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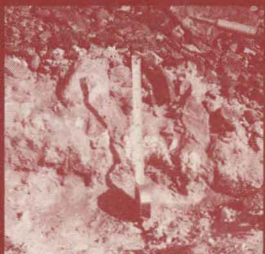
G.G.C. CLARIDGE

ANTARCTICA: SOILS, WEATHERING PROCESSES AND ENVIRONMENT



DEVELOPMENTS IN SOIL SCIENCE 16

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ANTARCTICA: SOILS, WEATHERING PROCESSES AND ENVIRONMENT

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PREFACE

New Zealand soil scientists became interested in the study of Antarctic soils when a biscuit tin of soil scooped up by Mr A. S. Helm during the construction of Scott Base in 1957, at the beginning of the International Geophysical Year, was sent to the New Zealand Soil Bureau for analysis. The report on this soil sample from Antarctica was the first since the pioneering work carried out many years ago on material collected by Shackleton's expedition of 1907–09. Subsequently, in 1959, J. D. McCraw and G. G. C. Claridge went to Antarctica at the instigation of N. H. Taylor, the Director of Soil Bureau, with the intention of preparing a soil map of the Ross Dependency. In the event, they were able to produce a soil map of part of Taylor Valley and, by extrapolation, a very broad-scale map of soils along the Transantarctic Mountains. These maps were exhibited at the International Society of Soil Science Congress in Madison, Wisconsin, in 1960 and helped to show that the interests and experience of New Zealand soil scientists extended from the equator to the Pole. The results of this work showed that soils exist in Antarctica, and that their properties are a consequence of the special Antarctic environment.

From that time, interest in Antarctic soils has grown considerably. Since 1964, we have worked together, investigating soils and soil processes in as many parts of Antarctica as we have been able to get to, by one means or another. We have shown how Antarctic soils vary with differing environmental conditions, how soil processes in Antarctica compare with those in other parts of the world, and how the soils provide valuable information for reconstruction of the history of Antarctica.

At the same time, many other workers have taken up studies of a pedological nature in Antarctica, and a great deal of information is now available. With the current world-wide interest in Antarctica because of its supposed potential for minerals, or alternatively, because of its very high aesthetic and environmental values, it seems timely to review the current state of soil science in Antarctica, for, as is found elsewhere in the world, land management needs to be in accordance with soil attributes.

In this book we have assumed that the reader has little previous knowledge of Antarctica, and therefore we have attempted to give sufficient background information to allow the Antarctic environment as it is related to soil formation to be understood. We have not attempted to write a treatise on all aspects of Antarctica, and hence there are many omissions in our discussions on the geology, climatology and biology of the continent. We have emphasised only those features which have seemed relevant to us from a soil point of view.

We acknowledge the support of New Zealand Soil Bureau, and the New Zealand Department of Scientific and Industrial Research, who made the time and resources available for this work. Particular acknowledgement is made of the Department's Antarctic Division, especially its past and present Superintendents, G. W. Markham and R. B. Thomson, for the logistical support and interest in our work provided over many years. We also wish to acknowledge the support given by the many pilots of VXE-6 Squadron, U.S. Naval Support Force, Antarctica, who have transported us to many remote parts of the continent in many varieties of aircraft. The support of our colleagues in Antarctic pedology, with whom we have had discussions, either in the field in Antarctica, or by correspondence is also gratefully acknowledged. Without their assistance our knowledge of Antarctic soils would have been limited to our own experience. We are very grateful to Merle Rae for typing the manuscript, to colleagues and others who read and made constructive criticisms of various sections of the drafts, and to Heather Simmonds and Dave Isaacs for editing and preparing the manuscript for publication. Except where otherwise indicated, all photographs are our own, taken during our many visits to Antarctica. Finally, the forebearance of our respective families for the collective absence for a total of two years, during numerous summers of field work in Antarctica, as well as for the many night-time and weekend hours of work spent on the manuscript, is gratefully acknowledged.

CONTENTS

INTRODUCTION

Antarctica is the world's fifth largest continent, with an area of approximately 14 million km². It is completely surrounded by the Southern Ocean which extends from about the 40th parallel to the Antarctic Circle at 66°S (Fig. 1.1), and is almost completely covered by ice to an average thickness of about 2100 m giving a volume of approximately 30 million km³. This mass of ice, amounting to about 90% of the world's total ice volume, has a very great influence not only on the climate of Antarctica but also on the oceans and the atmosphere of other parts of the world.

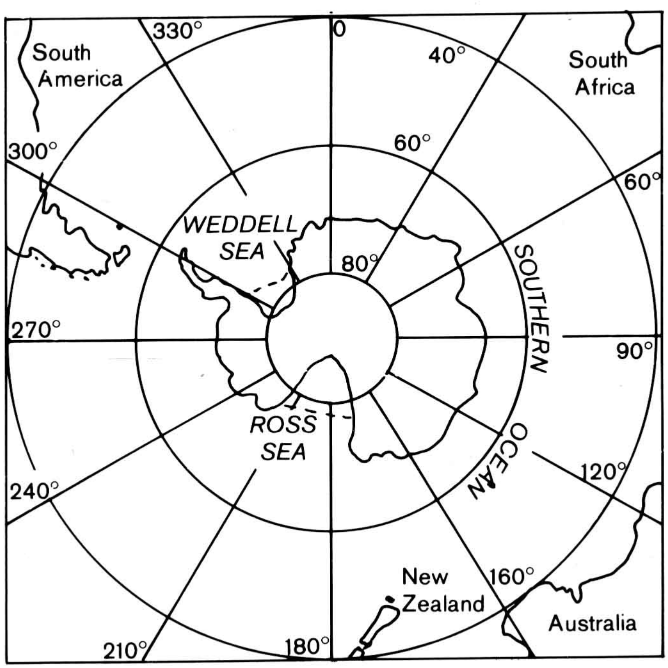

Fig. 1.1. Antarctica and the Southern Ocean in relation to the surrounding land masses.

Antarctica is shaped like an upturned saucer, rising steeply from the coast to a vast interior plateau (Fig. 1.2). It divides easily into two topographical units: East Antarctica, the larger unit, which lies between 30°W and 150°E and rises to an elevation of > 4000 m, and West Antarctica, including the Antarctic Peninsula, which lies between 150°E and 60°W and rises to an an elevation of 1500 m. The two masses of ice merge imperceptively to form an extensive ice sheet.

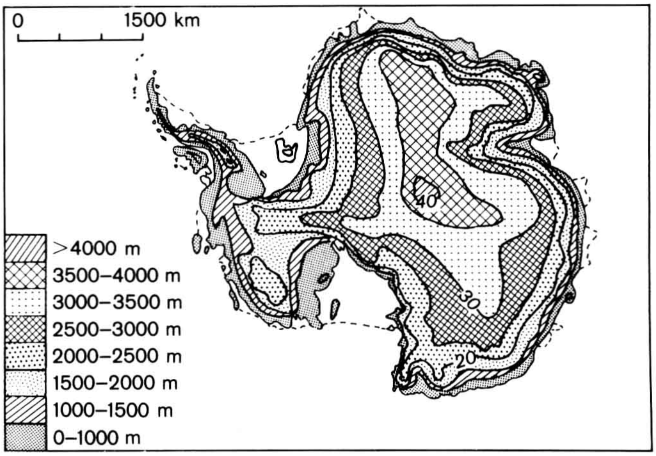

Fig. 1.2. Elevation of the ice cover of Antarctica.

Since the ice sheet reaches the sea almost everywhere around the perimeter of the continent, floating ice shelves are found in many places. Two particularly large ice shelves occupy the embayments between East and West Antarctica, the Ross Ice Shelf south of the Ross Sea, and the combined Ronne and Filchner Ice Shelves south of the Weddell Sea (Fig. 1.3).

Only about 2% of Antarctica is ice-free, comprising a number of small areas that, nevertheless, are equal to the size New Zealand. These areas (Fig. 1.3) occur as isolated patches of rock around the coast, particularly around East Antarctica, in the Prince Charles Mountains around the Amery Ice Shelf and in the Transantarctic Mountains which cross the continent from Cape Adare to the Shackleton Mountains to form one boundary of East Antarctica.

Earth scientists have, therefore, only a fragment of Antarctica available for study and it is from this small area that the continent's biology and earth science have largely been deduced. A considerable amount is known, however, about the structure, geology and topography of the land beneath the ice, from various investigations including seismic and radio echo-sounding surveys of the ice thickness and a very few holes drilled through or into the ice.

Over the last few decades, geographic and scientific exploration has led to a tremendous increase in understanding of the nature of the Antarctic continent; likewise, the soils of Antarctica have been studied in many places and found to be of considerable interest. Fundamental questions concerning many aspects of their development, weathering and distribution have been examined. These have included, for example, the nature of Antarctic soils; the extent and significance of their biological processes; the nature of chemical processes and chemistry of the soils, particularly aspects related to the presence and distribution of salts; the weathering processes in these soils; the characterisation of the soils and of the significance of their physical properties particularly in respect of climate, time, and parent material; the relationship of Antarctic soils to those of other polar or desert regions; and the information revealed by the soils in respect of

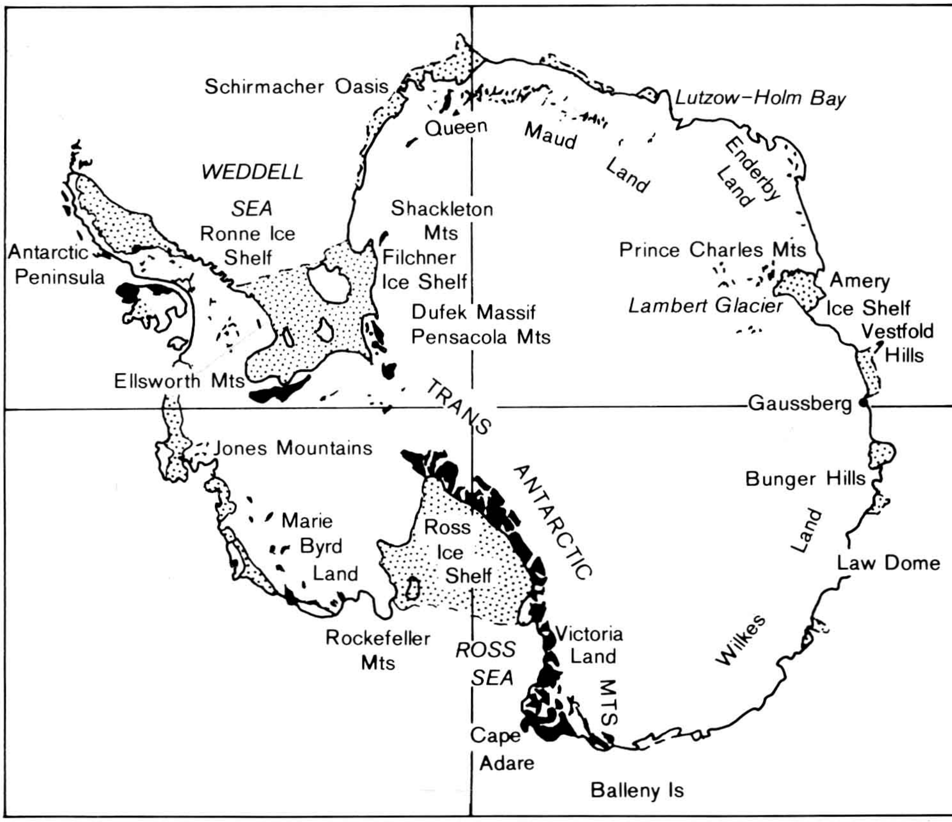

Fig. 1.3. Distribution of ice-free areas in Antarctica. The black areas represent localities where bare ground occurs but the true extent is much less than indicated.

glacial history and landscape evolution. These studies have shown that Antarctic soils possess many interesting features that distinguish them from soils of other regions, and that to accommodate them within the established framework of pedological knowledge, some widening of concepts and definitions may be necessary. In this book we shall review the work that has been carried out to date, summarising it to present a picture of the present state of knowledge of Antarctic soils.

A question that is often asked about Antarctica is, are there any soils there? Pedologists who have worked there normally answer this with an unequivocal and enthusiastic yes, because despite the virtual absence of an effective soil biological component in all but a few places, the common processes of soil formation can be shown to be taking place, albeit slowly. A later chapter of this book outlines the biology of Antarctic soils and shows that, while organic matter in various forms certainly influences soil development, soil-forming processes and profile development continue in its absence. Antarctic soils thus demonstrate the need for a broad rather than a narrow approach to the definition of soil.

Antarctica provides a unique environment for soil formation and for the study of many soil processes, some of which have unusual features. As shown in Chapter 2, the geology is comparatively simple and parent materials which often extend with little variation over very large areas can, through the absence of a vegetative cover, be more readily observed. One example of unusual soil processes is the occasional occurrence of parent materials that accumulate by accretion (through ablation of glacial ice) at the base of the profile while soil development is proceeding.

Further, the climate in Antarctica is unique, by virtue of the very low temperatures and the aridity. This continent has the lowest recorded temperatures in the world. As shown in Chapter 3, precipitation does not fall as rain because air temperatures are, nearly everywhere, well below freezing for most of the time. In terms of landform development and soil weathering processes, which depend throughout the world on climate, the extremely cold Antarctic climate produces severe aridity, with very little moisture available for the operation of geomorphic processes and soil development. The description of Antarctica as a cold desert is particularly apt, but the desert features have, to some extent, been overlooked. Although the landscape has everywhere been shaped or modified by ice, the desert features, as outlined in Chapter 5, include landforms shaped and sculptured by arid land weathering, desert pavements, desert varnish, cavernous weathering, pitted rocks, etc., while soil features indicative of desert conditions include surface crusts, vesicular or salt floc structure and salt horizons containing soluble salts such as nitrates.

Time is the third unique feature of the Antarctic soil-forming environment. Initially, geologists believed that the soils and the surfaces on which they are formed dated mainly from the Last Glaciation, but in recent years, results from potassium–argon dating and extrapolations from biostratigraphy indicate that the time scale for landform and soil development in the Transantarctic Mountains may extend back in time much further, possibly to the Early Miocene or even earlier. Given the frigid climate, the lack of moisture and the very slow rate at which many processes operate, this soil time-scale may not be unrealistic. Pedological features that indicate great age include comparatively deep weathering of bedrock, case hardening of surface stones, very pronounced reddening in old soils, thick accumulations of salts and perceptible increases in the fine (clay) fraction of the soils. The prolonged time available for soil formation means that the effects of some weathering processes, not normally observable because they occur at a very slow rate, may be expressed in the soil.

Soil chemistry and soil mineralogy, discussed in Chapter 6, also reveal a very slow rate of weathering. In normal pedological terms, these soils would be regarded as completely unweathered. Notwithstanding the simplicity of the weathering systems, Antarctic soils differ across the landscape in their chemical properties, in response to subtle differences in the major soil-forming factors of climate, time and parent materials. The ways in which these factors interact and influence soil morphology are described in detail in Chapters 7 and 8. However, although