A polar paradise: the glaciation of South Victoria Land, Antarctica
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CHAPTER 1: INTRODUCTION

1.1 Terra Incognita

Antarctica is unique among continents, being the world’s most windy, cold, arid and high land-mass and the last pristine environment on Earth. However, it is rarely in the forefront of people’s minds, and few popular maps illustrate its full extent. Despite this, Antarctica is a significant component of the global climate system (Fig. 1) as recognised in general circulation models (Sloan et al., 1996). The massive East Antarctic Ice Sheet (EAIS) holds approximately 70m of sea level equivalent and influences sea ice formation and oceanic-atmospheric circulation far beyond its land mass.

Antarctica acts as a major heat sink for the Earth, with transfer of heat from the tropics to the poles. For example, Taylor Valley and the Allan Hills (Fig. 2) receive approximately 40% less radiation per year than equatorial regions. As a result the polar regions are highly sensitive to global climate change and it remains critical that we continue to improve our understanding of Antarctica due to the inevitability of climate change (Alley, 2000).

1.2 Global climate change and Antarctica

The third assessment from the Intergovernmental Panel on Climate Change (IPCC) at the turn of this century, announced that latest modelling results project a rise in average global temperature from CO$_2$ emissions of between 1.4°C and 5.8°C by the end of this century (Barrett, 2001). The degree to which humans are to blame for climate change and increases in CO$_2$ remains open to speculation, because climate change is a natural phenomenon well established in the geologic record. Therefore, to understand how the global climate system works, an understanding of the polar regions in general, and Antarctica in particular, is crucial.

One aspect of obtaining this knowledge is through the use of ice-cores that provide a detailed record of temperature, precipitation and composition of the atmosphere. Records in central Antarctica go back as far as 400,000 years, but this is a relatively short time geologically speaking because
Fig. 1  Planet Earth demonstrating the polar position of the Antarctic. Antarctica significantly contributes to the global climate system, acting as a crucial heat sink for excess radiation received in equatorial regions.

Fig. 2  The Antarctic Continent. Note the position of South Victoria Land, and the two key study sites referred to in the thesis: Taylor Valley and the Allan Hills. Note also the flight path to and from Antarctica and New Zealand.
global climate in 50 years time might be warmer than anything Earth has experienced in the last 12 million years (Barrett, 2001). The second avenue of investigation lies in the layers of sediment eroded over millions of years from the Antarctic continent, which have then been deposited in sedimentary basins off its coastline. This has lead to numerous drilling operations along the Antarctic continental margin, which most notably included the highly ambitious and successful Cape Roberts Project. A summary of the results from this project are shown in Fig. 3 and essentially demonstrate a steady decline in climate towards colder conditions over the last 34 million years. The relevance that this has to the 'man on the street' is that Earth's climate is predicted to be 3 to 4 degrees warmer in one hundred years time; and the last occasion the planet experienced temperatures as warm as this, was 20 to 30 million years ago (Fig. 3).

1.3 Glaciers and Glaciation

Appreciation of glaciers and glaciation is also of wider significance because Earth could be viewed essentially as a Glacial Planet, which occasionally experiences conditions similar to the warmer periods of today (Menzies, 2002). Almost all aspects of life on Earth have been affected by previous glaciations, from the distribution of early humans and animals through to biodiversity and landscape fertility. In January 2001 the Economist published an article titled 'The Great Ice-Age Division' where they even correlated American political demographics to the distribution of glacial deposits and former ice-masses. The understanding of past glaciers and glaciation becomes more potent in relation to potential global sea level rise as a result of climatic warming and ice sheet deterioration. However, the causal links between these two processes remains the subject of considerable controversy (Kasting, 1993).

In many respects all glaciers could be viewed as filters which translate a complex climate signal into a relatively simple landform record (Kirkbride and Brazier, 1998). So in examining Antarctic glacial landscapes and sediments considerable knowledge may be gleaned from both past glacial events and the environments and climates that shaped them. In this way, and by looking through the 'glacial lens', we gain a perspective on Antarctica's natural history.
Chapter 1

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25 to 34 Million Years Ago

Photo 3: Low woodland vegetation with ice calving into open water, southern Chile. Inferred for coastal Victoria Land between 25 to 34 million years ago. Estimated average summer monthly temperature; +10 to +12 degrees C. (Photo: H. Morgan)

Fig. 3  The log of the 1500m of strata cored by the Cape Roberts Project, showing their ages and main features (from Barrett, 2001; printed with author’s permission). The photographs on the right compare the present day cold and frozen Antarctic landscape of coastal Victoria Land, with how it would have appeared 17-25 million years ago (herb-tundra vegetation) and 25 to 34 million years ago (low woodland vegetation and ice calving into open water). The global temperatures that created this environment are projected to return by 2100 (Barrett, 2001; 2003).
However, one perspective that has been relatively neglected, in our quest to discover the ‘ground truth’ of Antarctica’s natural history, is a terrestrial record reflecting the character of Antarctic glaciation over time. This is partially because much time and energy have been invested into the mentioned ice-core records, continental shelf drilling campaigns and the ‘Sirius debate’ (Miller and Mabin, 1998 and references therein), which argues for and against mid-Pliocene EAIS collapse.

1.4 Glaciation of Antarctica-the big picture

The glaciation of Antarctica spans a long period as best illustrated in Fig. 3. Continental glaciation began as early as the Oligocene-34 million years ago, while mountain glaciation must have existed earlier at some point from the early Tertiary onwards. This sudden, widespread glaciation of Antarctica is one of the most fundamental reorganizations of global climate found in the geologic record (DeConto and Pollard, 2003). The reasons for this have been attributed to the thermal isolation of Antarctica with the tectonic opening up of the southern ocean and formation of the Antarctic Circumpolar Current (Kennett, 1977). However, DeConto and Pollard (2003) recently published a model indicating that the decline in atmospheric CO₂ was the primary stimulant for Antarctic wide glaciation. Furthermore, despite the current stability of the Antarctic ice sheets, glacioecigenic evidence points towards a more dynamic and temperate past over the Palaeogene (Barrett et al., 1987) where Antarctic ice sheets were paced by Milankovitch orbital parameters (Naish et al., 2001; Grützner et al., 2003). Still, when trying to understand the character of Antarctic terrestrial glaciation, the recognition of a set of features indicating glacial deposition at a particular place and point in time might be relatively straightforward, whereas the actual employment of glacial deposits to reconstruct a history for the nature of continental ice cover is more challenging (Barrett, 1997).

However, by use of micromorphology this project attempts to use a tool that will help reveal aspects of Antarctic glacial character and history on the local scale of South Victoria Land. Micromorphology has quietly revolutionized glacial sedimentology and has proved effective in differentiating between diamictons of different origin from many locations across the globe including Antarctica (van der Meer and Hiemstra, 1998; Hiemstra, 2001; van der Meer et al., 2003a).
1.5 *Glaciation of South Victoria Land, its nature and history*

This thesis aims to report on aspects of Antarctic glaciation in South Victoria Land (Fig. 2), which inevitably has wider implications for Antarctica's glacial nature and record. In turn this adds to the bigger picture of Antarctica's natural history and thus contributes to our understanding of how global environmental change operates.

Chapter 2 and 3 are brief methodological chapters. Chapter 2 provides an overview of the various techniques used. The primary technique is of course micromorphology, even though this involved extensive field work in the Transantarctic Mountains (TAMs) in order to collect the diamictic material. Moreover, micromorphology is supported by textural and (clay-) mineralogical analysis and these are described. The reason for supplementary support is that clay and carbonate content, as well as clay mineralogy, are of importance when interpreting micro-structures (van der Meer, 1996).

Chapter 3 reports the pre-impregnation of friable, diamictic material in the polarfield, a cheap, straightforward and effective method easily employed in other climates. Indeed, rate of induration appears related to ambient temperature, so its effectiveness is likely to be increased in lower latitudes.

Chapter 4 provides an introduction to the issue of cold-based glacial (in)activity. Conventional wisdom states that cold-based glaciers are basally inert, whereas recent developments in glaciology, followed by the three case studies from South Victoria Land provide evidence to the contrary. This chapter also 'paves the way' for chapter 5.

Chapter 5 documents first hand evidence for cold-based glacial erosion, deposition and glacitectonism in the Allan Hills, South Victoria Land, during the Last Glacial Maximum (LGM). Additionally, these features are discussed in terms of their preservation potential and perceived absence in the Quaternary record. A map documenting the complete range of features hitherto attributed to cold-based glacial activity in the Allan Hills, is the central linchpin of the chapter.

Chapter 6 is a micromorphological analysis of a cold-based till deposited in the Allan Hills, which we informally propose to be the Manhaul tectomict.
The study of thin sections allowed 'in situ' analysis regarding the style of cold-based subglacial tectonic formation as well as diagenetic alteration.

Chapter 7 is another micromorphological study, but this time at the lower elevation of Taylor Glacier in the Dry Valleys. The study investigates glacigenic processes and sediments at the glacier terminus and evaluates its status as a classic site for sublimation till.

Chapter 8 returns to the Allan Hills and discusses evidence for a warmer and more dynamic glacial regime in the distant past. This is reflected by impressive glacitectonised bedrock structures and their role in local till formation.

Chapter 9 continues along the theme of chapter 8, and takes a micromorphological view of subglacial clastic dykes and a tillite wedge pertaining to a wetter and equally dynamic glacial past. The identification of several micro-WESs within the clastic dykes themselves provide a unique perspective into the mode of their formation, and thus by deduction, the nature of the ice masses that created them.

Chapter 10 is the conclusion that recapitulates this thesis.

Finally, this thesis is part of the wider N.W.O (The Netherlands Organisation for Scientific Research) funded Antarctic project on the micromorphology of Antarctic glacigenic deposits and their bearing upon Antarctic glaciation. The project comprises present day glacimarine sediments (Hiemstra, 2001), older glacial events such as that investigated by the CIROS core (Hiemstra, 1999) and Cape Roberts Project (van der Meer and Hiemstra, 1998; van der Meer, 2000). Both these drilling campaigns were situated off coastal Victoria Land. Finally, there is this project, with its contribution of studies covering present day terrestrial and Late Tertiary glacigenic deposits. In the future, further research will continue into the Sirius Group and older sequences of the Cape Roberts Project core.
“I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.”

Sir Isaac Newton, 1643-1727