CHAPTER 1

Geology: An Australian perspective

Australia is a continent new to science, of long history, stability, aridity and flatness. This chapter provides a brief review of when, how and why geological knowledge of Australia was obtained. It also describes how the new technologies of the satellite and the computer age, and of subsea exploration, have changed our perspective of the continent.

CONNECTIONS

Some call Australia the world's largest island, but it is a true continent, one of the primary building blocks of planet Earth, with rock systems and history that extend back to the earliest recorded episodes of the Earth's development. Traditional stories of the Aboriginal people tell of the creation of this continent and of many of its landscape features. These stories run parallel to this book, because they emphasise the close spiritual relationship between all of us and the land to which we were born, or by which we were adopted, and which supports us.

This book tells how the rocks formed, and how the present landscape and climate developed over millions of years, from an Australian perspective. As the Reverend John Milne Curran wrote in one of the earliest explanations of Australian geology, in 1898, 'Australia has a history far more ancient than any written by men – to read this history is one of the objects of geology – records preserved in the great stone-book of nature.'

Early progress

Australia was the last habitable landmass to be discovered by Europeans. Early exploration was undertaken happenstance by navigators and traders, mainly Dutch, reaching out to the spice islands of Indonesia. By the late 1600s much of the coast had been charted, but the first complete maps of Australia, resulting from the French exploration of Louis-Claude de Freycinet and the British voyage of discovery by Matthew Flinders, did not appear until 1811 and 1814. The much-later expedition of discovery by James Cook did more than just put Australia on the map. Thorough documentation of its eastern coast in 1770 provided the basis for the First Fleet and British settlement in 1788. At first the new colony was simply an outpost at the end of the Earth, addressing a perceived home-based social problem. But within 30 years an outward, trade-based outlook was in place, delivering Australian wool to Britain. In this early phase of settlement and enterprise the settlers sought to build on knowledge of the Australian environment started in earnest by Cook's *Endeavour* expedition.

Records of geography, landscape, plants and animals grew apace. The earliest systematic geological investigations followed rather later, but not long after geology was established as a discipline of science in Europe. Pawel Strzelecki engaged in systematic geological investigations of Victoria and Tasmania during 1848–1851. His achievements included the discovery of gold, knowledge famously suppressed by the then governor of Victoria, who feared social disruption should details of the find become widely known.

The rush for gold by the forty-niners in California, newly settled by Europeans, provided an uncharted path to riches for individuals previously well outside the frame of privilege. Gold-prospecting success in southeastern Australia during 1851 launched a similar wave of both home-based and immigrant fortune seekers. State governments were immediately receptive to wealth generation from gold, a theme in Australian development that has continued to the present across a wider spectrum of mineral resources. Victoria and Tasmania fostered potential gold production by the appointment of geological surveyors during the 1850s.

Rushes in Queensland quickly followed those in the southeast, also resulting in the appointment of a state government geologist. Robert Logan Jack, holding that position in the late 1800s, as well as documenting the context of gold occurrences and identifying prospective ground, recognised the rock geometry of the Great Artesian Basin with its economic potential for artesian water. This resource was utilised shortly after and remains a major benefit to the pastoral industry in inland eastern Australia.

Serious gold exploitation in Western Australia was delayed until the 1890s, with a consequential delay in development of that state. Thus, the link between the Australian Commonwealth, Earth resources and geology was established at a formative phase in Australian settlement history, and the relationship continues. Gold mining and the wealth that it created in the second half of the 19th century set European colonisation of the continent on the path to prosperity, as well as revolutionising Australian social structure. From 1870 to 1890, backed by gold production, Australia led the world in per-capita income.

Geological enquiry made simply in the pursuit of knowledge also has an enduring pedigree in Australia. In 1836 Charles Darwin, on the voyage of the *Beagle*, documented aspects of Australian geology. A rudimentary geological map of Australia was produced in 1850 by Joseph Beete Jukes, who served as a surveyor on the voyage of colonial exploration by the *Fly*. Not surprisingly, its documentation is largely of the coastal zone, with the continental interior left blank (see Figure 1.1).

Early overland expeditions in the mid 1800s, including those of John McDouall Stuart, Ludwig Leichhardt, Robert O'Hara Burke and John Wills, made note of the rocks traversed, which helped fill the huge inland gap. The Reverend William Clarke, the first formally trained geologist active in Australia, centred his investigations on New South Wales, starting in around 1840. He had a special interest in gold occurrence, but his early finds, like those of Strzelecki in Victoria, were kept secret, at the state governor's request.

Frederick McCoy was appointed as professor of natural science at Melbourne University in 1854, with a brief that included geology. He wrote extensively on fossils, relicts of earlier life, discovered within Australian sedimentary rocks. Julian Tenison-Woods, a Catholic priest, similarly described Australian fossils but also published *Geological Observations in South Australia* in 1862. As with European rocks, documentation of Australian rocks had a strong focus on mapping their distributions and relationships, and deciphering their ages from the fossils they contained. British experts such as Robert Etheridge Jr helped document the Australian fossil record from collections sent to Britain in the later 1800s. The comprehensive, large-scale geological map of the continent, with its various rock units ordered in terms of both type and age, published in 1920 by Edgeworth David, then a long-established professor of geology at Sydney University, is widely regarded as a milestone in Australian geology.

The two strands of geology, one driven simply by enquiry and the other by commercial interests and the search for Earth resources, were entwined from the earliest days of the discipline in Australia. This mutually beneficial relationship has characterised the science of geology in Australia and is continuing. It will be explored in later chapters.

The progression of geological concepts

In the early days of its colonisation Australia was so different from Europe that extraordinary theories were proposed to explain how this came to be so. The Reverend William Clarke, in an address to the Philosophical Society of New South Wales in 1861, took time to refute the following notions:

> *It was once maintained by a philosopher of some eminence that New Holland, being so singular and anomalous a region, must have originated in a corner of the sun knocked off by a comet, and that, tumbling into the Pacific Ocean, it*

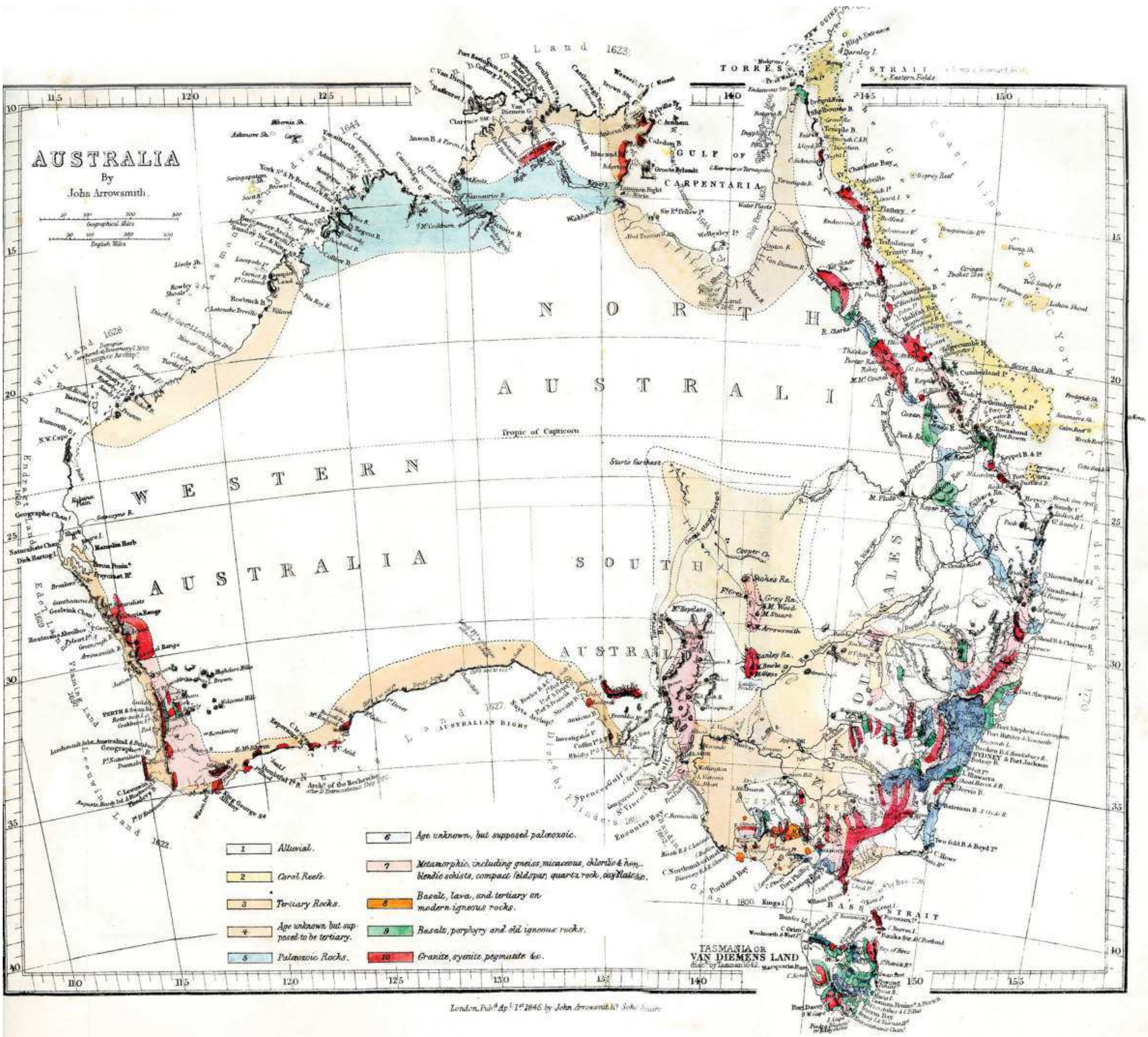

Figure 1.1 The geology of Australia by Joseph Beete Jukes, published in 1850, showing the geology mapped along the coast but a dearth of information on the inland. Note the track of data in northeastern Australia, based on reports by Ludwig Leichhardt of his journey in 1844–1845. There is detail on the Great Barrier Reef, investigated in some detail by Jukes in a pioneering study. Tasmania is labelled also as Van Diemens Land [*sic*].

Source: David Johnson

> *soon became the suitable abode of those bizarre marsupials … which are only an imperfect development of life upon the more recently raised lands, such as Galapagos and Australia.*

All the early explorers, and the naturalists who sailed with them, were struck by the strange animals and plants they encountered. Australia did not fall out of the Sun, but it is still a very individual place, with unusual animals and plants inhabiting extraordinarily diverse landscapes, many of which are unmatched elsewhere.

To early theorists, Australia was not only very young but also populated by totally different life from that known from the natural worlds of Europe, America and Africa. They thought they had discovered a completely new existence, something which must have formed after their established order. However, this theoretical stance was not supported by the rocks. In the 1800s many geologists spent time confirming that there were fossils and rocks in Australia which matched, and were demonstrably of the same kinds and ages as, those in Europe. Past life in Australia, unlike the plants and animals that now characterised its landscapes, was much like that of the other continents.

In the development of geology as a discipline, during the 19th century, initially in Europe but with contributions from North America following soon after, three major rock systems contributing to the Earth's surface were found to be common to all the continents. That the same generalisation applied to Australia was recognised by its geological pioneers.

Crystalline rocks, in which mineral grains are obvious, like granite, marble and schist, formed deep in the Earth's crust and were later exhumed due to uplift and erosional removal of overlying rocks. Large-scale tracts of crystalline rocks form **cratons** and are considered to be old because of this history. Cratons are held to form the ancestral nuclei of the continents, to which other rock systems were added through time. Commonly, the crystalline rocks of the cratons have been reshaped by forces deep within the Earth and show complexity of internal structures and patterns. In addition, such rocks lack any sign of interaction with life forms and are devoid of fossils. Their origins generally precede the development of animals and terrestrial plants.

Sedimentary rocks were formed at the Earth's surface, mainly from the accumulation of erosion products such as sand and mud. Rocks in this category are very extensively developed on the continents, where they characteristically overlie, and are therefore younger than, the rocks of the cratons. They generally form substantial layered sheets kilometres thick and commonly hundreds of kilometres across. These rock bodies are referred to as **sedimentary basins**, because they represent once-depressed sections of the Earth's crust in which sediment was trapped, accumulated and, with deep burial and time, transformed to rocks. Having formed at the Earth's surface, either on land or on the seafloor, sedimentary rocks have generally interacted with animals and plants and therefore characteristically contain fossils. Mostly, they are little disturbed from their time of accumulation and show clear evidence of the sedimentary processes by which they were formed.

A third category of rock systems embraces rocks which form large-scale linear strips on the continents termed **orogenic belts**. These also mostly comprise sedimentary rocks, but these show a much more complex history than their counterparts in sedimentary basins. They are characteristically buckled and broken, indicating that their original form has been reshaped by powerful compressive forces in the Earth's crust during episodes of orogeny. Fossil occurrences are widespread. Crystalline rocks are also common parts of orogenic belt rock assemblages, showing that in part they have been exhumed from deep crustal levels.

A striking feature of several continents, in particular North America but also Australia, is that orogenic belts are characteristic of continental margins, as distinct from their interiors. Progression in geological knowledge through the 19th and most of the 20th century brought a detailed understanding of how the crystalline rocks of the cratons and the sedimentary rocks of the basins were formed. However, an understanding of orogenic belts and what they signify in the construction of the continents was long delayed. Their origins confounded the geological community in spite of much attention being devoted to them. But a geological revolution starting in the late 1960s and continuing apace for several decades succeeded in putting the third part of the rock system puzzle in its proper place. We now know that the continents and oceans have been mobile through time and appreciate the drivers of such behaviour. Orogenic belts result from these dynamics.

The rock systems of Australia and of the other continents were built almost entirely through materials and processes internal to the Earth. However, the surface of our nearest celestial neighbour, the Moon, is extensively cratered, and similar surface features mark the rocky inner planets of our Solar System. Such craters are the results of collisional impacts by extraneous material within the Solar System drawn by gravitational force to the larger bodies. It is thought that all the planets owe their origin to the concentration of matter in this way, through accretion and progressive growth. Although its accretionary phase has long passed and has been supplanted by internal dynamics, the Earth originated in a similar way.

Faint evidence of this history remains. The Earth is still occasionally the collector of meteorites by impact. About 27 impact sites, mostly craters, of various ages are scattered across Australia. Most were formed in deep geological time, are cryptic and are recognised only from detailed research. Wolfe Creek Crater (see Figure 1.2a), south of the Kimberley region, in Western Australia, is an exception. Its rim of impact ejecta is little changed from when a meteorite with an estimated weight of 50 000 t crashed to the Earth 30 000 years (30 ka) ago. Fragments of the meteorite have been collected from the vicinity of the crater.

Observation of meteorite impact is extremely rare. Australian examples include the penetration of a house at Dunbogan, north of Newcastle, in New South Wales, by a small meteorite in 1999 and a small meteorite impact on Binningup Beach, south of Perth, in 1984.

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Excerpt
More Information

One of the most productive areas for meteorite collection known anywhere on the Earth is the Nullarbor Plain, in southern Australia. The meteorites are pebble- to boulder-sized lumps of debris that were too small to create enduring impact structures (see Figure 1.2b). They are very rare, are scattered over the ground surface and vary in composition. Some are composed of iron with minor nickel, a material similar to that inferred as forming the core of the Earth. Others are stony and can be matched with rocks known from the upper part of the Earth. Uncommon varieties are carbonaceous, composed mainly of rock-forming minerals common on the Earth but also containing water and organic compounds. They were sourced from a part of the Solar System of which we have very little knowledge.

Smooth, pebble-sized, globular to button-shaped objects made of fused glass (see Figure 1.2c), generally known as tektites (Australian examples are also called australites) are known from many locations across the continent. Their origin is disputed; however, their compositions and textures are like those of common rocks melted and fused. It is likely that they resulted from the energy of meteorites melting and fragmenting rocks at the Earth's surface on impact.

Building Australian geological knowledge

Mapping the distribution of rock types, grouping them as rock systems, assigning ages to them based on fossils they contained and deducing the processes by which they originated attracted interest from the early

Figure 1.2 Evidence of extraterrestrial impacts on the Earth's surface and of the accretionary process by which the Earth was built. Although the accretion of the planets was essentially complete in the early history of the Solar System, the process continues at a very slow rate.
a. Wolfe Creek Crater, in northern Western Australia, one of the best preserved impact craters known. It measures almost 1 km across and was formed 300 000 (300 ka) ago.
b. A large meteorite in Mundrabilla, on the Nullarbor Plain, in South Australia, shown with its finder, John Carlisle.
c. A tektite, measuring 25 mm across.

Source: a. Ted Brattstrom; b., c. Trustees of the Western Australian Museum days of Australian colonies. However, a comprehensive knowledge of Australian geology was not achieved until 200 years later. It resulted in large part from an initiative of the Commonwealth government commencing in the 1960s, supported by the states and territories, to undertake systematic, uniform and quite detailed (using a map scale of 10 mm to 2.5 km) geological mapping of the whole continent. Its purpose was to document the mosaic of rock systems and their distribution across the entire continent to provide a template for resource exploration.

This huge undertaking involved field parties investigating towards 500 individual map sheets, each covering about 17 000 km^2, most of them in remote areas. Imaging of the ground surface by aerial photography underpinned the mapping on the ground. It took several decades to complete the program. In later years, the advent of new techniques assisted in the mapping. Satellite imagery is now used rather than photographs taken from aeroplanes. Across much of Australia a thin cover of soil and other surficial material, often only a few metres thick, obscures the bedrock beneath. Airborne instrumentation, in particular magnetometers, which sense the magnetic properties of the land beneath, can 'see through' this cover and register the magnetic properties of the bedrock. This technology is now routinely used to assist geological mapping.

The continental margins, extending beneath the shallow sea that surrounds Australia, have also been geologically mapped. Under the *United Nations convention on the law of the sea*, Australia's exclusive economic zone covers an oceanic area approximately the same size as the ground surface. The zone is the area that a country has the right to explore and exploit for living and non-living resources of the seafloor, including the underlying substrates and overlying waters. Rock systems below the seafloor of this zone, and the resources they may contain, are an important part of the national estate. Seafloor bathymetry and subsea geological mapping have depended almost entirely on shipborne instrumentation. Sonar and seismic technologies have been key tools. Energy pulses, such as those generated by explosives or sound emissions, are propagated through the water column and into the rocks beneath in the case of high-energy events. Their reflections back to the surface can be interpreted in terms of seafloor bathymetry and the geometry of rock bodies to depths of up to 10 000 km, and in some cases even more. Mapping of the offshore sedimentary basins using seismic techniques has been done through both the federal government and companies engaged in petroleum exploration. It is an expensive procedure undertaken largely over the last 50 years and continuing. The same seismic technologies have also been extensively applied to documentation of the onshore sedimentary basins and in the last 10 years have been used to investigate the deep geological fabric of the continent to depths of 50 km.

Accurate interpretation of seismic records depends on holes drilled into the Earth to enable sampling of the materials beneath its surface. The contents of all Australian sedimentary basins have been sampled in this way, mostly by companies exploring for petroleum, gas, coal and groundwater resources. This knowledge has been extended by a multinational scientific consortium based in the USA but supported with finance and scientific staff from many other nations, including Australia. The International Ocean Discovery Program and similar programs which preceded it (collectively known as the Ocean Drilling Program) have sampled sub-seafloor sediments and rocks on a worldwide basis, particularly for the deep ocean to depths exceeding 5000 km. Commencing in 1968 and continuing, these programs have focused on understanding ocean history. Pioneering technologies have been developed in deep ocean drilling relating to drill strings kilometres in length, mostly freestanding in the water column, and in hole re-entry for core recovery following the replacement of drill bits. Several drilling campaigns completed within the extended economic zone of Australia have provided invaluable information on the history of deep ocean sectors as well as the ages and contexts of sedimentary basins closer to shore.

Technologies for imaging the ground surface are now satellite based. New techniques have been developed to use the full spectrum of light, especially light in the infrared range, reflected from the ground surface and recorded by satellites. Analysis of such information, particularly that recorded for the infrared part of the spectrum, is used to sense particular minerals which occur in soil and rocks on the ground surface as an additional mapping tool. Contemporary mapping programs dependent on satellites and aircraft and seismic surveys (see Figure 1.4) are underpinned by modern advances in computer-based information technologies.

Results from the mapping have identified the detail of Australia's geological complexion (see Figure 1.5). Its sedimentary basins, like those of all continents, are dominant and cover its bulk. The largest of these, the Great Artesian Basin, covers most of eastern Australia. Sedimentary basin rocks lap onto those of the cratons, and sedimentary basins are extensively developed beneath the shallow seas at Australia's margin, with the exception of the

Figure 1.3 The *JOIDES Resolution*, a long-serving vessel supporting the International Ocean Discovery Program, has been the platform for most deep ocean drilling around Australia.
Source: International Ocean Discovery Program and *JOIDES Resolution* Science Operator

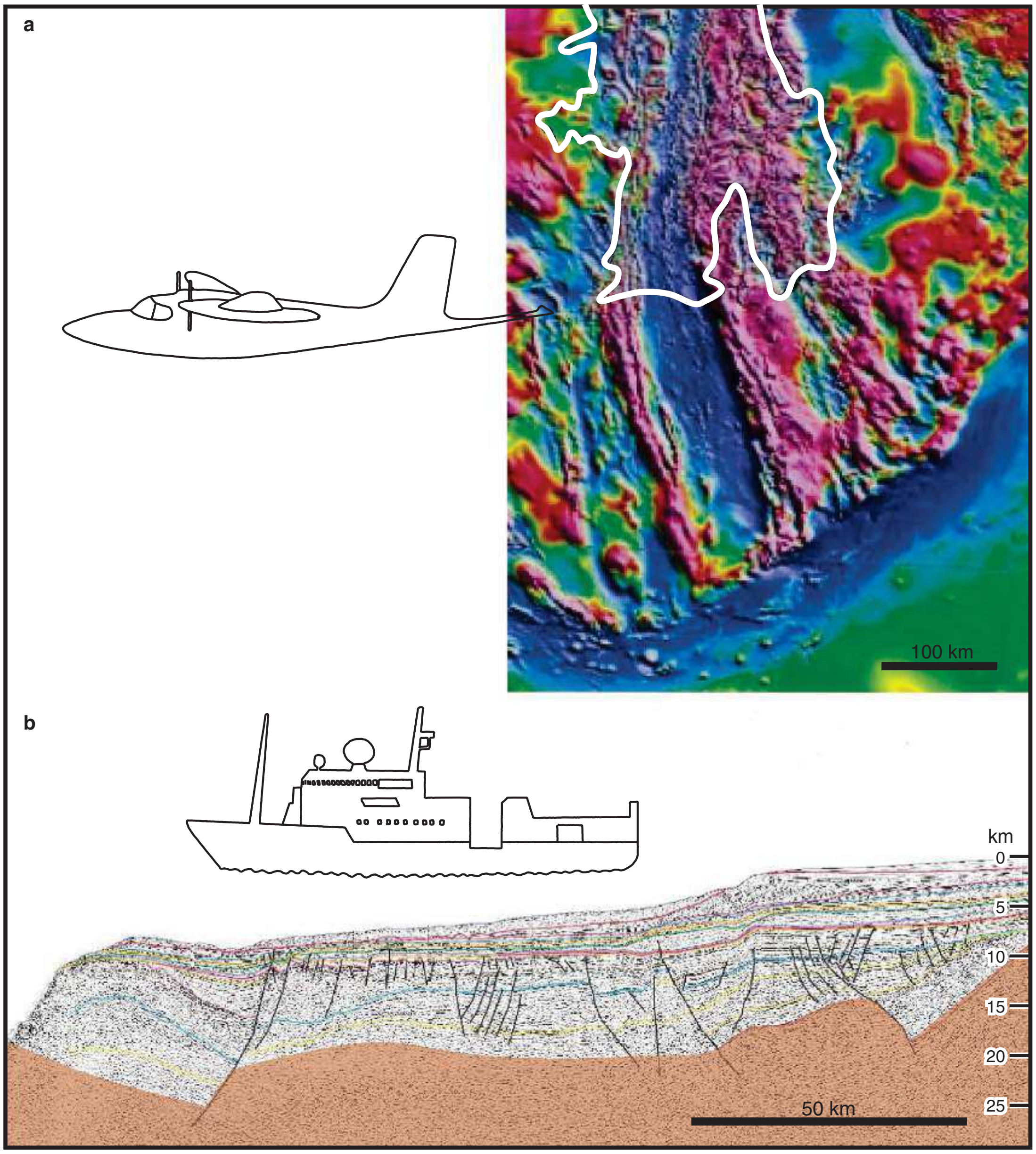

Figure 1.4 Australian rock systems documented through geophysical imaging where they are obscured by surficial cover or by shallow sea.
a. Aeromagnetic map of western Queensland, accomplished using low-flying aircraft. Cratonic rock systems exposed at the ground surface (bounded by the white line) can be followed outwards beneath shallow cover (less than 500 m thick) at the margin of extensive sedimentary basins. The geological fabric mapped at the ground surface can be followed into the subsurface through application of this technique. Its abrupt termination to the south represents a major geological discontinuity, not shown at the ground surface, where different types of crust (cratonic and orogenic) are juxtaposed.
b. Shipborne seismic survey along a transect line perpendicular to the coast of northwestern Australia. The layering within a sedimentary basin is developed on a substrate of cratonic crust (brown) beneath the seafloor. This type of survey has been an essential tool in developing the subsea petroleum and gas resources of the northwestern shelf of Australia.

Source: Geoscience Australia and Robert Henderson

eastern coast. Their offshore development is a consequence of reorganisation of the southern continents deep in geological time. Cratons, representing the older rock assemblages in Australia's makeup, are extensively developed in western and central Australia, whereas the part of the continent occupied by orogenic belts is restricted to the eastern margin. The locations of both reflect past continental and oceanic configurations.