2015

A Palynological Analysis of Seymour Island and King George Island off the Antarctic Peninsula: A Dating and Climatic Reconstruction

Caven Madison Kymes

Louisiana State University and Agricultural and Mechanical College

A PALYNOLOGICAL ANALYSIS OF SEYMOUR ISLAND AND KING GEORGE ISLAND OFF THE ANTARCTIC PENINSULA: A DATING AND CLIMATIC RECONSTRUCTION

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Geology and Geophysics

by
Caven Madison Kymes
B.S., Louisiana State University, 2013
December 2015

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

During the Cretaceous and early Paleocene, Antarctica was covered by lush vegetation. However, Antarctica today is covered with ice and snow leaving less than 1% of the continent inhabited by vegetation. By studying this decline in vegetation and reconstructing past environments, we can gain a better understanding of environmental changes and use this knowledge to predict future changes.

In this thesis, I present my results and interpretations of palynological changes across the Antarctic Peninsula during the Late Eocene, Middle Oligocene, and Miocene. The first study discusses a paleoenvironmental reconstruction of the upper La Meseta formation (Late Eocene), Seymour Island, and Polonez Cove formation (Middle Oligocene), King George Island. My results indicate a relatively decent abundance of *in situ* podocarp conifers and southern beech *Nothofagidites* (*brassii*, *fusca*, and *menziesii* gp.) palynomorphs present within the lower section of the studied La Meseta Formation. This implies the area was relatively free of ice and sparsely inhabited with a temperate-like forest in the Late Eocene. Progressing up section, the presence of sea-ice indicative acritarchs called *Leiosphaeridia* spp. and the dominance of cool-loving *Nothofagidites* sp. (*fusca* gp.) indicate a climate cooling as the region became more glaciated. Evidence of this cooling is more apparent based on the majority of palynomorphs which appear broken and the samples being dominated with *Leiosphaeridia* spp. in the upper most studied section of La Meseta formation and through the entire section of the Polonez Cove formation. Lastly, my second study discusses a palynological interpretation of Miocene samples collected from the Cape Melville formation on King George Island. The samples revealed a near-shore depositional environment dominated by sea-ice as indicated from the abundance of leiospheres. These samples are also dominated by various reworked palynomorphs of Permian to Paleogene

age, mixed with rare *in situ* Miocene specimens. This study provides new insight into the provenance of the reworked assemblage and give new information on probable glacial advances.

CHAPTER 1: INTRODUCTION TO ANTARCTIC EARTH SCIENCE

1.1 Thesis style

This thesis is presented in the style of stand-alone articles that have been published or are in preparation for publication in multiple scientific journals at the time of defense. This article discusses a palynological analyses of samples collected from two islands located off the Antarctic Peninsula. Chapter 2 discusses a paleoenvironmental reconstruction using palynomorphs observed in samples collected from the upper section of the La Meseta Formation, Seymour Island, and Polonez Cove Formation, King George Island. Chapter 3 examines palynomorphs observed in samples collected from the Cape Melville Formation, King George Island, to determine the paleoenvironment present during the Miocene as well as to identify possible provenances for reworked palynomorphs witnessed throughout the section. Chapters 2 is preceded with a brief introduction of Antarctic paleoclimates since the Tertiary and is followed with a broad conclusion.

1.2 Brief overview of projects and materials studied

In order to better understand climate change in Antarctica over the last ~36 Ma, I analyzed palynological assemblages (e.g. pollen, spores, and marine dinoflagellate cysts) in samples collected from three outcrops, spanning three geologic epochs, on two islands off the Antarctic Peninsula. (1) Palynological assemblages were observed in fourteen samples collected from the La Meseta Formation, Seymour Island, to better date the formation and understand the vegetation's response prior to the Eocene-Oligocene Transition (EOT). (2) Analyzed palynomorphs were observed in sixteen samples collected from the Polonez Cove Formation, King George Island, to understand the vegetation's response after the climate shift into the cooler Oligocene epoch. (3)

Finally, observed palynomorphs in twelve samples collected from the Cape Melville Formation, King George Island, were analyzed to determine the vegetation's response to further cooling in the Miocene epoch, as well as, to identify possible provenances for glacial migration.

The two research projects discussed in this thesis focus on two islands located off the Antarctic Peninsula: (1) Seymour Island, part of the James Ross Island Group, and (2) King George Island, the largest island of the South Shetland Island Group (Figure 1.1).

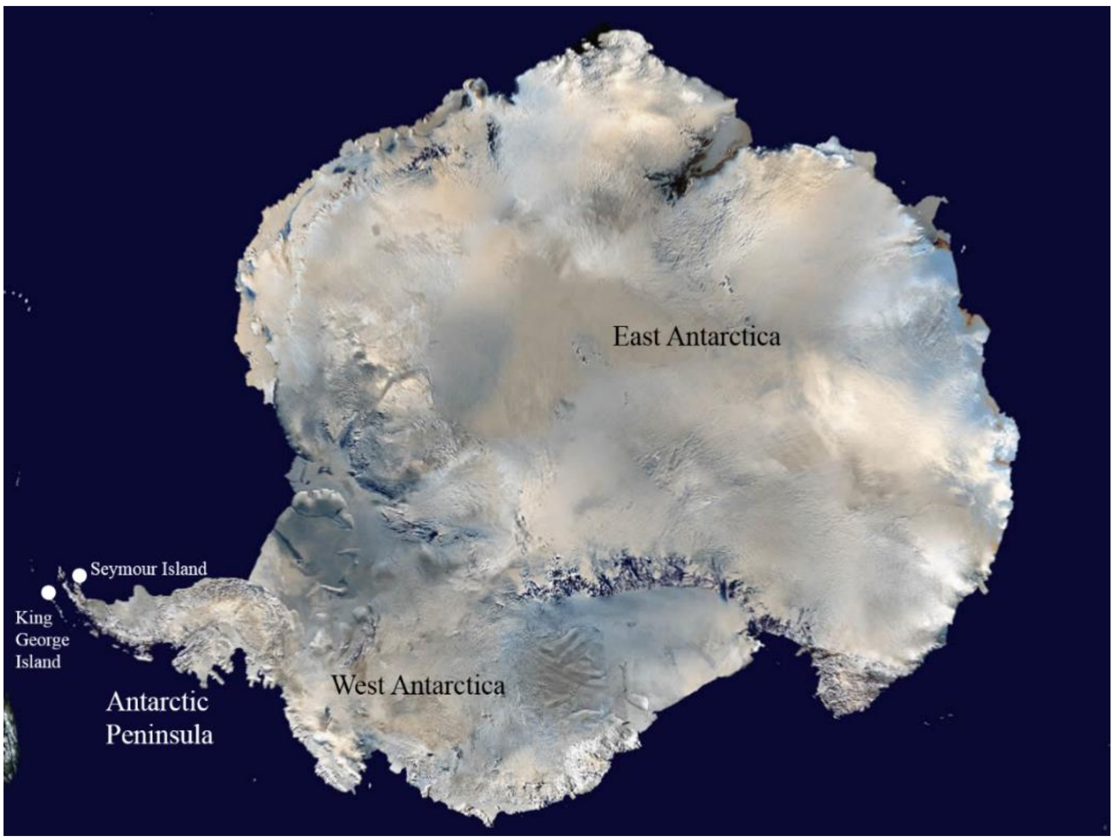

Figure 1.1. Satellite image of Antarctica with key geographic locations. Site locations located off the Antarctic Peninsula highlight Seymour Island and King George Island.

1.3 Antarctic Cenozoic history

By the early Ordovician, the landmasses comprising the supercontinent known as Gondwana had assembled. The large landmass remained intact until the continents began to separate during the Permian due to intrusion and extrusion of mantle-derived magmas (Anderson, 1999). During the Middle Jurassic, large normal faulting engendered rift systems which separated East Gondwana from West Gondwana (de Wit et al., 1998). Separation of Antarctica from Gondwana continued into the Late Cretaceous (~72 Ma) where West Antarctica diverged from New Zealand and settled to its current isolated location (Stock and Molnar; 1987).

While Antarctica was part of Gondwana, the climate was warm and the continent was lush with vegetation. However, once Antarctica was completely separated from Gondwana, the climate began to cool sometime around the Eocene-Oligocene boundary (~34 Ma) and vegetation began to deteriorate (e.g. Birkenmajer and Zastawniak, 1986; Anderson et al., 2011). This decline in vegetation continued through the Oligocene where the majority of the vegetation was comprised mostly of the cool loving *Nothofagidites fusca* group and rare *Podocarpidites* sp. (e.g. Warny and Askin, 2011b; Warny & Kymes, 2013). Cooling of the Antarctic Peninsula continued into the Miocene where vegetation was minimal and glaciation became very prominent, covering most of the region.

CHAPTER 2: LATEST EOCENE AND MIDDLE OLIGOCENE PALYNOLOGY AND CLIMATE TRENDS IN THE ANTARCTICA PENINSULA

2.1 Abstract

The Eocene-Oligocene Transition (c. 34 Ma) is a time when Earth's climate shifted from a relatively ice-free world to one with glacial conditions spreading to many regions of Antarctica. This climatic transition has been studied from various proxies including oxygen isotope ($\delta^{18}O$) values and atmospheric carbon dioxide accumulation rates. This paper focuses on changes in vegetation (pollen and spores) and marine algae (dinoflagellate cysts) around this important transition thanks to a palynological analysis of 30 samples collected from two islands (Seymour Island and King George Island) located west of the Antarctic Peninsula. Our results indicate that conditions in the Peninsula were cool in the latest Eocene. Terrestrial vegetation was low diversity and dominated by *Nothofagus* of the cool-cold climate *fusca* group, and the marine organic-walled phytoplankton was reduced to mostly leiospheres and rare species of dinoflagellate cysts such as *Vozzhennikovia rotunda*, *V. apertura*, *Senegalinium asymmetricum,* and *Spinidinium macmurdoense*. This latest Eocene vegetation, similar to Valdivian-type forest found in modern day Chile and Argentina, was drastically reduced by the mid to late Oligocene, as very few *in situ* palynomorphs were observed in the Oligocene samples analyzed. By mid-Oligocene, the algal content is almost entirely comprised of the sea-ice indicative leiospheres, confirming that cooler climate and sea-ice was present in the Peninsula, and this northernmost region of Antarctica was already trending towards modern polar climatic conditions.

2.2 Introduction

The Eocene-Oligocene Transition (EOT) (ca. 34 Ma) denotes a global cooling event marked by substantial ice growth in Antarctica and high latitude sea-surface temperature changes from ~18˚C during the beginning of the Eocene to ~6˚C transitioning into the Oligocene (Stott et al., 1990; Liu et al, 2009). This ice growth ensued as temperatures changed from the "greenhouse" conditions of the Early Cenozoic to the present day glacial state (Prothero et al., 2003; Lear et al., 2008). This ~12˚C temperature change has been correlated with an increase in deep-sea benthic foraminiferal oxygen isotope ($\delta^{18}O$) values, as well as records of atmospheric carbon dioxide concentrations (Zachos et al., 1996; Prothero and Berggren, 2014). Although several recent studies have been conducted on this transition based on sediments cored off the Antarctic Peninsula by the SHALDRIL program (Anderson et al., 2011; Griener et al., 2013; Feakins et al., 2014), only a few studies have focused on the analysis of the Eocene/Oligocene continental climate evolution, mainly because of a dearth of exposed sediments or core samples of this age on the Antarctic continent.

Here we revisited one of the best studied Eocene sections by focusing on the uppermost portion of La Meseta Formation on Seymour Island, and compared the Eocene assemblage we recovered with that of a less studied Oligocene section; the Polonez Cove Formation on King George Island. A total of thirty (30) samples were analyzed for palynology; 14 collected from La Meseta Formation on Seymour Island and 16 from the Polonez Cove Formation on King George Island (Figure 2.1), both sites are adjacent to the Antarctic Peninsula. These islands provide a rare opportunity to study Eocene/Oligocene outcrops as they are part of a handful of locations in Antarctica where ice cover is minimal, allowing us to access sections of this age without international drilling efforts.

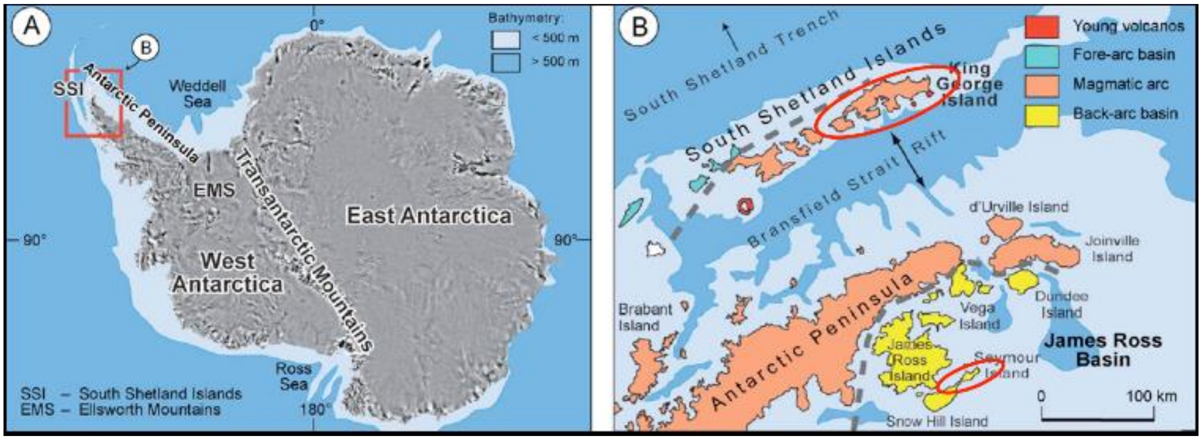

Figure 2.1. (A) Map of Antarctica highlighting the location of the Antarctic Peninsula, and (B) the locations of Seymour Island and King George Island circled in red.

2.3 Geologic Setting

Seymour Island is located approximately 100 km to the southeast of the Antarctic Peninsula (Figure 1B) at 64˚17'S latitude and 56˚45'W longitude. The island is roughly 20.5 km long, 9.6 km wide, and reaches 200 m above sea level at the highest point (Elliot et al, 1975). Seymour Island outcrops are well exposed, due to the lack of permanent ice, making it an ideal location for this study. The geology of the island is subdivided into four formations known as the Lopez de Bertodano (upper Campanian-lower Danian), Sobral (Danian), Cross Valley (Late Paleocene), and La Meseta (Eocene) (Elliot and Trautman, 1982; Rinaldi et al., 1978; Marenssi et al., 1998a) (Figure 2.2).

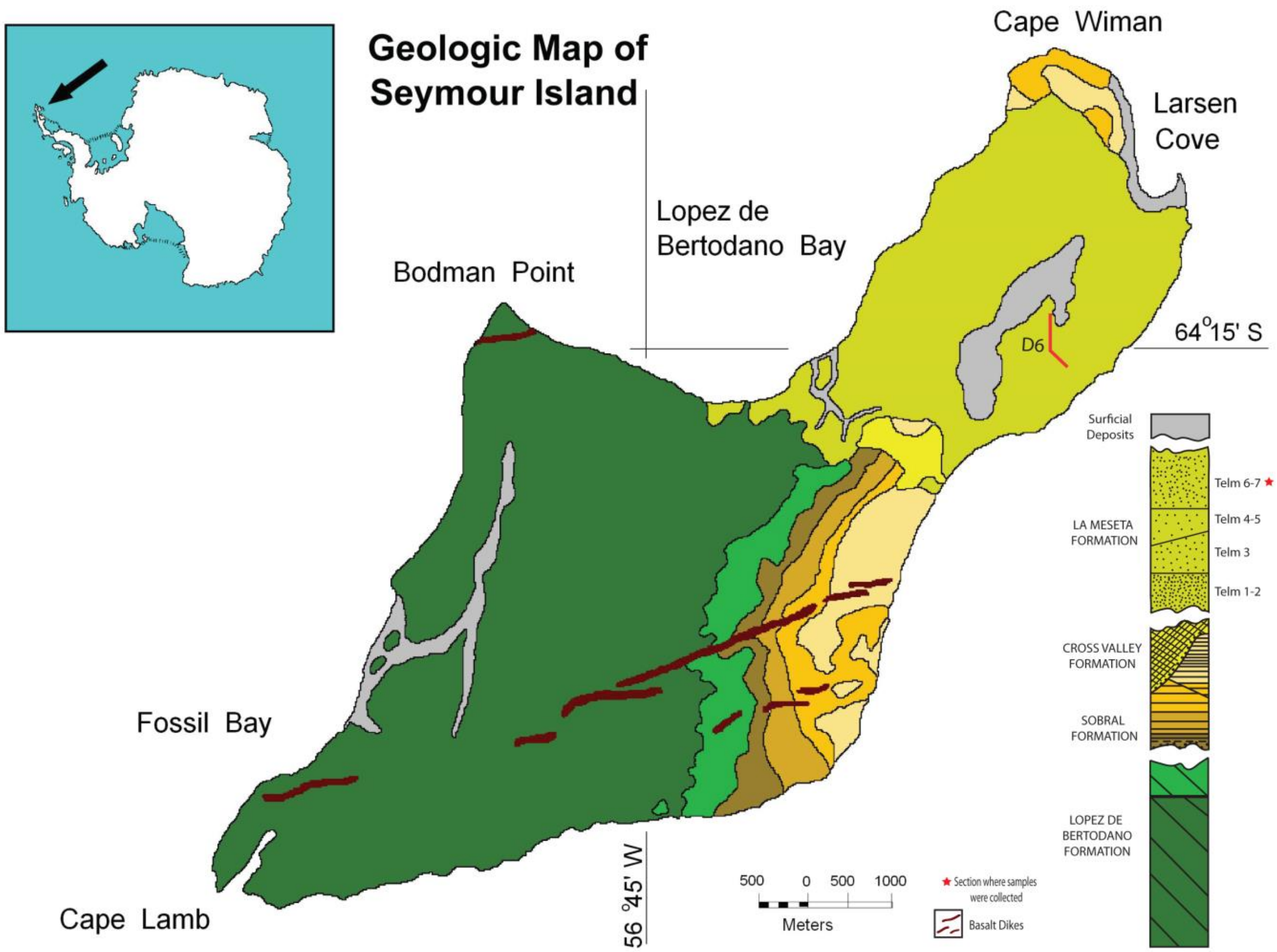

Figure 2.2. Geologic map of Seymour Island modified from Sadler (1988) highlighting the four major formations. The samples collected from La Meseta Formation are represented by the D6 transect line. The star next to the stratigraphic column marks the location of the samples. Legend: Grey- recent fluvioglacial deposits, Yellow- La Meseta Formation (Eocene), Light yellow- Cross Valley Formation (Early late Paleocene), Light tan- Sobral Formation, unit 4 (Early Paleocene), Orange- Sobral Formation, unit 3 (Early Paleocene), Tan- Sobral Formation unit 2 (Early Paleocene), Brown- Sobral Formation, unit 1 (Early Paleocene), Light green- Lopez de Bertodano Formation, unit 10 (Late Maastrichtian-Early Paleocene), Dark green- Lopez de Bertodano Formation, units 1 - 9.

Seymour Island, and the surrounding James Ross Island group, developed as part of a back-arc basin in the Antarctic Peninsula area, when the Phoenix Plate (Pacific lithosphere) subducted beneath the Peninsula (Barker 1982; Macdonald et al., 1988; Guterch et al. 1985). The back-arc basin experienced oblique extension along the easternmost margin, which controlled the development of the surrounding sedimentary basins (Storey and Nell, 1988). This basin infill is categorized as a mega-regressive clastic sequence measuring between 6 and 7 km thick and dating from Barremian to Eocene in age (Macdonald et al., 1988). Volcanism in the area was sporadic and lasted from Jurassic to possibly Eocene. During this time, tilting of synsedimentary strata was congruently intermittent with the volcanism. This succession is in exposed sections of Seymour Island (Macellari, 1988; Rieske, 1990).

Deposition of Seymour Island strata occurred as sediment was proximally supplied by an active magmatic arc from Cretaceous to Paleocene (Lopez de Bertodano Formation). Distal sediment accumulated through Eocene times (Hoffman et al., 1991; Macellari, 1992; Marenssi et al., 1999). During the Danian age, around the time deposition of the Sobral Formation occurred, the magmatic arc was dissected; exposing metamorphic and plutonic rocks. The Late Paleocene's Cross Valley Formation, on the other hand, experienced periodic volcanic activity, resulting in a rejuvenated volcanic source area (Hoffman et al., 1991).

The unconsolidated samples collected from the uppermost sandstones of La Meseta Formation are the focus of the Late Eocene portion of this climatic study. This formation was deposited as a mix of deltaic, estuarine, and shallow marine setting (Marenssi et al., 1998a,b).

King George Island (KGI) is the second island sampled for this study. KGI is located approximately 120 km off the northern coast of the Peninsula and lies at 62˚01'S latitude and 58˚33'W longitude (Figure 2.1B). KGI is roughly 95 km long and 25 km wide; making it the

largest island of the South Shetland Islands (SSI). The island itself is detached from the Peninsula by a young back-arc rift structure, the Bransfield Strait (Figure 2.1B), which spans 500 km along the Pacific margin (Galindo-Zaldívar et al., 2004). This arc was also developed as the Phoenix Plate (Pacific lithosphere) subducted beneath the continental crust of the Antarctic Peninsula, much like the James Ross Island Group (Barker, 1982; Guterch et al., 1985). The geology of KGI consists mostly of Mesozoic and Cenozoic eruptives and associated pyroclastics, which are cut by hypabyssal and abyssal intrusions (Smellie et al., 1984; Haase et al., 2012). The majority of these eruptives and pyroclastics are a result of high volcanic activity, which took place during the Eocene (Wang et al., 2009; Nawrocki et al., 2011). However, volcanism abated as the transition from the Eocene to the Oligocene occurred, coinciding with a northward progradation of the Antarctic ice sheet and marine transgression (Baker, 2007).

KGI is comprised of three stratigraphic sequences consisting of the Upper Cretaceous through Oligocene and Lower Miocene (Birkenmajer, 1990, 2001). These sequences are divided into three main groups: Chopin Ridge Group, Moby Dick Group, and the Legru Bay Group. The Chopin Ridge Group consists mostly of marine tillites, porphyritic lava flows, and sandstones, which make up the three formations of the Chopin Ridge Group (Birkenmajer, 1987). Of the three formations, the Polonez Cove Formation serves as the focus of KGI and the portion of this paper in which we discuss the environment present during the Oligocene (Figure 2.3).

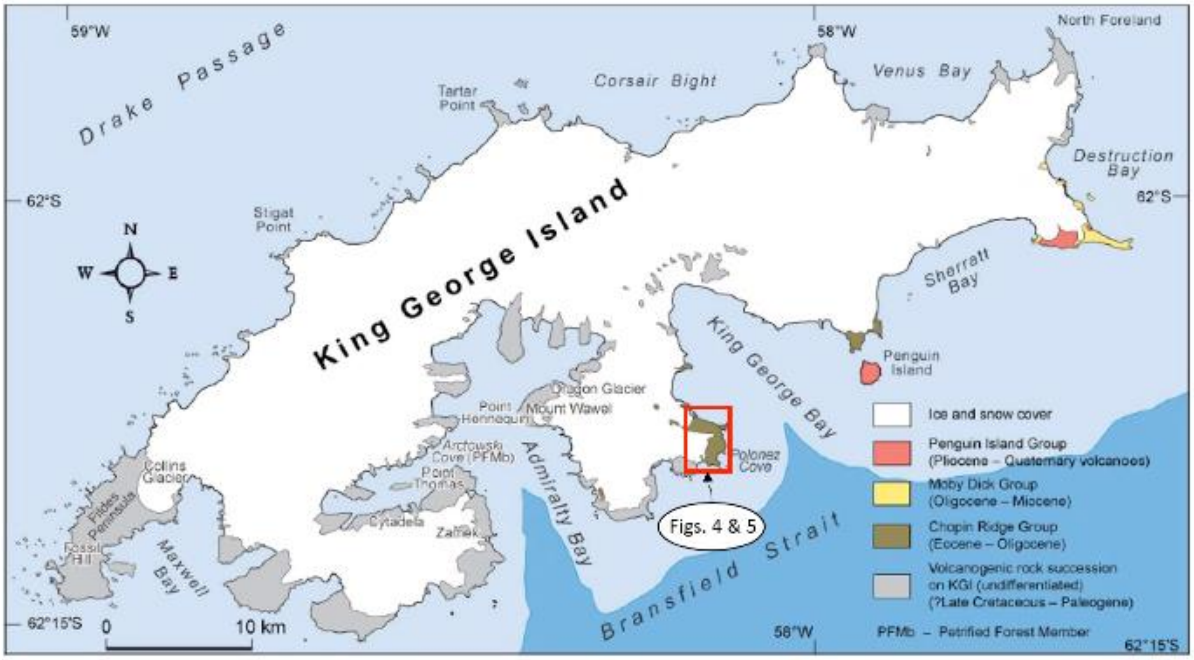

Figure 2.3. Geological map of King George Island highlighting the location of the Polonez Cove Formation outcrop where samples were collected.

2.4 Studied materials

Fourteen samples from La Meseta Formation and sixteen samples from the Polonez Cove Formation were analyzed. All fourteen latest Eocene (?earliest Oligocene) samples were collected from the uppermost La Meseta Formation. These samples were collected for Dr. Rosemary Askin in 1984 and were obtained for this study from the Polar Rock Repository (PRR) at Ohio State University. The sixteen mid to late Oligocene samples analyzed for this study come from a suite of exposed sections of the Polonez Cove Formation (see Fig. 2.4 for details). However, the majority of the samples were collected from the Linton Knoll profile (Figure 2.5). All samples analyzed from the Linton Knoll profile were collected by the Polish Academy of Science (PAS) two-part expedition, which took place in January 2007 and January 2009.

2.5 Methods

Samples were processed using standard chemical palynological processing techniques. Dry sediment was weighed and spiked with a known quantity of *Lycopodium* spores to allow for calculation of palynomorph concentrations. Dry sediment was successively treated with hydrochloric acid, hydrofluoric acid, and heavy liquid separation (e.g. Brown, 2008). Samples were sieved between a 10 and 250 μm fraction, and the remaining residue was mounted on microscope slides using glycerin jelly.

Palynomorph counting was conducted in the Louisiana State University's Center for Excellence in Palynology (CENEX) lab. When possible, 300 palynomorphs were tabulated per sample using an Olympus BX41 microscope. Palynomorphs were identified to the lowest taxonomic level possible. After palynomorphs were tallied, palynomorph concentration was calculated for each specimen using the equation from Benninghoff (1962): $C=(P_c \times L_t \times T)/(L_c \times W)$, where C = concentration (per gram of dried sediment, gdw^{-1}), Pc = the number of palynomorphs counted, L_t = the number of *Lycopodium* spores per tablet, T = the total number of *Lycopodium* tablets added per sample, L_c = the number of *Lycopodium* spores counted, W = the weight of dried sediment.

2.6 Results

2.6.1 Palynological results from the La Meseta Formation

The fourteen La Meseta samples studied yielded well-preserved palynomorphs, but with a relatively low diversity (Plates 1-6 see appendix B). The majority of palynomorphs identified in the oldest part of the studied section (D6-01 through D6-07) are *in situ* (~42% *in situ*), but the

assemblage progressively becomes more reworked (~40% reworked) (excluding the leiospheres) in the upper portion of the outcrop (D6-08 through D6-14). Reworked species of palynomorphs range from Permian to Paleocene in age and have been well documented on Seymour Island and the islands surrounding the Antarctic Peninsula (eg. Askin & Elliot, 1982; Askin, 1983, 1988, 1990; Dettmann & Thomson, 1987; Riding & Crame, 2002; Bowman et al., 2012). Age-significant dinoflagellate species were corroborated with age ranges from Ocean Drilling Program's (ODP) publication 189 (Sluijs et al., 2003). The presence of *Vozzhennikovia rotunda* (Lentin and Williams, 1981), *V. apertura* (Lentin and Williams, 1981), *Senegalinium asymmetricum* (Stover and Evitt, 1978), and *Spinidinium macmurdoense* (Wilson, 1967) indicates that the uppermost section studied is Eocene in age. The concentrations in palynomorphs ranged from 119 to 987 per gram of dried sediments (Table 2.1), which overlaps the Eocene concentrations of 500 and 18,000 recovered palynomorphs from the Eocene section sampled by the SHALDRIL program off the Antarctic Peninsula (Warny and Askin, 2011a). The following information provides an overview of the species found per sample, from the oldest to the youngest sample. All fourteen samples were collected from the Telm6 (1 sample) and Telm7 (13 samples) section of La Meseta Formation. The Telm6 section is composed of unconsolidated green and purple sand. The Telm7 section is composed of mostly unconsolidated green and purple sand with intermittent shells dispersed throughout (Sadler, 1988).

Table 2.1. Palynomorph concentration for the uppermost Eocene section (Telm6 and Telm7) of the La Meseta Formation.

La Meseta Formation Samples and Palynological Concentrations				
Sample name	Elevation (m)	Sample recovery	Palynological counts	Concentration of palynomorphs (gdw^{-1})
D6-14	39	Good	300	753
D6-13	36	Good	300	634
D6-12	33	Good	300	759
D6-11	30	Good	300	812
D6-10	27	Fair	300	652
D6-09	26	Fair	300	557
D6-08	21	Fair	300	669
D6-07	18	Good	300	760
D6-06	15	Good	300	873
D6-05	12	Fair	300	844
D6-04	9	Fair	300	776
D6-03	6	Fair	300	987
D6-02	3	Poor	86	373
D6-01	0	Poor	98	119

La Meseta: sample D6-01 (0 m), Telm6

The sample yielded a majority of reworked palynomorphs comprising *Cyathidites minor*, *Dictyophyllidites* spp., *Laevigatosporites ovatus*, *Leiotriletes directus*, *Podocarpidites* sp., *Punctatisporites* sp., *Triporopollenites* sp. *In situ* species included *Leiosphaeridia* spp., *Myricipites harrisii*, *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Nothofagidites* sp. (*menziesii* gp.), *Phyllocladidites* spp., *Proteacidites* cf. *p. parvus*, *Vozzhennikovia rotunda*

La Meseta: sample D6-02 (3 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Alisporites* sp., *Clavifera triplex*, *Dictyophyllidites* sp., *Osmundacidites wellmannii*, *Podocarpidites* sp., *Proteacidites* sp., *Triporopollenites* sp. *In situ* species included *Cyathidites minor*, *Leiosphaeridia*

spp., *Myricipites harrisii, Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Nothofagidites* sp. (*menziesii* gp.), *Senegalinium asymmetricum*, *Spinidinium macmurdoense, Vozzhennikovia rotunda*. This sample showed a dramatic increase of *Podocarpidites* species compared to that of the D6-01 sample.

La Meseta: sample D6-03 (6 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Alisporites* sp., *Cyathidites minor*, ?*Manumiella* sp., *Microcachryidites antarcticus, Peninsulapollis* spp., *Phyllocladidites* spp., *Podocarpidites* sp., *Spinidinium lantern, Tricolpites* sp., *Vozzhennikovia apertura*,. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Nothofagidites* sp. (*menziesii* gp.), *Peninsulapollis* spp., *Phyllocladidites* spp., *Podocarpidites* sp., *Senegalinium asymmetricum, Spinidinium macmurdoense, Vozzhennikovia apertura*, *Vozzhennikovia rotunda.* This sample is heavily dominated by *Nothofagidites* spp. and *Vozzhennikovia rotunda.*

La Meseta: sample D6-04 (9 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Diconodinium cristatum*, *Dictyophyllidites* spp., *Foraminisporis ?dailyi*, and (Rw), *Nothofagidites* sp. (*fusca* gp.), *Osmundacidites wellmannii, Peninsulapollis* spp., *Phyllocladidites* spp., *Podocarpidites* sp., *Proteacidites* spp., *Pterospermella australiensis, Tricolpites* sp., *Triporopollenites* sp., *Vozzhennikovia apertura*, *Vozzhennikovia rotunda* (*in situ*). *In situ* species included *Alterbidinium distinctum, Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), Nothofagidites sp. (*menziesii* gp.), *Phyllocladidites* spp.,

Podocarpidites sp., *Proteacidites* spp., *Senegalinium asymmetricum, Spinidinium macmurdoense*, *Vozzhennikovia apertura*, *Vozzhennikovia rotunda.*

La Meseta: sample D6-05 (12 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Dictyophyllidites* spp., *Foraminisporis ?dailyi, ?Manumiella* sp., *Peninsulapollis* spp., *Podocarpidites* sp., *Proteacidites* spp., *Triporopollenites* sp. *In situ* species included *Alterbidinium distinctum, Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. *(brassii gp.), Nothofagidites* sp. (*fusca* gp.), *Podocarpidites* sp., *Proteacidites* spp., *Senegalinium asymmetricum, Spinidinium macmurdoense*, *Vozzhennikovia rotunda.*

La Meseta: sample D6-06 (15 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Dictyophyllidites* spp., *Foraminisporis ?dailyi,,* ?*Manumiella* sp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Peninsulapollis* spp., *Phyllocladidites* spp., *Podocarpidites* sp., *Proteacidites pseudomoides, Pterospermella* spp., *Stereisporites antiquasporites, Trilobosporites trioreticulosus, Triporopollenites* sp. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Myrtaceidites parvus, Nothofagidites* sp. *(brassii* gp.*), Nothofagidites* sp. (*fusca* gp.), *Nothofagidites* sp. (*menziesii* gp.), *Phyllocladidites* spp., *Senegalinium asymmetricum, Spinidinium macmurdoense*, *Vozzhennikovia rotunda*.

La Meseta: sample D6-07 (18 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Cyathidites minor*, *Dictyophyllidites* spp., *Foraminisporis ?dailyi,, Laevigatosporites ovatus, Nothofagidites* sp. *(brassii* gp.*), Nothofagidites* sp. (fusca gp.), *Peninsulapollis* spp., *Phyllocladidites* sp.,

Podocarpidites sp., *Proteacidites pseudomoides, Trilobosporites trioreticulosus, Triporopollenites* sp., and *Vozzhennikovia apertura. In situ* species included *Alterbidinium distinctum*, *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (fusca gp.), *Nothofagidites* sp. (*menziesii* gp.), *Senegalinium asymmetricum, Spinidinium macmurdoense*.

La Meseta: sample D6-08 (21 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Cyathidites minor*, *Dictyophyllidites* spp., *Foraminisporis ?dailyi, Laevigatosporites ovatus, ?Manumiella,* sp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Peninsulapollis* spp., *Phyllocladidites* sp., *Podocarpidites* sp., *Proteacidites pseudomoides, Pterospermella australiensis*, *Tricolpites* spp., *Triporopollenites* sp. *In situ* species included *Alterbidinium distinctum*, *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Senegalinium asymmetricum, Spinidinium macmurdoense*, *Vozzhennikovia rotunda.*

La Meseta: sample D6-09 (24 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Cyathidites minor*, *Dictyophyllidites* spp., *Foraminisporis ?dailyi, Laevigatosporites ovatus, ?Manumiella* sp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Peninsulapollis* spp., *Phyllocladidites* sp., *Podocarpidites* sp., *Proteacidites pseudomoides, Pterospermella australiensis, Tricolpites* sp., *Triporopollenites* sp. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*fusca* gp.), *Senegalinium asymmetricum, Spinidinium macmurdoense, Vozzhennikovia apertura., Vozzhennikovia rotunda*

La Meseta: sample D6-10 (27 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Laevigatosporites ovatus*, *Phyllocladidites* sp., *Podocarpidites* sp., *Proteacidites* spp., *Spinidinium lanterna Tricolpites* sp., *Triporopollenites* sp. *In situ* species were comprised entirely of *Impletosphaeridium* sp., *Leiosphaera* spp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites flemingii*, *Nothofagidites* sp. (*fusca* gp.), *Nothofagidites lachlaniae*, *Peninsulapollis* spp., *Spinidinium macmurdoense*, and *Vozzhennikovia* spp. *In situ* species included *Leiosphaeridia* spp., *Spinidinium macmurdoense*, *Vozzhennikovia rotunda*.

La Meseta: sample D6-11 (30 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Cyathidites minor*, *Diconodinium cristatum*, *Dictyophyllidites* spp., *Foraminisporis ?dailyi*, *Laevigatosporites ovatus*, *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites flemingii*, *Nothofagidites* sp. (fusca gp.), *Peninsulapollis* spp., *Phyllocladidites* sp., *Podocarpidites* sp., *Proteacidites pseudomoides*, *Pterospermella australiensis*, *Stereisporites ?antiquasporites*, *Triporopollenites* sp. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (fusca gp.), *Senegalinium asymmetricum*, *Spinidinium macmurdoense*, *Vozzhennikovia rotunda*.

La Meseta: sample D6-12 (33 m), Telm7

The sample yielded a majority of reworked palynomorphs comprising *Cyathidites minor*, *Nothofagidites* sp. (*brassii* gp.), *Nothofagidites* sp. (*fusca* gp.), *Nothofagidites* sp. (*menziesii* gp.), *Peninsulapollis* spp., *Phyllocladidites* sp., *Podocarpidites* sp., *Stereisporites ?antiquasporites*. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp., *Spinidinium macmurdoense*.

La Meseta: sample D6-13 (36 m), Telm7

The sample yielded a majority of reworked species such as *Cyathidites minor*, *Nothofagidites* sp. (*brassii* gp.) *Nothofagidites* sp. (*fusca* gp.), *Paleocystodinium golzowenze*, *Peninsulapollis* spp., *Phyllocladidites* sp., *Podocarpidites* sp., *Spiniferites* sp., and *Stereisporites ?antiquasporites*. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp.,

La Meseta: sample D6-14 (39 m), Telm7

The sample yielded a majority of reworked species such as *Cyathidites minor*, *Nothofagidites flemingii, Nothofagidites* sp. (*fusca* gp.), *Nothofagidites lachlaniae, Paleocystodinium golzowenze*., *Phyllocladidites* sp., *Podocarpidites* sp., *Tricolpites* sp. *In situ* species included *Impletosphaeridium* spp., *Leiosphaeridia* spp.

2.6.2 Palynological results from the Polonez Cove Formation

Unlike La Meseta Formation samples, the Polonez Cove Formation samples contained very few palynomorphs. Abundance of the Polonez Cove rarely exceeded 100 specimens per slide. However, the few species it did contain yielded a mixed group (Plate 7 see appendix B). Most of the specimens analyzed in the Polonez Cove samples were reworked (~85% reworked) (excluding leiospheres), the majority of which were past the point of recognition. The concentrations of *in situ* palynomorphs ranged from 0 to 117 per gram of dried sediments, and the concentrations in reworked palynomorphs ranged from 0 to 73 per gram of dried sediments (Table 2.2), which is drastically lower compared to Oligocene concentrations extending up to 2,000 recovered palynomorphs from the Oligocene section sampled by the SHALDRIL program off the Antarctic Peninsula (Warny and Askin, 2011b). The following information describes the palynological

assemblages identified from the Krakowiak Glacial Member (KGM), Low Head Member (LHM), and the Chlamys Ledge Member (CLM) of the Polonez Cove Formation (Figure 2.4 & 2.5). These members are listed from oldest to youngest, respectively.

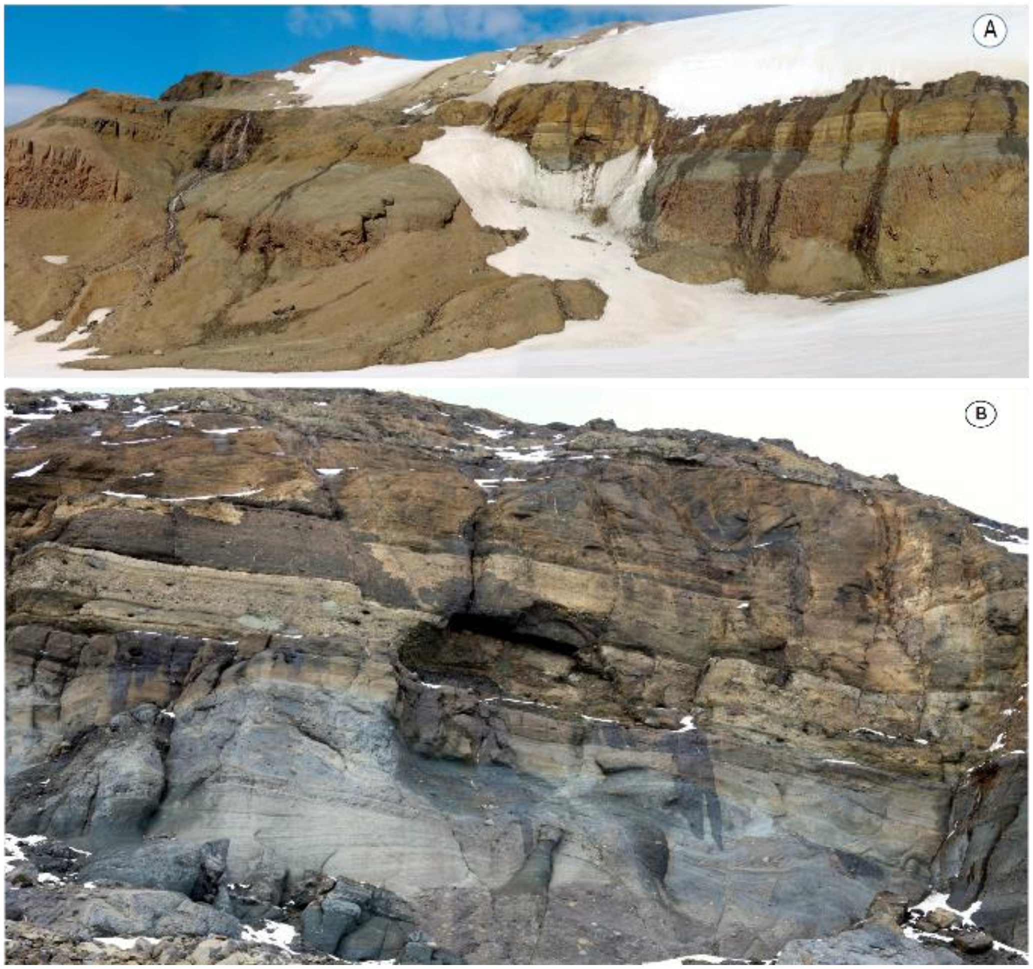

Figure 2.4. **A.** Photograph of the section of the Polonez Cove Formation exposed in the Linton Knoll profile where samples were collected. **B.** Enlarged section of the Polonez Cove Formation.

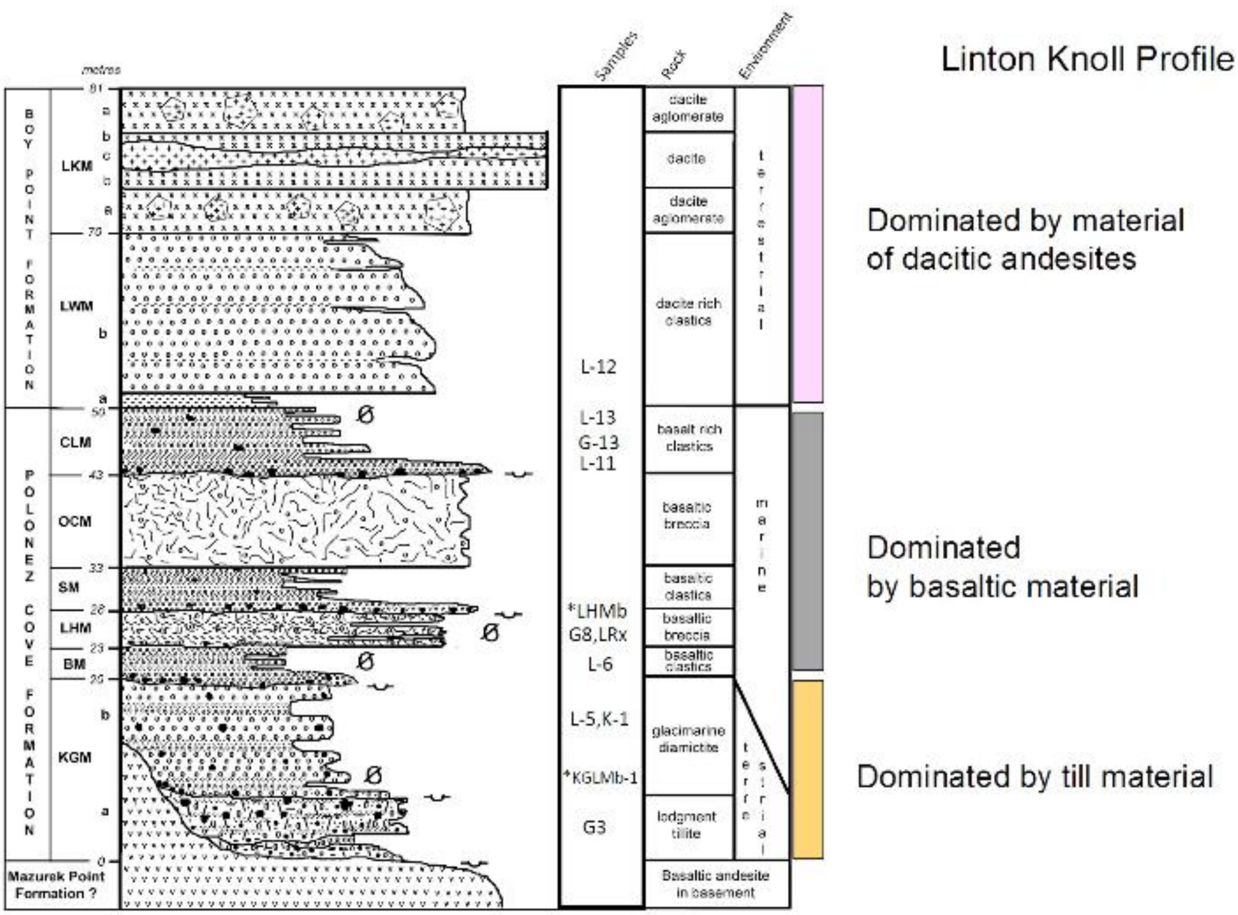

Figure 2.5. Detailed lithology of the Polonez Cove Formation and sections where samples were collected during the PAS expedition in 2007 and 2009. * indicates samples were collected from multiple locations containing the Polonez Cove Formation.

Table 2.2. Palynomorph concentrations of reworked (Rw) and *in situ* palynomorphs from the sampled Polonez Cove Formation.

Polonez Cove Formation Samples and Palynological Concentrations					
Sample name	Elevation (m)	Sample recovery	Palynological counts	Concentration of palynomorphs (gdw^{-1}) (Rw)	Concentration of palynomorphs (gdw^{-1}) (*in situ*)
L-12	55	Poor	11	41	9
L-13	48	Poor	7	5	4
G-13	46	Poor	11	1	1
L-11	43	Fair	46	9	20
LHMb	26	Poor	101	4	20
LHMb	26	Poor	40	7	10
G8	25	Poor	37	73	44
LRx	25	Fair	46	8	21
L-6	21	Fair	73	11	18
L-5	14	Poor	54	4	10
K-1	14	Fair	64	15	21
KGLMb	7	Poor	95	29	33
KGLMb	7	Poor	45	4	18
KGLMb-2	7	Poor	10	7	1
KGLMb-1	7	Poor	0	0	0
G3	5	Poor	40	44	117

Krakowiak Glacial Member

Specimens analyzed throughout the KGM (excluding leiospheres and a few other species of palynomorphs) were mostly comprised of reworked palynomorphs and filled with charred organic matter indicative of volcanic activity. The majority of reworked species are most likely species that are Jurassic to Cretaceous in age. They included reworked species of *Calamospora* sp., *Cyathidites minor*, *Deflandrea* sp., *Diconodinium* sp., *Dictyophyllidites* sp., *?Microcachryidites antarcticus*, *Myricipites* sp., *Odontochitina operculata*, *Peninsulapollis gillii*, *Phyllocladidites* sp., *Podocarpidites* spp., *Triporopollenites* sp. *In situ* species included *Chenopodipollis* sp., *Haloragacidites* sp., *Leiosphaeridia* spp., *Nothofagidites* sp. (*fusca* gp.),

Phyllocladidites mawsonnii, Podocarpidites spp., *Reticulatosphaera actinocornata, Triporopollenites* sp.

Low Head Member

The Low Head Member of the Polonez Cove Formation consisted of mostly reworked specimens and a plethora of volcanic material. The species were difficult to identify, but consisted mostly of reworked *Calamospora* sp., *Chenopodipollis* sp., *Cyathidites minor, Dictyophyllidites* sp., *Haloragacidites* sp., *?Microcachryidites antarcticus, Myricipites* sp., *Nothofagidites* sp. (*fusca* gp.), *Odontochitina operculata, Peninsulapollis gillii, Podocarpidites* sp., *Stelliopollis annulatus,* and *Triporopollenites* sp. *In situ* species consisted of *Chenopodipollis* sp., *Leiosphaeridia* spp.

Chlamys Ledge Member

The final section is the Chlamys Ledge Member. This member was comprised of reworked species of *Calamospora* spp., *Cyathidites minor, Haloragacidites* sp., *Myricipites* sp., *Phyllocladidites* sp., *Podocarpidites* sp. *Stereisporites antiquasporites,* and *Tricolpites gillii. In situ* species included *Impletosphaeridium* sp., *Leiosphaeridia* spp.

2.7 Discussion

2.7.1. Paleoenvironmental interpretation of recovered palynomorphs

To determine paleoenvironmental conditions, species analyzed from the assemblages were identified as being either reworked or *in situ.* When age-restricted species older than Eocene or Oligocene were found (e.g., the frequent Cretaceous species recovered), they were easily recognized as reworked. However, for species with longer age ranges, it is sometimes difficult to

distinguish reworked from *in situ*. This is because the spore and pollen's highly resistant exine polymer (sporopollenin) is capable of withstanding heat, aging, and some depositional pressure, which keeps the grain intact (Dickinson, H.G. and Heslop-Harrison, J., 1968). When stratigraphic ranges were too long to determine the reworking status, the preservation of the grains as well as the thermal maturity of their wall were considered. Figures 2.6 and 2.7 summarize the overall abundance of palynomorphs observed and show our interpretations of reworked vs. *in situ* species from both La Meseta Formation and Polonez Cove Formation. A detailed analysis of reworked vs. *in situ* palynomorphs from La Meseta and Polonez Cove formations are shown in Figures 2.8 and 2.9, respectively.

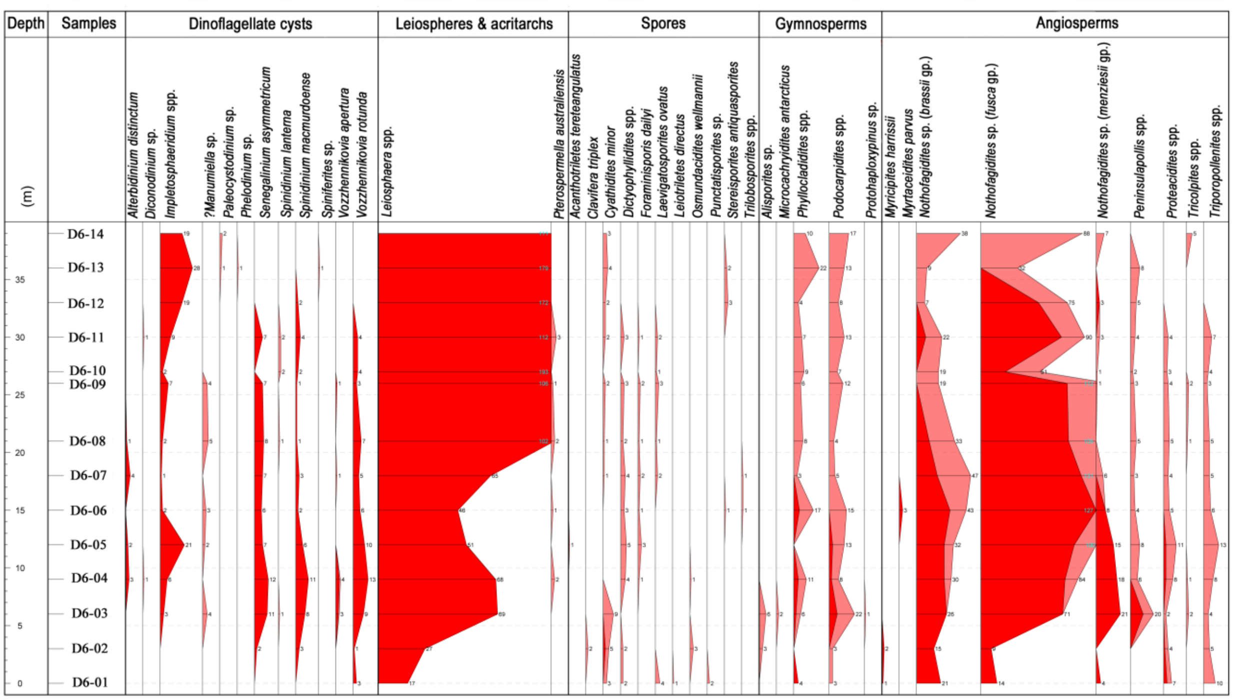

Figure 2.6. Overall abundance of palynomorph species observed in the La Meseta Formation of Seymour Island where red=*in situ* and pink=reworked.

Amongst the La Meseta Formation samples analyzed, a trend showing a passage from predominantly *in situ* specimens in samples D6-01 to D6-06, to an increase in reworked specimens

from samples D6-07 to D6-14 was observed. By mid-Oligocene, the Polonez Cove Formation was almost exclusively composed of reworked palynomorphs (Figure 2.6 & 2.8). The abundance of *in situ* species, from the lower section of the sampled La Meseta formation, predominantly included leiospheres, *Podocarpidites* sp., *Phyllocladidites* sp., *Nothofagidites* sp. (*brassii* gp.), and *Nothofagidites* sp. (*fusca* gp.). The *Podocarpidites* sp. and *Phyllocladidites* sp. are types of conifers that typically thrive in cool, temperate, climates. *Nothofagidites* sp. (*fusca* gp.) is also typically found in cooler more temperate environments. By observing an assemblage of *in situ* *Podocarpidites* sp., *Phyllocladidites* sp., *Nothofagidites* sp. (*brassii* gp.), and *Nothofagidites* sp. (*fusca* gp.) at the basal section of our La Meseta sample set, we can infer the environment was comparable to a cool, temperate, Valdivian-type forest, found in parts of modern day Chile, up to the time of sample D6-06. After sample D6-06, the increased relative abundance of both reworked species and the *in situ* sea-ice indicative leiospheres together infer a less vegetated, more glacially dominated, environment from the time of deposition of sample D6-07.

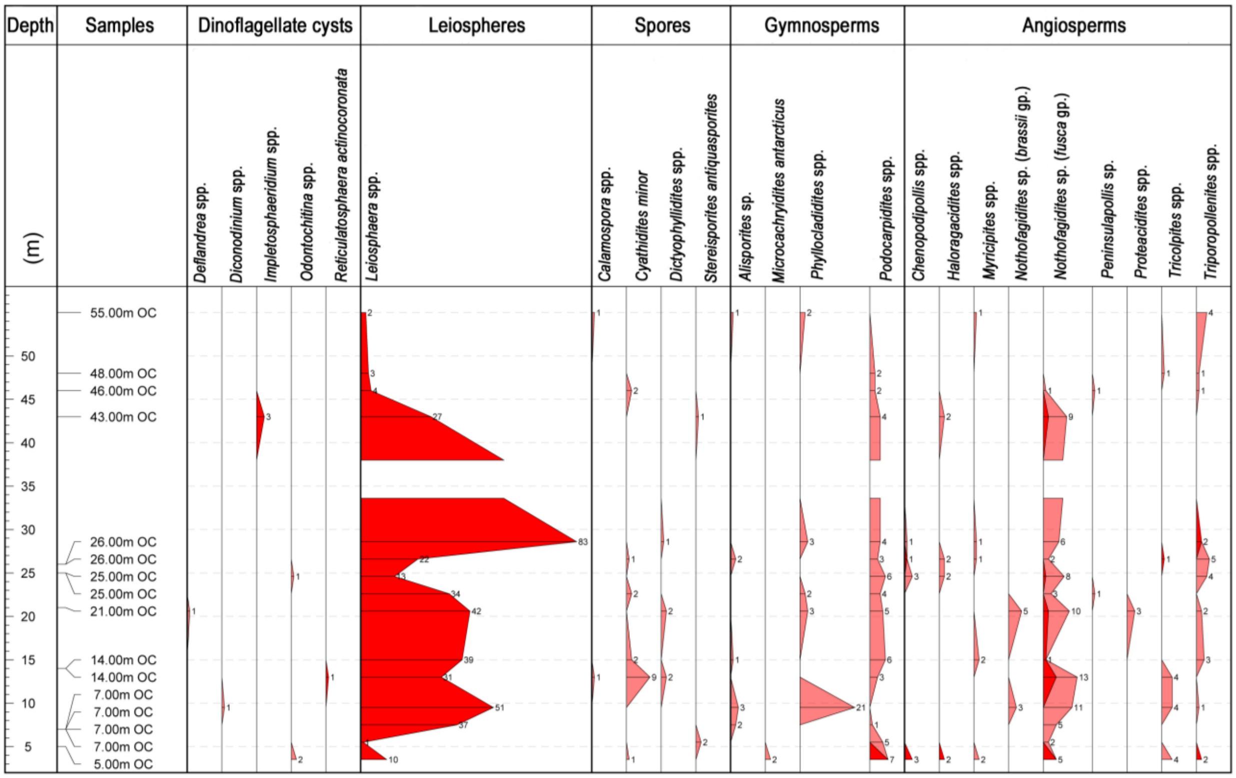

Figure 2.7. Overall abundance of palynomorph species observed in the Polonez Cove Formation samples from King George Island. Red=*in situ* and pink=reworked.

Although our sampling did not include the Early Oligocene, the mid to Late Oligocene sections studied in the Polonez Cove indicated that by that time, on the other side of the Antarctic Peninsula, vegetation was reduced to sparse occurrences consisting mostly of herbaceous plants with some southern beech and podocarp conifers. The fact that leiospheres were largely abundant indicates sea-ice was still present and mostly dominated the area off the Peninsula. Figures 2.7 & 2.9 highlight how the overall abundance, diversity and preservation of palynomorphs have greatly diminished compared to those of La Meseta Formation: This is a conclusion congruent with the results from the 2006 SHALDRIL campaign (Anderson et al., 2011; Warny and Askin, 2011b). The vast majority of the observed palynomorphs in these samples were reworked. Though the

occasional *in situ* terrestrial palynomorphs were witnessed, the majority of *in situ* palynomorphs consisted of *Leiosphaeridia* spp., a group often associated with the sphaeromorph acritarchs, and *Impletosphaeridium* spp., a group of dinocysts. These *Leiosphaeridia* spp. are known to be abundant at the limit between pack ice and sea ice (Mudie, 1992; Troedson and Riding 2002; Warny et al., 2006). Similar to *Leiosphaeridia* spp., *Impletosphaeridium* spp. are believed to be present during sea-ice formation (Warny et al., 2007).

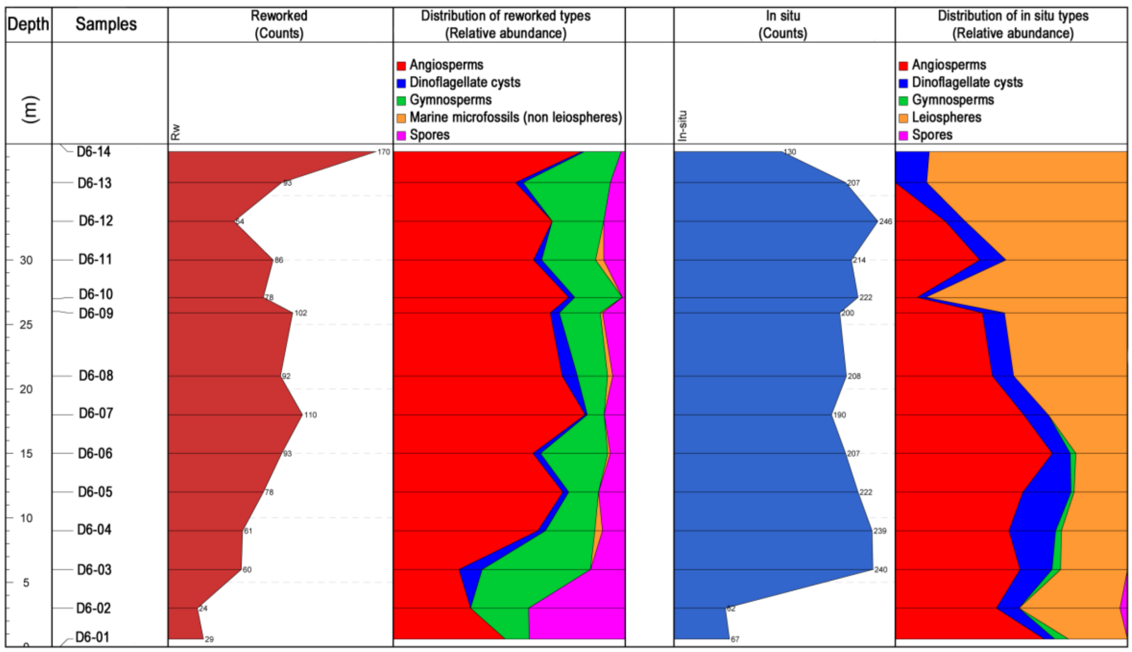

Figure 2.8. Relative abundance of reworked (Rw) and *in situ* palynomorphs in these La Meseta Formation samples.

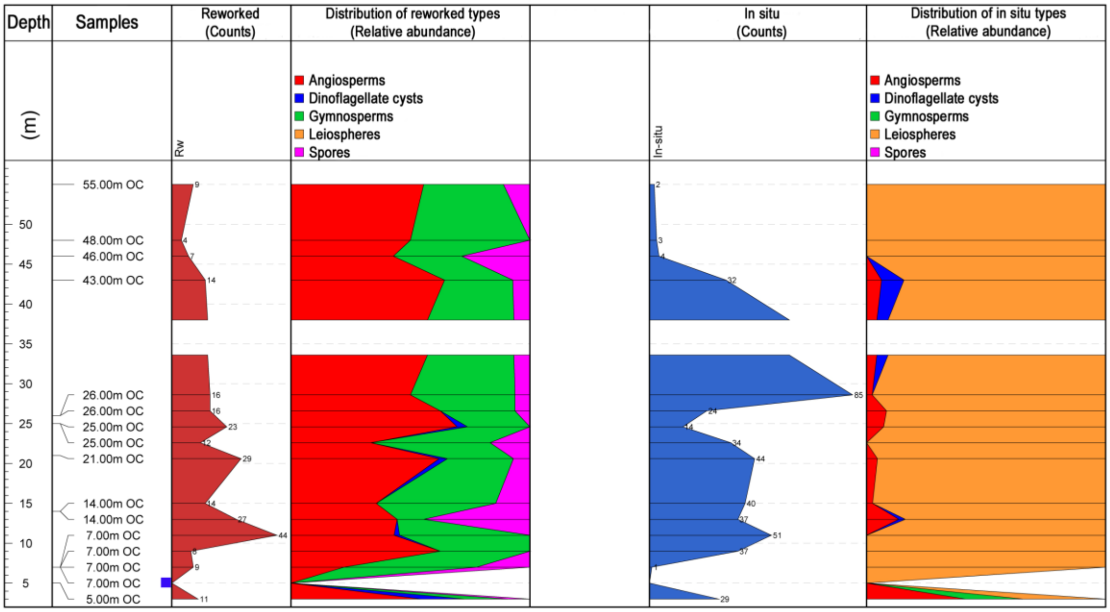

Figure 2.9. Relative abundance of reworked (Rw) and *in situ* palynomorphs in these Polonez Cove Formation samples.

2.7.2. Palynological response compared with previous studies

Dating for the La Meseta Formation has been determined through the years of paleontological and isotopic analyses. These analyses included the use of vertebrate (Simpson, 1971; Gelfo et al., 2015) and mollusk fossils (Zinsmeister, 1977; Elliot & Trautman, 1982) and palynological studies (Hall, 1977; Askin & Flemming, 1982; Wrenn & Hart, 1988; Askin et al., 1991), which concluded a general age ranging between Early Eocene at the base to Late Eocene at the uppermost section of the La Meseta Formation. Recent strontium-isotope analyses were conducted on *Cucullaea* specimens collected throughout the Submeseta allomember (Telm1-Telm7) of the La Meseta Formation and supported the previously assigned age range of Early Eocene to Late Eocene (Dutton & Lohmann, 2002 and references therein). Specifically, the Dutton & Lohmann study placed the upper most section of La Meseta Formation's Telm7 between 34-36 Ma. The last occurrence datum (LAD) for *Vozzhennikovia rotunda* and *Spinidinium*

macmurdoense observed in our samples confirmed an Eocene age and narrowed the Telm7 range to 33.7 to 37 Ma (Wrenn & Hart, 1988; Williams et al., 2003).

Dating for the Polonez Cove Formation has been determined through strontium-isotope dating of mollusk fossils (Dingle et al., 1997; Dingle & Lavelle, 1988) and $^{40}Ar/^{39}Ar$ dating of interbedded basaltic lava flows (Smellie et al., 1998; Troedson & Smellie, 2002). These results yielded a middle to late Oligocene age. Specifically, results from the Sr-isotope ages ranged between 28.5-29.8±0.8 Ma. $^{40}Ar/^{39}Ar$ ratios from basalt lava, collected from the Low Head Member and southern Mazurek Point, ranged between 26.0±2.59 Ma and 25.6±1.3 Ma, respectively (Dingle & Lavelle, 1988; Dingle et al., 1997). Unlike the La Meseta Formation, biostratigraphic markers were absent from the observed samples, making an age constraint based solely on isotopic dating. By using the age overlap of the above data, it is believed that the studied samples from the Polonez Cove Formation are ~26-28 Ma.

Although the age constraint from the aforementioned overlapping data could only narrow the uppermost La Meseta Formation to 34-36 Ma and the Polonez Cove Formation to ~26-28 Ma, palynological results from these sampled intervals provided a general understanding of the climatic changes that occurred in the Antarctic Peninsula during these times. Observations of the sampled intervals revealed palynomorph status changed from mostly *in situ* in the older section of the uppermost La Meseta Formation and progressively became more reworked. This trend of increasingly reworked palynomorphs continued into the Polonez Cove Formation where the majority of palynomorphs were comprised of reworked species. The abundance of reworked palynomorphs coupled with the large occurrence of *Leiosphaeridia* spp., which increased from the youngest samples of the La Meseta Formation to the Polonez Cove Formation, indicate the Latest Eocene was already cool and continued to cool into the Oligocene. This palynological response

is supported is with shifts in the $\delta^{18}O$ curve which indicated temperatures cooled in the Latest Eocene and continued throughout the Oligocene (Figure 2.10).

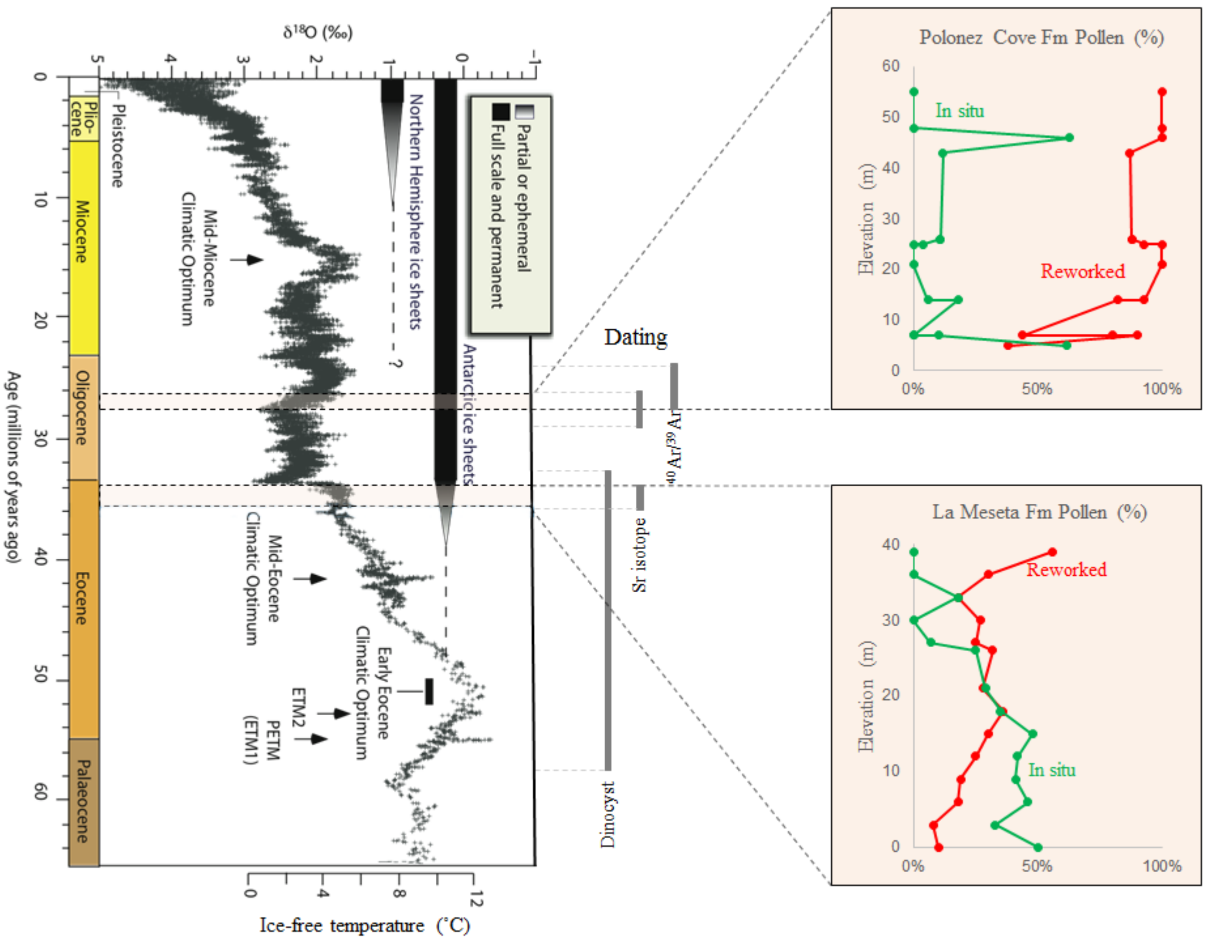

Figure 2.10. Stratigraphic position of sampled La Meseta Formation and Polonez Cove Formation in relation to the $\delta^{18}O$ global climate. Age of sampled interval for the La Meseta Formation was determined based on the overlap of LAD of observed biostratigraphic markers (*Vozzhennikovia. rotunda* and *Spinidinium macmurdoense*) and Sr-isotope analyses in Dutton & Lohmann, (2002). Age of sampled interval for the Polonez Cove Formation was determined based on the overlap of Sr-isotope dating in Dingle & Lavelle, (1988) and Dingle et al., (1997) and $^{40}Ar/^{39}Ar$ dating in Smellie et al., (1998) and Troedson & Smellie, (2002). Modified from Zachos et al., (2008).

2.8 Conclusions

The samples collected from La Meseta Formation on Seymour Island, and the Polonez Cove Formation on King George Island provide insight into the climatic evolution that occurred at the latest Eocene and in the mid to Late Oligocene in the Antarctic Peninsula. Dinoflagellate cyst biostratigraphy confirms an Eocene age for the youngest part of the La Meseta Formation. Our results revealed that this latter stage of the Eocene so-called "green-house" climate was already experiencing cooler climatic conditions as seen in the low diversity of *in situ* *Podocarpidites* sp., *Phyllocladidites* sp., *Nothofagidites* sp. (*brassii* gp.), and *Nothofagidites* sp. (*fusca* gp.) taxa recovered from the basal section (samples D6-01 through D6-06). The "green-house" latest Eocene conditions were in fact more similar to, cool, temperate, Valdivian-type forest. These conditions started to become even cooler in the top of La Meseta as evidenced by increased abundance in reworked species and sea-ice indicative marine phytoplankton in samples D6-07 to D6-14. The fact that our data show cool climate conditions during the latest Eocene is further supported by data presented from other studies across Antarctica which describe cool conditions occurring during the latest Eocene (e.g. cores from Prydz Bay in Hambrey et al., 1991 and erratics from McMurdo Sound in Askin, 2000). By the mid to Late Oligocene, as evidenced by a mostly reworked assemblage found in the Polonez Cove Formation samples and abundance of sea-ice indicative species, the Peninsula was well into an ice-covered environment with extremely reduced vegetative cover.

2.9 Acknowledgments

The authors would like to thank the Institute of Geological Sciences, Polish Academy of Sciences for providing the Polonez Cove samples. Field assistance of Marcin Klisz and Mariusz Potocki during 2007 expedition and Grzegorz Zieliński during 2009 expedition is greatly appreciated. Fieldwork was financially supported by the Polish Ministry of Science and Higher Education (Grant No. DWM/N8IPY/2008). This is a contribution to the Antarctic Climate Evolution (ACE) program.

We are grateful to NSF Polar and CAREER program for funding this research. Funding for this research was provided by the U.S. National Science Foundation ANT-1048343 to SW. Thanks are extended to HESS corporation for funding the Stratabugs software license for CENEX and to HESS staff members (D. Pocknall, P. Griggs and M. Thomas) for Stratabugs training.

CHAPTER 3. CONCLUSION

The results presented in this thesis help to shed new light on Antarctic earth science and the climate that was present from the Late Eocene to the Early Miocene. Palynological assemblages observed in the samples collected from the Late Eocene La Meseta Formation reveal climate was already experiencing cooler conditions prior to the EOT. This was observed from the low diversity of *in situ Podocarpidites* sp., *Phyllocladidites* sp., *Nothofagidites* sp. (*brassii* gp.), and *Nothofagidites* sp. (*fusca* gp.) taxa witnessed in the lower section (D6-01 through D6-06), which is similar to a cool temperate type forest found in modern day Chile, and Argentina. However, Antarctic climate continued to decline into the youngest section of the La Meseta Formation (D6-07 through D6-14) as indicated by the reworked palynomorphs and sea-ice indicative *Leiosphaeridia* spp., which progressively became more abundant. This palynological interpretation of Antarctica's vegetation response to climate shifts from a cool-temperate climate to one much cooler coincides with evidence of cooler conditions, prior to the EOT, seen in other studies that have been conducted on Late Eocene sections across Antarctica (e.g. Hambrey et al., 1991; Askin, 2000; Anderson et al., 2011; Warny and Askin, 2011a).

Although palynomorph abundance was not as prominent or as diverse as in the La Meseta samples, the assemblages observed in the Polonez Cove Formation samples yielded valuable results. The palynomorphs from these samples were mostly reworked with the exception of the occasional *in situ Podocarpidites* sp. and *Nothofagidites* spp. The majority of the species that were *in situ,* and dominated the samples, were the sea-ice indicative *Leiosphaeridia* spp. These results indicate climate was much cooler than that of the Eocene epoch and the large presence of *Leiosphaeridia* spp., and mostly reworked species of palynomorphs, indicates glaciation had already occurred in the Antarctic Peninsula by the Middle Oligocene.

REFERENCES

Anderson, J. B. (1999). *Antarctic marine geology*. Cambridge University Press.

Anderson JB, Warny S, Askin RA, Wellner JS, Bohaty SM, Kirshner AE and Majewski W. 2011. Progressive Cenozoic cooling and the demise of Antarctica's last refugium. *Proceedings of the National Academy of Sciences*, 108(28), p. 11356-11360.

Arche A, López-Martinez J, and Martinez de Pison E. 1992. Sedimentology of the Miers Bluff Formation, Livingston Island, South Shetland Islands. In: Yoshida Y, Kaminuma K and Shiraishi K. (eds.) Recent Progress in Antarctic Earth Science, Tokyo, Terra Antartica Publication, p. 357-362.

Askin RA. 1983. Tithonian (uppermost Jurassic) – Barremian (Lower Cretaceous) spore, pollen and microplankton from the South Shetland Islands, Antarctica. In: Oliver, R.L., James, P.R. and Jago, J.B. (eds.), Antarctic Earth Science, Australian Academy of Science, Canberra, p. 295-297.

Askin RA. 1988. Campanian to Paleocene palynological succession of Seymour and adjacent islands, northeastern Antarctic Peninsula. In: Feldmann, R.M. and Woodburne, M.O. (eds.), Geology and paleontology of Seymour Island, Antarctic Peninsula, Geological Society of America, Memoir, 169, p. 131-153.

Askin, R. A. (1990). Campanian to Paleocene spore and pollen assemblages of Seymour Island, Antarctica. *Review of Palaeobotany and Palynology*, *65*(1), 105-113.

Askin RA. 1999. *Manumiella seymourensis* new species, a stratigraphically significant dinoflagellate cyst from the Maastrichtian of Seymour Island. *Journal of Paleontology*, 73(3), p. 373-379.

Askin RA & Elliot DH. 1982. Geologic implications of recycled Permian and Triassic palynomorphs in Tertiary rocks of Seymour Island, Antarctic Peninsula. *Geology*, 10(4), p. 547-551.

Barbeau DL Jr, Davis JT, Murray KE, Valencia V, Gehrels GE, Zahid KM and Gombosi DJ. 2009. Detrital-zircon geochronology of the metasedimentary rocks of north-western Graham Land. *Antarctic Science*, 22, p. 65-78.

Barker PF. 1982. The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: ridge-crust-trench interactions. Journal of the Geological Society, London 139, p. 787-801.

Baker PF. 2007. The history of Antarctic Peninsula glaciation. In A. K Cooper, C R. Reymond et al (eds) Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES. USGS Open-File Report 2007-1047, Short Research Paper 042, 5p.; doi:10.3133/0f2007-1047.srp042.

Barker DHN & Austin JA. 1998. Rift propagation, detachment faulting, and associated magmatism in Bransfield Strait, Antarctic Peninsula. *Journal of Geophysical Research*, 103, p. 24017-24043. doi:10.1029/98JB01117.

Bart PJ & Anderson JB. 1995. Seismic record of glacial events affecting the northwestern Antarctic Peninsula continental shelf: in: Cooper AK, Barker PJ and Brancolini G. Eds. Antarctic Research Series: Washington, D.C., American Geophysical Union, p. 74-95.

Bart PJ, Egan DC and Warny S. 2005. Direct constraints on Antarctic Peninsula Ice Sheet grounding events between 5.12 and 7.94 Ma, Journal of Geophysical Research – Earth Surface (110) doi:10.1029/2004JF000254.

Benninghoff, W. S. (1962). Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities.

Berggren, W. A., & Prothero, D. R. (1992). Eocene-Oligocene climatic and biotic evolution: an overview. *Eocene-Oligocene climatic and biotic evolution*, 1-28.

Birkenmajer, K., & Zastawniak, E. (1986). *Plant remains of the Dufayel Island Group (Early Tertiary?) King George Island, South Shetland Islands (West Antarctica)*.

Birkenmajer K. 1987. Oligocene-Miocene glacio-marine sequences of King George Island (South Shetland Islands), Antarctica. *Palaeontologia Polonica*, 49(1), p. 9-36.

Birkenmajer K. 1988. *Tertiary glacial and interglacial deposits, South Shetland Islands, Antarctica: geochronology versus biostratigraphy (a progress report)*.

Birkenmajer K. 1990. Geochronology and climatostratigraphy of tertiary glacial and interglacial successions on King George Island, South Shetland Islands (West Antarctica).

Birkenmajer K. 1992a. Trinity Peninsula Group (Permo-Triassic?) at Paradise Harbor, Antarctic Peninsula. *Studia Geologica Polonica,* 101, p. 7-25.

Birkenmajer K. 1992b. Trinity Peninsula Group (Permo-Triassic?) at Hope Bay, Antarctic Peninsula. *Polish Polar Research,* 13(3-4), p. 215-240.

Birkenmajer K. 2001. Mesozoic and Cenozoic stratigraphic units in parts of the South Shetland Islands and Northern Antarctic Peninsula (as used by the Polish Antarctic Programmes). *Studia Geologica Polonica*, 118, p. 5-188.

Birkenmajer K & Keller RA. 1990. Pleistocene age of the Peak Melville volcano, King George Island, West Antarctica. Bulletin, Polish Academy of Sciences, Earth Sciences 38, p. 17-24.

Birkenmajer K & Łuczkowska E. 1987. Foraminiferal evidence for a Lower Miocene age of glaciomarine and related strata, Moby Dick Group, King George Island (South Shetland Islands, Antarctica). *Studia Geologica Polonica*, 90, p. 81-123.

Birkenmajer K. & Zastawniak E. 1989. Late Cretaceous-early Tertiary floras of King George Island, West Antarctica: their stratigraphic distribution and palaeoclimatic significance. In Crame, J.A. (ed.), *Origins and Evolution of the Antarctic Biota,* Geological Society Special Publication No.47, p. 227-240.

Bowman VC, Francis JE, Riding JB, Hunter SJ and Haywood AM. 2012. A latest Cretaceous to earliest Paleogene dinoflagellate cyst zonation from Antarctica, and implications for phytoprovincialism in the high southern latitudes. *Review of Palaeobotany and Palynology*, 171, p. 40-56.

Brown C. 2008. Palynological Techniques. Edited by James Riding (U.K.) and Sophie Warny (LSU). AASP Special Publications. ISBN# 9780931871078. pp. 137.

Cantrill DJ. 1998. Early Cretaceous fern foliage referable to Lophosoriaceae from President Head, Snow Island, Antarctica. *Alcheringa,* 22, p. 241-258.

Davies BJ, Hambrey MJ, Smellie JL, Carrivick JL & Glasser NF. 2012. Antarctic Peninsula Ice Sheet evolution during the Cenozoic Era. Quaternary Science Reviews 31, p. 30-66.

De Witt, M., Jeffery, M., Bergh, H., & Nicolaysen, L. (1988). Geological map of sectors of Gondwana. In *American Association of Petroleum Geologists*. Tulsa Okla.

Deng X, Zheng X, Liu X, Ouyang S and Shen Y. 2002. Terrestrial palynomorphs from the Miers Bluff Formation of Livingston Island, West Antarctica. In: Gamble JA, Skinner DNB and Henrys S (eds.) Antarctica at the close of a millennium. *Royal Society of New Zealand Bulletin*, 35, p. 269-273.

Dettmann ME & Thomson MRA. 1987. Cretaceous palynomorphs from the James Ross Island area, Antarctica – a pilot study. *British Antarctic Survey Bulletin*, 77, p. 13-59.

Dickinson, H. G., & Heslop-Harrison, J. (1968). Common mode of deposition for the sporopollenin of sexine and nexine.

Dingle RV & Lavelle M. 1988. Antarctic Peninsula cryosphere: Early Oligocene (c. 30 Ma) initiation and a revised glacial chronology. Journal of the Geological Society, London 155, p. 433-437.

Dingle, R. V., McArthur, J. M., & Vroon, P. (1997). Oligocene and Pliocene interglacial events in the Antarctic Peninsula dated using strontium isotope stratigraphy. *Journal of the Geological Society*, *154*(2), 257-264.

Doktor M, Swierczewska A, and Tokarsi, AK. 1994. Lithostratigraphy and tectonics of the Miers Bluff Formation at Hurd peninsula, Livingston Island (West Antarctica). *Studia Geologica Polonica*, 104, p. 41-104.

Duane AM. 1994. Preliminary palynological investigion of the Byers Group (Late Jurassic-Early Cretaceous), Livingston Island, Antarctic Peninsula. *Review of Palaeobotany and Palynology*, 84, p. 113-120.

Duane AM. 1996. Palynology of the Byers Group (Late Jurassic-Early Cretaceous) of Livingston and Snow islands, Antarctic Peninsula: its biostratigraphical and palaeoenvironmental significance. *Review of Palaeobotany and Palynology*, 63, p. 1-11.

Duane AM. 1997. Taxonomic investigations of palynomorphs from the Byers Group (Upper Jurassic-Lower Cretaceous), Livingston and Snow islands, Antarctic Peninsula. *Palynology*, 21, p. 123-144.

Duane AM, Pirrie D and Riding JB. 1992. Palynology of the James Ross Island area, Antarctic Peninsula, Numerous authors, Special Issue, *Antarctic Science,* 4(3), p. 259-362.

Dutra TL & Batten DJ. 2000. Upper Cretaceous floras of King George Island, West Antarctica, and their palaeoenvironmental and phytogeographic implications. *Cretaceous Research*, 21, p. 181-209.

Dudziak J. 1984. Cretaceous calcareous nannoplankton from glaciomarine deposits of the Cape Melville area, King George Island (South Shetland Islands, Antarctica). *Studia Geologica Polonica*, *79*, p. 37-51.

Elliot, D. H., & Trautman, T. A. (1982). *Lower tertiary strata on Seymour island, Antarctic Peninsula*. Ohio State University, Institute of Polar Studies.

Feakins, S., Warny, S., and DeConto, Rob, 2014. Snapshot of cooling and drying before onset of Antarctic Glaciation. Earth and Planetary Science Letters, 404: 154-166. Fuenzalida H, Araya R and Hervé F. 1972. Middle Jurassic flora from north-eastern Snow Island, South Shetland Islands. In: Adie, R.J. (ed.), Antarctic Geology and Geophysics, Oslo, Universitetsforlaget, p. 93-97.

Galindo-Zaldívar, J., Gamboa, L., Maldonado, A., Nakao, S., & Bochu, Y. (2004). Tectonic development of the Bransfield Basin and its prolongation to the South Scotia Ridge, northern Antarctic Peninsula. *Marine Geology*, *206*(1), 267-282.

Gee CT. 1989. Revision of the Late Jurassic/Early Cretaceous flora from Hope Bay, Antarctica.

Griener, K. W., Nelson, D. M., & Warny, S. (2013). Declining moisture availability on the Antarctic Peninsula during the Late Eocene.*Palaeogeography, Palaeoclimatology, Palaeoecology*, *383*, 72-78.

Guterch A, Grad M, Janik T, Perkuć E and Pajchel J. 1985. Seismic study of the crustal structure in West Antarctica 1979-1980 – preliminary results. Tectonophysics 114, p. 411-429.

Haase KM, Beier C, Fretzdorff S, Smellie JL and Garbe-Schönberg D. 2012. Magmatic evolution of the South Shetland Islands, Antarctica, and implications for continental crust formation. Contributions to Mineralogy and Petrology 163, p. 1103-1119.

Hall, S. A. (1977). Cretaceous and Tertiary dinoflagellates from Seymour Island, Antarctica.

Hernandez PJ & Azcárate V. 1971. Estudio paleobotánico preliminary sobre restos de una tafoflora de la Península Byers (Cerro Negro), Islas Shetland del Sur, Antartica. *Serie Científica Instituto Antártico Chileno,* 2(1), p. 15-50.

Hunt RJ & Poole I. 2003. Paleogene West Antarctic climate and vegetation history in light of new data from King George Island. In S. L. Wing, P. D. Gingerich, B. Schmitz & E. Thomas (eds.) Causes and Consequences of Globally Warm Climates in the Early Paleogene. Boulder, Colorado. Geological Society of America Special Paper 369, p. 395-412.

Hoffman, S. M., & Elliot, D. H. (1991). *Petrology and provenance of the Paleocene strata at Cape Wiman, Seymour Island (Antarctic Peninsula).*

Hyden G & Tanner PWG. 1981. Late Paleozoic-Early Mesozoic fore-arc basin sedimentary rocks at the Pacific margin in western Antarctica. *Geologische Rundschau,* 70(1), p. 529-541.

Krajewski KP. 2013. Organic matter–apatite–pyrite relationships in the Middle Triassic Botneheia Formation of eastern Svalbard: Relevance to the formation of petroleum source rocks in the NW Barents Sea Shelf. Marine and Petroleum Geology 45, p. 69-105.

Krajewski KP, Tatur A, Pecskay Z, Molnar F, Mozer A and Zieliński G. in preparation. Transition from greenhouse (Eocene) to icehouse (Oligocene – Miocene) conditions on King George Island, West Antarctica.

Lear, C. H., Bailey, T. R., Pearson, P. N., Coxall, H. K., & Rosenthal, Y. (2008). Cooling and ice growth across the Eocene-Oligocene transition.*Geology*, *36*(3), 251-254.

Leppe M, Michea W, Muñoz C, Palma-Heldt S and Fernandoy F. 2007. Paleobotany of Livingston Island: The first report of a Cretaceous fossil flora from Hannah Point. *In* Antarctica: A Keystone in a Changing World. Online Proceedings of the 10^{th} ISAES, edited by Cooper AK & Raymond CR *et al*., USGS Open-File Report 2007-1047, Short Research Paper 081, 4p.; doi:10.3133/of2007-1047.srp081.

Liu, Z., Pagani, M., Zinniker, D., DeConto, R., Huber, M., Brinkhuis, H., & Pearson, A. (2009). Global cooling during the Eocene-Oligocene climate transition. *Science*, *323*(5918), 1187-1190.

Loske WP, Miller H and Kramm U. 1988. U-Pb systematic of detrital zircons from low-grade metamorphic sandstones of the Trinity Peninsula group (Antarctica). *Journal of South American Earth Sciences,* 1(3), p. 301-307.

Macdonald, D. I. M., Barker, P. F., Garrett, S. W., Ineson, J. R., Pirrie, D., Storey, B. C., & Marshall, J. E. A. (1988). A preliminary assessment of the hydrocarbon potential of the Larsen Basin, Antarctica. *Marine and Petroleum Geology*, *5*(1), 34-53.

Machado A, Limaa EF, Chemale FJr, Moratab D, Oteiza O, Almeida DPM, Figueiredod AMG, Alexandre FM and Urrutia JL. 2005. Geochemistry constraints of Mesozoic–Cenozoic calc-alkaline magmatism in the South Shetland arc, Antarctica. Journal of South American Earth Sciences 18, p. 407–425.

Macellari, C. E. (1988). Stratigraphy, sedimentology, and paleoecology of Upper Cretaceous/Paleocene shelf-deltaic sediments of Seymour Island.*Geological Society of America Memoirs*, *169*, 25-54.

Marenssi, S. A., Santillana, S. N., Net, L. I., & Rinaldi, C. A. (1999). Heavy mineral suites as provenance indicator: La Meseta Formation (Eocene), Antarctic Peninsula. *Revista de la Asociación Sedimentológica Argentina*, *5*(1), 9-19.

Marenssi, S. A., Net, L. I., & Santillana, S. N. (2002). Provenance, environmental and paleogeographic controls on sandstone composition in an incised-valley system: the Eocene La Meseta Formation, Seymour Island, Antarctica. *Sedimentary Geology*, *150*(3), 301-321.

Millar IL, Milne A and Whitham AG. 1990. Implications of Sm-Nd garnet ages for the stratigraphy of northern Graham land, Antarctic Peninsula. *Zentrallblatt für Geologie und Paläontologie*, 1, p. 97-104.

Mozer A. 2012. Pre-glacial sedimentary facies of the Point Thomas Formation (Eocene) at Cytadela, Admiralty Bay, King George island, West Antarctica. *Polish polar Research,* 33 (1), p. 41-62.

Mozer A. 2013. Eocene sedimentary facies in volcanogenic succession on King George Island, South Shetland Islands: a record of pre-ice sheet terrestrial environments in West Antarctica. *Geological Quarterly*, *57*(3), p. 385-394.

Mudie PJ. 1992. Circum-arctic Quaternary and Neogene marine palynofloras: paleoecology and statistical analysis. In: Head, M.J., and Wrenn, J.H. (eds.). Neogene and Quaternary Dinoflagellate Cysts and Acritarchs. American Association of Stratigraphic Palynologists Foundation, Dallas, p. 347–390.

Nawrocki J, Pańczyk M and Williams IS. 2010. Isotopic ages and palaeomagnetism of selected magmatic rocks from King George Island (Antarctic Peninsula). Journal of the Geological Society, London 167, p. 1063–1079.

Nawrocki J, Pańczyk M and Williams IS. 2011. Isotopic ages of selected magmatic rocks from King George Is land (West Antarctica) controlled by magnetostratigraphy. Geological Quarterly 55, p. 301–322.

Pankhurst RJ & Smellie JL. 1983. K–Ar geochronology of the South Shetland Islands, Lesser Antarctica: apparent lateral migration of Jurassic to Quaternary island arc volcanism. Earth Planetary Science Letters 66, 214–222Poole I & Cantrill DJ. 2001. Fossil woods from Williams Point Beds, Livingston Island, Antarctica: a Late Cretaceous southern high latitude flora. *Palaeontology,* 44, p. 1081-1112.

Poole I, Cantrill D and Utescher T. 2005. A multi-proxy approach to determine Antarctic Terrestrial palaeoclimate during the Late Cretaceous and Early Tertiary. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 222, p. 95-121.

Prothero, D. R., Ivany, L. C., & Nesbitt, E. R. (Eds.). (2003). *From greenhouse to icehouse: the marine Eocene-Oligocene transition*. Columbia University Press.

Prothero, D. R., & Berggren, W. A. (Eds.). (2014). *Eocene-Oligocene climatic and biotic evolution*. Princeton University Press.

Rees PM & Cleal CJ. 2004. Lower Jurassic floras from Hope Bay and Botany Bay, Antarctica. *Special Papers in Palaeontology,* 72, p. 5-90.

Rees PM & Smellie JL. 1989. Cretaceous angiosperms from an allegedly Triassic flora at Williams Point, Livingston Island, South Shetland Islands. *Antarctic Science,* 1(3), p. 239-248.

Riding JB & Crame JA. 2002. Aptian to Coniacian (Early-Late Cretaceous) palynostratigraphy of the Gustav Group, James Ross Basin, Antarctica. *Cretaceous Research,* 23(6), p. 739-760. doi:10.1006/cres.2002.1024.

Riding JB, Crame JA, Dettmann ME and Cantrill DJ. 1998. The age of the base of the Gustav Group, James Ross Basin, Antarctica. *Cretaceous Research,* 19, p. 87-105. doi:10.1006/cres.1998.0098.

Rieske, D. E. (1990). *The depositional environment, provenance and volcanic history of the Paleocene strata of the James Ross Island Basin, Antarctica* (Doctoral dissertation, The Ohio State University).

Sadler, P. M. (1988). Geometry and stratification of uppermost Cretaceous and Paleogene units on Seymour Island, northern Antarctic Peninsula. *Geological Society of America Memoirs*, *169*, 303-320.

Simpson, G. G. (1971). Review of fossil penguins from Seymour Island.*Proceedings of the Royal Society of London B: Biological Sciences*, *178*(1053), 357-387.

Smellie JL, Pankhurst RJ, Thomson MRA and Davies RES. 1984. The Geology of the Shouth Shetland Islands: VI. Stratigraphy, geochemistry and evolution. British Antarctic Survey Scientific Reports 87, p. 1-85.

Stock, J., & Molnar, P. (1987). Revised history of early Tertiary plate motion in the south-west Pacific. *Nature*, *325*(6104), 495-499.

Storey, B. C., & Nell, P. A. R. (1988). Role of strike-slip faulting in the tectonic evolution of the Antarctic Peninsula. *Journal of the Geological Society*, *145*(2), 333-337.

Stuchlik L. 1981. Tertiary pollen spectra from the Ezcurra Inlet Group of Admiralty Bay, King George Island (South Shetland Islands). *Studia Geologica Polonica*, 72, p. 109-132.

Thomson MRA. 1975. First marine Triassic fauna from the Antarctic Peninsula. *Nature,* 257, p. 577-578.

Torres T & Méon H. 1998. *Nothofagidites* Erdtman ex Potonié dans le Paléogène de l'Île Roi Georges, Antarctique. *Geobios*, 31 (4), p. 419-435.

Torres, T., Barale, G., Méon, H., Philippe, M., & Thévenard, F. (1997). Cretaceous floras from Snow Island (south Shetland Islands, Antarctica) and their biostratigraphic significance. *The Antarctic Region: Geological Evolution and Processes (Ricci, CA; editor). Terra Antarctica Publication Siena*, 1023-1028.

Troedson, A. L., & Riding, J. B. (2002). Upper Oligocene to lowermost Miocene strata of King George Island, South Shetland Islands, Antarctica: stratigraphy, facies analysis, and implications for the glacial history of the Antarctic Peninsula. *Journal of Sedimentary Research*, *72*(4), 510-523.

Troedson AL & Smellie JL. 2002. The Polonez Cove Formation of King George Island, Antarctica: stratigraphy, facies and implications for mid-Cenozoic cryosphere development. Sedimentology 49, p. 277-301.

Trouw RAJ, Pankhurst RJ and Ribeiro A. 1997. On the relation between the Scotia Metamorphic Complex and the Trinity Peninsula Group, Antarctic Peninsula. In: Ricci, C.A. (ed.), The Antarctic Region: Geological Evolution and Processes, Siena, Terra Antartica Publication, p. 383-390.

Wang F, Zheng XS, Lee JIK, Choe WH, Evans N and Zhu RX. 2009. A 40Ar/39Ar geochronology on a mid-Eocene igneous event on the Barton and Weaver peninsulas: Implications for the

dynamic setting of the Antarctic Peninsula. Geochemistry Geophysiscs Geosystems 10, Q12006, doi: 10.1029/2009GC002874.

Warny S, Wrenn JH, Bart PJ, Askin RE. 2006. Palynology of the NBP03-01A transect in Northern Basin, western Ross Sea, Antarctica: a Late Pliocene record. Palynology, 30, p. 151-182.

Warny S & Askin R. 2011a. Vegetation and organic-walled phytoplankton at the end of the Antarctic greenhouse world: latest cooling events. AGU Special Publication 63, p. 193-210. doi: 10.1029/2010SP000965.

Warny, S. and Askin, R., 2011b. Last remnants of Cenozoic vegetation and organic-walled phytoplankton in the Antarctic Peninsula's icehouse world. *AGU Special Publication* 63: 167-192. doi: 10.1029/2010SP000996.

Warny, S., Anderson, J. B., Londeix, L., & Bart, P. J. (2007). Analysis of the dinoflagellate cyst genus *Impletosphaeridium* as a marker of sea-ice conditions off Seymour Island: An ecomorphological approach (No. 2007-1047-SRP-079). US Geological Survey.

Wrenn JH & Hart GF. 1988. Paleogene dinoflagellate cyst biostratigraphy of Seymour Island, Antarctica. . In: Feldmann, R.M. and Woodburne, M.O. (eds.), Geology and paleontology of Seymour Island, Antarctic Peninsula, Geological Society of America, Memoir, 169, p. 321-447.

Zachos, J. C., Quinn, T. M., & Salamy, K. A. (1996). High-resolution (104 years) deep-sea foraminiferal stable isotope records of the Eocene-Oligocene climate transition. *Paleoceanography*, *11*(3), 251-266.

Zastawniak E. 1994. Upper cretaceous leaf flora from the Blaszyk Moraine [Zamek Fromation], King George Island, South Shetland Islands, West Antarctica. *Acta Palaeobotanica*, *34*(2), p. 119-163.

Zastawniak E & Szafer W. 1990. Late Cretaceous leaf flora of King George Island, West Antarctica. In *Procedures symposium: Palaeofloristic and palaeoclimatic changes in the Cretaceous and Tertiary*, p. 81-85.

Zastawniak E, Wrona R, Gazdzicki A and Birkenmajer K. 1985. Plant remains from the top Part of the Point Hennequin Group (Upper Oligocene), King George Island (South Shetland Islands, Antarctica). *Studia Geologica Polonica,* 81, p. 143-164.

Zinsmeister, W. J. (1977). Note on a new occurrence of the Southern Hemisphere aporrhaid gastropod Struthioptera FINLAY & MARWICK on Seymour Island, Antarctica. *Journal of Paleontology*, 399-404.

APPENDIX

Palynological plates used for Late Eocene and Middle Oligocene palynology and climate trends in the Antarctic Peninsula

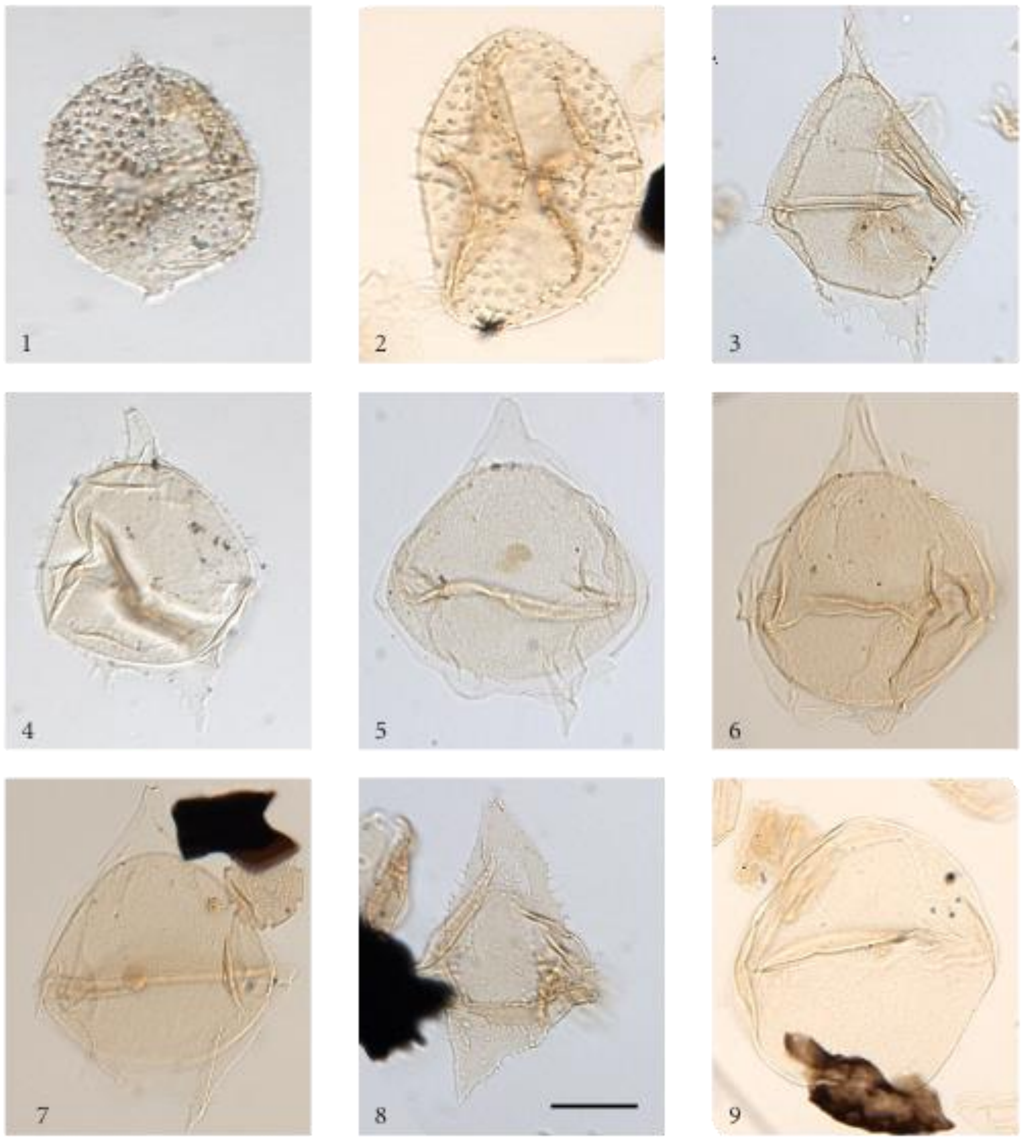

Plate 1. Light photomicrographs of dinoflagellate cysts specimens from the upper La Meseta Formation, Seymour Island, Antarctica. All images were taken at 60x. Black bar measures 20 μm. 1. *Vozzhennikovia rotunda* (sample D6-01 6.3x117.8) *in situ*, 2. *Vozzhennikovia apertura* (sample D6-03 16.0x139.1) *in situ*, 3. *Spinidinium macmurdoense* (sample D6-12 14.6x144.9) *in situ*, 4. *Spinidinium* cf. *macmurdoense* (sample D6-02 6.4x142.0) *in situ*, 5-7. *Senegalinium asymmetricum* (5. Sample D6-11 17.3x142.3; 6. Sample D6-09 14.1x144.4; 7. Sample D6-08 15.0x139.8) *in situ*, 8. *Spinidinium lanterna* (sample D6-11 17.3x145.4) reworked, 9. ?*Manumiella* sp. 3 (sample D6-05 15.1x138.7) reworked.

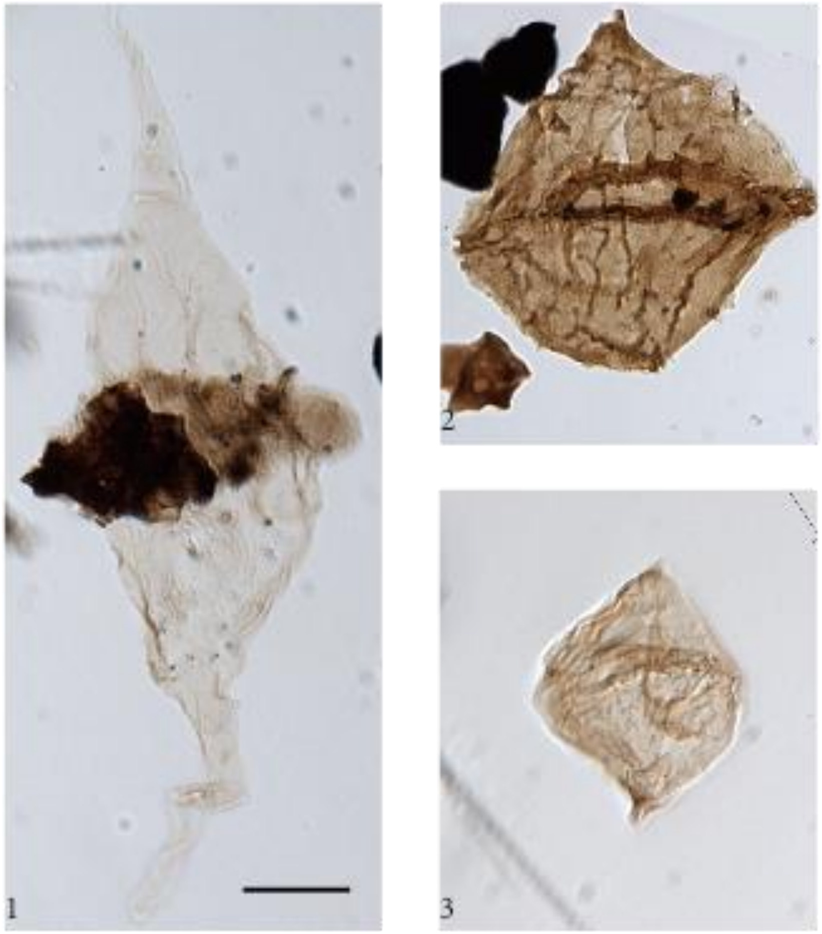

Plate 2. Light photomicrographs of dinoflagellate cysts specimens from the upper La Meseta Formation, Seymour Island, Antarctica. All images were taken at 60x. Black bar measures 20 µm. 1. *Paleocystodinium golzowense* (sample D6-13 15.4x138.2) reworked, 2. *Phelodinium* sp. (sample D6-13 15.4x138.2) reworked, 3. *Diconodinium cristatum* (sample D6-04 6.5x119.3) reworked.

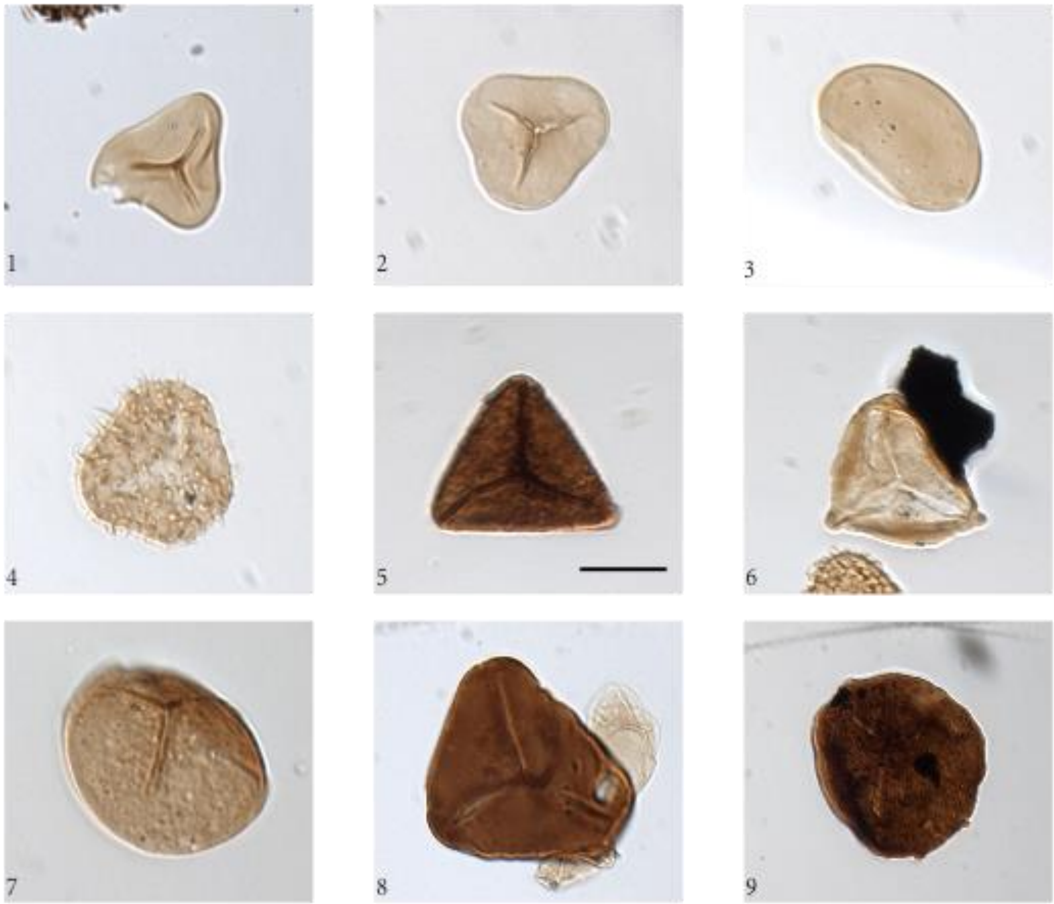

Plate 3. Light photomicrographs of trilete spores from the upper La Meseta Formation, Seymour Island, Antarctica. All images were taken at 60x. Black bar measures 20 μm. 1-2. *Cyathidites minor* (1. Sample D6-13 15.3x142.0; 2. Sample D6-03 7.8x127.2) *in situ*, 3. *Laevigatosporites ovatus* (sample D6-01 11.5x116.3) *in situ*, 4. *Acanthotriletes teretangulatus* (sample D6-05 4.2x146.0) reworked, 5. *Leiotriletes directus* (sample D6-01 13.5x138.8) reworked, 6. *Clavifera triplex* (sample D6-02 6.4x143.8) reworked, 7. *Punctatisporites* sp. (sample D6-01 4.8x132.1) reworked, 8. ?*Dictyophyllidites* sp. (sample D6-06 11.9x133.6) reworked, 9. *Punctatisporites* sp. (sample D6-01 4.9x144.2) reworked.

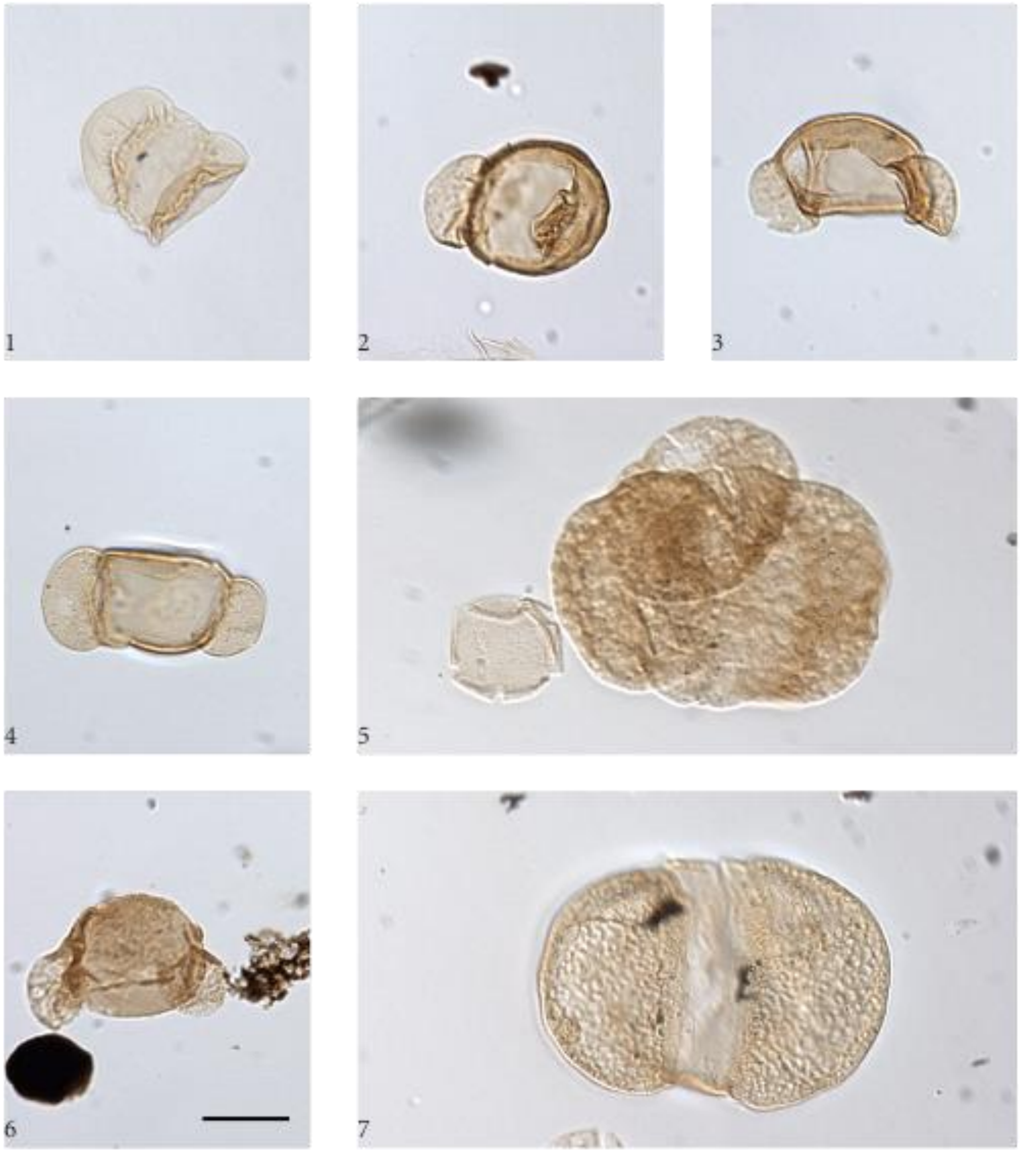

Plate 4. Light photomicrographs of gymnosperm specimens from the upper La Meseta Formation, Seymour Island, Antarctica. All images were taken at 60x. Black bar measures 20 μm. 1. *Phyllocladidites* sp. Cf. *P. exiguous* (sample D6-08 13.3x147.6) *in situ*, 2-4. *Phyllocladidites* sp. (2. Sample D6-05 15.1x138.7; 3. Sample D6-09 16.5x135.9; 4. Sample D6-08 13.4x148.5) reworked, 5. Large bisaccate is a taeniate *Protohaploxypinus* sp. (sample D6-13 15.2x140.6) reworked, 6. *Phyllocladidites* ?*mawsonii* (sample D6-03 3.7x133.1) reworked, 7. *Alisporites* sp. (sample D6-03 3.9x128.0) reworked.

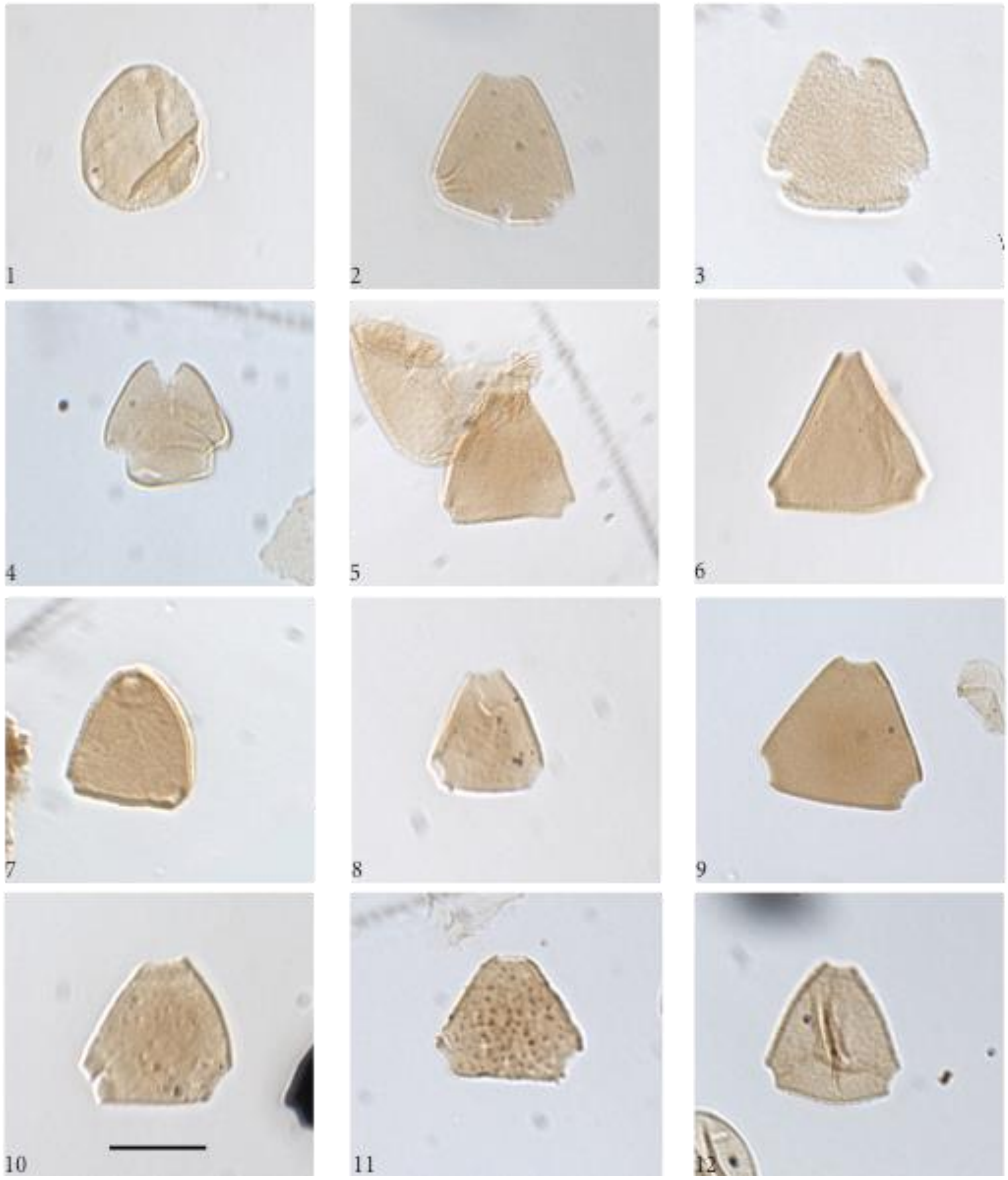

Plate 5. Light photomicrographs of angiosperms from the upper La Meseta Formation, Seymour Island, Antarctica. All images were taken at 60x. Black bar measures 20 μm. 1. *Myricipites harrisii* (sample D6-01 14.2x119.4) *in situ*, 2. *Proteacidites* sp. Cf. *P. parvus* (sample D6-01 13.4x143.9) *in situ*, 3. *Peninsulapollis askiniae* (sample D6-09 16.2x147.3) *in situ*, 4. *Peninsulapollis gillii* (sample D6-03 3.4x144.4) *in situ*, 5-8. *Proteacidites* spp. (5. Sample D6-03 8.0x142.7 (*in situ*); 6. Sample D6-03 8.0x143.4 (*in situ*); 7. Sample D6-05 4.2x139.8 (*in situ*); 8. Sample D6-03 i.0x130.9 (reworked)), 9. *Proteacidites* sp. (sample D6-02 6.5x128.7) reworked, 10. *Propylipollis subscabratus* (sample D6-02 6.5x128.7) reworked, 11. *Proteacidites* sp. (sample D6-10 17.3x132.2) reworked, 12. *Proteacidites* sp. (sample D6-08 13.7x142.5) reworked.

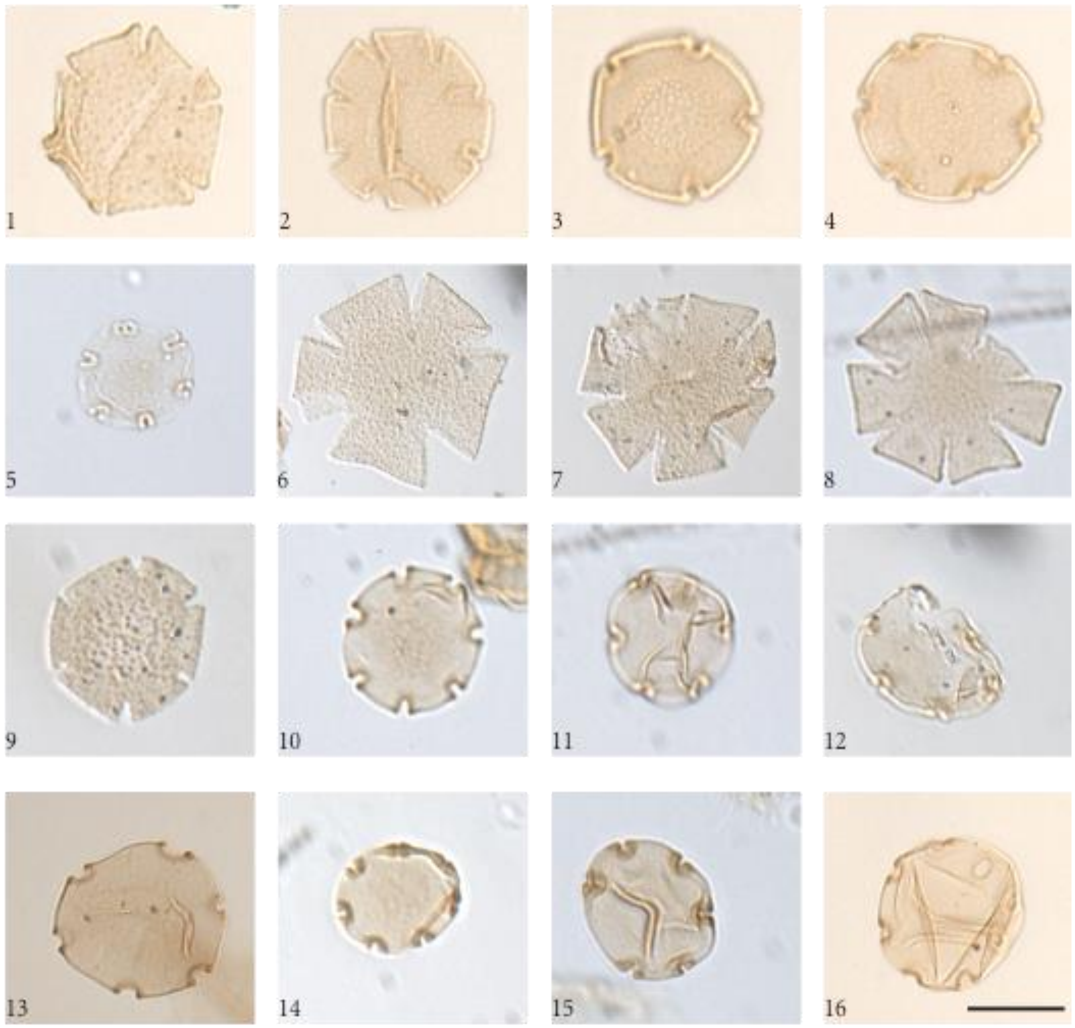

Plate 6. Light photomicrographs of *Nothofagidites* spp. angiosperms from the upper La Meseta Formation, Seymour Island, Antarctica. All images were taken at 60x. Black bar measures 20 μm. 1. *Nothofagidites mataurensis* (sample D6-05 4.1x143.5) *in situ*, 2. *Nothofagidites* sp. (sample D6-05 14.2x140.6) *in situ*, 3-5. *Nothofagidites rocaensis-saraensis* complex (3. Sample D6-05 14.4x136.2; 4. Sample D6-08 15.9x141.7; 5. Sample D6-09 16.2x139.1) *in situ*, 6-8. *Nothofagidites* sp. Cf. *N. asperus* (6. Sample D6-11 15.5x117.5; 7. Sample D6-01 6.4x120.4; 8. Sample D6-01 11.4x113.6) *in situ*, 9. *Nothofagidites lachlaniae* (sample D6-03 15.9x134.6) reworked, 10-16. *Nothofagidites rocaensis-saraensis* complex (10. Sample D6-07 13.2x141.8; 11. Sample D6-11 15.5x125.3; 12. Sample D6-01 11.5x131.1; 13. Sample D6-05 14.9x137.3; 14. Sample D6-05 6.1x125.5; 15. Sample D6-12 14.8x143.2; 16. Sample D6-09 13.2x121.8) reworked.

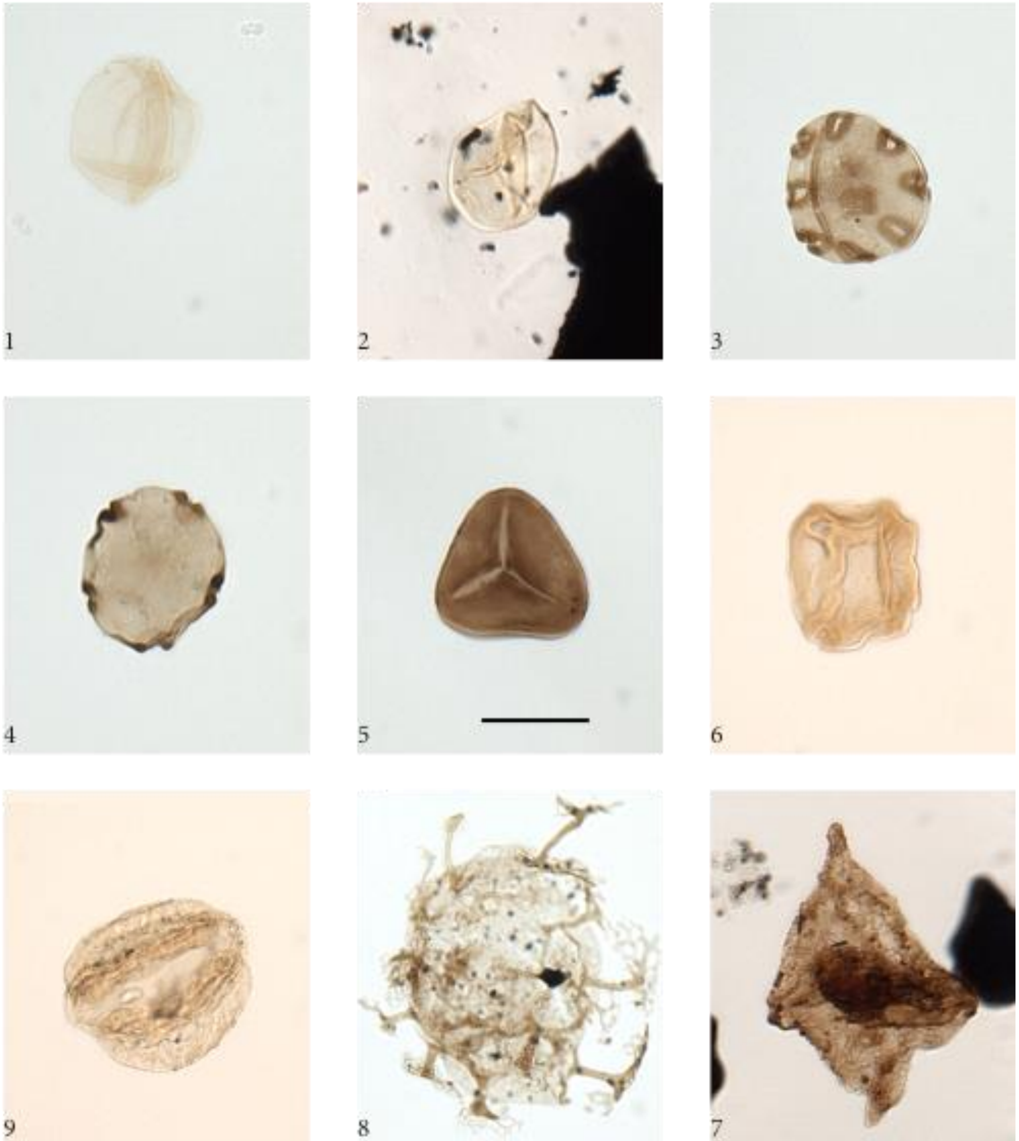

Plate 7. Light photomicrographs of mostly reworked samples collected from the Polonez Cove Formation, King George Island, Antarctica. All images were taken at 60x. Black bar measures 20 µm. 1-2. *Leiosphaeridia* spp. (1. Sample G-13 12.1x141.0; 2. Sample KGLMb-2 10.7x137.6) *in situ*, 3-4. *Nothofagidites rocaensis-saraensis* complex (3. Sample K-1 17.8x116.4; 4. Sample K-1 17.8x128.4) reworked, 5. *Cyathidites minor* (sample K-1 14.6x131.7) reworked, 6. ?*Haloragacidites* sp. (sample L-5 8.1x132.9) reworked, 7. *Podocarpidites* sp. (sample L-5 11.1x133.1) reworked, 8. *Reticulatosphaera actinocoronata* (sample K-1 9.3x121.1) *in situ*, 9. *Diconodinium* sp. (sample KGLMb 13.9x143.1) reworked.

VITA

Madison Kymes was born in Shreveport, Louisiana but spent the majority of his life in Madison, Mississippi. He graduated from Louisiana State University in Baton Rouge, Louisiana in 2013 with a B.S. in Geology and a minor in Anthropology. After completing his Master's, he plans to pursue a job in environmental geology.