakharov and Shurygin, 2010). These decreasing connections between the Arctic and North Paleo-Pacific are likely why the Arctic Boreal (including the Canadian sites from Pocock (1976), McIntyre and Brideaux (1980), and Davies (1983)) is so dissimilar to the Grassy Island and northeastern Siberian sites as the Late Jurassic - Early Cretaceous progresses.

Besides the Arctic-paleo North-Pacific physical barrier, there may have been other barriers between northeastern Siberia and Grassy Island that resulted in the local variation observed

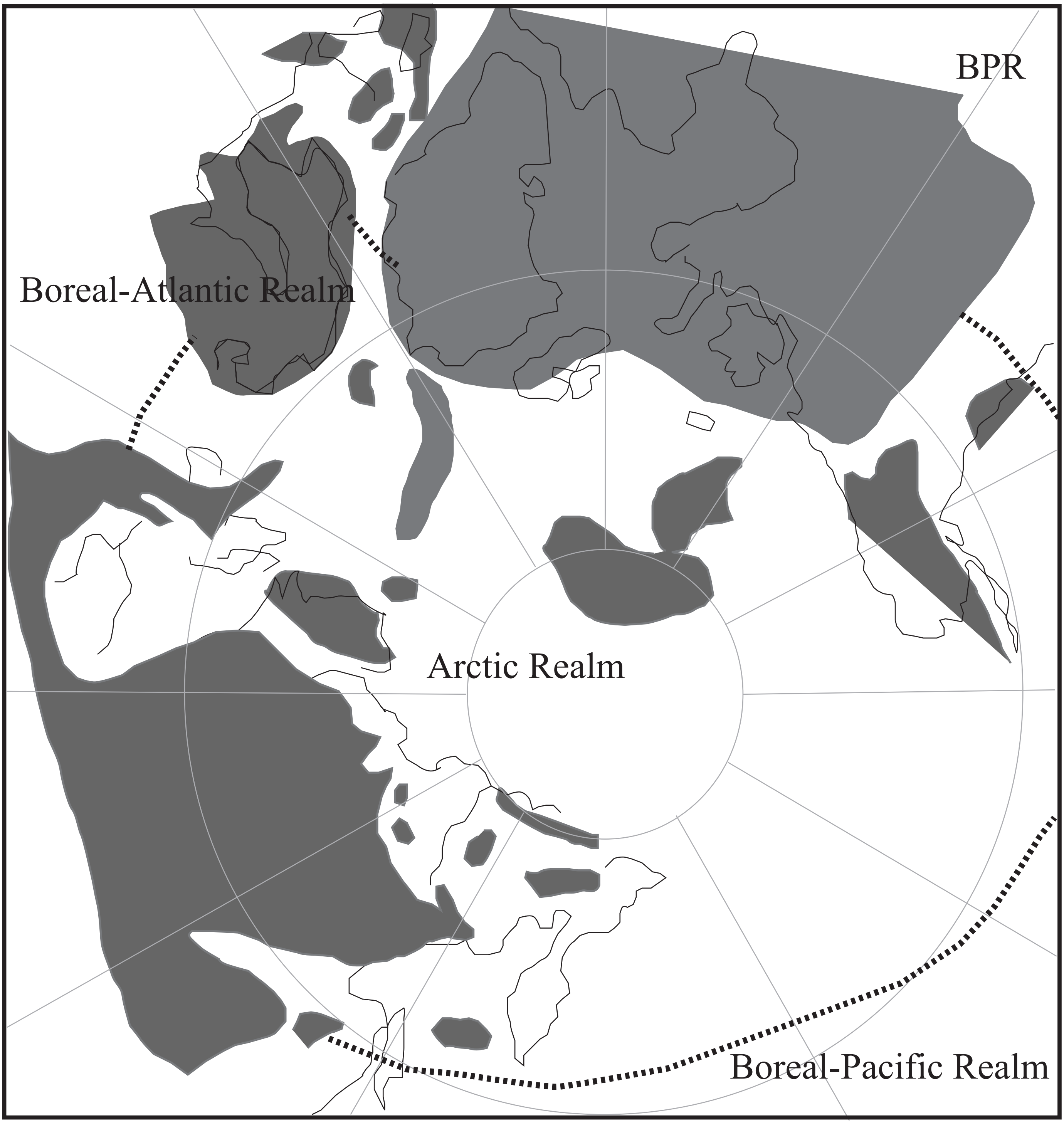

Figure 6. Boreal Realm in the Tithonian. Grey areas represent the paleo-land masses; Black outlines represent modern day land masses. Dashed lines show boundaries between sub-realms. BPR= Boreal-Pacific Realm. After Zakharov and Shurygin, 2010.

within the cyst assemblages from both localities. For example, northern and northeast Siberia share a zone in the middle Upper Tithonian, the *Scriniodinium* sp., *Imbatodinium kondratjevii* zone, which is coincident with the Cyst Type P zone on Grassy Island (Figure 5). While all three sites share *Scriniodinium* sp., *I. kondratjevii* is unique to Siberia and Cyst Type P is unique to Grassy Island. Further studies along the west coast of Alaska down through California may provide further data as to the interconnections between northeastern Siberia and the western Cordillera.

4.5. Dinoflagellate and *Buchia* Zonation

Five *Buchia* zones have been established for the Grassy Island section by Jeletzky (1965), and refined by Grey *et al.* (2008) (Figure 2). There is one *Buchia* zone in the Tithonian (Upper Jurassic), the *Buchia columbiana* zone. In the Berriasian (Lower Cretaceous), there are two zones, *B. okensis* and *B. uncitoides*. The Valanginian (Lower Cretaceous) has the final two zones, *B. tolmatschowi* and *B. pacifica*.

Four *Buchia* zones are recognised in the Cretaceous of the studied section, whereas only a single dinoflagellate cysts zone is recognised (Figure 2). The boundary between the Jurassic and Cretaceous represents a boundary between two *Buchia* zones, as well as between two dinoflagellate cyst zones, and thus likely represents a significant ecological change. For more refined zonation within the Upper Jurassic, dinoflagellate cysts would be quite useful as they indicate multiple zones where the *Buchia* suggests only one (Figure 2). Conversely, for more detailed biostratigraphy in the Lower Cretaceous, *Buchia* is a more appropriate faunal indicator as it displays four zones where the dinoflagellates display only one zone and they are less abundant overall. Also, the Lower Cretaceous shows very poor recovery of dinoflagellate cysts and so the zonation may be unreliable. *Buchia* provides a zonal organism in this section.

While the *Buchia* zonation is well established with many specimens present throughout the section, the same cannot be said of the dinoflagellate cyst zones, which saw very low recovery in the Lower Cretaceous section; this is related to facies change. The dinoflagellate cyst and *Buchia* zonations do complement each other despite sometimes poor recovery of cysts. Together, *Buchia* and dinoflagellate cyst zones provide a more comprehensive biostratigraphic record which can be applied to areas that are within the same faunal province, as suggested by Jeletzky (1965).

4.6. Paleoenvironmental Reconstruction

The local Late Jurassic ocean, in which were deposited the strata now exposed on Grassy Island, was characterised by high concentrations of dinoflagellate cysts, as well as high diversity and high species richness, which implies high primary productivity. The deeper part of the ocean was probably low in oxygen, if not close to anoxic. Black shales are indicative of high organic content and are generally formed in anoxic condition (e.g. Marz *et al.*, 2009; Tsandev and Slomp, 2009); these shales comprise the dominant lithology of the Upper Jurassic (Kapoose Formation) of the exposed section on Grassy Island. There is also distinct pyritisation in this section, as evidenced by the corroded palynomorphs and enclosed pyrite debris. Since pyrite also tends to form in environments with low oxygen content, it is likely that the pyritisation in the Jurassic of Grassy Island formed in a low oxygen environment. Finally, there is the high concentration of *Globorodunata* spp. As suggested by Duane (1997), high concentrations of this particular palynmorph are evidence of anoxic conditions. Concentrations of *Globorotundata* spp.

consistently over 500 palynmorphs g^{-1} (and up to over 2500 palynmorphs g^{-1}; Figure 4) suggests that, coupled with the high primary productivity, there would be high organic carbon deposition which, once degraded by bacteria, would result in anoxic conditions.

The ratio between dinoflagellate cysts and pollen and spores provides information on paleoenvironmental conditions at the time of deposition (McCarthy and Mudie, 1998). Since pollen and spores are almost strictly terrestrial and the vast majority of dinoflagellates are marine, the ratios between the two groups can provide a proxy to indicate distance from shore (McCarthy and Mudie, 1998). High pollen and spore values suggest an environment that is closer to shore. When dinoflagellate cyst numbers are much higher than the numbers of pollen and spores it suggests an environment that is further away from shore. Based on the ratios of marine to terrestrial palynmorphs, it is clear that this Upper Jurassic section is dominated by dinoflagellate cysts with pollen and spores playing a less dominant role (Figure 4). This would suggest that the recovered dinoflagellate cysts were from a basin that is somewhat distant from the shoreline, but close enough that terrestrial palynmorphs can still be deposited at the same location.

Also present in the Upper Jurassic of Grassy Island is *Buchia* which likely required a solid substrate to grow on, not the soft, muddy sediment of the deep ocean, as it has a mode of life similar to *Mytilus* (Jeletzky, 1965). Combined, the evidence suggests that the environment of the Upper Jurassic of Grassy Island was likely not an open ocean setting because pollen and spores tend not to be deposited in deep open ocean sediments, and *Buchia* requires a shallower environment in order to persist. This work suggests that the depositional environment could have been a shelf or a coastal site.

The values of dinoflagellate cyst taxa richness, diversity, productivity, oxygen and *Buchia* distribution suggest the Early Cretaceous ocean at Grassy Island was characterised by lower primary productivity, lower diversity and lower species richness (Figure 4) than the Late Jurassic section. It appears as though oxygen levels were higher than during the Late Jurassic, as black shales become less abundant in the section and sandstones dominate local lithology. The pyritisation is greatly reduced as well, and nearly disappears, as observed in the slide residues analysed.

The ratio of marine to terrestrial palynmorphs (Figure 4) shows that the Lower Cretaceous palynmorph assemblages of Grassy Island are dominated by pollen and spores. This parameter indicates higher terrigenous input than in the Upper Jurassic sediments. Increasing grain size may also be evidence for an increasing sedimentation rate during the Early Cretaceous and closer proximity to shore. Silt-sized particles predominate at the Jurassic - Cretaceous boundary and eventually are replaced by fine to medium sized sand in the Lower Cretaceous. This coarsening sequence suggests a shallowing sequence with decreasing distance to land.

Strata of the uppermost Valanginian, at the very top of the section, suggest active shallowing was occurring as the concentration of dinoflagellate cysts decreases and total pollen and spores increase. There are still *Buchia* present in this part of section indicating the environment likely shifted to very near shore rather than fully terrestrial. As well, the concentrations of dinoflagellate cysts decrease, and those of pollen and spores increase, from the base of the Lower Berriasian to the Valanginian at the top of the section. All the evidence identified points to active shallowing occurring during this time.

It is difficult to establish if the progression toward shoreline, or shallowing trend, is a result of tectonic uplift or global sea level change, but is likely a combination of the two. The west coast of British Columbia is a highly tectonically active area and was probably tectonically active at the time of deposition of the Grassy Island deposits. There is an unconformity at the Jurassic - Cretaceous boundary, which unfortunately obscures the change that might be preserved in the sedimentary record which occurs across this boundary, but is in itself evidence of significant tectonic activity. Haq *et al.* (1987) found that eustatic sea level tended to decrease from the Jurassic through to the Early Cretaceous and it is possible that this sea level change affected the environment of Grassy Island site. However, a combination of these two may explain the changes of the environment during the Late Jurassic to the Early Cretaceous in the basin.

Chapter 5

Conclusions

This work reports the first study of Mesozoic dinoflagellate cysts from western British Columbia. Dinoflagellate cyst abundance, richness and diversity are all higher in the Upper Jurassic than in the Lower Cretaceous. There is noticeable corrosion of cysts in the Upper Jurassic section, although there was still sufficient material to confirm and identify these specimens. The Lower Cretaceous part of the section proved to be slightly more difficult in identifying dinoflagellate cysts as the recovery was poor. Identification was challenging not only because of preservation, pyritisation, but because of the presence of taxonomically different or new taxa.

A total of 39 dinoflagellate cyst taxa were identified. Ten cyst taxa were identified to the species level, 21 to the genus level and a remaining eight cyst types. Based on the cyst assemblages four zones were established, three in the Upper Jurassic and one in the Lower Cretaceous. These zones are the first zones to be established for Mesozoic dinoflagellate cysts in the Pacific coast region of Canada and may be further refined in the future.

When the dinoflagellate cyst zones from this study are compared to those established elsewhere in the Boreal Realm (Arctic Canada and northern Siberia, and other Canadian sites), some similarities with Grassy Island are noticeable. Northeastern Siberia is most similar to the Grassy Island assemblages, also with three zones in the Upper Jurassic. The dissimilarities of the Grassy Island dinoflagellate cysts assemblages to other Canadian cyst assemblages (northeastern British

Columbia, northern Alberta, and the Canadian Arctic) is possibly a result of Grassy Island being part of a different biotic province than the Arctic and interior parts of Canada, most likely due to geographical separation. The same is true of *Buchia* from Grassy Island compared to Arctic and northeastern British Columbia (Jeletzky, 1965). These new dinoflagellate cyst zones should be confirmed by analysis of the Upper Jurassic and Lower Cretaceous sedimentary rocks of Alaska as well as those elsewhere in the Boreal Realm.

The newly established dinoflagellate cyst zones are capable of standing alone. If combined with the *Buchia* zones, however, the combined biostratigraphy provides a much more detailed biostratigraphic framework for the Kyuquot Group. When analysing Upper Jurassic samples, the dinoflagellate cyst zonation provides three zones in order to more precisely assign the age of a particular sample. If the goal of analysis is the Lower Cretaceous, *Buchia* zones provide much more precise zones than the single dinoflagellate cyst zone, having two zones in the Berriasian and two in the Valanginian. If further microfossil analysis is done on this locality, it would be advisable to analyse pollen and spores in the Kyuquot Group. With the high abundance of terrestrial palynmorphs, particularly in the Lower Cretaceous, it is possible that several pollen and spores zones may be recognised to complement the dinoflagellate cyst and *Buchia* zones.

Based on high concentration, diversity and species richness of dinoflagellate cysts, high abundance of *Globorotundata* spp., and low oxygen levels inferred from black shales, incidences of pyrite and this section being dominated by dinoflagellate cysts over terrestrial palynmorphs, the depositional environment at this time in the Late Jurassic of the Pacific coast of British Columbia was likely shelf or coastal.

In contrast, the Early Cretaceous of the Pacific coast of British Columbia saw lower primary production and higher oxygen levels in the water column. Grain size increased as did the terrigenous input, based on the change in the ratio of marine to terrestrial palynmorphs. This depositional environment likely was coastal during the Berriasian and became a beach environment by the top of the section in the Valanginian as a result of active shallowing. These changes in paleoenvironment are likely a result from a combination of tectonic uplift and sea-level change, either eustatic or local.

It is recommended that a comprehensive taxonomonic analysis of dinoflagellate cysts be completed to fully describe the eight new taxa reported in this study. Further samples should be analysed for dinoflagellate cysts along the west coast of North America, from Alaska to California. This will assist in confirming the Grassy Island zones established in this work and likely provide further insight into the paleogeography of the Upper Jurassic - Lower Cretaceous of the Boreal realm.

References

Alberti, G., 1961. Zur Kenntnis mesozoischer und alttertiarer Dinoflagellaten und Histrichosphaerideen von Nord- und Mitteldeutschland sowie einigen anderen eropaischen Gebieten. *Palaeontographica, Abteilung A*, **116**: 1-58.

Archangelsky, S., 1969. Sobre el paleomicroplancton des Terciario inferior de rio Turbio, Provincia de Santa Cruz. *Ameghiniana*, **5(10)**: 406-416.

Bally, A.W., 1989. Geology of North America: An Overview. GSA DNAG Volume A, Palmer, A.R., (Eds), Boulder, CO, 619 pp., 12 pls.

Bancroft, M.F., 1937. Gold-bearing deposits on the west coast of Vancouver Island between Esperanza Inlet and Alberni Canal. *Geological Survey of Canada, Memoir*, **204**: 34 pp.

Batten, D.J., 1996. Palynofacies and petroleum potential. In: Jansonius, J., McGregor, D.C. (Eds.), *Palynology: Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, Dallas, TX, 1065-1084.

Blakey, R., 2011. Global Paleogeography. Retrieved April 16, 2011, from http://cpgeosystems.com/globaltext2.html

Brideaux, W.W., and Fisher, M.J., 1976. Upper Jurassic-Lower Cretaceous dinoflagellate assemblages from Arctic Canada. *Geological Survey of Canada, Bulletin*, **259**: 1-53.

Carter, E.S., and Haggart, J.W., 2006. Radiolarian biogeography of the Pacific region indicates a mid- to high-latitude (>30°) position for the Insular superterrane since the late Early Jurassic. In: Haggart, J.W., Enkin, R.J., and Monger, J.W.H., (Eds.), Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements. *Geological Association of Canada*, *Special Paper*, **46**: 109-132.

Clarke, R.F.A., and Verdier, J.-P., 1967. An investigation of microplankton assemblages from the Chalk of the Isle of Wight, England. *Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, Afdeeling Natuurkunde, Eerste Reeks*, **24(3)**: 1-96.

Cookson, I.C., and Eisenack, A., 1960. Upper Mesozoic microplankton from Australia and New Guinea. *Palaeontology*, **2(2)**: 243-261.

Cookson, I.C., and Eisenack, A., 1961. Tertiary microplankton from the Rottnest Island Bore, Western Australia. *Journal of the Royal Society of Western Australia*, **44**: 39-47.

Courtinant, B., 1989. Les organoclastes des formations lithologiques du Malm dans le Jura meridional. Systèmatique, biostratigraphie et éléments d'interpretation paléoécologique. *Laboratoires de géologie de la Faculté des sciences de Lyon, Documents no.* **105**, 361 pp.

Dalby, A.P., Patterson, R.T., and Haggart, J.W., 2009. Distribution of the Albian-Cenomanian foraminifera from Queen Charlotte Islands, British Columbia, Canada: constraints on the timing of the northward migration of the Wrangellia terrane. *Journal of Foraminiferal Research*, **39(3)**: 231-245.

Dale, B., 1996. Dinoflagellate cyst ecology: modeling and geological applications. In: Jansonius, J., McGregor, D.C. (Eds.), *Palynology: Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, Dallas, TX, 1249 – 1275.

Davey, R.J., 1969. Non-calcareous microplankton from the Cenomanian of England, northern France and North America, part I. *British Museum (Natural History) Geology, Bulletin*, **17**: 103-180.

Davey, R.J., 1982. Dinocyst stratigraphy of the latest Jurassic to early Cretaceous of the Haldager No. 1 borehole, Denmark. *Danmarks Geologiske Undersogelse, Series B*, **6**: 1-10.

Davey, R.J., and Williams, G.L., 1966. The genus *Hystrichosphaeridium* and its allies In: Davey, R.J., Downie, C., Sarjeant, W.A.S. and Williams, G.L., Studies on Mesozoic and Cainozoic dinoflagellate cysts; *British Museum (Natural History) Geology, Bulletin, Supplement* **3**, 53-106.

Davey, R.J., and Williams, G.L., 1969. General reallocations. In: Davey, R.J., Downie, C., Sarjeant, W.A.S., and Williams, G.L., Appendix to "Studies on Mesozoic and ainozoic dinoflagellate cysts". *British Museum (Natural History) Geology, Bulletin, Appendix to Supplement* **3**: 4-7.

Davey, R.J., Downie, C., Sarjeant, W.A.S., and Williams, G.L., 1966.VII. Fossil dinoflagellate cysts attributed to *Baltisphaeridium*. In: Davey, R.J., Downie, C., Sarjeant, W.A.S., and Williams, G.L., Studies on Mesozoic and Cainozoic dinoflagellate cysts. *British Museum (Natural History) Geology Bulletin, Supplement* **3**, 15-17.

Davies, E.H., 1983. The dinoflagellate Oppel-zonation of the Jurassic-Lower Cretaceous sequence in the Sverdrup Basin, Arctic Canada. *Geological Survey of Canada Bulletin*, **359**, 59 pp.

Deflandre, G., 1937. Microfossiles des silex crétacés. Deuxième partie. Flagelles *incertae sedis*. Hystrichosphaerides. Sarcodines. Organismes divers. *Annales de paléontologie*, **26**: 51-103.

Deflandre, G., 1939. Microplancton des mers jurassiques conservé dans les marnes de Villers-sur-Mer (Calvados). Étude liminaire et considèrations génerales. *Station zoologique de Wimereaux, Travaux,* **13**: 147-200.

Deflandre, G., 1947. Sur quelques microorganismes planctoniques des silex Jurassiques. Institut ocèanographique, *Monaco, Bulletin,* **921**: 1-12.

Deflandre, G., 1964. Remarques sur la classification des dinoflagelles fossiles, à propos d'*Evittodinium*, nouveau genre crétacé de la famille des Deflandreaceae. *Comptes rendus hebdomadaires des séances de l'Académie des sciences,* **258**: 5027-5030.

Deflandre, G., and Courteville, H., 1939. Note preliminaire sur les microfossiles des silex crétacés du Cambresis. *Bulletin de la société francaise de microscopie*, **8**: 95-106.

Dorhofer, G., and Davies, E.H., 1980. Evolution of archeopyle and tabulation in rhaetogonyaulacinean dinoflagellate cysts. *Miscellaneous Publication*, Royal Ontario Museum, Life Sciences Division, Toronto, Canada, 91 pp.

Drugg, W.S., 1978. Some Jurassic dinoflagellate cysts from England, France and Germany. *Palaeontographica, Abteilung B*, **168(1-3)**: 61-79.

Duane, A.M., 1997. Taxonomic Investigations of palynomorphs from the Byers Group (Upper Jurassic-Lower Cretaceous), Livingstone and Snow islands, Antarctic Peninsula. *Palynology,* **21**: 123-144.

Evitt, W.R., 1985. Sporopollenin dinoflagellate cysts: their morphology and interpretation. In: American Association of Stratigraphic Palynologists, Austin, TX (1985), 333 pp.

Fensome, R.A., MacRae, R.A., Moldowan, J.M., Taylor, F.J.R., and Williams, G.L., 1996a. The early Mesozoic radiation of dinoflagellates. *Paleobiology,* **22(3)**: 329-328.

Fensome, R.A., Riding, J.B., and Taylor, R.J.R., 1996b. Dinoflagellates. In: Jansonius, J., McGregor, D.C. (Eds.), *Palynology: Principles and Applications.* American Association of Stratigraphic Palynologists Foundation, Dallas, TX, 107–169.

Fensome, R.A., and Williams, G.L., 2004. The Lentin and Williams index of fossil dinoflagellates 2004 edition. *AASP Contributions Series,* **42**, 909 pp.

Gotcht, H., 1959. Microplankton aus dem nordwestdutschen Neokom (Tiel I). *Palaontologisch Zeitschrift,* **33**: 50-89.

Gotcht, H., 1970. Dinoflagellaten-Zysten aus dem Bathonium des Erdolfeldes Aldorf (NW-Deutschland). *Palaeontographica, Abteilung B,* **129**: 125-165.

Grey, M., Haggart, J.M., and Jeletzky, J.A., 2007. Uppermost Jurassic (Tithonian) to Lower Cretaceous (Valanginian) section at Grassy Island, west coast Vancouver Island, British Columbia. *Geological Survey of Canada, Open File,* **5666**: 52 pp.

Grey, M., Haggart, J.M., and Smith, P.L., 2008. Species discrimination and evolutionary mode of *Buchia* (Bivalvia: Buchiidae) from Upper Jurassic-Lower Cretaceous Strata of Grassy Island, British Columbia, Canada. *Palaeontology,* **51(3)**: 583-595.

Haggart, J.W., 1991. A synthesis of Cretaceous stratigraphy, Queen Charlotte Islands, British Columbia; In Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia. G.J. Woodsworth *eds*. *Geological Survey of Canada, Paper,* **90-10**: 253-277.

Haggart, J.W., 1993. Latest Jurassic and Cretaceous paleogeography of the northern Insular Belt, British Columbia. In Dunne, G.C. and McDougall, K.A., eds., Mesozoic Paleogeography of the Western United States - II. *Society of Economic Paleontologists and Mineralogists, Pacific Section, Special Volume,* **71**: 463-475.

Haggart, J.W., March 13, 2009. *Personal communication*.

Haggart, J.W., Ward, P.D., Raub, T.D., Cater, E.S., and Kirschvink, J.L., 2009. Molluscan biostratrigraphy and paleomagnetism of Campanian strata, Queen Charlotte Islands, British Columbia: implications for Pacific coast North America biochronology. *Cretaceous Research*, **30**: 939-951.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. *Science,* **235(4793)**: 1156-1167.

Irving, E., and Wynne, P.J., 1991. Chapter 3, Paleomagnetism: review and tectonic implications. In Geology of the Cordilleran Orogen in Canada. Gabrielse, H. and Yorath, C.J., Denver, Colorado, *Geological Society of America*. **G-2:** 61-86.

Jeletzky, J.A., 1950. Stratigraphy of the west coast of Vancouver Island between Kyuquot Sound and Esperanza Inlet, British Columbia. *Geological Survey of Canada Paper* **50-37**, 52 pp.

Jeletzky, J.A., 1965. Late Upper Jurassic and Early Lower Cretaceous fossil zones of the Canadian western Cordillera, British Columbia. *Geological Survey of Canada, Bulletin,* **103**: 70 pp, 22 pls.

Johnson, C.D., and Hills, L.V., 1973. Microplankton zones of the Savik Formation (Jurassic), Axel Heiberg and Ellesmere islands, District of Franklin. *Bulletin of Canadian Petroleum Geology,* **21**: 178-218.

Johnston, S.T., 2001. The Great Alaskan Terrane Wreck: reconciliation of paleomagnetic and geological data in the northern Cordillera. *Earth and Planetary Science Letters*, **193**: 259-272.

Klement, K.W., 1960. Revision der Gattungszugehorigkeit einiger in die Gattung *Gymnodinium* Stein eingestufter Arten jurassicher Dinoflagellaten. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte,* **9**: 408-410.

Kottachchi, N., Schröder-Adamns, C.J., Haggart, J.W., and Tipper, H.W., 2002. Jurassic foraminifera from the Queen Charlotte Islands, British Columbia Canada: biostratigraphy, paleoenvironments and paleogeographic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **180**: 93-127.

Marz, C., Beckham, B., Franke, C., Vogt, C., Wagner, T., and Kasten, S., 2009. Geochemical environment of the Coniacian-Santonian western tropical Atlantic at Demerara Rise. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **273**: 286-301.

McCarthy, F.M.G., and Mudie, P.J., 1998. Oceanic pollen transport and pollen:dinocyst ratios as markers of late Cenozoic sea level change and sediment transport. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **1998**: 187-206.

McIntyre, D.J., and Brideaux, W.W., 1980. Valanginian miospore and microplankton assemblages from the northern Richardson Mountains, District of Mackenzie, Canada. *Geological Survey of Canada, Bulletin*, **320**, 57 pp.

Mertens, K.N., Verhoeven, K., Verleye, T., Louwye, S., Amorim, A., Ribeiro, S., Deaf. A.S., Harding, I.C., De Schepper, S., González, C., Kodrans-Nsiah, M., De Vernal, A., Henry, M., Radi, T., Dybhjaer, K., Poulsen, N.E., Feist-Burkhardt, S., Chitolie, J., Heilmann-Clausen, C., Londeix, L., Turon, J., Marret, F., Matthiessen, J., McCarthy, F.M.G., Prasad, V., Pospelova, V., Kyffin Hughes, J.E., Riding, J.B., Rochon, A., Sangiorigi, F., Welters, N., Sinclair, N., Thun, C., Soliman, A., Van Nieuwenhove, N., Vink, A., and Young, M., 2009. Determining the absolute abundance of dinoflagellate cysts in recent marine sediments: The *Lycopodium* marker-grain method put to the test. *Review of Palaeobotany and Palynology*, **157**: 238-252.

Monger, J. W. H., Price, R.A., and Tempelman-Kluit, D.J., 1982. Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera. *Geology*, **10**: 70-75.

Monteil, E., 1991. Revision of the dinoflagellate cyst genus *Cometodinium* Deflandre & Courteville, 1939 emend. Enantiomorphy in a fossil dinoflagellate cyst population. *Bulletin des Centres de recherches exploration-production Elf-Aquitaine*, **15(2)**: 439-459.

Muller, J.E., Cameron, B.E.B., and Northcote, K.E., 1981. Geology and mineral deposits of Nootka Sound map-area Vancouver Island, British Columbia. *Geological Survey of Canada, Paper*, **80-16**: 53 pp.

Neale, J.W., and Sarjeant, W.A.S., 1962. Microplankton from the Speeton Clay of Yorkshire. *Geological Magazine*, **99**: 439-458.

Nikitenko, B.L., Pestchevitskaya, E.B., Lebedeva, N.K., and Ilyina, V.I., 2008. Micropaleontological and palynological analyses across the Jurassic - Cretaceous boundary on Nordvik Peninsula, Northeast Siberia. *Newsletters on Stratigraphy*, **42**(3): 181-222.

Norris, G., and Sarjeant, W.A.S., 1965. A descriptive index of genera of fossil Dinopyceae and Acritarcha. *New Zeland Geological Survey, Palaeontological Bulletin*, **40**, 72 pp.

Patterson, R.T., Haggart, J.W., and Dalby, A.P., 2010. A guide to Late Albian-Cenomanian (Cretaceous) Foraminifera from the Queen Charlotte Islands, British Columbia, Canada. *Palaeontologia Electronica*, **13(2)**: art. 12-A, 28 pp.

Pestchevitskaya, E.B., 2006. Early Cretaceous dinocysts of northern Siberia and their stratigraphic significance. *Paleontological Journal,* **40**(5): 5629-5647.

Pocock, S.A.J., 1962. Microfloral analysis and age determination of strata at the Jurassic - Cretaceous boundary in the western Canada plains. *Palaeontographica, Abteilung B,* **111**: 1-95.

Pocock, S.A.J., 1972. Palynology of the Jurassic sediments of western Canada. Part 2. Marine species. *Palaeontographica, Abteilung B,* **137**: 85-153.

Pocock, S.A.J., 1976. A preliminary dinoflagellate zonation of the uppermost Jurassic and lower part of the Cretaceous, Canadian Arctic and possible correlation in the western Canada basin. *Geoscience and Man,* **15**: 101-114.

Pospelova, V., Chmura, G.L., Boothman, W., Latimer, J.S., 2005. Spatial distribution of modern dinoflagellate cysts in polluted estuarine sediments from Buzzards Bay (Massachusetts, USA) embayments. *Marine Ecology Progress Series,* **292**: 23–40.

Poulsen, N.E., 1996. Dinoflagellate cysts from marine Jurassic deposits of Denmark and Poland. *American Association of Stratigraphic Palynologists, Contribution Series* **31**: 227 pp.

Poulton, T.P., Hall, R.L., Tipper, H.W., Cameron, B.E.B., and Carter, E.S., 1991. Current status of Middle Jurassic biostratigraphy of the Queen Charlotte Islands, British Columbia; In Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia. G.J. Woodsworth, *eds. Geological Survey of Canada, Paper* **90-10**: 237-252.

Pross, J., Pletsch, T., Shillington, D.J., Ligouis, B., Schellenberg, F., and Kus, J., 2007. Thermal alteration of terrestrial palynmorphs in mid-Cretaceous organic-rich mudstones intruded by an igneous sill (Newfoundland Margin, ODP Hole 1276A). *International Journal of Coal Geology*, **70**: 277-291.

Riding, J.B., and Thomas, J.E., 1988. Dinoflagellate cyst stratigraphy of the Kimmeridge Clay (Upper Jurassic) from the Dorset coast, southern England. *Palynology,* **12**: 65-88.

Riding, J.B., Fedorova, V.A., and Ilyina, V.I., 1999. Jurassic and lowermost Cretaceous dinoflagellate cyst biostratigraphy of the Russian Platform and northern Siberia, Russia. *American Association of Stratigraphic Palynologists Contribution Series*, **36**, 184 pp.

Sarjeant, W.A.S., 1962. Upper Jurassic microplankton fron Dorset, England. *Micropaleontology*, **8(2)**: 255-268.

Sarjeant, W.A.S., 1982. The dinoflagellat cysts of the *Gonyaulacysta* group: a morphological and taxonomic restudy. *American Association of Stratigraphic Palynologists, Contribution Series*, **9**: 1-81.

Sarjeant, W.A.S., and Stover, L.E., 1978. *Cyclonephelium* and *Tenua*; a problem in dinoflagellate cyst taxonomy. *Grana*, **17**: 47-54.

Schröder-Adams, C.J., and Haggart, J.W., 2006. Biogeography of foraminifera in tectonic reconstructions: limitations and constraints on the paleogeographic position of Wrangellia. In: Haggart, J.W., Enkin, R.J., and Monger, J.W.H., (Eds.), Paleogeography of the North American Cordillera: Evidence For and Against Large-Scale Displacements: *Geological Association of Canada, Special Paper,* **46**: 95-108.

Sha, J., Chen, S., Cai, H., Jiang, B., Yao, X., Pan, Y., Wang, J., Zhu, Y, and He, C., 2006. Jurassic - Cretaceous boundary in northeastern China: placement based on buchiid bivalves and dinoflagellate cysts. *Progress in Natural Science,* **16**: 39-49.

Shulgina, N.I., Burdykina, M.D., Basov, V.A., and Arhus, N., 1994. Distribution of ammonites, foraminifera and dinoflagellate cysts in the Lower Cretaceous reference section of the Khatanga Basin, and Boreal Valanginian biogeography. *Cretaceous Research*, **15**: 1-16.

Singh, C., 1983. Cenomanian microfloras of the Peace River area, northwestern Alberta. *Research Council of Alberta, Bulletin*, no. **44**, 322 pp.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, **13**: 615-621.

Stover, L.E., and Williams, G.L., 1987. Analyses of Mesozoic and Cenozoic organic-walled dinoflagellates 1977–1985. *American Association of Stratigraphic Palynologists Contribution Series* **18** (1987), 244 pp.

Tsandev, I., and Slomp, C.P., 2009. Modeling phosphorous cycling and carbon burial during Cretaceous Oceanic Anoxic Events. *Earth and Planetary Science Letters*, **286**: 71-79.

Van Helden, B.G.T., 1986. Dinoflagellate cysts at the Jurassic - Cretaceous boundary, offshore Newfoundland, Canada. *Palynology*, **10**: 181-199.

Vozzhennikova, T.F., 1967. Iskopaemye peridinei Yurskikh, Melovykyh i Paleogenovykh otlozheniy SSSR. Translation Lees and Sarjeant, 1971. 337 pp.

Williams, G.L., Fensome, R.A., Miller, M.A., and Sarjeat, W.A.S., 2000. A glossary of the terminology applied to dinoflagellates, acritarchs and prasinophytes, with emphasis on fossils: third edition. *American Association of Stratigraphic Palunologists Contribution Series*, **37** (2000), 370 pp.

Wolfard, A., and Van Erve, A.W., 1981. *Crussolia deflandrei* nov. gen. et nov. sp., a dinoflagellate cyst from the Jurassic (Callovian-Lower Oxfordian) of Montagne Crussol, Rhone Valley, France. *Review of Palaeobotany and Palynology,* **34**: 321-329.

Zakharov, V.A., 1987. The bivalve *Buchia* and the Jurassic - Cretaceous boundary in the Boreal province. *Cretaceous Research*, **8**: 141-153.

Zakharov, V.A., and Shurygin, B.N., 2010. Eastern Arctic in Jurassic: paleogeography and paleoclimatology. *Earth Science Frontiers*, **17**: 288-289.

Appendix 1

Photographs of Grassy Island. Provided by Jim Haggart

Photo 1. Grassy Island (2006)

Photo 2. View to One Tree Island from Grassy Island (2005)

Photo 3. Kapoose Formation (2005)

Photo 4. Basal One Tree Formation (at top) unconformably overlying Kapoose Formation (on bottom) (2006)

Appendix 1
Continued

Photo 5. Lower One Tree Formation (2005)

Photo 6. Middle One Tree Formation (2005)

Appendix 1
Continued

Photo 7. Upper One Tree Formation (2006)

Photo 8. *Buchia* bed (2005)

Appendix 2. Total counts and concentrations of pollen and spores, as well as total dinoflagellate cyst counts, species richness, Simpson's Index of Diversity, and counts of individual cyst taxa.

UVic ID	**Total Pollen and Spore Count**	**Total Pollen and Spore Concentrations (grains g^{-1})**	**Total Cyst Count**	**Species Richness**	**Simpson's Index**	*Callaiosphaeridium* sp.	*Canningia* sp.	*Catastomocystis* sp.	*Circulodinium* spp.	*Cometodinium habibii*	*Cribroperidinium* spp.	*Cribroperidinium?* spp.	*Crussolia* sp.	*Ctenodinium?* sp.	*Endoscrinium campanula*	*Endoscrinium* sp.	*Exochorosphaeridium* sp.	*Gonyaulacysta dualis*	*Gonyaulacysta jurassica*	*G. jurassica* var. *adecta*	*Gonyaulacysta* spp.	*Hystrichosphaeridium?* sp.	*Oligosphaeridium albertense*	*Oligosphaeridium patulum*	*Oligosphaeridium* sp.	*Paragonyaulacysta* spp.	*Pareodinia* spp.	*Perisseiasphaeridium pannosum*	*Pluriarvalium* sp.	*Prolixosphaeridium* sp.	*Rottenstia?* sp.	*Senoniasphaera* sp.	*Sentusudinium* sp.	*Sirmiodiniopsis orbis?*	*Systematophora areolata*	*Turbiosphaera?* sp.	Cyst Type D	Cyst Type G	Cyst Type J	Cyst Type L	Cyst Type M	Cyst Type N	Cyst Type P	Cyst Type Q
08-273	67	575	132	9	0.20	0	0	0	4	46	0	0	0	0	9	0	0	0	5	3	10	0	0	0	0	0	30	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	17	0
08-274	401	3805	121	8	0.26	0	0	0	54	16	0	0	0	0	20	0	0	0	2	0	2	0	0	0	0	0	16	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	9	0
08-275	467	1859	143	10	0.17	0	0	0	16	6	0	0	0	0	20	0	0	0	9	2	48	0	0	0	0	0	17	0	0	4	0	0	0	0	0	0	0	0	6	0	0	0	15	0
08-276	71	2986	136	13	0.21	0	0	0	10	9	2	0	0	0	1	1	0	0	6	4	39	0	0	0	6	0	6	0	0	2	0	0	0	0	3	0	0	0	0	0	0	0	47	0
08-277	310	1695	110	10	0.23	0	0	0	10	14	0	0	0	0	0	1	0	0	1	0	41	0	0	0	1	0	3	0	0	5	0	0	0	0	0	0	0	0	0	0	0	5	29	0
08-278	796	892	112	10	0.28	0	4	0	53	0	0	0	0	0	0	0	0	0	1	0	13	0	2	0	24	0	0	0	0	4	0	0	0	0	5	1	0	0	0	0	0	0	5	0
08-279	313	595	100	5	0.51	0	3	0	23	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0
08-280	294	680	105	10	0.26	0	0	0	5	8	0	0	0	0	3	1	0	0	0	0	17	0	2	0	15	0	0	0	0	0	3	0	0	0	0	3	0	0	0	0	0	0	48	0
08-281	777	633	32	5	0.20	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	2	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	8	0
08-282	361	148	41	8	0.19	0	0	0	6	0	0	0	0	0	2	0	0	0	3	0	14	0	0	0	1	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	10	0
08-283	299	115	103	5	0.74	0	0	0	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	88	0
08-284	251	229	104	3	0.86	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	96	0
08-285	1072	4580	105	5	0.71	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	88	0
08-286	607	4233	112	4	0.93	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	107	0
08-287	174	1675	103	7	0.57	0	0	0	5	2	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	6	8	0	0	77	0
08-288	34	343	251	4	0.89	0	0	0	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	236	0
08-289	445	2888	108	11	0.17	0	0	0	18	0	3	0	0	0	0	0	0	0	1	0	0	0	17	0	0	0	1	24	0	0	0	2	0	0	0	2	0	0	0	2	27	0	11	0
08-290	98	5455	117	5	0.69	0	0	0	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	6	0	0	0	0	0	0	0	0	0	8	0
08-291	1001	360	101	8	0.79	0	0	0	90	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	2	0
08-292	919	390	4	2	0.50	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
08-293	688	425	24	3	0.84	0	0	0	22	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
08-294	150	93	39	3	0.81	0	0	0	35	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
08-295	5	71	2	1	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
08-296	97	54	100	4	0.06	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08-297	357	1326	102	4	0.37	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
08-298	891	939	100	2	0.90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95	0
08-299	70	614	112	3	0.63	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	0
08-300	573	337	110	4	0.64	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	2	0	0	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0
08-301	81	925	266	4	0.50	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180	0
08-302	1252	1195	21	3	0.53	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
08-303	325	187	28	1	1.00	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-001	125	256	22	2	0.58	6	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-002	22	308	3	2	0.33	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-003	16	132	1	1	N/A	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-004	25	191	4	2	0.50	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-005	17	278	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-006	15	242	1	1	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
09-007	1008	2356	36	4	0.46	0	0	0	23	0	0	0	0	0	0	0	0	2	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
09-008	64	1742	6	2	0.47	0	0	0	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-009	72	2129	4	2	0.50	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
09-010	50	873	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-011	39	1336	4	2	0.50	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-012	45	936	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-013	37	476	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-014	41	441	2	2	0.00	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
09-015	28	1561	4	3	0.17	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
09-016	33	204	3	1	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
09-017	25	230	1	1	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-018	26	131	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-019	22	308	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-020	217	4692	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-021	99	5317	3	3	0.00	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
09-022	95	1019	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-023	107	1971	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-024	143	781	1	1	N/A	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-025	83	3671	4	2	0.50	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-026	41	150	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-027	135	1490	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-028	28	643	3	2	0.33	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
09-029	60	1683	9	3	0.44	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
09-030	71	3755	3	1	1.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
09-031	1856	6735	101	5	0.19	0	0	9	28	0	0	4	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0
09-032	1884	4734	101	4	0.43	0	0	14	6	0	0	0	0	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0
09-033	584	3258	13	5	0.18	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0

Appendix 2. Continued

UVic ID	**Total Pollen and Spore Count**	**Total Pollen and Spore Concentrations (grains g^{-1})**	**Total Cyst Count**	**Species Richness**	**Simpson's Index**	*Callaiosphaeridium* sp.	*Canningia* sp.	*Catastomocystis* sp.	*Circulodinium* spp.	*Cometodinium habibii*	*Cribroperidinium* spp.	*Cribroperidinium?* spp.	*Crussolia* sp.	*Ctenodinium?* sp.	*Endoscrinium campanula*	*Endoscrinium* sp.	*Exochorosphaeridium* sp.	*Gonyaulacysta dualis*	*Gonyaulacysta jurassica*	*G. jurassica* var. *adecta*	*Gonyaulacysta* spp.	*Hystrichosphaeridium?* sp.	*Oligosphaeridium albertense*	*Oligosphaeridium patulum*	*Oligosphaeridium* sp.	*Paragonyaulacysta* spp.	*Pareodinia* spp.	*Perisseiasphaeridium pannosum*	*Pluriarvalium* sp.	*Prolixosphaeridium* sp.	*Rottenstia?* sp.	*Senoniasphaera* sp.	*Sentusidinium* sp.	*Sirmiodiniopsis orbis?*	*Systematophora areolata*	*Turbiosphaera?* sp.	Cyst Type D	Cyst Type G	Cyst Type J	Cyst Type L	Cyst Type M	Cyst Type N	Cyst Type P	Cyst Type Q
09-034	2017	1617	100	7	0.29	0	0	5	28	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	43	18	0	0	0	0	0	1
09-035	18	330	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-036	117	2301	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-037	576	684	9	1	1.00	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-038	283	3693	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-039	556	682	15	3	0.49	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
09-040	1294	1854	28	3	0.58	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
09-041	2743	951	100	4	0.43	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	4	0	0	0	0	0	0
09-042	556	752	19	3	0.43	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0
09-043	491	654	1	1	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
09-044	2419	6196	34	5	0.22	0	0	0	9	0	0	0	0	2	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	11	0	0	0	0	0	0
09-045	1329	2256	4	3	0.17	0	0	0	2	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-046	820	886	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-047	93	455	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-048	447	3467	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-049	151	697	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-050	262	2669	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-051	162	505	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-052	133	3273	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-053	283	641	1	1	N/A	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-054	573	1346	0	0	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3. Results of dinoflagellate cyst analysis showing relative abundances (%) of individual taxa.

UVic ID	*Callaiosphaeridium* sp.	*Canningia* sp.	*Catastomocystis* sp.	*Circulodinium* spp.	*Cometodinium habibii*	*Cribroperidinium* spp.	*Cribroperidinium*? spp.	*Crussolia* sp.	*Ctenodinium*? sp.	*Endoscrinium campanula*	*Endoscrinium* sp.	*Exochorosphaeridium* sp.	*Gonyaulacysta dualis*	*Gonyaulacysta jurassica*	*G. jurassica* var. *adecta*	*Gonyaulacysta* spp.	*Hystrichosphaeridium*? sp.	*Oligosphaeridium albertense*	*Oligosphaeridium patulum*	*Oligosphaeridium* sp.	*Paragonyaulacysta* spp.	*Pareodinia* spp.	*Perisseiasphaeridium pannosum*	*Pluriarvalium* sp.	*Prolixosphaeridium* sp.	*Rottenstia*? sp.	*Senoniasphaera* sp.	*Sentusidinium* sp.	*Sirmiodiniopsis orbis?*	*Systematophora areolata*	*Turbiosphaera*? sp.	Cyst Type D	Cyst Type G	Cyst Type J	Cyst Type L	Cyst Type M	Cyst Type N	Cyst Type P	Cyst Type Q
08-273	0.0	0.0	0.0	3.0	34.8	0.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0	3.8	2.3	7.6	0.0	0.0	0.0	0.0	0.0	22.7	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	0.0
08-274	0.0	0.0	0.0	44.6	13.2	0.0	0.0	0.0	0.0	16.5	0.0	0.0	0.0	1.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0	13.2	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0
08-275	0.0	0.0	0.0	11.2	4.2	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	6.3	1.4	33.6	0.0	0.0	0.0	0.0	0.0	11.9	0.0	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	10.5	0.0
08-276	0.0	0.0	0.0	7.4	6.6	1.5	0.0	0.0	0.0	0.7	0.7	0.0	0.0	4.4	2.9	28.7	0.0	0.0	0.0	4.4	0.0	4.4	0.0	0.0	1.5	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.6	0.0
08-277	0.0	0.0	0.0	9.1	12.7	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.9	0.0	37.3	0.0	0.0	0.0	0.9	0.0	2.7	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	26.4	0.0
08-278	0.0	3.6	0.0	47.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	11.6	0.0	1.8	0.0	21.4	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	4.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0
08-279	0.0	3.0	0.0	23.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.0	0.0
08-280	0.0	0.0	0.0	4.8	7.6	0.0	0.0	0.0	0.0	2.9	1.0	0.0	0.0	0.0	0.0	16.2	0.0	1.9	0.0	14.3	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	45.7	0.0
08-281	0.0	0.0	0.0	28.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.9	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0
08-282	0.0	0.0	0.0	14.6	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.0	0.0	7.3	0.0	34.1	0.0	0.0	0.0	2.4	0.0	4.9	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.4	0.0
08-283	0.0	0.0	0.0	11.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.4	0.0
08-284	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.3	0.0
08-285	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	83.8	0.0
08-286	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.4	0.0
08-287	0.0	0.0	0.0	4.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	5.8	7.8	0.0	0.0	74.8	0.0
08-288	0.0	0.0	0.0	0.4	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.0	0.0
08-289	0.0	0.0	0.0	16.7	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	15.7	0.0	0.0	0.0	0.9	22.2	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.9	25.0	0.0	10.2	0.0
08-290	0.0	0.0	0.0	82.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	2.6	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.0
08-291	0.0	0.0	0.0	89.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0
08-292	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0	0.0
08-293	0.0	0.0	0.0	91.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0
08-294	0.0	0.0	0.0	89.7	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0
08-295	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
08-296	0.0	0.0	0.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08-297	0.0	0.0	0.0	47.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	37.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
08-298	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.0	0.0
08-299	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.8	0.0
08-300	0.0	0.0	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	79.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0
08-301	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.7	0.0
08-302	0.0	0.0	0.0	71.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0
08-303	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-001	27.3	0.0	0.0	72.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-002	33.3	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-003	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
09-007	0.0	0.0	0.0	63.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
09-008	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-009	0.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0
09-010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-011	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-012	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-014	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0
09-015	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0
09-016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
09-017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-018	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-021	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3
09-022	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-024	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-025	0.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-026	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-027	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-028	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-029	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-030	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-031	0.0	0.0	8.9	27.7	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-032	0.0	0.0	13.9	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-033	0.0	0.0	15.4	30.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-034	0.0	0.0	5.0	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	43.0	18.0	0.0	0.0	0.0	0.0	0.0	1.0
09-035	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-036	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-037	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-038	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-039	0.0	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-040	0.0	0.0	0.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-041	0.0	0.0	0.0	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
09-042	0.0	0.0	0.0	42.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-043	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-044	0.0	0.0	0.0	26.5	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.6	32.4	0.0	0.0	0.0	0.0	0.0	0.0
09-045	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-046	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 3. Continued

UVic ID	*Callaiosphaeridium* sp.	*Canningia* sp.	*Catastomocystis* sp.	*Circulodinium* spp.	*Cometodinium habibii*	*Cribroperidinium* spp.	*Cribroperidinium?* spp.	*Crussolia* sp.	*Ctenodinium* ? sp.	*Endoscrinium campanula*	*Endoscrinium* sp.	*Exochorosphaeridium* sp.	*Gonyaulacysta dualis*	*Gonyaulacysta jurassica*	*G. jurassica* var. *adecta*	*Gonyaulacysta* spp.	*Hystrichosphaeridium* ? sp.	*Oligosphaeridium albertense*	*Oligosphaeridium patulum*	*Oligosphaeridium* sp.	*Paragonyaulacysta* spp.	*Pareodinia* spp.	*Perisseiasphaeridium pannosum*	*Pluriarvalium* sp.	*Prolixosphaeridium* sp.	*Rottenstia* ? sp.	*Senoniasphaera* sp.	*Sentusudinium* sp.	*Sirmiodiniopsis orbis?*	*Systematophora areolata*	*Turbiosphaera* ? sp.	Cyst Type D	Cyst Type G	Cyst Type J	Cyst Type L	Cyst Type M	Cyst Type N	Cyst Type P	Cyst Type Q
09-047	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-048	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-049	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-050	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-051	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-052	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-053	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09-054	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 4. Concentrations of dinoflagellate cysts and *Globorotundata* spp. (cysts g^{-1}).

UVic ID	**Total cysts g^{-1}**	*Callaiosphaeridium* sp.	*Canningia* sp.	*Catastomocystis* sp.	*Circulodinium* spp.	*Cometodinium habibii*	*Cribroperidinium* spp.	*Cribroperidinium?* spp.	*Crussolia* sp.	*Ctenodinium?* sp.	*Endoscrinium campanula*	*Endoscrinium* sp.	*Exochosphaeridium* sp.	*Gonyaulacysta dualis*	*Gonyaulacysta jurassica*	*G. jurassica* var. *adecta*	*Gonyaulacysta* spp.	*Hystrichosphaeridium?* sp.	*Oligosphaeridium albertense*	*Oligosphaeridium patulum*	*Oligosphaeridium* sp.	*Paragonyaulacysta* spp.	*Pareodinia* spp.	*Perisseiasphaeridium pannosum*	*Pluriarvalium* sp.	*Prolixosphaeridium* sp.	*Rottenstia ?* sp.	*Senoniasphaera* sp.	*Sentusidinium* sp.	*Sirmiodiniopsis orbis?*	*Systematophora areolata*	*Turbiosphaera ?* sp.	Cyst Type D	Cyst Type G	Cyst Type J	Cyst Type L	Cyst Type M	Cyst Type N	Cyst Type P	Cyst Type Q	*Globorotundata* Type A	*Globorotundata* Type B
08-273	976	0	0	0	30	340	0	0	0	0	67	0	0	0	37	22	74	0	0	0	0	0	222	0	0	59	0	0	0	0	0	0	0	0	0	0	0	0	126	0	30	820
08-274	936	0	0	0	418	124	0	0	0	0	155	0	0	0	15	0	15	0	0	0	0	0	124	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	70	0	63	2647
08-275	431	0	0	0	48	18	0	0	0	0	60	0	0	0	27	6	145	0	0	0	0	0	51	0	0	12	0	0	0	0	0	0	0	0	18	0	0	0	45	0	2	387
08-276	3120	0	0	0	229	206	46	0	0	0	23	23	0	0	138	92	895	0	0	0	138	0	138	0	0	46	0	0	0	0	69	0	0	0	0	0	0	0	1078	0	0	643
08-277	477	0	0	0	43	61	0	0	0	0	0	4	0	0	4	0	178	0	0	0	4	0	13	0	0	22	0	0	0	0	0	0	0	0	0	0	0	22	126	0	12	348
08-278	111	0	4	0	52	0	0	0	0	0	0	0	0	0	1	0	13	0	2	0	24	0	0	0	0	4	0	0	0	0	5	1	0	0	0	0	0	0	5	0	11	260
08-279	157	0	5	0	36	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107	0	6	756
08-280	197	0	0	0	9	15	0	0	0	0	6	2	0	0	0	0	32	0	4	0	28	0	0	0	0	0	6	0	0	0	0	6	0	0	0	0	0	0	90	0	11	525
08-281	24	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	6	0	0	31
08-282	15	0	0	0	2	0	0	0	0	0	1	0	0	0	1	0	5	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0	0	7
08-283	37	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	53
08-284	87	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	80	0	7	379
08-285	408	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	12	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	342	0	0	169
08-286	774	0	0	0	0	0	7	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	746	0	0	27
08-287	598	0	0	0	29	12	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	35	46	0	0	447	0	20	1121
08-288	5199	0	0	0	21	228	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0	4888	0	0	1256
08-289	575	0	0	0	96	0	16	0	0	0	0	0	0	0	5	0	0	0	90	0	0	0	5	128	0	0	0	11	0	0	0	11	0	0	0	11	144	0	59	0	0	522
08-290	2920	0	0	0	2420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75	0	75	150	0	0	0	0	0	0	0	0	0	200	0	0	998
08-291	34	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	13
08-292	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	24
08-293	13	0	0	0	12	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
08-294	20	0	0	0	18	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	31
08-295	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
08-296	49	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
08-297	326	0	0	0	153	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	99
08-298	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0
08-299	618	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	475	0	3	72
08-300	51	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
08-301	7560	142	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	938	0	1364	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5116	0	0	48
08-302	18	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	259
08-303	14	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
09-001	24	7	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
09-002	16	5	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-003	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-004	12	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
09-005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-006	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
09-007	37	0	0	0	24	0	0	0	0	0	0	0	0	2	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	6
09-008	12	0	0	0	4	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51
09-009	11	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7
09-010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
09-011	13	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
09-012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
09-014	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
09-015	25	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0
09-016	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
09-017	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-021	13	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
09-022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-024	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-025	14	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-028	6	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
09-029	16	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0
09-030	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0
09-031	166	0	0	15	46	0	0	7	0	0	0	0	0	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0
09-032	148	0	0	21	9	0	0	0	0	0	0	0	0	0	0	0	91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0
09-033	73	0	0	11	22	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	11	0	0	0	0	0	0	0	0	0
09-034	80	0	0	4	22	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	34	14	0	0	0	0	0	1	0	0
09-035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4. Continued

UVic ID	**Total cysts g^{-1}**	*Callaiosphaeridium* sp.	*Canningia* sp.	*Catastomocystis* sp.	*Circulodinium* spp.	*Cometodinium habibii*	*Cribroperidinium* spp.	*Cribroperidinium?* spp.	*Crussolia* sp.	*Ctenodinium* ? sp.	*Endoscrinium campanula*	*Endoscrinium* sp.	*Exochosphaeridium* sp.	*Gonyaulacysta dualis*	*Gonyaulacysta jurassica*	*G. jurassica* var. *adecta*	*Gonyaulacysta* spp.	*Hystrichosphaeridium* ? sp.	*Oligosphaeridium albertense*	*Oligosphaeridium patulum*	*Oligosphaeridium* sp.	*Paragonyaulacysta* spp.	*Pareodinia* spp.	*Perisseiasphaeridium pannosum*	*Pluriarvalium* sp.	*Prolixosphaeridium* sp.	*Rottenstia* ? sp.	*Senoniasphaera* sp.	*Sentusidinium* sp.	*Sirmiodiniopsis orbis?*	*Systematophora areolata*	*Turbiosphaera* ? sp.	Cyst Type D	Cyst Type G	Cyst Type J	Cyst Type L	Cyst Type M	Cyst Type N	Cyst Type P	Cyst Type Q	*Globorotundata* Type A	*Globorotundata* Type B
09-037	11	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-038	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-039	18	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
09-040	40	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
09-041	35	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	1	0	0	0	0	0	0	0	0
09-042	26	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0
09-043	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
09-044	87	0	0	0	23	0	0	0	0	5	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	28	0	0	0	0	0	0	0	0
09-045	7	0	0	0	3	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-048	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-049	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-053	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09-054	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 5

Taxonomic Section

Taxa are depicted on Plates 1 to 7. An alphabetic index is provided below. Specimens and material are stored in the collection of the Paleoenvironmental Laboratory, School of Earth and Ocean Sciences, University of Victoria, British Columbia, Canada.

Callaiosphaeridium sp. Davey and Williams 1966
Canningia sp. Cookson and Eisenack 1960
Catastamocystis sp. Singh 1983
Circulodinium Type B
Circulodinium Type D
Circulodinium Type E
Circulodinium Type F
Cometodinium habibii Monteil, 1991
Cribroperidinium Type A
Cribroperidinium Type B
Cribroperidinium Type C
Cribroperidinium? Type D
Crussolia sp. Wolfard and Van Erve 1981
Ctenodinium? sp. Deflandre 1939
Endoscrinium campanula (Gotcht, 1959) Vozzhennikova, 1967
Endoscrinium sp. (Klement, 1960) Vozzhennikova, 1967
Globorotundata Type A Duane, 1997
Globorotundata Type B Duane, 1997
Gonyaulacysta dualis Brideaux and Fisher 1976
Gonyaulacysta jurassica (Deflandre 1938) Norris and Sarjeant 1965
Gonyaulacysta jurassica var. *adecta* Sarjeant 1982
Gonyaulacysta Type A
Gonyaulacysta Type B
Gonyaulacysta Type C
Gonyaulacysta Type D
Gonyaulacysta Type H
Gonyaulacysta Type I
Gonyaulacysta Type J
Hystrichosphaeridium? sp. Deflandre 1937
Oligosphaeridium sp. (Davey and Williams 1966) Davey 1982
Oligosphaeridium albertense (Pocock 1962) Davey and Williams 1969
Oligosphaeridium patulum Riding and Thomas 1988
Paragonyaulacysta Type A
Paragonyaulacysta Type B
Paragonyaulacysta Type C

Pareodinia Type A
Pareodinia Type B
Pareodinia Type C
Perisseiasphaseridium pannosum? Davey and Williams 1966
Pluriavalium? sp. Sarjeant, 1962
Prolixosphaeridium sp. (Davey *et al.* 1966) Davey 1969
Rottenstia? sp. Cookson and Eisenack 1961
Senoniasphaera? sp. Clarke and Verdier 1967
Sentsudinium? sp. (Sarjeant and Stover 1978) Courtinat 1989
Sirmiodiniopsis orbis? Drugg 1978
Systematophora areolata Klement 1960
Turbiosphaera? sp. Archangelsky 1969
Cyst Type D
Cyst Type G
Cyst Type J
Cyst Type L
Cyst Type M
Cyst Type N
Cyst Type P
Cyst Type Q