2 PRECAMBRIAN - ANCIENT FOUNDATIONS

Earth's oldest rocks have been recycled and 'destroyed' by the process of plate tectonics. The oldest rocks on Earth found so far are the Acasta Gneisses in northwestern Canada, which are 4.03 billion (4,030,000,000) years old. Ancient rocks exceeding 3.5 billion years in age are found on all of Earth's continents.

Ireland's Precambrian rocks extend back in time to about 1.8 billion years ago. These very old rocks have had a long and complex history, repeatedly affected by subsequent geological events, so that their origins can be difficult to decipher. All these rocks are shown simply as 'Precambrian' on the map, but it should be remembered that they represent a longer period of Earth history than all the rest of the rocks, from Cambrian to Quaternary, put together.

Precambrian rocks occur in the southeast corner of Ireland, around Rosslare, and over a larger area in the northwest, including much of Donegal, North Mayo and Connemara. These southeastern and northwestern provinces actually originated on separate continents and were brought together to form the foundations of Ireland by plate tectonic movements during the later Ordovician and Silurian Periods. There is therefore no relationship between the southeastern and northwestern Precambrian rocks and they are discussed separately below. The southeastern Precambrian rocks are collectively called the Rosslare Complex. Most of the northwestern Precambrian rocks belong to a unit called the Dalradian Supergroup, but within these are small areas of the very oldest rocks, together referred to as pre-Dalradian.

2.1 THE ROSSLARE COMPLEX

The Rosslare Complex is divided into two major units; a group of grey gneisses, coarsely crystalline metamorphic rocks that are well exposed at Kilmore Quay, and a group of dark-green metamorphosed igneous rocks called amphibolites that are seen around Rosslare Harbour and Greenore Point.

The gneisses typically have a banded appearance, in which pale-grey bands of the minerals quartz and feldspar are separated by darker bands rich in mica. These rocks are interpreted as originating as sediments, deposited as a succession of greywacke sandstones and interbedded mudstones. Several periods of metamorphism, under high temperature and pressure conditions deep in the crust, produced the present-day gneisses. In places, thin sheets of granitic composition were injected parallel to the banding in the gneisses. These suggest that particularly high temperatures caused partial melting of the sediments and re-injection of the melted rock as granite.

The metamorphosed igneous rocks are rich in a dark-green mineral called amphibole. They are the metamorphosed equivalents of gabbro and diorite. Although the relationship is not clear, these igneous rocks probably intruded the sedimentary rocks that later became gneisses.

Deformation and metamorphism of the Rosslare Complex were caused by the Cadomian Orogeny of Late Precambrian age, which also affected rocks in southern Britain and northern France. New minerals that grew in the rocks during metamorphism have been dated as 620 million years old, but the gneisses and amphibolites were both already in existence before this time and so were produced by an even earlier metamorphism.

2.2 THE DALRADIAN

Most of the Precambrian rocks of northwestern Ireland are part of a belt of metamorphic rocks, called the Dalradian Supergroup, which extends from the west of Ireland and Donegal, through Tyrone and northeast Antrim, into Scotland. The Dalradian is composed mainly of metamorphosed marine sedimentary rocks, but includes volcanic and intrusive rocks and metamorphosed glacio-marine deposits. Deposition of the youngest parts of the Dalradian sequences probably continued without break from the Precambrian into the Cambrian Period. However, the Cambrian parts are difficult to separate on the map and all Dalradian rocks are shown as Precambrian.

The story of the Dalradian starts with continental tension and crustal thinning about 800 million years ago during fragmentation of a single late Precambrian supercontinent, called Rodinia (Fig. 2.1), and formation of a basin in which the Dalradian sediments accumulated. Deposition was initially in shallow seas, but as the continent became more stretched, it rifted apart about 600 million years ago and a major new ocean, called Iapetus, gradually opened between the continental blocks of Gondwana and Laurentia. Volcanic layers and sills, the latter mainly seen in Donegal, were emplaced as a prelude to ocean opening.

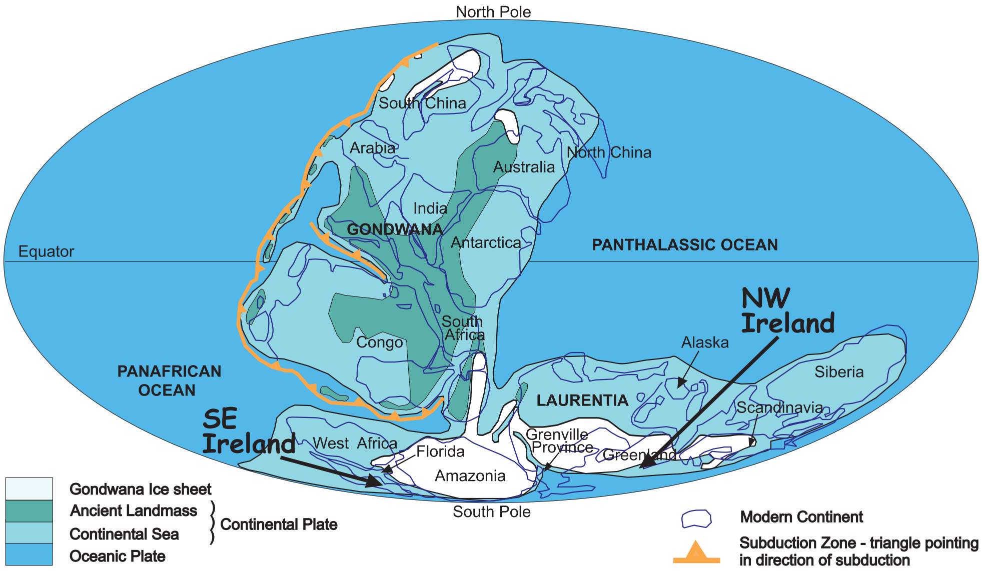

Figure. 2.1 *Plate reconstruction for late Precambrian time*

Depositional environments of the sedimentary rocks in the Dalradian Supergroup range through estuarine, intertidal, and shallow marine, to deep-water shelf and slope. A distinctive glacio-marine formation was deposited during an ice age about 720 million years ago. This ice age has been associated with the currently topical "Snowball Earth" hypothesis (see section 16.3).

In Ordovician times the Dalradian rocks were deformed into a major mountain belt by the Grampian Orogeny (section 4.1). The rocks were metamorphosed and repeated folding gave rise to complex structures. Regional-scale folding of the quartzite in the Connemara Dalradian rocks can be picked out on the map, while Fig. 2.2 shows small folds in an outcrop of Dalradian rock.

Figure 2.2 *Small-scale folds in an outcrop of Dalradian rock (lens cap in upper left for scale)*

White and pale-coloured quartzites and metamorphosed sandstones are common rock types in the Dalradian (Fig. 2.3). They are resistant to erosion, and form much of the notable high ground, such as the Twelve Bens in Connemara and the Errigal - Muckish range in Donegal. Metamorphosed mudstones and marbles (metamorphosed limestones) are other common rock types. The marbles include the well-known ornamental green marble of Connemara.

Figure 2.3 *Platy quartzites at Horn Head, Co., Donegal.*

2.3 IRELAND'S OLDEST ROCKS - PRE-DALRADIAN

The oldest rocks in Ireland occur on Inishtrahull, northeast of Malin Head, and in northwestern Co. Mayo on parts of the Mullet Peninsula and Blacksod Bay. These are coarsely-crystalline, banded gneisses produced by strong metamorphism of igneous rocks that formed approximately 1750 - 1780 million years ago. Similarly aged rocks are thought likely to lie deep below many of the younger rocks seen at the present day land surface.

The original igneous rocks were of generally granitic and gabbroic types. A complex sequence of intrusive, deformational and metamorphic events has affected these rocks during Precambrian and later orogenies.

2.4 PRECAMBRIAN LIFE

The fossil record of life spans a far greater time across the Precambrian, than from the base of the Cambrian to the present day. Presumed algal structures are known from rocks in Swaziland as old as 3500 million years, and slightly younger algal type stromatolites have been found in the African and North American continents. Very similar algal stromatolites can be seen today at Shark Bay, Western Australia (Fig. 2.4).

Figure 2.4 *Algal Stromatolites at Shark Bay, Western Australia.*

The first indications of animal life, as trace fossils of their burrows and tracks (see Study Box 8.2) are not seen until very latest Precambrian times. The Ediacaran fauna (Study Box 3.1) appears at this time, with a diversity of forms that have been compared with jellyfish, sea pens and worms.

Study Box 2.1 - Plate tectonics

The solid Earth is a dynamic planet. Internal heat generated by radioactive decay drives circulation of the rock of Earth's mantle, in turn moving the more rigid outer shell over the surface of the planet. The shell comprises a number of lithospheric plates (Fig. 1). Plates are composed of continental crust, oceanic crust or a combination of both, plus the upper part of the mantle. Movement of the plates is very slow, a few centimetres per year, but the forces are immense and account for the dynamic surface geology of Earth; earthquakes, volcanic eruptions and the construction and destruction of continents and oceans. Boundaries between adjacent plates are of three types; destructive (or convergent), constructive (or divergent) and conservative (or strike slip).

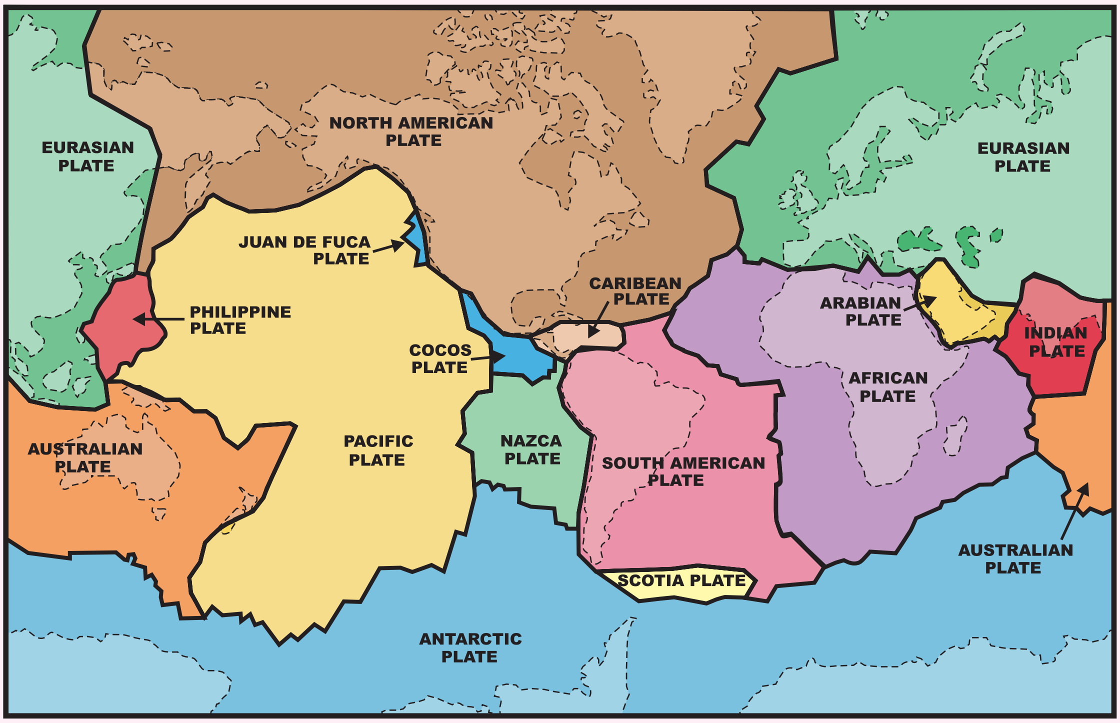

Figure 1. *Tectonic plates of the world*

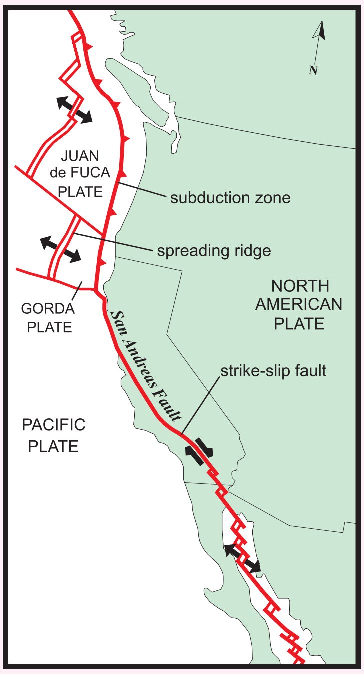

Figure 2. *The San Andreas Fault, California.*

Conservative (strike slip) plate boundaries

Some plate margins are neither constructive nor destructive; instead the plates slide horizontally past each other and are said to be conservative, i.e. crust is neither created nor destroyed. The sliding motion is far from smooth and gradual, but is episodic as stress builds up along the margin of the two plates to be suddenly released in earthquakes that can be of very large magnitude and very destructive in human terms. The San Andreas Fault in California (Fig. 2) is one such plate boundary, where the Pacific Plate is sliding northwards along the North American Plate.

As the continents move as a consequence of plate tectonic processes, they are formed and reformed in different configurations. The geological history of Ireland, as told in this book, is a history of Ireland's place amongst the evolving continents, as plate tectonics has continually modified the cycle of generation and metamorphism of rocks.

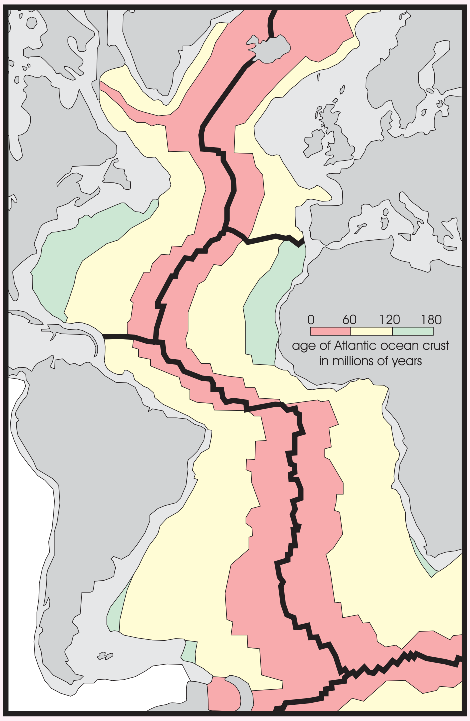

Figure 3. The Mid-Atlantic spreading ridge

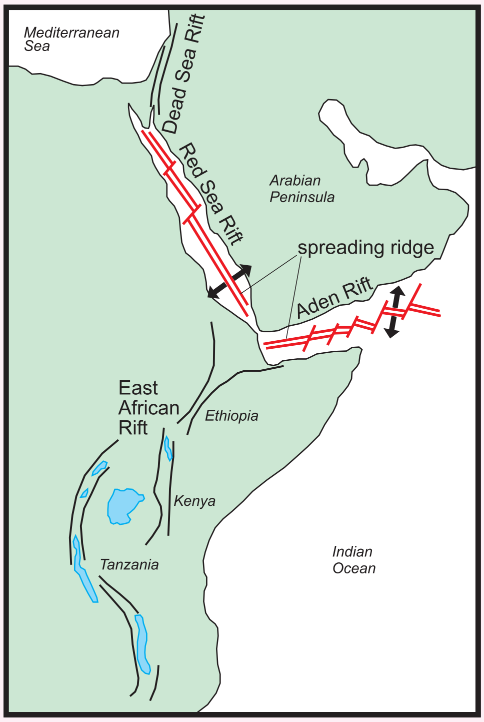

Figure 4. *The Red Sea Rift*

Constructive (divergent) plate boundaries
There are no gaps between the plates; at constructive margins, where plates move apart, magma wells up from the mantle to plug the gaps. Each increment of opening is filled by a sheet-like intrusion of magma that cools and crystallizes to form a dyke of igneous rock. Over millions of years new oceanic crust is formed as oceans get wider. This process is happening in today's widening Atlantic Ocean, for example, as the European and North American plates move apart at the mid-Atlantic ridge (Fig. 3).

A constructive margin can also form within a continent. At first the continental crust is extended and thinned, but eventually it is pulled apart, and new oceanic crust is formed as spreading continues. The Red Sea is a young ocean forming as the Arabian Plate pulls away from the African Plate, and the East African Rift is the continuation of this feature into the African Plate where extension has not yet led to formation of oceanic crust (Fig. 4).

Destructive (convergent) plate boundaries
At a destructive margin, where plates push together, one plate is forced down into the hot interior in a process called subduction (see Study Box 4.1). Subduction induces melting at a shallow level in the Earth's interior and results in a line of volcanoes on the overlying plate, whilst sending out the shock waves of an earthquake as plates grind past each other. A rim of volcanoes around the Pacific Ocean (the Pacific “Ring of Fire”) is a result of consumption of the Pacific plate by subduction under Asia and the Americas.

When two continents collide as a result of subduction, the huge force crumples (folds) the rocks into a mountain range, for example today's Himalayas, produced by India pushing into Asia. Rocks pushed down inside a mountain range are recrystallised by the great heat and pressure. Their original minerals change in the solid state into new minerals and the rock is said to be metamorphosed. With even greater heat the rocks might melt. The molten rock then rises back up through the crust and intrudes at higher levels where it cools in bodies called plutons to crystallize as granite and related igneous rocks.

Study Box 2.2 Radiometric dating and the age of the Earth

Rocks are made up of many individual crystals, and each crystal is usually made up of at least several different chemical elements such as iron, magnesium, silicon, etc. While most of the elements in nature are stable and do not change, some elements are unstable and change from one element to another by a process called radioactive decay. The original element, called the parent element, decays to another element, called the daughter element. This happens at a known and predictable rate, called the “half-life”, so that by measuring the amount of parent atoms and daughter atoms in a rock, an age can be calculated. For igneous rocks the calculated age is usually its cooling and hardening from magma or lava. For metamorphic rocks, the “age” is the heating event that caused recrystallization of the rock. Sedimentary rocks can't usually be dated directly, but their age can be constrained by dating volcanic layers within the sequence or cross-cutting igneous intrusions.

The table shows some of the more commonly used radioactive decay series used in dating rocks.

Radioactive Isotope (Parent)	Product (Daughter)	Half-Life (Years)
Samarium-147	Neodymium-143	106 billion
Rubidium-87	Strontium-87	48.8 billion
Thorium-232	Lead-208	14 billion
Uranium-238	Lead-206	4.5 billion
Potassium-40	Argon-40	1.26 billion
Uranium-235	Lead-207	0.7 billion

Table 1.

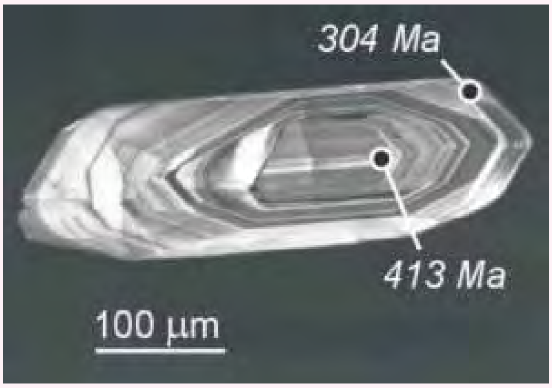

Figure 1. *Zircon crystal showing two phases of growth. A 413Ma crystal was recycled into a 304Ma magma where the crystal grew further.*

The age of the Earth cannot be determined directly from Earth's rocks because the oldest rocks have been recycled and destroyed by the process of plate tectonics (see Study Box 2.1). If there are any of Earth's primordial rocks left in their original state, they have not yet been found. The oldest rocks on Earth found so far are the Acasta Gneisses in northwestern Canada, which are 4.03 billion years old. Even older ages of as much as 4.4 billion years have been obtained for crystals of the mineral zircon that have been recycled into younger sedimentary rocks from Western Australia. The source rocks for these zircon crystals have not yet been found.

It is believed that all the bodies in the solar system were created at about the same time. Nearly all meteorites, which are pieces of asteroid, have ages around 4.56 billion years. The asteroids cooled quickly after formation and have not been remelted since, so their ages have generally not been disturbed. The ages of the meteorites are therefore a good estimate of the age of the Earth.