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1 Introduction

Spanning the continent of Antarctica for 3,500 km and rising to heights in excess of 4,000 m, the Transantarctic Mountains are among the great mountain ranges on earth. They are the physiographic boundary between East and West Antarctica, holding back the East Antarctic Ice Sheet that issues through them in giant outlet glaciers, emptying into the Ross Sea and the Ross Ice Shelf (Fig. 1.1). Between the Horlick Mountains and the Patuxent Range, the West Antarctic Ice Sheet inundates the Transantarctic Mountains merging with its East Antarctic counterpart. Beyond this the Pensacola Mountains are drained on both sides by broad ice streams flowing into the Filchner and Ronne Ice Shelves.

Unlike most major mountain belts, which owe their origin to plate-margin tectonics, either subduction- or collision-related, the Transantarctic Mountains are intracontinental and probably best described as a rift shoulder whose boundary follows the front of the range along the Ross embayment (Fitzgerald et al., 1986; Stern and ten Brink, 1989). Outboard of this is a region of extended continental crust (Cooper and Davey, 1987). The rift margin itself may arc outward from the Horlick Mountains to the west of the Whitmore and Ellsworth Mountains (Behrendt and Cooper, 1991), but there is geological continuity in the Thiel and Pensacola Mountains with the rest of the Transantarctic Mountains. However, the latter areas do have geological features distinct from the rest of the Transantarctic Mountains, in particular a lack of intense deformation during the Ross orogeny, as will be discussed later in the book (Chapters 6 and 7).

In a number of ways the Transantarctic Mountains are also distinct from other rift systems. Their scale greatly exceeds the rifts of the Rio Grande, Oslo, and Rhine. They are of a length comparable to that of the East African rift system, but there the rifts would appear to be wholly intracratonic, whereas in Antarctica they occur at the boundary between the cratonic basement of East Antarctica and Phanerozoic accreted rocks of West Antarctica. Perhaps the most analogous feature is the Wasatch Range at the eastern boundary of the Basin and Range province in the Cordillera of the western United States. The Wasatch front marks the boundary between the Phanerozoic Cordilleran geocline to the west and the onlapped cratonic sequences to the east, as well as the front of the Sevier fold and thrust belt. By contrast, the Basin and Range forms a terrestrial topography, while much of West Antarctica is below sea level.

As indicated by fission-track analysis, the main phase of uplift of the Transantarctic Mountains commenced around 50 Ma (Gleadow and Fitzgerald, 1987; Fitzgerald, 1992), but earlier precursors are also indicated at around 80 and 110 Ma (Stump and Fitzgerald, 1992). It is probably no coincidence that the present-day elongation of the range is parallel to structural features in its basement

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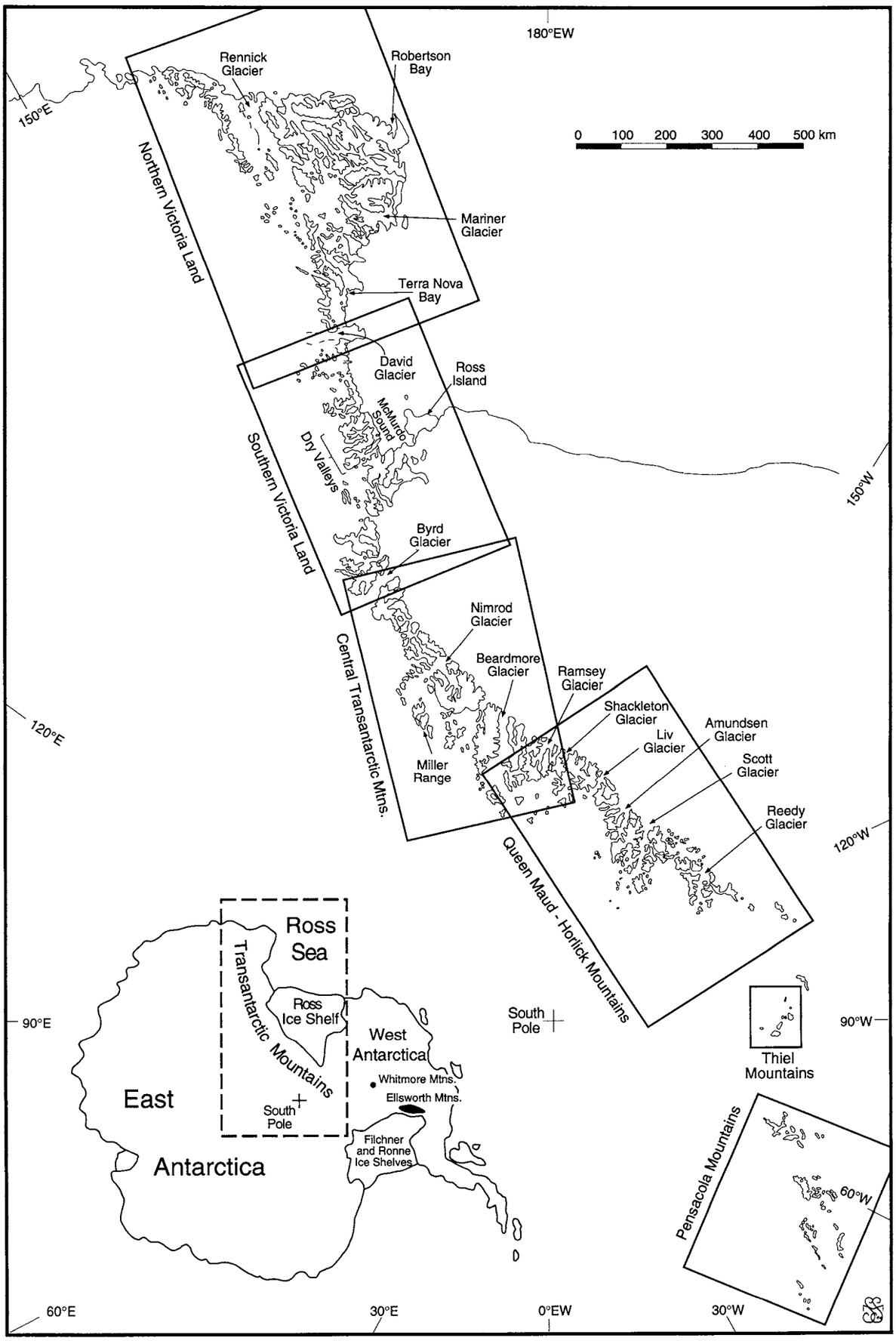

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formed approximately half a billion years earlier. This basement is the Ross orogen. Its temporal and spatial boundary is a mid-Paleozoic erosion surface, often called the Kukri peneplain, that is overlain by the Beacon Supergroup, a Devonian to Triassic sequence largely of terrestrial origin (Barrett, 1981; Collinson, 1991), intruded and overlain by Jurassic tholeiites of the Ferrar Group (Tingey, 1991).

The history of the Ross orogen commences in the Neoproterozoic with passive, continental margin sedimentation, perhaps following the rifting of Laurentia from Gondwanaland (Stump, 1992b). Earlier Proterozoic tectonism is indicated in the Miller and Geologists Ranges at the craton margin. The passive margin was activated by compressional deformation and plutonism in the latter part of the Neoproterozoic, which evolved through a full-blown cycle of orogeny during the Cambrian, with exhumation and cooling of the belt during the Ordovician, making way for Beacon sedimentation.

The history of the Ross orogen is the subject of this volume. The chapters are divided by geographical area, as shown in Figure 1.1. Although a common history runs through all of the areas, each has distinct characteristics within the boundaries as they are defined, and, as can be seen, uncertainties remain regarding correlation of some units from one area to another.

Figure 1.1 (*facing page*). Location map for the Transantarctic Mountains. The boxes outline areas covered by location maps in the succeeding chapters.

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2 Northern Victoria Land

Geological Summary

Northern Victoria Land boasts the widest exposure in all of the Transantarctic Mountains, spanning more than 350 km. Elements common to the Ross orogen occur on its western side, but to the east the area is underlain by rocks without kin throughout the rest of the Transantarctic Mountains. The concept of terranes provides the best framework for discussing the geological and tectonic development of the region. Their recognition by New Zealand geologists (Weaver et al., 1984a; Bradshaw et al., 1985b) closely followed the introduction of the notion to the discipline of geology as a whole (Coney et al., 1980; Howell, 1985). The original subdivision of Weaver et al. (1984a) of a western Wilson terrane, eastern Robertson Bay terrane, and medial, fault-bounded Bowers terrane (Fig. 2.4) is now widely accepted, although a consensus on the details of timing and kinematics of terrane assembly has not been reached. Because of differences among ranges within the Wilson terrane and the presence of likely major subglacial faults, this terrane may warrant further subdivision (Bradshaw, 1985).

The Wilson terrane is characterized by medium- to high-grade schists and gneisses and lesser low-grade metasediments, with nomenclature distinct to subareas. The original designation of "Wilson Group" for the metamorphics found throughout the Wilson terrane north of the Terra Nova Bay area has evolved to "Wilson metamorphics," confined to the western ranges, "Lanterman and Mountaineer metamorphics," occurring in those respective ranges, and several more local names discussed later. In the Terra Nova Bay area the rocks are called Priestley Formation. This unit has been interpreted to overlie unconformably an older suite called the Snowy Point Gneiss Complex. Although it seems likely that the metasedimentary rocks of the Wilson terrane are at least broadly related, the stratigraphic relationships between sequences in various areas are poorly constrained. Fragments of body fossils indicative of a Paleozoic age have been found in the Terra Nova Bay area (Lombardo et al., 1989), while a U/Pb zircon study from the Daniels Range has suggested that the metasediments there were involved in an early magmatic episode at around 544 Ma (Black and Sheraton, 1990). Elsewhere the depositional age of the metasedimentary rocks in the Wilson terrane is constrained only by crosscutting Granite Harbour Intrusives, and so may be considered either Proterozoic (?) or Cambrian (?) in age.

Deformation and metamorphism of the sedimentary component of the Wilson terrane are considered to be of the Ross orogeny. In the western area, plutonism appears to have been involved in the deformation and peak metamorphism at around 540–535 Ma, whereas plutonism in the Lanterman Range and Terra Nova

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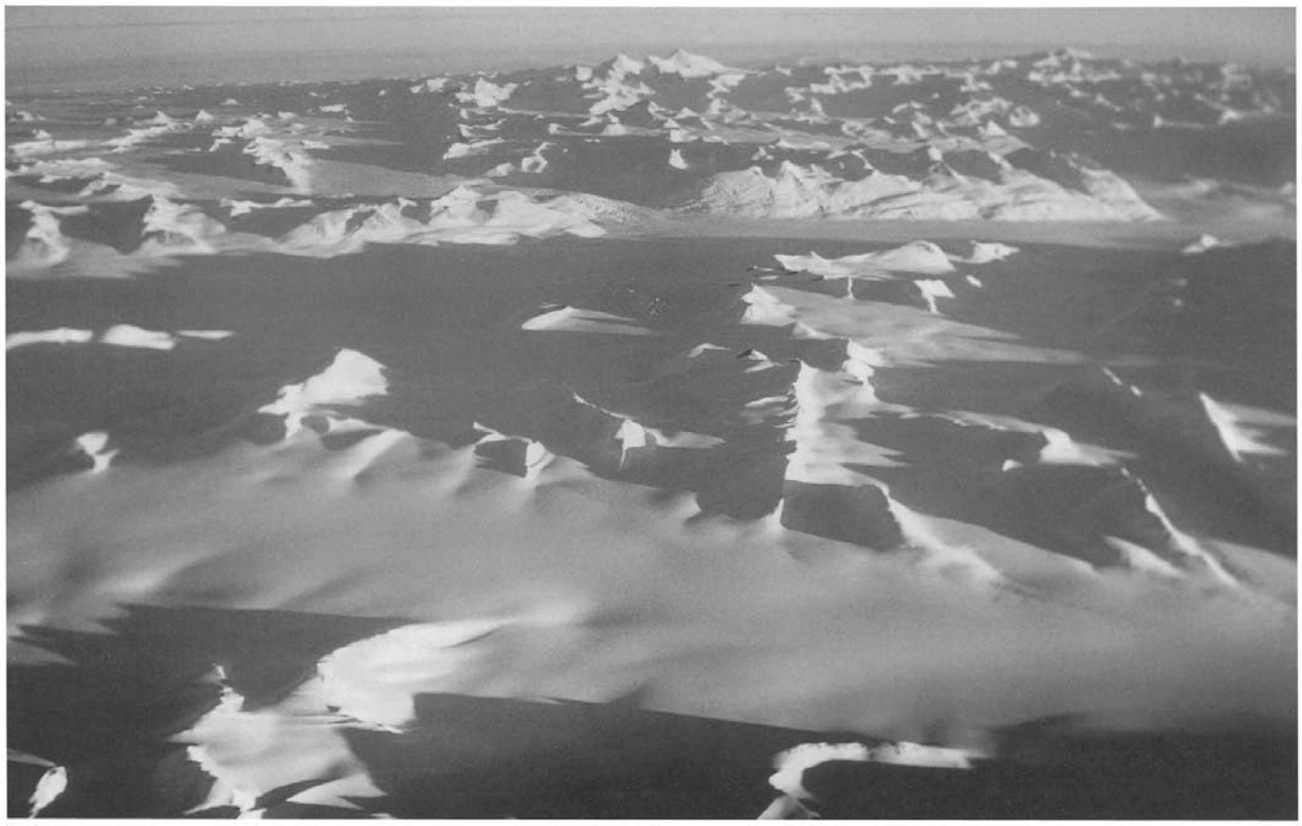

Figure 2.1. The heart of the Robertson Bay terrane, northern Victoria Land. View to east across Tucker Glacier (middle ground) and central Admiralty Mountains toward Mt. Minto and Mt. Adam, the high peaks on center horizon. Most of the area is underlain by Robertson Bay Group, with Mt. Adam composed of Admiralty Intrusives.

Bay area commenced after the main deformation. A major pulse of posttectonic Granite Harbour Intrusives occurred throughout the terrane around 480 Ma, cooling to argon retention temperatures within 10–15 m.y.

The Bowers terrane consists of a varied sequence of sedimentary and volcanic rocks primarily of Cambrian age, called the Bowers Supergroup. The lowermost Sledgers Group contains two interfingering formations, the volcanic Glasgow Formation and the sedimentary Molar Formation. The volcanics have affinities with primitive island arcs and, to a lesser extent, rifted or marginal basins (Weaver et al., 1984a). The sedimentary rocks are shelf or deeper basinal deposits containing abundant volcaniclastic fractions, but also conglomeratic horizons with granitic and metamorphic clasts. Fossils indicate that the Sledgers Group was probably deposited entirely within the Middle Cambrian.

Sledgers Group is followed conformably by Mariner Group, a sequence of fine-grained clastic and calcareous sedimentary rocks, which has been interpreted as representing a regressive marine environment. Abundant fossils within the group range from late Middle to Upper Cambrian. Leap Year Group lies above a subtle regional unconformity that cuts successively deeper into Sledgers Group toward the north. The group is characterized by coarse-grained sandstones and conglomerates, interpreted to have been deposited primarily in terrestrial settings. No body fossils have been found in these rocks.

The Bowers terrane was folded during a single event that produced a series of

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tight folds whose axes trend parallel to the elongation of the terrane. Accompanying metamorphism did not exceed prehnite–pumpellyite or lower greenschist grade, except along the terrane boundaries.

The Robertson Bay terrane is predominantly a sequence of graywackes and shales, probably Cambrian to Lower Ordovician in age, known as the Robertson Bay Group. Uppermost Cambrian to Tremadocian body fossils have been found in a slideblock of limestone within the Handler Formation, thought to be in the uppermost stratigraphic levels of the group. The Robertson Bay Group was deformed during a single episode that produced folds and cleavage under low-greenschist conditions. Ar/Ar dating of sericite indicates diachronous cleavage development between around 500 and 460 Ma from west to east across the terrane.

Both the Bowers and Robertson Bay terranes, and possibly the Wilson terrane, were intruded during the Devonian by high-level crosscutting plutons of the Admiralty Intrusives. Devonian to Carboniferous volcanics are scattered across all three terranes. Besides the history of the rocks within each terrane, the timing and mechanisms of assembly of the terranes are critical problems in the overall tectonics of the region.

Antecedent to the concept of terranes in northern Victoria Land, the subdivision of the region into discrete blocks or units dates to Klimov and Soloviev (1960), who recognized a block west of Matusevich Glacier containing phyllitic and limestone schists, which they named the "Berg series," a block east of Rennick Glacier with rocks equivalent to the graywacke and shale of Robertson Bay, and an intervening block composed of a complex of crystalline schists, migmatites, and granitoids, which they named the "Wilson series." Soloviev (1960) separated the blocks with meridional faults, one up the Matusevich Glacier, the other inland from Rennick Bay. He also noted that the one extending south from Rennick Bay is aligned on the same meridian with the boundary fault between the western Ross Sea and the Transantarctic Mountains south of northern Victoria Land.

Le Couteur and Leitch (1964) were the first to recognize the Camp Ridge Quartzite, which was incorporated into the "Bowers Group" of Sturm and Carryer (1970). By the time of production of the Antarctic Map Folio Series, the distribution of major rock units and their boundary faults were known in all areas except along the rugged coast between Borchgrevink and Aviator Glaciers (Gair et al., 1969). Mapping from helicopters in that area in 1981–82 demonstrated the continuance of the Bowers Supergroup from upper Mariner Glacier through to the coast (Stump et al., 1983b), and the application of terrane tectonics followed.

Chronology of Exploration

Serendipity has always been the handmaiden of exploration, and no truer case can be found than the discovery of the Transantarctic Mountains by the British expedition led by Capt. James Clark Ross. With two vessels, HMS *Erebus* and HMS *Terror,* strengthened for ice conditions, the expedition was charged to record magnetic observations at high southerly latitudes and, if possible, to reach

Figure 2.2 (*facing page*). Location map for northern Victoria Land.

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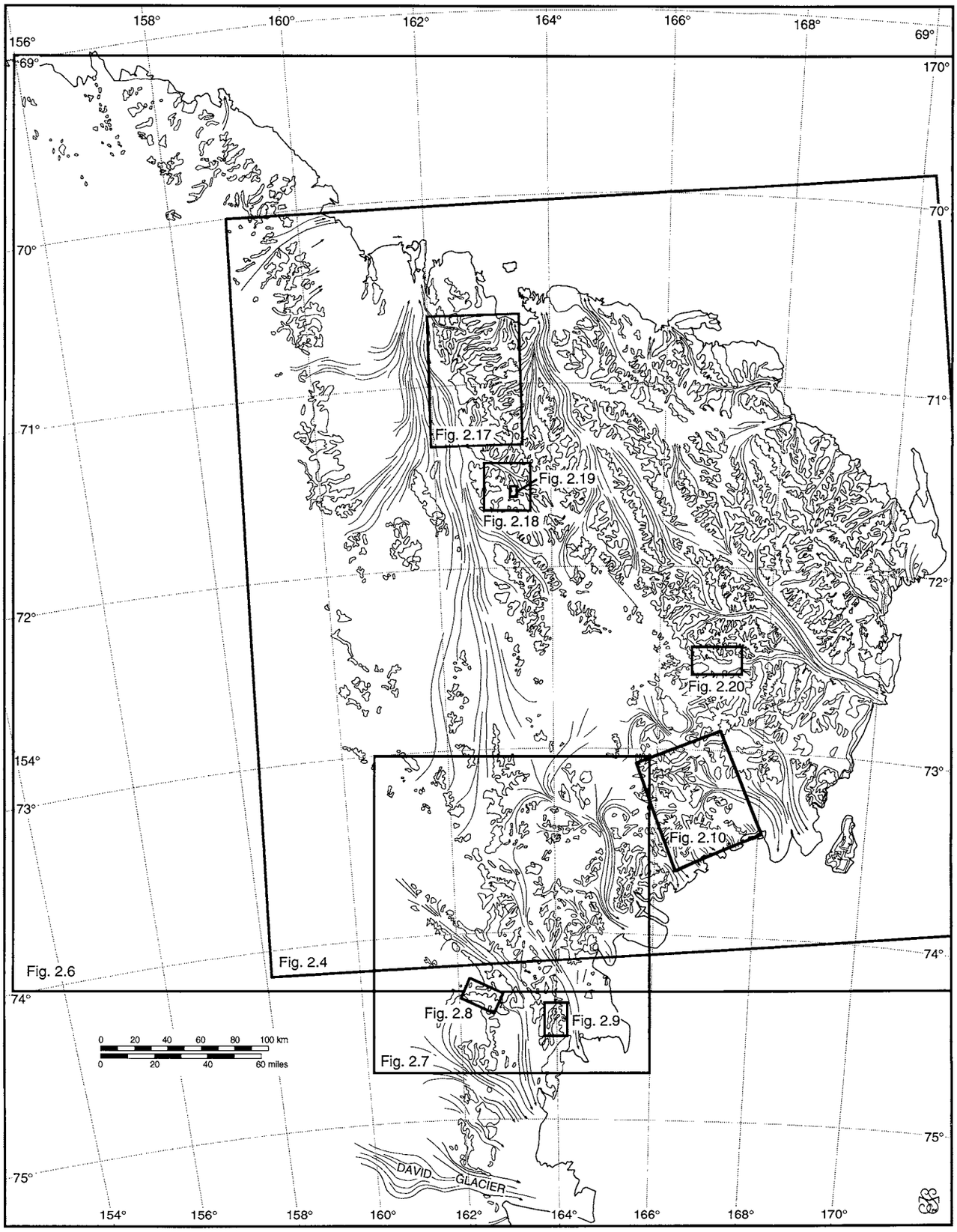

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the South Magnetic Pole. Ross was ably qualified for the undertaking, having made a study of terrestrial magnetism and having reached the North Magnetic Pole in 1831.

Upon arrival in Hobart in August 1839, Ross learned that his publicly announced southerly course along longitude 160°E had been preempted the previous season by a U.S. expedition, headed by Capt. Charles Wilkes. Piqued by this action and bound not to follow in the wake of such a ragtag flotilla, Ross chose instead to sail south along longitude 170°E, thereby making the most important discoveries of Antarctic exploration: the gateway to the icy interior of the continent, the world's largest ice shelf, and the last major mountain range to be discovered on earth.

On 31 December 1839 in heavy seas, the expedition encountered the ice pack. After three days, the weather became more moderate and the ships began their assault. Six days of pounding were rewarded when, on the morning of 9 January 1840, the ships broke free into open water. Ross reckoned that the South Magnetic Pole was at 76°S, 145°20′E and set a course in that direction. The excitement of possibly claiming both magnetic poles was cut short, however, when the following day land was sighted to the southwest.

As the ships moved in toward Cape Adare, the mountains rose up, filling the men with wonder. Robert McCormick, surgeon on the *Erebus,* described the view as "rising steeply from the ocean in a stupendous mountain range, peak above peak, enveloped in perpetual snow, and clustered together in countless groups resembling a vast mass of crystallisation, which, as the sun's rays were reflected on it, exhibited a scene of such unequaled magnificence and splendor as would baffle all power of language to portray or give the faintest conception of" (Ross, 1847, vol. 2, pp. 415–16).

Heavy seas prevented a landing on the mainland, but the following day a party put in at Possession Island, a small volcanic remnant, where the territory was claimed in the name of Queen Victoria and several rock specimens were collected. Following a half century of disinterest in things Antarctic, the specimens were finally described by Prior (1899) as consisting of basalt, palagonite–tuff, phonolite, and granite. The granite, containing muscovite, tourmaline, and garnet, apparently occurred as inclusions within the basalt.

From Possession Island the expedition headed southward parallel to the mountain front that continued to stand between themselves and the magnetic pole. On Franklin Island, another Tertiary volcano in the Ross Sea, the group made a second landing, before sailing on to the foot of Mt. Erebus, "covered with ice and snow from its base to its summit, from which a dense column of black smoke towered high above" (McCormick in Ross, 1847, vol. 2, p. 416).

The mountains appeared to continue south to beyond the horizon, but eastward from Mt. Erebus stretched the "Great Barrier" of the Ross Ice Shelf, dashing any lingering hopes of sailing to the magnetic pole. After charting the front of the ice shelf, Ross returned the ships to warmer waters.

The following year Ross again sailed south, this time along longitude 146°E. After 56 days beset in the pack, drifting eastward, the ships finally broke through, but were forced to continue their eastward course. They reentered the Ross Sea and returned to the barrier, but managed to extend the charting of the preceding year by only six miles before beating a prudent retreat. No landings were effected

Figure 2.3 (*facing page*). Location map for figures in Chapter 2.

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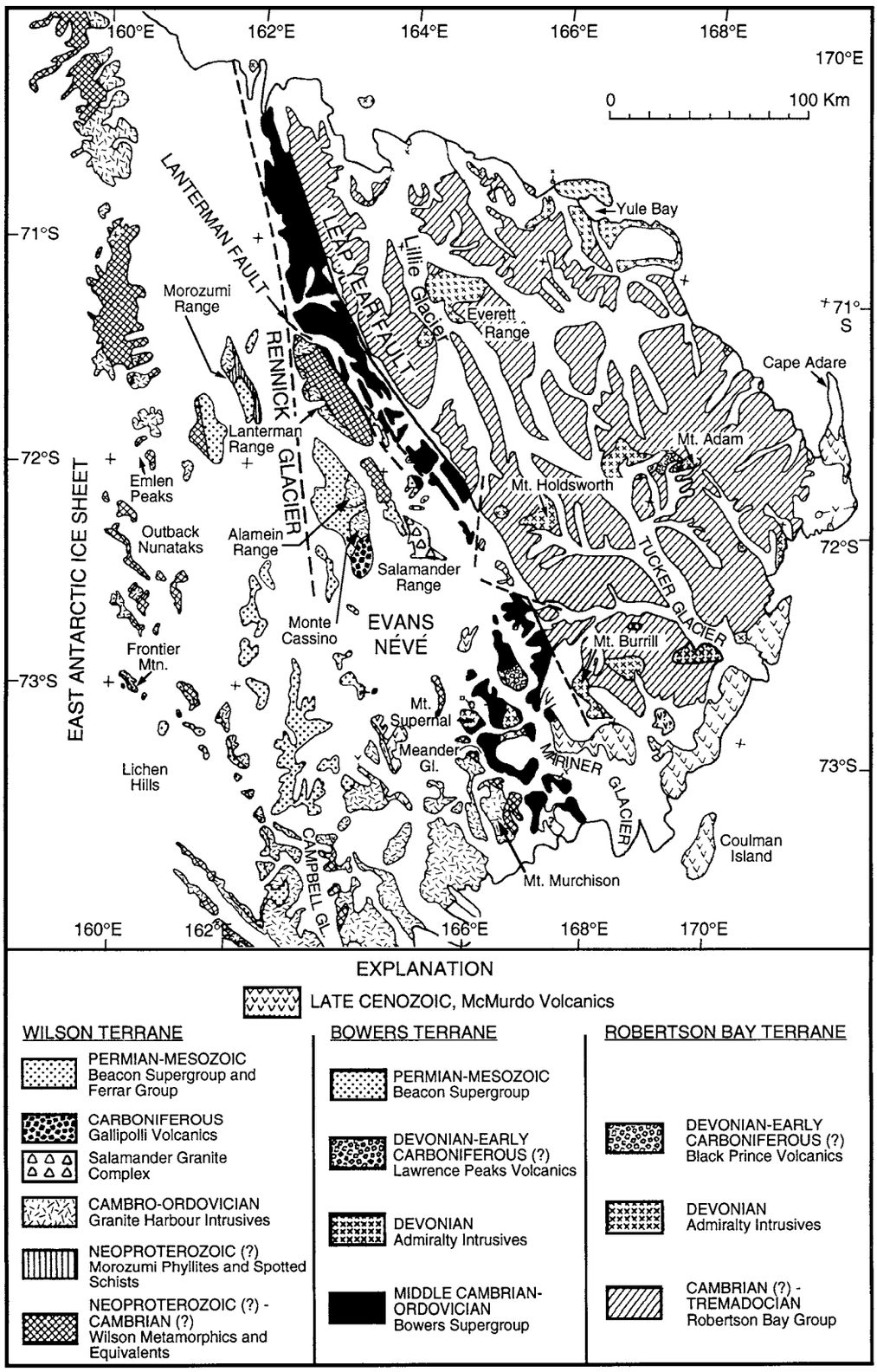

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