Chapter 2
West Antarctica: Tectonics and Paleogeography

The origin of West Antarctica (WANT) can be traced back to the Terra Australis orogenesis that began between 520 Ma and 510 Ma—shortly after the terminal suturing of Gondwana (Boger 2011). The onset of this event was responsible for the termination of passive margin sedimentation along much of the Pacific margin of Gondwana and marks the beginning of widespread and broadly coeval deformation and arc-type plutonism. It also began a long-lived process of accretion that added much of the crust that defines eastern Australia, West Antarctica (domain 5 of Boger 2011, Fig. 2.1), and western South America (Cawood 2005, 2009).

Post-Gondwana accretionary growth—the Terra Australis and Gondwanide Orogenies—The suturing of the West Gondwana and Australo–Antarctic plates along the Kuunga Orogen brought to an end the long-lived process of convergence between the pre-collision components of Gondwana. The result was a reconfiguration of the early to middle Cambrian plate system and the consequent transfer of ocean floor consumption from between the pre-Gondwana cratons to the outboard Pacific margin of newly formed Gondwana supercontinent (Cawood 2005). This led to the establishment of the accretionary Terra Austrais Orogen (Cawood 2005), a general name given to the orogenic belt that stretched continuously from northern South America to northern Australia and which began in the early to middle Cambrian and lasted until the late Carboniferous. In Antarctica Terra Australis (Ross) orogenesis also deformed and variably metamorphosed the pre-Gondwana passive margin (Fig. 2.2).

The Gondwana supercontinent underwent a sequential fragmentation over approximately 165 Ma. India and Madagascar may have maintained a link with Antarctica via Sri Lanka until the end of the Aptian (112 Ma) but by the earliest Albian a deep seaway separated India/Madagascar/Sri Lanka from East Antarctica. The continental separation between West Antarctica and Campbell Plateau (the first appearance of ocean crust) was produced at around 83 Ma (Larter et al. 2002). Rifting was thus achieved via a two-stage process—extension and crustal thinning between Australia–East Antarctica and New Zealand–West Antarctica between approximately 105 Ma and 95 Ma, followed by extension and then

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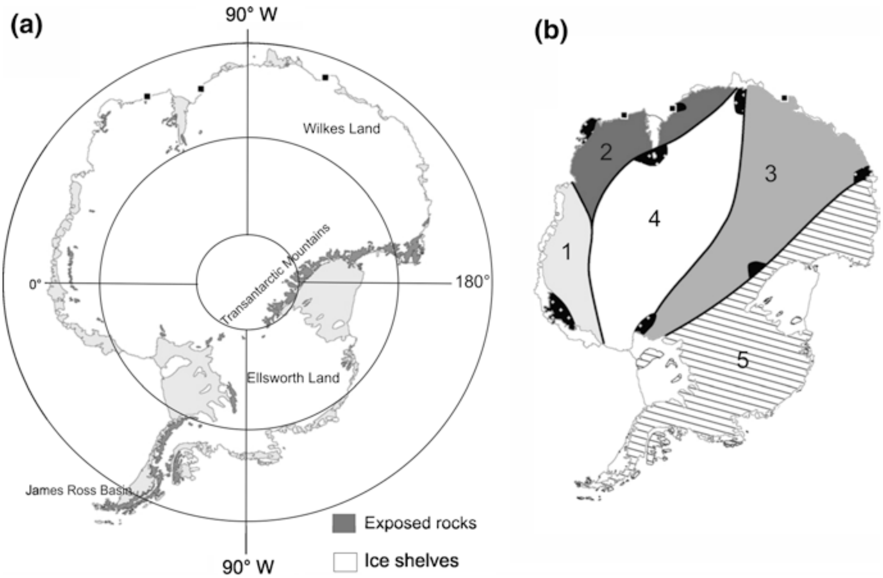

Fig. 2.1 Present day Antarctica: **a** Distribution of rock exposures and major geographic place names; **b** Tectonic domains of Antarctica differentiated on the basis of their affinities with Antarctica's correlatives within Gondwana (after Boger 2011)

separation along a slightly oblique axis between West Antarctica–Australia and New Zealand (plus related blocks) by 83 Ma (Kula et al. 2007). The separation of New Zealand from the margin of West Antarctica effectively formed the modern Antarctic continent as we recognize it today. Since rifting, the Antarctic plate has remained effectively stationary and geological activity has been limited to ongoing extension and volcanism within the West Antarctic rift system. Most deformation occurred between 43 Ma and 26 Ma during which time another 180 km of extension occurred (Cande et al. 2000). Deformation at this time is commonly linked to uplift and 4–9 km of denudation along the rift flank now defined by the Transantarctic Mountains (e.g. Fitzgerald and Gleadow 1988; Fitzgerald and Stump 1997; Miller et al. 2010).

West Antarctica is complex in two ways: first, its margin (together with that of Zealandia) has undergone convergence and divergence; second, West Antarctica itself is a complex of microcontinental blocks that have moved independently of each other and have been widely extended over the past 200 million years in the West Antarctic rift system. West Antarctica is thus an ensemble of blocks (shaded) that have moved independently of each other and of cratonic East Antarctica. The blocks of West Antarctica (Dalziel and Lawver 2001, Fig. 2.2) are crossed by the West Antarctic Rift System between the Bellingshausen Sea and the Ross Sea. The rift trough between the rift faults bounding the Transantarctic Mountains and the Ellsworth–Whitmore Mountains block on one side and Marie Byrd Land on the other contains basins in the Ross Sea (LeMasurier 2008). The volcanic islands around Antarctica are described by Quilty (2007).

Fig. 2.2 Antarctic palaeogeography from the middle Cambrian to the late Carboniferous. Westward subduction under the Pacific margin of Gondwana marks onset of Terra Australis orogenesis. Black stars mark exposures of the passive margin sequences: EM = Ellsworth–Whitmore Mountains, Ch = Chilenia Terrane, ChP = Challenger Plateau (western domain New Zealand (NZ(w))), CP(w) = Campbell Plateau (western domain New Zealand), Cu = Cuyania Terrane, D = Deseado Terrane, LH = Lord Howe Rise, MB(r) = Ross Province Marie Byrd Land, NEFB = New England Fold Belt, P = Pampean Terrane, RBT = Robertson Bay Terrane and T = Tasmanides. Outboard terranes: AP(cw) = central and western domains of the Antarctic Peninsula, CP (e) = Campbell Plateau (eastern domain New Zealand) and MB(a) = Amundsen Province Marie Byrd Land. Numbered regions (1–5) refer to the tectonic domains shown in Fig. 2.1

By the Late Cretaceous, the Antarctic Peninsula and the remainder of West Antarctica are believed to have been comprised of a number of discrete micro-continental blocks forming a single elongated landmass that extended southward from southern South America. Since at least that time the Antarctic Peninsula has been in its present position relative to South America, at almost the same paleolatitude (South 60–65°) (Lawver et al. 1992), but became glaciated only more recently: a cool but not glacial early Cenozoic Antarctic climate is well known (see, for example, Dingle et al. 1998; Stilwell and Feldman 2000; Dutton et al. 2002). Before that, the northern tip of the Antarctic Peninsula and southernmost South America (Magallanic region) were physically connected facilitating both florirstic and faunal interchange between both areas (Olivero et al. 1991; Marenssi et al. 1994; Shen 1995; Reguero et al. 1998, 2002; Reguero and Marenssi 2010).

Marine geophysical data demonstrates a major change in the motion of the South American and Antarctic plates at about 50 Ma (Ypresian, Early Eocene), from N–S to WNW–ESE, accompanied by an eightfold increase in separation rate (Livermore et al. 2005). This would have led to crustal extension and thinning, and perhaps the opening of small oceanic basins of the Weddell Sea, with the probable formation of a shallow (<1000 m) gateway during the Middle Eocene.

The climatic evolution of the Southern Ocean was in part brought about by rearrangement of the Southern Hemisphere land masses, and is related to circulation changes affecting global heat transport. The separation of South America from Antarctica cleared the way for a free Antarctic Circumpolar Current (ACC) to produce thermal and physical isolation of Antarctica. It developed at some time during the Cenozoic, as a series of deep-water gaps opened around Antarctica, and has been widely viewed as having reduced meridional heat transport, isolating the continent within an annulus of cold water and thus being at least partly responsible for Antarctic glaciation (e.g., Kennett and Barker 1990). Recent articles provide data which indicate a time frame for opening of the Drake Passage resulting in the development of ACC and subsequent onset of Antarctic climatic cooling, leading to the development of an earliest Oligocene ice sheet on the Antarctic Peninsula. The correlation between this history and determinations of falling ancient partial pressure of atmospheric CO_2 has been linked to global cooling (Pearson and Palmer 2000; Pagani et al. 2005). Livermore et al. (2005) propose a shallow water opening (<1,000 m deep) as early as 50 Ma based on tectonic evidence in the Weddell Sea. They correlated the formation of new tectonic basins in the area that will later become the Scotia Arc and the northern Antarctic Peninsula, with a drop in southern ocean temperatures based on oxygen isotope data from benthic foraminifera to represent the initial shallow water opening between South America and Antarctica. Eagles et al. (2006) indicate that subsidence in the area of some small oceanic basins in the southern Scotia Sea (Dove Basin and Protector Basin) east of Drake Passage, was underway at ~50 Ma, producing a deepening shallow- or intermediate- depth rift that gave way to seafloor spreading in the Dove basin by around 41 Ma. Basin opening coincided with a sustained period of global cooling that started after the Ypresian (Early Eocene). Extension in the region of the Dove and Protector basins would have opened Drake Passage to shallow or intermediate depth oceanic circulation between the Pacific and Atlantic oceans for the first time by 41 Ma (Fig. 2.3).

Scher and Martin (2006) utilized a rare earth element neodymium (Nd) contained in fish teeth extracted from deep sea cores taken in the south Atlantic Ocean between southern Africa and Queen Maud Land on the Antarctic craton to provide data on a deepwater opening of the Drake Passage. They used ratios of $^{143}Nd/^{144}Nd$ to determine the transition from non-radiogenic to radiogenic

Fig. 2.3 Scotia and Weddell seas (Smith and Sandwell 1997). **AP**, Antarctic Peninsula; **CSS**, central Scotia Sea; **DP**, Drake Passage; **ESS**, East Scotia Sea; **MEB**, Maurice Ewing Bank; **PB**, Protector Basin; **Pow**, Powell Basin; **JB**, Jane Basin; **SAAR**, South American–Antarctic Ridge; **SG**, South Georgia; **SST**, South Sandwich Trench; **TdF**, Tierra del Fuego; **WSR**, West Scotia Ridge; **WSS**, west Scotia Sea

Nd values which would mark the flow of the more radiogenic Pacific waters into the Atlantic Ocean as the signal for the deepwater opening of the Drake Passage in the late Eocene (ca. 41 Ma). Variations of Nd (Neodynium) isotope ratios ($^{143}Nd/^{144}Nd$) in the Atlantic sector outline the history of the opening of Drake Passage more directly than previous studies that relied on other paleoceanographic proxies to infer a Pacific–Atlantic connection. These variations suggest an influx of shallow Pacific seawater approximately at 41 Ma. Subsequent eNd increases during the late Eocene most likely represent progressive widening and deepening of the gateway. A pronounced eNd increase at Maud Rise ~37 Ma has been previously interpreted as an opening of Drake Passage to intermediate depths. For the Drake Passage region, there are at least two continental fragments, the South Orkney block (King and Barker 1988) and South Georgia (Dalziel et al. 1975; Ramos 1996), as well as other possibly continental, high-standing blocks in the central Scotia Sea (Barker et al. 1991) that may have impeded deep water circulation through Drake Passage.

2.1 East Antarctica/West Antarctica and Gondwanan Paleobiogeography

Vertebrate dispersal between South America and other Gondwanan continents or subcontinents (Australia, Indo-Madagascar) to and from West Antarctica across Late Cretaceous land bridges predicts the presence of their fossils in that continent. Although knowledge of Late Cretaceous vertebrates from Antarctica is still severely limited, and completely lacking for many small terrestrial and freshwater vertebrates (e.g. tortoise, lizards, snakes, crocodyliforms, mammals), it has expanded substantially over the last two decades and includes discoveries of avian and non-avian dinosaurs (Reguero et al. submitted).

The oldest Antarctic non-avian dinosaurs were found in the Early Jurassic Hanson Formation on Mount Kirpatrick in the Transantarctic Mountains in East Antarctica. The crested theropod *Cryolophosaurus ellioti* described by Hammer and Hickerson (1994) and a basal sauropodomorph, *Glacialisaurus hammeri*, described by Smith and Pol (2007) are considered part of an early Gondwana radiation of these groups. Although relative plate motions suggest that there could not have been any land bridge between South America, Africa, Antarctica, India and Madagascar after 108–112 Ma, Sereno and Brusatte (2008) based on the phylogenetic relationship of Abelisauroidea to Carnotaurinae and the finding of a abelisaurid fossil from the Cenomanian of Niger, proposed the existence of land bridges between South America and Africa and between India and East Antarctica at 97 Ma. By the mid–Late Cretaceous (latter part of the Santonian, end-Cretaceous Normal Superchron, 83.5 Ma), South America, Antarctica and Australia were the only Gondwanan continents that were still connected; the Indian subcontinent had begun its separation from Madagascar c. 5 Ma earlier (e.g., Storey et al. 1995).

Plate tectonics and the terrestrial vertebrate fossil record from the James Ross Basin suggest dispersal of vertebrate groups from South America (Patagonia) to Antarctica and possibly onto Australia until as late as the Eocene. Woodburne and Case (1996) assumed that there may have been a terrestrial link between South America and Australia via Antarctica but it ended by 64 Ma when the South Tasman Rise submerged. Late Cretaceous terrestrial vertebrates from West Antarctica are thus of interest to address a variety of questions, ranging from the dispersal patterns of major vertebrate clades to Gondwanan endemism.

A new South Polar Province based on Maastrichtian to Danian dinoflagellate cysts proposed by Bowman et al. (2012) excludes most southern South American marine palynofloras. This interpretation supported by models of ocean currents around Antarctica implies an unrestricted oceanic connection across Antarctica between southern South America and the Tasman Sea. This hypothesis does not therefore support the presence of a continuous geographical landmass through South America, the Antarctic Peninsula and West Antarctica to Australasia (e.g., Woodburne and Zinsmeister 1984; Case et al. 1987; Case 1988; Cantrill and Poole 2002). However, this does not preclude the presence of closely spaced islands forming an archipelago through this region to account for the dispersion of *Nothofagus* spp. and marsupials across Antarctica from South America (Schuster 1976; Case 1988).

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