A polar paradise: the glaciation of South Victoria Land, Antarctica
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SUMMARY

Antarctica is unique among continents, being the world’s most windy, cold, arid and high land-mass and the last pristine environment on Earth. The substantially lower radiation levels received by Antarctica, means that it is highly sensitive to global climatic change. Consequently, it remains critical that we improve our understanding of Antarctica’s nature and past, so to enhance predications regarding its future under inevitable climatic change. For example, the Intergovernmental Panel on Climate Change have announced that recent modelling results project a rise in average global temperature from CO\textsubscript{2} emissions of between 1.4°C and 5.8°C by the end of this century.

Appreciation of glaciers and glaciation is also of wider significance because Earth could be viewed as a Glacial Planet, which occasionally experiences conditions similar to the warmer periods of today. Moreover, glaciers are essentially filters that translate a complex climate signal into a relatively simple landform record. The investigation of this record allows a ‘backward glance’ into the environmental conditions under which the glacier once existed. Micromorphology is the technique employed in this thesis, because it has proven to be highly effective in gleaning information from glacially induced landform records.

The field methods used in this study (chapter 2) follow conventional micromorphological sampling techniques, but two new methods are also instigated. Firstly, the Stihl TS 400\textsuperscript{©} angle grinder proved effective in ambient temperatures as low as -30°C when sampling semi-lithified tillites. In contrast, the Stihl handheld drill core was ineffective as there was no way it could remove the gouge as it drilled. Secondly, a ‘field laboratory’ technique is developed (chapter 3), which allows sufficient induration of diamicots in the polar field. The primary laboratory technique used in this thesis is micromorphology, although particle size analysis, clay mineralogical analysis and differential thermal analysis are also employed in a supportive role.

Chapters 4 and 5 provide evidence for cold-based glacial activity in South Victoria Land, Antarctica. Chapter 4 reviews recent developments in glaciology and three case studies of cold-based glacial activity. These findings challenge the conventional view that cold-based glaciers are basally inactive because basal sliding does not occur. The three case studies differ in several respects, such as the scale of cold-based activity, the environmental context and type of overridden substrate. Chapter 5 is a research paper providing new evidence from the Allan Hills, which confirms that cold-based glaciers are capable of erosion, substrate deformation and deposition. Four types of erosion, three types of deposition and three scales of glacial tectonism resulting from cold-based glacial advance during the Last Glacial Maximum (LGM) are described. A model derived from these observations and those of advancing cold-based glaciers elsewhere is also proposed. The model entails: (i) ice block apron
overriding and entrainment and, (ii) ice bed separation leading to the formation of a cavity on the down-glacier side of escarpments. The model is most effective for a horizontally stratified, lithified sedimentary bedrock substrate. The preservation potential for cold-based glacial features is also discussed, and found to be high in polar climates (e.g. Antarctica) but very low beyond on account of the more rapid weathering in sub-polar or temperate climates. This explains the perceived absence of cold-based glacial features in the Pleistocene record of today’s temperate regions that most likely experienced cold-based glaciation during past glacial maxima.

Chapter 6 takes a close look at a cold-based tectonic by use of micromorphology. The tectonic is found in the Allan Hills, and is the result of an advance of the cold-based Manhaul Bay Glacier during the LGM. The descriptions reveal many features recognisable in temperate subglacial tills, but the difference lies in the style of deformation: the cold-based Manhaul till is dominated by a planar style whereas temperate tills are normally characterised by rotational deformation. A model, compatible with both field and micromorphological observations is described for Manhaul tectonic formation. Another micromorphological observation is that all Manhaul tectonic samples have been subjected to extensive post-depositional alteration despite the stable, polar arid environment in which they were collected. This again has implications regarding their preservation potential.

Chapter 7 is another micromorphological study set in the warmer and lower elevation Dry Valleys of South Victoria Land. Here the terminus of Taylor Glacier is widely regarded as one of the classic sites for sublimation till: the rarest till on Earth. The till is thought to cap ice-cored thrust moraines which are positioned as arcuate ridges flanking the north-eastern and south-eastern sides of Taylor Glacier snout. Field observations and thin section analysis of spatially varied till deposits around the glacial snout, reveal a dynamic sedimentological history, but no sublimation till. Therefore, sublimation till is presumed to only exist at Taylor Glacier terminus on theoretical grounds. In contrast, four other sediment types are identified in thin section from the relatively small area of Taylor Glacier terminus. These are: (i) aeolian fines, (ii) meltout till, (iii) meltout till that has experienced syn- and/or post-depositional flow and (iv) deformed proglacial lacustrine deposits. Furthermore, ~100μm thick clay coatings observed around grains in thin section are proposed as evidence for meltout till, and the high salt and carbonate content in the moraines at Taylor Glacier terminus severely inhibit plasmatic fabric birefringence. Finally, the chapter concludes that Taylor Glacier terminus should no longer be regarded the classic sublimation till site.

Chapter 8 returns to the Allan Hills and describes 22 glacitectonised bedrock sections and discusses their significance in terms of tectonic processes and regimes. This is especially pertinent because relatively few studies have focused on glacitectonised bedrock and its role in subglacial processes and local till production. A further objective of the chapter is to
provide an initial proposal for palaeo ice sheet flow in the Allan Hills, by combining strike and dip measurements from glacitectonised bedrock and striae data. Glacitectonic structures are readily distinguished from those of the ‘original’ bedrock geology, and are found to be formed primarily by subglacial simple shear. Examples include the first time reporting of clastic dykes from Antarctica, which are also diagnostic of high subglacial pressures and wet conditions. Fracturing is found to be the first stage in bedrock glacitectonism, and all sandstone cycles overlying brecciated beds are not in situ, but are proposed to have been horizontally displaced by overriding ice masses. It is further suggested that bedrock glacitectonism significantly contributes to local till production; but without direct glacial ice contact. The final conclusion is that former Neogene ice sheet(s) depositing the Sirius Group at Allan Hills flowed from the south(west) to north(east) and were warm-based.

Chapter 9 combines micromorphology and field observations so to investigate the clastic dykes and tillite wedges observed in the Allan Hills. This is of significance because hitherto clastic dykes and tillite wedges have not been reported from Antarctica. Moreover, their occurrence and connection with the wet-based Sirius Group tillite represents the existence of a more dynamic East Antarctic Ice Sheet (EAIS) in the past. This is in stark contrast to the stable ice sheet-landscape configuration that has remained relatively inactive throughout the Quaternary. Thin section analysis of the clastic dyke sediments, reveals evidence for rotational deformation and syn- or post-depositional brittle deformation; but no tillite. Additionally, the combination of extensive, diverse micro-Water Escape Structures (micro-WESs) with large, isolated turbates, grain lineations and a laminar, imbricate fabric are tentatively regarded as diagnostic for clastic dyke sediments examined in thin section. In contrast, the tillite wedge thin sections express evidence for subglacial shearing. The occurrence of complex three-dimensional micro-WESs is inferred to be the result of a pressure gradient generated by forceful dewatering in an unfrozen aquifer. This suggests that impermeable tills have the potential to drain large fluxes of subglacial meltwater downward and laterally. Field observations of downward tapering, bedrock-penetrating clastic dykes and tillite wedges are also compatible with such inferences, and the scale of the EAIS is comparable to that of former Pleistocene ice sheets. Moreover, field observations conclude that caution should be exercised when assessing clastic dyke strike in section view, as they tend to spread laterally. Finally, the particle size and clay mineralogy points towards a local genesis for the Allan Hills Sirius Group tillite, which contains rare swelling micas.

In conclusion, when studying contemporary glacial environments of South Victoria Land, Antarctica, a significant amount of information has been obtained in relation to its glacial nature and history. In essence, the new contribution that this thesis brings to the Antarctic Earth Sciences community and society at large is as follows:
Micromorphology has survived the ‘Antarctic terrestrial test’ and remains an effective tool in differentiating between diamictons of different origin.

Evidence is presented for cold-based glacial activity and tectomict formation. It is hoped that further research in ice free regions of the continent will verify this conjecture.

As the ‘classic sublimation till’ site of Taylor Glacier terminus is challenged, in one of the most arid and cold places on Earth, its current existence on our planet must be questioned.

Glacitectonised bedrock and clastic dykes relating to former glaciations that deposited the Sirius Group in the Allan Hills, demonstrate a warmer, wetter and more dynamic past in Antarctica. The timing of this is still an ongoing debate.

The above findings confirm that the Antarctic is a dynamic and changing environment. The more we understand its history, the better the profile on the continent’s nature and character. In this way a ‘ground truth’ is provided, that improves our predictions regarding inevitable climatic and environmental change, and in turn supplements a framework for environmental stewardship.