1 Antarctica: Geomorphology and Climate Trends

1.1 Introduction

Several regions of the Earth, such as Lake Baikal and the Himalayas, are usually described through several superlatives, but none can compete with Antarctica: the remotest, coldest, windiest, highest continent, with the biggest and thickest ice sheet. The ice moves towards the sea and calves the world's largest icebergs in the Southern Ocean, which has the deepest continental shelf, the largest wind-driven oceanic current, the highest number of endemic species and the largest seasonal variation in ice cover. Antarctica is a unique continent: it contains almost 80 % of the world's freshwater, yet it is the largest cold desert on Earth. Although it receives much more solar radiation in the summer than anywhere else in the world, it is the coldest place on Earth. In contrast with other continents, Antarctica is not located in plates with constructive and destructive margins; during the last 100 Ma, it has thus occupied a quite stable position with respect to the South Pole. Climatic changes in Antarctica during this period are therefore mainly due to global changes.

Through a better understanding of these unique features, it will become obvious to the reader why several research activities cannot be performed at more convenient locations and why this remote, cold and forbidding place, where field research is very difficult and expensive, has become a continent for science. The ice sheet, which deposited over thousands or millions of years, preserves a record of changes of atmospheric composition and climate, and the collection of meteorites in the ice ablation areas provides clues about the history of the solar system. The elevation of the continent, its dry, cold, clean atmosphere, and geomagnetic latitude allow unique astronomical and astrophysical observation and investigation of Earth's magnetosphere and ionosphere.

In spite of its remoteness, Antarctica is linked to lower latitudes through the circulation of the atmosphere and oceans. The large equator-to-pole temperature difference drives the poleward transport of heat and determines the general circulation of the atmosphere, making Antarctica the main heat sink of the Southern Hemisphere. The continuous low-level drainage of the continental surface by katabatic winds is compensated by the inflow of relatively warm air masses which converge and subside in the troposphere over Antarctica. The flow of cold air to the ocean in the shallow boundary layer, coupled with the tropospheric and stratospheric circulation, gives Antarctica a major role in the global climate system and makes it a sink for persistent atmospheric pollutants.

Global climate models predict that the greatest changes will occur at high latitudes. Feedback mechanisms might easily magnify relatively small changes in sea-ice extent and ice-sheet balance, and these changes are likely to be of global importance. Only Antarctica can provide essential data for better understanding these processes and the response of ecosystems to climatic and environmental change. Without Antarctic data, global models would not be able to accurately predict climate change and the impact of persistent airborne pollutants.

This chapter outlines the continental features (morphology, geology, climate) and involvement of Antarctica in global climate processes, with particular emphasis on its important role in establishing global baselines against which to monitor climate change and the impact of human activity. Given its potential contribution to the global increase in sea levels, the stability of Antarctic ice is of general concern and interest. The chapter also reviews available data on climatic variability and change in Antarctica, and estimates of how the Antarctic climate may respond to increasing concentrations of greenhouse gases.

In the last two decades, following the discovery of the recurring formation of the ozone "hole" in Antarctica, the possible effects of global warming on the stability of ice sheets, increasing sea levels and global environmental change, many books have been published on the climate, geography, geology, glaciology, environment and resources of Antarctica. This chapter will only briefly review these topics, with particular emphasis on climatic and atmospheric processes affecting the transport and deposition of persistent environmental pollutants. The reader wishing to further pursue issues of interest in greater depth can refer to specific books and papers quoted in the bibliography.

1.2 Physical Characteristics

The word Antarctic originates from the Greek name of the polar constellation (*arktos*, the bear) and indicates the region which lies opposite to it (anti-Arctic or Antarctic). The terms Antarctic and Antarctica are often used interchangeably, but it seems more proper to use the first to denote the region (i.e. the area of the Earth south of 60° S, which includes the continent, isolated islands and a large part of the Southern Ocean) and the second for the continent itself (Hansom and Gordon 1998). In spite of the theoretical hypothesis of ancient Greeks and Romans (the Latin geographer Pomponio Mela envisaged a southern continent, *Antipodi*, inhabited by the *Antictoni*), Antarctica was omitted in many geographical maps until the 18th and 19th centuries, when the seas around the "*Terra Australis nondum cognita*" became of interest for the sealing and whaling industries. Although parts of the coast and interior began to appear in some maps at this time, the cartography of the Antarctic region was only completed in the last century (e.g. Sugden 1982; Simpson-Housley 1992; Chaturvedi 1996).

Except for the northern part of the Antarctic Peninsula (Fig. 1), the continent lies entirely within the Antarctic Circle (i.e. the parallel at 66° 33′S, corresponding to the angle between the Earth's rotation axis and the plane of its orbit round the Sun). The continent, along with its islands and ice shelves, covers about 13.66×10^6 km^2, representing about 10 % of the world land surface and 30 % of that in the Southern Hemisphere. Excluding ice

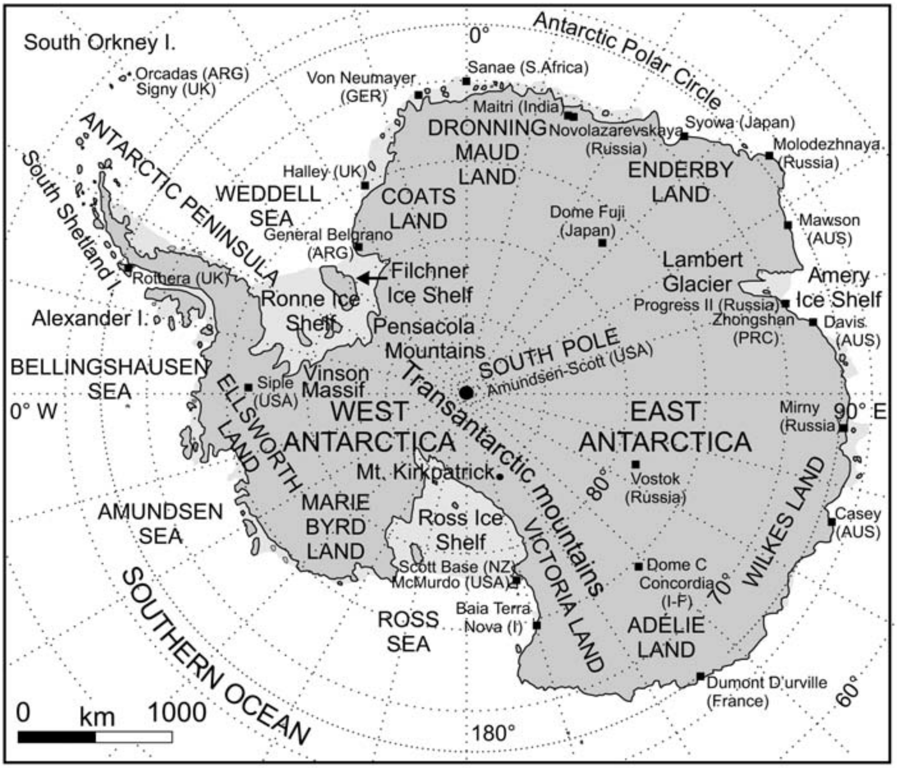

Fig. 1. Map of Antarctica and main places cited in the text

shelves, the land surface of the continent and islands covers 12.09×10^6 km^2, with the continent constituting more than 98 % of this area. The continental landmass under the ice sheet consists of two main units (East and West Antarctica) separated by the Transantarctic Mountains, which extend across the continent from the Ross Sea to the Weddell Sea. East Antarctica, or Greater Antarctica, comprises the Transantarctic Mountains and the large area extending from these mountains to the Indian Ocean (more than 10×10^6 km^2); it has an approximately circular, symmetric shape, with the coastline following the 62° S line of latitude, except at the Lambert Glacier–Amery Ice Shelf indentation (Fig. 1). The Transantarctic Mountains are a large mountain range, stretching for 3,500 km from Victoria Land to the Pensacola Mountains; Mt. Kirkpatrick (4,528 m) is the highest peak. In general, East Antarctica is characterised by narrow coastal strips and steep slopes rising sharply to the high Antarctic plateau. This huge mass of ice (about 28.5×10^6 km^3; more than 80 % of the world's freshwater) has an average elevation of about 2,300 m and, although its surface appears rather flat, in some zones the ice sheet may rise to altitudes of more than 4,000 m (4,776 m in Adélie Land, at 69° 54′S, 135° 12′E). The bedrock lies mostly close to or below sea level, with a maximum depression of –2,555 m in the subglacial Bentley Basin (81° S, 110° W).

West Antarctica, or Lesser Antarctica (surface area with islands and ice shelves of about 3.42×10^6 km^2), lies mostly to the west of longitude 165 to 315° E and comprises Marie Byrd Land, Ellsworth Land and the Antarctic Peninsula, a bedrock archipelago straggling 1,200 km northwards. Although the average elevation of West Antarctica is about 850 m and its ice sheet is generally lower than that of its eastern neighbour, several summits lie above 3,000 m, including the Vinson Massif (4,897 m), the highest peak in Antarctica. The Antarctic Peninsula constitutes a narrow north–south mountain barrier with an average width of 70 km and a mean height of 1,500 m. This barrier affects atmospheric circulation and contributes to determine markedly different climatic conditions between the west coast, facing the Bellingshausen Sea, and the east coast in the Weddell Sea.

From the interior, where it builds up, the ice flows down in ice streams at speeds of about 500 m year^{-1}. Ice streams at the edge of the continent may form large floating ice shelves, such as the Ross and Ronne ice shelves (about 0.5×10^6 km^2 each; Fig. 1), or ice tongues, which break up into widespread tabular icebergs throughout the Southern Ocean. The ice shelves make up more than 40 % of the continental coastline, with grounded ice walls, ice streams and outlet glaciers forming the remaining 60 % of coastline. Only a small percentage (about 5 %) of the coastline is covered by rocky cliffs or beaches (Drewry 1983). Thus, a large portion of the continental shelf is covered by ice shelves, and has undergone extensive glacial erosion, especially during the Pliocene–Pleistocene glacial advances (J.B. Anderson 1991). The removal of bedrock and the huge weight of the ice sheet have helped make the Antarctic continental shelf much deeper (about 500 m) and wider (mean 200 km) than other shelves. At the margin of the shelf, the continental slope falls rather steeply to the ocean basin at depths of 3,000–6,000 m. Mountainous submarine ridges connected to the break-up of the Gondwanaland supercontinent and the tectonic development of Antarctica rise from the ocean floor, encircling the continent.

1.3 Geology and Mineral Resources

1.3.1 Geology

Besides the huge mass of ice, several geological peculiarities, such as negligible seismic activity, the local concentration of meteorites on ice ablation surfaces, and subduction processes which led to the formation of West Antarctica through the aggregation of microcontinents (Ricci et al. 2001), distinguish Antarctica from other continents. In contrast with the other continents which are located in plates with constructive and destructive margins, Antarctica is completely surrounded by the sea and is located in a continuously expanding lithospheric plate. During the last 100 Ma, the continent has therefore occupied a quite stable position with respect to the South Pole. This is an important peculiarity, because it means that climate changes in Antarctica mainly reflect global changes.

In spite of difficulties due to the lack of rock outcrops (there are about 331,000 km^2 of ice-free areas, corresponding to less than 3 % of the continental area), the geology and evolution of Antarctica is becoming quite well known (e.g. Splettstoesser and Dreschoff 1990; LeMasurier and Thomson 1990; Tingey 1991; Thomson et al. 1991; Stump 1995; Ricci 1997; J.B. Anderson 1999). The broad structure of the continent is related to the amalgamation (about 500–550 Ma ago) and break-up (about 150 Ma ago) of Gondwanaland and earlier continents. Antarctica was once the central keystone of Gondwanaland, which also included South America, Africa, Madagascar, Arabia, Ceylon, India, Australia and New Zealand. After the fragmentation of Gondwana, the continental blocks dispersed and Antarctica drifted towards polar latitudes. Due to its central position in the supercontinent, the main geological structures, especially Antarctic orogenic belts such as the Transantarctic Mountains, are an extension of similar structural units in South America, Africa and Australia (Ricci 1991). Much palaeontological and palaeoenvironmental evidence indicates that the Gondwana continental blocks have a common history. The fossil fern *Glossopteris* and herbivorous reptile *Lystrosaurus* are among the organisms which lived on these continents until 180 Ma ago (Crame 1989; Gee 1989; Olivero et al. 1991; Crame 1992). The period of conti-