THE LAW DOME ICE CAP AND WINDMILL ISLANDS, EAST ANTARCTICA:

A GRAVITY-BASED STUDY OF ICE MASS BALANCE AND SUBGLACIAL GEOLOGY

By

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ABSTRACT

The Law Dome ice cap is a small to medium sized ice cap, approximately 200 km across, situated on the periphery of the East Antarctic Ice Sheet at 67°S 113°E. The Law Dome ice cap is separated from the East Antarctic Ice Sheet by a deep trench system, the Totten-Vanderord Trench, which diverts the flow on ice from inland around Law Dome rather than onto the ice cap. This process results in Law Dome's ice mass input, or ice accumulation regime, to solely be in the form of snowfall accumulation. Hence, Law Dome provides an ideal model to study the mass budget of ice caps in East Antarctica in the form of a relatively small ice cap allowing for feasible spatial survey coverage near a scientific research station – Australia's Casey Station.

During the Antarctic summer field season of 2004/05, gravity measurements were observed across the Law Dome ice cap and adjacent Windmill Islands. The primary objective of the Law Dome ice cap gravity survey was to re-occupy previously established gravity stations to continue the time-series gravity database and deduce changes in gravity with time across the ice cap (dg/dt). The dg/dt can be directly transformed to the change in ice surface height of each gravity site (dh/dt) such that snowfall accumulation rate trends could be established dating back to the early 1960's. For consistency, the same Lacoste and Romberg G-model gravity meters which were utilised for many of the previous surveys were again used during the 2004/05 gravity survey. The secondary objective of the Law Dome gravity survey was to process the data to generate a Bouguer gravity map of Law Dome and its surrounding environs such that a subglacial geological interpretation could be inferred. A gravity survey of the Windmill Islands on the west coast of Law Dome was carried out with the aim of modelling the various subsurface igneous and metamorphic rock units of the area.

Gravity data has been collated from each of the several gravity surveys on Law Dome dating back to 1962. Where sufficient data and information about the surveying practices are available, the data has been reprocessed in a consistent way such that each measurement at a specific site is comparable for the dg/dt analysis. The longest and most consistent gravity time-series history is in the northern central region of the ice where the majority of surveys ventured for measurements. In this region the snowfall accumulation trends have been deduced which correlate very well with ice core isotope analysis studies. Results from this study indicate that during the 1960's, the ice cap was undergoing a period of lower than average snowfall rates which in turn caused a lowering of the snow/ice surface and effectively thinning of the ice cap. A transition in atmospheric conditions is proposed to have occurred at approximately 1970 when a shift towards higher than average snowfall rates caused surface height rise and in turn causing ice cap thickening. Measurements recorded at Law Dome summit indicate lowering on the scale of 0.4 m/yr during the 1960's, and an average surface rise rate of more approximately 0.1 m/yr post-1970 to 2005. The results also indicate that the snow surface rise rate was fastest during the 1970's, comparable to the lowering rate observed during the 1960's, and has subsequently decelerated to a slower rate from the mid 1980's onwards.

An updated sub-glacial geological interpretation has been inferred using all available gravity data from this study in conjunction with airborne and satellite derived gravity and magnetic data, ice radar sounding derived bedrock topography data, sparse 2D seismic data, geological mapping and geophysical maps from SW Western Australia (the Gondwana reconstruction junction), and geological and gravity data from the adjacent Windmill Islands. Akin to the ice surface topography, the subglacial bedrock topography is also a dome-like structure. The bedrock is typically above sea-level beneath Law Dome, however, to the south a large deep trench is imaged from by seismic data. It is proposed that this trench is a down-thrown crustal block, possibly bounded by normal faults. It is also feasible that smaller scale normal faulting has developed east-west trending graben and horst structures further to the north across the bedrock dome. The Bouguer gravity indicates regions of low gravity which are hypothesized as being felsic or granite igneous/metamorphic provinces, whilst large high gravity anomalies are inferred to be very high density mafic/ultramafic igneous/metamorphic provinces. Upon observation of the sparse magnetic data available, these inferences are strongly supported by the magnetic susceptibility anomalies.

The aim of the Windmill Islands gravity survey was to investigate the subsurface geology of the Windmill Islands area. Ninety seven gravity stations were established. Additionally, 49 observations from a survey in 1993-94 were re-reduced and merged with the 2004/05 data. A complex three-dimensional subsurface model was constructed from the merged gravity dataset to determine the subsurface geology of the Windmill Islands. A relatively dense intrusive charnockite unit, the Ardery Charnockite, generates the dominant gravity high of the study area and has been modelled to extend to depths of 7-13 km. It has moderate to steep contacts against the surrounding garnet-bearing granite gneiss. The Ardery Charnockite surrounds a less dense granite pluton, the Ford Granite, which is modelled to a depth of 6-12 km and creates a localised gravity low. This granitic pluton extends at depth towards the east. A low density early granite gneiss unit is responsible for a dominant gravity low in the northern section of the study area. The modelling process has also shown that Mitchell Peninsula is linked to the adjacent Law Dome ice cap by an ‘ice ramp’ of approximately 100 m thickness, which if melted, would form an island or series of islands separated from the mainland by a narrow marine channel. The discovery of this ice ramp provides an ideal global warming test case for the edge of the Wilkes Land East Antarctic Ice Sheet in close proximity to one of Australia’s Antarctic research stations, Casey Station.

STATEMENT

I declare that all the work in this thesis is the authors own, except where otherwise acknowledged. Further, I certify that the material in this thesis has not been submitted for a higher degree to any other university or institution.

Brad Bailey

PREAMBLE

Chapters 1 provides introductory remarks detailing the aim ands scope of the project. Chapters 2 – 4 discusses the setting of the field area, previous science in the field area and the methodology used during surveying. The main section of the thesis follows with Chapters 5 – 7. Research articles are in draft derived from these chapters to been submitted to peer reviewed journals. The journal papers will be co-authored, however, I estimate that I have contributed 60 – 70% of the Windmill Islands Gravity paper and 60% of the Law Dome time-series gravity analysis and ice surface height change paper. The remaining part of the work was carried out by Assoc. Prof. Peter Morgan, who provided the means of collection of historical gravity data and reports, historical raw gravity data processing, tide and drift/tare corrections, creation of the Law Dome DEM, ice flow velocity analysis, and used his geodetic expertise to write Appendix A. Chapter 8 presents the conclusions to the study. All references are provided in a single reference list following Chapter 8. Appendix A details GPS calibration procedures used throughout fieldwork, Appendix B provides rock sampling information, Appendix C is the Windmill Islands gravity dataset, Appendix D lists the details of each of the historical Law Dome gravity survey vintages considered in this study, Appendix E is the unified historical gravity dataset used in the time-series gravity analysis, and Appendix F contains the Bouguer gravity dataset used in the subglacial geological interpretation component of the study.

The author wishes to dedicate this thesis to his grandmother, Jean Wallace, who battled illness for several years and passed away during the time it has taken to compile this work. My heart will always be with you Nan.

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